UNIVERSITY OF CALIFORNIA · COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
BERKELEY, CALIFORNIA

PLANT SUCCESSION ON BURNED CHAPARRAL LANDS IN NORTHERN CALIFORNIA

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A CHAMISE BUSH, AND THE SAME PLANT ONE, TWO, AND FOUR YEARS AFTER BURNING

BULLETIN 685
MARCH, 1944

UNIVERSITY OF CALIFORNIA · BERKELEY, CALIFORNIA

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FOREWORD

THE FOOTHILL LANDS of California have long been relied upon to furnish pasturage for large numbers of cattle and sheep. From the earliest days of settlement stockmen have planned their yearlong operations in accordance with the availability of forage in the different climatic and elevational areas. The most common practice is to graze the ranges at low elevation, nearest the ranch headquarters, as soon as the forage growth develops in the spring, and to hold the animals on these lands until growth is properly advanced on the summer ranges at higher elevations.

Although the greater part of the foothills support grass and other herbs, this cover is interspersed with brushland almost throughout the length of the state. This "hard brush" cover, characterized by simple, thick, leathery-textured leaves, collectively called chaparral, is composed of many species; but all have in common a dwarfed habit, an extensive root system, and the capacity to endure long, dry summers. As a whole, this chaparral cover inhabits thin soils of low productivity. The purer stands of the chaparral association occupy some 7,300,000 acres, or about 7 per cent of the total area of the state, and clothe the lower slopes of the mountain ranges which line the coast and flank the great valley areas. In addition, there is a large acreage of woodland and of cutover timber areas which have been invaded by a mixture of chaparral and thin-leaved brush species. In general, these wooded areas have relatively deep and productive soils. The brush-fields, like most of the uncultivated lands of the state, have multiple uses. Extending, as they do, into the timber belt of their more elevated northern distribution, and into the coastal lowlands in the southern part of the state, they are of importance in the production of livestock, game, timber, and as protection of watersheds.

The chaparral areas furnish limited seasonal pasturage to supplement that of the grassland of the foothills and the forested lands of the mountains. At best, however, the chaparral cover compares poorly with the grasslands as a source of forage, since the brush itself is of low palatability, and the understory herbaceous vegetation is sparse and largely inaccessible. Thus, the question arises as to how the chaparral areas may be made more permanently productive, and how chaparral invasions on the wooded lands may be curtailed or controlled. Opinions differ as to whether these brush invasions are largely the result of overgrazing and burning, or whether they are partly due to fire suppression resulting from restrictive state fire laws. Some believe that burning by prehistoric Indians was the natural means of suppressing the brush on these lands and that controlled burning today is the most, if not the only, effective means of increasing the yield and of improving the quality of the forage produced thereon. Stockmen who own brushlands, and who must rely upon them for part of their livelihood, naturally desire to obtain the best returns possible from them. In attempting to improve grazing on these lands, the most common practice is indiscriminate ("broadcast") burning of the brush. Although this practice may not result in converting the brush to grassland, it does open up the brush cover and temporarily favor growth of browse and of some palatable grasses, the volume of which depends largely upon the productivity of the soil.

Because various administrators and land-use investigators believe that extensive brush burning may not bring economic returns, and may jeopardize certain long-term public interests, controversy has arisen as to the best methods of management of the brushland areas. On the one hand, the stockmen who must pay taxes on their brushlands and earn a part of their living from them, feel justified in employing any rational method which promises even temporary increases in pasturage. On the other hand, public-land administrators contend that reasonable restriction in brush burning is necessary to preserve important watersheds and various other values. These differences of opinion are indicative of the complications of the problem, as well as of the lack of understanding of the issue as a whole. They are due chiefly to the fact that conclusions have been drawn largely from mere observation of practices instead of from the accumulation of measured results of scientific investigation: For many years, biased points of view for or against burning and even propaganda for some preconceived philosophy, in the written and spoken word, have confused, rather than clarified, the issues involved.

A broad and comprehensive understanding of the problems involved in brush control requires research in a number of sciences, including agrostology, silviculture, botany, geophysics, hydrology, soil physics, animal nutrition, and economics, as well as knowledge of many administrative practices, involving public and private land use, wild life and forest management, fire prevention and control, forage production, water conservation, and soil-erosion control.

For this reason I have encouraged especially qualified investigators of the College of Agriculture to study carefully the methods and results of brush burning over a number of years. In order to assure the broadest possible approach to these studies, I set up in the College of Agriculture in 1933 a standing Committee on Range Management, consisting of nine investigators with special knowledge in the fields of agricultural economics, agronomy, animal husbandry, irrigation engineering, forestry, soil technology, and zoölogy. Among the studies which the Committee has already undertaken are some dealing with the effect of brush burning on runoff and soil erosion, silting of streams and reservoirs, water penetration and water-holding capacity of soils, and the ultimate vegetative succession. The findings of these studies will be reported by the College of Agriculture from time to time as evidence is accumulated.

The present report, based upon studies conducted in the northern part of the state during the past fifteen years, presents essentially measurements of changes in the plant cover on burned brushlands, introduced by a brief historical résumé, and with some discussion of related points. Some members of the Committee feel that the report presents too specialized a viewpoint of the problem. It should be noted, however, that the bulletin does not purport to answer all questions pertaining to brush burning. Nevertheless the data presented should be helpful to those who desire information concerning plant succession and related subjects on burned brushlands of the types studied.

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PLANT SUCCESSION ON BURNED CHAPARRAL LANDS IN NORTHERN CALIFORNIA[1,2]

ARTHUR W. SAMPSON[3]

THE CHAPARRAL LANDS of California must be regarded as having an integral part in any rational, long-time land-use program. In the formulation of such a program the more productive areas may prove to be of greatest usefulness under private ownership and management. On the other hand much of the

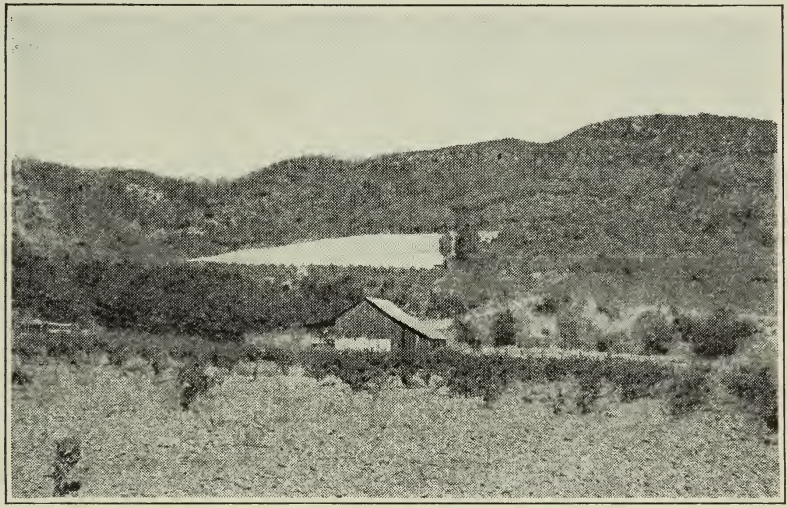

Fig. 1.—Subsistence homesteads are often occupied by industrial laborers who can obtain only seasonal employment. Chamise area cleared for growing grain and orchard crops, in Mendocino County.

less fertile chaparral lands may prove to be most valuable in such public uses as watershed protection, recreation, and game production. The analysis which follows points out the dominant industries and uses of the five major chaparral regions of the state.

USES OF CHAPARRAL LANDS

The chaparral areas extending along the dry eastern slopes of the northern coast ranges, from Shasta to Napa counties, are of importance both to private owners and to the public. Where these stands are not too dense, or where they give way to grass, they are used for spring and early summer grazing; also they are of great importance as watersheds in some localities. Moreover, the large resident deer population on these lands constitutes a

[1] Received for publication October 17, 1942.

[2] Acknowledgment is made to the Works Progress Administration for assistance rendered through its Official Project No. 465–03–3–630, Unit B–12. Grants for the support of this project were also obtained from a special state appropriation for research in forestry in coöperation with federal agencies.

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valuable hunting and recreational resource accessible to large centers of population.

The western half of the northern coastal ranges, extending north and west from Santa Rosa and St. Helena, in Napa County, to a point 50 miles or more from Dyerville, in Humboldt County, ranks among the highest of the chaparral areas in economic importance. The slopes adjoining the narrow, fertile valleys are covered with chaparral and woodland-grassland, which are used extensively for the growing of cultivated crops, notably, fruits, grapes, and grains (fig. 1).

Timber production is also of importance commercially. A large island of second-growth pine, which is readily accessible and therefore of rather high potential value, is found in Sonoma County (fig. 2). The all-important red-

Fig. 2.—Distribution of timber regions in the foothill areas.

woods also occur in this region. These trees produce high yields per acre, and the cutover areas are readily restocked by sprouting or planting; this favors a permanent forestry industry (*74*)[4]. Except for the highly fertile flats, attempts to convert the redwood cutover lands to agriculture or pasture have been largely unsuccessful. These lands are difficult to clear, the invading plants are of low forage value, and artificial seeding to cultivated grasses is seldom successful (*17*). The lands around Clear Lake and along the Russian River are of high recreational value, being used for hunting, and in the more favored areas, for homesites. Lake, Mendocino, Humboldt, Sonoma, and Marin counties head the state in numbers of deer killed per square mile; but other

[4] Italic numbers in parentheses refer to "Literature Cited" at the end of this bulletin.

game animals are little hunted (*45*). These lands also function as watershed (*81*).

The relatively dry eastern-slope foothill region of the southern coastal ranges lying adjacent to the San Joaquin Valley, south from San Francisco, is predominantly covered with grassland and chaparral. Grazing is almost the sole industry, large areas being relied upon for seasonal pasturage. Although losing its nutritive qualities early in the season, the vegetation is so extensive and diversified as to afford fair-to-good grazing for various periods of time. The hunting of deer, pigeons, quail, and cottontail rabbits is another important land use.

The western portion of the south coastal strip has many uses. Recreational activities in the Santa Cruz Mountains and adjacent areas, as far south as Los Angeles, are enjoyed on a large scale the year round. Many week-end and summer residential homesites are located in these areas. Small retreats are especially abundant near the city of Los Angeles. The demand for this type of homesite has been recognized by the federal government, as evidenced by recent legislation.[5] The large populations of deer, cottontail rabbits, pigeons, and quail afford recreation; and coyote, fox, skunk, and raccoon, particularly on the foothills away from the coast, furnish a fairly large revenue of fur. From the standpoint of wildlife production the chaparral areas south from San Francisco are the most important in the state.

The chaparral lands along the western slopes of the Sierra Nevada represent the most diversified agricultural uses of the units here designated, largely because of diversity in climate, topography, and vegetation. The cover consists chiefly of pine timber, oak woodland, chaparral, and grassland. Irrigation favors the growing of fruits and various farm crops, but dry-land farming and grazing are also extensively pursued. The livestock raised in this region are grazed on the grass and brush areas during the spring and early summer months, and a fair proportion of the animals are moved to the mountain ranges of the national forests for most of the summer, being returned again to the foothills in the fall. At the upper limit of the chaparral areas is an interspersion of second-growth ponderosa pine (fig. 2). This forest area possesses great possibilities as a source of future timber. Although the stands are somewhat understocked, many sites are exceedingly productive, and the annual yields are high (*16*). These cutover pine stands are readily accessible and are rapidly approaching maturity, so that they will presumably come into strong demand in the near future. Their chief uses will be those of common lumber, box wood, mine props, pilings, posts, shingles, and shakes (*51*). Some of the lower areas which were formerly in forest might be replanted to timber, but the present high cost of reforestation, the high fire risk, the present limited demand for lumber, and the time required for the undertaking preclude putting them into timber at the present time. The area is also used as watershed. Many species of wild life found here serve as an important and inseparable part of the land values of this region; they attract recreation seekers and hunters from remote parts. Deer and mountain quail use the chaparral cover

[5] On July 27, 1940, the Izac Five-Acre-Tract Law went into effect. Under this law tracts of five acres are leased or sold by the federal government primarily for use as part-time camping, health, convalescent, or recreational homesites.

as a seasonal foraging ground. Also many species of fur animals furnish added local revenue.

With full recognition of the varied uses of the foothill area, the place of the chaparral lands must be fully acknowledged in the development of a land-use program for the state as a whole. Further study should aim at classifying them into their major permanent uses. To accomplish this satisfactorily implies intimate knowledge of the ecology of the chaparral cover.

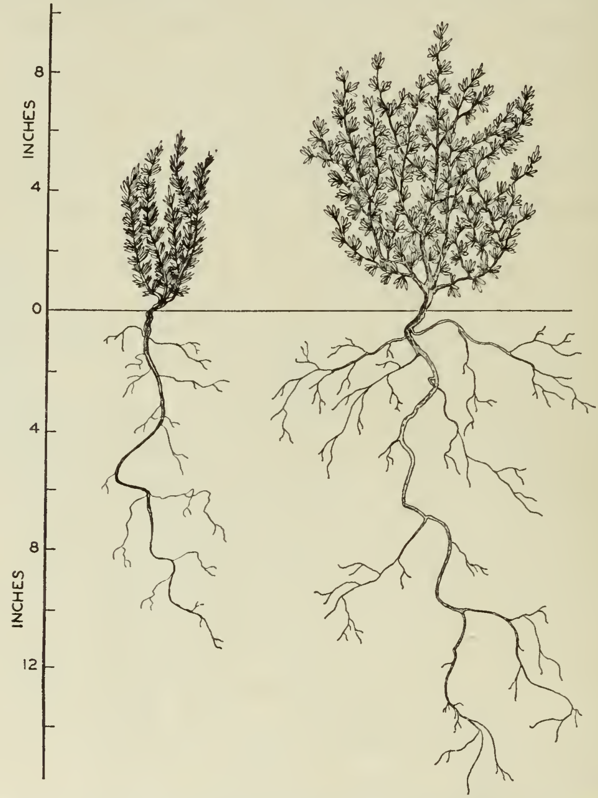

Fig. 3.—Left, chamise seedling, one year old, showing taproot 10 inches long. Right, chamise seedling two years old, showing extensive root branching.

ECOLOGICAL CHARACTERISTICS OF THE CHAPARRAL ASSOCIATION[6]

Knowledge of the ecological peculiarities of the chaparral association is basic to a consideration of the brush-control problem, and to the ultimate management of these lands. The present discussion considers the growth habits of chaparral vegetation, the climate and soils peculiar to these areas, and discusses the ecological characteristics of the chaparral vegetation by regions.

[6] In the nomenclature and characteristics of plants discussed in this bulletin, the author has in most instances followed W. L. Jepson, *Manual of Flowering Plants of California*, Associated Students Store, Berkeley, Calif. 1925.

GROWTH HABITS OF THE CHAPARRAL

The shrubs of the chaparral lands are closely branched, 2 to 10 feet in height, and somewhat treelike in appearance. The leaves are mostly small, thick and simple. Several prominent species have dual root systems, characterized by widely spreading superficial branch roots, and more or less of a taproot (fig. 3). The thin-leaved, deciduous, "soft brush" understory of the coniferous forests of the upper mountain slopes intermingles extensively with the more drought-enduring "hard" chaparral only in localities where conditions of growth are rather favorable.

The chaparral species may be conveniently considered in two groups—sprouting forms and nonsprouting forms; the most common species in each, including some of only local importance, are listed below. A complete list of species pertinent to this study, with scientific names, is given at the end of the bulletin.

Sprouting species

Brewer oak
California buckeye
California scrub oak
Canyon live oak
Chamise
Chaparral coffeeberry
Chaparral whitethorn
Coast live oak
Coast whitethorn
Deerbrush
Dwarf canyon live oak
Dwarf interior live oak
Eastwood manzanita
Greenbark ceanothus
Indian manzanita
Interior live oak
Leather oak
Lemmon ceanothus
Mission-manzanita
Poison oak
Ribbonwood
Shagbark manzanita
Toyon
Western mountain-mahogany
Woollyleaf ceanothus
Woollyleaf manzanita
Yerba santa

Nonsprouting species

Bigberry manzanita
Bigpod ceanothus
Blue blossom
Common manzanita
Cupleaf ceanothus
Gregg ceanothus
Hairy ceanothus
Hoary manzanita
Jim brush
Mariposa manzanita
Parry ceanothus
Parry manzanita
Pecho mountain manzanita
Pointleaf manzanita
Ramona bush
Serpentine manzanita
Stanford manzanita
Stripeberry manzanita
Wartleaf ceanothus
Wartystem ceanothus
Wedgeleaf ceanothus
Whiteleaf manzanita

Stands of nonsprouting species are killed when heavily burned or when chopped, but fields composed of sprouting species send up new shoots from the crowns or rootstocks when burned or cut back. The root crowns of chamise, like those of some sprouting species of manzanita, are distinctively swollen, enlarge with age, and develop rapidly but irregularly after a fire. The presence or absence of sprouting brush species, as shown in later discussions, greatly influences the methods and success of brushland clearing.

Another distinction between the different forms of chaparral is made according to leaf width. On this basis are recognized the broad-leaved forms as

TABLE 1

COMPARATIVE CLIMATIC AVERAGES OF FIVE CHAPARRAL REGIONS

Region*	Annual precipitation, inches			Winter precipitation,† inches			Summer precipitation,† inches			Snow, inches			Per cent of total precipitation each season				Annual temperature range, degrees Fahr.			Growing season,‡ days		
	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Winter	Spring	Summer	Autumn	Max.	Av.	Min.	Max.	Av.	Min.
Region I																						
In and near chaparral	59.74	34.62	17.14	33.22	19.72	10.69	1.75	0.55	0.15	50.7	34.0	23.4	57	22	2	19	116.0	56.6	−3	322	218	108
Entire region	86.31	38.03	17.14	50.27	21.65	9.51	2.04	0.74	0.15	106.4	46.5	22.0	57	23	2	18	128.0	57.0	−9	362	232	108
Region II																						
In and near chaparral	45.10	18.71	10.27	32.87	10.95	5.20	0.37	0.14	0.03	.....	....	....	58	26	1	15	113.0	57.3	0	350	267	160
Entire region	55.91	20.98	6.55	33.24	11.84	3.69	0.98	0.18	0.03	.....	....	....	56	26	1	17	116.0	57.8	0	360	273	160
Region III																						
In and near chaparral	38.61	25.74	13.01	20.08	13.31	3.28	1.85	0.91	0.05	51.4	30.8	6.7	52	32	3	13	118.0	58.2	−1	353	259	151
Entire region	47.97	18.75	6.41	25.42	10.26	3.28	1.85	0.37	0.03	68.9	36.7	6.7	55	30	2	13	121.0	59.9	−7	365	279	151
Region IV																						
In and near chaparral	63.31	33.83	16.21	32.58	18.24	7.80	1.11	0.63	0.19	130.80	63.22	23.80	54	27	2	17	116.0	58.1	−3	279	218	140
Entire region	69.63	37.67	10.03	36.63	20.15	7.80	1.42	0.59	0.14	273.60	96.25	23.80	53	29	2	16	122.0	57.3	−4	301	216	120
Region V																						
In and near chaparral	32.58	18.27	8.21	16.59	9.43	2.89	0.73	0.42	0.14	23.20	18.25	13.30	52	32	2	14	115.0	59.6	−2	265	210	175
Entire region	54.49	14.15	4.84	32.58	7.23	2.66	1.47	0.29	0.03	246.20	34.65	13.30	51	34	2	13	118.0	61.6	−2	274	237	175

* "In and near chaparral" includes climatic stations within brush areas and immediately adjacent thereto, for example, Santa Monica, but does not include stations a few miles remote from brush areas, as in central Los Angeles.

† Winter precipitation includes December, January, and February; summer precipitation includes June, July, August.

‡ Although the growing season usually implies the period from the last killing frost in the spring to the first killing frost in the fall, in areas such as those here concerned, many of which are virtually frostless throughout the year, the growing season includes that period of the year when temperature, moisture, and the soil conditions are favorable to growth.

contrasted with the slender-leaved chamise. Within the broad-leaved chaparral forms are many species whose leaves are from several to many times as broad as they are thick; these include both sprouting and nonsprouting species. The chamise, on the other hand, includes only one widely distributed species, which bears heathlike, needle-shaped leaves in fascicles. Chamise is a strongly sprouting form of chaparral. This distinction of chamise as a major component of chaparral has important ecological significance, for vast chaparral lands are dominated by almost pure chamise stands, and these stands are mostly found on sites of particularly low productivity.

Herbaceous plants form a sparse understory of more or less suppressed, mostly annual plants in undisturbed chaparral lands. Before burning of the brush, this undergrowth produces little seed, whereas after burning, the herbaceous forms grow robustly, fruit freely, and increase rapidly in numbers.

CLIMATE AND SOILS OF THE CHAPARRAL

Climate.—The foothills and valleys of California are characterized by rains which come late in the fall, in winter, and in early spring; by mild winter temperatures, and by hot, dry summers (*82, 83, 111, 112*). Eighty per cent or more of the yearly precipitation of the valleys and foothills occurs during the winter and spring seasons. Thus the climate is distinctly "Mediterranean." The yearly distribution of precipitation and temperatures in chaparral areas is shown in table 1, while the regions appear in figure 4.

The rapid growth period occurs in the spring months, especially March and April. At this time, the soil moisture is abundant, and air temperatures are far above the minimum necessary for growth. Most chaparral species also flower during those months; but in some species, such as the manzanitas, flowering starts as soon as growth begins, and continues until about late May, when growth for the year has practically ceased. In most species, the fruiting period is completed by June, a short time before the soil moisture is exhausted.

Chaparral occurs over a comparatively wide geographical range of precipitation and thermal belts of similar yearly patterns (*20, 75*). Areas of chaparral, although disrupted by areas of grass, are found from the margin of the fog-belt forest of the north-coast ranges to the edge of the deserts, except in the interior valleys and the higher mountains. This cover commonly occupies hillsides, and occurs only occasionally in the valleys, apparently because of increased depth of the soil and correspondingly stronger competition with grass cover. Climate, however, seems to play the major role in delimiting the principal boundaries of the chaparral association. The extremes of temperature and precipitation at critical periods for an extended length of time, rather than the average or mean of these values, appear to be the important climatic factors determining distribution of the chaparral. Thus this cover is found only limitedly, if at all, in the interior valleys and the deserts, where extremes of temperatures, in excess of 100° F, occur for several successive days at frequent intervals every summer. This is especially true where the average annual precipitation is below 14 inches. On the other hand, in localities where temperatures seldom exceed 100°, the chaparral may survive, even though the precipitation in some years drops as low as 10 inches. In such locations the stand assumes an open, desertlike aspect.

At the other moisture extreme, dense chaparral stands are rarely found where the average annual precipitation is in excess of 40 inches. In such heavy-precipitation zones, forest growth excludes the chaparral.

The relative humidity, and the direction and velocity of the wind, as indicated by various local studies, appear to have little correlation with the distribution of chaparral, except along the coast, where wind movement is more

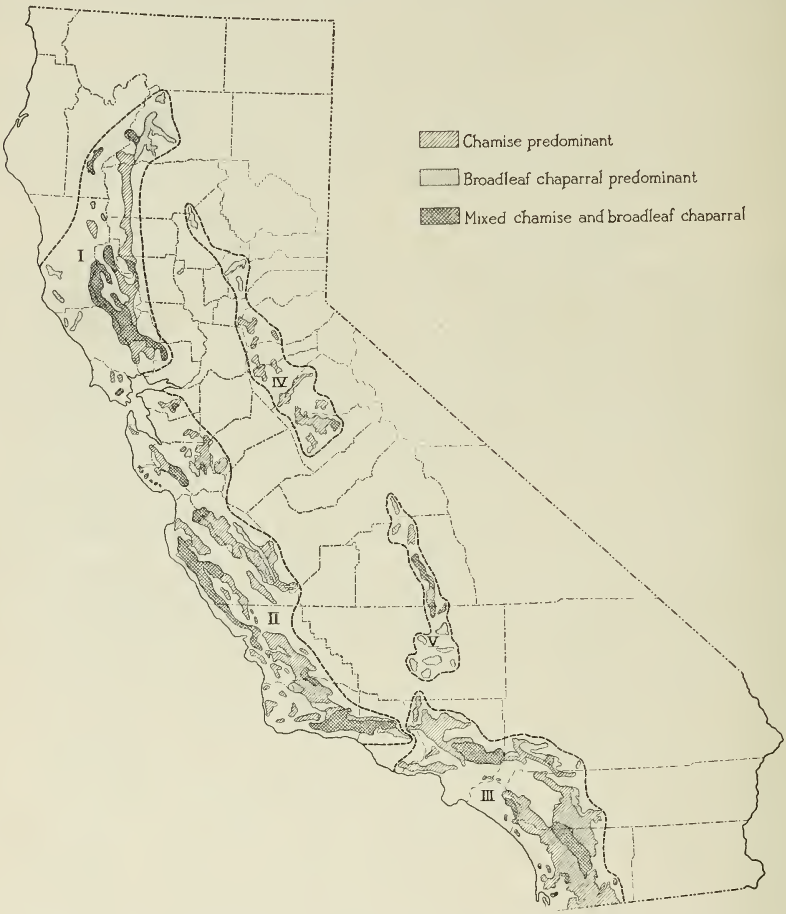

Fig. 4.—Distribution of the chaparral association by ecological regions.

or less continuous and often high. Grasses and prostrate shrubs dominate the wind-swept slopes facing the ocean, and trees are the predominant forms in the small protected valleys and coves along the coast. That the natural boundaries of chaparral are not rigidly defined by physical factors, but are strongly influenced by competition with other plant forms, is evidenced by the aggressiveness of chaparral invasions where the vigor of neighboring plant associations has been reduced by grazing, cutting, or fire.

Soils.—Chaparral is tolerant of widely different soil conditions (*103, 115*), being found on a large number of soil series. Some chaparral species occupy serpentine soils, which support few other plant species. Most of the dense stands of this hard brush, however, are found on relatively poor soils[7] where other plant forms fail to grow. These soils are usually shallow and are frequently interspersed with stones or concretions.

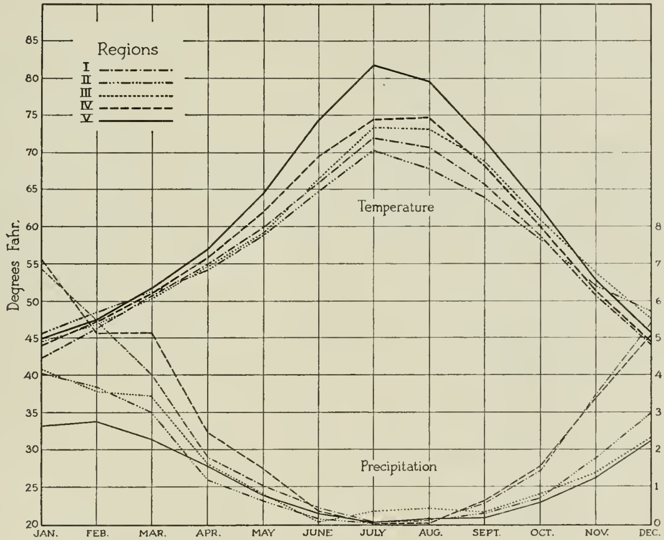

Fig. 5.—Comparative mean temperatures and precipitation in the five chaparral regions.

SPECIAL CHARACTERISTICS OF THE CHAPARRAL REGIONS[8]

On the basis of climatic variation, and differences in floristic composition, the California chaparral association may conveniently be separated into five ecological regions. These regions are designated in the present discussion as follows: (I) North Coastal Region, (II) Central Coastal Region, (III) South

[7] The term "good" or "productive" soil is here used to denote fairly deep soil, the subsoil of which is moderately to well covered with a layer of fine-textured, usually dark-colored top soil, and with relatively little rock outcrop or stony surface. Various luxuriant grasses and other herbs occur under the less dense brush and in the openings.

The term "poor" or "unproductive" soil is used here to denote areas whose soils are coarse textured or so thin, rocky, or low in organic matter that little grass or other palatable herbs will come in after the brush is burned. Serpentine or "green" soils, exposed subsoils, soft or hard bedrock, shale, or stones are indicative of unproductive soils. Little herbaceous growth is to be found under the brush or in the open spaces.

[8] Indebtedness is here expressed to the California Forest and Range Experiment Station of the United States Forest Service, and particularly to A. E. Wieslander, in charge of the cover-type-map compilation, for permission to use original field maps in the construction of this brush-distribution map, and for information on the vegetative characteristics of various species. Additional data for plotting were secured from the Geology Department of the California State Division of Mines, and from measurements and observations taken in the field.

Where distribution of the brush was questionable, as in certain northern counties, the present writer made a general survey to determine and verify boundary lines. Acreage was computed from planimeter readings taken from a large-scale map upon which the brush areas had been plotted as accurately as possible from the data available. Small islands separated from the larger stands of brush, which could not be shown on the small-scale map, have been disregarded in this computation. Moreover, jagged borders of the scrub cover, when transferred to the smaller-scale map, were of necessity smoothed out in many instances.

Coastal Region, (IV) North Sierran Region, and (V) South Sierran Region (fig. 4). Each of these regions has in common the same dominant growth forms, but there are differences in topography and, to some extent, in distinctive species. Differences in climate are also evident, as shown in table 1 and figure 5. Climatic averages and percentages were computed from the data of 346 county, state, and federal weather-reporting stations.

North Coastal Region.—This region extends northward from San Francisco Bay to Trinity and Shasta counties (fig. 4, I). Approximately the northern one fourth of this region, and the brush areas in the midwestern portion of Mendocino and Sonoma counties, support mostly broad-leaved chaparral, with only limited stands of mixed chamise-chaparral. The remainder of the region is composed of chamise and of mixed chamise-chaparral, in approximately equal proportions. The valley side of the coast ranges is dominated by chamise, whereas the coastal side of the range supports mostly mixed chamise-chaparral. Whiteleaf manzanita is conspicuous on the serpentine areas of Napa and Lake counties, and in the extreme northern portion of the broad-leaved chaparral association. The dominant chaparral species appearing in the region are listed below:

SPROUTING SPECIES	NONSPROUTING SPECIES
California scrub oak	Common manzanita
Chamise	Hoary manzanita
Eastwood manzanita	Stanford manzanita
Interior live oak	Wedgeleaf ceanothus
Leather oak	Whiteleaf manzanita
Western mountain-mahogany	

The climate of this region varies from the comparatively cool, humid coastal fog belt, to the drier region of the inner coast ranges, where the summer temperatures frequently exceed 100° F. The average temperature values for January are 39°, 44°, and 46° degrees, respectively, for weather stations immediately above, within, and immediately below the chaparral zone; and for July the average temperatures of the respective stations are 70°, 72°, and 73°. The corresponding mean annual temperatures are 53°, 57°, and 59°.

The average winter precipitation is the heaviest of the five chaparral regions, being 25, 18, and 16 inches above, within, and below the chaparral zone, respectively. The average annual precipitation is 46, 31, and 27 inches in these same zones. The average summer precipitation is less than 1 inch in any of the three zones. For seasonal divisions, see footnote of table 1.

The shallow Konokti soil series—a heavy clay loam soil of granular structure and with neutral to slightly acid reaction—supports the densest stands of chamise and chaparral in the region.

Central Coastal Region.—This region extends from the San Francisco Bay area, southward through the coast ranges to the Santa Ynez and San Rafael mountain ranges, covering Santa Barbara County and part of Ventura County (fig. 4, II). In most of this region chamise predominates, but chamise and broad-leaved chaparral occur along the coastal side of the ranges in Monterey and San Luis Obispo counties, and along the coast facing the Santa Barbara Channel in Ventura and Santa Barbara counties. Much of the broad-leaved chaparral is restricted to serpentine soils. The dominant chaparral species appearing in the region are listed below:

Sprouting species	Nonsprouting species
California scrub oak	Bigberry manzanita
Canyon live oak	Jim brush
Chamise	Parry ceanothus
Chaparral whitethorn	Wartleaf ceanothus
Eastwood manzanita	Wedgeleaf ceanothus
Greenbark ceanothus	
Interior live oak	

The average temperature values for January are 46° and 49° F, respectively, for weather stations within and immediately below the chaparral zone; and for July the average temperatures of the same stations are 70° and 65°. The mean annual temperatures are 56° and 58° within and below the chaparral, respectively.

The winter precipitation of this region is light, averaging 11 inches within the chaparral and in the zone below; and the average annual precipitation is 18 and 19 inches, respectively, for these zones. No rainfall, other than traces, has been recorded during the summer in the chaparral, and an average of only 0.2 inch has fallen below the chaparral; the region is practically without snow.

Chaparral is the dominant vegetation throughout, there being no forests except in small protected valleys along the coast, and on some of the higher peaks where the precipitation is greater.

There are fewer valleys than in the North Coastal Region, but some, like the Salinas Valley, are more extensive. Also there is a wide variety of soils, most of which have been derived from sedimentary or mixed parent materials. In some localities poor drainage and alkali are serious deterrents to plant growth. The extensively occurring sandy or loamy-sand soils of this region are perhaps the most easily eroded of California soils.

South Coastal Region.—This region extends through the counties of Ventura, Los Angeles, and San Bernardino, south to Lower California (fig. 4, III). The brush is confined to the coastal ranges, and to the San Bernardino Mountains, the area to the east being largely desert. The native vegetation is predominantly chamise. A rather extensive area of intermingled chamise and broad-leaved chaparral cover, however, occurs in the San Gabriel and San Bernardino mountains, and an area of predominantly broad-leaved chaparral extends south through the Cuyamaca Range, from Riverside County into San Diego County. Numerous small areas of broad-leaved chaparral are also found along the lower limits of the extensive chamise belts. The dominant chaparral species are listed below:

Sprouting species	Nonsprouting species
Canyon live oak	Bigberry manzanita
Chamise	Bigpod ceanothus
Chaparral whitethorn	Cupleaf ceanothus
Eastwood manzanita	Hairy ceanothus
Interior live oak	Parry manzanita
Mission-manzanita	Wartystem ceanothus
Ribbonwood	Wedgeleaf ceanothus
Western mountain-mahogany	

The average temperature values for January are 38°, 46°, and 52° F, respectively, for weather stations immediately above, within, and immediately below the chaparral zone; and for July the average temperatures of the same weather stations are 70°, 73°, and 73°. The average annual temperatures for these stations are 54°, 59°, and 62°.

This unit of the chaparral association is marked by low precipitation. The average winter rainfall is 19, 11, and 9 inches for weather stations above, within, and below the chaparral, respectively; and the average annual precipitation for the same stations is 39, 22, and 16 inches. An average of 1 inch of rainfall has been recorded during the summer months above and within the chaparral, whereas mere traces of rainfall have been recorded in the zone below the chaparral. Rainfall appears to be the most decisive factor in limiting the extent of the brush cover in this region, but here the most extensive and diverse hard-brush areas of the state occur. The brush is apparently a climax, or permanent cover, over the greater portion of these foothills.

The topography of this region is extremely irregular, extending from sea level to more than 8,000 feet, a condition which gives rise to many soil types. Several of the soil series have an "iron" hardpan beneath the loamy coarse sand. Most of these soils are relatively infertile; hence they support only sparse vegetation.

North Sierran Region.—This region extends from Butte and Tehama counties, southward along the Sierra Nevada foothills to Mariposa County (fig. 4, IV). The chaparral occurs intermittently within open forests and is composed of isolated stands, compared with the extensive areas of the coast ranges. North of Bear River the brush fields are essentially composed of broad-leaved chaparral, whereas south of the river, a combination of chamise and broad-leaved chaparral predominates. The dominant chaparral species of this region are given below:

Sprouting species	Nonsprouting species
Brewer oak	Mariposa manzanita
California scrub oak	Wedgeleaf ceanothus
Chamise	Whiteleaf manzanita
Indian manzanita	
Toyon	
Western mountain-mahogany	
Woollyleaf ceanothus	

This is essentially a region of localized climates, modified by topography. The precipitation and temperature factors for the region, and for the adjoining areas, are summarized as follows: The average temperatures for January are 41°, 44°, and 46° F, respectively, for weather stations immediately above, within, and immediately below the chaparral zone; and for July the average temperatures of the same weather stations are 73°, 74°, and 79°. The mean annual temperatures are 56°, 59°, and 60° for the corresponding stations.

Here the winter precipitation is 26, 17, and 11 inches, respectively, for stations above, within, and below the chaparral, whereas the average annual precipitation is 49, 32, and 20 inches, respectively. During the summer months, an average of approximately 1 inch of rainfall is received above the chaparral; none has been recorded within or below the chaparral zone.

Much of the annual precipitation comes as snow, the yearly distribution being somewhat similar to that of the north-coast ranges; but here the average annual precipitation in the brush areas may vary from 10 to 60 inches in different years in the same localities. Also the extremes of temperature are greater than in any other chaparral area of the state.

South Sierran Region.—This region forms a rather narrow strip along the foothills, through Tulare County, and into central Kern County (fig. 4, V). Its nearest chaparral connection toward the south is in the South Coastal Region in Los Angeles County; on the north the chaparral is separated from the North Sierran Region by Madera and Fresno counties, in which there are no extensive brush fields. The northern portion of the region, in Tulare County, has a cover of chamise and chamise-chaparral in about equal proportion, whereas the southern portion, in Kern County, has no chamise and is made up entirely of a broad-leaved chaparral cover. The dominant chaparral species appearing in this region are as follows:

Sprouting species	Nonsprouting species
Brewer oak	Mariposa manzanita
California scrub oak	Wedgeleaf ceanothus
Chamise	
Interior live oak	
Western mountain-mahogany	

Because of aridity and high temperatures, this region is not especially favorable to the growth of brush, as the following summary shows. The average atmospheric temperatures for January are 40°, 45°, and 47° F, respectively, for weather stations immediately above, within, and immediately below the chaparral zone; and for July the temperatures are 73°, 82°, and 83° for the same stations. The mean annual temperatures are 54°, 61°, and 63° for the corresponding stations.

The precipitation is limited in this region; only 9, 10, and 6 inches of precipitation is received during the winter months at stations above, within, and below the chaparral region, whereas the annual mean precipitation for these stations is 18, 16, and 11 inches, respectively. Only traces of rainfall have been recorded in these three zones during the summer months.

The average precipitation is the lowest, and the average length of the growing season the shortest, of these factors in the five chaparral regions. Unlike the short growing season in the North Sierran Region, however, which is limited primarily by frequent frosts, the growing season of the South Sierran Region is severely limited by high temperature and low moisture availability.

The soils are similar in most respects to those of the North Sierran Region, except that there are fewer well-developed profiles. The more shallow, rocky soils are predominantly derived from acid igneous rock. There are also a few scattered areas with soils of basic igneous derivation. The Vista soil series, which is neutral in reaction, and is derived from acid igneous rock, is most characteristic of the chaparral areas in this region.

To summarize: The data presented indicate that temperature and precipitation are the most important factors in determining the general distribution of the chaparral cover. Extended periods of cold and snow in the winter, or several consecutive days of temperatures higher than 100° F recurring throughout the summer, appear important in limiting the distribution of the hard-brush association. Annual precipitation below approximately 10 inches is evidently insufficient to maintain chaparral, and annual precipitation over 35 to 40 inches is apparently more favorable to forest growth which usually replaces the chaparral in such climatic areas.

SURVEY OF VIEWPOINTS AND PRACTICES CONCERNING BRUSH BURNING

A survey of past and present management practices prevailing in chaparral lands influenced the planning of certain aspects of the studies reported here. Although conflicting interests and viewpoints have made the practice of brush burning a controversial one, outspoken expression of these points of view has perhaps exaggerated the problem. Among the viewpoints frequently supported by various factions is that of the favorable effect of the Indians' holding the brush in suppression. Thus it is contended by some that until fires were curtailed by state laws an acute brush-invasion situation did not exist. A review of the burning activities of the Indians, and of the state fire-control policies, together with a consideration of experiences and attitudes of stockmen concerning brush burning, is presented in the following pages.

BURNING BY INDIANS IN CALIFORNIA

According to some advocates of broadcast burning, the Indians of California burned vegetation so frequently and extensively before white men settled in the region that the brush was kept down, and the timber and woodland kept open. Others claim that most of the fires were accidental, and not purposely set. Since the assertions of widespread burning by the Indians have not hitherto been studied closely, this phase of the present investigation was undertaken in an attempt to bring together the most reliable documentary evidence on the following questions: Why, where, how extensively, and under what conditions did the Indians burn grassland, chaparral, and forest? Answers to these questions are summarized here, according to the most reliable documentary evidence available.

"Broadcast burning" has become a common term, and is used here to denote burning of standing brush or other cover, with or without the adequate safeguard of fire breaks, and with or without the presence of an adequate crew of ranchmen during the burning.

The term "controlled broadcast burning" is here used to imply so-called "sanctioned" burning of standing brush or other vegetation through the granting of a permit, issued by the State Division of Forestry. The season and actual time of burning, location of firebreaks, and size of the crew deemed necessary to control the fire are stipulated or recommended in the regulations.

Critical review of the mass of documents published from 1542 to about 1853 leads to the conclusion that California Indians burned vegetation, limitedly at least, to facilitate hunting, to secure native plant foods, and to clear small areas of woody vegetation for the growing of tobacco. But these same documents indicate that the fires were seldom extensive. Kroeber (*56*), Barrett,[9]

[9] Barrett, L. A. A record of the forest and field fires in California from the days of the early explorers to the creation of the forest reserves. Official records of U. S. Dept. Agr., Forest Service, Region 5, San Francisco. 1935.

and Barrett and Gifford (*7*) incline to the belief that burning by Indians was somewhat general in California, but that by far the most extensive and destructive fires have occurred since the coming of the white man. An indication that Indians probably did not burn extensively is suggested by the fact that only a small proportion of the more than five hundred narratives examined even mentioned fires in grassland, brushland, or forest.

Some Indians, notably those of the central Sierra Nevada, are reported to have cleared the underbrush with fire to facilitate travel, hunting, and planting. Gordon-Cumming (*28*), for example, stated in 1883 that the Indians in the Yosemite Valley burned some areas so frequently as to keep down the woody undergrowth. The Miwok Tribe, which inhabited the eastern edge of the grassland, and whose territory extended through the brush and into the lower part of the tree zone, burned grassland somewhat frequently, according to Barrett and Gifford (*7*). These Indians probably did little to prevent the spread of fire to the trees, and some of the fire-scarred older trees may have come about from such grass burning (*28*). Drucker,[10] however, concluded that in Riverside, Orange, and San Diego counties the Indians did not set fire to the brush or trees. Nothing was found in the literature to refute this.

A few chroniclers reported Indian burning as locally destructive. Thus Costanso (*21*), who was on the Portola expedition to San Francisco Bay in 1769–1770, reported that at one point near the present Palo Alto, the progress of the expedition was halted because of the absence of pasture where the natives had burned. Palou (*72*), with the same expedition, reported several burns along the coast. Of one place in Monterey County, he stated that "the soil is whitish and short of pasture on account of fires set by the heathen."

In a critical review of this manuscript, however, the late Dr. C. Hart Merriam, who devoted much of his life to the study of California Indians, stated in 1935 that he did not recall having heard of the use of fire in agriculture by the Indians except to clear the tiny spots used as seedbeds for tobacco. This conclusion is corroborated by Kroeber (*56*), who also points out that the Indians of the northwestern part of California practiced some degree of controlled burning in the preparation of seedbeds for small patches of tobacco.

The use of fires to drive rabbits, deer, and other game into the open, or into ambush, is reported by a number of writers (*7, 10, 22, 46, 52, 53, 69, 100*). Before the valleys were settled by white men, the native tribes living in the grassland area burned small circular areas occasionally to collect grasshoppers and small game (*5, 11, 33, 44, 53, 77, 105*).

Fire was also used to some extent by the Indians as a means of obtaining plant food. Hinds (*40*) and Belcher (*12*) of H.M.S. *Sulphur* noticed in 1837 some trees and stands of small shrubs burning along the Sacramento River. They mentioned that the natives set fire to the bases of large oak trees, thereby destroying some of them while attempting to get acorns. Helper (*34*) reported that the Digger Indians, when driven by extreme hunger, collected acorns by burning down oak trees the bark of which was used as a storage chamber of these fruits by birds. Kroeber[11] reported some burning in oak groves for the

[10] Drucker, Philip. Field notes taken in 1934–1935. Official records of Department of Anthropology, University of California, Berkeley, Calif.

[11] Kroeber, A. L., Professor of Anthropology, University of California, in a memorandum to the author dated September 3, 1941.

purpose of clearing ground so that acorns could be collected more easily. Baxley (*9*) observed that Indians in Yosemite Valley burned small areas to facilitate gathering of their winter supply of acorns and wild sweet-potato roots. Gibbs (*27*) reported that Indians burned grass spots along the Russian River so that aniseed might be collected with greater ease.

Kroeber concluded that the Indians burned "considerably" in both open country and forest for various reasons, but he expressed the opinion that "this burning was not indiscriminate, but tended to be limited to certain tracts in which they were interested." This worker furthermore concluded: "In general, the Indians nowhere burnt the chaparral with the idea of getting rid of it. A good stand of it is harder to get through after burning than before. If they fired the chaparral occasionally it was with the idea of driving the game out." Kroeber also affirmed that "the aggregate extent [of California lands] burned over occasionally or more or less regularly must have been considerable," but he expressed uncertainty as to whether burning in brushlands was extensive.

Various other references (*9, 12*) indicate that Indian burning of brushlands was on such a restricted scale that it could have influenced little, if at all, the present composition, or the distribution, of the chaparral over the state. This conclusion is supported by the fact that the major Indian population was along the coastal slopes and in the valleys, away from the present distribution of the chaparral lands. A compilation by Kroeber (*56*), giving the geographical ranges and population of tribes before the coming of the white man, shows the distribution to be as follows:

Area	Indian population
Coastal	62,500
Valley	54,500
Plateau	8,500
Mountain	7,500
Total	133,000

Areas remote from the coastal and valley regions evidently were relatively little subject to directed or systematic burning. It is probable, therefore, that at least a fair (if not the major) proportion of the fires reported by the early explorers at the higher elevations were started by lightning, as they are today.

Review of historical documents indicates that the California Indians frequently used fire temporarily to clear various kinds of lands, including some chaparral areas, for different purposes. Since the few Indians who lived in the brushfields were apparently interested chiefly in local or "spot" burning to facilitate hunting of deer, it seems doubtful that they burned frequently or extensively enough in the chaparral association to keep much of the cover open, or that such burning resulted in either expansion or contraction of the brush cover as a whole. Evidently areas remote from the coastal and valley regions were little subject to Indian burning. A large proportion of the fires reported by early explorers, particularly in the higher elevations, were presumably started by lightning. Accordingly, study of Indian burning in California is historically interesting, but of little application in the present-day effort of brush suppression.

HISTORY OF STATE FIRE-CONTROL POLICIES PERTAINING TO BRUSHLANDS

Although burning of vegetation antedates the advent of the white man, it was apparently not until after the gold rush of 1849 that burning was entered into on an extensive scale. Legislative recognition of the effects of fire is first found in a proclamation against burning practices issued by Governor Jose Joaquin Arrillago on May 31, 1793. The statement comments on the serious damage done by fires started by "Christians and gentiles," and suggests that offenders be punished when fires are started.

Early Legislation.—The first fire legislation in California was passed in 1872.[12] This law made the setting of fires on state or federal lands an offense punishable by fine or imprisonment. This legislation, however, was poorly enforced, and consequently was of little avail in controlling burning (*80*).

Effective legislation against promiscuous burning awaited a more aroused public consciousness, which came shortly after the creation of the national forests. On March 18, 1905, an act "to provide for the regulation of fires on, and the protection and management of, public and private forest lands," was passed by the legislature and approved by the governor (*15*). Malicious or negligent setting of fires on land, other than that owned by the individual, or allowing fires to escape to other lands, was defined as a misdemeanor and made punishable by fine or imprisonment. Burning of brush, stubble, or other vegetation on any lands without a permit was illegal between May 15 and October 31. Restitution of damage from fire which escaped from private lands was made possible by holding the offender liable for double the amount of damage, provided such escaped fires were due to neglect; but the offender was liable only for the actual damage if the fire spread from unavoidable causes. Administration of the act was provided for by creation of a Division of Forestry, a State Board of Forestry, and the office of the State Forester. The function of the State Forester was to carry out the policies adopted by the Board (*14, 15*).

Reorganization of the administration of state resources was undertaken in 1927, with the creation of a Department of Natural Resources. The Division of Forestry was made a part of this organization under the jurisdiction of a State Board of Forestry and a State Forester. At this time fire legislation was changed but little; the definitions of offenses were retained as in the original law, but the punishment was made more severe. Liability for damage was set as the costs of the actual damage and control of the fire. Burning on any forest land, grassland, or brush area without permit was prohibited between April 15 and December 1 (*15*).

Despite the strict effort at prohibition of fire, and the efficient control system of the state and federal forestry services, fire has continued to be a major problem in the state. The fire problem has been further complicated by the belief of many landowners that strict fire control is impracticable and undesirable (*13, 70*). This view apparently applies particularly to the chaparral areas of northern California (*91*).

First Investigation on Controlled Burning.—The desire for more practical knowledge on the question of burning was crystallized in 1930, when, on

[12] For source see footnote 9, p. 18.

demand of the stockmen, the Conservation Committee of the North Coast Council, California State Chamber of Commerce, requested the State Board of Forestry to delegate two members of the Board to investigate "clearing of brush" by burning in Lake, Mendocino, and Sonoma counties. Sheepmen in those areas desired that the State Board of Forestry adopt a policy favorable to livestock operations because they felt that it provided a means of maintaining their ranges in a somewhat more productive state.

The conclusions of the survey were that, in general, burning appeared to be detrimental, but that on limited areas burning did show some promise of temporarily increasing the range carrying capacity. General burning of the lands in question was considered inadvisable because of their watershed and recreational values. As most of the chamise-covered areas responded poorly after a fire, it was concluded that the adoption of a burning program would probably be of little value as a general measure.[13]

The committee on burning recommended that the Board of Forestry take no formal action on the question, but that the State Forester instruct inspectors in Lake, Mendocino, and Sonoma counties to issue burning permits on areas approved by the local county farm advisor, or by some other state agricultural agency. In this connection, a state forest ranger gave his entire time to coöperation with the citizens of Mendocino County; but since the results of this undertaking were reported to be unsatisfactory, this plan was also discontinued.

State-Controlled Brush-Burning Policy.—Further progress on the question of burning of brushlands in public and private ownership was made on March 26, 1932. On this date the State Board of Forestry adopted a resolution to segregate the lands under its jurisdiction into units of strict fire protection as compared with those of intermediate and of limited importance in fire suppression. Three vegetation zones were recognized with respect to importance in fire protection. Zone 1 consists of the more valuable timber and watershed lands, and also includes state parks and monuments, as well as other such areas subject to serious economic loss by fire. The lands of Zone 2 are regarded as "buffer" or boundary strips between the grasslands of the valleys, and the forests of the higher elevations. They embrace much of the brushy cover and the rougher privately owned woodland-grass areas, hence are less important in the matter of fire protection. The lands of Zone 3 include the grassy valleys and agricultural lands, and are chiefly of local interest.

Reports on the brush-burning coöperative policy following the 1938 field season appeared to be somewhat favorable with respect to decrease in incendiarism.[14] From the upper Sacramento Valley region, and the north coast area, came reports of some decrease in malicious burning. In 1939, on the other hand, incendiary fires covered an unusually large acreage; but the number of incendiary fires was again somewhat lower in 1940. The State Forester expressed the belief that some success in reducing incendiary fires is being achieved through the coöperation of the California Wool Growers' and the

[13] Report by H. S. Gilman and Swift Berry on range clearing under state burning permits on private lands in north coast counties outside of national forests to the State Board of Forestry. November 29, 1930.

[14] Report by C. G. Strickland, Deputy State Forester, to the State Forester on agricultural and range improvement brush-burning policy. November 16, 1938.

California Cattlemen's associations.[15] It is realized, however, that the data on incendiarism are still meager and that before concrete recommendations can be made, more accurate knowledge of the values, relative gains, and losses to the present and future vegetation and soil must be obtained. Preliminary information on some of these points might be obtained by contact with representative stockmen.

EXPERIENCES AND ATTITUDES OF STOCKMEN CONCERNING BRUSH BURNING

In the course of the present study, it seemed desirable to secure a cross section of the observations and convictions of successful livestock men operating in or near the brushland areas of northern California counties. It was hoped that such a survey would not only provide a picture of current sentiment on brush burning, but might also point to some of the more practical phases of the subject especially in need of study. Accordingly, a questionnaire was prepared in 1934, which formed the basis for a series of interviews with stockmen in the same year. In Lake, Mendocino, Humboldt, Shasta, Tehama, and Colusa counties, 85 operators were consulted. To ensure that the views obtained should be those of stockmen with long tenure, broad experience, and respected judgment, the farm advisor of each of the above-named counties furnished a list of owners who he especially felt should be consulted. The men from these lists, most of whom were large operators, filled out copies of the questionnaire while being personally interviewed and were, in addition, questioned in detail on related points.[16] Most of the field contacts were made during the summer and autumn of 1934. The following are the chief points embraced in the questionnaire: Location of ranch, and acreage of chaparral and other lands; kinds and number of stock owned; number of stock grazed before and after burning; condition of the animals; frequency of burning; quality and palatability of the forage; extent of erosion; damage to improvements; cost of burning; injury from snagging; and losses from poisonous plants.

From 11 to 24 men were interviewed in each county except Colusa, where only 3 were questioned. A total of 638,729 acres was included in the survey, of which 96,000 acres were brushlands, much of which had been burned at one time or another. Excluding Colusa County, the stockmen who were consulted controlled an average of 10 per cent of the total brushlands in their respective counties, 12 per cent of the sheep, and 26 per cent of the cattle. The stability and success of operation among these men are indicated to some extent by the fact that more than half of them have owned their ranches for twenty-five to fifty years before the interviews.

There was little agreement in response to questions on the quality of forage on burns. Thirty-four out of 85 of the men interviewed said that the quality of forage on burns was "good," but 25 said that burning made no difference in forage quality. Smaller numbers stated that the forage on burns was "fair" or "poor." Thus opinion seemed to be sharply divided between two extreme

[15] In a letter to the author from M. B. Pratt, State Forester, dated August 11, 1941.

[16] Most of the interviews were conducted by J. O. Bridges, a graduate student of range management in the Department of Forestry, University of California.

positions. The great variation in the quality of the soil and in the kinds of brush doubtless accounts for the wide variation reported in the amount and quality of the forage.

More general agreement was reflected in the answers to the question on the condition of the animals grazed. Fifty-two men out of 85 agreed that the condition of animals grazed on burns was "good," 25 men said that it was "fair," whereas 6 stated that the condition was "poor." Several men pointed out that the period of satisfactory forage use on most brush areas is only in the spring and that these lands are commonly utilized only at that time.

Considerable hesitancy seemed to be shown by the stockmen interviewed when asked to estimate changes in the original grazing capacity of their lands irrespective of burning. Of the 85 men consulted, only 58 reported, and 28 of these would make no grazing-capacity estimates. Those men who would hazard an estimate were almost evenly divided among the opinions that the grazing capacity of their ranches had decreased from the original, that it had increased somewhat, or that it had remained constant. Some of the men who reported a decline in forage attributed it to encroachment of brush. It was evident that the ranchers as a group were not accustomed to considering the carrying capacity of their pasture land in quantitative terms.

Similar uncertainty was noted in the responses to the slightly different question as to how much the desirable feed was increased or decreased by burning brushlands. Again, the answers were almost equally divided among those who believed that there was no change in the amount of desirable feed, that there was a slight increase, or that there was an appreciable increase in desirable forage. Only 1 man out of the 76 answering believed that the increase amounted to as much as 75 to 100 per cent for a considerable period of time after burning, while several men believed that there was a definite decrease. There was a tendency in Shasta and Tehama counties, however, for stockmen to value the forage of burned areas appreciably higher than did the men of other counties.

Answers to questions on the frequency of chaparral burning in the past showed that by far the most prevalent practice in the counties concerned is that of broadcast burning every eight to fifteen years. Few men had made a practice of burning patches each year, but a few reported broadcast burning at fairly regular intervals of five to ten years. Again Shasta and Tehama counties were distinguished from the other counties in that none of the Shasta and Tehama men reported planned or systematic burning programs.

While an appreciable number of stockmen preferred to make no statement as to whether the brush was killed and the invading grass made permanent, among those men who did express an opinion, the conviction seemed overwhelming that the brush is *not* killed by fire. This majority agreement was common to all the six counties surveyed.

Although the majority of stockmen reported that they had burned their brushlands every eight to fifteen years, most of them seemed convinced that more frequent burning would be desirable from the standpoint of increased palatability and yield of forage. About one third of the answers favored burning every two to three years if it were possible, while another third favored burning at intervals of four to five years. Smaller numbers believed that burning should take place at intervals of eight to fifteen years. A relatively small group of men had been convinced by experience that burning on their land was never desirable. Most of the stockmen believed that there would be enough fuel in the brush for another burning by the fifth or sixth year. Indeed, a few believed that fire could be run through the brushfield every year. The apparently general conviction that burning increases the palatability and yield of forage on brushlands is especially interesting in the light of the hesitation and uncertainty of the stockmen in estimating benefits on their own ranches.

Few of the stockmen considered erosion to be an important consequence of brush fires. Nearly three fourths of the men believed that soil erosion is insignificant in their region, both before and after burning. A few had observed small increases in soil erosion the first year after burning, while a small number reported a considerable increase in soil loss during the first year after a fire. Only 2 men of the 80 questioned on this point expressed themselves as being aware of serious erosion. Part of this general failure to observe appreciable erosion after brush fires seems to have resulted from lack of training in detecting soil movement, and lack of understanding in evaluating its importance. On numerous ranches showing advanced sheet and gully erosion, the stockmen averred that the loss of surface soil was not serious.

From one third to one half of the stockmen in different counties reported accidental damage to property as a result of brush burning. Grassland, fence, hay and grain fields, and farm buildings were reported burned. Less than half of the damaging fires were admittedly caused by stockmen. Motorists and hunters were blamed for most of the damage.

There was considerable variation in the reports on damage to livestock on chaparral burns. Of the 79 men consulted on damage to livestock, 49 made no report on injury to lambs by snagging. Twenty-seven men reported that no snagging occurred, whereas 3 men, all from Tehama County, reported that some lambs were snagged. Ten men reported some wool pulled out by the dead, burned stems, whereas 13 men reported no greater loss of wool than before burning. Since 44 men made no report on the loss of wool, it seems likely that they, too, failed to observe any such loss. Twenty-two men reported losses of cattle and sheep from poisonous plants (*65*). It may be significant that 16 of these were from Shasta County. Larkspur was blamed for more losses than any other plant genus, but death camas was also blamed for some losses, especially sheep (*66*). Eleven of the 16 men reporting livestock deaths from poisonous plants in Shasta County were unable to identify the plant or plants causing the losses. Thirteen men reported losses of cattle, while only 6 reported losses of sheep from poisonous plants.

Questions on the extent of firebreaks needed in the chaparral-burning operation, their cost, and the cost of burning, revealed that 36 men out of 80 consulted do not intentionally burn their brushlands. Part of these men refrain because they have become convinced that exclusion of fire is the best policy. Others do not burn because brushland comprises only a small part of their pastures. Still others are dissuaded by danger to their own or neighbors' croplands and pasture areas, buildings, and fences, or by the responsibilities imposed by the state laws. Most of those who practice burning reported that only a backfire is necessary for control, but a relatively large minority reported that more extensive control measures are necessary. It is interesting to note that in Lake County no one believed that control measures more elaborate than backfires were necessary, whereas in Tehama County 8 out of the 10 men consulted believed that greater precautions were necessary.

Estimates of the cost of firebreaks and of burning were given with great uncertainty and hesitation. Only 6 men reported definite costs of burning. These ranged from 5 to 10 cents per acre in Lake County to 5 dollars per acre in brush and timber in Humboldt County. Most stockmen believed that proper control of more or less isolated areas can be achieved with a small labor cost, whereas in other instances the cost of burning is high.

The survey as a whole showed that 50 out of the 85 men questioned favored the burning of brushfields, but emphasized the importance of protecting grasslands and cultivated areas. Twenty more men recommended the burning of all natural vegetation types not especially suitable for timber growth. Only 14 men were against burning of all kinds of natural vegetation. In view of the uncertainty shown by stockmen in their answers to questions concerning the effects of fire on the quality of forage, and the carrying capacity of their lands, the sentiment in favor of burning was apparently based more on common belief than upon firsthand experience. The sentiment favoring burning was especially strong in Shasta and Tehama counties. Eighteen out of the 20 men who favored burning of all types of woody vegetation lived in Shasta and Tehama counties, whereas no one from these counties was against some form of burning. The survey strongly revealed the need of critical study of plant succession and related aspects of chaparral burns.

PLANT-SUCCESSION STUDIES ON CHAPARRAL LANDS

REVIEW OF RESULTS BY EARLIER WORKERS

In southern California and on various sites of severe conditions elsewhere in the state, the chaparral association, especially when dominated by chamise, is generally regarded as forming a climax cover, or the final stable vegetation (*18, 75*).

The climax cover is not always the most desirable for grazing. Restriction of grazing on some ranges of the Wasatch Mountains of Utah, for example, to favor complete reëstablishment of the wheatgrass climax vegetation, resulted in economic loss. In that connection Sampson (*88*) pointed out that in certain covers in Utah it was most desirable to favor the next highest successional stage—the needlegrass and yellow brush—while at the same time maintaining a fair amount of wheatgrass.

Both the nature and the duration of changes in vegetative cover resulting from burning depend on many factors, notably climate, topography, soil, nature of the original vegetation, and land-use practices. Topography,[17] through the effect of slope and exposure, may directly affect succession subsequent to a fire by causing variation in soil temperature and soil moisture; and it may indirectly affect succession through its influence on erosion. Larsen (*58, 59*), for example, found that steep south slopes present a serious situa-

[17] Climatic factors of the chaparral association are discussed on p. 11.

tion on burns in Idaho, where erosion is so pronounced in many places as to prohibit establishment of all but the hardiest pioneering plants. Topography also largely regulates the intensity and the extent of fires, hence determines when and where islands of the original vegetation may be left for regeneration (*49*). Show and Kotok (*96*) concluded that topography is one of the most important factors determining local distribution of brush in California. Certain topographic features favor hot fires, which may partly destroy the established vegetation and its accumulated litter, and permit invasion by brush (*98*).

The severity of the burn may affect succession by its influences on the existing stand, on the accumulated seed, and on the soil itself. Isaac (*48*) believes that the ground cover present in original Douglas-fir forests, and the extent to which it is killed out by fires, partly determine the extent to which invading colonies of weed and brush species appear in the succession that follows. Some of the original invading species persist, while others die out (*86, 87, 88*). In the Pacific Northwest, exposure to direct sunlight resulted in raising temperatures in the surface soil so high that seedling plants were killed (*41, 48*).

Many shrubs show remarkable capacity to sprout after a fire; hence rapid revegetation of burned areas may generally be expected after burning such vegetation. Plummer (*75*), working with chaparral in California, noted rapid recapture of the lands by chamise, and some species of chaparral, after burning. Cooper (*20*), on the other hand, concluded that whereas a single or intermittent burning of California chaparral resulted in a crop of sprouts more dense than before, yearly burning, though seldom possible because of insufficient fuel, tended to destroy the brush, or prevent its further invasion. This worker also contended that extensive areas now dominated by grass, or by scattered stands of drought-enduring trees, were formerly controlled by chaparral, or had been kept in a grass cover by repeated burning, and would eventually support brush if fire were eliminated. Cooper (*20*) further concluded that along its border of mesophytic climax, California chaparral has transgressed its normal climatic limits through invasion into the forest, whereas along its bordering dry zone it has been pushed back by grass and drought-enduring plants in the north, and by coastal sagebrush in the south. Fire is claimed to be the causative agent in each case. Isaac (*49*) agrees that most sprouting brush species are retarded by one fire, and some may be killed out by successive fires. His evidence indicates, however, that successive fires in some plant covers prolong the presence of weeds and brush. Clements (*18*) concluded that repeated fires of the past are indicated by extensive occurrence of sprouting chaparral.

Ingram (*47*), working on Douglas-fir cutover lands, noted that various shrubs soon reclaimed the soil unless they were reburned at three- to five-year intervals. This worker pointed out that the use of fire to convert forest land to grazing should be carefully controlled because of the many failures recorded. Although frequent burning is necessary to suppress the brush, this practice often results in heavy invasions of bracken fern, a species of no grazing value.

It has been generally assumed that revegetation of burns formerly occupied by a nonsprouting cover is accomplished by means of seed dispersed from bordering areas. Little, however, has been done to determine the rate and extent of brush invasions in this manner. Studies of forested lands indicate that much of the seedling growth of burned areas is due to seed already on the forest floor at the time of the fire (*38, 41, 42, 58, 59, 67*). The possibility that an analagous situation occurs in grassland and brushfields has led to investigation of the relative resistance of various seeds to heat. Thus Wright (*117*), studying germination of several plant species common in the Sierra Nevada, found that the seeds of certain chaparral forms endured much higher temperatures than did those of trees or grass. As pointed out elsewhere this may be one of the primary factors influencing the aggressive invasions of burns by chaparral vegetation in California.

The fact that soil conditions may influence succession after burning was demonstrated by Stallard (*98*), who found that repeated fires progressively destroy much of the soil organic matter. This results in retrogression of the plant succession after each fire, the area finally reaching denudation—essentially comparable to primary successional conditions.

Where excessive grazing has resulted in reducing the natural grass cover to a point favorable to invasion by relatively unpalatable *nonsprouting* brush, burning may aid in the restoration of grass. Morris (*67*), for example, found that in the Great Basin region burning or grubbing of sagebrush increased some species of grasses and broad-leaved herbs.

The most outstanding fact consistently appearing in the literature on fire and plant succession is that no single criterion or formula may safely be used to predict the outcome. An unusually dry or wet season preceding or following burning may unpredictably affect the plant population of burned areas. The seed of some inconspicuous plant which has accumulated in the soil for many years may germinate in large numbers under the suddenly changed conditions brought about by burning, and thus result in the conspicuous presence of that particular species after the fire. Only as a result of careful study in a particular area, taking into account all possible biotic, climatic, and topographic factors, can rational prediction of plant succession be made.

ORGANIZATION OF THE STUDY

In initiating the brush-burning study in northern California, two major problems seemed to merit careful attention. One of these was to note the effect of burning on the plant cover; the other was to study the effects of burning on the fertility of the soil. Accordingly, the principal tasks of the present study were to record the changes in vegetation produced naturally on burned areas in the years immediately following a fire, to determine the extent to which plant succession subsequent to burning may be modified by various management practices, and to determine the effects of these changes on the soil.

Although plant succession on burned brushlands is modified by many local influences, the results presented in the section on changes in plant cover are believed to show characteristic trends, and to provide underlying principles which may be applied in the management of burned chaparral lands.

As previously shown, ranchers of northern California do not generally consider the effects of brush fires on the soil to be important, although there is a feeling by many that the ashes fertilize the soil. A few of the ranchers have also become aware of losses of soil fertility through erosion. Since it is generally conceded that soil losses are not replaceable within any reasonable time, it is important that such destruction be recognized in its early stages. Accordingly, studies were instituted to ascertain the effects of burning on certain chemical soil properties. The findings reported should be helpful in gaining a better understanding of the effect of fire on the soil, and in counteracting the menace of resultant losses.

Inquiry was also made into some of the changes in environment which might influence succession. Thus the temperatures which prevail at various depths of soil during a fire invited study because of their probable direct effects on seed germination and survival of sprouts. The sudden, widespread appearance of certain plants on burns, coincident with the disappearance of unrelated forms, suggests that the seeds of some plants were more tolerant to extremes of heat than others.

Efforts of ranchers to influence plant succession after a fire induced the writer to include various trials in reseeding. To determine the effectiveness of such practices, numerous experimental reseeding trials were undertaken, using many cultivated plants and some native species, under various brushland conditions.

HERBACEOUS PLANTS COMMON TO CHAPARRAL AREAS

It seemed desirable in the present study to compare the species and abundance of herbaceous plants commonly found on recent burns, with the forms which normally occur on mature unburned stands of chaparral.

Extensive surveys revealed that the species listed below make up the major herbaceous cover both on burned and on unburned chaparral areas.

COMMON HERBACEOUS PLANTS OF BRUSH AREAS OF NORTHERN CALIFORNIA[18]

Broad-leaved herbs

Bishop lotus (*m*)	Dove lupine (*m*)
Blue gilia (*p*)	Dwarf Bridges grassnut
Bolander bedstraw	English plantain
California everlasting (*m*)	Field suncup (*p*)
California figwort (*m*)	Fineleaf lotus (*m*)
California filago (*m*)	Fireweed (*m*)
California goldenrod	Foothill death camas
Cantua spurge	Fremont death camas (*m*)
Chaparral cottonweed (*m*)	Fremont globemallow (*m*)
Chaparral pentstemon (*m*)	Gamble weed
Coast larkspur (*m*)	Gold fern
Common mullein	Gold-wire (*m*)
Common peppergrass	Grassnut (*m*)
Common soap-plant (*p*)	Greenbrier
Common yellow mustard	Hill lotus (*p*)
Coyote tobacco	Horned snapdragon (*p*)
Crown brodiaea	Horseweed (*m*)
Cut-leaved thelypodium (*m*)	Indian pink
Dotseed plantain	Indian tobacco

[18] Plants marked (*m*) are moderately persistent, and often fairly abundant, on recently burned chaparral lands; those marked (*p*) are persistent and often very abundant on such lands.

Broad-leaved herbs (cont.)

Leafy gilia (*m*)
Little-bill loco
Longleaf filago
Meadow death camas
Menzies larkspur (*m*)
Milk aster
Moth mullein
Mountain nievitas (*m*)
Nada stickleaf (*m*)
Napa star thistle (*p*)
Narrowleaf soap-plant (*m*)
Northern rockcress (*m*)
Nuttall bedstraw (*m*)
Prickly lettuce (*m*)
Purple nightshade (*m*)
Rattlesnake weed (*m*)
Red larkspur (*m*)
Redmaids
Red ribbons (*m*)
Redstem filaree
Rush lotus
Scouler St. Johnswort
Sheep sorrel (*m*)
Silverleaf lupine
Slender buckwheat (*p*)
Slender madia (*m*)
Small-flowered lotus (*m*)
Small meadow death camas
Spanish-clover (*m*)
Summer cottonweed (*m*)
Sword fern (*m*)
Tobacco mimulus (*m*)
Tomcat clover (*m*)
Torrey nievitas (*m*)
Turkey-mullein (*m*)
Valley tassels (*m*)
Western lupine (*m*)
Western thistle
Whispering bells (*p*)
White everlasting (*p*)
White-flowered navarretia (*m*)
White forget-me-not (*m*)
White hawkweed (*m*)
Whitestem filaree
Wild carrot (*p*)
Wool-mat
Woolly yarrow (*p*)
Yellow star thistle (*m*)

Grasses

Bent-head fescue
Blue wild-rye (*m*)
California melic
Downy chess (*m*)
Fotxail fescue (*m*)
Junegrass
Little quaking grass (*m*)
Malpais bluegrass
Mouse barley (*m*)
Nitgrass (*m*)
Pacific fescue
Perennial ryegrass
Purple needlegrass
Rat-tail fescue (*m*)
Red brome (*m*)
Ripgut
Silver hairgrass (*m*)
Six-weeks fescue (*m*)
Slender oat (*m*)
Spanish brome (*m*)
Wild oat

Only 16 per cent of the species included in the foregoing list of plants which become conspicuous after fires tend to persist in comparatively large numbers five years or more after burning, although these plants may also gradually decrease in abundance as the burn becomes older. Most of the species decrease sharply in population by the third year, so that by the fourth or fifth year after burning they are little or no more abundant than on unburned brushlands. Few of the common grasses occur in abundance after about the third year, except on nonsprouting-chaparral areas. Habit sketches of the more abundant common broad-leaved herbs appear in figures 6 to 10, and of the commoner grasses in figure 11.

RESULTS OF PLANT-SUCCESSION STUDY

The most conspicuous change in the vegetation may be expected where a dense woody cover is largely or completely burned. Since the post-burning successional stages are mainly composed of annual or short-lived perennial herbs, the cover may fluctuate conspicuously in species and density from year to year, with development towards the original relatively stable brush vegetation in the form of sprouts and chaparral seedlings. Such development is usually rapid.

RECOVERY OF BRUSH AFTER BURNING

The different kinds of chaparral vary greatly in the time required to reoccupy the soil after burning. If the stand is composed predominantly of the much more restricted nonsprouting forms, the seedling brush species will not completely recapture the soil for several years after burning; and even then many openings will often occur where the reproduction fails to gain a foothold. In the much more extensive sprouting stands of chamise, and in mixed,

Fig. 6—*A*, Deerweed, a half-shrub. *B*, Bush monkey-flower, and *C*, gold-wire—both herbaceous. All are common on burned areas.

sprouting chaparral, however, recovery after burning is generally rapid and complete, and may extend well beyond the pre-fire boundaries of the burn.

The rate of growth and recovery of sprouting brush stands has a significant bearing on subsequent treatment of the lands. In order to obtain quantitative data relative to the annual growth rate of such extensive brush covers, all of the brush plants were cut at the surface of the ground, and weighed, from a series of plots varying in size from one milacre to 20 feet square.[19] The measurements were recorded in September, well after completion of the season's growth, in 1937, 1938, and 1939, on burns from one to eight years old. The cut brush of each plot was tied in bundles of a size convenient for weighing with a steelyard scale beam. The dry weights of the samples representing each age class were averaged, and the results are presented graphically in figure 12.

[19] The growth-recovery study was made in Mendocino County, to represent coastal conditions, and in Shasta County to typify the interior brush region, on burns of known history and age. Ten to 13 milacre plots and 5 to 7 random plots of 20 feet square were cut and weighed for each age class in each county. The dry weight of samples was computed from oven-dry composite samples consisting of proportional parts of the coarse stems and the leafy branches.

Fig. 7.—Five broad-leaved herbs common to chaparral and chamise areas: *A*, woolly-yarrow; *B*, leafy gilia; *C*, chaparral penstemon; *D*, Torrey nievitas; *D-2*, enlargement of tip of stem of Torrey nievitas; and *E*, blue gilia.

Some of these sample materials were analyzed for their contents of certain mineral constituents.

Table 2 shows that recovery of chamise and of sprouting chaparral stands is rapid for several years after a burn. The average dry weights of chamise per acre, for example, one and five years after burning, were 1,560 pounds and

Fig. 8.—One of the most conspicuous broad-leaved herbs on burned chaparral areas is common soap-plant (*A*). Others are: *B*, common madia; *C*, nada stickleaf; *D*, field suncup; and *E*, Fremont death camas.

8,920 pounds, respectively. A similar trend is indicated in broad-leaved chaparral forms (figs. 13 and 14). In the sixth year after burning the rate of recovery of both chamise and chaparral covers was slower; and the annual increment declined appreciably in the eighth year. When total dry weight

Fig. 9.—*A*, Whispering bells, one of the most abundant and characteristic broad-leaved herbs on chaparral burns. Other abundant forms are: *B*, hill lotus, with detailed flowering branch shown at *B-2; C*, longleaf filago; *D*, rattlesnake weed, with detailed fruiting branch shown at *D-2;* and *E*, Napa star thistle.

Fig. 10.—Some broad-leaved herbs common to chaparral and chamise areas: *A,* California figwort; *B,* tobacco mimulus; *C,* purple nightshade; *D,* horned snapdragon; and *E,* red ribbons.

per acre is plotted against time in years (fig. 12), an almost straight line of increment is produced during the early years, indicating a rapid and nearly constant annual rate of growth for a period of four to six years after burning. The more flattened trend of the curves after the sixth year indicates an appreciable decline in growth rate.

Fig. 11.—Grasses common to chaparral and chamise areas: *A*, foxtail fescue; *B*, red brome; *C*, silver hairgrass; *D*, nitgrass.

From the standpoint of brushland management, the chief significance of the growth-rate trend is that it shows the approximate period of maximum growth in sprouting brush cover; this indicates when replacement of the herbaceous understory vegetation is most rapid. The poundage of fuel present at stated intervals after burning is also shown in the table. The amount of fuel may be of some value as an index to the probable reaction of heat on the seed and the soil.

Rapid growth rate of brush has proved to be distinctly a deterrent to maximum production of herbaceous vegetation after the second year because of shading, and the composition for soil moisture by sprouts and seedlings of the chaparral vegetation (figs. 13 and 14). The curve shown in figure 12 indicates rapid growth of sprouting chaparral covers, with its consequent reduction in herbaceous vegetation, until the sixth year. Even so, experience has shown that in order to get a fairly clean burn, firing should not be done more frequently than at about seven- or eight-year intervals. Burning at shorter

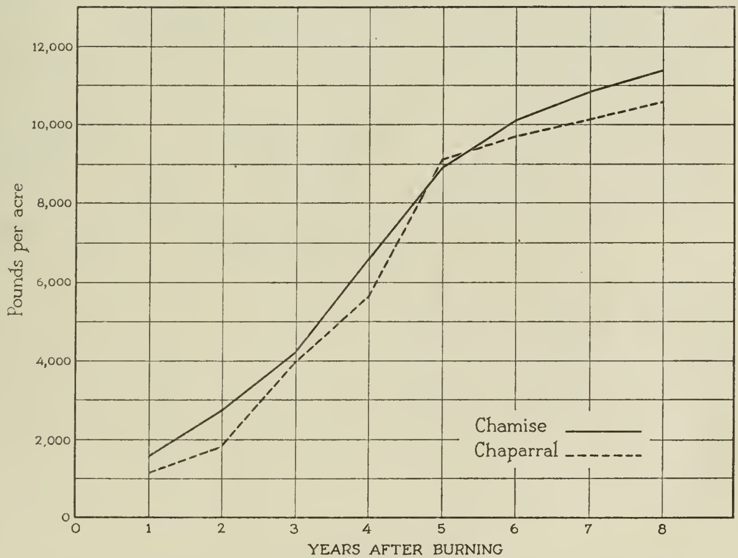

Fig. 12.—Annual rate of recovery of sprouting brush after burning, expressed in pounds of ovendry weight per acre of top growth.

intervals often results in only partial burning of the chaparral, or in leaving numerous patches of brush unburned.

The ash liberated by burning has some effect on plant succession, as is shown later. Table 2 also gives the approximate amount of potassium, calcium, and phosphorus released by burning. A series of plot measurements showed that about 30 per cent, by weight, of shrubby growth is merely charred rather than reduced to ashes by the ordinary brush fire, parts of most of the coarser stems remaining. This 30 per cent of remaining unburned stems was taken into account in computing the probable total yield of ash in a brush fire. The percentage values used in computing these yields of liberated salts were determined by analysis of several oven-dried samples. The following data embrace both chamise and mixed growth of chaparral:

MINERAL	CHAMISE	CHAPARRAL
Potassium, per cent	0.640	0.730
Calcium, per cent	0.709	0.920
Phosphorus, per cent	0.062	0.073
Total, per cent	1.411	1.723

The weight of the different elements subject to liberation as ash on burned chaparral lands (table 2) is seen to be approximately the same as that on chamise areas. Also there is little difference in the total amounts of salts in the two types of covers.

As pointed out elsewhere (p. 83), evidently only a small fraction of the liberated ash is ordinarily available for plant growth on a newly burned area. On hillsides, particularly, a large part of the newly liberated ash is blown into drainage channels where it is washed away. Of that which remains on

TABLE 2

DRY WEIGHTS OF CHAMISE AND CHAPARRAL COVERS OF DIFFERENT AGE CLASSES, AND CALCULATED MINERALS LIBERATED BY BURNING

County	Plot area	Chamise				Chaparral			
		Dry weight per acre, pounds	Mineral constituents available for liberation by burning, pounds per acre			Dry weight per acre, pounds	Mineral constituents available for liberation by burning, pounds per acre		
			Potassium	Calcium	Phosphorus		Potassium	Calcium	Phosphorus
One-year-old burns									
Mendocino	1	1,630	7.3	8.1	0.7	1,220	6.2	7.9	0.6
Lake	2	1,820	8.2	9.0	0.8	1,460	7.5	9.4	0.7
Lake	3	1,170	5.2	5.8	0.5	1,040	5.3	6.7	0.5
Shasta	4	2,250	10.1	11.1	1.0	1,010	5.2	5.0	0.5
Shasta	5	1,260	5.6	6.2	0.5	1,000	5.1	6.5	0.5
Shasta	6	1,030	4.6	5.1	0.4	1,130	5.8	5.6	0.6
Shasta	7	1,780	8.0	8.8	0.8	1,020	5.2	6.6	0.5
Average		*1,560*	*7.0*	*7.7*	*0.7*	*1,130*	*5.7*	*6.8*	*0.6*
Two-year-old burns									
Mendocino	1	2,680	12.0	13.4	1.2	1,030	5.2	5.1	0.5
Mendocino	2	3,270	14.6	16.2	1.4	1,640	8.4	8.1	1.6
Lake	3	1,830	8.2	9.1	0.8	2,590	13.2	16.6	1.3
Lake	4	2,000	8.9	9.9	0.9	1,430	7.3	7.1	0.7
Shasta	5	3,010	13.5	14.9	1.3	2,360	12.1	15.2	1.2
Shasta	6	3,790	17.0	18.8	1.6	1,870	9.6	12.1	1.0
Average		*2,760*	*12.4*	*13.7*	*1.2*	*1,820*	*11.8*	*10.7*	*1.0*
Three-year-old burns									
Mendocino	1	3,960	17.7	19.6	1.7	5,260	26.9	33.9	2.7
Mendocino	2	5,070	22.2	25.1	2.2	3,980	20.3	25.6	3.2
Lake	3	3,750	16.8	18.6	1.6	3,070	15.7	19.4	1.6
Lake	4	4,180	18.7	20.7	1.8	4,980	25.5	32.1	2.5
Lake	5	3,930	17.6	19.5	1.7	2,730	13.9	17.6	1.4
Shasta	6	3,430	15.3	17.0	1.5	4,620	23.6	29.8	2.4
Shasta	7	4,030	18.0	20.0	1.7	3,000	15.3	19.3	1.5
Shasta	8	4,870	21.8	24.2	2.1	3,260	16.7	21.0	1.7
Average		*4,150*	*18.5*	*20.6*	*1.8*	*3,860*	*19.7*	*24.8*	*2.1*

TABLE 2—(*Continued*)

County	Plot area	Chamise				Chaparral			
		Dry weight per acre, pounds	Mineral constituents available for liberation by burning, pounds per acre			Dry weight per acre, pounds	Mineral constituents available for liberation by burning, pounds per acre		
			Potassium	Calcium	Phosphorus		Potassium	Calcium	Phosphorus
Four-year-old burns									
Mendocino	1	6,190	27.7	30.7	2.7	4,860	24.9	31.3	2.5
Mendocino	2	5,970	26.7	29.6	2.6	5,670	29.0	36.5	2.9
Mendocino	3	7,400	33.2	36.7	3.2	7,000	35.8	45.1	3.6
Lake	4	6,030	27.0	29.9	2.6	5,320	27.2	34.3	2.7
Lake	5	7,980	31.3	34.6	3.0	4,970	25.4	32.0	2.5
Lake	6	7,000	31.4	34.7	3.0	5,840	29.8	37.6	3.0
Average		*6,600*	*29.5*	*32.7*	*2.9*	*5,610*	*28.7*	*36.1*	*2.9*
Five-year-old burns									
Mendocino	1	7,990	35.8	39.6	3.5	7.970	40.7	39.5	4.1
Mendocino	2	9,200	41.2	45.6	4.0	8.730	44.6	56.2	4.5
Mendocino	3	8.370	37.5	41.5	3.6	8,840	45.1	43.8	4.5
Lake	4	9,270	41.5	46.0	4.0	9,260	47.3	59.6	4.7
Lake	5	7,930	35.5	39.3	3.4	9,870	50.4	49.0	5.0
Shasta	6	9,250	41.5	45.9	4.0	8,690	44.4	56.0	4.4
Shasta	7	10,420	49.5	51.8	4.5	9,770	49.9	48.4	5.0
Average		*8,920*	*40.4*	*44.2*	*3.9*	*9,020*	*46.0*	*50.3*	*4.6*
Six-year-old burns									
Mendocino	1	10,240	45.9	50.8	4.4	8,930	45.6	57.5	4.6
Mendocino	2	9,250	41.4	45.8	4.0	10,860	55.5	69.9	5.5
Lake	3	11,330	49.9	56.2	4.9	8,930	46.0	57.5	4.6
Lake	4	11,220	49.8	55.6	4.9	10,440	53.3	67.2	5.3
Lake	5	10,020	49.3	49.7	4.3	9,380	47.9	60.4	4.8
Lake	6	9,940	44.5	49.3	4.3	8,480	43.3	54.6	4.3
Shasta	7	8,760	39.2	43.4	3.8	10,940	55.9	70.4	5.6
Shasta	8	9,920	44.5	49.2	4.3	9,740	49.8	62.8	5.0
Average		*10,080*	*45.4*	*50.0*	*4.4*	*9.710*	*49.6*	*62.5*	*5.0*
Seven-year-old burns									
Mendocino	1	9,340	41.9	46.3	4.1	9,130	46.6	58.8	4.7
Mendocino	2	10,830	48.5	53.7	4.7	11,270	57.6	72.6	5.7
Lake	3	10,760	48.2	53.4	4.7	8,920	45.6	57.5	4.6
Lake	4	11,930	53.5	59.2	5.2	9,860	50.4	48.8	5.0
Shasta	5	11,390	51.0	56.4	4.9	10,930	55.9	70.4	5.6
Shasta	6	10,760	48.2	53.4	4.7	10,570	53.9	52.4	5.4
Average		*10,840*	*48.5*	*53.7*	*4.7*	*10,115*	*57.7*	*60.0*	*5.2*

TABLE 2—(*Concluded*)

County	Plot area	Chamise: Dry weight per acre, pounds	Chamise: Mineral constituents available for liberation by burning, pounds per acre: Potassium	Calcium	Phosphorus	Chaparral: Dry weight per acre, pounds	Chaparral: Mineral constituents available for liberation by burning, pounds per acre: Potassium	Calcium	Phosphorus
Eight-year-old burns									
Mendocino	1	10,370	46.5	51.4	4.5	12,030	61.5	59.7	6.1
Mendocino	2	11,060	49.5	54.8	4.8	10,741	54.9	69.2	5.5
Lake	3	11,900	53.3	59.0	5.2	11,690	59.7	58.0	6.0
Lake	4	12,800	57.3	63.5	5.5	9,020	46.1	44.8	4.6
Shasta	5	10,090	45.2	50.1	4.4	10,070	51.4	64.8	5.1
Shasta	6	12,060	54.0	59.8	5.2	9,950	50.8	64.0	5.1
Average		*11,380*	*50.9*	*56.4*	*4.9*	*10,580*	*54.0*	*60.0*	*5.4*
Unburned unusually dense, luxuriant old stands									
Shasta	1	25,660	114.9	127.2	11.1	30,150	153.3	194.1	15.4
Shasta	2	37,940	170.0	188.0	16.5	36,010	184 0	231.9	18.4
Shasta	3	29,230	130.9	144.8	12.7	21,950	112.1	141.3	11.2
Mendocino	4	19,480	87.2	96.5	8.4	22,540	115.1	225.4	11.5
Average		*28,070*	*125.8*	*139.1*	*12.2*	*27.660*	*141.1*	*198.2*	*14.1*

the burned area, a fair proportion of the potassium fraction, being readily soluble, would presumably be leached away by the winter rains, but part of it would certainly be utilized by the vegetation. Moreover, fixation of the calcium and phosphorus, and the insolubility of the phosphorus in soils having alkaline reaction, would appear to leave relatively little of these two elements available for immediate plant nutrition.

INVASION OF HERBACEOUS PLANTS

The kinds and combinations of the more dominant herbaceous plants that occupy an area after burning, and the number of years that they continue to occur abundantly on the area, determine the success or failure of a burning venture for grazing. In order to procure reliable data on plant succession in diversified burned brushlands, a series of experimental plots were established, on burned and unburned areas, in both chamise and chaparral cover, occupying a variety of soil types.[20]

Chamise Cover.—The first study was conducted on chamise lands in Mendocino County. The records were averaged for 26 milacre plots, located on slopes

[20] The techniques employed included line and belt transects, which traversed both burned and adjoining unburned areas; and rectangular plots varying in size from a milacre to several acres. Refined grazing reconnaissance methods were employed on the larger plots. To assure use of identical areas for subsequent measurement over a long period of time, the plots were marked by driving numbered iron stakes at diagonal corners of their boundaries, after which the plots were located on a map by means of compass and chain.

and flats. The plots were located mostly on the Hugo, Los Osos, and Aiken soil series, including a good cross section of variation in soil depth. The results appear to be typical of chamise areas, as revealed in more extensive work later in interior counties. The area was heavily burned in September, 1927. Species which constituted less than 1 per cent of the cover during the years of observa-

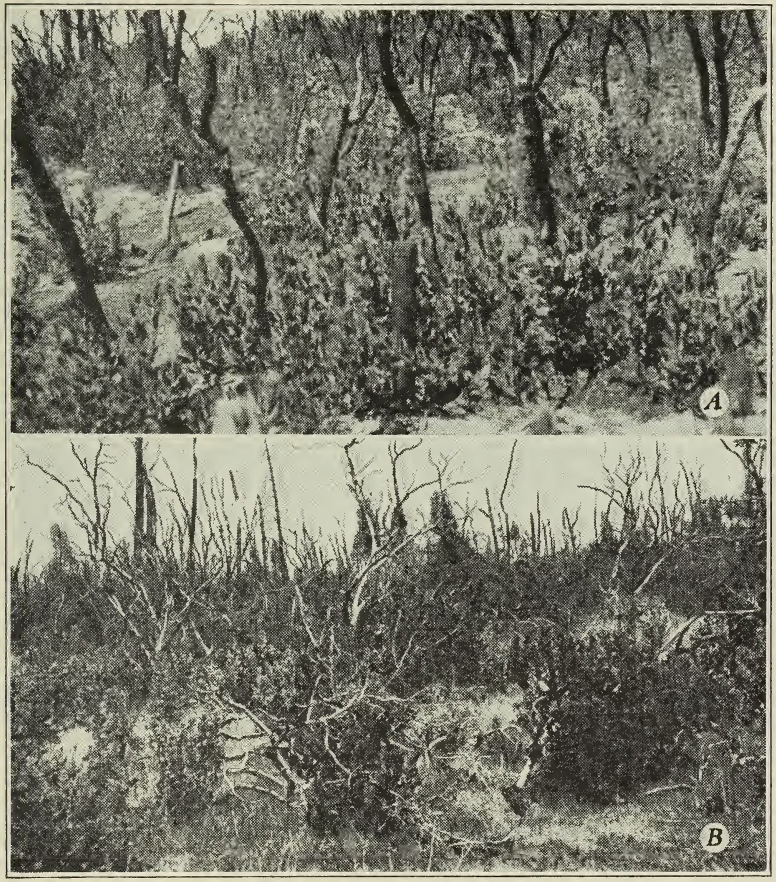

Fig. 13.—*A*, One-year-old burn of greenleaf manzanita which is rapidly reoccupying the soil. *B*, Two-year-old burn of interior live oak and Lemmon ceanothus, with areas of grass occupying the openings.

tion, in this and in the other brush areas studied, are not listed in the data here presented. The results are summarized in table 3.

Of the 16 species of broad-leaved herbs recorded in the 26 plots after burning, all but 2 were found at least limitedly on the sample plot areas before burning, as shown by the data for 1927. Much the heaviest stands of broad-leaved herbs occurred during the second and third years after the fire. A sharp decline in the abundance of these plants occurred thereafter until in 1932, the fifth year after burning. Several of the herbaceous species approached in sparseness those of the unburned area of 1927, although about three times more herbaceous vegetation was present than before the fire. Much of this cover, however, was unpalatable to stock. In contrast, the maximum density two years after the fire was seventeen times that of the pre-fire density, and the grazing capacity was appreciably increased in the better sites. Conspicuous downward trends in the amount and density of herbaceous vegetation occurred in the third, fourth, and fifth years after burning.

Because of their abundance, robust growth, and showy inflorescence, woolly-yarrow, whispering bells, chaparral cottonweed, and two species of death camas were perhaps the most conspicuous herbaceous species during the first two years after burning.

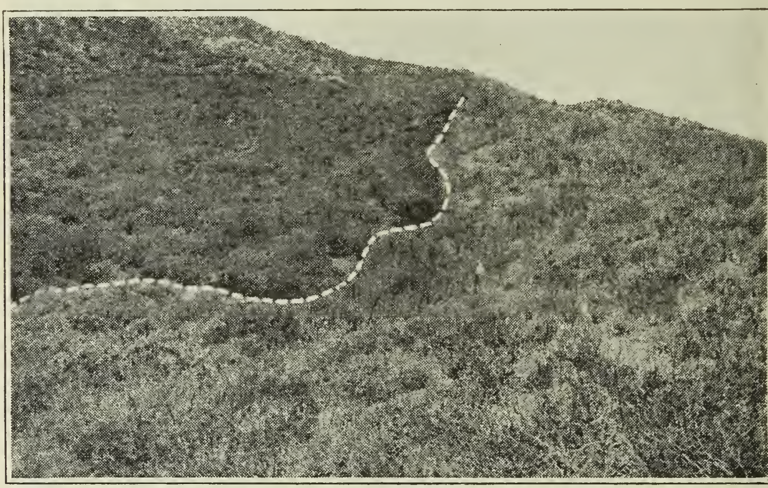

Fig. 14.—Greenleaf manzanita cover. The upper part of the slope (left) was not burned for fifteen years, and is virtually devoid of understory vegetation. The lower slope (right) shows abundant, vigorous sprouts, and some herbaceous plants. The estimated dry weight of the unburned brush was 11,000 pounds; of brush on the burn, 1,300 pounds.

The grasses, all but one species of which were annuals, were the most abundant numerically of the herbaceous forms, both before and after burning. They were most abundant during the first two years following the fire, declining thereafter somewhat gradually and reaching the lowest point in 1932, the fifth year after burning. Silver hairgrass, nitgrass, and foxtail fescue were by far the most abundant. These species yield lightly, mature early in the season, and decline rapidly in nutrition.

Perhaps the most significant effect of the fire was the heavy invasion of brush seedlings. No young plants of the dominant chamise, or of greenleaf manzanita, were found on any of the plots before burning, whereas chamise, in particular, was conspicuously abundant on all plots the first year after burning, and many were well established by the fifth year after the fire. These seedlings, and a strong growth of brush sprouts, evidently are primary factors in the decline of the herbaceous vegetation, as they occupy much of the top-growth space. A review of the plant record of these plots in 1934, the seventh year after the fire, revealed that a large proportion of the brush seedlings

TABLE 3

Average Number of Understory Plants per Milacre Plot in Chamise Cover before Burning in 1927, and at Yearly Intervals Thereafter; Mendocino County*

Species	Before burning	After burning				
		First year	Second year	Third year	Fourth year	Fifth year
Broad-leaved herbs						
Bolander bedstraw	0.2	2.6	5.0	3.4	1.6	2.2
Bush beardtongue	0.4	3.5	3.6	2.5	1.5	1.2
Chaparral cottonweed	0.2	13.8	10.8	8.1	5.2	0.0
Common peppergrass	1.1	7.8	3.8	3.1	2.8	0.0
Common soap-plant	0.5	2.7	3.9	2.2	2.2	2.2
Fineleaf lotus	1.1	9.7	11.7	4.9	3.4	2.0
Foothill death camas	0.0	1.4	2.4	1.5	1.6	0.3
Fremont death camas	0.1	5.9	7.2	3 4	1.7	2.1
Menzies larkspur	0.2	3.8	5.4	4.8	2.2	2.6
Napa star thistle	0.3	6.3	11.3	8.2	4.3	4.1
Rattlesnake weed	0.0	4.2	2.6	2.4	0.0	0.0
Redstem filaree	0.2	5.2	7.1	3.6	1.7	2.1
Turkey-mullein	1.3	8.4	11.9	3.7	2.4	1.9
Whispering bells	0.1	17.2	21.3	7.6	2.4	1.3
White-flowered navarretia	0.3	6.1	7.4	2.6	3.1	1.7
Woolly-yarrow	1.4	6.8	7.9	6.2	2.4	2.1
Total	7.4	105.4	123.3	68 2	38.5	25.8
Grasses						
Foxtail fescue	6.6	46.3	57.5	34.8	22.4	19.4
Nitgrass	9.2	64.2	78.4	29.2	21.6	12.3
Purple needlegrass	0.7	1.4	1.0	1.0	1.0	1.0
Red brome	3.6	16.3	24.8	19.6	11.3	8.5
Silver hairgrass	6.2	83.7	97.3	51.6	42.8	38.6
Wild oat	2.8	12.1	15.4	8.4	10.1	6.1
Total	29.1	224.0	274.4	144.6	109.2	85.9
Brush seedlings						
Chamise	0.0	47.6	28.0	14.3	12.2	12.2
Deerweed	1.0	5.4	3.8	3.4	2.4	2.4
Greenleaf manzanita	0.0	7.2	4.0	2.6	2.6	2.6
Lemmon ceanothus	0.3	4.2	4.7	3.2	2.1	2.1
Poison oak	0.12	4.2	5.4	3.5	3.3	2.4
Wedgeleaf ceanothus	0.04	3.1	3.1	2.2	2.2	2.1
Total	1.46	71.7	49.0	29.2	24.8	23.8

*Average of 26 plots.

present in 1932 had survived, and that the sprouts had developed into robust plants.

Several plots established on chamise burns of various ages in Lake, Shasta, and Tehama counties, from 1926 to 1937, gave results similar to those presented in table 3 with respect to the identity and permanence of the invading herbaceous species, and particularly the establishment of chamise sprouts and seedlings. These observations lend weight to the conclusion that the successional behavior outlined is fairly typical of burned chamise areas throughout

Fig. 15.—Heavy invasion of yerba santa on the two-year-old chamise burn. The chamise sprouts and seedlings eventually suppress this competing growth. El Dorado County.

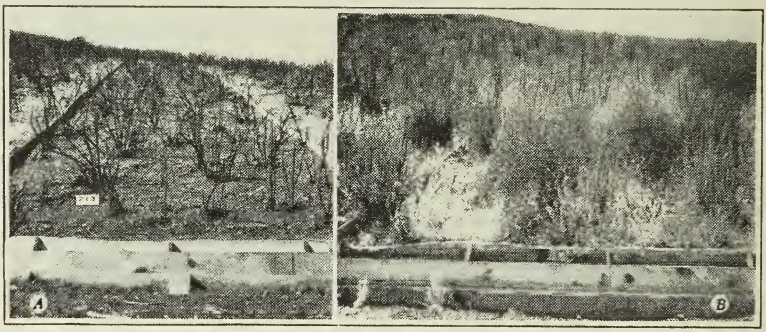

Fig. 16.—Chamise plot, burned in 1934, upon which succession and soil erosion were recorded: *A*, the plot after burning and installation of run-off measurement equipment; *B*, the same plot as it appeared in 1936. The herbaceous vegetation, consisting mostly of weeds, was being crowded out by the chamise sprouts and seedlings. Shasta County.

northern California. In some localities one group of herbs would be much in evidence, in other localities another group of herbs would dominate; but all were much the same in aspect and successional reaction. In all instances, sprouts of chamise, manzanita, poison oak, and frequently yerba santa, appeared early in the season of the first year after burning (fig. 15). The sprouts and brush seedlings continued to develop in subsequent years until little other vegetation remained (fig. 16); but in the interim the carrying capacity was

TABLE 4

AVERAGE NUMBER OF UNDERSTORY PLANTS PER MILACRE PLOT IN SPROUTING MANZANITA AND CEANOTHUS COVER, BEFORE BURNING IN 1927, AND AT YEARLY INTERVALS THEREAFTER; LAKE AND MENDOCINO COUNTIES*

Species	Before burning	After burning				
		First year	Second year	Third year	Fourth year	Fifth year
Broad-leaved herbs						
Common soap-plant	0.3	1.4	2.6	1.8	1.2	1.4
California figwort	0.3	3.9	5.1	2.3	1.4	0.6
Fineleaf lotus	0.4	3.8	4.1	2.9	0.4	0.2
Foothill death camas	0.3	3.9	3.7	1.4	0.9	0.4
Gamble weed	0.6	2.7	4.6	1.8	0.9	1.2
Gold-wire	0.8	2.8	2.3	1.7	1.6	0.7
Grassnut	0.4	3.4	2.6	3.1	2.2	2.4
Nada stickleaf	0.2	4.8	4.1	3.2	0.8	0.1
Nuttall bedstraw	1.4	6.4	5.8	2.9	3.1	2.2
Rattlesnake weed	2.3	5.8	4.3	2.6	2.7	3.1
Red ribbons	1.0	4.6	2.3	2.4	1.6	0.5
Redstem filaree	2.1	5.9	4.6	5.8	3.1	2.6
Small meadow death camas	0.4	3.1	2.5	2.3	1.6	0.9
Tarweed	1.2	9.3	4.2	3.1	1.4	1.6
Tobacco mimulus	0.3	2.3	2.1	1.6	1.2	0.4
Turkey-mullein	1.5	12.3	13.7	4.8	1.9	1.2
Western thistle	0.1	8.3	5.7	2.8	1.6	1.2
Willow herb	0.1	3.7	6.4	4.1	3.4	1.9
Woolly-yarrow	1.3	5.7	7.9	4.0	2.8	2.6
Total	15.0	94.1	88.7	54.6	33.8	25.2
Grasses						
Foxtail fescue	8.2	29.8	47.3	27.7	18.3	14.9
Malpais bluegrass	0.7	2.6	3.8	1.4	1.2	0.9
Nitgrass	5.3	31.7	42.1	19.2	21.3	11.6
Red brome	2.8	11.6	7.8	10.4	5.6	4.8
Ripgut grass	4.6	9.1	14.3	11.4	8.3	9.2
Soft chess	0.3	4.1	6.5	3.8	5.1	2.8
Spanish brome	1.6	18.7	12.6	15.2	7.9	5.4
Wild oat	1.4	5.1	6.7	2.4	1.7	2.1
Total	24.9	112.7	141.1	91.5	69.4	51.7
Brush seedlings						
Chaparral coffeeberry	0.0	4.4	3.8	3.3	2.3	2.3
Common manzanita	0.0	3.7	2.1	1.6	1.4	1.4
Eastwood manzanita	0.0	9.7	7.6	7.2	7.2	7.2
Lemmon ceanothus	0.0	16.4	12.2	10.5	10.1	10.1
Poison oak	0.0	1.7	2.8	1.2	0.9	0.9
Yerba santa	0.0	4.3	2.3	1.4	1.4	1.4
Total	0.0	40.2	31.8	25.2	23.3	23.3

*Average of 19 plots.

increased on areas of productive soils, whereas on thin soils little or no improvement was obtained. Occasionally areas several acres in extent were overrun with deerweed, an unpalatable species that sometimes grew so densely and vigorously for two or three years after the fire as to appear to replace the brush sprouts. By the fourth or fifth year after burning, however, the deerweed usually became heavily infested with dodder, which in turn yielded its space to the taller, more persistent hard brush.

Sprouting Manzanita-Ceanothus Cover.—The *sprouting,* broad-leaved chaparral cover, composed mainly of species of manzanita and ceanothus, with a subdominance of dwarf interior live oak, chaparral, coffeeberry, and yerba santa, was most intensively studied in Lake and Mendocino counties. These studies were later amplified by obtaining data on various plots in several interior counties. The Los Osos, Konokti, Hugo, and Aiken soil series were represented. A summary of the plant population of 19 milacre plots, mapped yearly from 1928 to 1932, inclusive, is presented in table 4.

Although this association of sprouting chaparral contained a fairly large number of herbaceous forms, namely, 19 species of broad-leaved plants and 8 species of grasses, the latter vegetation occupied only slightly more than 1 per cent of the ground cover before burning. Maximum density of herbaceous plants occurred the first and second years after burning, when the broad-leaved forms and the grasses were approximately nine and five times more abundant, respectively, than before burning. In the third, fourth, and fifth years after burning, the decline in density of these understory plants was sharp. By the fifth year, although the understory herbaceous plants were more numerous than before burning, the stand was so scattered as to furnish little forage. By this time the chaparral seedlings and sprouts had largely recaptured the areas.

That fire stimulated germination of the seed of brush species is impressively shown by the entire absence of brush seedlings before burning, as contrasted with the large number present after burning. The fact that only slightly less than two thirds of the number of chaparral seedlings recorded the first year after burning survived in the fifth year, despite the exceedingly heavy growth of sprouts, is indicative of the aggressive and persistent character of this cover. Moreover, in the fifth year after burning, the new plants fruited, illustrating the strong reproductive capacity and persistence of this vegetation.

Nonsprouting Manzanita-Ceanothus Cover.—Areas covered with the much less extensive *nonsprouting* chaparral, composed also mostly of various species of manzanita and ceanothus, react differently to burning than do lands occupied by sprouting forms of these genera. The fact that nonsprouting brush is killed by a single heavy burn appears to account for the relatively rich herbaceous flora that appears and usually persists well after burning on such areas (fig. 17).

The initial plots of nonsprouting chaparral, established in Mendocino County in 1927, were located on various slopes and flats of the Aiken, Mariposa, and Los Osos soil series. In general these soils were comparable in quality with more productive lands of the chamise and sprouting chaparral areas whose successional results are summarized in tables 3 and 4. The results of the plant study of the nonsprouting cover are summarized in table 5.

The table brings out two points which are in distinct contrast to those recorded in the chamise and sprouting chaparral vegetation. First, a much larger number of herbaceous species typically inhabited the nonsprouting cover, both before and after burning, possibly because the brush tends to be

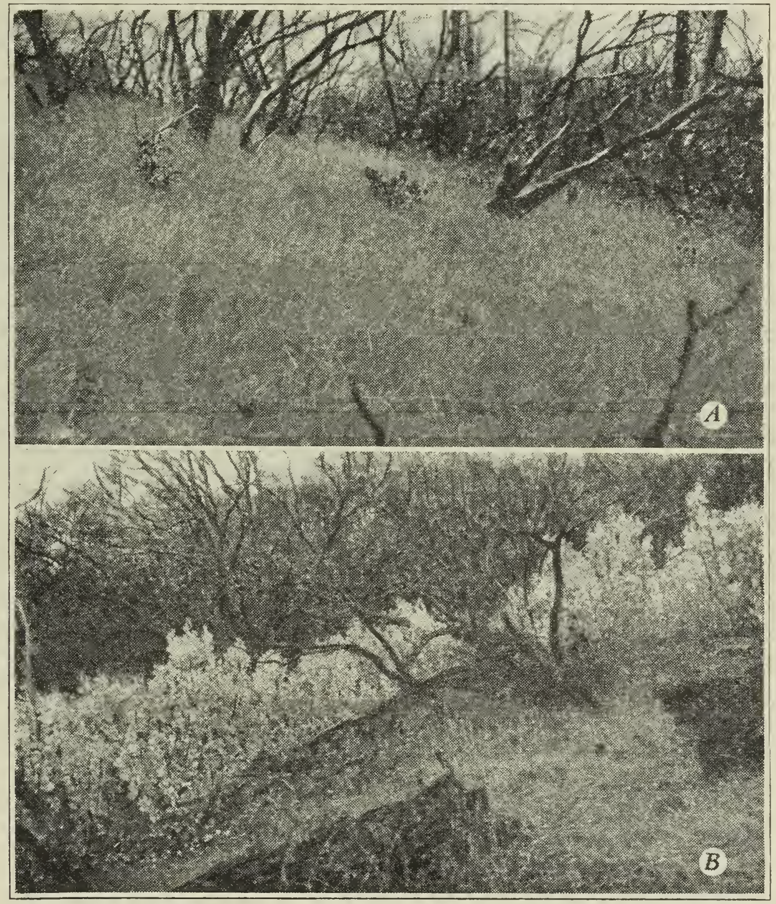

Fig. 17.—*A*, Nonsprouting manzanita burned two years previously, showing heavy growth of ungrazed annual grasses and a few young manzanita seedlings. *B*, Nonsprouting manzanita burned seven years previously, showing growth of six-year-old fruiting brush plants. Reburning of this area would greatly improve the grazing capacity by removing the dead brush and destroying much of the younger brush. Shasta County.

somewhat more open; and second, there was an increase in the density of the herbaceous species continuing even into the fifth year after burning. Although early-maturing annuals, such as foxtail fescue, rat-tail fescue, nitgrass, and silver hairgrass, were relatively abundant both before and after burning, such species as soft chess and slender oat reached maximum abundance in the fifth year after the fire. The increase in grass was partly offset, however, by the sharp decline in most of the broad-leaved herbaceous species, and the rapid

TABLE 5

Average Number of Understory Plants per Milacre Plot in Nonsprouting Manzanita and Ceanothus Cover before Burning in 1927, and at Yearly Intervals Thereafter; Mendocino County*

Species	Before burning	After burning				
		First year	Second year	Third year	Fourth year	Fifth year
Broad-leaved herbs						
Alkali clover	0.3	0.8	0.4	1.2	0.4	0.3
Chaparral pentstemon	0.2	0.6	0.4	0.6	0.6	0.3
Blue-eyed grass	0.2	1.6	0.3	0.1	0.0	0 0
Bolander linanthus	0.2	2.4	1.6	0.8	0.3	0.0
California filago	1.2	4.6	10.9	3.8	4.2	3.6
California goldenrod	0.5	2.5	1.4	0.8	0.6	0.6
Common soap-plant	0.6	2.7	3.5	2.1	2.1	2.0
Coyote tobacco	0.4	4.9	2.3	0.4	0.0	0.0
Dotseed plantain	1.1	2.9	1.7	0.4	0.0	0.0
Dwarf Bridges grassnut	0.0	2.4	1.0	0.1	0.2	0.0
English plantain	0.4	3.7	2.1	0.7	0.0	0.0
Foothill death camas	0.2	1.3	0.8	1.1	0.4	0.5
Fremont death camas	0.0	2.1	1.6	2.0	1.4	1.2
Gamble weed	0.4	2.3	0.2	0.0	0.0	0.0
Nuttall bedstraw	0.3	2.2	3.7	1.3	0.6	0.0
Slender popcorn flower	0.4	1.2	2.1	1.3	0.4	0.0
Purple nightshade	0.3	2.8	1.3	2.2	1.5	1.2
Redstem filaree	1.3	2.7	2.1	1.6	2.8	0.9
Sheep sorrel	0.0	1.8	0.6	1.2	0.9	0.4
Slender buckwheat	1.2	4.1	2.8	1.6	0.3	0.6
Small-flowered lotus	0.6	5.9	6.6	3.8	2.7	1.6
Spanish-clover	0.2	8.1	4.1	5.9	2.3	2.7
Summer cottonweed	1.3	3.6	1.2	0.6	1.4	0.3
Tarweed	0.2	4.1	17.3	8.3	4.2	3.0
Turkey-mullein	0.5	7.2	4.9	3.2	0.9	0.7
Valley tassels	0.3	1.3	0.5	0.2	0.0	0.0
Western lupine	0.1	0.6	0.4	0.6	0.3	0.3
Wild carrot	0.4	3.8	4.6	5.1	4.3	2.9
Woolly-yarrow	0.7	4.6	16.4	5.7	4.9	5.2
Total	13.5	88.8	96.8	56.7	37.7	28.3
Grasses						
Bent-head fescue	0.0	2.1	3.6	0.6	0.0	0.0
Blue wild-rye	0.6	0.8	1.8	2.6	3.9	4.7
Foxtail fescue	6.8	19.3	39.1	31.2	59.6	63.8
Junegrass	0.3	0.5	1.4	2.8	3.2	2.7
Little quaking grass	3.1	7.7	14.3	11.2	4.9	1.3
Nitgrass	6.4	21.8	38.3	30.7	21.7	36.3
Purple needlegrass	0.2	0.7	0.5	0.5	0.5	0.5
Rat-tail fescue	2.9	6.7	5.5	7.3	10.4	24.1
Red brome	2.3	8.4	12.6	16.8	7.2	9.4
Ripgut grass	1.8	6.5	4.2	6.7	3.1	2.8
Silver hairgrass	2.6	14.7	22.6	32.1	24.6	20.1
Slender oat	1.2	6.3	9.2	10.7	15.4	18.1
Soft chess	0.0	2.8	7.3	11.2	24.6	30.3
Wild oat	0.1	0.9	1.3	2.0	6.8	9.6
Total	28.3	99.2	161.7	166.4	185.9	233.7

* Average of 24 plots.

TABLE 5—(*Continued*)

Species	Before burning	After burning				
		First year	Second year	Third year	Fourth year	Fifth year
Brush seedlings						
Chaparral coffeeberry	0.0	1.6	1.2	2.0	2.0	2.0
Common manzanita	0.0	1.7	2.6	2.1	1.8	1.6
Lemmon ceanothus	0.0	0.6	1.3	2.8	1.6	1.6
Parry manzanita	0.0	0.0	0.4	0.3	0.3	0.3
Poison oak	0.2	1.2	0.9	0.6	0.7	0.5
Wedgeleaf ceanothus	0.0	2.4	3.7	3.5	3.2	3.2
Yerba santa	0.1	2.7	1.8	2.2	2.2	2.2
Total	0.3	10.2	11.9	13.5	11.8	11.4

growth of brush seedlings, in the third year after burning. This resulted in a plant pattern somewhat similar to that of the sprouting covers previously discussed, except that more grass vegetation was present.

Another point of difference noted in the *nonsprouting* cover was the marked fluctuation in density of the herbaceous plants during the three years immediately following burning. About one third of the species declined sharply in density the second year; but these same species increased again in the third year to a density greater than that of the first year. The decline in the second year and increase in the third probably were influenced directly by climatic conditions. Weather data show that precipitation was far below normal for the first two years after burning. In fact, rainfall in December, 1930, was only 11 per cent of normal, the lowest recorded for that month. The temperature,

Fig. 18.—Heavy initial invasion of turkey-mullein on heavily burned ceanothus areas. By the third year, grasses and other herbs usually replace the turkey-mullein. Lake County.

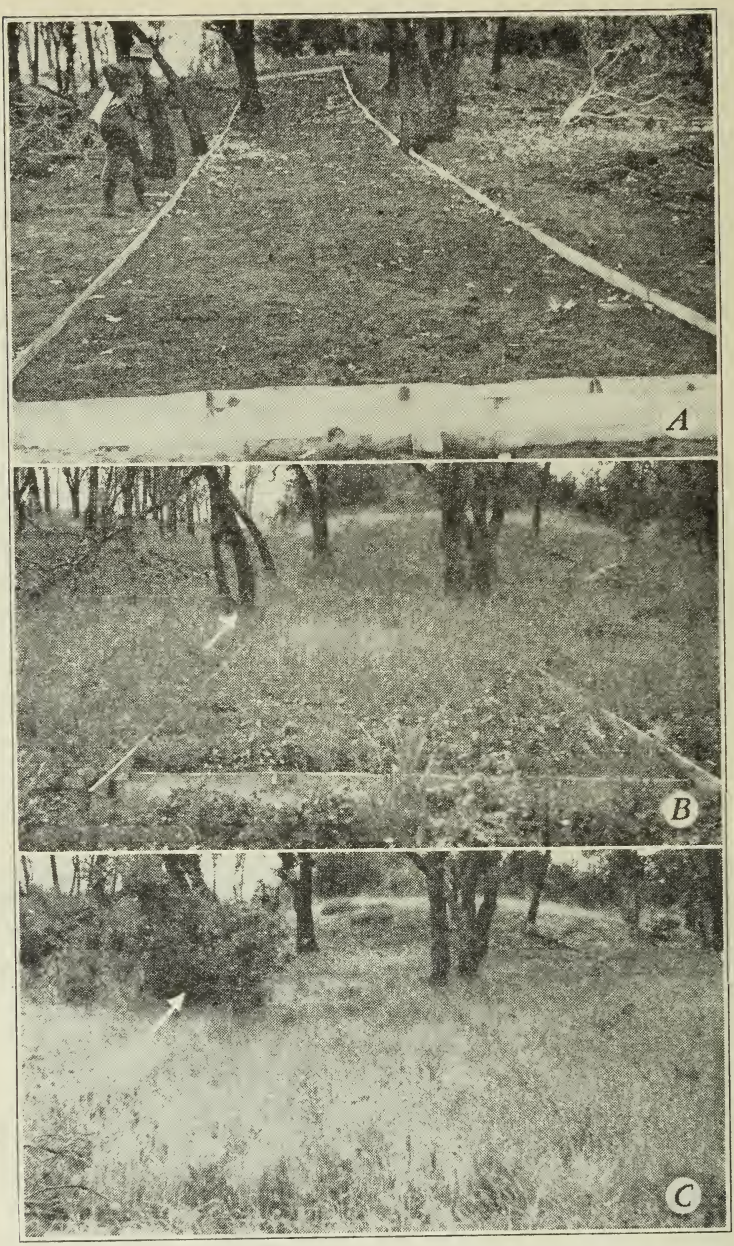

Fig. 19.—Plot of oak-grass association burned in 1934, upon which plant succession and soil erosion were studied. *A*, Showing removal by burning of low bushes, dead branches, and leaf litter. *B* and *C*, photographed in 1935 and 1936, respectively, illustrate the progression of the succession from mixed weeds and grass to a nearly pure grass cover. Note recovery of live-oak sprouts, indicated by arrows. Shasta County.

while fluctuating greatly, was well above normal during the first two years. Thus, apparently, only those seedlings that could withstand the high temperatures and low precipitation showed an increase during this time. The same tendency during the same years was evident, though less striking, in the other nonsprouting areas measured. The adverse climatic conditions appeared to affect little the growth of the sprouting forms, probably because of their relatively deep roots.

In this character of cover, chaparral seedlings were also found in moderate abundance after burning. They tended to occur, however, in rather small but dense patches, leaving much of the area to be occupied exclusively by herbaceous plants, of which turkey-mullein was among the first to invade, particularly on areas with abundant ash (fig. 18). The increased carrying capacity on the deeper, more level soils of this cover was much improved by burning.

Cover of Interior Live Oak and Blue Oak.—Since much of this rather extensive association, dominated by interior live oak and blue oak, common to the lower stretches of the foothill region, is readily accessible for pasture use, the brush and tree growth is often greatly altered by some form of clearing other than direct burning. (See p. 108 and 111.) The soils of most such areas are fairly deep and productive, and sprout and other reproduction come in promptly and vigorously following a fire. If permitted to develop undisturbed after burning, the sprouts readily suppress the understory vegetation, and often recapture the area almost to the exclusion of other vegetation.

The study of plant succession of the sprouting-oak cover was intensively undertaken in Shasta County in 1931, and was later supplemented by check plots in Tehama, Butte, Mendocino, Lake, El Dorado, and Alameda counties.

The Shasta County plots were located on rather level lands east and north of Redding, in an important livestock-producing area. Typical of this locality, the dominant cover consisted of interior live oak and blue oak, with subdominants of common manzanita, whiteleaf manzanita, buckbrush, madrone, and poison oak (fig. 19). Much the same association of brush plants occurs extensively in the counties named above, where check records were made. The soils, mostly of the Redding gravelly loam and Bellavista sandy loam types, varied from shallow to deep, and were of fair to good quality. The plant successional behavior is presented in table 6.

The table reveals a fairly large and diversified flora of broad-leaved herbs before and after burning, although before burning the understory vegetation was relatively sparse. Probably because of the tendency of the subdominant brush to form a more complete or nearly closed canopy, 5 of the 21 species of broad-leaved herbs listed were not in evidence on the 32 plots before burning; but they were found widely scattered over the experimental area as a whole. The largest population of broad-leaved herbs, fourteen times that of the unburned plots, appeared the first year after burning, following which there was a gradual decline as the sprouting brush reclaimed the area. Thus in the fifth year, there were barely three times more herbaceous plants than before burning, in 1931. The most conspicuous broad-leaved herbs in these plots, and in this cover in other counties, were turkey-mullein, Napa star thistle, willow herb, Spanish-clover, and the poisonous coyote tobacco, with subdominants of slender buckwheat, tomcat clover, and rattlesnake weed. The two first-named

TABLE 6

AVERAGE NUMBER OF UNDERSTORY PLANTS PER MILACRE PLOT IN LIVE OAK AND BLUE OAK COVER, BEFORE BURNING IN 1931, AND FOR EACH OF THE FIVE YEARS FOLLOWING*; SHASTA COUNTY

Species	Before burning	After burning				
		First year	Second year	Third year	Fourth year	Fifth year
Broad-leaved herbs						
Bush beardtongue	0.2	1.2	0.7	0.9	0.4	0.5
Cantua spurge	0.3	5.1	2.8	1.3	0.6	0.4
Chaparral cottonweed	0.1	4.6	2.9	5.2	2.1	1.6
Common soap-plant	0.1	1.4	1.3	0.7	0.4	0.4
Common vervain	0.0	3.7	1.2	0.8	0.4	0.4
Common yellow mustard	0.2	2.6	2.3	1.4	1.2	1.6
Cotton-batting plant	0.1	2.0	1.6	0.8	1.2	0.5
Coyote tobacco	0.1	3.9	4.2	1.7	0.8	0.3
Hill lotus	0.1	1.6	1.8	1.2	0.3	0.1
Horseweed	0.0	1.9	2.4	1.3	0.7	0.2
Indian pink	0.0	1.6	1.2	1.5	0.3	0.1
Napa star thistle	0.3	9.3	5.8	3.7	3.4	1.3
Purple nightshade	0.0	1.7	1.3	2.4	1.1	0.6
Redstem filaree	0.4	2.4	2.7	1.5	1.1	0.6
Nada stickleaf	1.3	4.7	3.2	2.8	1.2	0.3
Slender buckwheat	1.0	3.6	2.4	2.0	1.4	0.6
Small-flowered lotus	0.0	1.7	2.8	1.6	0.7	0.3
Spanish-clover	0.2	5.8	3.9	3.2	2.3	1.4
Turkey-mullein	0.4	3.5	3.8	3.6	2.1	1.7
White-flowered navarretia	0.2	6.2	3.7	3.4	1.7	1.2
Willow herb	0.2	3.8	3.3	4.1	1.6	0.8
Total	5.2	72.3	55.3	45.1	25.0	14.9
Grasses						
Bent-head fescue	0.0	1.2	2.4	0.4	0.1	0.0
Foxtail fescue	4.2	16.7	11.8	3.6	2.5	2.7
Little quaking grass	1.3	10.2	4.3	2.2	2.4	1.1
Mouse barley	0.0	0.7	1.9	0.3	0.0	0.0
Nitgrass	3.6	19.2	11.4	6.3	4.8	2.3
Rat-tail fescue	0.3	4.4	5.2	1.7	0.8	1.4
Red brome	0.4	7.6	3.9	3.8	1.7	1.4
Silver hairgrass	8.3	29.2	14.4	6.6	11.7	9.3
Soft chess	1.5	6.6	6.7	5.8	3.0	1.3
Wild oat	0.3	2.9	3.1	1.6	0.3	0.6
Total	19.9	98.7	65.1	32.3	27.3	20.1
Brush seedlings						
Chaparral coffeeberry	0.0	1.2	1.4	1.1	0.6	0.6
Common manzanita	0.0	2.2	2.4	2.0	1.3	1.3
Interior live oak	0.0	0.0	0.2	0.2	0.2	0.2
Poison oak	0.0	0.4	0.3	0.3	0.2	0.2
Whiteleaf manzanita	0.0	3.4	2.3	2.1	2.1	2.1
Total	0.0	7.2	6.6	5.7	4.4	4.4

*Average of 32 plots.

species often are the exclusive occupants of spots where much ash has accumulated. On such spots, for three or more years, these plants frequently compose most of the cover (fig. 20).

Although the grass vegetation consisted exclusively of annual species on the plots in Shasta County, a few perennials occurred on some of the sample areas

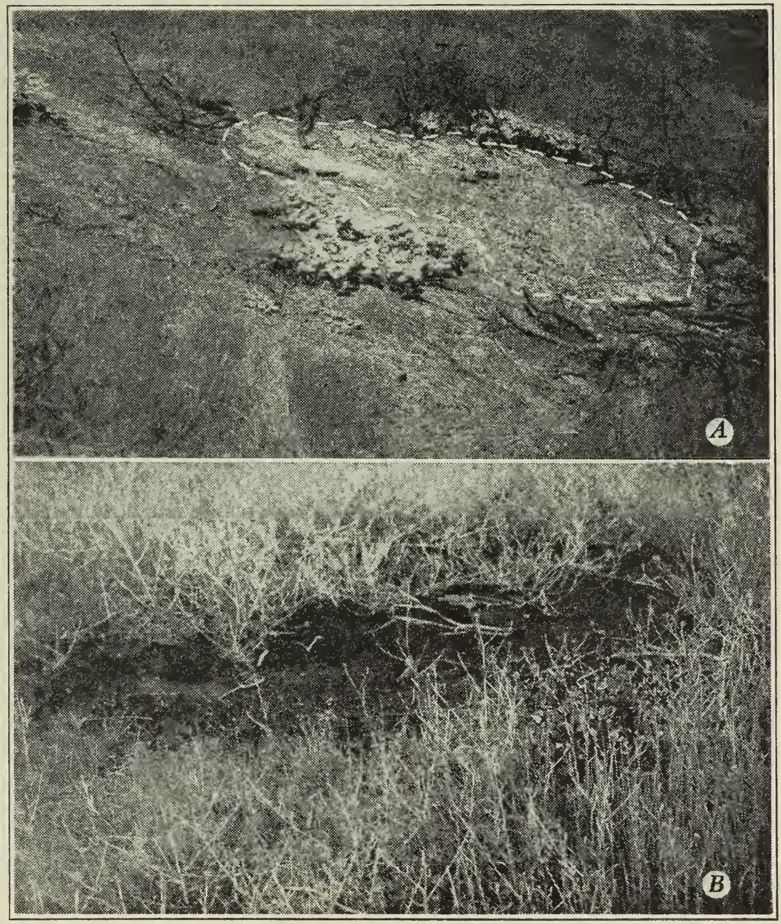

Fig. 20.—*A*, The dotted line indicates the heavy accumulation of ash left from burning of a dense stand of manzanita; turkey-mullein is the first invader. *B*, Napa star thistle encircling and encroaching upon the ground the following year, as a secondary invader. In the third or fourth year grasses and other herbs also appear. Lake County.

in other counties, purple needlegrass being the most common and widespread. Soft chess, one of the most valuable of the annual grasses, was well represented for four years after burning. As in the other covers reported, however, the early-maturing and less robust fescues, silver hairgrass, and nitgrass were numerically the most abundant. By the fifth year after burning, the invading brush sprouts and seedlings had nearly choked out the grasses and broad-leaved herbs.

Despite the presence of the dense, vigorous sprouting, the brush stand was further rejuvenated by the establishment of seedlings of the various brush species which were abundant before burning. More than half of the brush seedling stand recorded the first year after burning appeared to have promise of permanence in the fifth year. Broadcast burning usually resulted in considerable increase in carrying capacity, but this increase was of short duration unless followed with measures to suppress the aggressive brush.

Comparisons of the succession of grasses, broad-leaved herbs, and brush seedlings recorded on all the plots of the sprouting and nonsprouting chaparral areas are shown in figure 21. The number of grass plants, although com-

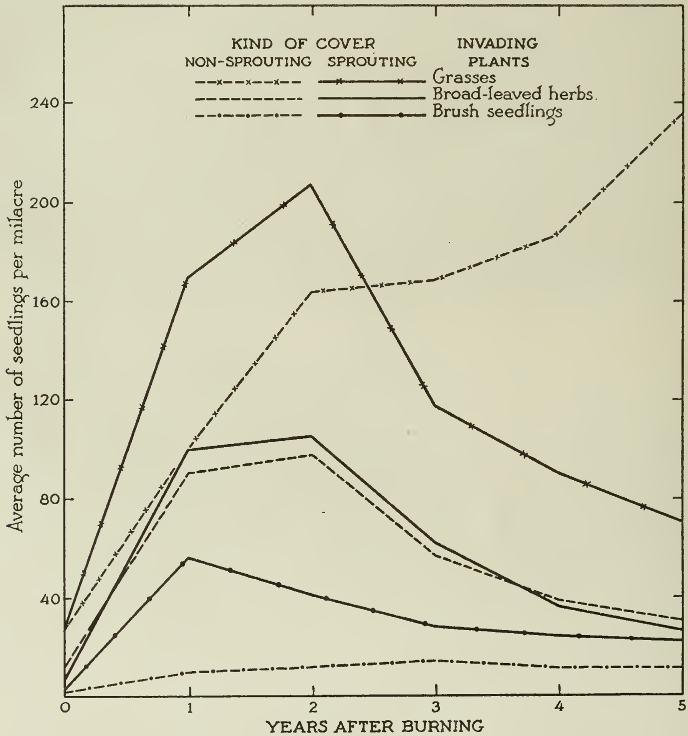

Fig. 21.—Average number of herbaceous plants and brush seedlings per milacre on sprouting and on nonsprouting covers, before and after burning.

posed largely of the early-maturing, low-yielding foxtail fescue, is seen to have increased in general on the plots of sprouting brush for the first year after burning. In the second year the grass stand increases only slightly on the sprouting chaparral plots, and thereafter the grasses typically decline in number. In contrast, on the plots of the nonsprouting chaparral lands the grasses continue to increase for each of the five years after burning, and the more robust and valuable forage grasses gradually replace the inferior foxtail fescue. The successional population of broad-leaved herbs (weeds) on the sprouting and nonsprouting brushlands is of the same general pattern, being highest in the second year, and then rapidly declining. The brush seedlings are most numerous in the plots of sprouting chaparral, the maximum number occurring the first year after burning. Competition with the abundant, vigorous crown sprouts and seedlings of the sprouting chaparral accounts chiefly for the decline in grasses and broad-leaved herbs of that cover, whereas the

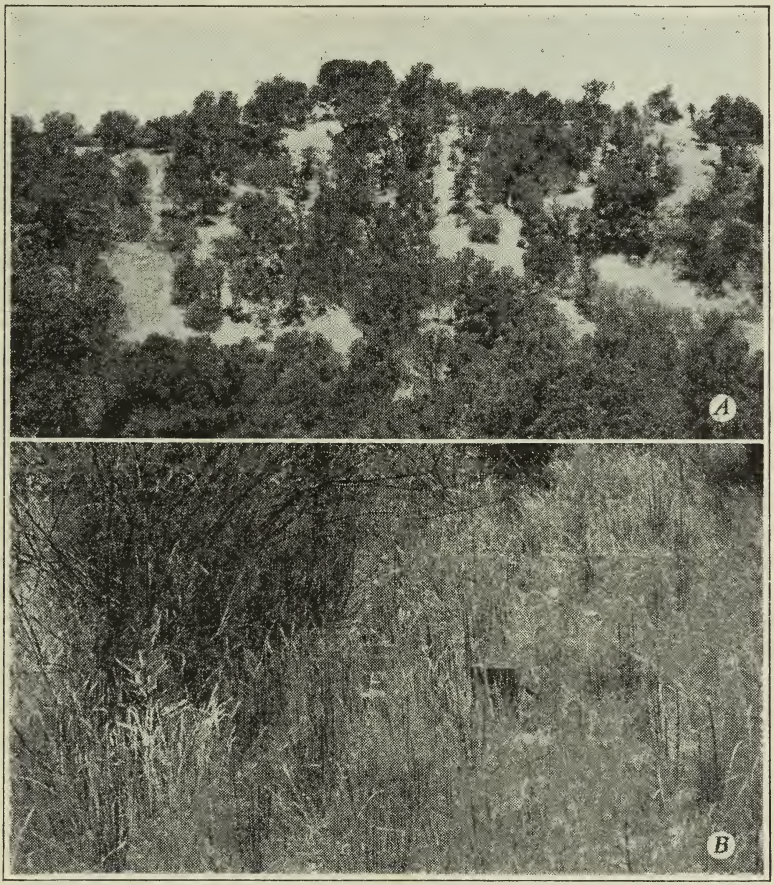

Fig. 22.—*A,* Oak and grass cover of good grazing capacity which should not be broadcast-burned if chamise is in or near the area. Removal of the trees by girdling or chopping would improve the land for grazing. *B,* Chamise seedlings, recognized by the dark stems in the grass cover, show extent of invasion from a single chamise bush following burning; the mother plant is shown at the left. El Dorado County.

increasing abundance of grass during the five-year cycle, and to a lesser extent of the invading brush seedlings, evidently accounts for the decline in the broad-leaved herbs on the nonsprouting areas. In sites of thin soil, especially those located on steep south and west slopes, there are conspicuously limited invasions of grasses and other herbs. North and east slopes of similar brush types, on the other hand, produce considerably more forage following burning than do the drier south and west slopes.

WIDENING OF CHAPARRAL AREAS BY BURNING

A statement often made by those who own foothill lands is that the brush fields now occupy greater acreage than formerly. This contention has been supported by several workers. Kotok (*55*), for example, has pointed out that in the Sierra Nevada foothills sweeping changes have taken place in the forest in the past fifty to seventy-five years as a result of fire. After fire, or logging and fire, pure ponderosa pine lands have largely passed to a deerbrush and whiteleaf manzanita association, and the warmer slopes have become a thicket of interior live oak. In other areas where severe fires have been frequent, the pine lands have given way first to a manzanita–chamise cover, and ultimately to pure chamise. Moreover, on grassland bordered by areas of chaparral, as in El Dorado County, fire has resulted in extending the chaparral into the grassland (fig. 22). According to Weeks, Wieslander, and Hill (*114*), "burned-over chaparral areas indicate that brush fields are extended as a result of fire at the expense of grass."

The plot technique already discussed was used on a number of grasslands bordering chaparral in Mendocino, Lake, and Shasta counties. The aim was to note the degree and distance of extension of the brush into the adjoining grassland. Plots were established only where one-year-old brush seedlings had come in. Several such plots were mapped yearly to ascertain the survival percentage of the invading brush seedlings. These small-plot measurements were supplemented by extensive observations and approximate measurements to verify the more restricted quantitative records.

Although the findings with respect to brush invasion varied, extension of chamise, and various species of manzanita and ceanothus, into the burned brush-bordered grassland was found to occur with rather marked regularity. On the side of the mature brush areas leeward to the prevailing winds, scattered brush seedlings occasionally extended as much as 50 yards into the burned grassland, whereas at distances of 5 to 15 yards from the brush border they were much more abundant, varying from 1 to as many as 15 seedlings per milacre. On the windward side of the brush field, chaparral seedlings were considerably more restricted, both as to numbers and distance from the parent stand, except occasionally along the steeper slopes where the seed had presumably been carried farther from the adult plants by force of gravity.

Survival of the invading seedlings varied from a total loss, as where the growth of grass was heavy, to complete establishment where grass competition was weak. The survival percentage of the one-year-old plants doubtless was also greatly influenced by the climate of that season. On an average, slightly more than 50 per cent of the invaders survived at the end of the first year, and only about 15 per cent of the remainder died thereafter. This more or less dense advance growth appeared to serve as a potential source for further extension of the brush during the eight-year to ten-year interval between burnings. During this interval, seed crops are accumulated in the soil, and further extended into the grassland. A small proportion of these may germinate without the stimulus of fire, but the majority remain dormant until a fire revisits the area, after which they germinate vigorously.

One of the most impressive cases of brush advancement following burning was that of a 3-acre community of chamise in the steeper part of an oak woodland cover of Lake County (fig. 23). Superficially, the stand gave the appearance of uniformity in height and age, except for a bordering circle of young, low-growing chamise plants; on the uppermost edge of the stand these ex-

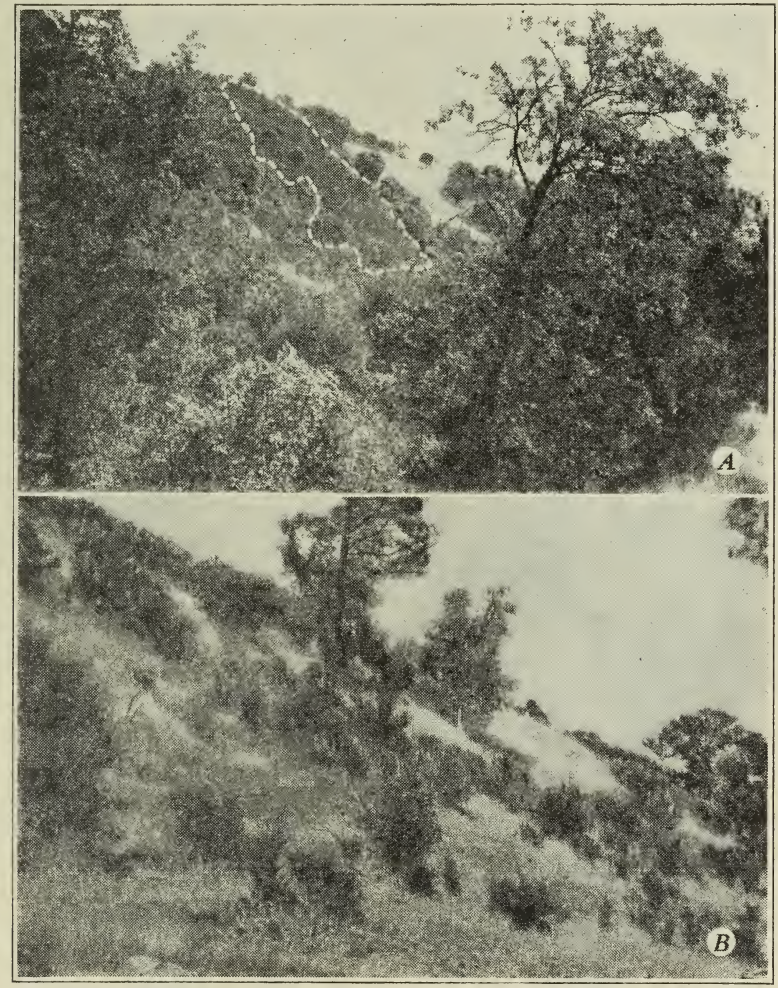

Fig. 23.—*A*, Chamise area, outlined by dotted line, containing three units of even-aged stands evidently resulting from fires, as determined by growth-ring counts and fire scars of crowns. *B*, Chamise and wedgeleaf ceanothus advancing into formerly open grassy oak woodland after one fire. Another fire is likely to result in a much denser stand of the brush. Lake County.

tended only a few yards, but laterally and beyond the lowermost edge of the mature stand, they extended from 15 to 50 yards in width.

In an attempt to establish age of isolated stands of chamise and to note any interruptions in its development, growth-ring counts were made of the root crowns on milacre sample plots. The plots were spaced at intervals of 20 feet through the stand referred to above, starting at the uppermost portion of the young stand and ending at the lowermost edge of the chamise community, and also traversing the area laterally at two well-spaced intervals. These ring counts showed that the mature portion of the stand was composed of at least

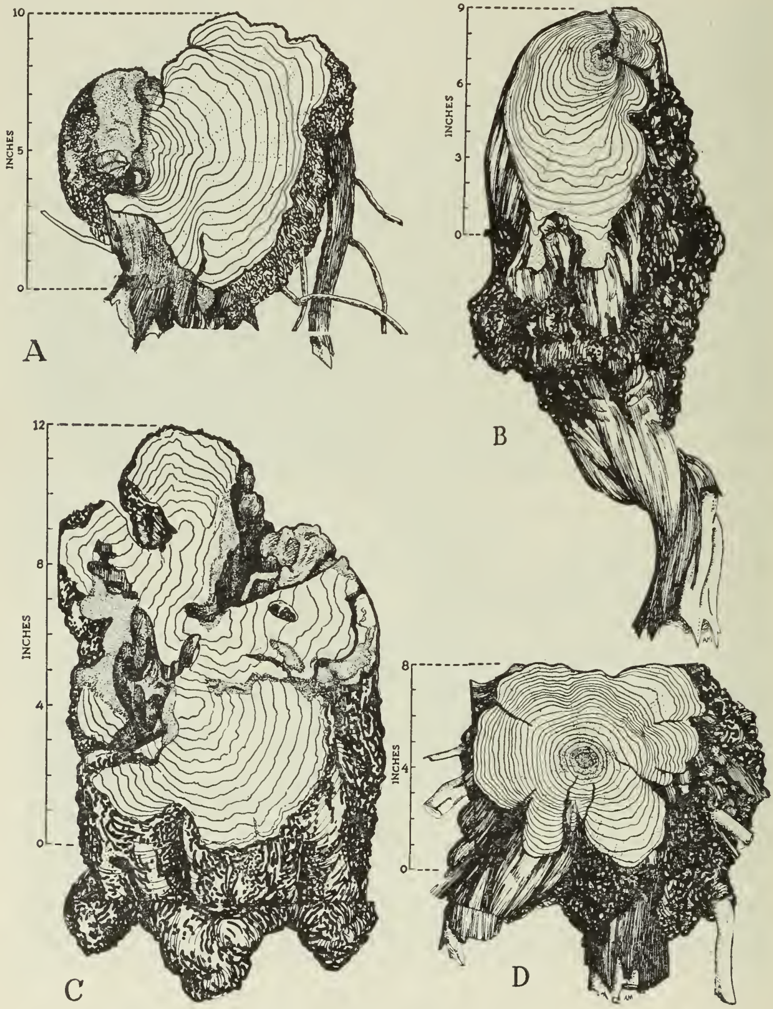

Fig. 24.—Cross sections of chamise crowns taken from the oldest portion of the area illustrated in figure 23. The crowns in *A, B,* and *C* show asymmetrical widths resulting from fire; *D* shows symmetrical development of a crown little damaged by fire. Because of growth distortions on burned areas, the maximum age attained by chamise and other such crown-producing species cannot always be determined accurately.

two distinct age groups, even though the brush was approximately uniform in height. Occurring as an irregular patch through the central portion, and occupying about one fifth of the total area of the stand, were chamise plants whose root crowns averaged 22 growth rings, varying from 18 to 24 (fig. 24).

The development of nearly all the root crowns within the central area was asymmetrical, most of the rings having been formed on the side opposite the healed-over but discolored fire scars. The remainder of the even-height growth, with its fully developed crowns, composing approximately three fifths of the stand, contained bushes with root crowns averaging 11 growth rings, the variation being 10 to 12. The root crowns of this growth were relatively more symmetrical, although most of them were fire-scarred. The crowns of the young chamise plants, located on the periphery of the older stand, had 4 growth rings, but showed no fire scars. Thus, the central portion of the stand showed an average age of twenty-two years, and the effects of at least two heavy fires. Surrounding this, the greater portion of the area averaged eleven years, and showed the effects of moderate burning by one heavy fire. The outermost circle of young brush showed no effects of burning, indicating that the last fire had crossed the area about five years previously. The extension boundary of the brush area after each fire was clearly indicated in the ring counts of the root crowns.

This plot and ring-count study, supplemented by extensive observations and ring counts made in many localities of the northern counties, supports the conclusion of other workers that burning at infrequent intervals may, and often does, extend the chaparral cover. The heat generated by a brush fire, as shown by laboratory tests (p. 61), activates the seeds of some chaparral species which apparently lie dormant for long periods under the unburned ground cover (fig. 23, *B*). Moreover, the root crowns of sprouting brush species are remarkably adjusted to endure severe and frequent burning. Unless the entire periphery of the root crowns is deeply charred, as seldom occurs, subsequent vigorous sprouting takes place after a fire. The precautions of operators to keep fire out of areas of scattered brush are justified by the studies here reported.

REPLACEMENT OF CHAPARRAL BY GRASS THROUGH EXCLUSION OF FIRE

Although chaparral is evidently the most permanent and persistent vegetation occupying extensive foothill areas of the southernmost counties of the state, as well as many of the more inferior sites in the northern counties, it also occurs sometimes as a subclimax, or more temporary cover, on sites favorable to the growth of other vegetation. The fact that fires often result in thickening the existing chaparral stands, and in extending the brush into bordering lands, does not necessarily imply that total exclusion of fire would reverse the process and result in replacement of the brush by herbaceous vegetation.

A few chaparral areas have been examined which, according to fire scars, ring counts of the root crown, and historic records, had not been burned for more than half a century. Even with this long period of nonburning, shallow and poor soils continue to support brush which forms nearly a complete cover, with no tree growth, and with little competing understory vegetation. Such unburned stands are largely composed of uneven-aged plants, indicating that as clumps of chaparral naturally opened up or died out, an occasional hardbrush seedling would survive, its establishment being favored by the declining competition of the decadent brush. Most old unburned chaparral stands, however, become decadent within a relatively short time. Branches of old chamise plants, for example, as judged by their growth rings, die off or become virtually defoliated at twenty to twenty-five years of age. After this decadent stage, the brush areas which happen to occupy the better soils are strongly reclaimed by grass or forest, according to which form of vegetation was climax. In such replacement, the few brush seedlings which appear simultaneously with the opening of the chaparral cover are suppressed and eventually eliminated by competition with the invading climax vegetation. Beneath the brush cover, on sites of good soil, a fairly dense, vigorous stand of purple needlegrass and various herbs is frequently found, the roots of which occur in abundance throughout the upper foot or so of soil. Luxuriant grass growth also occupies open spaces between the brush plants, giving the grass vegetation an appearance of dominance over the chaparral.

Where the replacement of brush by grass is so far advanced that the understory vegetation occupies 20 to 30 per cent of the ground under a combination of dead and growing branches of the brush, burning is almost certain to result in reversion of the vegetation of the area to its former tangle of brush. A noteworthy instance of this was observed over a period of several years in Mendocino County. Approximately 100 acres of a mature, gradually opening stand of chamise was being invaded by a heavy needlegrass cover. Despite the fact that sheep were able easily to forage over most of the tract, the area was heavily burned. The profusion of vigorous chamise sprouts and seedlings which followed the fire so greatly suppressed the grass vegetation after the second year as to render the area useless for grazing for several years thereafter. Had fire been kept out, this area would likely have become predominantly or wholly a grass cover, similar to the adjoining lands which supported a fair amount of bunch-grass vegetation.

In brief, the evidence strongly indicates that the less favorable sites, now almost completely occupied by chaparral and chamise, have supported, and will continue to support, the brush cover for indefinite periods. Neither burning nor the exclusion of fire is apt to affect measurably the character or abundance of the brush occurring on thin or otherwise inferior soils. On sites of high quality on the other hand, exclusion of fire will in many instances result in replacement of the brush by the true climax vegetation. Thus, where the brush is thinning out because of decadence and is being replaced by grasses, especially perennial forms, fire should be kept out. If, however, the brush cover on productive lands is vigorous, the period of fire exclusion necessary to induce an abundant growth of grass should be weighed against the cost and hazards of brush burning in adopting a management plan. Fire-exclusion periods of twenty years or more may have to elapse before the brush on most good lands will thin out sufficiently to favor the growth of an abundant understory vegetation. Such extended fire-protection periods are not always economically practical, especially if many of the intervening years are marked by low forage values. Recognition of the turning point in a brush-and-grass struggle for successional supremacy is, notwithstanding, of great importance in a brush-suppression program on areas that have not been recently burned.

SOIL TEMPERATURES DURING BURNING

The heat of fire has an obvious effect in killing the leaves and branches of plants; but its effects on the chemistry of the soil, and especially on germination of seeds lying in the soil litter, are also important influences in affecting the plant cover. This view is widely accepted and has been verified by several research workers.

Heyward (*37*) measured soil temperatures during fire in longleaf pine forests. Hofman (*42*), working in the Douglas-fir region, and Korstian (*54*), in deciduous forests, also studied soil temperatures during fires. Results from forest fires are not directly applicable to brushland, however, and information concerning the actual magnitude and duration of high temperatures is lacking. For this reason it seemed desirable to obtain data as to the heat created in the litter and surface soil during the burning of different amounts of brush fuel. The data here presented include also the more pertinent results of studies by Craddock.[21]

The field fire temperatures were measured by a recording Bristol pyrometer of special design.[22] After selection of a site for study, the thermocouples were inserted in the ground. In recording most of the readings, the hot junction of one thermocouple was placed ½ inch deep in the litter; the second and third junctions ½ and 1½ inches deep, respectively, in the soil proper. Where temperatures were procured under chaparral, the tips of the thermocouples were placed midway between the stem bases and the periphery of the crown radius; and for readings in the grass cover the tips were located outside of the crown periphery. Temperatures were recorded at 1-minute intervals for each thermocouple until the fire had subsided.

The pyrometer fire data are presented in table 7. These data show that the time required to reach the maximum temperature is relatively short in the litter and duff compared with that in the surface soil. In the 11 field brush fires studied the maximum temperature in the litter was reached in 1 to 9 minutes, whereas at depths of ½ to 2 inches in the soil proper the time required to reach maximum temperatures, with one exception, varied from 7 to 31 minutes. The duration of temperatures above 150° F in the soil was directly proportional to the duration and the intensity of the temperatures at the surface, as shown in figures 25, 26, and 27. Figures 25 and 26 bring out the characteristic sharp rise in temperature in a heavy litter, with abundant burning fuel above, where the maximum temperature was reached in the litter in less than 10 minutes. Figure 27 shows the more gradual rise to the maximum temperature in the litter where less fuel is available. The lag in reaching the maximum temperature in the deeper soil layer, as shown in curve *C* of figure 25, is characteristic of all such readings.

[21] George W. Craddock, working under the direction of the writer at the University of California, in 1927 presented data on soil temperatures during chaparral fires in his thesis, "The Successional Influence of Fire in the Chaparral Type." This is on file in the University of California Library, Berkeley, California.

[22] In checking the instrument against a standard potentiometer, the readings were found to be in agreement within 5 degrees in the range of 100° to 500° F, and within 10 degrees above the 500° range. The sensitive pendulum marker responded accurately at 10-second intervals to wide fluctuations in temperatures as transmitted from the thermocouples when variously situated with respect to the heat factor.

TABLE 7

TEMPERATURE RECORDED IN DUFF AND IN SOIL ON AREAS OF DIFFERENT PLANT COVERS

County	Fire plot no.	Vegetation	Air temperature, degrees F	Wind, miles per hour	Relative humidity, per cent	Depth of thermocouples, inches	Maximum soil temperatures, degrees F*	Minutes to reach maximum temperature	Minutes soil remained over 150° F
Sonoma	1	Wedgeleaf ceanothus and annual grasses	93	5	15	½, in litter	805	9	120
						1¾, in soil	395	31	90
Humboldt	2	Blue-oak and Douglas-fir slash (duff 2 inches deep)	72	7	40	½, in litter	975	2	20
						2, in duff and soil	170	31	12
						3, in soil	...	..	..
Humboldt	3	Common manzanita and dense annual grasses	74	7	36	½, in soil	555	11	26
						1½, in soil	160	12	5
Humboldt	4	Common manzanita, scattered grasses and weeds	70	3	42	½, in litter	960	8	34
						1½, in soil	215	16	17
Humboldt	5	Wedgeleaf ceanothus with scattered grasses	76	5	32	½, in litter	300	5	11
						1½, in soil	...	..	..
						½, in soil	200	1	5
Mendocino	6	Common manzanita, scattered herbs	75	5	32	½, in litter	800	4	24
						1½, in soil	...	..	..
Mendocino	7	Chamise, scattered herbs	78	8	31	½, in duff	1,200	8	60
						1½, in soil	630	27	60
						½, in soil	310	5	19
Mendocino	8	Chamise, common manzanita, wedgeleaf ceanothus	91	11	18	½, in duff	990	4	52
						¾, in soil	420	7	80
						1½, in soil	240	12	103
Shasta	9	Chamise, fairly dense grasses and weeds	89	10	21	On soil surface	635	2	3
						¾, in soil	320	9	12
						1½, in soil	230	16	17
Shasta	10	Mixed chaparral of blue oak, dwarf interior live oak, wedgeleaf ceanothus, with scattered herbs	87	8	23	½, in duff	840	4	40
						½, in soil	410	7	61
						1½, in soil	235	13	74
Shasta	11	Mixed chaparral of wedgeleaf ceanothus and dwarf interior live oak	93	4	24	½, in duff	920	6	22
						1, in soil	390	12	47
						2, in soil	210	21	71

* The instrument used does not record below 100° F; this accounts for blanks in the three last columns.

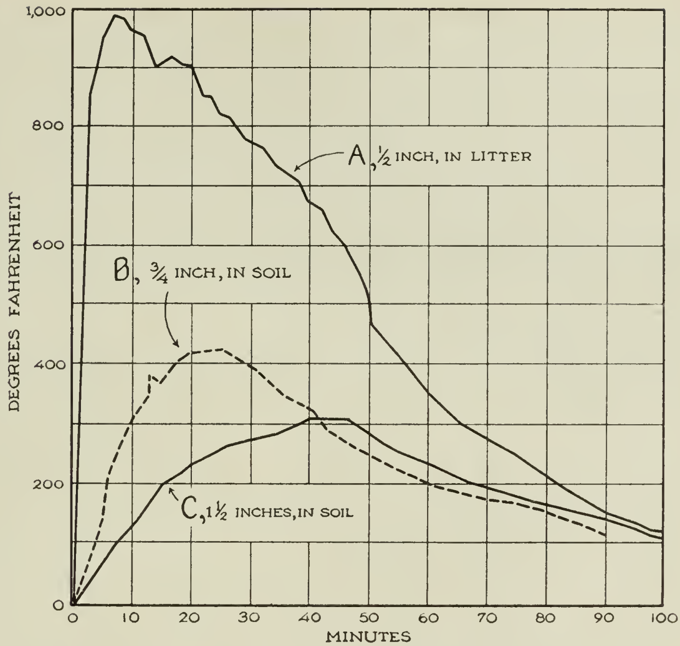

Fig. 25.—Soil temperatures recorded during chamise fire number 8: *A*, Thermocouple, ½ inch in duff; *B*, ¾ inch in the soil; *C*, 1½ inches in the soil. Mendocino County.

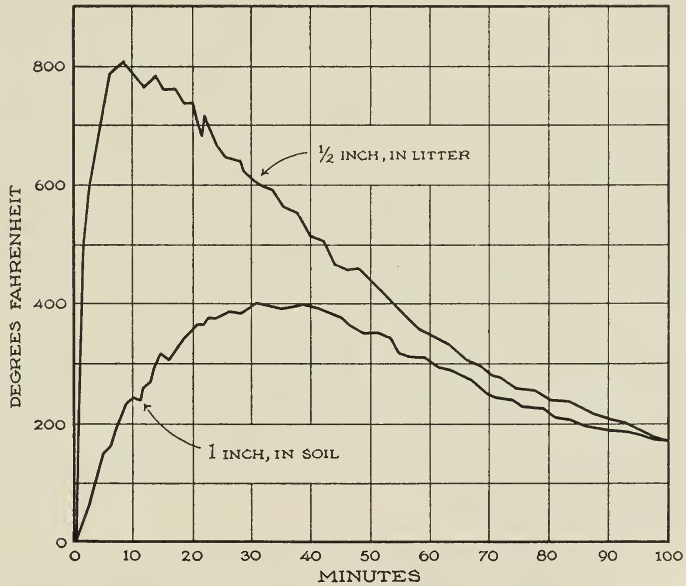

Fig. 26.—Soil temperature recorded during a fire in mixed chaparral and grass. Sonora County. (After Craddock.)

Probably the most significant point brought out in these records is the duration of the heat in the surface soil where most of the seeds have lodged. Temperatures above those endured by most seeds were recorded in several instances, notably in experimental field fire stations 1, 7, 8, 10, and 11, shown in table 7. This fact was verified by subjecting to conditions of germination the seed contained in the burned soil collected at the depths to which the thermocouples had been set, and comparing the results with those of corresponding soil samples taken on adjoining unburned spots. Transfer of these samples to flats in the greenhouse, where they were watered at suitable intervals, revealed that the seed of nearly all species had been killed where the soil temperature was maintained for several minutes above 300° F.

The soil-temperature data here presented for individual fires may not be wholly representative of the temperatures created when a large brush field is

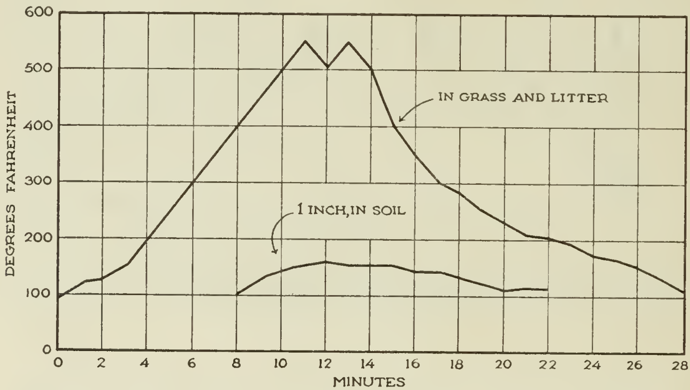

Fig. 27.—Soil temperatures recorded during a fire in a manzanita and grass cover. The litter layer was thin. Humboldt County.

burned, yet the trends of the data appear to conform to specific patterns. Figures 25, 26, and 27, for example, show irregularities in the temperature curves for the litter which are purely local. The falling of burning twigs and branches, the exact placing of the thermocouples in relation to the fuel, the kind of fuel, the extent to which the fuel was consumed, wind movement, relative air humidity, and many other related factors influence to some extent the "spot" temperature records. The hottest fires were recorded in slash, the mixed chaparral coming second, chamise next, and the grass last. The fact that surface-soil temperatures within the crown circumference of the larger individual bushes frequently exceeded the viability endurance of the accumulated seed appears partly to account for the temporary barrenness of small areas within larger burns. The toxicity of heavy accumulations of ash, however, must not be overlooked as a factor adverse both to the germination of seeds and to the establishment of seedlings.

HEAT STUDIES WITH SEEDS

Evidence supports the belief that seeds of the hard sclerophyll species, like those of many other kinds of cover, may lie dormant, but retain their viability for many years (*23*). In some species the after-ripening process may last for considerable time regardless of the treatment of the seed; in others the integuments may be so thick or of such dense structure as to preclude oxidation and the absorption of moisture until some factor alters the seed coat (*8*, *23*). Heat treatment is one factor which may hasten germination of the seeds. Moreover, conditions to which seeds are subjected after being heated may affect their viability and rate of germination (*78*).

Where sufficient fuel is available to kindle a particularly hot fire, a "selective" seedling stand appears to come in, with the result that certain hard sclerophylls become chief occupants of the site. This apparent selectivity of species induced the writer to initiate a study of the effect of heat on the germination of several of the more common chaparral and associated herbaceous species. The more pertinent results of several carefully supervised researches of Wright (*117*) are included with the data here presented. The chief aim was to note the relative high-temperature endurance of the seeds of various chaparral and grass species, with a view to explaining why certain plants commonly reclaim burned areas.

The shrub and grass seeds used in the laboratory heat treatments were collected in the chaparral belt from the current crop of four different years. The shrub species tested were[23] coffeeberry, California snow-drop bush, chamise, chaparral whitethorn, common manzanita, hoaryleaf ceanothus, laurel sumac, Parry manzanita, sugarbush sumac, and western chokecherry. The grasses tested were purple needlegrass, ripgut, blue wild-rye, soft chess, and wild oat. All seed collections were air-dried and freed of capsules, glumes, and other such covering before being tested. They were stored in a dry, cool room until treated.

Artificial heating of the seeds was done in lots of 50 to 100 of each species, and 100 unheated seeds were used in the check lots. The seeds were exposed exclusively to dry heat. A thermostatically controlled electric oven was employed in heating the seed.

In order to ascertain the temperature endurance of the different species of seeds used, the several lots were exposed for 5-minute periods to temperatures ranging from 120° to 300° F, at intervals of 20 degrees. After heating, both the treated and the check (unheated) seed lots were placed between moist blotters in an electric germination oven, where they were maintained at a temperature of 68°. In addition, several lots of both were germinated in sand beds in a greenhouse, as a further check. Tap water was applied daily to keep the medium moist. Germination counts were made weekly. The germination data of the several common chaparral and grass species are given in table 8. The table shows that the seeds of 14 of the 21 species of shrubs studied gave consistently higher germination percentages after being heated than did those of the checks, or unheated seeds. Samples numbered 7, 10, 11, 12, 14, 15, 17, 18, 19, 20, and 21, which represent seeds having various forms of integuments and densities of the testa, gave much higher germination percentages after heating. The seeds of several of the other species reacted slightly in favor of the heat treatment, whereas the germination of some was not affected by exposure to the temperatures used. Studies of germination under field conditions have

[23] The several species that failed entirely to germinate with or without heat treatment are not here listed.

TABLE 8

LABORATORY TESTS OF GERMINATION OF CHAPARRAL AND GRASS SEED AFTER 5-MINUTE EXPOSURE TO VARIOUS TEMPERATURE RANGES

Seed sample no.	County	Year	Species	Per cent germination after heating to the temperatures indicated										
				100° to 120° F	120° to 140° F	140° to 160° F	160° to 180° F	180° to 200° F	200° to 220° F	220° to 240° F	240° to 260° F	260° to 280° F	280° to 300° F	Controls (untreated)
			Shrubs											
1	San Bernardino	1928	Chaparral coffeeberry	46	60	64	70	48	26	2	0	0	0	59
2	Mendocino	1930	Chaparral coffeeberry	54	51	62	67	44	38	12	0	0	0	47
3	Shasta	1934	California snowdrop bush	5	4	8	7	6	8	6	10	11	0	8
4	Shasta	1934	California snowdrop bush	4	2	5	3	4	6	6	9	7	0	4
5	Mendocino	1927	Chamise	4	6	12	8	8	16	8	0	0	0	15
6	Mendocino	1928	Chamise	9	7	8	7	13	12	14	17	12	0	10
7	Lake	1928	Chamise	14	16	12	11	13	22	26	31	29	3	19
8	Lake	1933	Chamise	13	12	13	12	14	21	20	25	27	2	21
9	Shasta	1934	Chamise	..	11	19	13	12	10	9	18	22	4	18
10	San Joaquin	1927	Chaparral whitethorn	12	14	14	24	40	34	34	68	28	0	12
11	San Joaquin	1933	Chaparral whitethorn	13	16	17	28	46	51	53	79	34	0	15
12	Tehama	1934	Common manzanita	0	0	0	3	2	5	6	11	5	2	3
13	Santa Barbara	1927	Hoaryleaf ceanothus	8	4	16	12	8	2	0	0	0	0	16
14	San Diego	1927	Laurel sumac	8	12	20	34	44	52	52	28	6	2	13
15	San Diego	1931	Laurel sumac	16	19	17	40	53	57	61	31	12	3	18
16	Orange	1927	Bigpod ceanothus	6	12	8	6	14	8	24	10	0	0	15
17	Santa Barbara	1931	Bigpod ceanothus	11	9	10	12	11	17	26	15	6	0	13
18	Lake	1934	Parry manzanita	0	0	0	0	0	2	4	9	7	0	2
19	Los Angeles	1927	Sugarbush sumac	2	2	10	4	32	22	28	26	2	0	6
20	Los Angeles	1931	Sugarbush sumac	3	3	8	13	22	20	30	27	3	0	4
21	Shasta	1934	Western chokecherry	5	2	7	4	10	16	21	17	12	0	6
			Grasses											
1	Mendocino	1931	Purple needlegrass	34	32	37	33	38	33	27	0	0	0	31
2	Alameda	1933	Purple needlegrass	..	54	49	43	46	43	49	2	0	0	41
3	Lake	1927	Soft chess	98	96	90	92	100	82	78	34	0	0	91
4	San Joaquin	1933	Soft chess	..	87	83	84	89	81	72	11	0	0	86
5	Humboldt	1934	Soft chess	..	85	91	92	89	97	86	3	0	0	94
6	Contra Costa	1934	Blue wild-rye	31	39	30	33	39	17	2	0	0	0	37
7	Alameda	1927	Ripgut grass	100	100	100	100	100	2	0	0	0	0	100
8	Mendocino	1931	Ripgut grass	94	91	89	98	89	22	7	0	0	0	93
9	Mendocino	1934	Ripgut grass	86	85	92	91	83	10	2	0	0	0	88
10	Shasta	1927	Wild oat	52	50	54	68	74	82	60	0	0	0	60
11	Alameda	1931	Wild oat	49	48	46	57	63	61	42	0	0	0	53
12	Lake	1934	Wild oat	66	70	64	68	72	70	48	0	0	0	74

also led to the conclusion that the seed of some of the species listed in table 8 are activated little or not at all by the heat treatment. Even when the seed coats of such species were all but filed through, or when the testa was wholly removed, as was done in some instances, and the seed subsequently placed under germination conditions favorable to most seeds, the time of germination was not hastened.

The seed of some of the chaparral species endured much higher temperatures than did others. For example, the seed of only three species, namely, chamise, common manzanita, and laurel sumac, showed any life when subjected to temperatures between 280° and 300° F. The species whose heat-treated seed gave much higher percentages of germination than the checks are chaparral whitethorn, common manzanita, Parry manzanita, laurel sumac, bigpod ceanothus, sugarbush sumac, and western chokecherry. Although the testa of the seed of some of these species, notably those of the two manzanitas and that of the western chokecherry, is stony, thick, and dense, yet the interior of the seeds of such structures reached the oven temperature in 3 to 4 minutes, as first noted by Wright (*117*) and subsequently verified by the present writer. This fact was determined by inserting thermocouples 0.006 inch in diameter through closefitting holes made in the seed coat.

Table 8 shows that the grasses studied do not endure the higher temperature ranges nearly so well as the chaparral species. No seed germination took place among the five grass species when they were heated above 260° F. Moreover, none showed appreciable increase in germination percentage under heat treatment. This fact is best shown in those species whose germination check records were relatively low, such as samples 1, 2, 6, 10, 11, and 12. Thus not only do certain species of shrubs which often predominate on chaparral areas endure high temperatures, but their germination capacity is sharply increased thereby. The seed of other brush species, some of which constitute an important part of the chaparral cover, are not stimulated to germination by the heat treatments used. Although the seeds of grasses do not endure such high temperatures as many associated shrubby forms, they do appear on new burns, evidently from adjoining areas. The space occupied by established brush seedlings soon becomes relatively great compared with that of the invading grasses. The stimulated germination of the chaparral seed appears to account, in the main, for the aggressive invasions of the chaparral species on burns.

Experimentation seemed to be justified by the extent to which the succession of herbaceous vegetation on burns could be favored by the introduction of seed of promising species.

RESEEDING OF BURNED AREAS

In 1926, reseeding experiments with cultivated forage plants were initiated by the writer on burned chaparral and chamise lands in some of the northern counties of the state. Since that time many such experiments have been undertaken on burns. Some of these tests were made in the interior counties, where the summers are hot and dry, and where the annual precipitation may vary from 25 to 40 inches; other such experiments were made in the cooler northern coastal strip, where the annual rainfall ranges from 45 to more than 60 inches. A large variety of burned brushland was included, particularly in the interior counties; in many instances ranch owners coöperated by furnishing areas for reseeding. In addition, a large number of reseeding trials were made on public lands and on railroad holdings. Sixty-two plots were established between 1926 and 1937, most of which were seeded to a mixture of two to five species. Most of the seeding was done at the rate of 20 pounds per acre. The plots varied in size from one-fortieth to one-half acre.

In these reseeding experiments many forage species were employed. In most instances the seed was covered by raking or brushing it into the soil; but where unusually hot fires had left the soil loose, or even "fluffy" by burning of the humus, the seed was merely scattered on the ash-covered soil, with no attempt at harrowing it in. The latter plan is popular along the north coast, where some success has been attained in reseeding of burned brush ranges. Both spring and fall seedings were attempted. In some instances the seed was scattered early in the autumn before any rain had fallen; in other experiments the sowing was delayed until after the first fall rains had thoroughly wetted the soil and carried a portion of the soluble fraction of the ash into the soil.

Reseeding in Interior Counties.—The interior counties included in the reseeding trials were Butte, Glenn, Shasta, and Tehama. The species employed were as follows:

Cultivated Grasses	Native and Mediterranean Grasses	Leguminous Species
Bulbous bluegrass	Blue wild-rye	Bur-clover
Canada bluegrass	California brome	Spanish-clover
Crested wheatgrass	Mouse barley	White sweet-clover
Harding grass	Purple needlegrass	Yellow sweet-clover
Italian ryegrass	Soft chess	
Meadow fescue	Western needlegrass	
Orchard grass	Wild oat	
Perennial ryegrass		
Redtop		
Sheep fescue		
Smilo		
Timothy		

All but two of the above-listed species are known to be growing without cultivation in various parts of California, and some seem to be adapted to desert habitats (*79*).

The results of these experiments were exceedingly disappointing. Trials with most of the twelve cultivated grasses failed to produce practical forage stands in the interior counties, regardless of season of seeding, covering of the seed, the site quality, or the species used. Except for an occasional sparse stand of some species, most of which endured for only two or three seasons, no success was obtained. In this respect the results are similar to those recorded in the Douglas-fir region of the Northwest (*3*) where, in order to retain the grass cover, it is usually necessary to reseed every third year.

Generally, the few plants which survived the rigors of the first summer were choked out in the second season by the abundant sprouts and seedlings of the native brush cover, and by the weeds which temporarily invaded the burns. Among the native perennial grasses, blue wild-rye and purple needlegrass gave the greatest promise of success, although the stand was never dense.

Among the annual grasses, wild oat and soft chess were the most successful. Most of the other species listed above either failed to germinate, or the seedlings did not live through the first summer. Bulbous bluegrass, one of the species not reported as growing without cultivation in California, was perhaps the most persistent of any perennial grass on poor sites, but in no case was the stand sufficiently dense to influence measurably the carrying capacity. Mouse barley, though undesirable when mature because of the troublesome awns, produced fairly dense stands on several plots the first season after seeding; but although viable seed was produced by this species, seldom were more than a few plants found the second year.

TABLE 9

Height Growth and Density of Wild Oat Seeded on Burned Chaparral, Shasta County, 1933 and 1934

Plot no.	Date burned	Date seeded for first year's crop,* and precipitation since burning	Density, per cent		Average height at maturity, inches	
			First year	Second year	First year	Second year
31	Autumn 1932	Autumn 1932, after 3 inches of rain......	40	5	51	13
32	Autumn 1932	Autumn 1932, after $1\frac{3}{4}$ inches of rain....	35	2	54	12
33	Autumn 1932	Autumn 1932, before any rain...........	27	3	47	9
34	Summer 1931	Autumn 1932, after about 35 inches of rain..................................	8	0	11	..
35	Autumn 1931	Autumn 1932, after about 35 inches of rain..................................	12	2	14	12
36	Summer 1931	Autumn 1932, after about 35 inches of rain..................................	4	0	16	..
37	Autumn 1931	Autumn 1932, after about 35 inches of rain..................................	10	5	13	11

* The natural seeding from the first year's growth was augmented by scattering and raking in the same amount of seed, in October, as was seeded on the plots the first year after burning. The resulting stand gave the second year's crop.

Among the few species that gained even a temporary foothold, the height growth and the density of the cover were superior on the plots burned during the summer or fall of the year seeded, the densest cover and healthiest growth being obtained on plots seeded after the rains had started. Wild oat, when seeded in superior sites, was particularly conspicuous in its growth response on areas heavily burned during the current season; but in the second year the vigor of growth and the density declined greatly, as shown by the measurements presented in table 9.

Where the seeding of this species was delayed until the second year after burning, the height growth was much lower and the stand thinner, indicating that the soil nitrogen content, and perhaps the stimulating growth effect of the ash, may have diminished. On plots 34, 35, 36, and 37, which were not seeded until the autumn of the next year after burning, many chaparral sprouts, seedlings, and weeds had reclaimed the area, so that light and moisture were in unfavorable balance. Also the looseness characteristic of the surface soil of hot, fresh burns was absent; and the nitrate supply was measurably lower than on recently burned areas, a factor discussed in connection with the effect of fire on the soil.

The trials with leguminous species were generally no more encouraging than were those with the cultivated grasses, as indicated in the following discussion. Seeding with bur-clover and the sweetclovers resulted in consistent failures, whereas Spanish-clover produced a scattering of plants on some plots, but failed entirely on others.

Reseeding in Coastal Counties.—The same species were used in the coastal counties as were employed in the interior counties, and the same methods of seeding were carried out. Work was done in Humboldt, Lake, Mendocino, and Sonoma counties.

The results of these experiments were somewhat more successful than those reported for the interior foothills, for temporary stands were often obtained

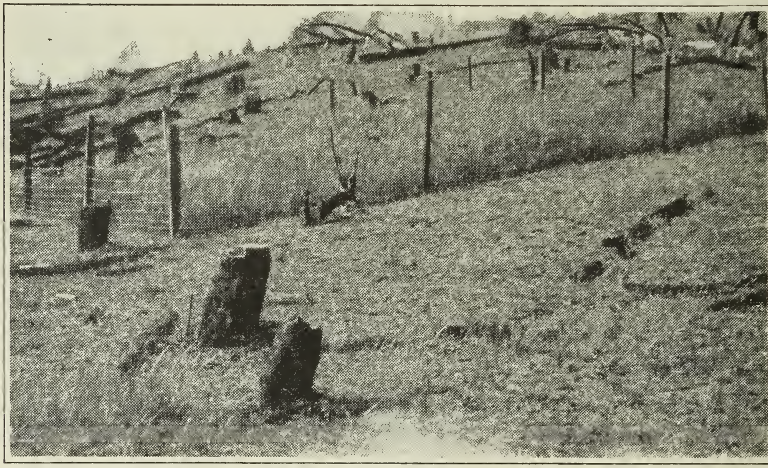

Fig. 28.—Gentle slope of heavy Douglas-fir stand cut and burned, followed by seeding with 30 pounds of redtop per acre. A redtop cover of 60 per cent density occupied the ground for the first two years after burning, both in the protected enclosure and on the adjoining grazed area. In the third year annual grasses and weeds replaced much of the redtop. In the fifth year after burning and seeding, practically no redtop remained. The soil was deep and fertile. Anderson Valley, Mendocino County, 1926.

in the better sites, particularly on plots close to the coast. Among the perennial grasses, Italian ryegrass, perennial ryegrass, Harding grass, orchard grass, redtop, and smilo gave somewhat consistently the best results (fig. 28). A mixture of equal parts of seed of perennial ryegrass, orchard grass, redtop, and smilo, sown at the rate of 20 pounds per acre, in sites of especially high quality, proved the most satisfactory in the preliminary trials. Especially was this the case in redwood cutover areas, where thickets of blue blossom were first lopped and allowed to dry before being burned late in the fall, the area being seeded after the coming of the first heavy autumn rain. In such sites the seed was broadcast, with no attempt at soil treatment. The first year after seeding, the yield on some plots was sometimes the equivalent of ⅓ to ½ ton per acre. The forage was relatively lush and was much more highly relished than that of the native annual grasses, or than that of the Mediterranean introduced grasses. It was noted that the cultivated species retained their succulence several weeks later in the season than did the annual grasses, hence there was a tendency to overgraze them. By far the largest yield was produced the first year. Indeed, the stand proved distinctly ephemeral, so that in the third year most of the cover of cultivated grasses, regardless of its promising appearance the first year, was largely if not entirely replaced by the early-maturing annuals, of which the inferior foxtail fescue usually predominated. In a seeding mixture, redtop was usually the last to disappear.

Among the grasses which produced the heaviest yields on sites of exceptionally high quality, such as flats or gentle slopes of logged-off redwood forest, Harding grass deserves special mention. Seeded in the autumn at the rate of 5 pounds to the acre, after the coming of the first rains, and without subsequent

Fig. 29.—Harding grass seeded on a burn of logged-over redwood on a coastal range in Humboldt County. A good stand was procured for the first two or three years after burning.

soil treatment, this species sometimes yielded heavily, despite its being pastured closely (fig. 29). As in most other species, or seeding combinations, the yield of Harding grass was heaviest the first year after seeding on fresh burns. In the third season after seeding, the cover tended to decline measurably; but where grazing was conservative the stand gave promise of reasonable longevity, in some instances possibly affording economic returns. Only sites of high quality are suited to this species. The forage of Harding grass is palatable to all kinds of livestock; the other perennial grasses appearing in the list are clearly of secondary value.

Because of the relatively greater promise of the perennial grasses in high-quality sites, only a few plots were seeded to the annual grasses and to the legumes. Wild oat and soft chess responded moderately well in localities too poor for the growth of perennial grasses, as on the better chaparral burns inland from the redwood belt. Except on deep soil, bur-clover and the other legumes showed no response whatever.

The seeding trials of burned chaparral areas in the interior northern counties, with the several species commonly employed in range revegetation, indicated that reseeding of such areas is seldom economically feasible. Further reseeding experiments, however, would be justified, on burns of good lands, as more drought-enduring plants become available. The best possibilities of reseeding in the drier coastal areas appear at present to be with such native or naturalized species as needlegrass, blue wild-rye, wild oat, and soft chess. In the humid coastal areas, Harding grass and perennial ryegrass gave the best promise of success. Even these species, however, frequently are soon crowded out by the vigorously sprouting brush and by the numerous volunteer herbs.

EFFECT OF CHAPARRAL ASH ON SEED GERMINATION AND GROWTH OF GRASSES

Reseeding of burned chaparral areas is frequently undertaken before the autumn rains have dissipated the accumulated ash from the soil. Moreover, reseeding experiments have been observed to give variable results on burned areas where ash deposits are heavy. Recently burned areas frequently exhibit spots barren of any form of vegetation for several years. On the other hand, some chemical constituents of the ash appear to stimulate growth and development of certain plants. In view of these confusing observations, it seemed desirable to study the effects of ash upon germination and growth of some grass species commonly selected for range reseeding. The study resolved itself into three aspects: chemical analysis of the ash of selected chaparral species to determine mineral composition of the ash before and after leaching; experiments to note the effect of chaparral ash on grass-seed germination; and experiments to determine the effect of ash on growth of grass from the seedling stage to maturity.

Relatively little research has been done with respect to the effects of ash on plant growth. Alway and Rost (*2*) reported that clover and timothy, when seeded in the spring on an area burned the previous summer, produced abundant forage the first year, but that this cover all but disappeared the second season. Isaac and Hopkins (*50*) recorded low seedling survival on burned forest lands, and the root systems of seedling plants were poorly developed. Schmidt (*93*) reported that seed germination was lowered in direct proportion to the amount of ash in the soil. Fabricius (*25*) applied thin layers of ash of burned duff to forest soils. Of the seed of several species of trees planted on the ashed soil, the germination of some appeared not to be affected, whereas that of others was lowered. The survival of seedlings of all species was much lowered by treatment with ash.

Harris and Pittman (*31*) conducted studies to determine the effect of alkali on several common grasses. Potted soils were treated with varying amounts of sodium chloride, sodium carbonate, and sodium sulfate. Each of these salts proved toxic, and the degree of injury to the young plants decreased in the order of the salts named. The species most seriously affected were Kentucky bluegrass and timothy. Meadow fescue was only moderately affected, whereas orchard grass and Italian ryegrass appeared indifferent to moderate amounts of these salts.

Ash Content of Chaparral Species.—In the present study the chemical composition, both of individual chaparral species and of combinations of such species, was determined. Some samples were ashed in the field to simulate burning practice, while other chaparral samples were burned under the hood in the laboratory. The latter method resulted in somewhat more complete ashing than that done in the field. The samples were collected in July from a large number of bushes. The ash was derived from leaves, twigs, and stems in such proportions as to be representative of entire bushes.

As shown in table 10, both the total ash and the silica-free ash are highest in the leafy branch samples of blue oak, and lowest in wedgeleaf ceanothus. Blue

TABLE 10

COMPOSITION OF LEAFY BRANCHES OF COMMON CHAPARRAL SPECIES
(Expressed as per cent of ovendry weight)

Species	Total ash	Silica	Silica-free ash	Calcium	Phosphorus	Potassium
Wedgeleaf ceanothus	1.78	0.15	1.63	0.716	0.060	0.255
Chamise	3.14	.39	2.75	1.141	.084	0.490
Pacific madrone	3.32	.21	3.12	1.082	.083	0.709
Dwarf interior live oak	2.27	.34	2.93	0.707	.069	0.335
Bigberry manzanita	1.95	.22	1.73	0.614	059	0.475
Toyon	2.50	.31	2.20	0.630	.071	0.683
Blue oak	5.07	0.24	4.83	1.200	0.155	1.209

TABLE 11

COMPOSITION AND ALKALINITY OF THE ASH OF COMMON CHAPARRAL SPECIES WHEN BURNED IN THE OPEN, TO SIMULATE NATURAL BURNING

Sample	Silica, per cent	Silica-free ash, per cent	Calcium, per cent	Phosphorus, per cent	Potassium, per cent	pH of saturated solution	Moles of sodium carbonate per gram of ash
Wedgeleaf ceanothus	6.1	90.1	34.9	2.68	8.99	12.4	0.0108
Chamise	28.3	64.1	27.7	1.58	9.50	11.1	.0084
Pacific madrone	4.9	92.6	30.2	1.98	17.24	12.4	.0114
Dwarf interior live oak	9.6	86.4	24.4	3.10	15.10	11.4	.0090
Bigberry manzanita	6.6	89.1	25.3	2.27	19.08	12.4	.0103
Toyon	6.9	89.4	23.6	1.99	17.25	12.4	0111
Blue oak	11.8	85.6	25.0	2.97	10.92	11.6	0.0124

oak is also highest in calcium, phosphorus, and potassium. Bigberry manzanita and wedgeleaf ceanothus are the lowest in calcium and phosphorus; the latter species contains the lowest percentage of potassium of those studied.

Analysis of the ash of common chaparral species burned in the open to simulate broadcast burning showed that chamise ash is much higher in silica content than are any of the other species analyzed (table 11). The calcium content is fairly constant in all the species analyzed, whereas the phosphorus and potassium content vary more widely according to species. In all the ash samples the calcium content is much higher than that of potassium, being more than three times greater in some species.

Total alkalinity, for convenience, was expressed in moles of sodium carbonate per gram of ash, but the values are seen to be so high that all the alkalinity could not be due to carbonates alone. The carbonate values are greatest in the madrone and blue oak, and lowest in chamise. With these high alkalinity data, the recorded pH values, all in excess of 11, are not surprising. It seems likely that the alkaline nature of the ash may be partly or largely responsible for the germination and growth effects which are discussed later.

Leaching of Ash.—Knowledge of the solubility of the ash in water is of importance in estimating the effect of rains in the leaching of ash on fresh burns. Accordingly, known weights of ashed residues of sundry chaparral species, collected in the first week of August, were placed over filter paper, and slowly sprinkled with water in an amount equivalent to ½ inch of rainfall. The loss in weight, due to leaching, was then determined. The samples were sprinkled a second time with the same amount of water and in the same manner, after which the loss in weight was again noted.

TABLE 12

SOLUBILITY OF THE ASH OF COMMON CHAPARRAL SPECIES WHEN SPRINKLED WITH 1 INCH OF WATER

Species	Loss of salts after first ½-inch sprinkling, per cent	Loss of salts after second ½-inch sprinkling, per cent	Total loss from sprinkling, per cent	Loss of elements from the two sprinklings		
				Calcium, per cent	Phosphorus, per cent	Potassium per cent
Wedgeleaf ceanothus	11.75	1.10	12.85	0	0	75.6
Chamise	11.68	2.22	13.90	0	0	68.1
Pacific madrone	25.00	2.19	27.19	0	0	82.4
Dwarf interior live oak	16.13	3.19	19.32	0	0	65.1
Bigberry manzanita	26.70	2.50	29.20	0	0	80.0
Toyon	25.70	1.31	27.01	0	0	81.9
Blue oak	12.07	1.27	13.34	0	0	52.8
Average	*18.43*	*1.97*	*20.40*	*0*	*0*	*72.3*

Table 12 shows that the loss of soluble ash by leaching, through sprinkling, was many times greater from the first half inch of sprinkling than from the second half inch of sprinkled water. This would indicate that the first rain after a fire would have much greater effect in removing soluble constituents of the ash than would subsequent rains. The ash of different species, however, is seen to respond to leaching somewhat differently.

As would be expected from the relative solubility constants of calcium, phosphorus, and potassium in an alkaline medium, no appreciable loss took place in the calcium and phosphorus contents of the leached ash, whereas nearly three fourths of the potassium content was lost in the two slow sprinklings representing a total of 1 inch of water. The high solubility of potassium in the ash suggests that this element may be a source of the stimulated plant growth observed in greenhouse experiments and in the field.

Effect of Ash on Seed Germination and on Seedling Growth.—Effects of chaparral and chamise ashes on seed germination and the seedling growth of certain grasses were studied in the following manner: Seeds of each species were shallowly planted in lightly compacted, well-moistened soil in terra cotta pots, 10 inches in diameter. Before use, the pots were coated on the inside with asphalt paint. Three ash treatments were given each species, as follows: The seeds in some of the pots were covered to a depth of ⅛ inch with chamise ash; some of the pots were similarly treated with mixed ash consisting of equal parts of chamise, wedgeleaf ceanothus, dwarf interior live oak, and blue oak; the seeds of the third group of pots were merely covered lightly with earth, to serve as controls.

Half of the pots of each ash treatment contained red soil of the Aiken series, whereas the rest of the pots contained yellow-brown loam of the Manzanita series, both of which support extensive areas of chamise and chaparral. All the pots were placed in terra cotta saucers. The pots with each soil, and each ash treatment, were maintained at close to field capacity of moisture by keeping the saucers filled with water, to avoid excessive leaching of the ash. The rest of the pots were kept moist by sprinkling lightly from above, to simulate rain. Germination was counted daily for 12 days, then the seedlings were thinned to 6 plants per pot. Since there was little or no difference in the height growth of the seedlings in the subirrigated and the sprinkled pots, or in the two soil series, the measurements were averaged together. Measurements were recorded at 7-day intervals for the first 4 weeks after the seeds were planted.

Figure 30 shows that orchard grass is the only species of the seven grasses studied that gave considerably higher germination percentage in one of the ashed soil groups, namely in chamise ash, than in the unashed soil. This species, however, gave a correspondingly lower average germination percentage in the mixed-ash series. Germination of the seed of smooth brome was nearly the same in the chamise-ashed soil as in the control series, but it was lower in the mixed-ash soil than in the control set. The seed of redtop and timothy was much lower in the ashed cultures; and although crested wheatgrass, Harding grass, and meadow fescue gave lower germination results in the ashed soils, the decrease was less conspicuous than in redtop and timothy. In all species the mixed ash had the most depressing effect on germination. Thus the general effect of fair amounts of chaparral ash in the surface soil, in this experiment, is seen to decrease the percentage of seed germination, and in some species to delay sprouting of the seed.

The fact that seed germination in the chamise-ashed soil cultures is better than in the mixed-ash appears to be correlated with another fact already pointed out—namely, that chamise ash is much higher in silicon, and lower in other minerals, per unit of weight of plant material, than the ash of any of the other chaparral species analyzed.

In order to note the effect of ash dressings on the growth of the seedling plants, the seed-germination experiment was continued 4 weeks after the first leaf blades appeared. The results are presented in figure 31.

Seedling growth is seen to be less, as recorded by measurement of the length of the leaf blades, in the soils treated with ash in six of the eight grass species used. Crested wheatgrass and Harding grass exhibited slightly greater leaf elongation in the chamise-ashed soil throughout the period of measurement. Harding grass, however, made less growth in the pots treated with mixed ash, and crested wheatgrass seedlings also grew more slowly in this ash until in the fourth week, when they exceeded the growth of the control cultures.

Effect of Chamise Ash upon Growth to Maturity.—Whether the effect of chamise ash would stimulate or actually retard the growth of grasses if the measurements were carried to maturity of the plants, or whether the ash

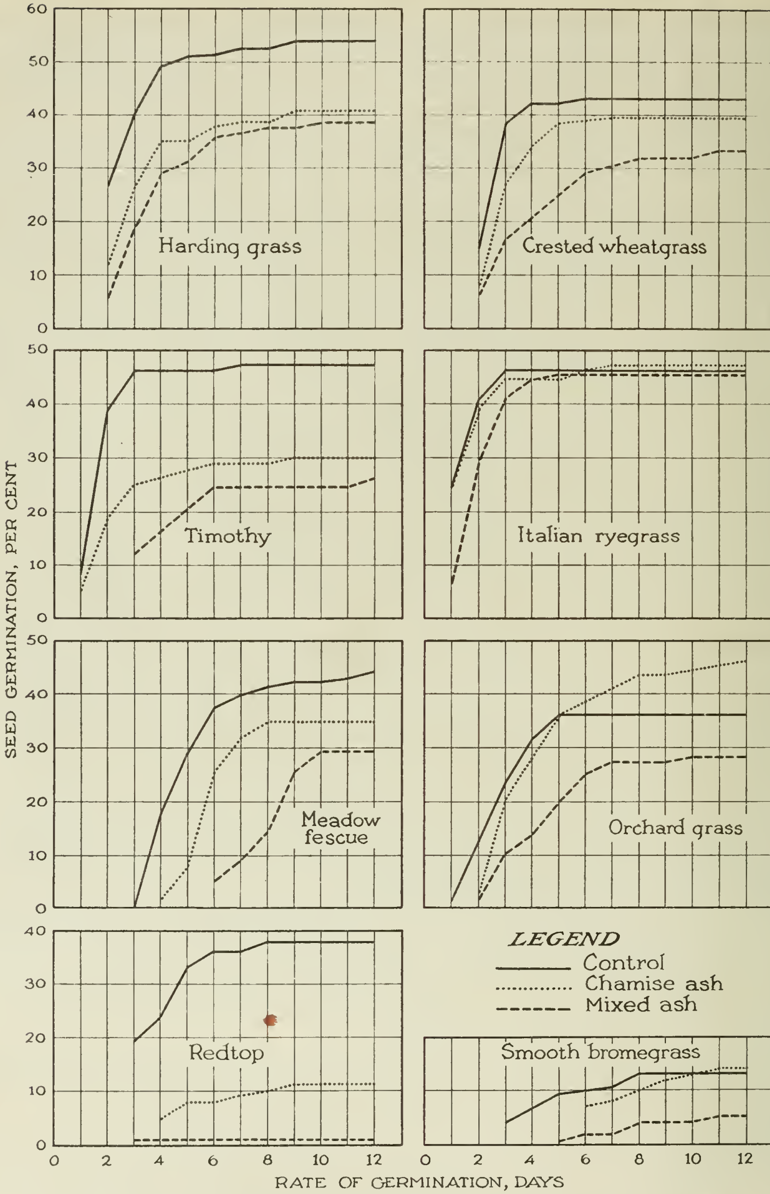

Fig. 30.—Effect of ash on germination of seed of cultivated grasses.

would influence the length of the growing cycle of the grasses used, required special study, and the use of large containers. Accordingly, a special series of cultures were set up as follows: The grass seed was germinated in an incubator; and the resulting seedlings, selected for uniformity in size and apparent vigor, were transplanted to galvanized iron garbage cans and filled with moistened soil when the radicals of the seedlings were approximately 3/8 inch long. The cans were 12 inches in diameter and 18 inches high. The soil used in the experiments was sandy clay loam of the Manzanita series, collected under a heavy stand of chamise in Mt. Diablo State Park. The soil was kept near field capacity by sprinkling the surface with tap water. When the grass blades had attained a height of ½ to ¾ inch, chamise-ash treatments were applied.

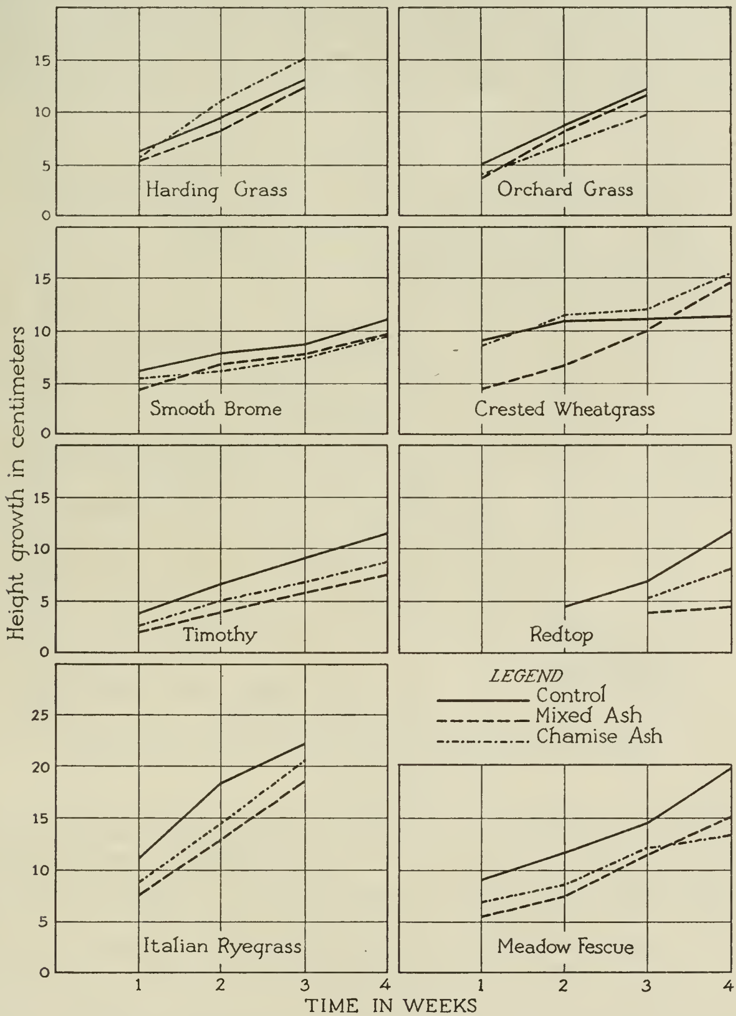

Fig. 31.—Seedling growth under different ash treatments.

One complete set, including all the species studied, was grown without ash treatment, to serve for control. One set including Harding grass, Kentucky bluegrass, and perennial ryegrass was treated with ash by sifting it lightly over the surface until the ash was ¼ inch deep. One set of redtop and one of soft chess, respectively, were treated with ⅛ inch of ash. Another set of redtop and of soft chess received ½ inch of ash. A third set of redtop and of soft chess received ¼ inch of ash upon the surface of the soil, after which the ash of this set was mixed with the upper 2 inches of soil. The plants in this last instance were transplanted into the mixed soil.

Figures 32 and 33, which summarize these data, show that in the early growth stages there was little difference in height in the five species studied, regardless of ash treatment. It was not until between the third and fifth weeks of growth that differences in size of the plants became apparent. After this period the control plants of Harding grass, Kentucky bluegrass, redtop, and perennial ryegrass grew faster and produced more leafage than did those

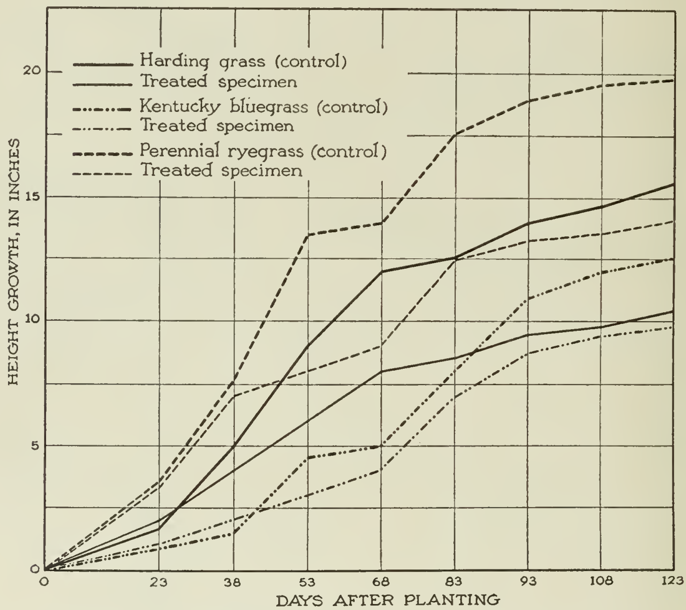

Fig. 32.—Comparative growth of grasses when treated with chamise ash.

treated with ¼ inch of chamise ash. The only species which grew as well when treated with ¼ inch of ash, as under control conditions, was soft chess (fig. 33). Indeed, growth of this species was considerably stimulated by treatment with ⅛ inch of ash. Mixing the ash with the soil stimulated the growth of soft chess in the early growth stage, but this advantage was lost as the grass approached maturity. The field notes showed that flowering was affected adversely by the ash treatment in all the species. The first evidence of flowering was noted 93 days after planting, when 10 per cent of the plants in the control cans were in the early flower stage, whereas in the treated cultures there were merely a few flowers in the "boot" or sheath at that time, none being unfolded. After 123 days, 75 per cent of the plants grown in the control cans were in flower, whereas only 8 per cent of the treated plants displayed flowers. On extensive chaparral burns, flowering was also observed to be slightly delayed.

During the first 6 weeks of growth the plants of the ash-treated cultures were characterized by a dark bluish-green color of distinctive cast. However, the leafage of the ash-treated soft chess plants began to show slight yellowing after 59 days. This chlorotic condition continued to intensify until 123 days after planting, when the herbage dried up just before flowering. In the controls, inflorescence was much in evidence after 123 days, whereas the treated plants showed but few flowers. Chlorosis of the leafage in the ash-treated redtop series was noted 108 days after planting in the cultures treated with the heaviest application of ash. This condition became correspondingly more pro-

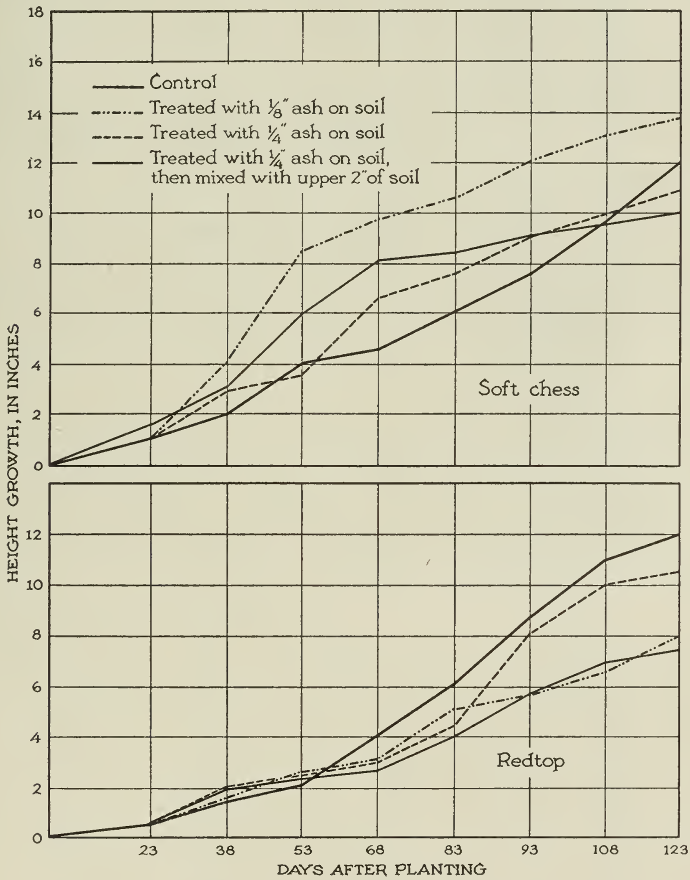

Fig. 33.—Growth of soft chess and redtop treated with various amounts of chamise ash.

nounced until the termination of the experiment, when approximately one half of the ash-treated redtop plants had died. The untreated plants showed no premature discoloration.

Composition of Treated Plants.—At approximate maturity the ash-treated and the control samples of soft chess, redtop, and Harding grass were collected for analysis, the sampling including plants of as nearly the same growth stage as possible. The results are given in table 13.

None of the species studied showed appreciable differences as compared

TABLE 13

PERCENTAGE COMPOSITION OF GRASSES GROWN IN ASH-TREATED SOIL, COMPARED WITH THOSE UNTREATED
(Expressed as per cent of ovendry weight)

Treatment	Growth stage	Total ash	Silica	Silica-free ash	Calcium	Phosphorus	Potassium	Crude protein	Ca:P ratio
				Soft chess					
None (control)	Leafage mature, seeds hard	12.67	5.96	6.71	0.455	0.481	3.76	13.5	0.95
1/8 inch ash on soil surface	Leafage mature, seeds in stiff dough	11.58	4.35	7.23	0.402	0.445	3.53	12.3	0.90
1/4 inch ash on soil surface	Plant mature	12.48	6.48	6.00	0.346	0.437	3.45	10.3	0.79
				Redtop					
None (control)	Plants dry, seeds nearly mature	10.64	5.41	5.23	0.315	0.268	3.14	10.8	1.10
1/4 inch ash mixed with soil	Plants mostly dry, seeds nearly mature	10.13	5.69	4.44	0.303	0.269	2.35	12.0	1.13
				Harding grass					
None (control)	Leafage mostly dry, seeds mature	8.66	3.05	5.61	0.276	0.291	3.25	10.5	0.95
1/4 inch ash on soil surface	Leafage two-thirds dry, leafage mature	10.09	5.13	4.96	0.345	0.321	2.93	12.8	1.07

with the controls in either total ash or its constituents, as a result of the various ash treatments. The crude protein content was also not affected. The percentage of total ash was nearly the same in the treated and untreated plants of soft chess and redtop. In Harding grass, however, the total ash was slightly higher in the ash-treated plants because of the relatively high silica content. Also the ash treatment did not appear to influence the proportion of calcium and of phosphorus in the species studied, the ratio being maintained close to 1; Gordon and Sampson (*29*) found the calcium : phosphorus ratio of approximately 1 to be characteristic of California grasses regardless of stage of development.

Under field conditions the reaction of fire on the soil is not only reflected in the liberation of ash, but also profoundly affects the activities of microörganisms, some of which increase the fertility of the soil.

SOIL-NUTRITION AND PLANT-GROWTH STUDIES

BACKGROUND FOR THE STUDIES

It has long been contended that the burning of plant cover results in reduction of soil nutrients. Burning, it has been claimed, causes accelerated soil erosion, the leaching of soluble minerals and nitrogen, and decreases the organic matter of the soil. These deductions are supported by an extensive literature.

More recent studies have indicated that the effect of burning on the soil is not always detrimental to plant nutrition, but that it may, under certain conditions, even enhance growth of some forms of vegetation (*6*). The liberated ash, among other things, would appear to enrich the soil solution. Many soils, however, are known to have strong fixing power for ash constituents; hence their liberation by fire may affect vegetation little or not at all (*2*). Moreover, if runoff and soil erosion proceed at a rapid rate, the top soil with its free ash content may be largely washed away.

According to Shaw (*95*), Lowdermilk (*64*), and Larsen (*60*), erosion usually carries off the finer soil particles first, which contain much of the accessible plant nutrients; this exposes a lower layer, with its covering of the coarser fractions. Sampson and Wehl (*90*) and later Forsling (*26*) found that plants did not produce nearly so much growth in soil with the top layer removed, as in soil with an undisturbed, well-formed A-horizon. Erosion on heavily burned slopes is sometimes so serious as to remove much, if not all, of the upper soil horizon, leaving the B-horizon, or subsoil, exposed. Thus Taylor (*106*) concluded that destruction of soil fertility after repeated burning was the result of erosion rather than the direct influence of heat. Sinclair and Sampson (*97*) found that in the absence of the A-horizon soil the original climax vegetation is exceedingly difficult to reestablish.

Heyward (*37*) found that the heating influence of fires in the longleaf pine forests extends to only shallow soil depths. At a depth of ⅛ inch, temperatures of 212° F were infrequent. At a depth of ¼ inch the rise in temperature was only a few degrees. Even these temperature rises lasted but a few minutes. The extent to which burning may destroy the leaf mold was found, by Alway and Rost (*2*), to vary widely in different soils. Rather wide variations in the total volatile matter and in the nitrogen content of the leaf mold per unit area of surface on burned lands was reported. Even exceedingly hot fires did not consistently destroy the entire leaf mold, nor did they always greatly alter the chemical composition of the soil solution. Fires with limited fuel supply had little effect on the leaf-mold content of the soil, or on subsequent plant growth. Moreover, Aldous (*1*), investigating the effects of burning on grass-covered Kansas pastures, reported that the soil nitrogen content showed very slight differences on burned and unburned plots during eight years of study. Hensel (*35*), who also studied Kansas pastures, noted but slight change in forage growth, but reported an increase in the botanical composition of the herbaceous cover in early spring, followed by a decline in the number of species with the advance of the season.

In a study of the southern longleaf pine belt, Heyward and Barnette (*39*) found that soils subjected to burning contained larger amounts of replaceable calcium and were lower in hydrogen-ion concentration than unburned soils; but these differences were almost entirely confined to the upper 3 inches. They concluded that the nitrogen and the replaceable calcium contents were higher in newly burned areas; that the pH values were slightly higher in the burned plots; and that no consistent differences were found in the organic matter. In line with this study, Greene (*30*) concluded that the plant debris on the surface is lost to the soil whether it is left to rot, or is burned. This worker attributes the accumulation of the soil organic matter mainly to the decay of plant roots. Greene also reported that soil nitrogen content and the organic matter averaged somewhat higher on the burned plots early in the season. Samples taken later in the season varied, being greater in either the burned or unburned areas according to the season and the rapidity of plant growth on the respective areas. Heyward and Barnette (*39*) found that a period of eight to twelve years is necessary to establish an approximate balance between the accumulation and decomposition of the forest floor upon protection from burning. After the balance is reached no increase in depth or weight of humus on the forest floor occurs. Physical conditions under the humus layer following protection from fire, they found, are favorable for plant growth, and the humus layer on soils protected from fire appears in a healthy condition.

That certain plant species react more vigorously to the burned soil than do others has been shown by several workers. Thompson (*107*) grew oats, potatoes, and sunflowers on forest soil, one area of which was cleared by the most severe burning possible, whereas the check area was cleared merely by chopping. The experiment was repeated annually for eight years. The oats and potatoes yielded heavier on the unburned ground, whereas sunflowers yielded heavier on the burned ground. Hesselman (*36*) likewise reported instances where forest fires increased the rate of growth of young conifers. Where raw humus had accumulated in thick layers fires were of some benefit by destroying part of the litter.

Although more or less indirect study has been made of the effect of burning on the fertility of soils, the data are far from conclusive. Consistent differences in the nutrition of burned and unburned soils are lacking, but in many instances burning increases the nitrogen. Such effects as burning may have on subsequent plant growth, however, appear to be confined essentially to the surface soil layer.

RESULTS OF CHEMICAL SOIL STUDIES

Soil Acidity, or pH.—Measurements of acidity, or pH of the soil, showed no significant differences between that of the burned and unburned areas, except in localized spots. The pH range was from 6.3 to 7.2 for the various burned and unburned soils examined. In localized spots where much ash had accumulated, the pH range was from 7.5 to 8.6. Except in small areas where much ash had accumulated, the change in pH was apparently too slight measurably to affect plant growth.

Types of Covers Whose Soils Were Analyzed for Nitrate Nitrogen.—Although much nitrogen is volatilized when vegetation is burned, the total soil nitrogen may not be greatly changed, since the decomposed roots, rather than the top growth, apparently furnish the chief source of organic soil nitrogen (*30*). The effect of burning on soil nitrate seemed worthy of study, as the amount present might account partly, or even largely, for the identity, luxuriance, and stability of the invading vegetation. This phase of the study was initiated in Mendocino County in 1928, when the field and laboratory techniques were developed, following which the study was extended elsewhere in northern California. Samples were taken from the soil surface to 1 inch depth, and at specified lower depths, to a maximum of 24 inches.[24] The study included the sampling of four of the more extensive soil series, and of three distinct plant covers, namely, the mixed chaparral, the pure chamise, and areas dominated by interior live oak.

Nitrate Content of Mariposa Silt Loam in Mixed Chaparral Cover.—Here the dominant vegetation consisted of greenleaf manzanita, California scrub oak, and wedgeleaf ceanothus. The understory cover was composed of scattered stands of foxtail fescue, nitgrass, rat-tail fescue, small-flowered lotus, narrowleaf soap-plant, and Napa star thistle. The area sloped gently to the south and east. The soil was fairly deep, and erosion had not exceeded the normal rate.

The data obtained from the analyses of the soil samples, together with their mean values, are presented in table 14 and are summarized in figure 34. This figure compares, for three successive years, beginning in 1929, the trends of nitrate nitrogen at different depths in the soils of burned and of similar adjoining unburned areas. The Mariposa soil series here studied was sampled in Mendocino County. Table 14 shows that the upper 1 inch of soil taken on the burned plots contained an average for all such samples of 48.5 per cent more nitrate the first year after burning than did the soil on the unburned plots. On the other hand, the soil samples representing the lower soil depths

[24] Paired burned and unburned plots were selected for sampling. All samples from each specified depth were made up of composite soil collections, no one sample being composed of less than 7 random samples. Collections were obtained in various habitats. The earliest samples were taken in the spring, when soil moisture and temperature favored initial vigorous growth; a second sampling was done in early summer, when the major herbaceous growth had been produced, but before the wilting point of the soil had been reached a foot or so below the surface; and a third series of samples was obtained in the autumn, when the first 18 inches or so of the soil was dry, and the surface soil more or less baked.

Immediately after collecting, the samples were taken to the laboratory for analysis. Two hundred grams of sieved soil were thoroughly mixed with 200 cubic centimeters of water for 5 minutes, then filtered through four layers of cheesecloth. Nitrate nitrogen in 15 cubic centimeters of each of the turbid solutions was at once determined by the Devarda method.

TABLE 14

NITRATE NITROGEN CONTENT OF SOIL IN A CHAPARRAL AREA BURNED IN 1928, AND OF A SIMILAR ADJACENT UNBURNED AREA; MARIPOSA SOIL SERIES, MENDOCINO COUNTY

Date of sampling	Composite sample no.	Soil reaction, pH		Nitrogen content, p.p.m. NO_3		Per cent increase in NO_3 with burning
		Burned	Unburned	Burned	Unburned	
First year after burning (1929); sampling depth, 0–1 inch						
March 4	1–2	7.3	7.2	39.4	20.5	92.2
April 16	3–4	7.6	7.4	46.8	18.0	160.0
May 19	5–6	7.4	7.4	29.3	25.1	16.7
June 11	7–8	7.3	7.2	33.7	29.4	14.6
July 13	9–10	7.3	7.5	39.0	31.8	22.6
Sept. 10	11–12	7.3	7.3	21.1	16.2	30.2
Average	.....	*7.4*	*7.3*	*34.9*	*23.5*	*48.5*
First year after burning (1929); sampling depth, 1–6 inches						
March 14	13–14	7.2	7.4	28.3	27.6	2.5
April 16	15–16	7.4	7.2	27.9	23.8	17.2
May 16	17–18	7.3	7.2	37.4	21.3	75.6
June 11	19–20	7.2	7.1	25.6	17.8	43.8
July 13	21–22	7.1	7.3	30.1	28.3	6.4
Sept. 10	23–24	7.3	7.2	28.0	24.1	16.2
Average	.....	*7.3*	*7.2*	*29.5*	*23.8*	*23.9*
First year after burning (1929); sampling depth, 6–12 inches						
March 4	25–26	7.0	7.3	34.3	28.7	19.5
April 16	27–28	7.2	7.2	29.6	27.2	8.8
May 16	29–30	7.3	7.0	22.3	31.6	−29.4
June 11	31–32	7.4	7.3	29.8	23.8	25.2
July 13	33–34	7.3	7.2	19.5	24.7	−21.1
Sept. 10	35–36	7.2	7.2	23.4	18.0	30.0
Average	....	*7.2*	*7.2*	*26.5*	*25.7*	*3.1*
First year after burning (1929); sampling depth, 12–24 inches						
March 14	37–38	7.0	6.3	22.5	24.3	− 7.4
May 16	39–40	6.9	6.8	14.4	16.6	−13.3
July 13	41–42	6.8	6.7	16.1	13.3	21.1
Sept. 10	43–44	6.8	6.8	9.2	11.6	−20.7
Average	.....	*6.9*	*6.7*	*15.6*	*16.5*	*− 5.5*
Second year after burning (1930); sampling depth, 0–1 inch						
March 16	45–46	7.3	7.4	28.2	25.6	10.2
May 14	47–48	7.4	7.3	24.3	27.3	−11.0
Aug. 12	49–50	7.5	7.4	21.6	20.0	8.0
Average	.....	*7.4*	*7.4*	*24.7*	*24.3*	*1.6*

TABLE 14—(*Continued*)

Date of sampling	Composite sample no.	Soil reaction, pH		Nitrogen content, p.p.m. NO_3		Per cent increase in NO_3 with burning
		Burned	Unburned	Burned	Unburned	
Second year after burning (1930); sampling depth, 1–12 inches						
March 16	51–52	7.4	7.2	24.8	22.8	8.8
May 14	53–54	7.3	7.4	30.6	27.6	10.9
Aug. 12	55–56	7.3	7.2	19.3	25.2	−23.4
Average	.....	*7.3*	*7.3*	*24.9*	*25.2*	*−11.9*
Second year after burning (1930); sampling depth, 12–24 inches						
March 16	57–58	7.0	6.9	15.9	18.3	−13.1
May 14	59–60	6.8	6.8	12.0	13.0	− 7.7
Aug. 12	61–62	6.8	6.8	10.2	12.1	−15.7
Average	.....	*6.9*	*6.8*	*12.7*	*14.5*	*−12.4*
Third year after burning (1931); sampling depth, 0–1 inch						
March 16	63–64	7.4	7.5	25.8	23.8	8.4
May 15	65–66	7.3	7.5	26.2	27.6	− 5.1
Aug. 10	67–68	7.5	7.4	22.0	25.7	−14.4
Average	.....	*7.4*	*7.5*	*24.7*	*25.7*	*− 3.9*
Third year after burning (1931); sampling depth, 1–12 inches						
March 6	69–70	7.3	7.3	23.1	26.2	−11.8
May 6	71–72	7.4	7.4	20.2	19.3	4.7
Aug. 14	73–74	7.4	7.3	17.8	13.7	29.9
Average	.....	*7.4*	*7.3*	*20.4*	*19.7*	*3.6*
Third year after burning (1931); sampling depth, 12–24 inches						
March 5	75–76	6.8	6.9	13.0	9.6	35.4
May 6	77–78	6.8	7.0	15.7	13.0	20.8
Aug. 16	79–80	6.9	6.9	8.6	11.2	−23.2
Average	.....	*6.8*	*6.9*	*12.4*	*11.3*	*9.7*

gave nearly the same nitrate values for both the burned and unburned plots. In recording the values in figure 34 for the 1 to 12 inch samples, the nitrate data for the first year after burning were averaged for the 1 to 6 inch samples and for the 6 to 12 inch samples.

The nitrate values of samples taken from 0 to 1 inch in depth, during the second and third years after the fire, were not significantly different in any burned and unburned areas. At depths of 1 to 12 and 12 to 24 inches, the nitrate content was approximately the same on the burned and unburned plots the first year after the fire. Likewise, the second and third years after burning no effect on the nitrogen content was discernible.

Nitrate Content of the Hugo Clay Loam in Pure Chamise Cover.—Old, dense chamise composed most of the cover. The nitrate nitrogen content of field samples of this habitat, in Mendocino County, obtained from several depths of the Hugo clay loam series, representing the first and second years after burning, is presented in table 15, and summarized in figure 35. The small amount of nitrate nitrogen in this soil series, despite the heavy growth of chamise, is one of the most striking features revealed in this study. Despite these low nitrate values, however, the trends paralleled those of the samples of the Mariposa silt loam, as summarized in figure 34. Table 15 shows that the

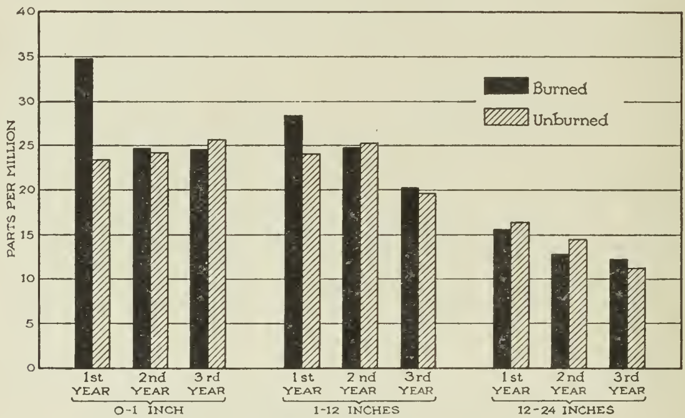

Fig. 34.—Nitrate nitrogen in field samples taken at three different soil depths in the Mariposa silt loam of the mixed chaparral cover. Mendocino County.

samples taken during the first year after the fire, from the 0 to 1 inch layer of soil on the burned and unburned plots, averaged 6.2 and 3.0 parts per million nitrate, respectively, or an increase of 106.7 per cent the first year after burning. Samples of the same depth, taken during the second year after burning, revealed that the nitrate content had declined to an average of 3.9 parts per million, whereas on the unburned plots there were 2.7 parts per million, or an increase of only 44.4 per cent. Changes in the nitrate nitrogen content resulting from burning appeared to be insignificant in the lower soil depths. Thus the nitrate values of samples taken from the 6 to 12 inch and 12 to 24 inch depths in the first and second years after burning are nearly the same in the burned and unburned plots. In no soil sample did burning reflect any measurable effect on the nitrate content in these lower depths studied. In fact, table 14 shows that only such slight differences as 2.2 and 1.8 parts per million of nitrate were recorded in burned and unburned soils, respectively, when sampled 1 to 6 inches deep and collected the first year after burning.

Nitrate Content of Aiken Clay Loam in Pure Chamise Cover.—Chamise formed more than 90 per cent of the cover of this area in Shasta County. Here and there scattered bushes of western mountain-mahogany, California buck-

TABLE 15

NITRATE NITROGEN CONTENT OF SOIL IN A CHAMISE AREA BURNED IN 1928, AND OF A SIMILAR ADJACENT UNBURNED AREA; HUGO CLAY LOAM SOIL SERIES, MENDOCINO COUNTY

Date of sampling	Composite sample no.	Soil reaction, pH		Nitrogen content, p.p.m. NO_3		Per cent increase in NO_3 with burning
		Burned	Unburned	Burned	Unburned	
First year after burning (1929); sampling depth 0–1 inch						
March 7	81–82	6.4	6.3	12.1	4.6	163.0
May 10	83–84	6.4	6.5	6.3	3.0	110.0
July 8	85–86	6.5	6.5	4.1	2.2	86.4
Sept. 11	87–88	6.4	6.4	2.2	2.3	– 4.3
Average	.....	*6.4*	*6.4*	*6.2*	*3.0*	*106.7*
First year after burning (1929); sampling depth 1–6 inches						
March 7	89–90	6.3	6.3	3.6	2.9	24.1
May 10	91–92	6.5	6.4	2.2	1.4	57.1
July 8	93–94	6.4	6.3	1.1	2.0	–45.0
Sept. 11	95–96	6.4	6.2	1.8	1.0	80.0
Average	.....	*6.4*	*6.3*	*2.2*	*1.8*	*22.2*
First year after burning (1929); sampling depth 6–12 inches						
March 7	97–98	6.4	6.3	3.6	2.0	80.0
May 10	99–100	6.3	6.2	1.2	1.6	–25.0
Sept. 11	101–102	6.2	6.2	1.4	2.1	–33.3
Average	.....	*6.3*	*6.2*	*2.1*	*1.9*	*10.5*
First year after burning (1929); sampling depth 12–24 inches						
March 7	103–104	6.2	6.3	2.1	3.2	–34.4
Sept. 11	105–106	6.5	6.4	3.6	3.8	– 5.3
Average	.....	*6.4*	*6.4*	*2.9*	*3.5*	*–17.1*
Second year after burning (1930); sampling depth 0–1 inch						
March 10	107–108	6.5	6.4	3.4	3.0	13.3
May 8	109–110	6.6	6.4	5.6	3.1	80.6
Sept. 18	111–112	6.4	6.5	2.8	1.9	47.4
Average	.....	*6.5*	*6.4*	*3.9*	*2.7*	*44.4*
Second year after burning (1930); sampling depth 6–12 inches						
March 10	113–114	6.3	6.3	3.0	3.3	– 9.1
May 8	115–116	6.3	6.4	2.7	2.4	12.5
Sept. 18	117–118	6.5	6.3	2.1	1.9	10.5
Average	.....	*6.4*	*6.3*	*2.6*	*2.5*	*4.0*
Second year after burning (1930); sampling depth 12–24 inches						
March 10	119–120	6.3	6.3	2.8	2.1	33.3
May 8	121–122	6.6	6.5	1.6	1.8	–11.1
Sept. 8	123–124	6.4	6.4	0.8	1.4	–42.9
Average	.....	*6.4*	*6.4*	*1.7*	*1.8*	*– 5.6*

eye, and wedgeleaf ceanothus tended to break up the otherwise uniform appearance of the dominant shrub. The more common herbaceous plants were foxtail fescue, nitgrass, downy chess, red larkspur, wild carrot, whispering bells, and Fremont death camas. The area sloped to the west and had an average gradient of 12 per cent. The soil was shallow to moderately deep, and the surface contained many rock fragments. Soil erosion appeared to be normal.

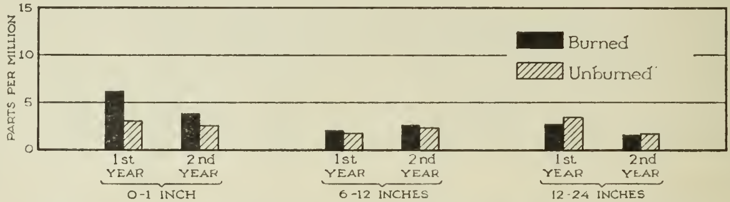

Fig. 35.—Nitrate nitrogen in field samples taken at three soil depths in the Hugo clay loam of the chamise cover. Mendocino County.

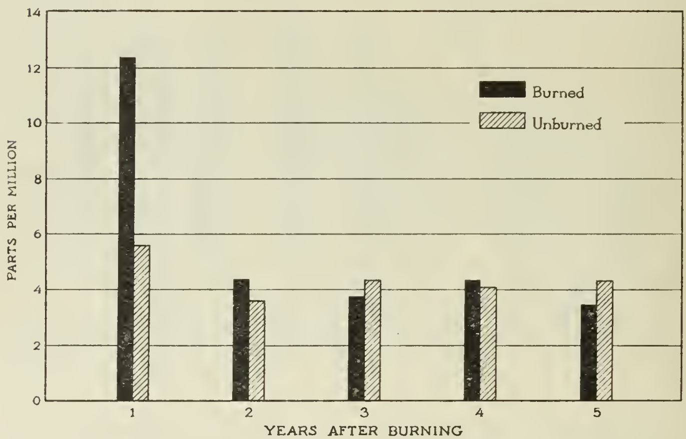

Fig. 36.—Nitrate nitrogen in field samples at 0 to 1 inch depth in Aiken clay loam, chamise cover. Shasta County.

The analytical data of samples taken at the 0 to 1 inch depth over a period of five years following burning are summarized in figure 36. The nitrate content shows the same general trends as those obtained for the soils of the Mariposa and Hugo series, as summarized in figures 34 and 35. The sampling was done in June of each year. It will be noted that the nitrate content of the burned field samples was slightly more than twice that recorded in the unburned samples the first year after the fire, but that this differential was nearly lost in the second year after burning. In the following three years, the nitrate contents of the soil samples representing the burned and unburned plots were not significantly different one from the other. This evidence indicates, as in the previously discussed soil series, that the effects of burning on nitrification of the soil take place essentially only the first year after the fire. The nitrate content of the Aiken soil series is seen to be low and corresponds closely in this respect to that of the Hugo clay loam soil series where chamise predominated.

Nitrate Content of Los Osos Clay Loam in Interior Live Oak Cover.—This flat area, located in Shasta County, had moderately deep to deep soil, and supported a heavy stand of interior live oak, with secondary woody plants of Pacific madrone, hoary manzanita, whiteleaf manzanita, and coffeeberry. The herbaceous vegetation consisted chiefly of foxtail fescue, ripgut grass, sheep sorrel, coyote tobacco, field suncup, Napa star thistle, and Spanish-clover. Soil erosion had apparently not exceeded the normal rate.

Since previous studies had revealed that burning did not appreciably affect the nitrate content at lower soil levels, the sampling in this series was confined to 0 to 2 inches in depth. The samples were first collected in 1933, which was the first year after the fire, and were continued for three successive years. The averaged data gave the following results: first year after burning, 39 parts per million, as compared with 24 parts on the control plot; second year after burning, 21 parts per million, as compared with 22 parts on the control area; third year after burning, 19 parts per million, as compared with 22 parts in the control samples. The levels of the nitrate content of this relatively productive soil series are seen to be fairly high for chaparral soils. Also on this burn the increase in nitrate nitrogen was significantly high only the first year after burning. After the first year the nitrogen content on the burned plot leveled off to nearly the same values as on the control area.

Nitrate Content as Affected by Exposed but Not Burned Chaparral Soils.—It seemed important to obtain some indication whether the increase in soil nitrate is associated with the heat created by burning heavy brush stands, or whether significant nitrification would result from mere exposure of soil to the full play of the sun. Accordingly, in the autumn of 1932, a heavy chamise growth, in Mendocino County, on an area 80 feet square, of the Aiken soil series, was cut at the surface of the ground and removed from the plot, leaving the soil fully exposed to the sun. The soil sampling, taken at 0 to 2 inches in depth, was done in spring, summer, and autumn for three successive years after removal of the top growth.

The nitrate content was found to be affected little or not at all by the brush-removal and soil-exposure treatment. The first year after removal of the brush there was an average of 7.9 parts per million of nitrate in the spring, summer, and autumn samples, as compared with 6.7 parts in the samples of the control, or unchopped adjoining chamise plot; and in the following two years the data were even more nearly of the same values. It was significant too, perhaps, that only a few chaparral seedlings appeared on the chopped plots, despite the fact that surface soil temperatures reached 160° F on several occasions during the hottest part of the summer.

Comparative Nitrate Content of Different Covers.—The nitrate nitrogen content in the *shallow* soil samples which supported mixed chaparral was consistently higher after burning than in similar soil samples which supported the pure chamise cover. Slightly higher than in the mixed chaparral soils, however, was the nitrate content of the soils which produced a heavy growth of interior live oak. Nevertheless, all soil samples from these plant covers showed perceptible increases in nitrate nitrogen in the surface layer the first year after burning. In the second and subsequent years after burning, the nitrate content declined so sharply as closely to approach the levels in unburned soils. Some evidence was obtained to indicate that the increase in nitrate content following burning may be associated with soil productivity, and with the heat of the fire. The deeper, more productive soils seemed to build up considerable nitrogen after burning; but even such soils showed little response when sampled on areas which had been burned so heavily as to have been left more or less sterilized.

By way of explaining the increased nitrate content of the surface soil after a fire: it is possible that the heat of the fire destroys the microflora and microfauna of the surface soil layer. Later, unusually active colonization of nitrogen-fixing and other bacteria may be favored until organisms, which feed extensively or exclusively upon the large numbers of bacteria, also come up

Fig. 37.—Hill lotus, showing proportionate sizes of plants: *A*, grown on unburned chamise area; *B*, on chamise land burned two years previously; *C*, on chamise area burned the previous summer.

from lower soil depths, and multiply at an unusually rapid rate. This hypothesis has been suggested by Hesselman (*36*).

The ecological significance of the increased soil nitrate resulting from burning would obviously be most conspicuously reflected in the growth response of those plants which feed largely in the surface soil layer. For example, the numerous shallow-rooted annual herbs, which usually appear in greatest numbers the first year after a fire, are most favored by the increased nitrate of freshly burned areas. The characteristic robust growth of these plants in the first year after burning, and the striking sharp decline in their size and numbers during subsequent years, parallel significantly the sharp increase and decline in nitrate which has been described.

CHEMICAL COMPOSITION OF VEGETATION ON BURNED AND UNBURNED AREAS

Domestic foraging animals, as well as native herbivores, have been observed to feed upon newly-burned chaparral and chamise areas in preference to adjoining unburned lands. Whether this behavior may be attributed to the fact that the feed is more readily available because of the reduced height of the brush, whether the change in the species composition is a factor of importance, or whether the claim is valid that "the forage is sweeter and more nutritious," is problematical.

Plant Succulence.—A rather consistent difference in the vegetation produced on newly burned areas, as compared with that of unburned lands, is the more rapid growth, greater volume of individual specimens, somewhat higher

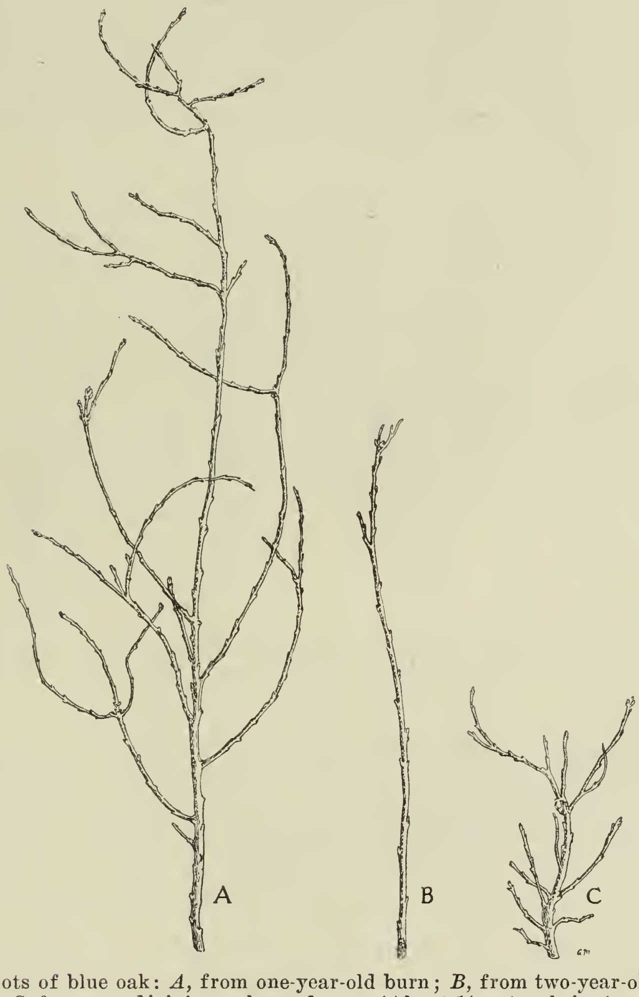

Fig. 38.—Shoots of blue oak: *A*, from one-year-old burn; *B*, from two-year-old burn; and *C*, from an adjoining unburned area. (About ⅓ natural size.)

moisture content of the herbaceous plants, and more numerous production of vigorous shoots of shrubby plants for the first year or two after burning (figs. 37, 38, and 39). The decreased competition for soil moisture and the stimulation produced by the addition of nutrient salts in the ash probably account for the more rapid and luxuriant growth and the higher moisture content of the plants on burned areas. Table 16 shows the moisture relations of some plants common to burned and unburned chaparral lands.

In the early growth stage only small differences in the percentages of moisture in favor of the plants collected on the burns were recorded in the shrubs and herbs. A wider difference in the percentage of moisture was noted, however, with the advance of the season, followed by a decrease and a tendency toward equalization in moisture percentage towards midsummer, when the vegetation approaches maturity. This difference in succulence might partly account for the forage choice shown by the animals on the burned areas in March and April, when the succulence of the vegetation has declined measurably on the unburned areas. The character of the herbaceous vegetation, especially with respect to the extent and depth of the root systems in propor-

Fig. 39.—Shoots of yerba santa: *A*, from an unburned area; *B*, from an adjoining one-year-old burn. (About ⅓ natural size.)

tion to aerial growth, may account for the differences in succulence in some plants on burned and unburned areas. The difficulty of finding plants of exactly the same developmental stage on the burned and unburned plots must also be considered in explaining these differences in percentage of moisture.

Chemical Composition.—The species sampled for chemical study were those most commonly found on chaparral and chamise lands. The samples of the species employed were taken at random, the collections being made at the particular growth stage most in evidence at the time. The somewhat delayed maturity of the vegetation on the burned areas made it difficult to procure samples of exactly the same growth stage as on the unburned plots. There appeared to be an average lag of about 1 week in plant development of most herbaceous species worked with on the burned areas studied. Perhaps a similar lag in development occurred in the sprouting shrubs; but no concrete difference could be recognized, since the young sprouts and seedlings on the burned areas do not flower the first year after a fire. Most samples of the shrubs and trees consisted of leafy stems or the foliage, which was stripped from the stems

TABLE 16

Relative Moisture Content of Browse and Herbaceous Plants at Different Growth Stages

Plant	Date sampled	Plant parts	Stage of growth	Moisture content, per cent	
				Burned	Unburned
Shasta County, 1936					
Blue oak	April 11	Leafy stems	Leaves half developed	61.3	59.6
Blue oak	May 16	Leafy stems	Leaves fully developed	57.4	51.3
Blue oak	June 24	Leafy stems	Leaves changing color	49.7	43.8
Blue oak	June 24	Leaves only	Leaves changing color	52.5	50.1
Chaparral coffeeberry	April 11	Leafy stems	Leaves half developed	67.1	66.0
Chaparral coffeeberry	May 16	Leafy stems	Leaves fully developed	61.8	53.6
Chaparral coffeeberry	June 24	Leafy stems	Leaves fully developed, fruit forming	54.2	46.1
Chaparral coffeeberry	June 24	Leaves only	Leaves fully developed, fruit forming	56.4	53.3
Chamise	April 11	Leafy stems	Leaf scales half developed	68.9	69.6
Chamise	May 16	Leafy stems	Leaf scales and shoots fully developed	59.2	55.0
Chamise	June 24	Leafy stems	Leaf scales and shoots fully developed	53.7	47.8
Chamise	June 24	Leaves only	Leaf scales and shoots fully developed	56.8	49.1
Six-weeks fescue	April 11	Leaves and culms	In full bloom	70.3	68.4
Six-weeks fescue	May 16	Leaves and culms	Herbage mostly dry, some seeds cast	45.8	40.2
Six-weeks fescue	June 24	Leaves and culms	Herbage dry, seeds mostly cast	31.3	29.0
Nitgrass	April 11	Leaves and culms	In full bloom	67.9	64.5
Nitgrass	May 16	Leaves and culms	Herbage mostly dry, some seeds cast	40.2	34.6
Mendocino County, 1937					
Spanish-clover	April 3	Leafy stems	Early leaf stage	80.6	81.7
Spanish-clover	May 10	Leafy stems	Seeds in dough stage	61.4	53.8
Spanish-clover	June 15	Leafy stems	Mostly dry, seeds cast	34.7	31.3
Whispering bells	April 3	Leafy stems	Early leaf stage	77.8	76.2
Whispering bells	May 10	Leafy stems	Seeds half formed	58.3	51.1
Whispering bells	June 15	Leafy stems	Mostly dry, seeds cast	27.8	25.3

TABLE 17

PERCENTAGE COMPOSITION OF BROWSE AND HERBACEOUS SPECIES GROWN ON BURNED AND ON ADJOINING UNBURNED CHAPARRAL LANDS
(Expressed as per cent of ovendry weight)

County in which collected	Year burned	Date of sampling	Plant parts and growth stages	Silica-free ash		Potassium		Calcium		Phosphorus		Ca : P ratio		Crude protein		Crude fiber	
				Burned	Unburned	Burned	Unburned	Burned	Unburned	Burned	Unburned	Burned	Unburned	Burned	Unbruned	Burned	Unburned
Chamise; Aiken clay loam soil*																	
Mendocino	1930	Sept. 17, 1931	Current leafy stems	2.80	3.74	0.71	0.75	0.559	0.616	0.126	0.144	4.44	4.28	5.74	5.60	22.61	20.10
Mendocino	1930	Sept. 17, 1931	Current leaves	4.27	4.10	0.95	0.84	0.840	.947	.183	.199	4.59	4.71	7.31	6.92	12.10	11.20
Mendocino	1930	Sept. 17, 1931	Current stems only	2.07	2.18	0.64	0.71	0.653	.769	.130	.151	5.02	5.09	3.08	3.01	34.21	33.32
Mendocino	1931	Nov. 6, 1932	Current leafy stems	2.69	2.78	0.47	0.69	0.584	.557	.126	.139	4.63	4.01	4.62	4.81	22.68	21.11
Mendocino	1931	March 4, 1932	Current leafy stems	3.78	3.91	1.40	1.71	0.604	.526	.181	.162	3.34	3.25	13.63	12.71	15.34	14.46
Mendocino	1931	May 9, 1932	Current leafy stems	3.13	3.24	1.79	1.88	0.598	.562	.207	.181	2.89	3.10	9.02	8.91	22.56	21.89
Mendocino	1931	Aug. 21, 1932	Current leafy stems	4.42	4.81	2.00	2.63	0.453	.462	.135	.136	3.36	3.40	7.10	6.93	24.68	24.39
Mendocino	1931	Nov. 14, 1932	Current leafy stems	4.88	4.96	1.83	1.66	0.552	.587	.113	.104	4.88	5.64	5.61	5.37	26.36	25.22
Contra Costa	1935	Feb. 1, 1936	Current leafy stems	3.45	3.61	1.48	1.34	0.640	.239	.141	.132	4.54	1.81	5.78	5.41	25.41	24.96
Contra Costa	1935	May 6, 1936	Current leafy stems	3.67	3.52	1.63	1.80	0.840	.362	.163	.176	5.15	2.06	8.18	7.29	24.86	23.90
Contra Costa	1935	May 6, 1936	Current leaves	3.81	3.69	1.12	1.23	0.720	.830	.279	.268	2.58	3.10	10.31	9.14	13.27	13.93
Contra Costa	1935	May 6, 1936	Current stems only	4.21	4.27	2.24	2.17	0.410	.440	.124	.133	3.30	3.34	3.91	3.56	37.21	37.38
Contra Costa	1935	Oct. 21, 1936	Current leafy stems	5.68	5.76	1.63	1.50	1.341	0.982	0.092	0.106	14.59	9.26	5.29	4.02	23.38	25.24
Blue oak; Sites stony clay loam soil																	
Mendocino	1931	March 21, 1932	Leaves, very young	5.96	5.82	1.69	1.60	0.572	0.498	0.531	0.546	1.08	0.91	28.31	25.64	13.36	12.11
Mendocino	1931	May 15, 1932	Leaves developed, fruit stage	5.02	4.79	1.04	0.98	0.792	0.821	.201	.193	3.94	4.25	15.60	14.79	14.30	13.82
Mendocino	1931	Nov. 24. 1932	Leaves, mature, most fruits cast	7.01	6.88	0.57	0.62	2.436	2.559	0.131	0.146	18.59	17.53	8.24	8.03	12.21	12.07
California buckeye; Sites stony clay loam soil																	
Mendocino	1931	Feb. 15, 1932	Leaves, early stage	6.29	6.09	2.30	2.41	0.510	0.489	0.683	0.699	0.75	0.70	28.72	27.31	10.43	9.78
Mendocino	1931	May 17, 1932	Leaves, fully developed, green	10.92	11.07	1.93	2.07	2.461	2.321	.246	.261	10.00	8.89	19.32	17.29	11.63	10.01
Mendocino	1931	Nov. 21, 1932	Leaves, mature, brown	5.39	6.21	0.67	0.53	1.923	1.727	0.158	0.139	12.17	12.42	10.02	9.34	12.33	11.24

Poison oak; Sites stony clay loam soil																	
Mendocino	1931	March 27, 1932	Leaves, early stage	8.07	7.82	2.97	2.84	0.369	0.361	0.921	0.937	0.41	0.39	31.87	29.77	15.18	13.98
Mendocino	1931	May 17, 1932	Leaves, nearly full grown	8.72	8.94	1.59	1.47	2.539	2.621	.627	.632	4.05	3.99	17.58	16.21	15.03	14.22
Mendocino	1931	July 6, 1932	Stems only, leaves mature	4.35	4.47	1.38	1.46	0.505	0.537	.196	.173	2.58	3.10	4.27	3.97	29.32	26.41
Mendocino	1931	Sept. 14, 1932	Leaves, changing color	10.68	10.79	0.83	0.91	3.816	3.642	.170	.174	22.45	20.93	8.31	8.62	13.38	13.04
Mendocino	1931	Oct. 21, 1932	Leaves, brown, fallen	10.47	10.68	0.74	0.83	3.962	3.847	0.186	0.164	21.30	23.46	6.29	6.03	13.06	12.82
Whiteleaf manzanita; Hugo clay loam soil																	
Shasta	1932	May 13, 1933	Young leaves	3.87	3.64	1.03	1.14	0.384	0.361	0.179	.....	2.15	.....	15.92	13.42	14.28	14.02
Shasta	1932	May 13, 1933	Young leaves and stems	3.26	3.41	1.44	1.32	.471	.459	.438	.....	1.08	.....	7.24	6.38	22.80	22.70
Shasta	1932	May 13, 1933	Leaves of 1932 growth	3.36	3.49	0.59	0.65	.077	.069	.048	0.051	1.60	1.35	4.79	6.51	13.25	11.47
Shasta	1932	July 31, 1933	Stems only	2.14	2.01	0.76	0.82	.086	.092	.041	0.052	2.10	1.77	3.41	3.27	27.31	26.76
Shasta	1932	Oct. 23, 1933	Fully mature leaves of seedlings	3.51	3.44	1.23	1.33	0.497	0.479	0.050	0.071	9.95	6.75	5.92	5.34	12.31	10.03
Deerweed; Konokti clay loam soil																	
Lake	1933	March 26, 1934	New leaves and stems, before flowering	9.82	8.97	1.92	2.17	1.368	1.049	0.338	0.379	4.05	2.77	22.84	20.03	17.21	14.80
Lake	1933	June 4, 1934	New leaves and stems, full bloom	7.04	6.71	2.29	2.10	0.683	0.721	.201	.213	3.40	3.38	13.38	11.26	29.34	26.38
Lake	1933	Oct. 12, 1934	New shoots, plants with leaves cast	3.18	3.39	0.89	0.78	0.572	0.538	0.063	0.079	9.08	6.82	6.28	5.97	33.72	30.86
Chaparral coffeeberry; Aiken clay loam soil																	
Shasta	1935	May 4, 1936	Leaves, half developed	6.69	....	1.61	1.49	1.348	1.297	0.237	0.264	5.69	4.92	19.21	18.61	13.36	13.06
Shasta	1935	June 28, 1936	Leaves, developed	6.98	6.84	1.34	1.18	2.529	2.486	.246	.230	10.28	10.81	16.21	12.82	14.76	12.81
Shasta	1935	Nov. 24, 1936	Leaves, mature, turning brown	7.03	6.99	1.22	1.11	2.738	2.841	0.203	0.216	13.49	13.15	12.69	12.83	15.62	14.03
Foxtail fescue; Aiken clay loam soil																	
Shasta	1934	Jan. 3, 1935	Young leaf stage	0.617	0.592	2.74	2.53	0.447	0.423	0.389	0.410	1.15	1.03	17.94	16.12	21.81	18.69
Shasta	1934	Feb. 24, 1935	Just before flowering	4.830	4.760	2.11	2.01	.382	.379	.261	.273	1.46	1.38	14.63	12.04	28.62	25.84
Shasta	1934	March 22, 1935	In full bloom	3.020	2.950	1.23	1.04	.324	.318	.254	.249	1.28	1.28	8.82	7.29	33.09	30.91
Shasta	1934	April 30, 1935	Leaves mostly dry, seeds mature	2.910	2.880	0.92	0.86	.304	.298	.221	.215	1.38	1.39	6.74	7.03	32.80	32.27
Shasta	1934	May 12, 1935	Dry, some seeds cast	2.700	2.740	0.90	0.85	.223	.236	.137	.146	1.62	1.61	6.29	6.40	34.20	33.01
Shasta	1934	June 20, 1935	Dry, seeds cast	1.870	1.830	0.87	0.83	0.268	0.272	0.089	0.069	3.01	3.94	2.41	2.49	41.61	40.58

* Soil type of Contra Costa County was that of Manzanita clay loam.

TABLE 17—(*Continued*)

County in which collected	Year burned	Date of sampling	Plant parts and growth stages	Silica-free ash		Potassium		Calcium		Phosphorus		Ca : P ratio		Crude protein		Crude fiber	
				Burned	Unburned	Burned	Unburned	Burned	Unburned	Burned	Unburned	Burned	Unburned	Burned	Unburned	Burned	Unburned
Redbrome chess; Sites stony clay loam soil																	
Shasta	1934	Jan. 3, 1935	Young leaf stage	6.84	6.96	2.78	2.66	0.572	0.561	0.411	0.426	1.39	1.31	25.36	24.97	23.59	21.34
Shasta	1934	March 22, 1935	Full bloom	5.97	5.78	2.58	2.56	.304	.296	.211	.224	1.44	1.32	17.89	14.26	26.31	24.83
Shasta	1934	May 12, 1935	Dry, seeds mature, some cast	3.41	3.50	0.88	0.81	0.197	0.183	0.043	0.051	4.58	3.59	2.67	2.71	41.68	38.72
Hill lotus; Aiken clay loam soil																	
Mendocino	1935	March 24, 1936	Early leaf stage	13.21	12.83	3.52	3.31	2.843	2.739	0.429	0.438	6.63	6.25	25.84	24.97	17.81	16.02
Mendocino	1935	April 6, 1936	In full bloom	12.23	12.04	2.91	2.67	2.631	2.427	.312	.309	8.43	7.87	19.32	17.09	19.67	17.24
Mendocino	1935	June 7, 1936	Dry, seeds cast	7.51	8.01	1.69	1.53	1.762	1.674	0.063	0.071	27.97	23.58	5.21	4.96	31.38	30.27
Fineleaf lotus; Hugo clay loam soil																	
Mendocino	1935	March 24, 1936	Early leaf stage	13.46	13.02	3.81	3.47	3.07	2.89	0.367	0.388	8.36	8.55	25.39	23.81	16.74	14.83
Mendocino	1935	April 6, 1936	In full bloom	11.12	11.04	3.41	3.26	2.58	2.50	.321	.314	8.04	7.96	22.63	19.02	18.42	16.14
Mendocino	1935	June 7, 1936	Nearly dry, some seeds cast	6.71	6.59	1.38	1.24	1.36	1.43	0.136	0.153	10.00	9.34	4.23	4.16	32.67	29.41

by hand, whereas those of the herbs included the entire top growth. All samples were treated in the same manner in their preparation for analysis.[25]

Table 17 gives information on sampling, and the results of the analysis.

The crude protein content is seen to be somewhat higher in the plant samples collected on the burned areas, from the early growth stage until after flowering. This observation agrees with the results of other workers. Hart, Guilbert, and Goss (*32*) found certain species to contain a higher crude protein content on burned California chaparral areas. Aldous (*1*) reported the percentage of crude protein of bluestem grasses to be slightly higher in early June in the regenerated growth on areas burned late in the spring. Wahlenberg, Greene, and Reed (*113*) partly support this point for burned pine lands of the South. Neal and Becker (*71*) found the samples of wire grass taken from burned areas to have a higher crude protein content than those collected from adjacent unburned areas.

In the late growth stages, the data in table 17 show no consistent difference in the percentage of crude protein in the two groups of samples. Both the shallow-rooted grasses and the broad-leaved herbs show greater increases of crude protein when growing on burned areas than do the deeper-rooted shrubs. This may partly be accounted for by the addition of ash and the increased nitrification in the surface soil layer of the newly burned areas (see page 83).

The crude fiber content shows higher values in the plants collected on the newly burned plots, notably in the intermediate growth stage. Burning has the least effect on the crude fiber content in two nondeciduous shrubs, chamise and whiteleaf manzanita, but even in these species the content is slightly higher in the samples collected on the burned areas. The relatively larger, heavier leaves and the longer, coarser, more woody stems of the samples collected on the recently burned lands would appear to account for the percentage differences in the crude fiber content of these species.

The mineral constituents (table 17) showed no consistent differences within specific growth stages, in either the shrubs or herbs grown on burned or unburned areas. In all species the levels of phosphorus and potassium are highest in the earlier growth stages.[26] The percentage of calcium, on the other hand, increases in the shrubs and decreases in the herbs with the march of the season. Thus in the fall, in most of the chaparral and other woody species studied, the ratio of calcium to phosphorus is conspicuously high, an indication of an undesirable balance from a forage viewpoint (*68*).

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[25] The fresh weights of the samples were recorded in the field immediately following the collection, after which the material was dried in an electric oven, with circulating air, at a temperature of 70° C. When dry, the samples were finely ground, bottled, and tightly stoppered. After the analyses of the samples were completed, an aliquot part of each sample was dried at 100° C to constant weight; the analytical data were then expressed on this moisture-free basis.

In the determination for nitrogen, calcium, ash, and moisture, *Official and Tentative Methods of Analysis of the Association of Agricultural Chemists* (*4*) was followed. Phosphorus was determined colorimetrically, as described by Kuttner and Cohen (*57*). Crude fiber was determined by the method described by Sharrer and Kurschner (*94*). Silica was determined by treating the ignited residue of the sample with concentrated HCl and 60 per cent $HClO_4$, igniting the residue after digesting on the steam bath, and then filtering.

[26] It is not surprising, perhaps, that this constituent does not show higher values even in the shallow-rooted annual species, since the phosphorus liberated by burning is readily fixed by the soil complex, or is precipitated as insoluble ferric phosphate, or, in the presence of excessive calcium and a high pH, forms calcium phosphate.

Although burning apparently affects but little the chemical composition of individual species at a specific stage of growth, the change in cover and the frequently greater vegetative growth resulting from burning do increase the total nutrients on the area, and therefore favor greater nutritional intake of the grazing animals.[27] The abundant, rapidly growing, succulent shoots of the browse plants, with their relatively large leaves, are within easy reach of the animals; and, as pointed out, there is a slightly prolonged period of succulence of the vegetation as a whole.

FIELD OBSERVATIONS OF AREAS BURNED UNDER STATE PERMIT

In the preceding pages detailed measurements and study of plant succession, forage yield, soil reactions resulting from burning, and chemical values of the forage have been reported. In the discussion which follows, based on field observations, the broader trends resulting from burning of a large number of diversified areas are presented. The points recorded are essentially those which determine the value of the burning venture.

In 1938 several privately owned chaparral and chamise areas in the northern counties of the state were burned under the sanction and supervision of the State Division of Forestry. Seven weeks during the summer and autumn of 1939 were devoted by the writer and a field assistant to a critical review of these supervised burns and several others, 34 in all, in an effort to evaluate the degree of success attained by burning. Although close comparison with the carrying capacity before burning of each specific area was not possible, the vegetation on similar adjoining unburned areas was noted and compared. Most of the areas had been burned one to two years prior to the examination. A field observational outline guide was used in recording the conditions. The points noted included such facts as general history of the area, topography, soil type, character and density of the vegetation before and after burning, extent of utilization, degree of erosion, and estimated carrying capacity.

The degree of soil erosion was classified as "normal to light," "moderate," or "severe." *Normal* to *light* soil erosion implied no appreciable departure from the geologic rate, and was characterized by the presence of fragments of charred wood scattered over recently burned areas, the occurrence of rounded out and revegetating older gullies, and in some instances by a well-developed top soil which contained abundant organic matter. *Severe* soil erosion was recognized by the presence of numerous new or well-defined gullies, most of which were V-shaped and which were revegetating little if at all, by exposure of dark areas on the crowns of chaparral denoting current removal of soil by general sheet erosion, and sometimes by the presence of soil deposition on drainage areas below. *Moderate* soil erosion was recognized as being in the early stages of accelerated soil movement, and was indicated by the presence of a few incipient gullies, and of considerable sheet erosion.

The grazing-capacity estimates, always difficult to derive, were obtained in part by taking into account the period of time that a known number of animals

[27] Owe, John L. The effect of nitrification upon vegetation and forest reproduction in some California pine forests. Thesis for the degree of Master of Science, University of California, 1930. Copy on file in the Library of the University of California, Berkeley.

actually grazed upon the area, the reaction of the range to this stocking, and partly by the employment of established grazing reconnaissance computations. Forage requirements were computed on the basis of 0.6 of a forage acre per cow month, or per animal unit per month. As here used, *animal unit* is the acreage required to provide one cow, or its equivalent of 5 sheep, with this amount of forage. The term "stand" is used to indicate the amount of ground covered by vegetation, and is expressed in per cent. Allowance was made for the forage values of plants which are in evidence only during the spring period. The following discussion summarizes, by counties, the successional and other important information recorded during the inspection of these areas.

Lake County.—Area 1: The original vegetation on this 150-acre area, burned in 1936, consisted of a dense stand of pin oak 2 to 12 feet in height. At the time of inspection, two years after burning, pin oak sprouts were rapidly replacing the annual grasses and weeds, which then had a density of 20 per cent. The area had been grazed by sheep and cattle; about 6 acres was required per animal unit per month. No artificial reseeding had been attempted. The stony loam soil of the Los Osos series of this steep area, averaging 50 per cent slope, varied from bare rock to 8 inches in depth, and had dried hard on exposed areas. Soil erosion was light, and was chiefly confined to spotty sheet erosion, and to the formation of a few incipient gullies.

On the portion of this ranch where the cover consisted primarily of chamise, greenleaf manzanita, canyon live oak, and annual grasses, the vegetation had been so closely browsed that much of the brush was killed before the area was burned. The vegetation at the time of inspection consisted of yerba santa, Junegrass, foxtail fescue, wild oat, Napa star thistle, and chamise.

Area 2: Part of this area, consisting of 500 acres, was burned in 1938, and was unusual in that in some units the chamise sprouts and seedlings, and some other brush species, were so closely browsed by deer since burning as to open up the cover conspicuously. Little herbaceous vegetation had appeared when the area was inspected, but the chamise and deerbrush comprised a density of 15 per cent. No stock was grazed on the newly burned unit owing to the poor forage conditions. The soil, a stony clay loam of the Hugo series, varied from surface rock to 3 feet in depth. The average slope was 10 per cent. Soil erosion was light, and was essentially limited to sheet erosion on the more exposed slopes. Other areas on this ranch had been previously cleared of brush by the use of fire through a planned and continuous long-time burning program. Only the more gentle slopes which embrace the deeper, more fertile soil had been burned. These clearings supported the following species: foxtail fescue, wild oat, red brome, silver hairgrass, nitgrass, needlegrass, Napa star thistle, tarweed, and St. Johnswort. Wild oat had been seeded artificially with some apparent success. Success in clearing of the brush, and the invasion of an annual herbaceous cover, were particularly impressive. The grazing capacity was fairly high, and the burning had been economically successful.

Area 3: In 1936 the heavy stand of chamise was completely burned on this 150-acre unit. At the time of inspection, in 1939, a cover of chamise sprouts and seedlings of about 40 per cent density had recaptured the area, with almost no other vegetation in evidence. There was so little forage that 9 acres was estimated as required per animal unit per month; hence the area had practically no pasturage value. The soil, a gravelly, sandy clay loam of the Konokti series, varied in depth from surface rock to 1½ feet. The average slope was 5 per cent. No abnormal soil erosion was indicated. The owner stated that he had burned this area not with the hope of procuring a grass cover, but merely to have the use of the browse for a short time in the spring.

Area 4: In 1938 a chamise area of 150 acres which adjoined area 3 was heavily burned. When inspected, it was virtually devoid of vegetation other than chamise seedlings and sprouts of about 25 per cent density, the latter being short and bushy as a result of their having been closely browsed by deer. This area was pastured neither before nor after burning. In its state of low forage growth when inspected, this burn could carry no stock economically, unless it be merely to provide an occasional menu of chamise to serve as variety with the grass diet from nearby lands. The gravelly, sandy loam of the Konokti series varied from exposed rock to 1½ feet in depth, and was unusually stony. The average slope was 3 per cent. There was little evidence of abnormal erosion.

Area 5: Originally supporting a dense stand of California scrub oak and Stanford manzanita, this 200-acre tract was burned in 1938. The area had not been grazed in 1939 when inspected; in fact, there was almost no vegetation except scrub oak sprouts and scattered plants of St. Johnswort (*89*). With a plant cover of only 15 per cent density, the carrying capacity was obviously too low to utilize for domestic grazing animals. Nevertheless the soil, a sandy loam of the Konokti series, showed only normal erosion, with some sheet erosion on some of the steeper facings. The average slope was 10 per cent.

Mendocino County.—Area 6: The rapid return of the mixed chaparral was distinctly conspicuous on this 15-acre burn, despite the fact that the fire of 1938 resulted in removing the top growth of nearly all the old stand. Overutilization of the area in 1939 had resulted in leaving little of the herbaceous vegetation, even of species of secondary palatability. Although the area was pastured only in the spring, when the forage was at its best, estimates indicated that 7 acres was required per animal unit per month. The average slope for the area was 15 per cent, whereas the steeper slopes averaged 42 per cent. The gravelly, sandy clay soil, of the Mariposa series, showed severe erosion on the steeper slopes. The erosion ranged from small gullies to slips of large blocks of soil. Before burning, the area was occupied by oak woodland, with some redwood present. Following burning, browse furnished limited feed the first year, whereas grass composed the bulk of the forage during the second and third years. The owner stated that reseeding or cultivation of any sort was impossible because of the presence of the numerous, extensive gullies.

Area 7: Burning some five times during the last twenty years was the history of this 140-acre area, with the last fire occurring in 1935. Wavyleaf ceanothus and greenleaf manzanita, which formerly predominated, formed a density of about 35 per cent, and were rapidly reoccupying the site. Herbaceous vegetation, composed primarily of foxtail fescue and Scouler St. Johnswort, was so sparse that the soil was nearly devoid of an understory cover. Grazing values were so low as to be little or nothing, about 8½ acres being required per animal unit per month. The average slope was 50 per cent. The unprotected surface soil showed the pebbly pavement common to the action of sheet erosion, whereas a few soil slips, associated with prominent fresh gullies, indicated active but moderate soil erosion.

Area 8: After a heavy stand of redwood timber was logged, a particularly dense, tall growth of blue blossom took over this entire tract. The woody growth on 300 acres was lopped in 1936, and burned late in the autumn of 1937, after the vegetation had dried. For the past several years 50 acres or so had been cut and burned each year, until some 400 acres had been more or less temporarily cleared, except for the extensive sprouting of the numerous redwood stumps and scattered stands of various brush plants. The lopping and burning cost from $7 to $10 an acre. After one or two heavy rains, the recently burned areas were seeded by the owner to a mixture of redtop, timothy, perennial ryegrass, velvet grass, Kentucky bluegrass, and orchard grass at the rate of 20 pounds to the acre, and at a cost for the seed of about $2.50 per acre. Also, in the earlier operations, mustard seed was included with the mixture at the rate of 3 pounds to the acre. This seeding resulted in the establishment of a cover of from 20 to 50 per cent for the first and second years after seeding. In the third year, however, annual grasses, weeds, California huckleberry, Pacific madrone, and blue blossom had all but crowded out the cultivated plants. Because of this failure, Harding grass was later substituted in the reseeding endeavor on the chopped and subsequently burned areas; it made a much better showing than did the other grasses. A good stand of Harding grass was obtained for the first three years or so after seeding, but later on this grass tended to wane; yet it was clearly the most stable species introduced. Although artificial reseeding had been partially successful, approximately 6 acres was nevertheless required per animal unit per month. The area has been grazed by sheep. Aside from the encroachment of the brush and redwood sprouts, excessive yearlong grazing mostly accounted for the rather limited forage supply. The average slope was 25 per cent. Recent erosion of the light Melbourne sandy clay loam soil had been severe on many of the steeper slopes, and was reflected in the low productivity of the site. Soil slip, with prominent fresh gully formation below, was particularly impressive on several of the steeper, earlier-cleared slopes. It is significant, perhaps, that this ranch changed hands three or more times in the past ten years, but following each of these transactions the property reverted to the original owner.

Area 9: This 10-acre area, located in a nearby level swale, was of superior site quality and until recently, when the area was logged and burned, was occupied by redwood trees 10 to 60 inches in diameter. The average slope was 20 per cent. The soil was deep, and varied from friable loam to rocky clay. There was no evidence of abnormal soil movement or loss. Many redwood sprouts 4 to 34 inches in height, and many seedlings of blue blossom, were reinvading this burned area. Despite reseeding in 1938 to various cultivated grasses, annual volunteer species of grasses, thistles, and many weeds clearly predominated, and formed a density of 45 per cent. The area was lightly grazed by sheep in the spring of 1939, following which herbaceous growth of fair to good quality was produced.

Area 10: The general soil conditions of this 4,000-acre burn appeared serious. Erosion of one form or another was severe and was taking place at a rapid rate. The average slope was 63 per cent. Soil slip was particularly impressive in that area; on many slopes, areas of 2 to 5 acres had moved down hill; most of these slides occurred slightly below the summit on the steeper slopes. Although there were a few small grassy flats, most of the topography was exceptionally rough for grazing; many slopes had a 65 per cent gradient, and a few more than 90 per cent. The clay loam soil of the Hugo series varied in depth from a few inches to 3 feet, with considerable rock outcrop on the more prominent ridges and slopes. A large acreage had been cleared of brush by repeated burning, but at a great sacrifice of the top soil. The exposed subsoil was heavily baked when examined. No charred wood remained on the slopes of recent burns. The density of the vegetation over the steeper country did not exceed an average of about 10 per cent, whereas it attained a density of 20 to 35 per cent on the gentler slopes and flats. Because of the inferior grazing value of the dominant herbaceous species, composed chiefly of foxtail fescue and nitgrass, 6 acres per animal unit per month was estimated to be the range requirement. Range use at the time of inspection was clearly excessive. Numerous reseeding trials, made by the owner, had failed.

Area 11: This 60-acre chamise area was burned three times within eight years, the last burn being in 1936. The area had been largely cleared of brush, but the present herbaceous vegetation, with a density of approximately 20 per cent, had been severely overgrazed. There was little palatable browse. Some 7 acres was required to maintain an animal unit for 1 month. The average slope was 47 per cent. The soil, a Pinole gravelly alluvium, without clay subsoil, had eroded severely, and the clearing of the brush had been accompanied by heavy soil loss. There had been much soil slippage, subsequently accompanied by the formation of many prominent gullies. Sand, gravel, and debris had washed to the lower levels and had been deposited along the main drainage channel.

Area 12: The original dense stand of this 60-acre chamise area was burned in 1938. When examined, there was a scattering of foxtail fescue, and a rather heavy stand of deerweed, together with an abundance of chamise seedlings and sprouts. For the entire area burned, the density of vegetation averaged 20 per cent. The gradient averaged 50 per cent, and sheet and gully erosion were pronounced on the upper slopes. It was estimated, exclusive of the limited browse value of the chamise, that 10 acres would be required per animal unit per month. In the season after the fire, sheep grazed the area for a short time in the spring. Soil erosion was moderate. Charred wood, ashes, and some soil had been deposited on lower levels by surface runoff.

Area 13: This 130-acre chamise area, with an average of 25 per cent slope, supported vegetation similar to that of area 12. The chamise was approximately 3 feet in height and occupied about one fourth of the ground cover. The herbaceous vegetation, with a density of 60 per cent, included several superior native forage grasses. The forage was far superior to that on area 12, the grazing requirement being about 4 acres per animal unit per month. The average slope was 35 per cent. Soil erosion was classed as light. Although this burn contained a large soil slip of recent origin, and several large gullies, no portion of the area appeared recently to have eroded abnormally.

Area 14: The vegetation of this 1939 early summer burn of 35 acres consisted essentially of young chamise sprouts a few inches in height, and of numerous chamise seedlings. Although no reseeding was attempted, the owner expected, in the spring of 1940, to get some feed for a few animals from the sprouts. The average slope was 25 per cent. Most of the charcoal had been removed by surface runoff, and moderate current sheet or gully erosion had taken place. On a small portion of the area, which was dominated by interior live oak, were found purple needlegrass, red brome, and blue wild-rye grass, these forming a density of 10 per cent. Because of the limited forage, no attempt was made to graze the area in 1939.

Area 15: The madrone sprouts on this four-year-old burn of 100 acres were of such density that it was difficult to walk through them. The few areas which were sparsely occupied by brush supported a scattered stand of herbaceous vegetation. Wisely, no livestock were placed on the area in 1939 because of the inferior forage. The average slope of this unit was 8 per cent. No abnormal soil erosion was noticed, but the soil was heavily baked. An adjoining unburned area of Douglas-fir, madrone, and interior live oak was practically devoid of an understory of brush, but supported considerable grass, which gave it a parklike appearance. This area afforded much more grazing than did the burned area, and was being utilized effectively by sheep.

Area 16: On this 80-acre two-year-old burn chamise and manzanita were coming in strongly, but heavy grazing appeared to have reduced the herbaceous vegetation so that it formed only 10 per cent of the ground cover. The average slope was 20 per cent. Despite the fact that the light-textured soil had been severely trampled, there had been only moderate sheet and gully erosion. Apparently the whole ranch had been subjected to heavy overutilization. On the burned area the grazing requirement was estimated as some 8 acres per animal unit per month.

Humboldt County.—Area 17: After a young stand of Douglas-fir had been slashed on this 100-acre unit, and subsequently burned, the area had been fired on an average of every four years for twenty years in an unsuccessful effort entirely to kill the manzanita, blue blossom, and poison oak. Each burning was followed by seeding with perennial ryegrass, but this effort had proved uneconomical. Generally, a good stand of this grass was obtained the first year after seeding; a scattered cover remained the second season, whereas almost none was to be found thereafter. The pasture was grazed lightly by sheep throughout the year. About 3 acres was required per animal unit per month. The soil, a stony loam of the Melbourne series, varied from 1 to 3 feet in depth. The average slope was 18 per cent. Soil erosion was light; there was but little soil slip, and there were only a few small gullies. The erosion appeared not to be of recent origin, since the scars and rounded-out gullies were reasonably well healed over with vegetation. The clearing of this area was highly successful.

Area 18: This 300-acre area, last burned in 1935, was predominantly Douglas-fir, Pacific madrone, and tanoak, much of which had been replaced by grass. After cutting and burning, the area was reseeded to perennial ryegrass and orchard grass. Although both grasses became established, the latter gave the better results, notably on the north slopes, where, under deferred grazing and moderate stocking, it had produced a fair to good cover for four years and appeared to be strong. The practice had been to graze the area lightly in the spring and summer by sheep and cattle, with the result that only 1½ acres was required per animal unit per month. The average slope was 12 per cent.

The stony loam soil of the Melbourne series varied from surface rock to 3 feet in depth and showed no abnormal erosion. The soil was mellow, and there was little evidence of baking of the slightly exposed soil surface.

Area 19: In 1938 the Douglas-fir, Pacific madrone, and tanoak on this 100-acre area were cut and burned; then, in late autumn, came reseeding to perennial ryegrass, little of which was in evidence at the time of inspection. Small areas had been alternately burned each year in an effort to destroy remnants of the original woody cover, and this operation had been followed by artificial reseeding with cultivated grasses. The introduced grasses had failed to become established, according to the owner, because of heavy grazing. The herbaceous cover had a density of 20 per cent, but it was rapidly giving way to bracken fern and to the original woody vegetation. Only 2½ acres was estimated as being required per animal unit per month. The average slope was 25 per cent. The stony loam soil had eroded but lightly, and there was only limited baking of the exposed soil.

Area 20: The California hazelnut brush, Douglas-fir, and tanoak of this 300-acre coastal ranch, located about a half mile from the ocean, was burned in 1938 and was reseeded in the autumn to perennial ryegrass and ribgrass. The rather heavy forage at the time of inspection consisted of perennial ryegrass, bluegrasses, Junegrass, English plantain, and thimbleberry. The long period of succulence and the relatively heavy yield of this herbage appeared to be accounted for by the fact that fog from the ocean provided moisture at critical periods. The 60 per cent density of vegetation, and the light spring and summer grazing, partly accounted for the low requirement of 1 acre per animal unit per month. The slope averaged 10 per cent. The rich clay loam soil, of the Melbourne series, varied from 2 to 6 feet in depth, and showed little abnormal erosion of any form.

Area 21: This 100-acre area was similar in native cover, soil, and topography to the one just discussed. It likewise was burned in 1938 and was seeded to perennial ryegrass in the autumn of that year. In common with other stockmen in the area, the owner slashed and permitted the brush to dry before burning, but left the Douglas-fir stand to be killed by the fire. There was a herbaceous cover of about 40 per cent density when the area was inspected, and only 1 acre per animal unit per month was required for moderate spring and summer grazing. Unless the area was reburned every three or four years, tanoak sprouts, thimbleberry, and bracken fern tended to recapture the soil to the virtual exclusion of other vegetation. The average slope was 10 per cent. The loam soil, of the Melbourne series, varied in depth from 2 to 6 feet. Neither erosion nor baking of the soil was abnormal.

Shasta County.—Area 22: This 100 acres of relatively level brush and woodland, burned in 1936, for the most part occupied a ridge top. Parry manzanita and canyon live oak produced a dense stand before burning, and the understory vegetation then consisted chiefly of foxtail fescue and red brome. When inspected, the invading vegetation formed a density of only about 15 per cent, but even so the fire had resulted in effectively opening up the brush. Canyon live oak sprouts and manzanita seedlings, however, were clearly regaining possession of the ground. The area had been grazed by cattle for a few weeks each spring. Five acres was required per animal unit per month. The average slope was about 20 per cent. The grayish-red stony loam soil showed only light sheet erosion, and there was no serious baking of the soil.

Area 23: The extensive chaparral flats east of Redding are fairly well characterized by this 70-acre burn, as well as by that designated as area 24. Dwarf interior live oak predominated throughout. The area was heavily burned in 1937. The soil was thin, with much outcrop in evidence. The average slope was 15 per cent, and current erosion was light. Prior to burning, only the openings supported any appreciable amount of herbaceous vegetation. The second year after burning, a mass of woody sprouts and seedlings had occupied the area, and primarily consisted of dwarf interior live oak, blue oak, and poison oak; this invasion of chaparral had also extended into many former openings. The various annual grasses, with a fair sprinkling of Spanish-clover, were so sparse as to afford little grazing, and were of value only early in the spring, when a few cattle utilized the area. Five acres was required per animal unit per month. Considerable sheet erosion took place the first year after burning, as indicated by measurement with erosion stake levels, and as evidenced by the pebbly soil surface. Infiltration studies showed that water percolated into the soil much more slowly than on a similar adjacent, long-protected area, where humus and partly decomposed plant material had accumulated. All attempts at artificial reseeding failed.

Area 24: This area of 140 acres, burned in 1937, was similar to that just discussed, except that the cover consisted of a more balanced mixture of dwarf interior live oak, wedgeleaf ceanothus, Parry manzanita, and herbs. After burning, the live oak clearly predominated, and soon crowded out most of the herbaceous vegetation. This rapid replacement of the herbaceous cover reduced the grazing capacity, so that, in 1939, 6 acres per animal unit per month was required. The area was used for spring grazing by cattle. The average slope was 20 per cent. Soil erosion was moderate, and the soil was heavily baked.

Area 25: The extensive, hilly, red-soil country, extending from the village of Beegum to Ono, was rather well characterized by this 350-acre area. Before burning, in the fall of 1937, various openings supported grass and other herbs with densities ranging from 10 to 30 per cent, whereas under the heavy brush there was but little herbaceous vegetation of any kind. Two years after burning, chamise and sprouting forms of manzanita largely reoccupied the ground, forming a density of about 40 per cent; but interspersed between the clumps were many broad-leaved herbs and a sprinkling of annual grasses. Hill lotus was perhaps the most valuable forage plant, although some palatable browse was available. Cattle had been grazed upon the area for a short time in the spring. This and similar burns of the locality have afforded satisfactory early-spring goat browsing for three years after burning; but the lands are regarded by local stockmen as inferior for cattle, and only fair for sheep, except in the draws where a variety of forage was found both before and after burning. About 8 acres of the typical hillside chamise was estimated as required per animal unit per month. The average slope was 30 per cent. Soil erosion in general was moderate, but was severe on some of the steeper south slopes. Attempts at seeding to cultivated grasses had consistently failed on this area.

Tehama County.—Area 26: There was evidence that a lava flow had covered this general region within recent geological time. The area specifically concerned consisted of 1,200 acres. The soil was a dark brown, coarse, rocky loam, little more than 3 inches deep, with many large rocks and boulders in evidence. The cover consisted of interior live oak, California scrub oak, species of manzanita, yerba santa, poison oak, and various annual grasses. After burning there remained a tangle of partially dead woody vegetation, as inspection revealed the following summer. Because of the small amount of forage growth, no stock was placed on the area in 1939 or in 1940. At the time of inspection the main reproduction consisted of California scrub oak sprouts, and of manzanita. The average slope of this area was 12 per cent. There was no abnormal soil loss by erosion, in part perhaps because the rainy season was nearly over when the burning was done, and partly because of the covering of rock fragments and pebbles. Because of inferior soil, the returns from this burn were particularly poor.

Area 27: Before burning in 1938, the vegetation on this 30-acre area consisted chiefly of blue oak, poison oak, and coffeeberry, with a scattered understory of foxtail fescue. After burning the area was grazed by sheep. At the time of inspection, sprouts of blue oak, poison oak, and annual grasses occupied approximately 30 per cent of the area as a result of the opening up of the brush. The grazing requirement per animal unit per month was 2¾ acres. The average gradient was 12 per cent. The soil, an alluvial deposit, averaged approximately 1¼ feet in depth. There was little evidence of abnormal erosion, probably because the tract is nearly level. Burning temporarily improved the grazing capacity of this area without lowering its productivity.

Area 28: A dense stand of canyon live oak and Parry manzanita originally occupied this 1,200-acre area. The burning was done in 1936, following which the area was grazed in the spring period by cattle. In 1939, the area supported a sparse stand of wild oat, soft chess, ripgut grass, and foxtail fescue; but sprouts of canyon live oak and seedlings of Parry manzanita were rapidly reoccupying the ground. The total density of the vegetation was 30 per cent. About 5 acres was required per animal unit per month. The average slope was 30 per cent. The clay loam soil, of the Hugo series, varied in depth from 4 inches to 2 feet. There were healed-over gullies as evidence of past erosion, but few gullies were actively eroding at the time of inspection; sheet erosion, too, was light when the area was inspected.

Amador County.—Area 29: Before burning, this 260-acre brush field supported a full stand of chamise, greenleaf manzanita, poison oak, and toyon. In 1939, one year after burning, the plant cover, consisting chiefly of toyon and chamise sprouts and seedlings, was sparse, with the extensive areas nearly barren. In 1938, timothy and red clover were sown, but no plants became established from this effort despite the fact that stock had not been placed on the area because of the limited forage growth. The combined density of the browse and herbaceous vegetation amounted to only about 25 per cent cover. The average slope was 15 per cent. The stony, loam soil, of the Auburn series, did not exceed 8 inches in depth, and was conspicuously rocky. Soil loss by sheet and gully erosion was classed as moderate.

Area 30: This chamise range of 50 acres was burned in 1935. By 1939, it had been almost completely reinvaded by a dense stand of chamise sprouts and seedlings. The herbaceous vegetation consisted merely of small patches of annual grasses, and most of these were being replaced by the brush. The total density was 50 per cent. No stock had been grazed on the area because of the inferior quality of the forage. The average slope was 20 per cent. The soil, a grayish-black clay loam, did not exceed about 9 inches in depth. There was little evidence of an abnormal rate of erosion.

Area 31 : A full chamise stand occupied this 200-acre area before burning in 1936. At the time of the 1939 inspection, the chamise, interspersed with yerba santa and toyon, had reclaimed the area to the virtual exclusion of herbaceous vegetation, which was represented chiefly by scattered patches of nitgrass, foxtail fescue, and wild oat. For two years after the fire, according to the statement of the owners, this burn carried a few stock, but the forage decline was so rapid that no animals were grazed in 1939. At that time not less than 7 acres would have been required per animal unit per month; the season of use would be short, and the quality of forage inferior. The average slope was 5 per cent. The dark grayish-brown sandy loam showed only slight evidence of abnormal erosion.

Calaveras County.—Area 32: Before burning in 1938, the vegetation on this 80-acre area consisted of a dense stand of chamise and a few annual grasses. At the time of inspection, chamise sprouts and seedlings made up approximately one fifth of the total vegetation. The understory cover of foxtail fescue, nitgrass, wild oat, red brome and chaparral cottonweed, together with the brush sprouts, formed a density of 30 per cent. Cattle grazed the burn lightly in the spring, 4 acres being required for each animal unit per month. The average slope was 15 per cent. The grayish-brown, sandy clay loam varied in depth from 4 to 18 inches. Soil erosion had not exceeded the normal rate after burning.

Area 33 : Since the fire of 1938, this heavily stocked chamise area of 60 acres had been heavily overgrazed by cattle; indeed many chamise sprouts had been cropped down to the basal crown. Apparently because of the presence of large accumulations of ash, many spots several feet in diameter were devoid of vegetation. On sites where the fire had been less intense, the vegetation consisted of a mere scattering of foxtail fescue, nitgrass, red brome, silver hairgrass, ticklegrass, and wild oat. It may be assumed that if this range had not been so severely overgrazed the 10 per cent density of the herbaceous forage at the time of inspection would surely have been considerably greater. Computations showed that with this inferior forage 6 acres per animal unit per month was required. The average slope was 10 per cent. The light yellowish-gray, gravelly clay loam soil varied in depth from 6 to 24 inches, and showed only light sheet and gully erosion.

Area 34 : Three years after the fire, chamise had again virtually recaptured all available space. It varied in height from about 6 inches for the seedlings to 24 inches for the sprouts. With a ground cover of 40 per cent, composed primarily of chamise and annual grasses, 4½ acres was required per animal unit per month. Cattle were grazed upon this unit during spring and early summer. The average slope was 25 per cent. The reddish-brown, coarse gravelly clay soil varied from exposed parent rock material to 3 feet in depth, with much rock outcrop. Current soil erosion was classed as moderate; sheet erosion was conspicuous, and there were several small gullies of recent origin.

Summary of Field Observations on Burns.—Of the 34 ranches examined, 29 showed rapid reoccupation of the original brush. On 7 of the burns no animals were grazed because of the small amount of good forage produced. Twenty-two of the 34 burns showed only normal or light erosion. It is significant that the average gradient of these areas was only about 15 per cent. The tabulated records revealed that 30 of the burns had slight or no soil slippage, whereas on 4 areas soil slippage had been severe. Twenty-two burns had little or no gully erosion, whereas on 4 burns, soil erosion of a general nature was severe, and on 8 burns, soil erosion was moderate. The 4 severely eroded areas had an average slope of approximately 44 per cent, whereas those classed as moderately eroded had an average slope of about 32 per cent. Thus the extent of soil erosion of these areas, under grazing use, seemed to show rather strong correlation with steepness of slope, with the amount of ground cover, and with the intensity of grazing. Artificial reseeding had been fully successful on only 2 sites, both of these being in the humid coastal region of Humboldt County. On the several other burns where artificial reseeding was tried the results showed only slight and purely temporary success, or they were complete failures from the outset. The estimated acreage required for pasturage of an animal unit was especially high on burns in Lake, Mendocino, Shasta, and Tehama counties; thus many of these areas had to be classed as inferior for livestock grazing. In Humboldt County, on the other hand, the soils of the areas inspected were productive, and the carrying capacity was high; hence these burns proved profitable.

The two factors most favorable to burning were that the animals could graze over most of the area, whereas this was often not possible before burning; and that more palatable vegetation generally became available after burning. Perhaps the two most adverse factors noted on the controlled burns examined, on the other hand, were the temporary nature of the forage produced and the shortness of the grazing season, which on most of the areas was only a few weeks in the spring, or from spring into the early summer. Only on fairly level sites, and on the more productive soils, was there measurable success from broadcast burning. In general, and particularly on the steeper south and west slopes, heavy or nearly pure stands of chamise, which characteristically occupies thin soils, produced the least forage after burning of all brush covers here examined. Many such burns yielded so little forage that no stock was grazed upon them.

METHODS OF BRUSHLAND IMPROVEMENT

The studies described in the previous sections have largely been concerned with the effects of the common practice of broadcast burning. In this section are presented a number of current practices employed to maintain the forage on the brushlands when the chaparral stand has been opened up. Some of the methods discussed or proposed involve the use of fire alone; others are combinations with mechanical or biological means of controlling the brush.

Frequent Burning to Keep Cover Open.—Burning chaparral areas at frequent intervals is occasionally practiced with a view to decimating the chaparral sprouts, killing the new crop of seedlings, and removing as many of the old dead stems as possible.

Where burning at intervals of two to three years is possible, stands of sprouting chaparral tend to give way more or less to grass and weeds. Few such frequently burned areas, however, produce enough herbaceous growth to assure the running of sufficiently hot fires to consume the brush seedlings, the sprouts, and the charred, dead stems. Only on the better sites may a follow-up fire be hot enough, after the two years or so of protection, to destroy most of the incoming chaparral seedlings, and at the same time reduce a portion of the sprout growth. The availability of pasturage elsewhere will determine whether the forage produced after the first fire can be sacrificed solely for improvement purposes.

Although most of the smaller leafy branches, and much of the accumulated litter, are consumed by the initial fire, a large proportion of the coarser brush stems remain erect and intact five to eight years after burning. Since they are an annoyance to the stock, as well as to the operator, disposal of them is desirable.

Standing, as these bare stems do, well above the current growth, it is important that some mechanical means be employed to break them down before reburning. Thus, in late summer or early autumn of the second or third year following the first fire, the stems may be leveled to the ground by dragging a log over the area with a tractor.[28] This method of leveling the stems has been employed successfully by several operators. After the dragging operation, the area is reburned. With ample dry fuel this second fire consumes the old stems and snags, as well as the young brush seedlings, and favors further invasions of herbaceous plants.

The success of the reburning operation depends essentially upon the growth habits of the brush. One hot second fire, or follow-up burn, may transform what was formerly a well-nigh useless *nonsprouting* brush area to a fairly permanent cover of herbaceous vegetation. Far less satisfactory results are obtained on areas which support *sprouting* forms of brush; few of the plant crowns are killed by the burning, and sprouting continues. Also additional brush seedlings come in after the second burn. Unless the brush seedlings and sprouts are kept closely browsed, as they seldom are, the chaparral soon recaptures the area at the expense of the herbaceous plants. Since livestock, particularly cattle, mostly consume only the herbs, the brush is favored in survival.

Overstocking with cattle or sheep to kill sprouts and brush seedlings is sometimes resorted to for two to three years after burning. This practice, however, except where goats are used, has generally resulted in failure to destroy the brush, except in nonsprouting cover, where heavy, continuous browsing may eventually destroy all but the less palatable chaparral seedlings. Unfortunately very heavy grazing by cattle and sheep also results in destruction or thinning of the grass, and often favors invasions of such unpalatable plants as tarweed, the buckwheats, Napa star thistle, and turkey-mullein, over that of the choicer forage species. Moreover, losses of stock from consuming poisonous plants, and damage of soil erosion on the steeper slopes, have been noted.

[28] The cost of leveling charred stems is about 50 cents per acre, where a stockman uses his own equipment to drag a log about 16 feet long by 14 to 16 inches in diameter across the burned areas.

Rotation Burning.—Ranch owners who favor somewhat regular burning of their brush fields, and whose properties are so situated that the chaparral lands constitute an integral and essential part of the grazing unit, should have a burn as young as possible available each year in order to procure maximum forage from those areas. On productive lands burning of the entire brushfield in one fire might provide more seasonal forage than could be utilized to advantage. Following this period of lush growth there would be several seasons of limited growth of forage while the brush is reclaiming the land, and while it is too diminutive to reburn.

In order to derive the greatest sustained benefit and return from burning brush areas, one may adopt a rotation plan of broadcast burning. Provided water for the stock is available, the brush field should be divided into units which may be systematically burned at intervals of eight to ten years. Such a plan is illustrated below, in which the area, growing the sprouting kinds of brush, is divided into three units, each of which would be burned at intervals of nine years.

YEAR	UNIT 1	UNIT 2	UNIT 3
1943	Burned	Not burned	Not burned
1944	Not burned	Not burned	Not burned
1945	Not burned	Not burned	Not burned
1946	Not burned	Burned	Not burned
1947	Not burned	Not burned	Not burned
1948	Not burned	Not burned	Not burned
1949	Not burned	Not burned	Burned
1950	Not burned	Not burned	Not burned
1951	Not burned	Not burned	Not burned
1952	Burned	Not burned	Not burned
1953	Not burned	Not burned	Not burned

Unit 1, or approximately one third of the brush field, is selected for broadcast burning in 1943. This portion must be relied upon to furnish most of the forage of the brush area during 1944, 1945, and 1946. In 1946, unit 2 is burned. Thus, in 1947, unit 1 should furnish some pasturage, whereas unit 2 should produce a relatively large amount of forage. In 1949 unit 3 is burned; hence in 1950 unit 2 should still be producing some forage, although the major pasture use would be expected from unit 3. In 1952 the burning rotation starts all over again, since in the intervening nine years enough brush growth will have taken place on unit 1 for effective reburning.

A plan of rotation burning, such as proposed, must not be construed as a method of ridding an area of sprouting brush and permanently replacing it with grass. Within about five years after burning, the brush may have reoccupied the area even more densely than before burning. In the interim, however, there should have been an increase of palatable forage for a period of two to four years, perhaps without excessive cost to the operator.

Cost of Broadcast Burning.—Actual cash outlay by landowners for broadcast burning of brush fields is usually small, partly because they use rancher coöperative help during the actual burning. Most of the labor involved consists of building fire breaks prior to burning. From 7 to 12 men, according to the control necessary, are generally adequate to burn an area of about 100 acres.

Prior to burning, the cost for construction of the necessary fire breaks, as directed by the state forest ranger, varies from about 25 cents to 85 cents an acre—the cost depending on topography, natural barriers, character of borderland areas, season, kind of brush, and the type of adjoining lands that must be protected from fire. The range in cost of broadcast burning is illustrated by two cases given below; the data were furnished by the State Division of Forestry.

Case 1. White Cottage Ranch, Napa County; cost of burning standing chaparral on a 100-acre area:

	Per 100 acres	Per acre
Construction of fire lines, 2 men at 35 cents an hour, 4 days of 8 hours each	$ 22.40	.....
Actual control time, 5 men at 35 cents an hour, 3 days of 12 hours each	63.00	.....
Cost per acre to stockman	.....	$0.85
State Fire Control man, 5 days at $130 per month	21.65	.....
Travel expense and car	20.00	.....
Cost per acre ot state	.....	0.42
Total costs	$127.05	$1.27

Case 2. Linser Ranch, Napa County; cost of burning standing chaparral on a 150-acre area:

	Per 150 acres	Per acre
Construction of fire lines	$ 0.00	.....
Actual control time, 3 men at 35 cents an hour, 3 days of 12 hours each	37.80	.....
Cost per acre to stockman	.....	$0.25
State Fire Control man, 5 days at $130 per month	21.65	.....
Travel expense and car	20.00	.....
Cost per acre to state	.....	0.28
Total costs	$79.45	$0.53

The rancher must pay all expenses incurred in burning, except those of the special fire-control man, who is paid by the state.

Although the Linser area was 50 per cent larger than the other, the total cost to the stockman of burning the area was less than half that for the smaller one. This difference in cost was due to variations in natural conditions, such as character of cover, topography, burning weather, natural barriers, and season of the year. The last two factors directly affected the labor expenditure for firebreaks and for fire control.

The two examples, as indicated, show that the cost depends largely upon local conditions and that each proposed burn presents specific problems. Hence no set rule or formula to compute cost can be set down which will cover all cases. In the two extreme cases cited, the total average cost of burning would be 90 cents per acre, of which the cost to the owner would be 55 cents per acre.

REMOVAL OF BRUSH AND TREE GROWTH BY METHODS OTHER THAN BROADCAST BURNING

Scattered throughout the oak-woodland and chaparral associations are some areas of deep soils which are *much above average* in productivity. Necessary administrative restrictions by the state on season and locality of broadcast burning, as well as the risk of such burning, have resulted in the initiation of various fire-safe methods by ranchers for removing the brush from these better lands. Where areas are being cleared for a specific form of cultivation, the initial cost of the removal of the brush is often a relatively small factor as com-

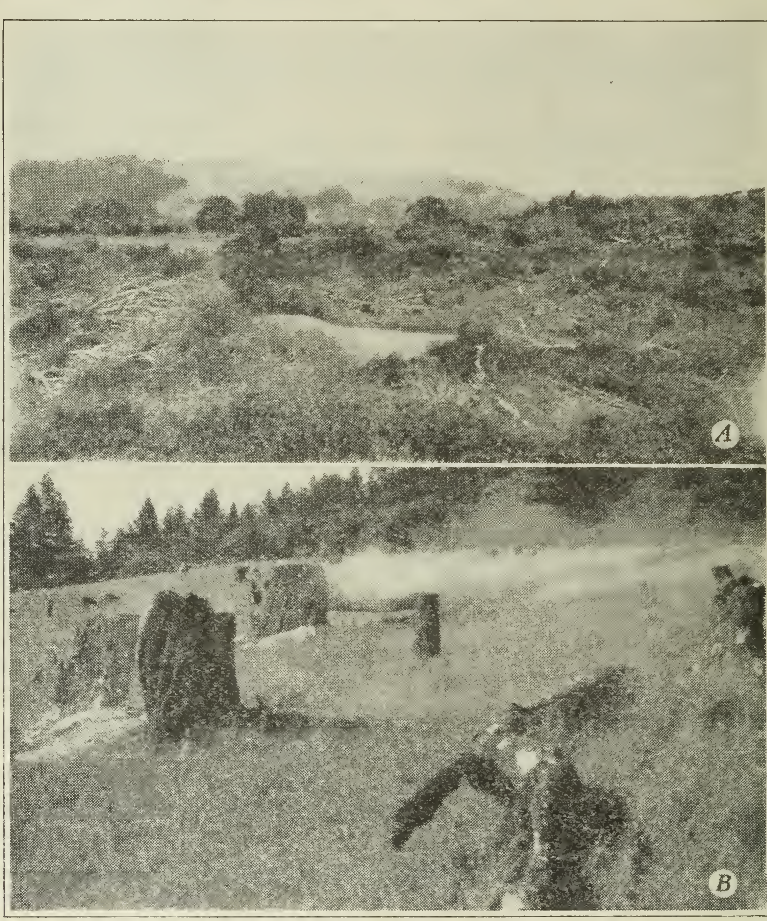

Fig. 40.—*A*, Interior live oak felled in winter and permitted to dry until autumn, when the area was burned. *B*, Oak stumps on part of area shown in *A*, in process of removal by further burning. Natural grass cover was more than doubled by this clearing process. Mendocino County.

pared with the returns subsequently obtained from the land. When permanently cleared of the brush and tree growth, such areas become a highly important and continuously reliable asset to the owner. But where brush is removed merely to increase the grazing capacity, and the land is not to be cultivated, the cost of clearing is speculative. In any case, however, such cost must not be disproportionate to the value of the land. Clearing methods which are in fairly common use are still in the developmental stage, and are

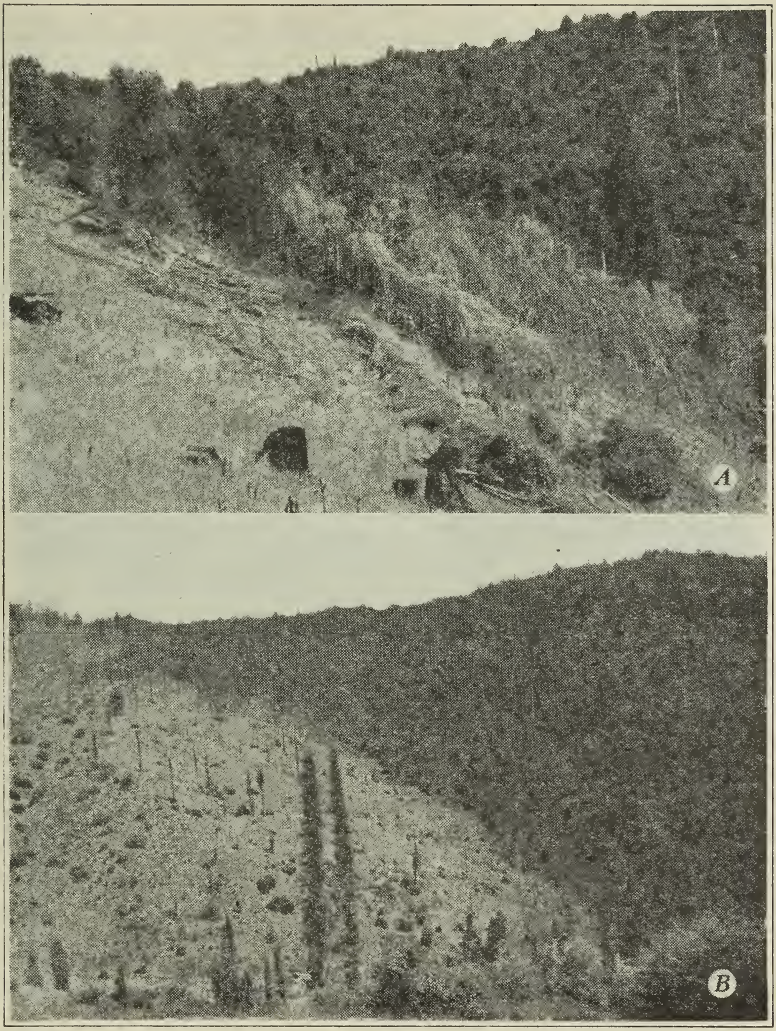

Fig. 41.—Redwood slope logged off, followed by heavy growth of blue blossom and redwood sprouts, which must be chopped and burned if area is to be opened up. *A,* At left is shown the lopped and burned portion, with good grass cover; at right, a charred tangle of brush is left standing after broadcast burning. *B,* Area temporarily cleared by chopping and burning, at a cost of about $10 an acre. After burning the lopped, dry brush late in the autumn, the area was heavily seeded to redtop, perennial ryegrass, smilo, orchard grass, and common yellow mustard. A good stand of these plants was procured the first year after seeding, but in the third season the introduced plants had almost completely given way to annual grasses and weeds. Coastal region, Mendocino County.

based more upon initial cost of removal of the brush than upon long-time returns from the cleared lands. Brush-disposal practices, other than by broadcast burning, may be grouped under three headings: hand methods, mechanical methods, and biological methods.

Hand Methods.—Hand methods include lopping, cutting, and girdling of brush and trees. One or more of these operations may be used in conjunction with burning, and are frequently an essential part of the other methods described later.

Lopping[29]: This procedure is too expensive for general use on dense chaparral lands. Even on oak-woodland areas the cost of lopping is prohibitive, except where the soil is unusually fertile, as oak brush can seldom be cleared for less than about $20.00 per acre (fig. 40). On logged redwood lands, however, the common blue blossom can be lopped at a cost of $7.00 to $10.00 an acre. After lopping, the blue blossom brush is allowed to dry until autumn, when it is burned. The large numbers of young lush seedlings of this species

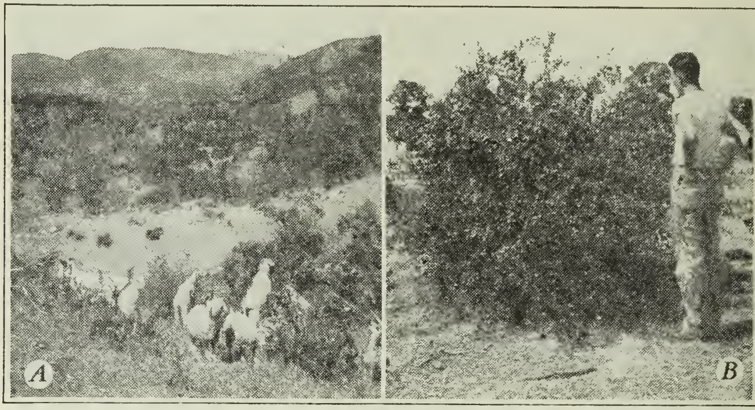

Fig. 42.—*A*, Angora goats in grass-woodland cover feeding upon brush of ceanothus, manzanita, and wild rose. The central grassy portion of the area formerly supported a heavy brush stand, but the goats killed sprouts and seedlings after the bushes were chopped and burned. Tehama County. *B*, Two-year-old sprouts from a stump of interior live oak. Such sprouts are killed by continuous close browsing by goats. Live-oak sprouts are harder to kill than those of other oaks, and must be cut back if they get beyond reach of the goats. El Dorado County.

which come in after burning furnish superior browse for sheep and goats for two seasons (fig. 41).

In order to kill all the sprouting species of brush, the suckers must be cut back every year or two. As many as three to five cuttings of the sprouts may be required before all the oak, or sprouting chaparral, is killed. Despite the high cost, the subsequent removal of the sprouts is a necessary supplement to other clearing methods.

Cutting[30]: On many oak-woodland areas, oak trees are cut for commercial fuel in conjunction with clearing of the land. Following the initial cutting, spring sucker growth must be kept down by hand-cutting, or by close browsing by goats (fig. 42). Wooded areas located near a favorable market yield an average of $1.50 to $2.00 per cord stumpage, and usually yield from one to

[29] Lopping, as here used, refers to the removal of brush and small trees by chopping at or near the ground level.

[30] Cutting is a term used to designate the felling of trees of commercial size by sawing or chopping or both.

three cords of wood per acre. Provided fencing is already adequate, the owner can also make a small profit, or he can at least break even, by pasturing goats on the sprouts. Even the expense of fencing may be offset by the sale of wood. Fuel wood sells for about $8.00 per cord in the field (fig. 43).

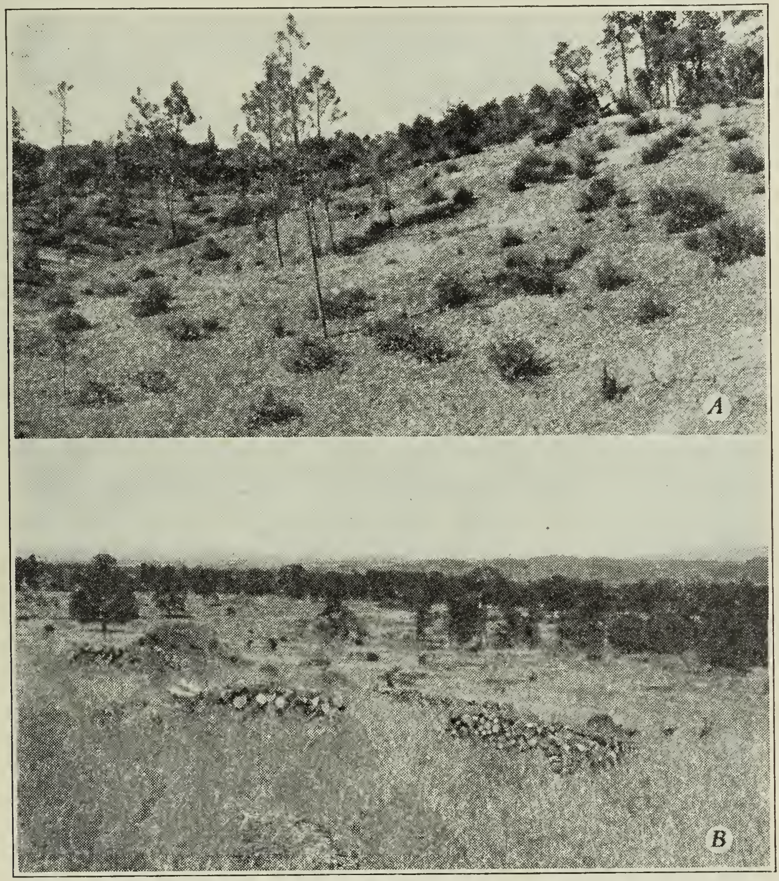

Fig. 43.—*A*, An area cleared by cutting oak for fuel wood. The land will be covered with oak brush in five or six years if sprouts are not controlled. Goats confined to this area would kill the sprouts in approximately three years. *B*, Oak woodland in the process of being cleared by cutting and goat-browsing. Note the shade trees in the background. There is a dense stand of California melic grass in the foreground. The ricked wood is to be sold. Sprouting stumps in the background will be killed by goat-browsing. El Dorado County.

Girdling: This method is used for disposing of trees, or patches of timber on productive lands, with a minimum of expense. Girdling is a relatively inexpensive method, where it is not the aim to salvage the wood for fuel, posts, or other purposes. Moreover, after girdling the live-oak trees sprout much less than after burning or cutting.

Digger pine is the only conifer girdled to any extent in the foothills for land-clearing purposes, but occasionally Douglas-fir and redwood are so treated. Girdling of conifers is done with an ordinary ax, in the spring of the year when the "sap is flowing." The trees usually die in one or two years, and fall to the ground in three or four years after girdling, following which the refuse is burned on the ground.

The chief advantage of girdling oak trees in a land-clearing operation, as indicated, is to prevent extensive sprouting after removal of the top growth. Not more than about 10 per cent of older live oak trees sprout after being girdled, whereas most of the stumps sprout when the trees are merely felled. In contrast, about 50 per cent of the young live oak trees sprout after girdling, about 5 per cent of the younger white oaks sprout, and it is a rarity to find a mature white oak which sprouts after girdling. Oak trees are girdled by ham-

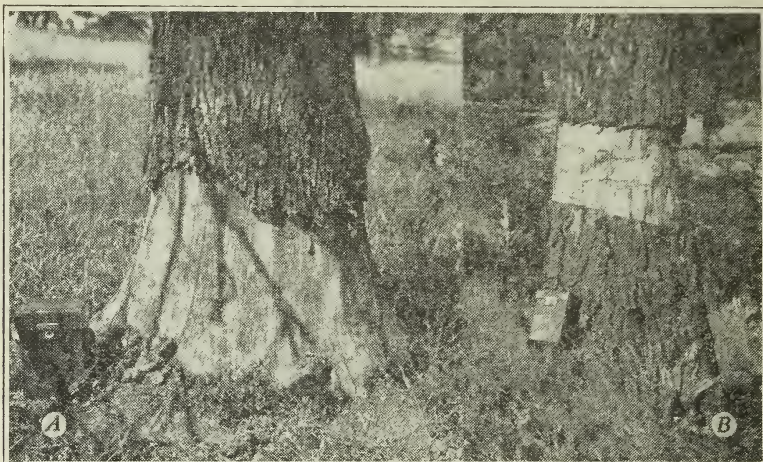

Fig. 44.—*A*, Girdled blue oak, showing how the bark is broken away from the base of the tree with a poleax. One man can girdle 125 to 150 trees in a single day. *B*, Digger pine girdled with an ax. Trees thus girdled die and fall to the ground within three years. The wood of Digger pine is valueless; unwanted trees are easily disposed of in this way. Amador County.

mering away the bark 12 to 16 inches above the base of the tree with the back of a poleax (fig. 44). The initial cost of girdling oak lands of average stand amounts to about $5.00 per acre. With stands of smaller trees, additional work must be undertaken on the area each season until all the sprouts are killed. The individual trees die in one to three years after girdling—most of them the first year—and topple over in four to six years. Since the wood of fallen trees is hard and tough, burning during low-fire-risk periods is recommended for their disposal. If fires are run over the area about three times at two-year intervals after girdling, many of the oak sprouts are killed, and the period required for the trees to fall to the ground is shortened.

Mechanical Methods.—Mechanical methods are those concerned with removal of brush by machinery. Two rather widely adopted brush-removing practices, both involving the use of a caterpillar tractor, are outlined below.

Bulldozing: This method involves the use of a bulldozing blade fastened to a caterpillar. It can be used on lands up to about 30 per cent gradient. Nearly all kinds of brush, as well as oak and pine trees up to about 8 inches in diameter, can be removed. The initial cost of clearing chamise lands in this way, in normal times, averages around $3.50 per acre; for bulldozing out heavy stands of oak brush and trees the cost is much higher. The work is usually done in the

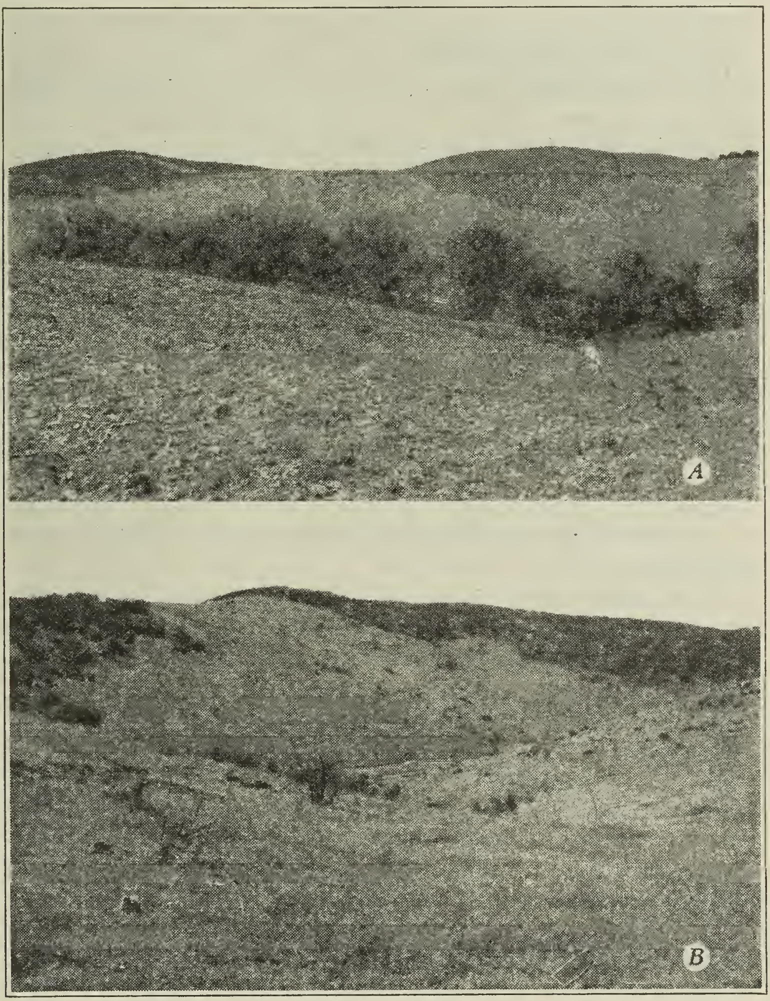

Fig. 45.—*A*, Heavy chamise stand bulldozed and plowed after seed of the brush had germinated. *B*, Area treated two years previously as indicated in *A*. The volunteer cover consists of annual grasses and weeds of fair to good forage value. Amador County.

spring when the subsoil is moist enough to afford minimum root resistance, but when the ground has become dry enough to give traction for the caterpillar. The method has sometimes had a disturbing influence upon the soil on hilly land, resulting in erosion. In later operations the soil is plowed or disked; erosion loss may be prevented by plowing hilly lands along the contour. The contour furrows also kill the older remaining brush plants by exposing the root crowns, and also kill many chaparral seedlings (fig. 45). The additional cost of plowing and removal of suckers is about $3.00 an acre, making the total cost about $6.50 per acre. Occasionally there is some sprouting after bulldozing where the stand of brush is heavy, or where the root crowns are not removed. A limited amount of hand work with an adz will usually eliminate such young sprouts and root suckers.

Caterpillar-cable method: This less popular method involves the use of 50 to 75 feet of heavy cable, fastened to the tractor as a dragline. The free end of the cable is hooked around a clump of brush, and as tension is applied by the forward movement of the tractor, the brush is pulled out by the roots. This method works well in heavy stands of manzanita, but it is usually more expensive than bulldozing. Where larger brush is eradicated by this method, the disturbing influence upon the soil is sometimes severe since the earth is deeply gouged as the caterpillar gains traction.

In the mechanical methods described, the brush is windrowed or dragged into large piles, allowed to dry, and burned after the serious fire season has passed.

Biological Methods.—Brush clearing by so-called "biological" methods is essentially concerned with destruction of sprouts and woody seedlings after the cover has been lopped, chopped, or burned broadcast. Goats, and to a less extent deer, are the most effective animals used in killing interior live oak, which is common to the extensive woodland-grass area, and certain other chaparral plants.

Clearing by goats: When sprouts of interior live oak begin to appear, after cutting or burning, goats are placed on the area, the aim being to keep the young shoots and seedlings browsed down. The browsing must be heavy enough to prevent the sprouts from getting out of reach of the animals. Thus the goats are restricted to relatively small areas, usually by fencing. In order to destroy the oak sprouts, some areas require three goats to the acre the year round, and others as low as one goat on 2 acres, for the first two years after cutting. In the third and subsequent seasons larger acreage per animal is required to maintain the goats in fairly good condition, for the vegetation gradually changes from a browse cover to one of grass. The lands must be continuously stocked to the full capacity of the browse, usually for three to five years; otherwise only a portion of the sprouting growth will be destroyed.

If the area to be cleared is not fenced to assure adequate browsing by the goats, or if the animals are not properly cared for, the owner may receive no direct profit from them, yet he will gain through destruction of some of the brush. True, the construction of goat-proof fence is costly. If the cost of fencing is not taken into consideration, $0.75 to $2.00 profit a year on each nanny, while clearing the brush, may be realized. Profit from goats, however, is likely to be low when the time required to take care of the kids is considered; a kid crop entails about three times more work than does a lamb crop. The investment in goats, in the necessary permanent improvements, and in fences, makes for fairly high initial clearing costs by this method, but records show it has paid well on fairly productive areas.

Goats are partial to young sprouts of interior live oak, and to wedgeleaf ceanothus, which commonly grow in combination in the woodland-grass association; they prefer this browse to that of many other chaparral species. They will, however, feed upon young sprouts of many other brush species, such as chamise, lemmon ceanothus, poison oak, and manzanita, where there is limited live oak; but these plants are not browsed close enough to be killed unless the goats are starved to feed upon them.

Clearing by deer: Young chaparral sprouts and seedlings on small burned areas may be so heavily browsed by deer as to be destroyed in two or three seasons. The burns must be small enough to encourage complete utilization of all the new woody growth. Under such close cropping, the leaves of chamise, one of the most vigorously sprouting forms, grow stemless over the root crown after the first year, and may be completely eliminated by the end of the second year. Larger burns, which do not compel such concentrated deer browsing. fail to result in clearings. The experience of one Lake County stockman indicated that burns of about 6 acres were the maximum which could be cleared by deer on his ranch; 4 to 5 acres were more likely to be cleared. The density of deer populations chiefly determines the maximum practical size of clearing in different regions. Only on choice sites may heavy grass stands be expected to replace the brush killed out by the deer.

The higher moisture content of repeatedly browsed and regenerating sprouts and seedlings on burns, associated with relatively low crude-fiber content, and high crude-protein levels, as revealed by chemical analysis, might seem to be reasons why deer browse these small burns so much more closely than the contiguous unburned chaparral.

COMPARISON OF BRUSH-REMOVAL METHODS

The advisability of using any one specific brush-clearing method is limited by so many different factors and conditions that only general recommendations can be made. On steep slopes, total removal of brush by any method, followed by close grazing or cultivation, is usually not advisable because of the danger of excessive erosion. Even on moderately steep slopes, the mechanical methods are not applicable because of difficulties of manipulation, and the danger of soil loss. On the gentle slopes the method most adaptable depends upon a number of other conditions. Cutting or chopping should precede use of the area by goats, but these methods are tedious and fairly expensive; therefore they are applicable only on the better lands.

Heavy broadcast burning, although entailing fire risk, is the least expensive in temporarily opening up the dense stands of sprouting forms of brush; but the benefits derived seldom exceed a duration of about three to four years. A rotation-burning plan, in which advantage is taken of the temporary influx of herbaceous plants, is useful on areas of *sprouting* brush, if they are to be used more or less regularly for grazing. On *nonsprouting* brush areas a two-year burning plan, with little or no grazing during that period, is usually effective in converting the brush cover to grassland.

Where dense chaparral, or oak browse, occupies soils of high quality, one of the mechanical methods described above is useful, as the brush is immediately and almost completely eliminated, and is followed by strong successions of grasses of fairly high carrying capacity. Care must be taken, however, to furrow on the contour in order to avoid excessive soil loss by erosion, and to destroy the brush seedlings.

In localities of heavy deer population, close browsing by these animals is effective in eliminating sprouting brush from small burns. Four to 6 acres has been effectively cleared in a few localities of heavy deer population by this means.

In the adoption of any method of clearing, it is important to weigh probable returns against the costs. Areas of steep, rocky, and thin soils are wholly unsuitable for mechanical clearing effort, or even for the less expensive broadcast burning. Only highly productive sites should be considered in complete mechanical clearing. On such sites, broadcast burning, with the hope of only two to four years of increased forage, may be less practical in the long run than the use of one of the more expensive but more permanent mechanical or biological methods described.

COMPARATIVE GRAZING VALUES OF DIFFERENT BRUSH COVERS

Relative Forage Values.—Some forms of burned brush stands are clearly superior to others for grazing purposes. Although the relative palatability of the different kinds and combinations of brush merits consideration, other factors may have greater weight in determining the usability of the brush fields.

The nonsprouting stands of chaparral, restricted in area but generally fairly accessible, with relatively few exceptions have productive soils, and clearly rank first in value among the brush stands, in that they give much the best immediate and permanent results after broadcast burning. The purest and most extensive stands of nonsprouting hard brush occur typically in the lower margins of cutover and burned timberlands, and in the upper stretches of the grassland zone below the timber. Conversion of such lands to a volunteer grass cover is relatively simple and inexpensive. After destruction of the brush by burning, the grass cover soon becomes abundant, and is generally composed of a number of the better annual grasses and broad-leaved herbs, with some scattered perennials.

The association of interior live oak and blue oak ranks second in forage value after cutting, girdling, or burning. Since this cover is also generally accessible, it is useful for grazing during fall, winter, and spring. The productivity of these lands is fairly high, and may be judged in advance by the luxuriance of the tree growth. After the removal of the trees and the destruction of the sprouts (p. 71) a permanent, dense, and high-yielding grass cover usually comes in. A carrying capacity of 10 to 20 acres per cow unit for the grazing season of about 8 months is not exceptional on cleared lands in this association. The grazing capacity of many such oak lands has been more than doubled by removal of all but desirable shade trees, and by destruction of the Oak sprouts.

Chamise and other sprouting chaparral covers, which comprise by far the most extensive part of the chaparral association, are of third rank. Of these lands the more or less pure chamise has an even lower rating than the mixed sprouting chaparral cover. When mixed chaparral stands on moderately fertile soils are burned, they usually produce a somewhat larger amount, and greater variety, of herbaceous growth than do those of chamise; and the assortment of browse is more palatable when young.

The extensive, poorer chaparral and chamise lands leave little in the way of choice. It is the burning of these inferior, sprouting chaparral areas that accounts for much of the adverse opinion concerning the value of brush burning or mechanical clearing. These covers occupy the more rugged lands of the chaparral association, which, generally considered, embraces the most inferior soils found in the foothill regions of the state. Much of the area supporting these covers is relatively inaccessible to livestock. So inferior are many of these lands that removal of the brush by mechanical devices, or even leveling the unburned stems in order to dispose of them by burning a second time, is not justified.

The soil types of some of the more extensive brush-covered areas appear to influence the results obtained by burning. The Aiken soil series, for example, often referred to as "the red soil," is among the most extensive and the least productive of the soil series in the northern counties of the state. In the intermediate to more elevated lands of the foothill belt this soil type is often occupied by chamise. A large proportion of these lands, burned or unburned, is of low value for grazing, a fact which many stockmen have come to recognize through experience. The old unburned stands found on these soils contain almost no understory cover, and when burned they frequently produce but little herbaceous vegetation of good forage quality. Two to three years of inferior grazing is about all that can be expected after burning such areas; they are clearly submarginal for grazing purposes.

Utilization by Cattle, Sheep, and Goats.—Cattle forage upon a large variety of herbaceous plants common to burned chaparral areas after adapting themselves to this vegetation. They show strong preference for the young grass, but species of such plants as filaree, lotus, mustard, white hawkweed, and several others are taken throughout the grazing period. Early in the season, common soap-plant, woolly-yarrow, California figwort, Napa star thistle, and a fair number of other such broad-leaved herbs are closely cropped, these being taken with a small proportion of the young chamise, sprouting manzanitas, and other such chaparral sprouts. Later in the season, young shoots of California buckeye, ceanothus, interior live oak, California scrub oak, poison oak, and western mountain-mahogany are also browsed. On unburned chaparral lands cattle are inclined to feed upon the browse at an earlier date than on the burned areas, presumably because of the lesser abundance of understory herbs.

Sheep feed upon a combined diet of grasses, broad-leaved herbs, and browse, throughout the grazing season, and thus utilize more fully the vegetation of burned chaparral areas than do cattle. Also sheep seem to have less seasonal preference for forage and browse than do cattle; they feed upon a large variety of early-season chaparral sprouts and seedlings, including chamise and broad-leaved herbs. In some instances sheep have been observed to maintain themselves in good condition on burned areas where cattle have been restless and in poor condition because of unsuitable forage. And where many coarse stems are left on an area after burning, sheep seem to make better use of the forage than do cattle.

Although goats browse extensively upon chamise and sprouting chaparral lands after broadcast burning, in only a few instances do these animals destroy the brush, except around small camp sites or on holding grounds. Several factors account for the failure to destroy the brush, foremost of which is the fact that owners of large bands of goats must keep the animals in good condition if satisfactory returns are to be obtained. For this reason, the goats are not held overlong on burned areas, but are moved to fresh areas before the browse of any one portion is closely cropped. Moreover, burned chaparral lands are suitable for goats, as they are for other kinds of livestock, only during the period when the sprouts are young and succulent. One peculiarity in the utilization of the sprouts of hard brush by goats is that most of this vegetation becomes unpalatable to these animals at a specific growth stage. In feeding on chamise, for example, the goats strip the young sprouts of their leaf fascicles with some eagerness for several weeks in the spring. As this vegetation hardens slightly, in April in Tehama and Shasta counties, an entire band of goats, within a day or two, completely loses appetite for this browse, and tends to travel extensively, apparently in search of other feed. The herd must then be removed to a different form of vegetation or the gains, or good condition previously attained on the area, will be lost. In about 2 weeks after removal of the goats, the browsed chamise bushes are refoliated, thus recuperating their vigor. This sudden lack of appetite for chamise also applies to several other species of chaparral, but not to the live oak and white oak cover, which is browsed with gusto throughout the season.

Poisonous Plants.—The marked influx of such poisonous plants as larkspur and death camas, following burning in some areas, is important in considering forage values on burns. The danger is so great in some localities that stockmen decline to place their stock, especially sheep, on brush areas until the second or third year after burning. Experience has taught them that this delayed use is necessary to avoid heavy losses from poisoning.

Obviously, not all chaparral areas contain large numbers of poisonous plants. Because of early maturity of the forage, and its marked inferiority at later growth stages, however, there is a tendency to place the animals on burned brush areas too early in the season. Some species of poisonous plants are known to be several times more toxic in the very early growth stage than later. Some such species are among the earliest to appear in the spring; therefore, in the absence of ample, wholesome, early forage, toxic or lethal amounts of poisonous plants may be taken. Larkspur, for example, has been reported to be three to ten times more toxic to cattle in the early leaf stage than when in flower, and as much as sixteen times more toxic than when in the late fruit stage (*89*). Some cattlemen have wisely used the flowering stage of larkspur as a guide in determining when to admit cattle on burned areas. Accordingly, some burned brush areas afford safe and satisfactory pasturage for only about 4 to 6 weeks in the late spring. Even so short a period of use, however, is of value under many circumstances, for the brushland pasturage may tide over a period until better forage is available elsewhere.

Not only are the early weeks of the spring period dangerous in some localities, but losses to sheep from feeding upon death camas may be somewhat serious throughout the season. Other poisonous plants may cause losses to cattle. In one authenticated instance an operator in Shasta County placed

1,000 cattle of various ages, and of both sexes, on a chamise area burned the previous fall. Fifty-three of these animals, including both old and young individuals, died mainly from larkspur poisoning during early spring, and many

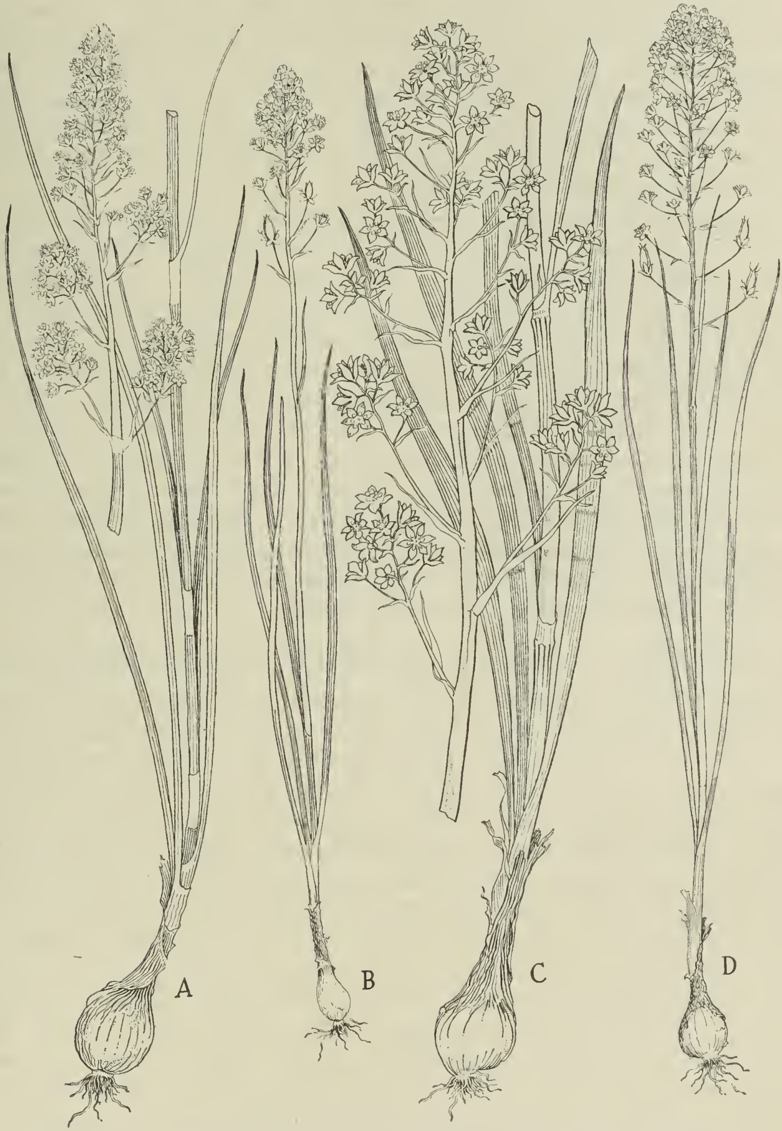

Fig. 46.—*A*, Foothill death camas; *B*, Meadow death camas; C, Fremont death camas; *D*, small-meadow death camas.

others recovered from poison sickness. This operator placed no cattle on the area in the following seasons.

Although the toxicity of some poisonous plants, such as death camas, varies little with the season, seasonal change differs between species (*65, 66*). Different parts of the plant also vary in toxicity.

Death camas is widespread in distribution; one or more species may appear among the earliest plants on burned areas in northern California. The various species of these plants differ markedly in their poisonous properties. The large-flowered forms, such as Fremont death camas (fig. 46), with relatively few flowers on an open stalk, are far less toxic than the small-flowered forms, such as meadow, foothill, and small meadow death camas (fig. 46, *a, b,* and *d*). The latter have numerous small flowers, more or less congested into a pyramidal inflorescence at the apex of the stem. The greater part of all losses of sheep from these species in California, and in fact throughout the West, is caused by some form of the meadow death camas.

Summary of Grazing Values.—Cattle feed only limitedly upon species of chaparral, unless forced by hunger to do so. Usually cattle are not maintained in good condition on brush fields unless there is a fair abundance of grass. Sheep, on the other hand, feed throughout the spring and early summer on a combination of herbs and young chaparral browse. They can often be maintained in good condition on brush areas which are unsatisfactory for cattle. Goats may be maintained upon sprouting chaparral and chamise during the first two years after burning. They are not nearly so effective in clearing the hard brush cover, however, as they are in destroying sprouts of live oak and associated browse plants, since they will only feed for a part of the spring period upon sprouts of chaparral and chamise. During the season of non-palatability, the brush regains its vigor. In some localities poisonous plants are so abundant on newly burned areas that the increased forage produced may be offset by losses and sickness of the stock.

EFFECT OF FIRE ON WILDLIFE AND RECREATION

Wildlife and, to a lesser extent, recreation sites are of importance in some chaparral areas. Considering the general increase in hunting and outdoor life the public in the future is likely to place more value on these resources. Since fire may greatly influence the animal numbers and recreational land values, the more pertinent data on the effects of brush burning are here presented.

Effect on Small Mammals.—Various small mammals suffer temporary population reduction from the effects of fire because of the nature of the habitats which they occupy. Tree squirrels and other tree and brush dwellers, for example, are reduced in numbers during large conflagrations because they instinctively dash to their homes for protection; naturally such burned areas are not restocked by these animals until the taller vegetation has been re-established (*63, 84, 85*). On the other hand, the destruction by fire of the smaller mammals which dwell on the surface is mostly temporary (except rabbits, whose population remains low for several years), for enough animals escape the fire to provide a breeding nucleus (*61, 62*). Moreover, the natural succession of annual vegetation following burning usually provides an improved habitat for the rapid breeding of most surface dwellers during the following few years (*24*). Animals that burrow, such as ground squirrels, gophers, badgers, and some species of mice are little harmed directly by fire (*43, 85*). Thus Horn,[31] working on experimental chaparral burns in northern California,

[31] Unpublished data. E. E. Horn, U. S. Fish and Wildlife Service. University of California, Berkeley.

found by actual trapping records covering several successive years, that mice and squirrels soon reached higher populations on the burned areas than occurred on adjoining unburned plots. Usually enough food was found to remain on newly burned chaparral lands to support the surviving mammals. The food supply of those rodents that go into summer and autumn dormancy underground, such as various small ground squirrels, are not immediately affected by fire, since they do not emerge until a new crop of vegetation is available.

Since the larger predators, such as coyote and fox, are relatively mobile, they are little affected by fire unless extensive areas are burned. These creatures temporarily move to adjacent food sources of unburned areas, but return when their prey increases.

The destruction of small mammals has a secondary detrimental effect on carnivorous fur-bearing animals. Many such mammals may escape the direct effect of the fire, but the reduction of their food supply, notably that of the rodents, causes the fur-bearers to starve after large fires. Where the acreage burned is small these animals migrate to more favorable adjoining habitats (*63*).

Effect on Deer Population.—Extensive fires are known to kill many deer, whereas small fires are more often beneficial than harmful. Although only limited data are available to show the effect of extensive chaparral fires on deer, reports indicate that the direct kill due to large fires is often great. After the 1928 Cahuila fire, for example, 300 deer carcasses were found on a relatively small area (*92*); and the Anderson Valley fire caused the death of 59 deer on 212 acres.[32] Loss of forage for deer is often a serious indirect effect immediately after large fires. California deer are more or less dependent upon the lower chaparral areas as a source of food during the winter,[33] these lands being a limiting factor on some deer ranges. Fires occurring on these critical areas aggravate overgrazing by, and starvation of, deer.

Evidence indicates, on the other hand, that small fires are generally not harmful to deer. The agility of these animals allows them to leave burns of a few acres without being injured. Furthermore, according to Horn (*43*), these animals usually return to burned brush areas the following year to feed upon sprouting chaparral and other succulent feed. In northern California the writer noted on many occasions that deer fed extensively upon the young chaparral sprout growth.

Special chemical studies of browse samples have revealed that the nutritional level of chaparral may be somewhat extended by encouraging the growth of crown sprouts, especially where such regeneration growth is kept closely browsed down. Just how this finding may be applied to deer management plans on intensively used areas in the state is yet to be determined. Removal of the top growth on small, relatively level areas, by carefully controlled burning, or in some other way, might, perhaps, be instituted without serious deterioration of the site.

[32] Report to the writer from J. R. Hall, Forest Supervisor, Stanislaus National Forest, California.

[33] Conference of writer with Ivan Sack, in charge of Fish and Game Management, Region 5, U. S. Forest Service, San Francisco, California, 1939.

The attraction of deer to fresh burns was known to the Indians, who evidently burned small areas in order to localize deer for hunting purposes. Small burns are usually intensively browsed because of the adjoining protective cover and the relatively high palatability of the chaparral sprouts. The concentration of deer on small burned areas is often so acute as to cause excessive killing or poaching, and may necessitate closed seasons and strict supervision (*45, 109, 110*).

The attraction of deer to recently burned areas has received some attention as a means of diverting these animals from agricultural lands. However, a survey of the observations of ranchers who have practiced brush burning showed that deer move to lower elevations at certain periods in the winter regardless of the treatment of the brushlands, and that cereal crops, cultivated pastures, and vines are preferred to chaparral, whether the latter has been burned or not.

Influence on Bird Life.—Game birds are killed in large numbers by fire, and their nests, cover, and food may be largely destroyed (*101, 102*). Clarke (*17*) noted that three or four years elapsed before pre-fire numbers of birds occurred again on the burned areas studied.

The direct kill of game birds by fire has been severe in parts of California. In 1928, for example, more than 4,000 quail were lost in relatively large, rapidly moving brush fires in southern California; and a 12,000-acre fire in Yolo County accounted for the death of approximately 3,000 quail (*108*). The destruction of food and cover by fires is also noteworthy. Stoddard (*102*) has shown that burning of grass of the previous years' growth is unfavorable to the building of quail nests. Leopold (*61, 62*) noted the need of luxuriant vegetation for nests in the spring, and for food and cover in fall and winter.

Small, controlled fires, where burning is done at the proper season, appear to be beneficial in some areas, in intensive quail management. Schierbeck (*92*) noted the dependence of some forms of wildlife on food plants produced on burns. Stoddard (*102*) observed that carefully controlled, small fires on some areas in the South are favorable to the propagation of the bobwhite. Sumner (*104*) also concluded that burning of patches of an acre or so of brush is beneficial to the quail population in California. The aim should be to spot-burn small areas where suitable food plants may supplement the spring and winter quail feed. The adjacent thickets serve as protective cover. Such restricted burning, however, is expensive since the operation must be carried out under careful planning and absolute control.

Secondary Effects on Fish.—Consideration of the essentials of a good fishing stream, and the reactions imposed upon it by a fire, seems important since a number of fishing streams head in or pass through the chaparral areas. Pearse (*73*) has mentioned various requisites of a fish stream, some of which may be adversely affected by burning, namely: ample, prolific stream-bank vegetation; range in temperature suitable to the species of fish concerned; sufficient oxygen to support aquatic life, without excess of carbon dioxide; water relatively free of suspended silt, ash, and dissolved impurities; and acidity relations which are not beyond the range of endurance of the fish.

By destruction of stream-bank vegetation, fire reduces the insect supply normally inhabiting this vegetation; and it also affects indirectly temperature and oxygen relations (*76*). Rise in temperature reduces the dissolved gases in the water and upsets the oxygen balance. The increased supply of organic matter carried into the streams after a fire, undergoes decomposition and thus reduces the oxygen content of the water (*19*). Fish are less able to withstand a decreased oxygen supply in alkaline water (*116*). A hot, extensive fire on a watershed, followed by rains and heavy runoff, may carry such quantities of ash, sand, and silt into the water as to be injurious or destructive to all species of fish. The damage may be essentially mechanical by scouring the streambeds of food, and by silting the water so heavily that fish are unable to respire normally (*85*). Although the pH concentration of stream water may be measurably changed by the additions of ash from burns, fish seem to endure wide ranges of pH. The pH factor is apparently not of especial importance unless the change is great, such as may occur in some small streams (*73*).

Effect on Recreational Areas.—The chaparral lands are used only limitedly for recreational purposes other than for hunting and fishing. The extent and location of the areas so used, however, emphasize the importance of knowledge of the relation of fire to recreation. Studies indicate that extensive brush fires are injurious to the best interests of the tourist trade. Hunting, fishing, relaxation, and enjoyment of natural beauty are the chief attractions of areas sought by the public. Tourist travel to areas recently blackened by burning is greatly reduced both during fires and for some years thereafter. Tourists not only leave areas in or adjacent to fires, but they bring back stories of the unsatisfactory condition of the area, with the results that friends and neighbors spend their vacations elsewhere (*99*).

MAGNITUDE OF THE BRUSH-BURNING PROBLEM

Earlier in this report several important aspects of brush burning were considered with regard to individual areas. In evaluating brush burning from the viewpoint of management and administration, one question in particular arises, namely: What is the importance and the magnitude of brush burning, or brush control, in the chaparral area of the state as a whole?

Figure 1 shows that the chaparral association occurs throughout the foothill areas of the state, extending almost from its northern boundary to its most southerly border. The fact that the chaparral cover occurs in many counties might lead to the conclusion that brush control is of importance over the state as a whole. This viewpoint is not supported by the actual conditions.

Except for isolated spots in other areas, brush burning is largely confined to certain counties in regions I and IV (fig. 1). Region I, embracing Lake and Mendocino counties on the coastal slope, and Tehama and Shasta counties in the interior of the state, constitutes the principal area in which broadcast burning is rather extensively practiced. The northern portion of region IV, from Yuba to Calaveras County, contains most of the brush-burning or brush-control areas of the Sierra Nevada slopes. In the other three regions the necessity of maintaining the natural plant cover intact on important watersheds and water storage areas precludes intentional burning of standing brush, except in localized areas. The elaborate federal-, state-, and county-sponsored flood-control programs, now well under way in parts of southern California, have provided a network of fire lanes and roads designed to aid in controlling fires which might otherwise spread over extensive areas. Facilities for speedy re-establishment of the cover on areas accidentally burned have also been provided. So strongly entrenched has become the philosophy of fire prevention with the public, and with officials who are responsible for the administration of these lands on important watersheds in the southern part of the state, that occasional requests by landowners to burn even small areas of brush are usually refused.

The areas upon which brush burning is commonly practiced involve no more than about 30 per cent of the state's chaparral land. Even in the northern counties where land clearing or brush control now constitutes an important problem, broadcast burning is localized because of wide diversity of land uses and conditions. Where public interests clearly outweigh the probable values that might accrue to the landowner from burning, public opinion, fire damage, and state and local laws, all compel the landowner to curb his fire program.

The brush-burning problem is further restricted locally by recognition among some stockmen that the cost of the forage obtained by the burning of some chaparral lands is too high owing to its low yield and poor quality, and to the protective and control measures that must be taken. In some areas, however, families are found who own so little open country that they can make a livelihood only by systematically burning the brush. Sympathy for the efforts of these small operators appears in some instances to have assumed such prominence that the general importance of brush burning over the state has been exaggerated.

The most general desire of accomplishment of a brush-clearance program is that of permanent removal of the brush, rather than merely to burn down the cover and await its recovery. A program of permanently clearing away the brush, the techniques of which have been discussed, should obviously be focused upon the more productive areas. Brush-burning or other brush-clearance expenditures on the submarginal lands of thin, often steep-sloping, inferior soils, whose forage yield at best is low and inferior, should be held to the minimum.

SUMMARY AND CONCLUSIONS

A study of plant succession on burns in the chaparral and oak-woodland associations of California, initiated in 1925, was conducted on sample plots, and the broader phases verified by surveys of ranches, chiefly in the northern counties of the state. The field work was supplemented by laboratory experiments. Special background studies were included to aid in the interpretation of the results.

Extent, Nature, and Uses of Foothill Lands.—Slightly more than 7 per cent, or about 7,300,000 acres of the foothill area of the state, lying below 5,000 feet in elevation, is occupied by chaparral, the species of which are characterized by simple, small, thick leaves, and extensive root systems. This cover occurs in two strips which run nearly the length of the state. Chaparral is represented by two distinct growth forms—sprouting and nonsprouting species. When cut or burned, the sprouting forms send up vigorous shoots from a swollen base or "crown," and therefore are exceedingly difficult to eradicate by fire. In contrast, stands of the nonsprouting forms are destroyed by cutting, or by a single fire, although the invading seedlings must be killed later on.

The chaparral association may be divided into five regions according to differences in climate, topography, soil, and species of brush. Its distribution seems chiefly to be delimited to areas where the temperature does not exceed 100° F for long periods and where the average annual precipitation does not fall below about 10 inches, or go much above 35 inches. The three most important uses of the chaparral lands are those of watershed, grazing, and timber production; additional uses are those of playground sites, hunting and some fishing, summer homesites, and areas cleared for permanent residences. Intermingled with, or adjacent to the chaparral association are redwood, Douglas-fir, and ponderosa pine forests of present or future commercial value.

Brush-Burning Viewpoints and Practices.—Contrary to the claims of some persons, burning of brushlands by the Indians evidently was restricted both because of their sparse population in chaparral regions, and because of their mode of life. Fire, when used, was primarily to facilitate hunting and to aid in gathering food plants. Burning for such purposes apparently was not extensive enough measurably to enlarge or to decrease the present chaparral areas, or to keep extensive stands open by repeated burning.

Broadcast chaparral burning apparently reached maximum proportions through activities of the white settler, in the eighties. Enforcement of fire laws since then, together with the adoption of the permit system of burning, appears to have resulted in some decrease in accidental and in incendiary burning.

A survey of experience and opinion among 80 stockmen in northern counties concerning broadcast bursh burning indicated that the forage on burns is fair to good in quality during the spring and early summer, and that the carrying capacity is usually increased for two to four years, according to the quality of the soil. They also felt that soil erosion is not generally a serious problem. Although strongly marked differences of opinion were reported concerning the value of burning in different localities, including most of the familiar claims such as increased water supply, protection from destructive fires, and insect, rodent, and rattlesnake control, 18 of the 20 stockmen who favored burning of all forms of vegetation resided in Shasta and Tehama counties. In contrast, several stockmen of other counties felt that burning of the more severe manzanita and chamise sites was not worth the effort. Several also discouraged burning of open-brush stands, maintaining that fire merely increased the density of such brush areas. The present study has substantiated this belief.

Plant-Succession Studies.—Few plants of sprouting forms of chaparral were killed, and few such stands were destroyed or materially thinned out by periodic burning, whereas the much more restricted nonsprouting brush was killed by a single hot fire. Following burning, numerous annual grasses, broad-leaved herbs, and brush seedlings appeared on most chaparral lands. On areas of sprouting chaparral, the herbaceous growth generally attained maximum abundance the first or second year, and then declined to a mere scattered stand by about the fifth year, owing chiefly to the suppressive effect of the numerous brush sprouts. In contrast, on areas of nonsprouting brush, most of the invading herbaceous plants continued to increase in density well after the third year. The yield of forage on productive chaparral-supporting soils, both of sprouting and nonsprouting brush areas, was temporarily increased by burning, whereas the extensive lands of thin and unproductive soils responded poorly regardless of the growth habit of the brush.

Invasions of chaparral species into brush-bordered grassland occurred commonly and with some regularity after burning, and were more extensive and dense on the side of the brushfields leeward to the prevailing winds, where abundant seed had lodged. Extensions of brush into grasslands surrounding old chaparral patches corresponded roughly in pattern to that of such border areas burned over.

Germination of some chaparral species was stimulated by heat. The seeds of most of the chaparral species studied were more resistant to heat injury than were those of associated species of grasses or broad-leaved herbs. Soil temperatures recorded during chaparral fires more often exceeded the endurance of seeds of herbaceous plants, but they were less often lethal to seeds of brush species. The results appear to account for the many seedlings of some chaparral species which invade burned areas. On grassy woodland areas, fairly open except for occasional clumps of more or less decadent stands of chamise or other aggressive sprouting forms, a single fire sometimes resulted in heavy invasions of chaparral seedlings, and vigorous sprouts of the old bushes. Special effort should be made to keep fire out of such brush-decadent areas.

In the interior counties artificial reseeding trials, using 24 species, were mostly failures, owing chiefly to the long, hot, dry summers, and frequently to inferior soils. Along the more humid coastal strip, on the other hand, greater reseeding success was attained, but results of distinct economic value were confined to soils of high productivity. Here Harding grass, perennial rygrass, and to a lesser extent, wild oat, soft chess, and needlegrass, were among the most successful introductions. Further experimental trials with highly drought-enduring forms, or with early-maturing species which may escape the summer drought, seem justified.

Seeds of common range grasses sown on typical brushland soils, and treated with fairly heavy dressings of chaparral ash, resulted in slightly lower percentages of seed germination, lower yield, and, in most species, in slower development of the later growth stages, than in untreated soils. Soil applications of ash, simulating in amounts those of the heavier accumulations on fresh burns, brought about chlorosis and death of common pasture grasses before they reached the fruiting stage. Chemical analysis of plant specimens of corresponding development stages grown in ashed and unashed soils, respectively, showed no significant difference in mineral content, or in crude protein.

Chaparral ash was found to be appreciably higher in calcium than in potassium. Only on small units of broadcast-burned areas, where abundant ash had accumulated, were the pH values so high as to hold in check, for one or more seasons, normal invasions of grasses and other herbs. Accordingly, attempts at reseeding those freshly burned areas which are heavily strewn with ash had best be delayed until one or more autumn rains have dissipated toxic ash concentrations. This conclusion is corroborated by leaching experiments with chaparral ash which showed heavy loss of potassium and carbonates, and lower pH values. In general, light, slow-moving fires, which are not so likely to sterilize the soil, are followed by more rapid and denser succession of forage plants than where the fire moves rapidly, creates great heat, and burns out the entire cover.

Most of the 34 brush-burned ranch areas inspected in 1938, 29 of which had been burned under state permit, produced more forage than did the dense adjoining unburned brush units. The grazing capacity and the quality of the forage of most of these burns, however, were low; indeed, some were not pastured because of the limited growth of herbaceous vegetation. The dominant grasses were mostly the early-maturing annual forms reported on most of the plots especially established to study plant succession. The most adverse results noted on most of these burns were the poor quality and the temporary nature of the forage, the low grazing capacity, and, on several areas, the occurrence of accelerated erosion, notably on the steeper, heavily grazed slopes. Many of these areas had been reseeded to cultivated forage plants, but except on good soils of the coastal counties, where some reseedings were successful, most such trials failed from the outset, or the stands were so readily replaced by volunteer vegetation that the effort did not pay.

In late spring several common herbaceous species and some brush sprouts on newly burned areas were slightly higher in moisture content than on adjoining unburned lands, and they were 6 to 10 days later in reaching maturity. This prolongation in succulence tended to enhance the nutritive value of the forage proportionately, and presumably it also accounted for its higher palatability in late spring. Thus the three most outstanding benefits of burning of areas with productive soils were: a slightly prolonged period of somewhat higher nutrition of the vegetation as a whole; a temporarily greater variety and abundance of accessible forage; and greater accessibility of the area to the animals and to the operator.

Soil-Fertility Studies.—Except in heavy localized spots of ash on new burns, as pointed out, changes in acidity, or pH, of the soil were so slight as to affect little the seed germination and subsequent plant growth. On the other hand, the nitrate content of the upper soil layer of practically all chaparral covers studied was higher on fresh burns. Although these differences were largely or wholly nullified the second and subsequent years after the fire, the increased supply of nitrate nitrogen would seem largely to account for the characteristic robust growth of the invading plants the first year after burning. The extensive, frequently thin Aiken soil series, referred to as the "red soil," was among the lowest in nitrogen content of those studied, both before and after burning; especially was this noted where chamise dominated the cover. Moreover, these soils were conspicuously low in grazing capacity.

Broadcast-Burning Techniques.—Burning to control invasions of chaparral involves consideration of both sprouting and nonsprouting forms. In sprouting cover, periodic burning was generally found only temporarily to suppress the brush. In nonsprouting chaparral, on the other hand, the brush was destroyed by two judicious burnings, preferably two years apart, the second burn being preceded by leveling the charred stems with a "drag." Attempts to destroy brush seedlings and sprouts by heavily overstocking new burns of any kind were not successful because of abundant invasions of unpalatable weeds, some poisonous plants, heavy packing of the soil, and accelerated soil erosion, notably on the slopes.

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Seeds of common range grasses sown on typical brushland soils, and treated with fairly heavy dressings of chaparral ash, resulted in slightly lower percentages of seed germination, lower yield, and, in most species, in slower development of the later growth stages, than in untreated soils. Soil applications of ash, simulating in amounts those of the heavier accumulations on fresh burns, brought about chlorosis and death of common pasture grasses before they reached the fruiting stage. Chemical analysis of plant specimens of corresponding development stages grown in ashed and unashed soils, respectively, showed no significant difference in mineral content, or in crude protein.

Chaparral ash was found to be appreciably higher in calcium than in potassium. Only on small units of broadcast-burned areas, where abundant ash had accumulated, were the pH values so high as to hold in check, for one or more seasons, normal invasions of grasses and other herbs. Accordingly, attempts at reseeding those freshly burned areas which are heavily strewn with ash had best be delayed until one or more autumn rains have dissipated toxic ash concentrations. This conclusion is corroborated by leaching experiments with chaparral ash which showed heavy loss of potassium and carbonates, and lower pH values. In general, light, slow-moving fires, which are not so likely to sterilize the soil, are followed by more rapid and denser succession of forage plants than where the fire moves rapidly, creates great heat, and burns out the entire cover.

Most of the 34 brush-burned ranch areas inspected in 1938, 29 of which had been burned under state permit, produced more forage than did the dense adjoining unburned brush units. The grazing capacity and the quality of the forage of most of these burns, however, were low; indeed, some were not pastured because of the limited growth of herbaceous vegetation. The dominant grasses were mostly the early-maturing annual forms reported on most of the plots especially established to study plant succession. The most adverse results noted on most of these burns were the poor quality and the temporary nature of the forage, the low grazing capacity, and, on several areas, the occurrence of accelerated erosion, notably on the steeper, heavily grazed slopes. Many of these areas had been reseeded to cultivated forage plants, but except on good soils of the coastal counties, where some reseedings were successful, most such trials failed from the outset, or the stands were so readily replaced by volunteer vegetation that the effort did not pay.

In late spring several common herbaceous species and some brush sprouts on newly burned areas were slightly higher in moisture content than on adjoining unburned lands, and they were 6 to 10 days later in reaching maturity. This prolongation in succulence tended to enhance the nutritive value of the forage proportionately, and presumably it also accounted for its higher palatability in late spring. Thus the three most outstanding benefits of burning of areas with productive soils were: a slightly prolonged period of somewhat higher nutrition of the vegetation as a whole; a temporarily greater variety and abundance of accessible forage; and greater accessibility of the area to the animals and to the operator.

Soil-Fertility Studies.—Except in heavy localized spots of ash on new burns, as pointed out, changes in acidity, or pH, of the soil were so slight as to affect little the seed germination and subsequent plant growth. On the other hand, the nitrate content of the upper soil layer of practically all chaparral covers studied was higher on fresh burns. Although these differences were largely or wholly nullified the second and subsequent years after the fire, the increased supply of nitrate nitrogen would seem largely to account for the characteristic robust growth of the invading plants the first year after burning. The extensive, frequently thin Aiken soil series, referred to as the "red soil," was among the lowest in nitrogen content of those studied, both before and after burning; especially was this noted where chamise dominated the cover. Moreover, these soils were conspicuously low in grazing capacity.

Broadcast-Burning Techniques.—Burning to control invasions of chaparral involves consideration of both sprouting and nonsprouting forms. In sprouting cover, periodic burning was generally found only temporarily to suppress the brush. In nonsprouting chaparral, on the other hand, the brush was destroyed by two judicious burnings, preferably two years apart, the second burn being preceded by leveling the charred stems with a "drag." Attempts to destroy brush seedlings and sprouts by heavily overstocking new burns of any kind were not successful because of abundant invasions of unpalatable weeds, some poisonous plants, heavy packing of the soil, and accelerated soil erosion, notably on the slopes.

Ranchers who favor burning, and who must rely largely upon continuous pasturage from these lands, may well consider the adoption of a plan of "rotation" burning to provide the maximum nutritious forage year after year. The plan proposed provides that the brush field be divided into three operating units, and that the burning be done in sequence at intervals of approximately three years, or on a nine-year rotation basis.

Under state supervision the cost to the owner of broadcast burning in northern California has varied from approximately 25 cents to 85 cents per acre; in addition the cost of supervision by the state has ranged from about 27 cents to 40 cents per acre burned. Many local factors influence the cost, such as the intervals between burnings; amount of coöperative help available; topography; season; natural barriers; kind, age, and amount of chaparral; proximity of the area to neighboring ranchmen who do not desire to burn; and proximity to forested lands. Isolated brush areas cost least to burn. The cost of burning, the speculative benefits to be derived, and the responsibility which the individual stockman must assume for damage to other property, chiefly account for the small acreage of controlled burning done to date under official supervision.

All factors considered, it is evident that the meager forage yield resulting from burning areas of thin, low-producing soils, especially when remotely or inconveniently located with respect to the main operating ranch unit, usually does not pay. The fact that much of the foothill brushland still remains in public domain, or is in railroad ownership, is indicative of the low value of extensive units of this land.

Brush Removal by Methods Other Than Fire.—To avoid fire hazard, and to procure more immediate and lasting results, the use of brush-clearing methods, other than that of broadcast burning, is sometimes justified on productive lands. Hand methods such as lopping, chopping, and girdling have been effectively used, but each method is limited in application by the cost. In oak-woodland, the cost of cutting may sometimes be offset by the sale of cordwood. Girdling, which is best done early in the spring, is less expensive, and is used where the wood is not to be salvaged. Removal of brush by a bulldozer has been successfully employed in restricted localities. This method is particularly applicable to sprouting-brush areas on fairly level lands of productive soils. Browsing animals, particularly goats, have been used to advantage to destroy sprouts and brush seedlings which come in after girdling, chopping, lopping, or burning cleanups. Enough goats should be held on the area to keep the sprouts and seedlings browsed down closely. Where deer are plentiful these animals will often destroy the brush sprouts and seedlings on small, localized burns.

Comparative Grazing Values of Brush Covers.—Based upon grazing capacity, quality of forage, and accessibility of the lands, the brushland covers may be classified, in the order named, as follows with regard to their relative values when burned or cleared of brush: nonsprouting chaparral; interior live oak and blue oak; and chamise, together with other sprouting chaparral cover. The last is by far the most extensive.

Sheep utilize all types of brushland more completely than cattle, and exhibit fewer seasonal preferences in their choice of forage.

In localized areas, regardless of the kind of brush, poisonous plants sometimes come in so extensively after burning that stockmen fear to pasture them until the second or third year after the fire, when the toxic species usually decline in abundance. Where the more poisonous forms of death camas occur, grazing on fresh burns by sheep should be avoided. Likewise, on larkspur-infested burns, cattle should be kept off in the spring until the larkspur plants are in the full bloom stage.

Effect of Fire on Wildlife and Recreation.—Wildlife and recreation sites are important in various chaparral areas. Fire destroys many small mammals, notably brush and tree dwellers, or they may die later from starvation. Destruction by fire of small surface-dwelling mammals, on the other hand, is mostly temporary; frequently, because of the increased food supply, mice and squirrels soon increase in numbers in excess of those present before burning. Because of their mobility, coyotes and certain other large predators are little affected by fires of ordinary size. Deer are seldom injured by small fires, but extensive burns have sometimes resulted in their starvation, injury, or death. Small openings may appreciably increase the forage for deer, but larger burns destroy the protective cover and temporarily deplete the food supply. Extensive brush fires are also adverse to bird life, whereas small, judiciously placed spot fires may be beneficial by providing secluded feeding areas adjoining the unburned cover. Unfavorable reactions of streams, which may follow extensive brush fires on surrounding watersheds, may decimate the fish population. Moreover, destruction of natural vegetation by fire greatly lowers the value of otherwise attractive camp and recreation sites, and tends to divert the normal tourist trade from fire-swept regions for some time thereafter.

Importance of Brush Burning.—Although the chaparral association occurs over extensive foothill areas of the state, brush burning is resorted to somewhat commonly in only about 30 per cent of its entire range, mainly the northern counties. The geographical limits of burning are essentially determined by the relatively high value of undisturbed chaparral lands, such as watershed in the southern part of the state, and by federal, state, and local interests in some chaparral lands elsewhere. Even in the northern counties, where burning is most prevalent, the practice is not county-wide. Although some large operators fire the brush, the greater number of habitual burners are those small stockmen who own little open land, and who must rely for their pasturage upon more or less submarginal brushlands in order to get some use of their holdings. They commonly burn the brush wherever a fire will go through it, and they can ill afford to apply tested mechanical methods of brush suppression after burning. Even though some of these frugal operators present a difficult land-use problem, they justify the fullest tolerance and coöperation of public agencies. Such local cases, however, appear to have exaggerated the importance of brush burning in various parts of the state.

Some of the larger and more experienced ranchers are tending to confine brush burning to flats and gentle slopes of good soils, and to follow up with various brush-suppression measures. Such procedure usually justifies the cost of the operation, and frequently alleviates grazing pressure in spring and early summer on the more valuable lands. On the other hand, the burning of poor brush land does not pay.

Extent of Summer and Autumn Pasturage on Burns.—The greatest single need of the livestock industry of the interior northern counties is that of adequate nutritious forage during summer and autumn. Those who benefit most from grazing their animals on brushfields utilize the burns in late winter and spring, when the succulent growth is highest in nutritiveness and palatability. As summer approaches and the forage dries and the brush sprouts harden, the animals are moved to succulent and nutritious pasturage elsewhere. In contrast, those operators who are forced to hold their stock on the brushland throughout the summer and fall, must either overstock the area, or else cut down the breeding herd to the minimum. In either case the benefits derived from the early-season grazing are often largely lost because of the extended grazing season on poor feed.

Provision of the animals with ample nutritious summer and fall forage is seldom accomplished by brushland burning; with few exceptions, the period of nutritious forage of these areas is extended for only a relatively short time by burning. This critical situation of seasonal forage deficiency thus raises the question whether additional suitable permanent summer and fall pasturage could not be developed. True, most of the high mountain range is already fully stocked; but with the active water development of the northern region, and the established grazing values of Ladino clover and supplementary grasses, the possibilities of increased acreage of irrigated summer pastures should not be overlooked. The recognized need of a better balanced yearlong forage supply warrants further consideration of the use of water for establishment of permanent valley summer pastures. It should be emphasized that flats or gently sloping lands whose soils are fairly deep but have a layer of fine-textured, dark topsoil, and which have relatively little rock outcrop or stony surface, termed "good" or "productive" soils, usually produce abundant and satisfactory early-season forage after the brush is burned. Such areas may be further recognized by the presence of various species of luxuriant grasses and other herbs under the less dense chaparral and in the openings. On the other hand, those lands whose soils are coarse, thin, rocky, of serpentine origin, or those with abundant exposed subsoil, bedrock, or stones, termed "poor" or "unproductive" soils, yield little forage after burning. Moreover, burning of old, open stands of sprouting chaparral, with a strong understory of forage, is usually harmful because fire invigorates the decadent brush, induces invasion of chaparral seedlings, and subsequently chokes out the forage. Burning of distinctly steep slopes, notably those with thin soils and facing to the south or west, is generally uneconomical if for no other reason than that the forage yield is small, of inferior quality, and matures early. The energy which the animals must expend in grazing upon such areas may largely or wholly offset the temporary advantages obtained.

The Trend in Brush-burning Practices.—More rational controlled or "prescribed" burning, confined essentially to the better chaparral lands and complimented with management methods which will favor maximum succession and stability of the herbaceous vegetation, may be expected to supplant haphazard burning as experience accumulates.

The most successful use of fire requires careful planning in advance. The first step is to make sure that the expected benefits from burning, all economic factors considered, will more than offset the cost. The second step is to decide on the specific area to be burned, and to establish adequate fire breaks which will protect the units that are not to be burned. A third measure is to burn late in the fall those areas where the fire risk is high, and to start the fire when the wind and air humidity favor control of the fire. And, finally, there must be an experienced crew of adequate size to procure as clean a burn as possible and to forestall complications.

COMMON AND SCIENTIFIC NAMES OF PLANTS MENTIONED IN THIS BULLETIN

TREES AND SHRUBS

Bigberry manzanita (*Arctostaphylos glauca*)
Bigleaf maple (*Acer macrophyllum*)
Bigpod ceanothus (*Ceanothus megacarpus*)
Blue blossom (*Ceanothus thyrsiflorus*)
Blue oak (*Quercus Douglasii*)
Brewer oak (*Quercus Garryana* var. *Breweri*)
Buckthorn (*Rhamnus*)
California black oak (*Quercus Kelloggii*)
California buckeye (*Aesculus californica*)
California hazelnut (*Corylus rostrata* var. *californica*)
California huckleberry (*Vaccinium ovatum*)
California incense-cedar (*Libocedrus decurrens*)
California scrub oak (*Quercus dumosa*)
California snowbell (*Styrax californica*)
California snowdrop bush (*Styrax officinalis*)
California wild grape (*Vitis californica*)
Canyon live oak (*Quercus chrysolepis*)
Chamise (*Adenostoma fasciculatum*)
Chaparral-broom (*Baccharis pilularis*)
Chaparral coffeeberry (*Rhamnus californica* var. *tomentella*)
Chaparral pea (*Pickeringia montana*)
Chaparral whitethorn (*Ceanothus leucodermis*)
Christmasberry (*Photinia arbutifolia*)
Coast live oak (*Quercus agrifolia*)
Coast whitethorn (*Ceanothus incanus*)
Coffeeberry (*Rhamnus californica*)
Common manzanita (*Arctostaphylos manzanita*)
Common snowberry (*Symphoricarpos albus*)
Creambush (*Holodiscus discolor*)
Cupleaf ceanothus (*Ceanothus perplexans*)
Deerbrush (*Ceanothus integerrimus*)
Deerweed (*Lotus scoparius*)
Digger pine (*Pinus Sabiniana*)
Douglas-fir (*Pseudotsuga taxifolia*)
Dwarf canyon live oak (*Quercus chrysolepis* var. *nana*)
Dwarf interior live oak (*Quercus Wislizenii* var. *frutescens*)
Eastwood manzanita (*Arctostaphylos glandulosa*)
Foothill ash (*Fraxinus dipetala*)
Fremont silktassel (*Garrya Fremontii*)
Greenbark ceanothus (*Ceanothus spinosus*)
Greenleaf manzanita (*Arctostaphylos patula*)
Gregg ceanothus (*Ceanothus Greggii*)
Hairy ceanothus (*Ceanothus oliganthus*)
Hoary manzanita (*Arctostaphylos canescens*)
Hoaryleaf ceanothus (*Ceanothus crassifolius*)
Indian manzanita (*Arctostaphylos mewukka*)
Interior live oak (*Quercus Wislizenii*)
Jim brush (*Ceanothus sorediatus*)
Laurel sumac (*Rhus laurina*)
Leather oak (*Quercus durata*)
Lemmon ceanothus (*Ceanothus Lemmonii*)
Mariposa manzanita (*Arctostaphylos mariposa*)
Mission-manzanita (*Xylococcus bicolor*)
Mountain maple (*Acer glabrum*)
Mock orange (*Philadelphus Lewisii* var. *californicus*)
Ninebark (*Physocarpus capitatus*)
Pacific madrone (*Arbutus Menziesii*)
Parry ceanothus (*Ceanothus Parryi*)
Parry manzanita (*Arctostaphylos Parryana*)
Pecho mountain manzanita (*Arctostaphylos pechoensis*)
Pointleaf manzanita (*Arctostaphylos pungens*)
Poison oak (*Rhus diversiloba*)
Ponderosa pine (*Pinus ponderosa*)
Ramona bush (*Ceanothus tomentosus* var. *olivaceous*)
Redberry buckthorn (*Rhamnus crocea*)
Redwood (*Sequoia sempervirens*)
Ribbonwood (*Adenostema sparsifolium*)
Serpentine manzanita (*Arctostaphylos obispoensis*)
Shagbark manzanita (*Arctostaphylos rudis*)
Squawbush (*Rhus trilobata*)
Spicebush (*Calycanthus occidentalis*)
Stanford manzanita (*Arctostaphylos Stanfordiana*)
Straggly gooseberry (*Ribes divaricatum*)
Stripeberry manzanita (*Arctostaphylos pilosula*)
Sugarbush sumac (*Rhus ovata*)

TREES AND SHRUBS—(*Continued*)

Sugar pine (*Pinus Lambertiana*)
Tanoak (*Lithocarpus densiflora*)
Thimbleberry (*Rubus parviflorus*)
Thinleaf huckleberry (*Vaccinium membranaceum*)
Toyon (*Photinia arbutifolia*)
Valley oak (*Quercus lobata*)
Wartleaf ceanothus (*Ceanothus papillosus*)
Wartystem ceanothus (*Ceanothus verrucosus*)
Wavyleaf ceanothus (*Ceanothus foliosus*)
Wedgeleaf ceanothus (*Ceanothus cuneatus*)
Western chokecherry (*Prunus demissa*)
Western mountain-mahogany (*Cercocarpus betuloides*)
White alder (*Alnus rhombifolia*)
White fir (*Abies concolor*)
Whiteleaf manzanita (*Arctostaphylos viscida*)
Wild currant (*Ribes*)
Wild rose (*Rosa*)
Willow (*Salix*)
Woollyleaf ceanothus (*Ceanothus tomentosus*)
Woollyleaf manzanita (*Arctostaphylos tomentosa*)
Yellowbrush (*Chrysothamnus lanceolatus*)
Yerba santa (*Eriodictyon californicum*)

BROAD-LEAVED HERBS

Alkali clover (*Trifolium depauperatum*)
Bishop lotus (*Lotus strigosus*)
Bluebells (*Mertensia*)
Blue-eyed grass (*Sisyrinchium bellum*)
Blue gilia (*Gilia capitatum*)
Bolander bedstraw (*Galium Bolanderi*)
Bolander linanthus (*Linanthus Bolanderi*)
Bracken fern (*Pteris aquilina*)
Bur-clover (*Medicago hispida*)
Bush beardtongue (*Penstemon Lemmonii*)
Bush monkey-flower (*Diplacus aurantiacus*)
California everlasting (*Gnaphalium decurrens* var. *californicum*)
California figwort (*Scrophularia californica*)
California filago (*Filago californica*)
California goldenrod (*Solidago californica*)
Cantua spurge (*Euphorbia ocellata*)
Chaparral cottonweed (*Epilobium minutum*)
Chaparral penstemon (*Penstemon heterophyllus*)
Coast larkspur (*Delphinium californicum*)
Common madia (*Madia elegans*)
Common mullein (*Verbascum Thapsus*)
Common peppergrass (*Lepidium nitidum*)
Common soap-plant (*Chlorogalum pomeridianum*)
Common sunflower (*Helianthus annuus*)
Common vervain (*Verbena prostrata*)
Common yellow mustard (*Brassica campestris*)
Cotton-batting plant (*Gnaphalium chilense*)
Coyote tobacco (*Nicotiana attenuata*)
Crown brodiaea (*Brodiaea multiflora*)
Cut-leaved thelypodium (*Thelypodium lasiophyllum*)
Dodder (*Cuscuta*)
Dotseed plantain (*Plantago erecta*)
Dwarf Bridges grassnut (*Brodiaea Bridgesii*)
Dove lupine (*Lupinus bicolor*)
English plantain (*Plantago lanceolata*)
Field suncup (*Oenothera micrantha*)
Fineleaf lotus (*Lotus subpinnatus*)
Fireweed (*Epilobium angustifolium*)
Foothill death camas (*Zigadenus paniculatus*)
Fremont death camas (*Zigadenus Fremontii*)
Fremont globemallow (*Sphaeralcea Fremontii*)
Gamble weed (*Sanicula crassicaulis*)
Gayophytum (*Gayophytum* sp.)
Gold fern (*Gymnogramme triangularis*)
Gold-wire (*Hypericum concinnum*)
Grassnut (*Brodiaea laxa*)
Greenbrier (*Smilax californica*)
Hill lotus (*Lotus humistratus*)
Horned snapdragon (*Antirrhinum cornutum*)
Horseweed (*Erigeron canadensis*)
Indian pink (*Silene californica*)
Indian tobacco (*Nicotiana Bigelovi*)
Knotweed (*Polygonum*)
Leafy gilia (*Gilia gilioides*)
Little-bill loco (*Astragalus Gambelianus*)
Longleaf filago (*Filago gallica*)
Meadow death camas (*Zigadenus venenosus*)
Menzies larkspur (*Delphinium Menziesii*)
Milk-aster (*Stephanomeria virgata*)
Monkey flower (*Mimulus*)
Moth mullein (*Verbascum Blattaria*
Mountain death camas (*Zigadenus elegans*)
Mountain nievitas (*Cryptantha ambigua*)
Mule-ears (*Wyethia*)
Mustard (*Brassica*)
Nada stickleaf (*Mentzelia dispersa*)
Napa star thistle (*Centaurea melitensis*)
Narrowleaf soap-plant (*Chlorogalum angustifolium*)
Northern rockcress (*Arabis retrofracta*)
Nuttall bedstraw (*Galium Nuttallii*)
Prickly lettuce (*Lactuca scariola*)
Purple nightshade (*Solanum Xantii*)
Rattlesnake weed (*Daucus pusillus*)
Red clover (*Trifolium pratense*)
Red larkspur (*Delphinium nudicaule*)
Redmaids (*Calandrinia Menziesii*)
Red ribbons (*Clarkia concinna*)
Redstem filaree (*Erodium cicutarium*)
Rush lotus (*Lotus junceus* var. *Biolettii*)

Broad-leaved Herbs—(*Continued*)

Sagebrush (*Artemisia*)
St. Johnswort (*Hypericum perforatum*)
Scouler St. Johnswort (*Hypericum formosum* var. *Scouleri*)
Sedge (*Carex*)
Sheep sorrel (*Rumex Acetosella*)
Silverleaf lupine (*Lupinus albifrons*)
Slender buckwheat (*Eriogonum gracile*)
Slender madia (*Madia exigua*)
Slender popcorn flower (*Plagiobothrys tenellus*)
Small-flowered lotus (*Lotus micranthus*)
Small meadow death camas (*Zigadenus venenosus micranthus*)
Spanish-clover (*Lotus americanus*)
Star thistle (*Centaurea*)
Sulfur flower (*Eriogonum umbellatum*)
Summer cottonweed (*Epilobium paniculatum*)
Sword fern (*Polystichum munitum*)
Tarweed (*Hemizonia*)
Tobacco mimulus (*Mimulus Bolanderi*)
Tomcat clover (*Trifolium tridentatum*)
Torrey nievitas (*Cryptantha Torreyana*)
Turkey-mullein (*Eremocarpus setigerus*)
Valley tassels (*Orthocarpus attenuatus*)
Vetch (*Vicia*)
Western lupine (*Lupinus leucophyllus*)
Western thistle (*Cirsium occidentale* var. *Coulteri*)
Whispering bells (*Emmenantha penduliflora*)
White everlasting (*Gnaphalium microcephalum*)
White-flowered navarretia (*Navarretia leucocephala*)
White forget-me-not (*Cryptantha affinis*)
White hawkweed (*Hieracium albiflorum*)
Whitestem filaree (*Erodium moschatum*)
White sweetclover (*Melilotus alba*)
Wild buckwheat (*Eriogonum*)
Wild carrot (*Daucus Carota*)
Wild tobacco (*Nicotiana*)
Willow herb (*Epilobium*)
Wool-mat (*Psilocarphus tenellus*)
Woolly-yarrow (*Eriophyllum lanatum* var. *achillaeoides*)
Yellow star thistle (*Centaurea solstitialis*)
Yellow sweetclover (*Melilotus indica*)

Grasses

Barley (*Hordeum*)
Bent-head fescue (*Festuca reflexa*)
Blue wild-rye (*Elymus glaucus*)
Brome grass (*Bromus*)
Bulbous bluegrass (*Poa bulbosa*)
California brome (*Bromus carinatus*)
California melic (*Melica californica*)
Canada bluegrass (*Poa compressa*)
Columbia needlegrass (*Stipa columbiana*)
Crested wheatgrass (*Agropyron cristatum*)
Downy chess (*Bromus tectorum*)
Foxtail fescue (*Festuca megalura*)
Harding grass (*Phalaris tuberosa* var. *stenoptera*)
Italian ryegrass (*Lolium multiflorum*)
Junegrass (*Koeleria cristata*)
Little quaking grass (*Briza minor*)
Kentucky bluegrass (*Poa pratensis*)
Malpais bluegrass (*Poa scabrella*)
Meadow fescue (*Festuca elatior*)
Mouse barley (*Hordeum murinum*)
Mountain brome (*Bromus marginatus*)
Needle-and-thread (*Stipa comata*)
Nevada bluegrass (*Poa nevadensis*)
New Mexican needlegrass (*Stipa neomexicana*)
Nitgrass (*Gastridium ventricosum*)
Orchard grass (*Dactylis glomerata*)
Pacific fescue (*Festuca pacifica*)
Perennial ryegrass (*Lolium perenne*)
Pinegrass (*Calamagrostis rubescens*)
Pineland three-awn (*Aristida stricta*)
Needlegrass (*Stipa*)
Prairie beardgrass (*Andropogon scoparius*)
Purple needlegrass (*Stipa pulchra*)
Rat-tail fescue (*Festuca Myuros*)
Red brome (*Bromus rubens*)
Redtop (*Agrostis alba*)
Ripgut grass (*Bromus rigidus*)
Sheep fescue (*Festuca ovina*)
Silver hairgrass (*Aira caryophyllea*)
Six-weeks fescue (*Festuca octoflora*)
Slender hairgrass (*Deschampsia elongata*)
Slender oat (*Avena barbata*)
Slender wheatgrass (*Agropyron pauciflorum*)
Smilo (*Oryzopsis miliacea*)
Smooth brome (*Bromus inermis*)
Soft chess (*Bromus mollis*)
Spanish brome (*Bromus madritensis*)
Ticklegrass (*Agrostis hiemalis*)
Timothy (*Phleum pratense*)
Velvet grass (*Holcus lanatus*)
Western needlegrass (*Stipa occidentalis*)
Wild oat (*Avena fatua*)
Wild-rye (*Elymus*)

ACKNOWLEDGMENTS

In the course of these investigations the author has had the coöperation of many individuals. To Aida Montier goes the credit for the many plant drawings. A. H. Gold, H. G. Reynolds, and Dr. O. S. Walsh assisted in compiling field data, and they were helpful in many other ways. J. O. Bridges assisted in a major way with the field surveys pertaining to experiences and attitudes of stockmen concerning burning; and P. S. Pattengale assisted with the field observations of areas burned under state permit. To Mrs. Beryl S. Jesperson thanks are expressed for verifying the plant identifications and the common names of plants mentioned in the bulletin. Dr. A. Gordon was helpful in checking chemical analyses of plants collected on burned and unburned areas, and in reading the section on this phase of the study. Dr. A. L. Kroeber, Professor of Anthropology, extended to the writer the privilege of reviewing field notes recorded by his staff on the history of Indian burning; also he made available the archives of the library of his department, and critically read the section on burning by Indians in California. The preparation of the map showing the distribution of the chaparral association was made possible through the courtesy of A. E. Wieslander of the California Forest and Range Experiment Station, United States Forest Service; and he personally checked the distribution of the areas. M. B. Pratt, State Forester, contributed to the statement on the history of state fire-control policies in relation to burning, and also furnished cost data on burning operations conducted under state control. E. E. Horn, Biologist, United States Fish and Wildlife Service, critically reviewed the section on the effect of fire on wildlife, and amplified some of the points therein from unpublished field records. The following colleagues offered constructive suggestions on the paper as a whole: Dr. G. B. Bodman, Professor of Soil Physics; Dr. W. P. Kelley, Professor of Soil Chemistry; Dr. J. Kittredge, Professor of Forestry; Dr. D. Weeks, Associate Professor of Agricultural Economics; and W. W. Weir, Drainage Engineer. Special acknowledgment is due to H. E. Malmsten for valuable coöperation in the earlier pursuit of the brush-burning project. Mr. Malmsten was active in the field studies for several years, and contributed particularly to certain phases of the plant-succession investigation.

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18m-4,'44(8088)