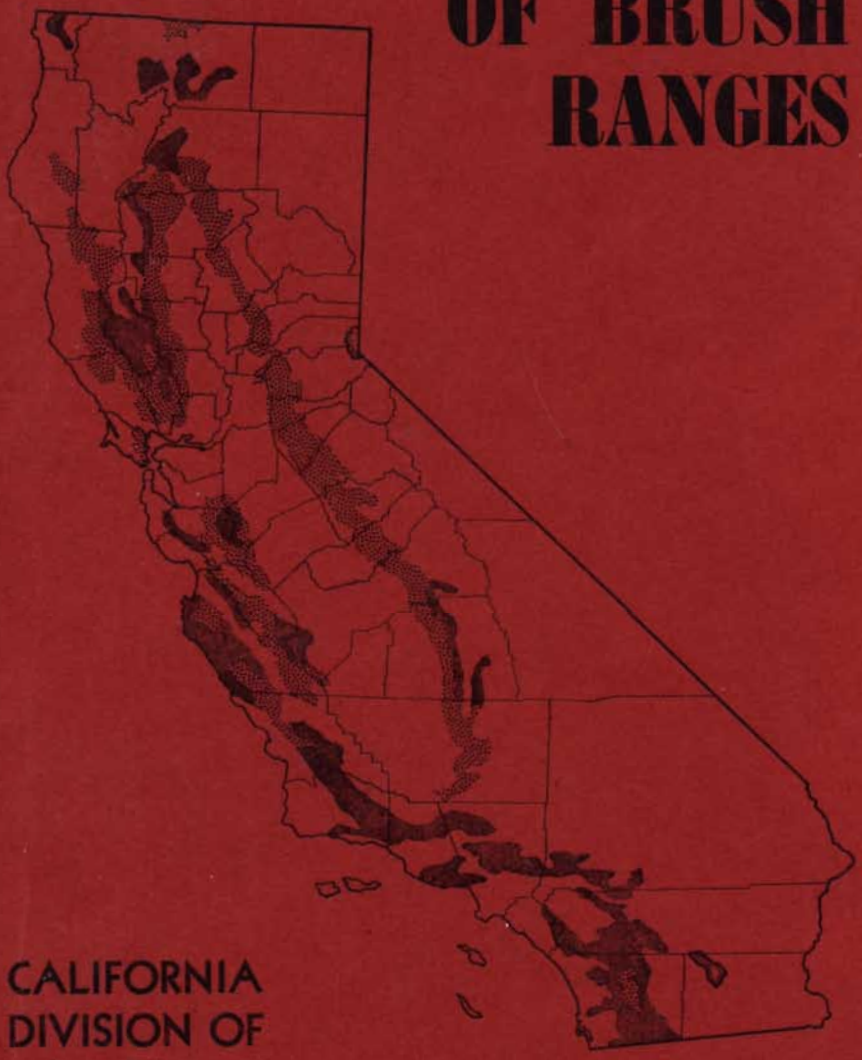
FIRE AS A TOOL IN MANAGEMENT OF BRUSH RANGES



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The Use of Fire as a Tool in the Management of the Brush Ranges of California

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"Many people have aided the writer in discussions, letters, memoranda and manuscripts. To these he is deeply indebted."

The chart on the cover is used through the courtesy of the California Forest and Range Experiment Station

(On the chart the woodland-grass areas are represented by the lighter shading. The cross-hatched areas represent brush associations.)

FOREWORD

Fire—a tool in range management—the use of which is an age-old problem, extending from the day of the nomadic tribesmen down to the present time in California. Dense fields of brush have always been looked upon as a nuisance and detriment to the herder of livestock. The conflict between the stockmen and brush has become more complex in this day as the interest of other citizens in these lands of economic marginal value has increased.

The simplest method of eliminating brush has been through the use of fire. The effect of this method of brush removal has long been a subject of study and research to determine the effect upon the range land from the standpoint of soil erosion, change in plant succession and economics. The varied records of most range research and experimental work have not been made readily available to ranchers and others interested in the management of wild land.

Therefore, in keeping with legislative authority and upon the recommendation of the livestock industry, the State Division of Forestry secured the services of Dr. Homer Le Roy Shantz, an internationally recognized authority on plant ecology, botany, plant geography and plant physiology. He was requested to review all available literature on the subject and to set forth in brief form, the pertinent facts dealing with this complex problem.

You will find his report readable and instructive. His summary not only rounds up the facts, but emphasizes that the use of fire is not the whole answer to an abundant forage crop but should be supplemented with range revegetation and proper livestock management. He also sets forth problems in which additional study and research should be conducted.

DeWitt Nelson
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HISTORY AND LITERATURE PERTINENT TO THE USE OF FIRE AS A TOOL IN THE MANAGEMENT OF THE BRUSH RANGES OF CALIFORNIA

H. L. SHANTZ

"Fire in vegetation:
A bad master,
A good servant, and a
National problem."
(Phillips, 1936)

"The earth denuded struggles against water.
The earth armed by vegetation struggles for water.
Who would master water must master the mountain.
Spontaneous vegetation everywhere protects against erosion."
(Favre, 1907.)

INTRODUCTION

Throughout the world there is a close correlation of soil types and plant communities with climate. This close correlation is reflected in the use of these lands by man. Timber production, range use, water supply and crop production are determined to a large degree by weather conditions. While plants, animals and soils are affected only by weather, the summation of the day-to-day weather is referred to as climate. Climate is an over-all controlling factor! It can be measured directly by recording temperature, precipitation, humidity, air movement, air pressure, and radiation, or it can be inferred by the reaction of animals, plants, or soils to the climatic conditions.

THE NATURAL PLANT COVER

"The original vegetation of any portion of the earth's surface is in approximate balance with the soil, weather, and biological factors." (Shantz, 1941:33.) Vegetation therefore "if properly interpreted can be used as an indicator of the climatic conditions under which it was produced, of the soils on which it grew, and of the practices of grazing or other use to which it has been subjected. It is of value in the rapid classification of land as to climatic conditions, soil types, soil texture, soil chemical composition, the value of soil for crop production under natural rainfall or under irrigation, the value of land for grazing with domestic stock or wild animals, and the value for wild life food production. It may also indicate the amount of overuse to which the vegetation has been subjected, the kind of animal responsible for this overuse, and the degree of destruction of the soil profile on which the vegetation is growing."

(Shantz, 1938:835.) This phase was emphasized more than half a century ago by one of California's greatest scientists. "Since, however, the object of soil surveys is essentially practical—is to enable us either to generalize from the experience had on other lands, or to predict the agricultural qualities of new lands—the prima facie evidence of the natural vegetation, which results from the secular co-adaptation of soils and plants under given climatic conditions, is manifestly of first importance. It is almost self-evident that whenever we shall learn to interpret correctly and accurately the meaning, from the farmer's standpoint, of the indications given by the local floras and sylvas, we shall be able to deduce from them, measurably, the same results we now gather from long agricultural experience, or from culture tests with fertilizers." (Hilgard, 1891:3.)

THE EFFECT OF HUMAN ACTION

At the present time man is conscious of his responsibility as a guardian of natural resources. This responsibility, which is becoming more evident each day, has been impressed upon man by the record of gradual deterioration of natural resources due to unwise or wasteful practices. Within a generation great areas of forests have disappeared, great areas of grazing lands have lost their perennial cover, the top soils have been lost from agricultural lands, productive rivers and lakes are almost barren of wild life, and nonrenewable resources have been lavishly exploited. There is abundant evidence in history to show that man has moved into productive and often forested regions and has had to leave them later as semidesert and nonproductive lands. The great valleys of the Tigris and Euphrates cradled the world's civilization and were destroyed by the pressure of populations and the resulting excessive use of the mountains which fed these rivers. The nomads overgrazed the wild lands of the mountains, and the valleys swung rapidly from luxuriant oases to drifting sand deserts. History is filled with the successive failures which man has made on the lands which he occupied. The outstanding exception is the Nile Valley and the explanation seems simple. Even today after continuous use for 6,000 years it is still one of the richest areas on the earth. The dense population of the valley has however never been connected industrially with the peoples of the headwaters, which lands today are wild areas not utilized to any great extent by modern man. Protected by thousands of miles of desert swamp and often by warlike tribes, it is in a natural condition and the watersheds which feed the Nile are as effective today as they were 6,000 years ago.

In the Near East

"Archæologists read to us the story of the rise and fall of civilization as they dig out the past from the discarded cradles of western civilization at Kish, Babylon, Nineveh, Ur of the Chaldees, Ctesiphon, Opis, and other ancient capitals. But little notice has been given to a human tragedy of still greater significance to be read in the vast ruins of abandoned irrigation works.

"The landscape of this ancestral home of western mankind is strewn with 'tells' or mounds of cultural layers upon layers, and relics of buried cities and of fallen empires." (Lowdermilk, 1939:3.)

"The history of civilizations is a record of struggles against the progressive dessication of civilized lands. The more ancient the civilization, the drier and more wasted usually, the supporting country.

"Recently the archeologists have turned back the pages of history, not merely centuries, but thousands of years. These post-mortems on buried civilizations suggest that it has been the hand of man, more than climatic change, which has reduced once rich and populous regions to desolation and poverty.

"We have a written record of encroaching deserts." (Lowdermilk, 1935:409-412.)

On the Italian Campagna

The Campagna of Italy once nourished a mass population which conquered Rome, the remainder of Italy, and most of the Mediterranean Basin. "Not only do all the authors preserve the traditions of forests and sacred groves that are mentioned in the tales of the early kings, but Theophrastus still knew of Latium as a source of timber as late as the Third Century: 'The land of the Latins is well watered, and the plains bear the laurel and myrtle and remarkable beech trees. Trunks are found that singly suffice for the keel beams of the great Tyrrhenian ships. Fir and pine grow upon the hills. The Circacean promontory is thickly overgrown with oaks, laurels, and myrtle.' (Frank, 1919:268.) "When, therefore, the early settlers pushed down into the Campagna and burned out 'clearings' for farming * * * they found a soil remarkably rich * * *. The population in time grew dense * * *. There is nothing improbable in the tradition of the 50 villages that Pliny has preserved * * *. Yet the wealth which made possible all this display * * * was the product of a rich soil cultivated with unusual intensity * * *." (Frank, 1919:269-270.)

"There are numerous relics from that remarkable agricultural period still to be found in Latium, traces of drains, tunnels, and dams * * *. The system involved hundreds of miles of excavating * * *. By diverting the rain waters from the eroding mountain gullies into underground channels the farmers not only checked a large part of the ordinary surface erosion of the hillside farms but also saved the space usually sacrificed to the torrent-bed. I know of no other place where labor has been so lavishly expended to preserve the arable soil from erosion. * * * The pressing demand for land resulted in the clearing out of every tract that could be made arable; the abundant population laid large demands upon the forests for lumber, and commerce * * * carried Latin timber as far as Greece, now well stripped of trees. The deforestation of the Volscian Mountains on the south of the Campagna resulted in ruin of that whole region, for the rains washed the mountain sides clear of soil * * *. The same process of deforestation of the Sabine Hills turned these also into bare rocks. The rain that fell found its quick course to the sea, and Latium became gradually the semiarid plain that it is today." The land use went from grain to grass for sheep. Sheep went to the mountains for summer feed. The "lack of grass in August and September * * * necessitated the laborious work of cutting leaves from trees.* * * The depopulation of the Campagna proceeded apace." (Frank, 1919:270, 273-275.)

"The Roman Campagna today" is "the most desolate plain of Italy * * *. Today the grass parches brown in June, not to revive again till near October, and the wheat is hurried to a premature harvest in the middle of June. But Varro sets July down as the month of harvest in his day and summer rains are frequently mentioned in the classical authors * * *. There can be little doubt that when the Sabine ridge from Praeneste to Monte Gennaro and the whole Volscian range were a thick forest instead of the parched white rocks that now stand out, the cool mountains caused condensations and precipitation over the plain when struck by the humid sirocco. * * *" Today "* * * the last rains of spring leap off the bare rocks and flow away at once in torrents to reach the sea." (Frank, 1919 :267, 269.) "Sirocco" is here used in a technical meteorological sense meaning "A warm sultry wind blowing from a warm region toward a center of low barometric pressure."

In India

A definite picture from India may illustrate the point. "To give you an instance, when the Emperor Jahangir built the castle of Nurpur for his Queen, Nur Jahan, the Light of the World, he writes in his memoirs that the forest was so thick that a bird could hardly spread its wings.

"But if you go to that place today, you will see nothing but a denuded hill country, with hardly more than a few tufts of grass and thorn bush on which a few goats eke out a miserable existence. All that has happened in a period of not more than 300 years * * *. They have utterly destroyed the whole vegetation of the hills by burning, cutting, and grazing.

"If you will turn to Plate III, you will see what you might imagine to be a watch-tower, but it is not. It is a well. When it was built it stood in cultivated land. The level of the land was naturally where you see the top of the well, and what you see before you is the remains of the well standing in a dry and sandy river bed. All this is entirely due to the erosion and denudation which has taken place on the outer hills to the Himalayas, subsequently to the year I have mentioned * * *. Erosion may be summed up as ill-treatment of the surface of the soil. Whatever the cause may be, and there are several causes; first of all, in my opinion, comes the destruction of the forests by mankind, which has so often turned a garden into a desert.

"* * * I would like to commend to you a few words from the preface to the 'Arabian Nights.' 'The lives of former generations are a lesson to posterity, that a man may review the remarkable events which have happened to others, and be admonished, and may consider the histories of people of preceding ages, and all that hath befallen them, and be restrained.' If you and the governments of the countries you represent will only realize this fact, and will consider the histories of people of preceding ages who have destroyed the virgin covering of the earth and what has in consequence befallen them. If you will take steps to see that in these enlightened days the same fate does not overtake us as has overtaken other nations, perhaps in a thousand years from now, the world will be in a better condition than it is today." (Trevor, 1935 :18-19.)

The story in the Euphrates and Tigris and many parts of the Mediterranean country, of India, China, and even parts of the United States

should at least cause land planners to give these phases careful consideration.

Man has been successful in moving the plant cover toward a more drought desert type. Man has been successful in causing dessication of lands largely by reducing hardwoods to conifers, forests to brushlands, and forests, brushlands and grasslands to deserts. The reverse of this process is exemplified in efforts of forestation of grasslands, of irrigation of desert lands, and in attempts to build back soil fertility and improve the physical condition by cultural methods. Praiseworthy as these efforts are, they have been pitiably slow and local as compared with the rapidity and extensiveness of the destructive processes. This, however, emphasizes eloquently the desperate need of the constructive processes.

Nature's Method

In nature there is a continual striving to develop the highest type of plant cover which can be attained under a given soil and climate. Throughout the world the climate determines the nature of this climax. A climax is the fully developed community in adjustment to soil, climate and biological factors, and a succession involves all the changes through which an originally bare or a denuded area passes in arriving at a climax stage. "A knowledge of the natural trends of succession enables the man who manages wild land to work with nature to bring about desired results. Artificial reseeding or planting for soil protection, improving grazing or timber production, for increasing the conditions favorable to man or wildlife should not be undertaken on wild land (land that is not intended to be cultivated or disturbed) without a clear perception of the natural succession on the area. To change this or reverse it means continued expense and in all probability ultimate failure. Often the reestablishment of the natural grass, brush or forest cover is delayed in proportion as a temporary success is secured by the use of the introduced species." (Shantz, 1940:316.)

The climax type, however, is not always most useful to man who often tries to throw back the succession to an early stage which better suits his present needs. "Agriculture applied to other than wild land is an intervention intended to stop or turn aside the natural development of the vegetation of the area." (Shantz, 1940:316.) We can always throw back the succession to an earlier stage, usually a dryer, more desert stage. See as examples redwoods thrown back to brush, and in extreme cases to an early weed grass stage and on some of the Bald Hills to moss and soil lichens; the perennial bunch grasses of the Pacific grasslands to wild oats and bromes and similar annuals; southeastern hardwoods to pinelands; the white pine forests of the Lake States to jack pine or even lower to ericacious brush; the forests of Asia to nearly desert clay hills; and the grasslands of Africa to waste lands. Such change is always to the dryer, less luxuriant type.

The changes in plant cover which tend toward dessication are both natural and man induced. Cultivation is so important an adjunct to production and civilization that it is almost everywhere accepted as the highest use of land for plant production. It has reduced much of the world's deciduous forests and many of the great grassland areas to crop land. On wild land, however, two other processes, one necessary and one often totally unnecessary, grazing and fire, have swung the

vegetation to dryer types. Grazing is closely linked with production and civilization, although it was practiced and is still practiced by uncivilized man. Grazing by herbivorous animals which were at times very numerous on the earth's surface was also a natural factor and must have exerted a great influence before man appeared and before the primitive shepherds controlled their domesticated herds. At the time of the appearance of the Europeans in America, herds of bison and antelope grazed the great prairies and plains and even now deer, elk, and antelope in places overuse the vegetation to deflect it into a community different from that which would develop without this overuse. In California and the Southwest the shepherds, with the background of generations of the Spanish Mesta which so thoroughly reduced so much of central Spain to a near desert condition, soon reduced the perennial grasslands of California to an annual weed stage which has not been improved by the use by later generations of Europeans.

THE EFFECT OF FIRE ON VEGETATION

A NATURAL FACTOR

Fire in vegetation was undoubtedly a factor long before man had appeared on the earth. Many of the species of plants must have been influenced by fire for hundreds of thousands of years to have so firmly fixed the physiological characteristics that they are now dependent upon fire for their continuance on earth. Many fires are caused by lightning and there is no reason to suppose that this condition did not also prevail long before man appeared upon the earth. From the earliest times fire has been a factor in the distribution of natural vegetation. Whenever vegetation was subjected to a hot drought period or even to a cold drought period, the vegetation has been greatly modified by recurrent fires.

Man's control over natural forces began with a partial control of fire. He soon began to use fire to warm his caves, to cook his food, to drive game from hiding and to clear land for cultivation. Civilized man appeared late on the stage of use of fire by man. Primitive man looked only to present benefits. But civilized man need not accept the natural conflagration as a necessary part of his planned use of resources or the practices of primitive man as necessarily safe guides to present day practices. The fact that primitive man used fire to aid his hunting or to improve his pasturage proves little as to its desirability in present day practices. It does, however, aid us to explain the conditions we now find and the distribution of forests and grasslands. Much of the earth's surface now in grasslands would without fire surely pass to forests, many coniferous forests would pass to hardwoods, and much of the higher and better parts of the Mediterranean type would pass to forest. Great tropical grasslands without fire would develop forest. On a broad basis the following world communities of natural vegetation are probably in their present state as the result of recurrent fires. The high grass savannas of the tropics and many of the tall grasslands, especially the moister side such as the eastern parts of the prairie would become forest. The Mediterranean types the world over with a long hot dry period which means recurrent fires, would become woodlands and forest. The pine lands of the southeast, would tend to change to hardwoods and the lodgepole pine lands of the Rocky Mountain forests would be replaced by Ponderosa pine, Douglas fir, and spruce and fir. Much of the northern heath and tundra regions are burned over rather frequently and parts of the area would develop forest cover if protected from fire.

A HUMAN FACTOR

It is difficult to separate natural fires from man made fires. Fire has been used by man both before and after the dawn of civilization. "In America, as throughout the world, as soon as men came into possession of fire the conquest of the animal kingdom was practically assured. The Indians used smoke to drive animals out of hiding, torches to dazzle

the eyes of deer and to attract fish and birds to their canoes, and firebrands and prairie fires for game drives." (Hodge, 1907, Part 1:581.) "The ancient Mayas burned their forests." (Riley, 1932.)

In the tropics, the Fang practice the cutting and burning of forest to produce land for crop production. This has been a most destructive process and in the monsoon type of forest is the chief source of fire. "The underbrush once cleared away, the men cut down the big trees, leaving here and there only some few giants * * *. In the beginning of March, after the long sunny days of February, the stalks of the bushes, the reeds, the branches of the trees are chopped up in pieces and burned, and soon, in place of the great forest, there remain only the big trunks lying on the ground, * * * the women place banana plants, stalks of manioc, and seeds of gourds." (Brunhes, 1920:359.)

Ancient history is filled with references to burning vegetation. "Such fires were a commonplace in ancient Palestine. Isaiah describes one in a metaphorical passage: 'It shall devour the briers and thorns, and shall kindle in the thickets of the forest, and they shall mount up like the lifting up of smoke.' Homer knows the effect of protracted drought and strong summer winds upon such a conflagration. 'Through deep glens rageth fierce fire on some parched mountain side and the deep forest beneath, and the wind, driving it, whirleth everywhere the flame.' * * *. Fires were often started, either intentionally or accidentally, by the herdsmen who ranged the mountain forests with their sheep and goats in the dry season." (Semple, 1931:290.)

"It is as when a shepherd sets scattered fires in the woods when the wind is right; the places between catch suddenly, and one terrible battle-line of Vulcan spreads through the wide plains: he, sitting victorious, looks down on the Trimphant flames." (Virgil, Aeneid X:405-411.) Even at that time opinions of the value and use of fire must have varied greatly. "The Arabs, who inhabit the Valley of the Jordan invariably put to death any person who is known to have been even the innocent cause of firing the grass." (Burckhardt, 1822:331). In North Carolina Bricknell in 1731 reports "they have such plenty of grass that they are obliged to burn it off the ground every tenth of March, by virtue of a law made in the country for that purpose." (Carrier, 1923:197.)

"Cabaza de Vaca states that in Arkansas about 1535 they (the Indians) take the pasturage for cattle (buffaloes) by burning, that necessity may drive them to seek in such places as it is wished they would go." "It is clear that in the early days burning off the vegetation was a common practice." (Sampson, 1923:217-218.)

In Spain the Mesta were for about 600 years a powerful group in determining land use. "The Charter of 1273 granted permission to the shepherds to cut as many branches as they might require for their corrals, fences, cabins, tan-bark, fodder, fuel, and dairy implements." "Far more serious to the life of the forests was the herdsmen's practice of burning the trees in the fall to provide better spring pasturage—a custom which has been common wherever sheep industry has prevailed." (Klein, 1920:306-307.)

"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." (Sampson, 1944:18.)

Tropical Forests

Since some of the present forests and grasslands have long been subjected to fires those who wish to keep them in the same condition often use fire as the most evident means of accomplishing this result.

In some of the monsoon forests of the tropics, fires have swept through, and the type is often a fire climax. When such fire trees are as desirable as the teak, fire may be a desirable tool in management.

"Fires are of great antiquity and therefore a determining factor in the present distribution of species. * * * Fangya cultivation, one of the principal causes of fire, is one of the earliest forms of cultivation. * * * innumerable species can exist in these forests, and possess considerable powers of resistance to fire." (Walker, 1912:437.)

"In certain forests, however, fire-protection unaided by other operations hinders the natural reproduction of the most valuable species, especially in the case of teak forests." (Fisher, 1912:221.)

"The teak is a deciduous and very fire-resistant tree, occurring scattered in mixed deciduous forests within a somewhat wide rainfall range. When fire-protection is introduced in the dryer regions of its habitat no radical change of type occurs, but if the moister type of teak forest—such as those prevailing over a large area in Burma—are protected from fire, there appears a heavy undergrowth which prevents the germination of teak seed and would prevent the survival of any seedlings if germination did take place; in time the teak and many of its deciduous associates disappear altogether, and the forest becomes evergreen or semi-evergreen in type.

"A consideration of these cases leads to the inference that if fire-protection is introduced into certain types of deciduous forest toward their moister climatic limits, the equilibrium, hitherto more or less stable, may be completely upset, and progression to a different and more hygrophilous type may take place rapidly. It would also indicate that were it not for annual fires the relative distribution of monsoon and rain-forests would be altered to the benefit of the latter." (Troup, 1919:308-309.)

Temperate Rain Forests

Central Africa

Much of the temperate rain forest of Central Africa is reduced to grassland. "Much of this temperate rain forest has been destroyed by the natives in order to prepare the land for agriculture. After a few years the land is abandoned and reverts rapidly. The reversion is often not allowed to become complete, and the temporarily abandoned areas are again put under cultivation. The result is the formation around these forest areas of immense tracts of what may be called brushland, dominated at times by bracken." (Shantz and Marbut, 1923:33.)

"Temperate Rain Forest of Urundi is now limited to two small areas * * * and to many small patches on steep or sheltered slopes naturally protected from destruction by primitive man or by fire or preserved as sacred groves * * *. These small forest patches are remnants of the great temperate rain forest or yellowwood (*Podocarpus*) forest which dominates the high mountain forest land of East Africa.

Formerly this forest must have been much more extensive. It has been invaded by the natives seeking new land for agriculture and pasture. Much of the mountain grassland would probably revert to forest were it not for the constant burning and grazing." (Shantz, 1929: 338 and 340.)

New Zealand

In New Zealand volcanic action results in fire in the forests. "* * * much forest must have been set on fire, and bracken and mamuka associations come into being then as now: * * * "From the economic standpoint" bracken "is far and away the worst weed which the farmer has to combat." The Maori cleared the forests with fire to produce Pteridium heath (bracken). (Cockayne, 1928: 188, 195 and 353.) Burning and overstocking have brought about a more xerophytic environment, * * *." (Speight, Cockayne and Laing, 1911:351.)

"When the whole of the tall trees are killed by fire, and the heat is sufficient to have burnt the surface humus and killed all the seeds therein, there will be no growth of any species of beech, but various plants appear, the most common being mamuka and bracken-fern, * * *." (Cockayne, 1926:60.)

Coniferous Forests

The Rocky Mountains

In the northern Rocky Mountains the fire types are less desirable than the climax types. Lodgepole pine, the first forest stage following burns, is a relatively undesirable type. In northern Idaho Larson (1925: 1196) reports "In every instance where a single fire destroyed a mature forest, as in the fires of 1870, 1889 and 1910, the natural restocking of the forest has been prompt, uniform, and complete * * *. In the case of double burns, however, as instanced by that of 1910 and 1919, restocking is woefully deficient." Again Larson (1929: 70-71) points out that the first forest stage in reproduction in northern Idaho is lodgepole pine and western larch, second western white pine and Douglas fir and third, western hemlock, western red cedar and grand fir which is the climax forest. This illustrates how necessary it is to know nature's method of reforestation for it is nearly impossible to change this process.

California

In California similar stages are established by human agencies. A careful survey of the vegetation cover in California has been made. "The survey not only provides information about the present vegetation cover, but also discloses that in many localities its character has been profoundly changed since the advent of the white man. The most striking and signficant of such changes are those representing a progressive deterioration from higher and more valuable to lower and less valuable types of vegetation as a result of such land abuse as destructive logging, accidental and wilful summer fires, the practice of annual burning in many foothill and mountain localities, and excessive grazing. As a consequence of such treatment, there have been extensive replacements of commercial timber stands by woodland, chaparral, or sagebrush; of big-cone spruce and Coulter pine by chaparral or woodland; of pinon by chaparral; of grasslands by chaparral or sagebrush; of chaparral by sagebrush." (Weislander, 1935: 142.)

Even in many of our forests, fire has probably occurred rather regularly. "In analyzing the data for fire scars * * *. During the past three centuries the years 1685, 1690, 1699, 1702, 1707, 1719, 1726, 1735, 1743, 1747, 1750, 1757, 1766, 1786, 1796, 1804, 1809, 1815, 1822, 1829, 1837, 1843, 1851, 1856, 1865, 1870, 1879, 1889 are indicated clearly as years of extensive fires.

"The forests have been most susceptible in the lower limits of the timber belt, since at best it must struggle severely to maintain itself along this transition zone in competition with the more drought resisting plants. It is therefore not surprising to find that at these lower limits the forest itself has been pushed back * * *." (Show and Kotok, 1924: 4 and 39.)

Pacific Northwest

The study of burns and cut-over areas in the Douglas fir region of the Pacific Northwest has brought out the following facts: The distance to which seed trees are capable of restocking the ground is limited to from 150 to 300 feet. The irregular, dense stands of young growth are due to seed stored in the forest floor or in cones. Seed stored in the duff are the principal source of seed responsible for restocking. (Hoffman, 1917:21-24.)

The plant association in the Douglas fir region, when destroyed by fire, goes through four distinct stages of succession before it reaches the climax type, unless interrupted by fire or logging. These stages are the "moss-liverwort," "weed-brush," "intolerant even aged Douglas fir" and "the tolerant all-aged hemlock-balsam fir": "the last named, so far as is known, will persist." (Isaac, 1940: 721.) "When brush species are held in check by successive fires and are replaced by herbaceous species, most of them run their course and disappear from the succession—but not so with bracken fern. It continues to build up and replace other herbaceous species as they fall out, and if the brush species continue to be held in check by occasional fires, bracken will dominate the succession and take possession of the site. This accounts for the thousands of acres of bracken-covered stump land to be seen today from the highways of western Washington and Oregon * * *. Bracken as it dries deposits a layer of highly inflammable material on the ground every autumn. This accumulation becomes a bad fire hazard with the first dry days of spring, which sometimes is months earlier than the ordinary brush will burn. Therefore not only does fire favor bracken, but bracken favors fire, creating a vicious cycle that tends to perpetuate the fern patch and eliminate other weed species, brush, and coniferous seedlings that would eventually form a new forest." (Isaac, 1940: 720, 721.) Bracken thus becomes a true fire climax—similar causes have operated to form the many other fire climaxes.

Redwood Region

"On the Siskiyou National Forest there are approximately 327,000 acres, exclusive of the Smith River watershed, out of 1,302,393 acres, that are covered with chaparral of many species, * * *." "The cause of their existence, however, is not difficult to ascertain, and is seen on

every hand. The charred stumps, tree trunks and fallen logs tell plainly that fire was the cause and has done its work.

"Could a man have seen this southern Oregon country before the original fires along the coast occurred, he would have seen a forest practically continuous and not broken by brush areas." (Haefner, 1942:83.)

"The virgin redwood forest has been irreparably damaged by past fires; current fires aggravate the damage and on cut-over land they materially reduce its ability to produce new tree growth." (Fritz, 1932:2.)

"Actually, foresters look upon fire as a nuisance that interferes with their real work and which hurts also your own business. It is not enough to leave trees. They must be left in good condition and they must be protected, otherwise the savings already noted will be lost to the owner. If the trees are barked or burned at the base, they do not have the capacity to grow as fast as they would if unharmed; furthermore, decay will get into the injured portions." (Fritz, 1939:619.)

"Although the redwood forests of California have supported active lumbering operations ever since the 'gold rush' days, there still remains roughly two-thirds of the original stand.

"For the most part, the forest was cut clean and nothing was left but stumps, while the cut-over land, in large part, became a liability." (Fritz, 1940:859.)

"* * * large areas of the finest redwood growing land in the State are being cut up into very poor quality farms and ranches which instead should be growing timber." "Ranch clearings in many instances have gone back to brush and are not usable by stock." "On the coast ranches a large percentage of the area in pasture inspected during the past summer is rapidly being taken over by bracken fern, iris, rhododendron, bush monkey flower, and other shrubs peculiar to the coastal fog belt." "Burning is not, and evidently has not been the answer here, as these forms of vegetation come back more densely than before." (Smith, 1945: 3 and 5.)

"The Humboldt ranchers quite definitely have a land clearing problem. Brush and ferns quickly take over open land, the reversion being to the original type, unless constant work is devoted to keeping down such species. This is expensive on originally timbered sites when brush came in after logging or burning. On the shore facing grassland, fern, both bracken and other coastal species of ferns, *Rrubus* spp., *Ceanothus* spp. and other coastal species of brush, are invading all areas and, as in Mendocino coastal ranches, bid fair to take over in time and render much area valueless for grazing. Fire does not kill out such species, but seems to spread them." (Smith, 1946:4.)

Southeastern Forests

In North Carolina, "Abandoned fields first grow up in brown sedge and brambles, followed the second year by sassafras, sumac bushes and yellow pine, and in a few years, except on badly eroded areas, there is a good stand of pine. Forested areas support a fair or good growth of white, red, black, post, scarlet and chestnut oaks, shortleaf or yellow pine, spruce, pitch and white pines, hickory, black gum, yellow poplar, dogwood, and a few persimmons, locust, sourwood, black walnut, white elm, sweetgum, red cedar and hemlock trees." (Lee, 1926:16.)

In discussing these results Bennett (1939:232) says: "This represents the natural secondary succession in old fields, which in many localities tend to remain more or less permanently in the stage of a pine subclimax as a result of frequent fires." Most of the pine stands of the Southeast are in a subclimax stage, in other words, in the pine stage, and will remain in that stage if frequently burned.

The longleaf pine forests of the Southeast have been subjected to fire and are adjusted to withstand occasional fires. Then again " * * * Annual spring fires retard height growth and ultimately kill a large percent of the seedlings but that a few survive eventually. Unburned seedlings grow much more rapidly, hence reach ultimate fire resistant size sooner." (Chapman, 1926:20.)

Stoddard who has worked in this area for years and is primarily interested in quail production says, "While a maximum crop of timber and a maximum crop of quail can seldom, if ever, be produced on the same ground, some timber can be produced on lands handled primarily for quail, and some quail can be produced on lands handled primarily for timber. * * * fire can frequently be utilized to advantage in controlling vegetation on portions of preserves that have a tendency to grow up to heavy wire grass, bromo sedge, or deciduous jungle. Quail cannot thrive in such areas.

"Fire is rightly comparable to a two-edged sword. While it may be used to good advantage at times to obtain definite desired results, its abuse, or careless uncontrolled use, may be productive of great harm." (Stoddard, 1931:413-414.)

"We would like it clearly understood that we are recommending controlled use of fire mainly on quail and wild turkey ground, where an abundance of these game birds is considered of first importance by owners of the land. We are also confining our discussion to the open pine land type of forest * * * . Nothing, for instance, can be more destructive to ground nesting game birds than summer fires which destroy nests and young, together with growing food supply and cover, and all conservationists should combine against them. We do, however, consider that carefully controlled fire, used at the proper season, under proper weather conditions, for the definite purpose of regulating cover and increasing food supply of game birds, is a necessary tool * * * ." (Stoddard, 1935:347.)

The importance of burns in increasing germination of longleaf pine seeds, and the time and relative occurrence of fires is important. "At Urania, Louisiana, longleaf pine seeds that fell in 1928 germinated at the rate of 30,000 per acre on a freshly burned-over surface, as contrasted with less than half this number on a surface that had escaped fire for two or three years. * * * another seed crop a year later did the same; about 15,000 seeds per acre germinated on the burn as against half the number on the rough surface. Fire that occurs during the first year after germination usually kills many individual longleaf pine seedlings. * * * Fire during the first year after seeding should be avoided." (Demmon, 1935:332-333.)

"Data taken from the tally sheets of the line plot survey of 35 counties in southeast Georgia, finished last summer, show that 85 percent of the 7,000,000 acres of land under forests of all types showed conclusive evidence of fire history. In the 6,000,000 acres occupied by the several

pine types as distinguished from the hardwood type, 91 percent of the area showed fire history.

"Explain it as you may, there is every evidence on the ground and in the history of this region to prove that this great pine forest was ushered into this world and has grown into its present development constantly subjected to the influence of wholesale periodic burning. * * * I know the fire problem can be solved—we need to get down to cases, to work this thing out by types, by regions, and by situations and apply the treatment called for by the diagnosis. * * * If controlled burning at certain periods is indicated as a correct procedure, then we should use it." (Eldridge, 1935:342-344.)

"The development of fire as a tool in forest management has come about gradually. First the realization by the forest owners and managers that certain fires, or parts of fires, resulted in little or no damage to the forests. This was followed by the recognition that fire of the less injurious variety might be good forest management if confined to appropriate areas. The proper use of fire is thus seen to consist of three steps: analysis, planning, and execution." (Bickford and Curry, 1943:3.)

"Fire is a deadly enemy of young trees, and must be kept under the strictest possible control. In the longleaf pine type, however, it may be practical for a forest owner to divide his forest into several parts and prescribed-burn a different portion each year to remove excessive rough and fire hazards, prepare a seed bed for pine, control brown-spot disease, and furnish fresh, easily accessible forage for the livestock. * * * Longleaf pine reproduction needs to be protected from any burning until it is in its second year of growth and from the time the buds are six inches high until the seedlings are five to eight feet high. * * * Burning is not recommended outside the longleaf pine forest type." (Campbell, 1945:6-7.)

Woodland and Desert Shrub

Cedar and Mesquite Land

Fire is not used as a control of cedar or mesquite which are controlled by the use of arsenite, bulldozing or grubbing. Both of these plants occur on a grass cover which is damaged in proportion to the amount of tree growth. (Parker and McGinnies, 1941; Lancaster, 1941; Parker, 1943; Sampson, 1946a:31-36.) "Fire is a dangerous method for clearing cedar. It leaves the soil bare and subject to severe erosion, burns valuable surface organic matter and destroys grass plants and seeds." (Bell and Dyksterhius, 1943:114.)

Sagebrush Land

The use of fire to remove sagebrush and by removing competition to increase the growth of grasses and herbs has been investigated. "There was a good stand of highly palatable and nutritious grasses and lupines in the summer following the burning and grubbing." "Seedlings and left-over stocks of sagebrush were very few on both grubbed and burned strips." "Reseeding did not naturally increase the stand." "The increase in the yield of vegetation the first year after burning varied from 40 to 222 percent over the yield in the native sagebrush the year before. The increase in the yield in the second year over the yield in the native sagebrush two years before varied from 238 to 336 percent." (Hanson, 1929:9-11.) These measurements are subject to seasonal change and

are therefore not comparable since we know nothing of the comparable production for the three seasons involved. As an example, the precipitation may be ten times the lowest in the Southwest (Lantov, 1940:1) and in another case the production of forage was 193 times the lowest. (Talbot, Biswell and Hormay, 1939:402.)

Sagebrush is entirely killed by fire and the roots do not sprout. Fire removes the sage and leaves the grasses and other plants without competition.

"The sagebrush-burning experiments in Clark and Fremont Counties of southeastern Idaho show that increased usability and greater grazing capacity of the range without damage to adjacent property are dependable results of planned burning." Burns were made in 1933, 1936 and 1939.

"The result was to increase grazing capacity an average of 69 percent on these experimental burns. Perennial grasses and weeds increased 60 percent in abundance, partially replacing the sagebrush.—Range with but little understory of perennial grasses and weeds should not be burned unless it is to be reseeded the first fall following the burn * * *.—The haphazard burn that runs over steep slopes or range land poorly protected by understory vegetation exposes the soil to the full play of wind and water erosion." (Pechance, 1944: 3, 4, 7, and 9.)

Grasslands

Shortgrass

"The effect of fire must be regarded as having been always operative in the Great Plains region. Fires are started by lightning during almost every thunderstorm, and the advent of man, has, if anything, tended to check rather than to increase their ravages. The effect of fires on short-grass vegetation in eastern Colorado results in modifying this vegetation very markedly. Grama grass seems to suffer but little, but in places that have been repeatedly burned the buffalo grass is completely killed out. Places of this kind are marked by a pure grama-grass vegetation."

"The wire grass, however, is badly burned. Where fires are very frequent their tendency is to convert this type of vegetation into a pure short-grass cover."

"Under conditions of frequent fires and excessive grazing the short grasses become established on land which otherwise would be occupied by bunch-grass." (Shantz, 1911:43, 53 and 57.)

"Burning of range pastures in either spring or fall caused reductions in forage yield, and from three to five years was usually required for complete recovery under conditions of moderate grazing. * * * The decline in yield of both spring and fall burned plots was greater on vegetation of the Agropyron type than on the upland communities dominated by Bouteloua and Stipa. * * * The decrease in yield following burning was due mainly to stunted growth rather than to killing of plants." (Clark, Tisdale and Skoglund, 1943:49-52.)

Mountain Grassland

In Utah "Observations show that areas of spring-fall range, long protected from grazing and fire, such as cemeteries and field corners, support a good cover of plants palatable to livestock * * * Observations on promiscuously burned areas which have been protected from

grazing indicate that burning tends to deplete the stand of perennial grasses and to allow annual grasses, chiefly downy brome, to increase sharply in density. * * * Observations on areas which have been subjected both to promiscuous burning and to heavy grazing show that a combination of these factors has seriously reduced the total density of the plant cover, and has depleted the stand of perennial grasses nearly 80 percent. Sagebrush cover likewise has been reduced 80 percent. Annual grasses and poor perennial and annual weeds are predominant. These changes in the plant cover due to fire and grazing have caused a reduction of over 50 percent in the grazing capacity of the spring-fall range."

"Observations on areas subjected to heavy grazing only show in every case a serious depletion of perennial grasses, a decided increase in density of sagebrush, in some cases a sharp increase in the density of poor perennial weeds and annual grasses and a decrease in the total plant density. These vegetational changes have resulted in reductions of 40 to 75 percent in the grazing capacity of areas studied in four districts." (Pickford, 1932:171.)

Prairie Grassland

"These grassland areas were often burned over in late summer or winter, and fires have doubtless been a factor in preventing forest growth on adjacent land. * * * In the eastern portion of the area fires have in all probability protected the grasslands from the encroachment of the forests. Aided by high winds, these fires swept with great rapidity across the grasslands of the prairies and plains, and early settlers and travelers could find safety only by starting back fires, since the broad band of burning grass, often 100 to 200 yards across, made it impossible to pass through the flames to the burnt areas of safety behind." (Shantz and Zon, 1924:16.)

On the western part of the Prairie Region in the bunch-grass, "The great mass of dry matter produced offers favorable conditions for the spreading of fires, which are often started by lightning. Burning injures the bunch-grass to such an extent that it does not fully recover for several years. * * * Under conditions of frequent fires and excessive grazing the short grasses become established on land which otherwise would be occupied by bunch-grass." (Shantz 1911:57.)

In Kansas, areas were burned early each year and charting of the vegetation made three times during the season. "The results show that in the early part of the season there was considerably more growth of grasses on burned areas than on those unburned, thereby substantiating the popular opinion that burning causes growth to start earlier in the spring. In the second charting there was always more vegetation on the burned areas but the difference was not so great as in the first charting. The third charting was done when the greater part of the season's growth had been made. The differences found in the third charting were slight, showing that as the season advanced the vegetation on the unburned sections tended to catch up with that on the burned area.* * * Burning caused a change in the composition of the grass type on the experimental area. Big bluestem (*Andropogon furcatus*) decreased on the burned plot, while on the unburned plot it showed a decided increase." (Hensel, 1923: 2 and 5.)

"Burning pastures is generally practiced through the prairie grass region of Kansas. It is done primarily to stimulate early growth in the

spring, to obtain more uniform grazing over the pasture, and to control weeds and brush. These investigations conducted over two years indicate that burning can be effectively used in controlling weeds and brush, but the burning has to be done late in the season about May 1st or later in the vicinity of Manhattan, to be very effective. The main difficulty encountered in the use of this system on extremely weedy or brushy pasture lands is that these areas do not usually produce sufficient dry material to make enough fire to kill the weeds and brush. The effective use of burning often necessitates the protection of such areas for at least one season." (Aldous, 1929: 661.) The brush in this case is *Symphoricarpos vulgaris*. More extended experiments were conducted between 1918 and 1933. "Burning decreased the yield of the mature vegetation. The yield was least on the plots burned in the late fall. The plot burned in the early spring was next, followed by the plot burned in medium spring. The plots burned in the late spring yielded more mature vegetation than plots under any of the other burning treatments." (Aldous 1934: 63.)

South Africa

The high veld in South Africa is dominated by *Themeda triandra*, called Rooigras, a grass similar to the little bunch-grass of central Kansas and Oklahoma. "If the tall, close Anthistiria-grass (*Themeda*) veld be burnt or very heavily grazed, or if it should suffer from very severe drought, the tall grasses are destroyed and will not reappear in the following season. Instead, the next crop of vegetation will be a short, open grass veld consisting of such grasses as *Tragus, Aristida, Eragrostis,* and *Sporobolus*. This short, open type of grass veld is more primitive than the tall, close grass veld. It also grows on drier and poorer soils.* * * Veld burning is not now practiced near Bloemfontein." (Potts 1923: 197.)

"Kolbe, in his Beschryving van de Kaap de Goede Hoop, 1727, informs us that the Cape farmers learned the practice from the Hottentots, who burned the grass when it became old and the cattle could not pasture there.* * * From the early days of the settlement the government set its face against this practice.* * * In 1687 a law was passed imposing the severest penalties * * *. This law had not become a dead letter with the taking over of the Cape by the British in 1806." (Botha, 1924: 351.)

However, the high veld, like our prairies, is partly a fire type and unless subjected to occasional burning the dominants would change. A series of experiments was made to determine the effect of fire on the high veld. "The site was chosen so as to include as much *Themeda triandra*, Forsk (Rooigras) as possible, this species being generally considered to be the most important grass from the grazing point of view." The results were summarized as follows: "That the dominant grass, Rooigras can well withstand yearly burning between June and September, if it is not grazed. That this type of Rooigras veld, even when covered by three seasons unburned dead litter, is not impaired by burning, if the burning is done under suitable conditions.* * * That burning in the beginning of January of a plot covered by three seasons' accumulation of dead litter very effectively killed out all the Rooigras as well as some associated species." (Staples, 1926: 5 and 17.)

"In drier areas over all the eastern high veld plateau, where the climax stage consists of Themeda and Andropogon spp., burning tends to destroy this also, and the pioneer stages * * * take possession. These being xerophytic are unpalatable to stock and of less value." (Bews, 1926: 346.) "The quantity of grazing and the density of cover in the grass lands and in the tree-and-grass savannas, have much deteriorated through the same agency (fire)." (Phillips, 1931: 2.) "Continuous grazing with cattle and sheep appears to be detrimental to the permanency of Rooigras veld." "Burning * * * below 30 inches of rainfall * * * detrimental." (Bosman, 1932: 295.)

"Where grass land is the climax type, however, excessive burning can do nothing but harm and will result in a deteriorated and weedy pasture hastening the onset of erosion. Each type of veld, depending on climate, altitude, soil and type of vegetation, must therefore be dealt with on its merits and the degree of burning necessary to remove the surplus dry vegetable matter determined. This surplus vegetation must be removed in order to allow the new grass room to develop; mowing is generally impracticable and fire is the only alternative. All the existing evidence, however, points to the fact that this burning should be carried out with great caution, that it should only be done when absolutely necessary, and that it should not take place when weather conditions are such that the blackened surface of the ground will be left for months uncovered at the mercy of the desiccating powers of the sun and wind." (Trevor et al, 1935: 15.)

"The succulent green leaves which come up from the ground after a burn cause the veld to be highly susceptible to damage by grazing. Over grazing is rendered more probable, owing to the grass being very much more palatable on the burnt area than on the unburned which is always mixed with a certain amount of hard unpalatable remains from the previous season's growth." (Rowland, 1937: 20.)

"Complete protection for five years, and also burning for more than three years in succession in August, leads to the decrease in *Themeda triandra* in this series of plots." (Glover and Rensburg, 1938: 278.)

New Zealand

Originally clothed with a fairly dense covering of tussock-grassland. The dominant members of this association would be Fescue tussock (*Festuca novae-zealandiae*) with the more palatable tall blue tussock (*Poa intermedia*), blue grass (*Agropyrum scabrum*) in its many forms and plume grass (*Dichelachne crinata*) would occur in considerable quantity.

"At the present time the scene is changed beyond recognition. Gone altogether is the brown mass of tussocks, and with it have disappeared nearly all of the members of the ancient grassland. Viewed from a distance the mountains resemble giant sand-dunes. A close acquaintance, however, shows that on sunny slopes this is due to the surface of bare hard soil in places destitute of all visible plant life, but usually having growing upon it in their thousands at from a few feet to several yards apart the large, flat, hard, silver, circular cushions or mats of the scabweed *(Ravulia lutescens)*." (Cockayne, 1922: 322 and 325.)

"On the winter country, in the spring, as soon as the ground is sufficiently dry, as much as possible is burnt over, the object being to destroy all the dead and harsh leaves of the tussock, and promote a rapid development of young and tender foliage which will be readily eaten by sheep. * * * Large portions of this country may again be burned later in the year, and much firing is done in mid-summer and autumn, more or less unintentionally.

"When constant burning takes place, the tussocks are either killed outright, and the whole vegetation quickly disappears, leaving large areas of absolutely bare ground, or else the tussock will gradually diminish in vitality and afford an inadequate shelter for other components of vegetation.

"After burning the tussocks rapidly shoot up again, but their vitality is much impaired, * * *. The strain that has been put upon them in having to develop rapidly a new growth of leaves uses up all the reserve food they may have accumulated. Consequently, they stop growing much earlier in the year than if they had not been burned over, and, although apparently yielding for a few weeks a more abundant supply of herbage, they do not produce the amount that is normally formed by an unburnt tussock. With regard to the blue-grass, the most important feeding-constituent of the pasture, the young herbage that is formed after burning, is greedily devoured by sheep, and in many cases the plants are eaten right out and killed. Such a condition would not occur on an unburnt pasture, and although the yield for any particular season would be less, there would be a succession of feed spread over a number of years;

"The spring burns lessen the general vitality of the pasture as a whole, and render it less able to withstand unfavorable climatic conditions. The summer burns actually kill out the tussock and hasten on the work of depletion. The autumn burns render the process of regeneration an impossibility by destroying both the seed and the most favorable medium in which it can develop.

"Under certain conditions burning is an essential feature in the management of natural pasturage; but whenever it is done the object should be to attempt to destroy some special undesirable element of the vegetation that by its spread or superabundance exerts an injurious effect on the ground for feeding purposes.

"Nature, in fact, is forced to build up a plant covering by a long series of stages, which may take many, many years before a similar type of vegetation to that existing when the land was first occupied can be produced. * * * The first step in this direction is the development of a desert flora, for the conditions at present prevailing on the depleted lands are eventually of a desert character." (Cockayne, 1910:7-14.)

"The tussock steppe of the Arrowsmith district is no longer a virgin formation. Burning and overstocking have brought about a more xerophytic environment, and, although probably all the original species are present, their relative proportion is much changed, the originally dominant tussock having decreased together with the mesophytic grasses and herbs which grew in its shelter, while various xeromorphs have increased and certain introduced plants have gained a footing." (Speight, Cockayne and Laing, 1911:351.)

"It is, however, fully recognized that over certain areas where through special circumstances the dominant tussock growth-form has

been eliminated profound alteration has occurred. This has resulted in the production of a totally different formation, approaching the desert type.

"During the past decade the utility of burning at all has been largely questioned, and at present the montane tussock-land runholders are divided into two distinct schools, one asserting the necessity and the other the fallacy of burning. The arguments adduced by both sides have not been subjected to scientific experimental investigation, so that the truth or otherwise of the premises laid down by both burners and anti-burners has never been accurately determined.

"The evidence on which the anti-burners base their claims is on the wide extent of country, more particularly in Central Otago, where the gradual disappearance of the tussock has been followed by the elimination of the whole of the association and the production of a virtual desert type of vegetation quite useless for grazing purposes. The pro-burners, on the other hand, assert that many stations which do not burn, although they keep the tussock grassland in an apparently unimpaired condition, cannot keep their stock in as good a condition as when burning is carried out." (Cockayne, 1916:158, 163-164.)

"Even in the earliest days of sheep-farming it was found that the fescue-tussock and silver-tussock were but little relished by sheep, but that, on being burned, green leaves upon which sheep could feed were put forth in abundance. Burning then has taken place yearly since the fifties or sixties of the last century * * * with the consequence that acres and acres of tussock-grassland have been turned into stony debris; that indigenous weeds * * * have replaced wide areas of more or less palatable grassland; that the subalpine shingle-slips have increased in size; that forests and shrubland—both valuable for shelter purposes—have disappeared; and finally that the depredations of rabbits have become intensified." (Cockayne, 1919:6.)

"Other classes of farming in New Zealand have been gradually made more productive by the adoption of new methods, but that of the tussock grasslands remains as in the begining, and, as a rule, fewer sheep are carried than at first, while in some localities there is great depletion." (Cockayne, 1926b:349.)

Southeastern Forest Grassland

The conditions are complicated on these lands since there is a conflict of land use. They are used simultaneously for the production of forest products and also are grazed by cattle and are sometimes managed for the production of quail and wild turkey.

"Frequently burning is one of the most serious and deceptive problems of east and central Texas." (Foster, 1916.)

"While a maximum crop of timber and a maximum crop of quail can seldon, if ever, be produced on the same ground * * * fire can frequently be utilized to advantage in controlling vegetation on portions of preserves that have a tendency to grow up to heavy wire grass, bromo sedge or deciduous jungle. Quail cannot thrive on such areas." (Stoddard, 1931:413.)

"The reasons advanced by cattlemen for burning the range are (a) to stimulate early growth of grass, (b) to remove dead grass and (c) to control the growth of brush and weeds." (Camp, 1932:17.)

On the coastal plains of Georgia "The burning is usually done against the wind in winter at a time when the fire will burn slowly and do the least damage to trees. The most common brush species invading the range are gall-berry and palmetto. The first is never eaten by cattle and the latter is utilized only very lightly. * * * About 40 percent of the farmers using forest range are practicing controlled burning, stating as their reasons: (a) to insure against devastating fires, (b) to improve the forage for grazing, and (c) to check brush invasion. Those who are practicing fire protection are fairly successful in keeping fires out of their forest areas * * *." (Biswell, Southwell, Stevenson, and Shepherd, 1942: 16-18 and 24.)

"Where ranges are burned during winter, cattle should be kept off of the burned portions from the time the burning is done until the new growth has made enough growth to maintain the cattle. * * * When burned areas are available rate of stocking should be based largely on the grazing capacity of these, since cattle should spend most of their grazing time on 'burns'." (Biswell, Shepherd, Southwell and Roggess, 1943:42.)

"Preliminary measurements indicate that in a vigorous seed stand there is no place for prescribed burning. Recent studies at the Blackland Branch Station near Plymouth, North Carolina, show that fires delay the grazing season about two weeks, reduce the carrying capacity the following year, and cause the reeds to be more easily killed by grazing." (Biswell, Foster and Southwell, 1944:196.)

"In many northwest parishes, in the eastern Florida parishes, and throughout most of the delta, farmers protect their own wood lots from fire and do not like to see the open range burned. * * * On the other hand, in the central Florida parishes and over much of southwestern Louisiana, it is customary to burn over the range during the fall, winter, or early spring." (Campbell and Rhodes, 1944:30.)

"In the switch cane or reed type, intentional burning to freshen the forage is not advisable—for several reasons. First, burning delays the grazing season from one to four weeks because new growth is easily damaged even by light grazing. Second, the foliage produced after a fire has low frost resistance the following fall and the leaves drop earlier than on unburned plants. Third, the amount of forage available during the first growing season after a fire is less than on unburned areas and a larger acreage is needed for each animal. Fourth, it is not only difficult, but usually impossible to control fires in the switch cane type because of the speed and severity with which they burn." (Campbell, 1945:7-9.)

In experimental plots estimated weights of green herbage on grazed plots gave the following results as total pounds per acre air dry for the season February to December inclusive. They were burned in January.

	Burned	*Unburned*	*Ratio Unburned to Burned*
On pine	4,513	5,947	1.32
On oak	6,363	7,315	1.15
On grass	10,567	15,525	1.47

An increase of from 15 to 47 percent in green herbage on unburned over burned. (Campbell, 1946:199.) On the other hand Lemon (1946:115) found that burning improved forage and results in better cattle gains.

Sclerophyll Brushland
(Mediterranean Type)

One of the most widely scattered plant communities but one covering a relatively small area of the world's surface is the temperate brush, or sclerophyll brushland, generally referred to as the Mediterranean type. This type is known under many different names. In California it is generally referred to as "chaparral" or "brushlands"; in the Mediterranean region by the Corsican name "macchia" meaning wild and uncultivated land, and by the Provencal term "Garigue" which also means uncultivated land. The "Garigue," the dryer type, is mostly on calcareous soil and the "macchia" on siliceous soil, and this distinction is often applied when these terms are used. In south Australia it is called by a number of names, such as "mallee-scrub," "mulga-scrub," or "Brigalow-scrub." In South Africa it is often called "Fijnbos" and sometimes "macchia" or "Garigue," and also "heath." In Spain it is called "Tomillares" and in the Balkans "Phrygana." "Heath" is used for ericoid vegetation such as that of South Africa, southwest France, and would by European botanists probably be applied to areas of *Adenostoma* in California because of its heath-like foliage.

Throughout the world this sclerophyll brushland is regarded by plant geographers as a fire-induced type. Because of the adequate rainfall during winter when growth is active and because of a long dry hot period during late spring, summer, and early autumn, fires either man-induced or natural burn off the vegetation every few years. The brushland is reduced to burnt stubs on a bare burned soil. Many species which dominate this type are not killed by the fire, and sprout soon after they are burned. Many plants which are killed by fire are reproduced rapidly by the seeds which germinate in the ash following burning and are therefore not eliminated from the vegetation by fire. It is therefore not a true climax but a mixture of early or late stages in a succession which never passes to its final stage because of fire.

That this type was ever free of fire seems unlikely. Every plant in these regions survives because it is capable of passing through fire without being killed. Many of the plants are geophytes with storage bulbs, corm or rootstalks under ground. Many sprout quickly after fire, and many produce great quantities of seeds which often germinate only following burns. Fire must have been operating for thousands, yes probably hundreds of thousands of years, to have fixed the physiological habits of these plants and plant communities to such a degree that without fire they could not survive. The same physiological and ecological requirements are found in this type whether it be in South Europe, North Africa, Asia Minor, Southern Australia, South Africa, Central Chile, or in California. In all of these areas rainfall produces a brush or small tree cover very inflammable during the hot dry summer season. Since this type of plant cover burns often, it is a type made up of many different communities dominated by one or several species. The sprouts or seedlings usually are of equal age and began growth shortly after the last fire.

Throughout the area this type passes into a grassland or savanna on the lower warmer side and into a forest farther up on the mountains or into a desert on the dryer side where rainfall is not properly distributed to produce a grassland. In California, grasslands lie below and coniferous

forests above. Fire is a part of the environment of this type, and it is maintained by fire. Consequently it cannot be removed by fire alone. However, fire carries this type far beyond its natural area. This is especially true where it passes to higher elevations with higher rainfall and shorter, cooler, less severe drought periods into what would be without fire stands of timber trees. Again where rainfall is increased and where forests such as redwood grow naturally, a brush type, somewhat resembling the chaparral, becomes the only cover when the vegetation is burned frequently.

Under cultivation the whole environment is changed since fire does not run through farm lands. The rainfall is usually supplemented by pump or gravity water during the hotter, dryer part of the year. In some places, particularly North Africa, olives which are indigenous to the Mediterranean region are planted far apart without irrigation and grown with clean cultivation. Many California olive orchards are almost of this type. However, in all agricultural practices man has escaped fires which in this type have always been a part of nature's plan. The ranchmen have generally protected their grasslands from fire. But the brush has encroached on the grassland in South Africa in the form of Rhenoster Bush. Here in California it is the general belief that the brush is encroaching on the grassland. There are many explanations of this encroachment and much controversy and but little agreement as to the real cause. It is probably safe to say that there are so many variable facts controlling the plant succession in the various localities that arguments are often not pertinent.

Because of the equable climate and its adaptability to the production of subtropical fruits, vegetables, small grains, and almost any crops with some irrigation this Mediterranean type the world over has become an important agricultural region. With a favorable climate it has also become a resort and recreation land including such well known areas as the Riviera and other Mediterranean lands, Madeira Islands, the Cape Region of South Africa, Central West Chile, South Australia, and Southwestern California. The largest area of this type of vegetation is in the Mediterranean region in Europe, Africa and Asia. Other areas are found in the Cape Region of South Africa, in south and southwest Australia, in central Chile, in Lower California and other parts of Mexico, and in California.

"Broadly speaking, it is the total annual rainfall which is of the most significance to trees, while growing season rainfall is necessary to grasslands. Where the rain mainly falls in the late autumn and winter, but is sufficient in quantity, and there is a hot dry summer, the vegetation is of the evergreen sclerophyll type—trees or shrubs with rather small leathery leaves which are able to function during the winter and are yet able to stand the summer drought. Owing to the comparatively low winter temperatures the herbaceous vegetation is, for the most part, dormant during that season, and appears only with the spring rise of temperature. Sclerophyll regions always abut on desert regions." (Tansley and Chipp, 1926:99-100.)

In Mediterranean Lands

This great area contains over 80 percent of the world area of the sclerophyll brushland and includes most of the land bordering the

Mediterranean Sea in Africa, Europe, and Asia. The climate is moderate with a warm dry summer and a moist cool winter.

In the Mediterranean region this type is known by the Corsican name "macchia" which is often found on calcareous soil. A smaller type and found mostly on the saliceous soil is known by the Provencal name "Garigue." In the Balkans it is known as "Phrygana" and in Spain as "Tomillares." (Rubel, 1914:236-237.)

This vegetation is a fire type and has been subjected by man to repeated fires during the historic period and probably burned by natural fires for hundreds of thousands of years before. "The long dry summers and the resinous character of Mediterranean maqui shrubs made forest fires frequent and disastrous, while the high winds of the hot season fanned the flames." (Semple, 1931:290.) It is therefore probable that macchia was the cause of the disappearance of much of the forest from the Mediterranean region and is likewise true that the destruction of much of the forest by fire has resulted in the great extension of macchia over most of the area.

Like the California chaparral the more it is burned the more depauperate the vegetation and the less desirable. Near the Bay of Naples and the Islands of Capri and Ischia with limestone soils, the macchia shows such useless shrubs as *Cistus,* and such hard leaved shrubs as *Pistacia, Quercus ilex, Arbutus unedo, Myrtus communis,* and *Erica arborea.* (Bergen, 1903:351-355.) Blanc (1905:206) lists under the Garigue the worthless *Cistus monspeliensis.* In Portugal and Spain and also in southern France many species of Cistus and Erica are prominent parts of brushland. (Chodat, 1909:29 and 31.)

On the Adriatic, *Arbutus, Juniperus, Myrtus, Phillyrea, Pistacia* and *Quercus* are prominent. (Furlani, 1916:273 and 366.) An attempt to improve the forage of the central Apennines shows that the vegetation has been almost completely destroyed leaving a poor limestone rock with little soil. Much of the land is nearly useless for forage. (Trotter, 1920.)

On Sardinia the macchia is chiefly the worthless *Cistus salvifolius, Cistus monspeliensis,* and *Cistus incanus,* and a taller macchia of *Erica* and *Arbutus.* (Beguinot, 1922:29.) In countries where there is a recurrent long dry season, fires are a constant factor of the environment. "If the burnings are repeated at intervals over a long series of years a 'fire climax' (a subclimax in Clements' terminology) may be established, and this will be composed of species which can securely regenerate, vegetatively or by seed (lying in the soil or migrating from without), after the fire * * *." (Tansley and Chipp, 1926:147.)

Again and again in the Mediterranean one of the extreme fire types, useless for forage, is indicated as a prominent or dominant plant. Garigue at Montpellier on limestone is of *Cistus monspeliensis, Quercus* and *Rhamnus,* while the macchia has such plants as *Myrtus, Erica, Phillyrea, Pistacia* and *Quercus.* (Harshberger, 1926:58 and 59.) (Negri, 1932.)

In Corsica the macchia is of *Arbutus unedo, Phillyrea angustifolia,* and *Erica arborea,* and the plants are five to ten years old with great ability to sprout after fire. In Dalmatia there are *Arbutus unedo* and *Phillyrea media,* while in the eastern Mediterranean *Cistus* and *Myrtus* are more important. (Rübel, 1930:92-98.)

With repeated burning *Cistus* becomes more prominent and behaves in the Mediterranean much as *Adenostoma* does in California. It is prob-

ably less palatable than *Adenostoma,* but neither are much good as forage. The increase and importance of *Cistus* in the degenerated fire climax of the Mediterranean is indicated by Rübel. (1930:98-102.)

"Under the assault of the goats, the maqui even has grown shorter and thinner, exposing even larger spaces to the scouring action of rain in winter and wind in summer, till mountains have become quite bare, as in parts of Greece and Spain." (Semple, 1931:291.)

Cistus in Greece is called phrygana. (Fiori, 1932:454.) This indicates the low stage of the brushland brought about by both fire and heavy grazing.

The abundance of *Cistus* with *Callitris, Pistacia,* and *Phillyrea* in Morocco indicate a degenerate fire climax. (Emberger, 1930:71-78.)

A recent paper on grazing in Morocco would indicate that most of the grazing is done down on the agricultural lands. (Killough, 1945:325.)

The Mediterranean type has been subjected to fire and grazing, and is a fire type. Dr. W. Ludi of the Rübel Geobotanical Institute in Zürich, Switzerland, in a personal letter to the writer under date, Zürich, June 20, 1946, in response to an inquiry, says, "There is also a difference in point of view between investigators and land users on the subject of forest and brush burning. The research men place in the foreground soil erosion which becomes more rapid when the vegetation is removed. Others regard the storing of humus most important. Others regard the change in plant cover since only a part of the plant cover can survive burning. And finally it is recommended as a precaution that the better pasture vegetation is the result of the fertilization, but the facts are not clear. It seems to me that one should attack the problem experimentally. Only in this way can one determine quantitatively and qualitatively the significance of brush or forest burning for a desired sort of use of the plant cover."

Dr. Edward Rübel who established the Rübel Geobotanical Research Institute in Zürich, Switzerland, and who has directed much of the work to a better understanding of the Mediterranean type of vegetation, writes in response to an inquiry under date, Zürich, May 25, 1946. "In the chaparral burning both sides are right. When you burn it the soil is enriched the coming year in potash and the new growth is very good for sheep. But that is only on the short run. In the long run the vegetation degenerates more and more and the end is a waste and a desert. In the Mediterranean wide stretches of sclerophyll scrub and even old forests have degenerated by burning to poor garigue and bare stone fields with some mints and *Cistus,* which cattle detest. So you see sheep raisers are right in the short run and the scientists in the long run."

In Chile

In central Chile there is a large area of land with this type of vegetation on the mountains and in the valleys. As in California this area is an important agricultural region. Here grassy valleys give way to hills of shrubby matorral, similar to the chaparral of California or the macchia of the Mediterranean, but with very different species, and this brush cover in turn, at higher elevations, gives way to forests of beech and conifers. There is a hot and dry summer and a damp cool winter with the three dry months January, February and March. (Jefferson, 1921.) Much of this grass and brush area has been burned.

"The trees and shrubs of this intermediate zone have a characteristic crookedness of trunk, hardness of wood, and light sharply defined foliage."

"Its aspect is conclusively Mediterranean. The plants, and the herbage of the plains, grow and flourish during the rainy season (from Autumn to Spring). During the summer the vegetation disappears, or dries up, where protecting trees and shrubs do not exist."

"This herbaceous vegetation is composed of plants of European origin, and more particularly Mediterranean. The gramineae are predominant. * * * Some of these, and those which have prospered and extended most, were accidently exported from the old world, and have long ago become naturalized in Chile, such as the '*Alfilerillo*'." (Chile, 1915:31-32.)

"Situated between a coastal range and a mountainous background, the central valley of Chile is almost an exact replica of the Sacramento Valley of California, and like it, frankly Mediterranean in character. The valley itself has a grassy floor with thorny bushes mostly evergreen of mimosas, colletias, etc., recalling the chaparral and the maquis." (Hardy, 1920:168.) "In central Chile, between 1,000 and 2,000 meters elevation, a hardleaved bush, difficult to penetrate, is dominated by *Quillaja saponaria*, associated with *Kageneckia oblonga, Litsea caustica* and others." (Rübel, 1930:115.) "Many shrubs distinct from the California chaparral species, but similar in appearance, are such plants as *Aristotelia maqui, Cestrum parqui*, and genera such as *Colliquaya, Ovidia, Lobelia, Tupa, Fuchsia, Fabiniana* and *Berberis*. Here also is a rich and varied agriculture." (Reiche, 1907, and Martin, 1909:244.) These areas have been subjected to fires both natural and man induced.

In Mexico

Mexico has large areas of chaparral on the west coast and smaller amounts on the east. In Nuevo Leon, Mexico, Muller (1939:701-702) states "On the west side of the mountain range the desert plateau scrub gives way to a western montane chaparral in the foothills bordering the mountains, usually at an altitude of about 2,000 meters. * * * The genera *Rhus, Ceanothus, Quercus, Cercocarpus, Samuela* (*Yucca*), *Arbutus,* and *Arctostaphylos* are abundant constituents which attest to the relationship of this vegetation type to the California chaparral type." Chaparral of the typical California type extends down into much of Lower California.

In Australia

This type of vegetation occupies a rather large area in southwest Australia and a smaller area in south Australia. There are three main types of sclerophyll brushland known in Australia as "Mallee-scrub" mostly of Eucalyptus, "Mulga-scrub" mostly of Acacia, and the "Brigalow-scrub" of Acacia and Casuarina. In general character these areas are true sclerophyll brushland and lead to desert conditions. (Diels, 1906; Rübel, 1930:116.)

During the long dry summers the oily plants burn but are exceedingly resistant to fire and recover rapidly by sprout growth, and a vigorous crop of seedlings. A few annuals follow the fire. (Adamson and Osborn, 1924: 100.)

"The association of dwarf eucalypts known as the Mallee is a very important one from the settlement point of view, in so far as the areas so occupied are of no value to the pastoralist in their virgin state, and some form of agriculture must be available which will repay the cost of clearing. The most important extensions of the wheat areas in south Australia, Victoria, and western Australia have been in the Mallee belt. * * * Important and wide-spread characteristic species are *Eucalyptus dumosa, E. gracilis,* and *E. oleosa.*"

"The brigalow (*Acacia harpophylla*) association and related savannah woodlands have proved to be an ideal habitat for the introduced prickly pear (*Opuntia*), and much of the brigalow country has been invaded by pest pear." (Prescott, 1931: 57.)

In South Africa

In South Africa in the Cape Region the sclerophyll brushland is known as Fynbosch, but both the Corsican name Macchia and the Provencal word Garigue are used. "Sclerophyllous vegetation is characteristic of the southwestern region of the Cape, where the rainfall is mostly in winter and the summers are comparatively dry." (Bews, 1916: 135.)

The macchia termed Fynbosch includes olive, sumac and many proteaceous plants. The Rhenosterveld is characterized by Rhenosterbosch (*Elytropappus rhinocerotis*), covers large areas, but is the result of overuse and fire. A drier stage of macchia and more heath-like is made up of many species of Erica. (Bews, 1916: 137.)

"Of the various sclerophyll communities of the lower slopes two stand out by reason of their greater complexity and less degree of xerophytism. These are the communities of large bushes among which the Proteaceae play the dominating role, and the open woodlands of the silver tree, *Leucadendron argenteum.* These communities are to be regarded as the climax types. * * * Protea Bush. * * * The most abundant plants are *Protea lepidocarpodendron,* on the northern and western sides, and *P. incompta* on the sheltered eastern slopes." (Adamson, 1927: 285-286.)

"The vegetation can be divided into three types or formations: a sclerophyll type on the slopes, the climax of which is a xerophytic bush community characterized by an abundance of even dominance of the larger Proteaceae. Several forms of this are noted with varying dominants: *Protea lepidocarpodendron* on exposed slopes, *Protea incompta* on sheltered ones, *Protea grandiflora* on sandstone talus, *Leucospermum conocarpum* on sandy soils and boulders, and *Leucadendron argenteum* on deep soils, mostly at low levels." (Adamson, 1927: 307.)

"The 'heathland' is a treeless region, largely situated on the rounded foothills and lower mountain slopes. It receives less rain than most of the true macchia, and at the height of summer fairly dry conditions frequently prevail. It is more exposed to mountain fires and to interference by man and cattle. The vegetation is seldom here more than three or four feet high and many plants are common to it and to the macchia. Species of Erica are dominant." (Muir, 1929: 52.)

"Heath passes insensibly into true macchia. This sclerophyllous type of vegetation, known in South Africa as 'Fynbos' is closely related ecologically to the macchia of the Mediterranean region, and to the chaparral of California, although the constituent species of course differ."

"True macchia, when undisturbed by fires, varies from 6 to 20 feet in height, but typical tall growth is becoming more and more difficult to find, and nearly everywhere only a low insignificant vegetation, often three to five feet high, represents the luxuriant form * * *." (Muir, 1929: 55.) This macchia is dominated largely by *Protea* species.

In California (Chaparral)

"The mild temperate districts with winter rain and prolonged summer drought are the home of evergreen xerophilous woody plants, which, owing to the stiffness of their thick, leathery leaves, may be termed sclerophyllous woody plants.* * * Wherever original conditions have not been altered by man the sclerophyllous trees and shrubs of districts with a moist winter always form dense and continuous woodland, which in most cases consists principally or exclusively of shrubs, but which occasionally becomes tree forest, although of low or middle height only." (Schimper, 1903: 535.)

"Chaparral evolved from chabarra, the Basque word for a scrub oak of the Pyrenees. The Spaniard adapted it to a dwarf evergreen oak and spelled it chaparro." (Cronemiller, 1942: 199.)

When the national forests were set up, estimates were made of the relative amount of timberland and chaparral. On the San Jacinto Forest Reserve the timbered area was estimated to be 141,000 acres and the brush-covered area 530,000 acres. "It is almost certain that the entire brush-covered area of the reserve has been repeatedly destroyed by fire in the past * * *. Fires in the chaparral destroy the brush growth only temporarily; the roots are rarely killed, and the species are all perennials, a new growth soon springs up;" (Leiberg, 1899: 355 and 354.)

"The chaparral growth has been repeatedly burned over large tracts; in fact, traces of fire exist over the entire brush-covered area." The San Bernardino Forest Reserve had 310,000 acres of timber and 370,000 acres brush-covered. (Leiberg, 1899[a]: 368).

"The chaparral covers the greater portion of the reserve below the 5,500 foot contour." The San Gabriel Forest Reserve had 100,000 acres of timber and 547,000 acres of brush-covered land. (Leiberg, 1899[b]: 368 and 370.)

"The common height of the chaparral at middle elevations on the slopes varies from three to four feet. In the canyons, where there are favorable moisture and soil conditions, it may run up to 12 to 14 feet, or fall to two or three feet where it grows on dry declivities." (Leiberg, 1900: 418.)

On the lower slopes of the San Jacinto Mountains "* * * we find the principal shrub to be chamisal which covers the hills with almost impenetrable thickets often miles in extent, while growing with it but in less abundance are several species of *Manzanita, Ceanothus, Yucca* and, on shaded slopes, the mountain mahogany, the tree poppy, and other species."

"The chaparral of the higher altitudes occurs only in isolated patches. * * * By far the most common species in these patches is the Shrubby Chinquapin * * * less common are *Ceanothus cordulatus, Cercocarpus ledifolius* and *Arctostaphylos patula.*" (Hall, 1902: 18 and 19.)

On the northern Sierra Nevada "* * * chaparral proper is found only where the forest has been destroyed by fire. * * * It is in the Shasta fir type of forest where the most intensive and destructive burns have occurred that the typical chaparral occurs." (Leiberg, 1902: 86.)

In Northern California "Chaparral being rather an elastic term, it may be stated that it is used generally in the north to describe dense brush of any and all species growing on land once under forest cover and capable of supporting forest growth. Thin brush alone or under scattered timber, as found in canyons or in low elevations where aridity or scanty soil prevents better growth, is not considered as true chaparral."

In Northern California "Fire, either with or without the aid of lumbering is directly responsible for all chaparral, the usual sequence being a forest denuded by fire, and replaced by chaparral." (Sterling, 1904:210 and 212.)

In the region of Pasadena and the Santa Ana Watershed there are three classes of plant cover. "First, pure chaparral; second, chaparral with clumps of trees scattered through it; and third, an open stand of coniferous forest at high altitudes." "The density of chaparral increases when ascending from the lower zone 2,000 to 3,000 feet to the upper zone 3,000 to 5,000 feet on the east, south and west." "The density of the cover on north exposures decreases upon passing from the lower to the higher zone. * * * Soil conditions differ widely on north and south slopes. The poorly covered south slopes are subjected to much greater erosion * * *" (Miller, 1906:147 and 153.)

"It is necessary, for two reasons, to make a distinction between the true chaparral and the mock * * * in California chaparral holds complete possession of its domain, neither gaining on nor giving way to conifers or larger deciduous trees. In other states the several chaparral species have generally taken possession of logged, burned, or otherwise denuded forest areas. Their hold upon the soil is therefore temporary. They were preceded by a forest, and will in time give way to a new one if external interference ceases." (Plummer, 1911:9.)

"Chaparral * * * in Southern California at least, * * * is often an artificial subclimax, due to fire.

"Subclimaxes due wholly or partly to the activities of man are numerous. Conspicuous causes are burning, clearing, and grazing. These produce subclimaxes in a particular area by disturbance and destruction of the community. * * * Grassland areas are produced the world over as a result of burning and grazing combined, and they persist just as long as burning recurs. Woodland is frequently reduced to scrub by fire, and the scrub often persists wherever repeated fires occur. Even when fires cease with the settlement of a region, grassland and scrub subclimaxes persist for a long time because of the more or less complete removal of the forest." (Clements 1916:180 and 108.)

The chaparral climax as designated by Clements (1920:178-193) is characterized by a list of "major dominants belonging to 10 genera, namely, *Quercus, Ceanothus, Cercocarpus, Rhus, Prunus, Amelanchier, Symphoricarpus, Rosa, Arctostaphylus, and Shepherdia.*" He recognizes "The Petran chaparral, Cercocarpus-Quercus association" and "the coastal chaparral, Adenostoma-Ceanothus association." It would be difficult to associate petran and the coastal chaparral on the basis

of climatic and soil conditions. Also, to correlate this conception of floristic dominance with the Mediterranean types the world over. The possibility of correlating a vegetation type with land use practices would indicate that greater emphasis should be placed on the physiological and ecological relationships as often expressed in their physiognomy and less emphasis on floristic similarity. "The coastal association has been more subject to fire and its responses to this agency are correspondingly emphasized." (Clements, 1920:190.)

"The coastal sagebrush association is in intimate contact with the Adenostoma-Ceanothus Chaparral * * *." "Throughout its area, the sagebrush lies just below the Adenostoma consociation of the chaparral. The ecological requirements of the latter are so nearly equivalent to those of *Salvia* and *Eriogonum* in particular that these often seem an integral part of the chaparral." (Clements, 1920:161.)

"The chaparral may be defined as a scrub community, dominated by many species belonging to genera unrelated taxonomically, but of a single constant ecological type, the most important features of which are the root system, extensive in proportion to the size of the plant, the dense rigid branching, and pre-eminently the leaf, which is small, thick, heavily cutinized, and evergreen. This definition might be applied with equal accuracy to the macchie of the Mediterranean regions; chaparral and macchie appear to be ecologically equivalent." (Cooper, 1922:7.)

Cooper (1922) has studied the location of greatest differentiation of the chaparral type. He has separated the area into the Sierra Nevada region, North Coast Ranges, South Coast Ranges, and Southern California. He has, also, worked out areas of greatest number of species of chaparral. The greatest number of species are found north and south of Monterey Bay and also on the Los Padres Forest north and east of Santa Barbara. Cooper has also divided the vegetation into broad-sclerophyll formation which is largely in the oak or forest side of the area, and the chaparral formation." This in turn is divided into the climax chaparral association in which the chamiso is the most important plant, and the conifer forest chaparral association. In this association ponderosa pine, lies just above the climax chaparral, with which it overlaps. *Arctostaphylos viscida* and *Ceanothus integerrimus* are important in the climax chaparral.

"Our conclusion, then, extended to the larger vegetation units, is that the fundamental distinguishing difference between the two broad-sclerophyll climaxes—their continuing cause, so to speak is in the water-balance and its variations, whatever the indirect factors influencing it; that its importance is equally divided between wet and dry seasons, the greater excess of supply over loss in the forest during the growing-season explaining the size and luxuriance of the plants living there, and the higher evaporation-rate in the chaparral during the dry season, with equally severe soil-moisture conditions, accounting for the absence of mesophytic species in that habitat." (Cooper, 1922:71.)

"In conclusion, then, the climax chaparral has transgressed its normal climatic limits along its mesophytic border through its invasion of the forest, fire being the causative agent; on its xerophytic border it has been pushed back a considerable distance by the grasses and xerophytic forest in the north, and by the coastal sagebrush in the south." (Cooper, 1922:82.)

That the original perennial bunchgrass may have been much more aggressive as an invading competitor than the present short-lived annual grass should influence our interpretation of present studies of the line of competition between grassland and chaparral.

"Two classes of secondary successions may be distinguished—those after occasional burning or clearing (where the basal portions of the shrubs are left to sprout) and those after thorough destruction of the original vegetation, either by the grubbing out of the underground parts or by burning at very frequent intervals.

"In the first case the succession is a short one, bringing a return practically to the original state in a very few years. * * * Most of the species sprout readily from the stump, and the new shoots grow with astonishing rapidity, even in the driest part of the dry season. * * * With the first rains, seeds which have blown in or lain dormant germinate in enormous number and great variety * * * Ceanothi of several species, when present in large numbers, seem to be indicators of recent disturbance."

On a quadrat near Palo Alto after a burn "Of the first arrivals, 13 percent were *Adenostoma* and 62 percent *Ceanothus cuneatus,* although the original growth was nearly pure *Adenostoma.*" (Cooper, 1922:86.)

"Greasewood *(Adenostoma fasciculatum)* is the most plentiful of all chaparral species. It is found almost everywhere throughout the range of the Elfin Forest, and is estimated to form about one-third of all the cover." (Fultz, 1923:41.)

"The lower foothill belt is a grassland formation, sometimes with a scattered growth of *Quercus douglasii* and *Q. engelmannii.* * * * Next above the lower foothill belt is the chaparral belt, or hard chaparral, a very remarkable formation, so called by the writer to distinguish it from the soft chaparral. It has an average altitude of 1,000 to 4,000 feet and is characterized by the presence of extensive brushlands consisting of shrubs, some of which have been reduced in size from tree species. Most of the species represent extreme arid-land types and possess various markedly xerophytic structures, such as small or reduced leaves, entire leaves, thickened epidermis, hard and very dense wood, vertically placed leaves, small flowers, and seeds adapted to xerophytic conditions. The most widely spread and characteristic species are *Ceanothus cuneatus, divaricatus* and *sorediatus, Arctostaphylos glauca, glandulosa, viscida,* and *canescens,* and *Cercocarpus betuloides.* * * * True or hard chaparral is always a mixed formation. Chamise, characteristic of the same sub-life zone, is commonly a pure formation of *Adenostoma fasciculatum.*

"Chaparral is, for the most part, a firetype formation and shows evidences of long-continued fire-ravage. In all likelihood the factor of fire has contributed to the xerophytic character of the chaparral, because fire has, without doubt, run through the chaparral belt for many thousands of years, very likely 100,000 years at least. * * * The responses are of two main kinds and I have named them as follows: 1. Empyroism (Empyrophytes). Under which the individual continues to live. Some species, such as *Arctostaphylos glandulosa,* develop the root-crown horizontally in the form of woody platforms at and just below the surface of the ground after fire, and from these woody platforms crown-sprouts arise for the replacement of the shrub-crown. As fires run year after

year, or decade after decade, the woody platform continues to increase in diameter horizontally, and often becomes three to five feet broad. Other species, such as *Adenostoma fasciculatum,* form bulbous or carrot-like root-crowns which continue to enlarge under successive fires. 2. Pyrodaptism (Daptophytes). Under which the individual dies. Certain species, such as *Arctostaphylos sensitiva,* are shallow—rooting and are killed outright by chaparral fires. * * * They must depend for regeneration of the species wholly upon seeds. Seeds are produced in great abundance, germinate freely after fire and promptly establish seedlings on a burn. Such seedlings have the power to come into the reproductive stage in a short period—sometimes in five or six years." (Jepson, 1925:6 and 7.)

Köppen recognizes two types of Mediterranean climate, a hot summer type, "olive climate," and a cool summer type, "heather climate." "This distinction works fairly well in California.

"In the Sacramento Valley hot summer Mediterranean is the prevailing climate. Cool summer Mediterranean climate characterizes the Coast Range region of Central California. The lowlands of the area are generally grass covered, often with scattered oaks covering the open formation, a park landscape. Chapparal occupies considerable areas of the hills * * *." (Russell, 1926:81 to 82.)

"Even prior to the settlement of California it is reasonably certain that fires did much to bring about changes in the distribution and character of the chaparral, as they have surely done in recent years." "The commonest type of chaparral is that in which *Adenostoma fasciculatum* (chamise) is the dominant shrub, and often almost the only one. In relatively dry situations this type is common on both north and south slopes, often clothing ridge after ridge with remarkably uniform cover." (Shreve, 1927:37.)

"The vast chaparral association of California and Lower California, in its present life-form, is the product of Pleistocene and Recent periods. The characteristic structures appear to have developed in association with a progressively drying climate—decreased precipitation and decreased humidity. * * * Concurrently with these phenomena wild fires (originated by lightning or by the native tribes during the period of human occupation) played an important role in the development of the chaparral. Nearly all members of the chaparral show such influence.

"The three species *Arctostaphylos patula, stanfordiana,* and *manzanita,* are only slightly dissimilar as evinced by the usual morphological criteria. Their singular unlike behavior under fire is as follows: 1. *Arctostaphylos patula.* The individuals are not killed even by intense chaparral fires * * *. The root crown has developed a tuber-like hypogeal body which is uniformly resistant to destruction by ordinary chaparral fires. 2. *Arctostaphylos manzanita.* The individuals are killed outright by chaparral fires of even low intensity. 3. *Arctostaphylos stanfordiana.* Behavior similar to *A. manzanita.* Regeneration in the case of these two latter species shows the following adaptations: (a) Abundant production of seed, the seed itself protected by very dense and impervious layers of carpellary tissues. (b) The seeds hibernate and rest for indefinite periods, but germinate freely under the abrupt changes of conditions produced by fire. (c) Abbreviation of the period beween germination and reproduction." "All of these features (a), (b), and (c), indicate characteristic fire-type conditions.

"Large scale fires are now reducing forest lands to brush lands of semi-desert character." (Jepson, 1930:114-116.)

"Chamiso *(Adenostoma fasciculatum)*, often called chamise and greasewood, is an evergreen, somewhat resinous, mostly spreading shrub two to ten feet high, or occasionally higher, having small fascicled leaves, and small white flowers. * * * one of the most common and characteristic chaparral species of California, * * *. It quickly invades and occupies burns, and it is possible that its present abundance is due in large measure to this fact. Chamiso is especially characteristic on long steep slopes where it forms a chamisal, or dense impenetrable thicket, which travelers have frequently likened to the heaths of the Old World. It is almost everywhere regarded as a pest * * *." (Dayton, 1931:53.)

In experiments on the effect of high temperature on seeds of chaparral plants such as *Adenostoma* and *Ceanothus* it was found that they were not killed by high temperatures. "This may partially account for the aggressive invasion of shrubby plants on burns and the formation of typical brush fields as a result of forest fires." (Wright, 1931:686.)

"In California the 'climax chaparral association' (Cooper) is the dominant community over the whole of the southern Coast Ranges and the mountains of southern California and northern Lower California. *Adenostoma fasciculatum* is for the most part the dominant species, but many evergreens are conspicuous and quite a few consociations will be recognized within the association. Many species of *Arctostaphylos* and of *Ceanothus* are prominent." (Rübel, 1936:274.)

"Fires have always been of frequent occurrence in chaparral. * * * In much of the chaparral of the Santa Monica Mountains, no specimens over 12 years of age could be found. * * * *Adenostoma fasciculatum* was the outstanding species of the area, constituting 38.6 percent of all the vegetation touching the transect line * * *. The species of second importance was *Ceanothus macrocarpus* which made up 16.5 percent of the vegetation * * *. *Adenostoma fasciculatum* was found to be most abundant on all exposures. On the southerly-facing slopes it constituted 58.8 percent of the vegetation touching the transects * * *. The more xeric conditions of the southerly slopes do not favor the broad-leaved species but seem to have little effect on *Adenostoma*.

"The almost weekly rains maintained the moisture at somewhere near its field carrying capacity during January and February." While soil water was available at all depths from January 1st to June 15th, none was available July 16th to October 14th. "During several months of the dry season, July to the middle of November, the moisture in the soil at the station being considered was below the wilting coefficient and the plants were, therefore, unable to get enough water for normal activities and were practically in a state of dormancy." (Bauer, 1936:420, 424, 425, 431 and 433.)

On the Santa Cruz Mountains unit "Associations of the more or less hard-woody shrub species * * * the 84,080 acres coming under this classification" make up about 9 percent of the area. "Chamise being characteristic of relatively warm exposures and poor soils, the type is found most extensively on the interior side of the main divide. There, and in other sections as well, it occurs predominantly on southerly and westerly exposures and along ridges. From such localities its spread to adjacent areas is favored by recurrent fires." (Jensen, 1939:13 and 15.)

"At no place within these 'chaparral' districts does the summer precipitation exceed 20 percent of the yearly total, and in the areas of greatest concentration the summer precipitation is less than 10 percent of the total. * * * In areas where the precipitation averages much over 30 inches per year, conifers usually replace the chaparral species. * * * The great concentration of chaparral in the south Coast Ranges bears a close relation to the average precipitation which is 17.38 inches. The variation is from 6 inches to more than 45 inches of annual rainfall." (Sampson, 1940:1 and 2.)

"The hard brush areas of California, although composed of many species, are dominated for the most part by three genera of plants, popularly called chamise, manzanita and ceanothus. Chamise is the most common and abundant, occurring to some extent in most of the brush areas. * * * Ceanothus and manzanita are also found in most of the brush areas but are composed of many species * * * extremely woody, vary from 2 to 15 feet in height, are called 'hard brush.' There are 'two kinds, sprouting and nonsprouting.' Other important plants composing the hard chaparral are oaks, maples, mahogany, hazel, buckeye, poison oak, toyon, sumac, yerba santa, ribbonwood, choke cherry and several others notably in the rose family.

"Soft chaparral is commonly found as an understory in coniferous forests. It is composed of such species as ninebark, creambush, California huckleberry, common snowberry, thimbleberry, and wild currant.

"The northernmost portion of the brush areas in the Coast Ranges is composed predominantly of chaparral species, with no chamise present. From Shasta County to Santa Barbara County, chamise and chaparral are more or less intermixed, but the valley side of the coast range is dominantly chamise, whereas the coastal side consists of chaparral and mixed chamise and chaparral.

"The southern portion of the Coast Range brush fields is dominantly chamise with an extensive area of mixed chamise and chaparral in the San Gabriel and San Bernardino Mountains, and with true chaparral occurring through the higher parts of the Cuyamaca Range immediately below the coniferous forest and in small stands along the lower limits of the chamiso belts.

"The extreme southern portion of the Sierra region is composed of various chaparral species, exclusive of chamise. From Tulare County northward to the point at which the Bear River crosses the Sierra foothills the brushlands are composed mostly of mixed chamise and chaparral with occasional restricted stands of pure chaparral.

"North of the Bear River to the point of junction with the northern Coast Ranges, there is no chamise, the area being composed of chaparral similar in general character to that of the northern-most part of the Coast Ranges.

"In the southern part of the range most species start growth with the first heavy rains in the fall, usually November or December, whereas in the most northern part, growth is usually slight until the warmer spring period begins. The period of maximum activity for all species occurs in the spring months, especially March and April, when soil moisture is still abundant and soil and air temperatures are especially favorable for growth." (Sampson, 1940:1 to 3.)

In Bell Canyon of the San Dimas Experimental Forest Horton (1941) reports "The term 'chamise chaparral' is used in this paper to indicate vegetation that has chamise as a dominant shrub. This association is one of the most important in the chaparral formation of Southern California. Along the south face of the San Gabriel Range the two dominant species of the chamise-chaparral are the chamise and *Ceanothus crassifolius* with a small percentage of other chaparral and sage species. * * * The presence of chamise to an amount of over 20 percent of the total vegetation density distinguishes chamise-chaparral from other chaparral associations.

"On the more xeric sites with steeper than average slopes or with shallow soil, the chamise-chaparral is replaced by an open growth of vegetation which for the purposes of this paper has been called the chamise-sage association. * * * The northerly-facing slopes and the other more protected sites are covered with a so-called oak-chaparral with *Quercus dumosa* and *Ceanothus oliganthus* as major dominants.

"Chamise-chaparral, the most abundant of the associations in Bell Canyon, occupies 147 out of the 225 quadrats summarized * * *. In general as compared to the other chaparral groups the stand is more open, with an average vegetation density of 48.20 percent. *Adenostoma fasciculatum* and *Ceanothus crassifolius* are the dominant shrubs with average density or area percentages of 18.93 and 13.30 respectively." (Horton, 1941:459-461.)

On the eastern Santa Monica mountains "*Adenostoma fasciculatum,* the chief shrub of the chaparral was plentiful on both exposures, but reached about twice the size on the northerly as on the southerly exposure * * *. Autumnal growth began in general about mid-October with the first rain, 2.5 inches, and ceased during the interval from about the middle of November to the middle of December due to low soil temperature of around 60 degrees F. Growth began again in February with some species and as late as April with others. Growth stopped in the different species from about the middle of May to late in July; in most instances from mid-May to early June." (Watkins and deForest, 1941: 80 and 83.)

The chaparral and coastal sage associations of California have their present centers of distribution in the Diegan area, that is, in San Diego County and in adjacent Baja California.

"It seems probable that both communities have had a similar historical development and that both are derivatives of the Miocene vegetation which entered the southwestern United States from the northern Mexican Plateau." (Epling and Lewis, 1942:462.)

In a sector of the western slope of the Sierra Nevada foothills, the vegetation map shows "Forest types of the pine, pine-fir, and fir belts comprise over half of the total natural vegetation cover. Grassland types, located chiefly in the lower foothills, cover nearly one-third the area. Woodland and chaparral types, located in general above the belt of grassland, make up about one-sixth of the total." The woodland lies for the most part in scattered areas in the upper or near the contact line between grassland and pine and pine-fir forests while the chaparral occurs in scattered patches as above but extending through to the subalpine forest where the largest areas are found. The chamise-chaparral is found mostly in the grassland zone south of Auburn. The grassland

with brush problem forms a belt just below the conifer forest belt. "The classified area of the two foothill zones comprises 1,422,000 acres of which approximately 30 percent is grassland without a brush problem, 30 percent grassland with a brush problem, 20 percent conifer forest, 10 percent woodland, and 10 percent chaparral." (Weeks, Weislander, Josephson and Hill, 1943:21 and 37.)

In Tehama County the east side according to Fausett (1943:8-10) is more mixed, containing (a) the mixed-brush type being chiefly wedgeleaf ceanothus, greenleaf manzanita and blue oak, often on thin soils and not potential forest land, (b) the manzanita-black oak type adjacent to timberline on deeper soils which were originally timber land, greenleaf manzanita, black oak, sweet birch, poison oak, live oak and wedgeleaf ceanothus, and (c) the live oak-manzanita type on better soils in foothill areas generally along the canyon bottom and north slopes and in coves and pockets, and chiefly the live oaks (*Quercus wislizenii* and *chrysolepis*). On the west side the important types are (a) the chamise type and (b) the whiteleaf manzanita-blue oak type.

(A) The Chamise Type. "Where this type adjoins timberland, chamise is found in pure stands and with a mixture of other species such as greenleaf, and whiteleaf manzanita, wedgeleaf ceanothus and scrub oak. This type is found all along the west side and covers a wide belt from the woodland oak type in the lower foothills to the lower timberline. * * * Chamise invariably occupies the poorer-grade soils, often being the only species present. It seems to invade woodland-grass types in a few places where the soil is impaired and the grass cover is thinned.

(B) The Whiteleaf Manzanita-Blue Oak Type. "* * * Occurs in the lower foothills below the chamise belt. In Tehama County the distribution of it is scattered and limited, but in Shasta County it covers extensive areas. It consists of whiteleaf manzanita (nonsprouting) wedgeleaf ceanothus and live oak. The soils are usually eroded to mineral soils. Most of the woodland types adjoining these brush areas have scattered brush species in them, and it is believed that burning or other misuse of the woodland has converted it to brushland." (Fausett, 1943:8-10.)

"Chamise is not, as generally accepted, confined to rocky, sterile or poor, shallow, gravelly soils, but is found intermingled with other broad leaved shrubs on various soils where the general appearance of the shrubs show fair to good growing conditions. * * * The pure chamise type is usually composed of an open stand of low brush. Large openings with bare soil predominate. Mixed brush stands of Scrub-Oak, *Manzanita, Ceanothus* spp., etc., usually on north slopes, is denser and more vigorous." (Smith, 1946:2 and 6.)

An extensive study of the ecological characteristics of the chaparral association was made by Sampson (1944).

"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." Of the eight oaks listed, all are sprouting species as are poison oak, California buckeye,

chamise, toyon, western mountain mahogany and yerba santa. Of the manzanita species listed five are sprouting and eleven nonsprouting and of the Ceanothus six sprouting and eleven nonsprouting. "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." (Sampson, 1944:9.)

"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. Eighty percent 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 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 these 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. * * * 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. * * * 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.

"Chaparral is tolerant of widely different soil conditions 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 where other plant forms fail to grow. These soils are usually shallow and are frequently interspersed with stones or concretions." (Sampson, 1944:11-13.)

"On the basis of climatic variation, and differences in floristic composition, the California chaparral association may conveniently be separated into five ecological regions. * * * (I) North Coastal Region, (II) Central Coastal Region, (III) South Coastal Region, (IV) North Sierran Region, and (V) South Sierran Region.

North Coastal Region. This region extends northward from San Francisco Bay to Trinity and Shasta Counties. 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.

"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. 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.

"South Coastal Region. This region extends through the Counties of Ventura, Los Angeles, and San Bernardino, south to Lower California. * * * 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 extents south through the Cuyamaca Range, from Riverside County into San Diego County.

"North Sierran Region. This region extends from Butte and Tehama Counties, southward along the Sierra Nevada foothills to Mariposa County. 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.

"South Sierran Region. This region forms a rather narrow strip along the foothills, through Tulare County, and into central Kern County. 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 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." (Sampson, 1944:13-18.)

DOMINANT CHAPARRAL SPECIES IN EACH OF THE FIVE REGIONS

(Sampson, 1944:14 to 17)

	I North coastal region	II Central coastal region	III South coastal region	IV North Sierran region	V South Sierran region
Sprouting					
California scrub oak	X	X		X	X
Chamise	X	X	X	X	X
Eastwood manzanita	X	X	X		
Interior live oak	X	X	X		X
Leather oak	X				
Western mt.-mahogany	X		X	X	X
Canyon live oak		X	X		
Chaparral whitethorn		X	X		
Greenbark ceanothus		X			
Mission-manzanita			X		
Ribbonwood			X		
Brewer oak				X	X
Indian manzanita				X	
Toyon				X	
Woodyleaf ceanothus				X	
Non-sprouting					
Common manzanita	X				
Hoary manzanita	X				
Stanford manzanita	X				
Wedgeleaf ceanothus	X	X	X	X	X
Whiteleaf manzanita	X			X	
Bigberry manzanita		X	X		
Jim Bush		X			
Parry ceanothus		X			
Wartleaf ceanothus		X			
Bigpod ceanothus			X		
Cupleaf ceanothus			X		
Hairy ceanothus			X		
Parry manzanita			X		
Mariposa manzanita				X	X
Wartystem ceanothus			X		

Chamise and wedgeleaf ceanothus are common to all five regions. California scrub oak, interior live oak and western mountain mahogany are common to four regions. Wedgeleaf ceanothus, common to five departments, is the only one of the nonsprouting species which is common to more than two regions. It is interesting to note that the temperatures beginning with the highest are V, IV, III, I, and II, and the rainfall from the highest to the lowest are IV, I, III, II, and V. (Sampson, 1944:13-17.)

Description of individual watersheds on the Los Padres National Forest brings out the importance of chamise which varies from important to dominant in most of the areas. *Ceanothus crassifolius* is by far the most important associate. These surveys are very important to an understanding of the structure and physiology and ecology of the vegetation. (Coleman, Bean and Horton, 1945.)

Similar studies on the Angeles National Forest were made and show also the vast importance of chamise and certain species of ceanothus, manzanita and oak. (Horton, Coleman, and Bean, 1945.)

"The vegetative cover of the Angeles National Forest is predominantly chaparral * * *. Nowhere in the chaparral or sage formation did we observe any change in the spread of the various associations due to fire * * *. It must be emphasized that fire spread the chaparral types into the big cone spruce and pine forest associations with partial or complete loss of the original forest cover. Big cone spruce especially at the lower elevations has suffered greatly from this action in the last century." (Horton, 1945:1.)

The average density of chamise-sage which occurs at from 1,000 to 2,000 feet elevation, at an age of 20 years, is 40 percent. It is dominated by chamise and *Salvia mellifera* and *S. apiana*. Pure chamise with a small amount of *Arctostaphylos glauca* at 1,000 to 3,000 feet has a density of 35 percent at the age of 20 years. Chamise-ceanothus, chamise with *Ceanothus crassifolius* and some *Arctostaphylos glauca* at 2,000 to 3,500 feet elevation has a density of 65 percent at 20 years of age. Chamise-manzanita composed of chamise with *Arctostaphylos glandulosa, Ceanothus divericatus* and some *Arctostaphylos glauca* at 3,000 to 4,500 feet elevation has a density of 65 percent at 20 years of age. (Horton, 1945:7.)

"In summary, some phase of chamise-chaparral occupied practically all of the south-facing slopes throughout the lower coastal chaparral region.

"*Arctostaphylos glauca* kills when burned and the seedlings require a long period to become large enough to set seed. Consequently repeated burning may tend to remove this species from the chaparral. Conversely, presence of large amounts of *Arctostaphylos glauca* would probably indicate that the area has not suffered repeated burning.

"Upper coastal chaparral between 4,000 and 6,000 feet altitude. On south-facing slopes oak-manzanita chaparral predominates with some chamise on the most Xeric slopes. This type is dominated by *Quercus wislizenii, Q. chrysolepis, Arctostaphylos glandulosa, Ceanothus divaricatus,* and other chaparral species. All species, except *Arctostaphylos glauca* are vigorous sprouters and recovery is quite rapid though erosion losses may be large in the first few years.

"On north-facing slopes, either Quercus chrysolepis woodland or big cone spruce forests are found. In the spruce there is always a sprinkling of oak and severe fires will convert the forest to oak woodland. The relation between the two seems to tbe wrapped up in past fire history. The oak is a fire shrub and will form a cover similar to chaparral after burning. In time individuals become trees to form the woodland stands. Fires burn incompletely through the woodland leaving many individuals with the crown untouched so as to preserve the forest-like character of the more protected spots. It is in these spots that spruce invades and with protection from fire forms a forest. Spruce reaches its best development in this zone and seems in some of its areas to be holding its own. However, it must be stressed that repeated fires threaten its survival." (Horton, 1945:9 to 16.)

"The vegetation cover of the San Bernardino National Forest is composed about equally of chaparral and forest types, with important minor elements of sage, grass, and woodland.

"Here as on the Angeles big cone and pine are replaced by chaparral as a result of fire.

"The zone of chamise chaparral extends for the full length of the coastal front of the San Gabriel, San Bernardino, and San Jacinto Mountains. The zone enters Cajon Pass and extends around on the desert side of the San Bernardino Mountains to Deep Creek. It also enters San Gorgonio Pass on both sides to a few miles east of Cabezon. Its average upper limit is 4,000 feet. The rainfall is great, from 20 to 40 inches.

"This large zone is definitely a fire zone and one which has developed through the ages with fire as a factor of the environment until all species are marvelously adapted to withstand burning.

"Chamise chaparral is the predominant vegetation association in this zone. It is variable and separates readily into several subtypes but in general any association with *Adenostoma fasciculatum* 20 percent or more of the vegetation cover is classed as 'chamise' or more properly 'chamise-chaparral' if other shrubs are present. The chamise when pure produces a thin cover, usually 50 percent or less density and almost no litter, but in better soils cover density will average 60 percent with a corresponding increase in the litter layer.

"Chamise-ceanothus always has a major codominant *Ceanothus crassifolius,* and frequently, but often completely absent, *Arctostaphylos glauca.* The *Ceanothus* is a relatively short-lived plant whose seeds germinate freely after fire. Individuals start to die at about 40 years with the result that the cover begins to open up at that time and soon approaches pure chamise in character." (Horton, 1945a:1 to 5.)

"The vegetation cover of the Cleveland National Forest is composed largely of chaparral, woodland and sage types. Almost 50 percent of the area of the National Forest is dominated by chamise-chaparral. Oak chaparral and sage occupy over half of the remaining area with woodland and grassland types next in importance." (Horton, 1946:1.)

On the Los Padres National Forest "Chamise-chaparral stays chamise-chaparral and sage will stay sage, regardless of the frequency of burning. There is much chaparral that seems to be the direct cause of fire within former sage, grass and woodland types. Chaparral is undoubtedly spreading under the present frequency of burning. In the chaparral areas, fires have burned into the big cone spruce and other forest associations with partial or complete loss of the original forest cover."

Pure chamise has a density of 30 percent at an age of 20 years and ranges from 1,500 to 2,500 feet elevation. Chamise-sage, chamise with *Salvia mellifera, Lotus scoparius,* and *Eriogonum fasciculatum* has a density of 35 percent, ranges from 1,500 to 2,500 feet. Chamise-ceanothus, chamise with *Ceanothus crassifolius, C. cuneatus* and *C. megacarpus* ranges from 500 to 4,500 feet and has a density of 65 percent. Chamise-manzanita is chamise with *Arctostaphylos glandulosa, Ceanothus divericatus* and *Quercus dumosa,* ranges from 2,500 to 5,000 feet and has a density at 20 years of 65 percent. Pure chamise is the lower elevation, poorer site phase of the association. (Horton, 1946a:6.)

"Almost all of this type in this forest has been burned in recent years so that in general it is young cover and does not yet show the reversion to stand from a dense ceanothus stand to the pure chamise that is found on the Angeles and on the other southern forests. The ceanothus is a relatively short-lived plant and seeds germinate freely after fire. Fires thus stimulate the growth of ceanothus. However, the individuals start to die at about 40 years, with the result that the cover begins to open up at that time and soon approaches pure chamise in character.

"Chamise-manzanita is a high elevation phase of the chamise association * * *. The dominants found associated with the chamise are *Arctostaphylos glandulosa, Ceanothus divaricatus, Cercocarpus betuloides* and occasionally *Quercus dumosa.* All the species are vigorous stump sprouters.

"Oak-chaparral is found abundantly on north-facing slopes. *Quercus dumosa* is the principal dominant. *Ceanothus oliganthus, Cercocarpus betuloides* and occasionally other species of *Ceanothus* are commonly associated dominants. Recovery after fire is rapid.

"Upper Coastal Chaparral. On south-facing slopes of the mountain portion above 4,500 feet altitude, oak-manzanita chaparral predominates with some chamise on the most xeric slopes. This chaparral type is dominated by *Quercus wislizenii, Q. chrysolepis, Arctostaphylos glandulosa, Ceanothus divaricatus, Cercocarpus betuloides,* and *Garrya veatchii.* All species are vigorous sprouters. On the north-facing slopes either *Quercus chrysolepis* woodland or big cone spruce forests are found. There is always a sprinkling of oak in the spruce, and severe fires will convert these spruce forests into oak woodland." (Horton, 1946[a]:1 to 11.)

THE EFFECT OF THE REMOVAL OF THE VEGETATION COVER BY FIRE

Fire can destroy the plant cover changing a green transpiring surface to a blackened area with no transpiring surface and little moist surface to evaporate water. The destruction of forests and brushlands by fire removes from the surface of the earth a cover which is constantly equalizing the sun's light and heat by transpiration in which process heat is absorbed equivalent to the latent heat of steam (536 degrees C. per gramme) in changing water to vapor. Undoubtedly the surface of the earth is appreciably cooled by this process.

ON CLIMATE

That the many local effects or the effects on microclimate would affect precipitation to an appreciable degree is a matter of great doubt, and has been for a long time. "The scientific reputation of many writers who have maintained that precipitation has been diminished in particular localities by the destruction of forests, or augmented by planting them, has led the public to suppose that their assertions rested on sufficient proof. We cannot affirm that in none of these cases did such proof exist, but I am not aware that it has ever been produced." (Marsh, 1874:196.)

That rainfall is increased by forests has been affirmed and denied. "Any local modification of temperature and humidity caused by the presence or absence of forest covering * * * could not extend upward more than a few hundred feet * * *." (Moore, 1910:38.) There is, however, abundant evidence of the deterioration of land due to the removal of the plant cover. (Marsh, 1874, Willoughby and Sonderegger, 1932, Trevor, 1935, Zon, 1927.)

"After careful review of the data available, we are of the opinion that at various times and in different countries, altogether too much credence has been placed in the supposed influence of forests in increasing the total rainfall of a country. We can find no reliable evidence to this effect and would point out that the topographical features of a country exercise a far greater influence upon precipitation than can be exerted by forests alone, however vast. On the other hand, there is evidence to show that forests have some influence upon the local distribution of rainfall, by lowering the temperature of moisture-laden winds, and in other ways, and we affirm that from this viewpoint a judicious distribution of forests throughout a country is highly beneficial." (Trevor, 1935:8.)

"Studies of atmospheric-moisture relations reveal that the absolute amount of water vapor in the air has no immediate relation to the quantity of rainfall a region may receive. In fact, it is frequently found that a small concentration of water vapor in the lower atmosphere is associated with a greater amount of precipitation.

"Although it has been recognized for some time that the principal portion of continental precipitation is returned to the atmosphere by

evaporation and that this moisture forms a formidable supply of water vapor for a later cycle of precipitation, it was not known until recently that most of the moisture evaporated from the land is carried to the ocean and consequently is not immediately available for reprecipitation over continental areas. This is so because this moisture is generally absorbed by excessively dry continental air bodies that pass entirely across the continent without any reprecipitation. Continental precipitation is derived not from land-evaporated moisture but chiefly from great maritime air bodies whose moisture is obtained by evaporation from oceanic areas." (Holzman, 1937:3.)

"From a study of the water cycle we learn that the meteorological forces involved in precipitation are of such magnitude that no human endeavor can even modify them significantly. Runoff, on the other hand, is highly responsive to human management. Careless and promiscuous denudation of the land inevitably causes accelerated soil erosion and increased runoff, with resultant flood hazards. * * * We are limited in our ability to modify the hydrologic balance; we must take our rainfall as it comes, but we can influence runoff and evaporation." (Holzman, 1941:536.) (See also Rossby, 1941.)

ON MICRO-CLIMATE

There seems to be abundant proof that micro-climate is affected, and also that productive areas have been reduced to deserts, but that does not necessarily involve a decrease in precipitation and can be accomplished by increased runoff, and such an unfavorable condition at the soil surface that plants cannot grow. In Mendocino County, hills and ridges now supporting a very sparse worthless nitgrass cover giving way to mosses and soil lichens were once covered by a luxuriant redwood and Douglas fir forest. With no diminution of rainfall such a change can easily be brought about.

There is abundant evidence to show that a plant growing on a forest floor or in a brush cover or even in a field with other plants is being produced under less extreme conditions of temperature, wind movement and light, with resulting reduced transpiration or evaporation rate than if produced in the open. "* * * wheat grown in pots sunk in trenches and surrounded by a field of grain has a water requirement * * * 10 percent below wheat grown * * * in a freely exposed wind-swept position." (Briggs and Shantz, 1914:3.)

The increased dryness of the air following denudation or fire in vegetation, increase in temperature due to removal of transpiring plant cover and the blackening of the earth surface, free exposure to light and to air movement greatly increases the rate of loss of water from new plants which may sprout from old roots. This also affects the seedlings and is probably one of the chief causes of the failure of certain seedlings to survive until afforded sufficient protection by other plants better adjusted to the exposed conditions. These factors, light intensity, humidity of the air, and also air movement and temperature are all affected by the removal of the plant cover. All of these factors, increased by denudation, increase the loss of water from shoots or seedlings. (Briggs and Shantz, 1916, 1916a, and 1917.)

"Firing invariably—if for a short period only—results in the aerial factors of greater importance—light-intensity, sun-temperature, true

aerial or shade-temperature, humidity, wind-rate, evaporativity (the complex of light, heat, humidity, wind)—being made more severe than they were before the fire, upon the surface of the soil." (Phillips, 1936:39.)

ON THE SOIL

"It has often been useful to set fire to sterile fields and burn the light stubble with crackling flames: whether the lands thereby receive secret forces and rich nourishment, or every vice is cooked out of them by the fire, and useless water is evaporated; or that heat opens up more vents and hidden pores by which the moisture can reach the new plants, or, rather, hardens and closes the open veins, lest scanty rainfall and the violent force of the fierce sun or the piercing cold of Boreas parch the soil." (Virgil, Georgics I:84-93.)

"The burning of grasslands which it is desired to ultimately aforest with sal therefore is obviously injurious owing to the destruction of all humus and organic debris." (Hole, 1911:126.)

The harmful effects of heating soils have been summarized. "Both beneficial and harmful compounds were produced by heating the soils and were isolated. This bears out the experience of previous investigators with cultural tests. Cultural tests in these soils and their extracts showed that the heated soils gave a poorer plant growth." (Schreiner and Lathrop, 1912:37.) All organisms which normally occupy a fertile soil are killed by heat but nitrogenous materials are thereby liberated and made available. Heating produces an increase in soluble nitrogenous material, but harmful effects predominate.

"Comparing crop production on the burned virgin soil with production on like soil unburned, sunflower produced equally well or better; hay about as good; oats and potatoes distinctly less. Clover catches remarkably well in ash." (Thompson, 1925:19.)

"Fire reduces to a measurable extent the coloidal clay constituents of the surface inch of soil, as measured by sedimentation, and also reduces the organic material as here evinced by digestion in hydrogen peroxide. * * * Fire increases the amount of certain plant nutrients, notably, nitrate nitrogen, as shown when analyzed in 1:1 water extract solution." (Craddock, 1927:31 and 32.)

"Forest humus is made up (1) of a number of residual constituents, such as celluloses, hemicelluloses, fats, waxes, etc., of various plant products (leaves, twigs, roots, mosses, etc.) which are undergoing decomposition; (2) of the constituents of the plant products which are more or less recent in decomposition, such as lignins, cutins, tannins, resins, etc.; (3) of the microbial cells (fungus mycelium, spores, bacterial cells, protozoa, worms, etc.) synthesized in the process of decomposition of the natural or organic materials continuously added to the soil; and (4) of the products of decomposition of the natural materials and cell products, such as organic acids, ammonia, etc." (Waksman, Tenney and Stevens, 1928:142.)

"The largest source of available nitrogen for plant growth is produced in the surface soil through decomposition of dead organic matter, which the forest constantly yields to the soil in the form of leaves, needles, twigs, fruits, windfalls, etc." (Owe, 1930:2.)

In Florida yearly burning for 42 years decreased the organic matter 121,289 pounds per acre to a depth of 45 inches. (Barnette and Hester, 1930.)

Fire affects only the surface soil, the *A* horizon. "The rate of growth, both of the annual and perennial species studied, was appreciably greater in soil horizon *A* than in horizons of lower depths regardless of the soil series or the species used. Likewise, the amount of plant material produced in soil horizon *A* was consistently greater than on soil horizon *C*, regardless of species or soil series." (Sinclair and Sampson, 1931:172.)

"When fire sweeps an area covered with vegetation the latter is reduced largely or completely to mineral ash. The ash is shortly dissolved and carried into the soil where it becomes available for plants, especially those with superficial root systems. Where plants grow for a period of years without being burned, only a limited amount of mineral substance is returned annually in the leaf drop. When burning occurs the mineral in the surface débris as well as in the woody portions of plants is returned and made available for new growth." (Storer, 1932:324.)

"Burning and the increased nitrification increased the soluble mineral nutrients in the soil, probably for some time after burning. Burning destroys not only the organic matter on top of the soil, but may destroy some of that in the immediate soil surface. The temporary effect of burning may be helpful at least in some respects, but, since the productivity of the forest soil depends upon gradual mineralization of the fallen litter, it does not appear reasonable to expect continuous and often repeated burning to improve forest soil fertility." (Fowells and Stephenson, 1934:181.)

"The top soil oftentimes has been so severely baked and has had most of its rich supply of the important macro- and microorganisms burned out of it that it is impotent for a long time to reproduce the more exacting seedling tree growth." (Fritz, 1932:21.)

"Forest soil is much more porous than field soil * * *. Where the forest cover is adequately maintained, second-growth forest soil does not lose its porosity unless grazing has been practiced to excess or the litter has been destroyed by fire." (Auten, 1933:1014.)

"The soils subjected to frequent fires were found to be consistently less acid, and to have higher percentages of replaceable calcium and total nitrogen. An indication was found that these burned soils were also characterized by larger quantities of organic matter as judged by loss on ignition." (Heyward and Burnette, 1934:38.) (See Waksman, 1936.)

"Analysis of the soils taken after eight years of annual grass burning as compared with complete fire protection on rolling longleaf pine land in southern Mississippi showed 1.6 times as much organic matter in the burned-over soils as in soils protected from fire." (Greene, 1935: 820.) Again the organic matter in burned soil was 4.32 and in unburned soil 2.63 percent. (Greene 1935[a]:431.) "The average content of organic matter in all samples from burned areas was 4.32 percent as compared with 2.63 percent for the unburned areas or a ratio of about 1.6: 1." [1]Analysis made by ignition method. "The nitrogen was 0.072 percent on burned and 0.048 percent on unburned areas." (Greene, 1935[a]:3.) (See Waksman, 1936.)

"At McNeil, Mississippi, after fire had been excluded for seven years the surface soil was found to be less dense and more porous. The results from over 13,000 determinations of mechanical penetrability showed that protection from either annual burning or grazing alone had softened the surface from one to six times. This protection had likewise increased the capacity of the soil to absorb water from one to five times. * * * Thus although exclusion of fire benefits the soil physically, frequent burning benefits the soil chemically by slightly increasing the available supply of plant nutrients." (Demmon, 1935:332.) (See Waksman, 1936.)

"Studies to date reveal that soils protected from fire are much more penetrable and porous than soils subjected to fire. * * * Soils subjected to frequent fires show a slightly higher ignition loss due probably to charcoal. They contain more replaceable calcium and probably other ash constituents, and are, therefore, slightly less acid. They likewise contain a higher percentage of total nitrogen. No evidence is at hand to indicate severe soil degradation due to periodic fires, nor is there any indication that the forest soils of the longleaf pine region are definitely benefited from fire." (Heyward, 1936:42.)

"In other words, the black humus is an unfailing indication of a calcareous soil; and agriculturally it forms the crowning glory of soils. Its blackness makes it appear so abundant; in reality, when the amount is determined by the Grandeau method of extraction (not by the delusive one of combustion), the amount producing these dark tints is often found to be surprisingly small." (Hilgard, 1891:10.)

"The determination of the loss-on-ignition as a measure of the humus content of the soil may be justified only for the litter and *F*-layer, since the inorganic fraction in these formations is very small. When the content of inorganic matter in the soil layer is greater than 10 percent, as usually occurs below the *F*-layer, a large error is introduced in the determinations. * * * In most of the earlier analyses of the humus content of mineral soils, the loss on ignition was taken as the standard method of measurement. It was soon recognized, however, that when a soil is ignited, certain inorganic constituents also undergo various changes with a marked loss of weight. This is true especially for soils rich in carbonates and hydrated silicates; these complexes lose carbon dioxide and chemically combined water, upon ignition, thus tending to give too high humus values." (Waksman, 1936:224, 225 and 242.)

It is clear therefore that the results reported above of increase in organic matter following burning, in Heyward and Barnett 1934, Greene 1935, 1935[a], 1935[a], Demmon 1935, Heyward 1936, and Wahlenberg, Greene and Reed, 1939, especially the long series in the longleaf pine lands at McNeil, Mississippi, which have been so widely quoted, cannot be accepted as even an indication of an increase in organic matter. Loss on ignition, never reliable as a method in determining the organic matter in soils, is especially misleading when applied to the southern soils.

"The *A* horizon of unburned areas contained approximately five times as many microfaunal forms as the ground cover of burned areas. * * * The diversified active soil fauna of the unburned areas is believed to be responsible for the penetrable and well-aerated soil typical of such areas. This is in striking contrast to the more compact, less porous soil of frequently burned areas in which animal activity is much less abundant." (Heyward and Tissot, 1936:666.)

"Deterioration of habitat * * *.

"Soil temperature (surface, and to a depth of several inches), organic matter, acidity, water-supplying power, and total chemical solutes available to plants, are caused to change to a greater or lesser degree. Soil organisms—notably soil bacteria, fungi, protozoa, earthworms, and insects—in the upper layers, are influenced directly by the heat of fire, or indirectly by the change in aerial and soil factors following removal of the vegetation cover." (Phillips, 1936:39.)

"In the Duke Forest 48 collections were made each month for a year; * * *. From 576 samples collected and placed on Berlese funnels 353,026 animals were recovered, an average of 1,719 per square foot each week or 2,590,082 per acre. * * * An average of 65 percent of the animals were recovered from litter, 30 percent from a depth of 0 to 2 inches and 5 percent from a depth of 2 to 5 inches." (Pearse, 1946:144.) Burning the litter on the Duke Forest reduced the number of animals to 22.5 percent. (Pearse, 1943:422.)

The action of small animals has a great effect in mellowing the surface of the soil and this in turn on penetration of water. Fire destroys the active animals in the surface soil and duff.

"Another important effect of fire is that it leaves the soil surface coated with black, charred debris. This increases the soil's capacity to absorb heat. At air temperatures of 85 degrees F. for example at which surface temperatures of yellow mineral soil may rise to 125 degrees or higher, the surface temperatures of black charred soil may rise to 140 degrees or higher."

The usual heavy slash fire causes the following results "(1) a loss per acre of 20 tons (89 percent) of the organic matter contained in the duff; (2) a change in duff reaction, from a highly acid condition (pH 4.95) to an alkaline condition (pH 7.6); (3) the escape of approximately 435 pounds of nitrogen per acre; (4) an increase in the supply of plant nutrients available in the surface soil * * *; (5) an indicated loss of a considerable part of the mineral nutrients contained in the duff, presumably carried off in smoke." (Isaac and Hopkins, 1937:265 and 278.)

The committee on physics of soil moisture found that "incorporated organic matter increased the rate of entry of water into soil. * * * the presence of organic matter on the soil-surface increased the rate of entry of water." Some reported "that the surface litter filtered silty water and thereby increases the rate of entry of water," while others "attributed the increase in rate of entry to the prevention of puddling of the soil surface by raindrops." "There is agreement * * * that organic matter is effective in retarding runoff." (Veihmeyer, 1938:339.)

"Water falling as rain on bare soil dislodges silt and clay particles by its impact. These are taken into suspension and carried into the tiny pores and channels between the soil particles as the water makes its way downward. Very shortly the filtering action of the soil causes the openings to be clogged by the particles; water can no longer move downward through the soil, so it flows over the surface carying with it the dislodged silt and clay; and erosion is actively under way. A protective layer of litter prevents this chain of events by absorbing the impact of the falling drops of water. After the litter becomes soaked, excess water trickles gently to the soil surface, no soil particles are dislodged, the water

remains clear, pores and channels remain open, and surface flow is eliminated except in periods of protracted heavy rains." (Munns, Preston and Sims, 1938: 609 and 610.) Comparing the infiltration on a fire break and a forest over a six-year period and with 337 paired determinations led to the following conclusion: "On the whole, the four times more rapid infiltration under forest appears to be caused chiefly by the indirect influence of the forest canopy and floor in favoring the development and maintenance of a more porous structure consisting in part of channels of macro-organisms." (Kittredge, 1938:1157.)

"Soil organic matter is one of our most important national resources; its unwise exploitation has been devastating; and it must be given its proper rank in any conservation policy as one of the major factors affecting the levels of crop production in the future.

"Organic matter may well be considered as fuel for bacterial fires in soil, which operates as a factory producing plant nutrients. The organic matter is burned to carbon dioxide, ash, and other residues. This provides carbonic acid in the soil water, and the solvent effect of this acidified water on calcium, potassium, magnesium, phosphate, and other minerals in rock form is many hundreds of times greater than that of rain water. At the same time the complex constituents of the organic matter are simplified, and nitrogen in the ammonia is released and converted into the nitrate form." (Albrecht, 1936:347 and 348.)

While chaparral produces a small amount of litter as compared with forests the amount is considerable and represents the amount of material to be worked into soil by macro-organisms and micro-organisms as discussed above. Chaparral in metric tons per acre on San Gabriel Mountains showed differences depending on species and age. "The low group, with an average dry weight of forest floor of 3.1 metric tons, is characterized by the Eriogonum; the intermediate group, with 4.67 metric tons, contains the types with chamiso; and the high group, with 7.33 metric tons, a variety of types including those which have been suggested as more persistent.

"In Fern Canyon at elevations between 4,500 and 5,400 feet, the mean of the forest floor in the different types range from 4.7 metric tons for chamiso to 21.18 for manzanita.

"When the 14-year old chaparral of Bell Canyon below 4,000 feet is compared with the more than 50-year old vegetation of Fern Canyon above 4,000 feet, the difference between 5.3 and 15.0 metric tons per acre dry weight of forest floor is highly significant." (Kittredge, 1939:526.)

"The average annual accumulation of organic material in the chaparral communities of diverse composition, age, and location rarely varied beyond the amounts of 0.2 to 1.4 metric tons per acre, with a general average of 0.6." (Kittredge, 1939[a]:541.) This litter is removed by fire and this removal profoundly affects the surface soil.

"In 13,122 measurements the unburned areas showed universally higher average mechanical penetrability than the burned areas, the surface of the burned-over soil varying from slightly harder to five times as hard as unburned soil.

"The studies of the physical properties of soil consistently showed that porosity, mechanical penetrability, and ability to absorb water were several times greater on areas protected from grazing and fire." "In

brief the studies of the chemical properties of the soil at McNeil, including those of Heyward and Barnette, have shown that frequently burned-over soils were slightly less acid in reaction * * *. * * * Organic (as indicated by ton on ignition) total nitrogen, and replaceable calcium were found in greater quantities in frequently burned-over soils." (Wahlenberg, Greene and Reed, 1939:36, 40 and 42.)

As a result of repeated burns on the Mathews Ranch near Cloverdale "the combined sparse vegetation and the limited soil humus account for the heavy baking of the soil, notably on the south and west slopes. Such hardening of the surface soil greatly retards and decreases percolation of rains, and obviously promotes surface runoff and soil erosion. The large amount of soil removal, presumably from the steeper, heavily grazed country, was evidenced along the main drainage channels, where there are large deposits of soil and gravel." (Sampson, 1939:3.)

"Under four paired burned and unburned longleaf pine forests a study was made of field moisture percentages throughout the year.

"The differences in moisture utilization and mulching effects between the two classes of ground cover are believed to be responsible for the higher percentages of soil moisture in longleaf pine forests protected from fire as compared with similar forests subjected to annual fire." (Heyward, 1939:323 and 324.)

"In forests of the Appalachian region, up to 10,000 individual microanthropods (minute animals such as spiders, springtails, centipedes, etc.) may inhabit each square foot of forest litter. These small creatures, which feed upon the litter and other organic material, aid greatly in incorporating organic residue into the soil, and in maintaining porosity." (Forest Service and Soil Conservation Service, 1940:13.)

The influence of woodland-chaparral vegetation of the Sierra Nevada foothills at North Fork gave the following results over a 10-year period. "Changes in the environmental factors brought about by burning the vegetation has resulted in approximately 94 percent reduction in the infiltration capacity of the soil on the one-fortieth-acre annually burned plots. This reduction in the infiltration capacity of the soil was caused largely by an almost total destruction of the litter cover, a 70 to 75 percent reduction in the organic matter of the surface soil; a 70 to 80 percent reduction in the activities of certain of the soil fauna, such as earthworms and burrowing insects; the plugging of the soil pores, and the destruction of the surface soil structure, due to direct exposure to climate, surface runoff and erosion." (Rowe, 1941[a]:105.)

Different conclusion were drawn from a series of small plots in Tehama and Shasta Counties. On one set the vegetation was cut, piled, and burned and the trash and litter and small plants burned with a blow torch. The brush was cut September 25, 1941, and on December 22d in 1941. The soil moisture sampling from September, 1940, to September, 1941, are given as graphs for each six-inch depth down to 42 inches for each of six paired plots and from September, 1941, to September, 1942, on two of the plots.

"The records of soil-moisture conditions in paired plots, one of which was denuded annually by cutting and burning and the other left undisturbed, are presented.

"Denudation by burning did not prevent the soil from becoming wet throughout its full depth as soon as that in the unburned plots. In

fact, in most cases, the soil was wet earlier in the season in the burned plots than in the unburned ones. The interception of rain by the vegetation on the unburned plots may have been great enough to account for this difference by preventing the water from reaching the soil-surface. Water, however, did get into the soil of the burned plots as the records show and burning did not delay this process in comparison with the unburned plots. The soil-moisture records indicate that the infiltration-capacity of the soils on the burned plots was not impaired." (Veihmeyer and Johnston, 1944:83-84.)

"Mr. Rowe points out that the use of water by the plants on the unburned plots during the rainy season may be the cause of the differences in soil-moisture contents between these and the burned ones. During the winter months, our soil-moisture curves are substantially the same for both the unburned and burned plots. We had hoped to be able to determine the use of water by the vegetation during this time but the rains were so frequent during the three years the plots were sampled that we were unable to get periods during the winter free of rain long enough to detect with certainty the slope of the moisture-curves. There may have been enough use of water by the plants during the early fall months after the rains started to cause the soil-moisture in the covered to be lower than in the burned plots, but we believe if a reason for the difference other than increased infiltration in the denuded plots is sought for, that interception of rain by the vegetation is the most likely explanation. The fact is, however, denudation did not prevent the wetting of the soil-mantle in the burned plots and in most cases this was accomplished at an earlier date than in the unburned ones. * * *" (Veihmeyer and Johnston, 1944:87.)

To evaluate these moisture determinations it is necessary to review some facts of soil moisture well established early in this century by Russian and American workers in dry land agriculture. These are summarized. "* * * plant-transpiration is the chief means by which water is lost from soils, and that the loss of water by evaporation directly from the surface of the soil is almost entirely confined to a shallow surface layer of about four to eight inches * * * water, when applied to dry soils, is rather quickly distributed until a condition known as the field-capacity is reached. After this, the movement of the water, for practical purposes, may be considered to have ceased." (Veihmeyer and Johnston, 1944:72.) (See also Shantz, 1927:146 to 148.) It is therefore impossible to wet a soil under field conditions to any amount less than the field carrying capacity, or to wet it more, unless there is a hanging or real watertable just below. With this in mind it is difficult to understand that the water content of any six-inch level of the burned plot could be higher than the unburned as a result only of greater penetration. If available water below the field carrying capacity is shown in the sample it would indicate (1) a wetting of only part of the six-inch depth in which case the six-inch sample next below would not have shown any increase in water content or (2) a reduction of the soil water content below the field carrying capacity by the absorption of soil water by the chaparral on the unburned plot. "Five cores were taken for each depth at each sampling date and composited. Results are the averages for the five samples." Along the infiltration front this method could give results

intermediate between the field carrying capacity and the minimum moisture content if there was any difference in the depth of moisture penetration in the soils sampled. This could also happen in single tube samples if only part of the soil core had been wetted. Such values do not actually occur in the soil as a result of infiltration, and would only show in samples taken across the infiltration front.

During the critical months, September, October, November and December too few samples were taken, the number being from three to eight and in December when the greatest infiltration took place the sample dates number two for three of the graphs, one for four of the graphs and none for one of the graphs. The shallow rocky nature of much or most of the chaparral soils does not lend itself to the soil moisture method of experimentation. Even where samples can be taken to 42 inches this is not deep enough to secure a true picture of the amount of soil moisture stored. "The fact that the curves showing the extraction of moisture from the unburned plots were almost flat after about the middle of July indicates that the plants were getting very little water from the soil after this date. Since the deep-rooted brush plants did not die, it follows that it is very probable that some additional water was obtained from below the depth of sampling." (Veihmeyer and Johnston, 1944 :82.)

The Button Canyon plot was denuded by cutting and burning on September 25, 1940. The rains started during the latter part of October and by the end of December, 13.29 inches had fallen. This was enough to wet the entire soil-profile, which would only have required about 6.4 inches to raise the 42 inches of soil from the permanent wilting-percentage to the moisture-equivalent. It is interesting to note that the moisture-contents were the same in the unburned and burned plots until the rains started; then the moisture-content, as represented by the dotted line, for the burned was higher than on the unburned plot until the entire soil-profile in this plot was raised to its field-capacity. This means either that the infiltration-capacity of the soil on the burned plot was greater than on the unburned one or that the interception of rain by the vegetation cover reduced the amount of water reaching the soil-surface sufficiently to make the difference." (Viehmeyer and Johnston, 1944 :75.)

The differences if one accepts the conclusion that they are due to infiltration are small and might easily be due to the disturbed soil surface on the cleared and burned plot.

When water is added to a soil, unless it actually runs down through root or animal tunnels or soil cracks, the soil water content will be increased to field-carrying capacity before water passes on into the deeper soil. If twice as much water had entered the burned as had entered the unburned at one time the depth of penetration would have been twice as great, in the burned, but the water content would have been the same if the soils were comparable. The removal of soil moisture by the plant cover would reduce the soil moisture below field capacity. On the unburned plot the lower water content would indicate that such was the case.

It seems unlikely that these results have any significance as showing greater or equal infiltration into either the burned or the unburned plots. Moreover, on the Button Canyon plot for 1940-41 over half of the rainfall in October and December, 13.29 inches, is unaccounted for by the soil absorption of 6.4 inches if the soils had been fully filled which

they presumably were on the first of January. Six and nine-tenths inches are not accounted for.

Experiments of this kind conducted on uniform deep soil where frequent sampling can be carried down to 6 to 15 feet would present a very clear picture of infiltration and of absorption by the plants. This would contribute much to a better understanding of the role of soil moisture and plant cover in the chaparral, especially that occupying potential agricultural land.

Bauer (1936) found that the moisture reached a depth of 150 centimeters one month later than it reached a 10 centimenter depth in chaparral soils of the Santa Monica Mountains. This is also clearly shown in the results by Veihmeyer and Johnston (1944).

"Madson's statment concerning the observations made so far were that the figures on water peneration seemed to be significant, but that they were not satisfactory for measuring erosion." (Weeks, 1942:3.)

"Soil sampling for the past three years on the several paired test plots in Tehama and Shasta Counties have definitely shown that denudation does not produce undesirable change in the infiltration capacity of the soil." (Madson 1943:3.) These statements are based on Veihmeyer and Johnston's results discussed above.

The ash liberated in chaparral burning estimated in percent of oven-dry samples is as follows:

"Mineral	*Chamise*	*Chaparral*
Potassium, percent	0.640	0.730
Calcium, percent	0.709	0.920
Phosphorus, percent	0.062	0.073
Total	1.411	1.723"

(Sampson, 1944:37.)

"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 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." (Sampson, 1944:38 and 40.)

"Except in heavy localized spots of ash on new burns, * * * 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." (Sampson, 1944:131.)

Direct measurements of infiltration were made by "Auten's technique—modified by wetting the soil at the sampling point with 50 cc. of water immediately before measuring the infiltration capacity."

"One plot lay in an area that had not been burned for many years; the other in an adjacent area where burning had been practiced at intervals, terminating with a burn the autumn before the sampling. On the unburned area the average infiltration volume of 14 tests over a 20-minute period was 535 cc., whereas the average values of 11 tests conducted on the burned area was 184 cc."

"The study of soil-moisture relations shows such slight quantitative differences in freshly burned versus unburned chaparral soils as to be of little ecological or economic importance. At depths below about two

feet, the soil-moisture percentage is consistently somewhat higher in recently burned areas. As the invading brush reoccupies the soil, the differential in soil moisture declines, and is lost in a few seasons after burning where the characteristically abundant crown sprouts reclaim the area." (Sampson, 1944:180, 181 and 190.)

"The father of William Barnwell did not believe in fire and kept reproduction down to a fair degree by pulling up seedlings himself as he went around, and having his boys do the same. * * * Over a period of years falling limbs and twigs broke up and rotted and went towards building up the soil. Today the soil is loose and crumbly, and not only deep but has a good depth of humus on top, and this black loam shows no erosion characteristics. * * * The condition of the soil is generally remarkable when compared with soils on other ranches that have had the usual burning treatment."

"The next ranch visited * * * has land on both north and south slopes quite similar to Barnwell's * * * has done considerable burning. It is quite noticeable that on the open slopes the soil is quite hard and light colored * * * the soil is hard with little humus." (Smith, 1946:1-2.)

Fire sterilizes the top soil, destroys microorganisms, also humus, litter and the less heat tolerant seeds. (Sampson, 1946a:10.)

ON SOIL EROSION

Fire effects erosion principally by killing the plants growing upon the soil, by removing the litter and dead plant parts which lie on and in the surface of the soil, and by following down to consume partly buried logs and roots. The sterilization of the surface kills most of the insects, worms, and macro- and micro-fauna and flora. It is not possible to separate the effect of fire from the effect of denudation of vegetation. However, fire is much more destructive of certain types of vegetation than of others.

"During the years from 1881 to 1883, inclusive, fires were set by herdsmen back of Los Angeles. The year 1884 saw a number of disastrous floods in the region, which ruined much agricultural land. * * * At about the same time a tremendous fire covered practically the whole west face of the Santa Ana Range south of Los Angeles. * * * One particularly disastrous flood, following soon after the fire, did much damage in the Capistrano Valley. Many hundreds of acres of fine agricultural land were washed away, and others were so gullied as to be valueless." (Plummer, 1911:18 and 19.)

In northern Idaho "Steep south slopes, however, present a serious situation. Here the burns are so destructive to all vegetation and roots that finer particles of the soil leach out or wash away, leaving surface covering of fine angular rock and gravel which becomes very hot and very dry in the summer, so much so that natural seedlings, when these do come up, succumb to drought shortly after germination." (Larsen, 1925:1195.)

"Of all the man caused erosion, that resulting from fire has probably been the worst." (Bennett and Chapline, 1928:25.)

On the San Bernardino National Forest "* * * the total runoff from chaparral-covered plots was 1.2 cubic feet as against 4.4 cubic feet from the burned plots—a ratio of 1 to 3.7. Erosion from the chaparral

plots amounted to 15.7 pounds of material as against 284.4 pounds from the burned plots—a ratio of 1 to 18.1." (Lowdermilk, 1930:474.)

"Fire is the outstanding threat to California's watersheds. All the evidence so far adduced conclusively proves that fire detrimentally affects seepage, surface runoff, and stabilization of the soil." (Pardee, 1932:22.)

"Fire, especially that for which man is responsible, is probably the most inexcusable of the vegetation-destroying elements. * * * Fire may so completely destroy the cover that disastrous erosion immediately follows. A very striking example of erosion after fire occurred during the early spring of 1931 in the vicinity of Moorpark in Ventura County. Portions of this tract were so badly dissected by deep gullies that it has no further use as either pasture or timber land, and the damage caused by the deposit of eroded material on highways and cultivated fields amounted to several thousand dollars." (Weir, 1932:18.)

Repeated fires cause profound changes in local ecological conditions. Litter is destroyed, erosion accelerated on slopes, and on level land the cycle of normal evolution is interrupted. (Enquete international, 1933:431.)

"The fire of November 21st-24th burned the chaparral on 5,000 acres including several short steep watersheds tributary to alluvial fans and cones on which Montrose and other communities were built." Rainfall from December 29th to January 1st was from 11 to 19 inches. "On the burned area * * * many small parallel shoestring gullies formed. * * * Augmented in volume, cutting and carrying power toward the canyon bottoms."

"All this material spread out over the valley fans and coursed through the streets and highways with the all-too-well-known destruction of property and life. The 59-ton boulder deposited on the highway at least eight feet above the channel is evidence of the power of the flood."

"On the adjacent unburned watersheds where the slopes were protected by the brush and leaf litter, gullies did not form and the streams did not carry excessive loads of soil and rock." (Kittredge and Mulford, 1934.)

"When fires denude the sparse vegetation from steep mountain slopes, the flood intensities increase and added débris hazards occur, due to erosion." (Eaton, 1935:1021.)

"The intense rainfall of December 31, 1933, and January 1, 1934, particularly its effect upon the recently denuded mountain area effected by the Pickens Canyon fire, caused such loss of life and destruction of public and private property in the Montrose-Glendale area as to focus public attention upon the value of forest cover in flood control. The destruction caused by the swollen silt laden, boulder carrying streams from the burned area, in comparison to lack of abnormal streamflow from unburned areas were sufficient to convince both engineers and laymen of the great protection afforded by the native brush cover. The comparisons were as eloquent as no longer to leave the observer in doubt, in spite of the many reports and papers which have been written from time to time." (Morris, 1935:748.)

"The settlers used fire as a servant but it became a very bad master and burned the tree cover, then the underlying scrub, and finally they

burnt the grass itself. As a result, in many parts the subsoil of clay is showing on the top of the mountainside, the top soils have almost entirely disappeared." (Galbraith from Victoria, Australia in Trevor, 1935:21.)

An extensive survey concludes that "The forest is the most efficaceous element in the protection of the surface of the soil." (Enquête international 1937:132.)

"A disastrous flood swept out of Verdugo and Haines Canyons in Los Angeles County, California, on January 1, 1934, causing the loss of 34 lives. The flood was more mud than water. * * * Erosion debris removed amounted to 50,000 to 67,000 cubic yards per square mile. Neighboring watersheds subjected to the same rainfall, but with their forest cover intact, yielded clear water which caused no unusual erosion and did no damage."

"In the pine region of the Sierras, a five-year record of runoff and erosion from repeated burned and comparable unburned plots has shown a yearly runoff from the burned area ranging from 31 to 463 times that from the unburned, and yearly erosion ranging from 22 to 239 times that from the unburned. The runoff from a plot allowed to revegetate after a single burning exceeded the runoff from the unburned check plots by 31 times the first year, and by 11, 5, 15, and 14 times in the subsequent four years. After carrying off 485 times as much eroded material as the check plot the first year, runoff in the second year carried only 81 times as much." (Forest Service and Soil Conservation Service, 1940:36 and 39.)

On the Sierra Nevada Foothills "The surface runoff from the annually burned plots for the nine-year period of the experiment was equivalent to over 14 percent of the total precipitation, and was approximately 390 times greater than from undisturbed check plots. This runoff carried away the surface soil at a rate of more than 113 tons per acre, a soil loss approximately 18,000 times greater than that from the undisturbed plots."

"During individual storms of high rainfall intensities the the runoff rates from the annually burned plots have often exceeded 50 percent of the precipitation. In contrast * * * the runoff from the undisturbed vegetation plots has never exceeded 0.1 percent of the seasonal precipitation or 0.5 percent of the individual storm precipitation. Regrowth of the vegetation on the periodically burned plots rapidly reclaimed the site and, by the fourth season after the first burn, appeared to completely control the erosion; although the runoff was still approximately 12 times greater than that from the undisturbed plots." (Rowe 1941[a]:103 and 104.)

"During the four days, November 21-24, 1933, a fire swept the mountainous portions of small drainage areas of the San Gabriel Mountains lying northwest of La Canada Valley, * * *. On December 31, 1933, and January 1, 1934, record precipitation of 10 to about 15 inches fell in the mountain area. The resulting floods brought erosional debris out of the burned watersheds in amounts ranging from 50,000 to 67,000 cubic yards per square mile. Neighboring watersheds subjected to the same rainfall, but with their chaparral cover intact, yielded almost clear water, which did little damage." (Brown, 1943:120.)

"In the Tehama-Shasta area a number of small plots have been established to secure information on the effect of brush removal on

water penetration, runoff, and erosion." The summary of the findings to date may be stated as follows: * * * "Soil sampling for the past three years on the several paired test plots in Tehama and Shasta Counties have definitely shown that denudation does not produce undesirable change in the infiltration capacity of the soil. The results from these test plots also seem to indicate that removal of the vegetation is not harmful so far as runoff and erosion are concerned." Brush was removed by being cut, piled and burned. (Madson, 1943:2 and 3.)

"Measurements of the amounts of runoff and erosion from the plots have been made, but for most of them, these records have not been obtained for enough years to be conclusive. The Ono plots have been under observation for a longer period than the others. The measurements of runoff and erosion from these plots for the past four years are given in Table 3. The differences between burned and unburned plots have not been marked nor have they been consistently in favor of either one or the other. The shorter records of the other plots give similar results." (Veihmeyer and Johnson, 1944:83.)

"Cow Mountain has been repeatedly burned and the condition of the slopes shows that there has been a heavy soil loss, a decrease in amount of forage produced, a reduction in size and density of brush growing on such depleted sites, and a measurable loss in grazing value." (Smith, 1946:4.)

On university pastures near Ono, California, on burned chaparral "The rates of erosion, as measured by the three gully installations, ranged from 3.8 to 7.9 tons to the acre per year. * * * The figures for 1935 showed a mean soil movement of 0.21 inch on the unburned pasture, and of 0.56 inch on the burned area. * * * The movement between 1935 and 1937 averaged 0.09 inch on the unburned area, 0.15 inch on the burned."

"A similar study was made on a ranch north of Ukiah, in Mendocino County, in a mixed chaparral-woodland cover on a silt loam soil of the Mariposa series. A full stand consisting of chamise, poison oak and madrone, various species of manzanita and ceanothus, and a little herbaceous vegetation, made up the cover. Before 1934 the area had not been burned for 18 years; but it had been grazed lightly by sheep each year. In 1934 a part of the tract used for grazing was burned, and erosion stakes were then set on comparable slopes on the burned and unburned areas. Measurements were made in 1935, 1936 and 1939, * * * the data show, the soil movement was 140 percent greater on the burned than on the unburned area during the first year after burning, 85 percent greater the second year, and nearly 70 percent greater the third year." (Sampson, 1944:175, 176 and 178.)

"Summary of Field Observations on Burns. Of the 34 ranches examined, 29 showed rapid reoccupation of the original brush. On seven 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 gradiant of these areas was only about 15 percent. The tabulated records revealed that 30 of the burns had slight or no soil slippage, whereas on four areas soil slippage had been severe. Twenty-two burns had little or no gully erosion, whereas on four burns, soil erosion of a general nature was severe, and on eight

burns, soil erosion was moderate. The four severely eroded areas had an average slope of approximately 44 percent, whereas those classed as moderately eroded had an average slope of about 32 percent." (Sampson, 1944:108.)

"A destructive flood occurred in Salt Lake City, Utah, at about 10.30 p.m. on August 19, 1945. * * * The flood waters, carrying large quantities of rock, gravel and debris first debouched into the Wasatch Boulevard then moved on through the city cemetery and into the residential and business sections of the city * * *. The monetary value of the damages * * * totaled $347,000."

"Fully 80 percent of the areas, including all but patches of the headwater slopes and portions of the lower benchlands, was burned last fall. * * * The most deteriorated watershed slopes, * * * are riddled with a dense dendritic pattern of gullies. These vary from about one to six inches in width and from one to ten inches in depth. * * * The more extensive, headwater burned area is also seriously eroded by both sheet wash and gullying. * * * Channels heading from the eroded slopes are cut to depths of as much as seven feet in high gradient reaches. * * * One of the minor subbasins of Valley View Canyon which was not burned in 1944 and which has a dense stand of oakbrush and bunchgrass, did not contribute a drop of runoff to the flood. That this area was subjected to heavy rainfall is suggested by the fact that burned or otherwise deteriorated slopes on all sides of this nonflooded subbasin were cut by fresh gullies." (Craddock, 1945:35-38.)

"On one ranch in Lake County a program of controlled burning has been under way for five years. This is a typical chamise area with steep slopes and a thin, poor soil. Designated areas are burned each year, and domestic ryegrass is seeded in the fresh ash. At the end of five years the stand of ryegrass is still very good, and there has been no appreciable erosion."

"On the Pauba ranch in Riverside County, an area of the range near a nursery was accidentally burned in the summer of 1941. * * * there was no erosion, even though in one January storm over six inches of water fell in 12 hours." (Jones and Love, 1945:32.)

"Two principal kinds of damage commonly result from fire on Southern California watersheds. The first takes the form of immediate loss of resources and improvements of economic worth consumed by the fire. The second occurs mostly in the form of increased runoff and increased erosion from burned areas during subsequent storm periods. The latter damages are generally less immediately felt but may cumulate over long periods of years. They occur as flood and erosion damages to improvements both on the watershed and downstream from it, siltation of reservoirs, spreading grounds and other improvements, and in some cases to actual loss of water for economic use." (Buck, 1946:1.)

On the Angeles National Forest "There is a great increase in the size of flood peaks for all flood classes immediately after a fire. Flows for the smallest floods increase some 30-fold and the largest about two-fold."

"Normal erosion rates are seen to vary from about 1,000 to 4,000 cubic yards per square mile. Immediately after fire, however, they rise to 10,000 to 300,000 cubic yards per square mile. The increase from normal in the first year after fire is from 20- to 40-fold.

"From the best data available it appears that erosion rates drop back to normal in about eight years, despite the fact that peak flood flows are generally still far above normal at this time." (Buck, 1946a:3-5.)

"According to the results of experiments conducted by the University of California under Professor F. J. Veihmeyer, the burning of brush resulted in the saving of water and, at the same time, increased production of forage; furthermore, runoff and erosion were not greater on the burn plots as compared with the unburned plots in the areas where the experiments were conducted." (Crooks, 1946:1.)

"Total runoff * * *. Forests did not 'conserve the water supply,' because after their removal there was an increase in average annual yield amounting to 15 percent in a mountain area in Colorado and 29 percent in a Southern California coastal mountain area."

"In the Wagon Wheel Gap area there was an average increase of 46 percent in maximum daily discharge after deforestation." (Davis, 1946:41 quoting L. C. Bishop, State Engineer, Wyoming.)

"A very evident example of top soil loss was quite recently checked by residents and local forest officers at the edge of the lemon groves of Goleta Valley. A late summer fire burned over several thousand acres of chaparral watershed cover just above the valley, denuding a large part of the watershed of San Jose creek. The United States Forest Service, as is customary in such cases, promptly sowed mustard seed on such parts of the burned area as funds permitted. Lashing winter rains descended before the mustard plants had a chance to develop a protective covering. San Jose creek became a raging torrent, washing tons of boulders and silt down out to the valley floor. Water showed 18 percent silt on burned and was practically clear on unburned." (Nash-Boulden, 1945.)

ON WILDLIFE

The effect of burning vegetation on wildlife is direct and indirect. Probably the most important is the indirect effect caused by changing the micro-climate and conditions of the habitat. As an example of the latter "The occurrence of spasmodic floods, of comparatively short duration and separated by intervals of extreme low water, have a deleterious effect upon fish life in manifold ways." (Coker, 1915:93.) Direct effects are also important. "The following is quoted from a report by W. T. Cox on the big fires of 1902 in Washington and Oregon: 'In the dense smoke hundreds of grouse, quail and Mongolian pheasant were surrounded by fire and roasted to death. Hundreds more had their wings scorched, and now upon the blackened forest floor fall an easy prey to prowling vermin. Large and small mammals fared no better. Carcasses of deer, bear, cougar, and lynx have been found, and literally thousands of dead squirrels. Wolves and lynx are appearing in unusual numbers since the fires, evidently attracted by the number of ready-prepared roasts to be had in the forests.'

"J. H. Sizer, describing the Mazatzal fire on the Tonto Forest in Arizona in 1921 says: 'I encountered a bunch of deer hemmed in by a fire against a rock bluff. These, however, escaped by jumping high over the blaze as I approached.' * * * Frederic Winn, describing the Rose

Peak fire in the Apache Forest of Arizona in 1911, says: 'We saw a white-tail doe and fawn run blindly into a fiercely burning tangle of down timber.' " (Leopold, 1923:515 and 516.)

"More game and other useful wildlife is destroyed by needless grass fires turned loose in the spring than by illegal hunters and poachers during the entire year. * * * Burning of swamps and marshes also destroys great numbers of duck nests in places where these birds breed, * * *." (Leopold, 1926:726-727.)

"Forest Supervisor Humphrey of the Manti National Forest, says: 'In August, 1926, I was detailed to the Lost Johnny Creek fire, on the Flathead Forest of Idaho. * * * Along the edge of the fire, where we were trenching, we saw a number of pine squirrels that apparently had their feet so badly burned that they could not climb trees. The deer in this locality are of the whitetail species. I found two deer on the creek below the fire fighters' camp that were burned to a crisp. Two other deer—one a large buck and the other a yearling—died near the Riverside pasture gate. Another old buck with the hair over his hind quarters badly singed and his feet so burned he could hardly walk, was seen by the entire crew a number of times between Riverside and Murry creeks. I also saw a fawn in the vicinity of Spring Meadows that had evidently lost its mother. The feet of this fawn were badly burned.

'A great many grouse that had died from the effect of the fire were also found. In fact the fighters reported finding dead grouse almost daily.

'This fire did not travel fast enough to overtake either the game or the birds. It is my opinion that both, after the fire had died down, drifted back to their old range through the smouldering ashes. After getting in where the ashes were extremely hot and burning their feet, they would become bewildered and probably they ran on until they were so badly burned that, even though they got out of the fire, they would die later from the effect of the burns. Both deer and grouse appear very reluctant to move away from their home grounds which had been destroyed by the fire and returned immediately after the fire had quieted down, before the ground had time to cool. Nearly every day we would see deer wandering through the burn, especially on the meadows, even though the forage was practically all destroyed.'

"Ranger David Laing of the Boise National Forest, says: 'In May, 1919, Ranger John R. Smith reported to me that he found thousands of dead cutthroat trout in the creek above Smith Lake after a hot forest fire had burned over the area. The trout were spawning in the creek at the time and as there was a heavy brush along the creek making a hot fire, I believe the fire killed the fish'." (Rutledge, 1928:315-316.)

In California "Losses through destruction of game and other wildlife during the 333 fires which have been reported throughout the State to June 28th are so great that they can hardly be estimated, Fred G. Stevenot, Director of Natural Resources, has informed members of the Governor's Council. More than 4,000 quail were lost in southern fires while between two and three thousand perished in the disastrous Yolo County fire which burned over 12,000 acres.

"Not only did quail suffer, the director reported. Rabbits in considerable numbers are believed to have been burned as well as many birds and some deer." (U. S. Forest Service, 1928:3.)

"Tremendous loss of game occurred in the Cahuilla and Chihuahua fires which burned in Riverside and San Diego Counties during September, according to reports of Howard Small, President of the Riverside Chapter of the Isaac Walton League. The Cahuilla fire burned in the shape of a horseshoe, thus trapping game, and further destruction came when the wildlife found itself hemmed in between this fire and the Chihuahua fire coming north from San Diego County. These two fires finally burned together and covered approximately 300,000 acres of grass, brush and woodland.

"Carcasses of 300 deer which perished in the Cahuilla fire have been reported from Riverside County alone, and it is estimated that 15,000 quail perished in this territory. Frank Robertson, Foreman of the Frank Morris Ranch, reported that 700 quail which took refuge on the ranch were killed by smoke and flames, and that he was feeding over 1,000 quail and many deer on the lawn of the ranch house, the only building on the ranch that was not burned.

"Small said he observed 17 deer in one canyon, all pitifully thin from lack of food, and the many miles they had to run to escape the fires. These deer were eating the green leaves from unburned trees and brush and were so tame that they did not run when he approached and whistled." (Forest Service, 1928[a]:2.)

"During the summer of 1930, the worst forest-fire year Wisconsin has ever experienced, * * *. More than a score of deer were found dead after the fire. Undoubtedly, these were only a small percentage of the number destroyed. Surveys made by the Conservation Commission determined that 60 percent of the deer surviving the fire had badly burned feet. * * * For several months following the fire, freshly dead deer were reported both in the fire area and in the district surrounding it."

Of sharp-tailed grouse "* * * not more than 25 percent of the total population were actually killed. Prairie chickens, ruffed grouse and quail suffered great loss. Few rabbits were killed by the fire as they escaped into holes outside the peat beds. But the rabbits suffered particularly from hawks and owls following the fire, due to lack of protective cover."

"In this fire, as in most other fires, lack of oxygen, warmed and ash-poisoned water combined to kill thousands of fish. Dead fish were found in all parts of the drainage ditches and in the Yellow River, which flows through the burned area. Pickerel were hit the hardest. Many dead wall-eyed pike were observed. Dead suckers and minnows were seen in most of the ditches. In the Yellow River black bass and sunfish were found dead." (Kipp, 1931:323-324.)

"It seems very likely that the policy followed by forestry officials of restricting the burning of brush areas has had an unfavorable influence upon quail in some foothill regions. With the chaparral vegetation restricted, the native weeds and grasses, which constitute the chief items of food for quail, were correspondingly more abundant, whereas at present they have been largely choked out of such areas." (Summer, 1931:280.)

"While a maximum crop of timber and a maximum crop of quail can seldom, if ever, be produced on the same ground, some timber can be produced on lands handled primarily for quail, and some quail can

be produced on lands handled primarily for timber. * * * fire can frequently be utilized to advantage in controlling vegetation on portions of preserves that have a tendency to grow up to heavy wiregrass, broomsedge or deciduous jungle. Quail cannot thrive in such areas * * *."

"A system of plowed or plow-harrow fire lines that circle incipient thickets and divide the preserve into small units that can be burned out in winter by light fires of the creeping type in alternate years, or as needed, may be made to increase, diversify, and properly distribute the food supply, regulate density and extent of thicket and ground cover, and aid in safeguarding the nesting by bringing about more even distribution of nests as well as permitting sterilization against parasites and diseases of limited areas of cover where birds concentrate. While winter burning of preserves is permissible for these purposes, spring fires are injurious to the food supply in general, and summer fires are so destructive all around that their use is unjustifiable from any known viewpoint."

"Fire is rightly comparable to a two-edged sword. While it may be used to good advantage at times to obtain definite desired results, its abuse, or careless uncontrolled use, may be productive of great harm." (Stoddard, 1931:413-414.)

"A second item requiring attention in the deer problem is the policy of forestry officials in restricting burning on forest and chaparral areas. According to old-time residents, in foothill areas especially, fire was of common and repeated occurrence in earlier years. There were numerous small fires which ran only short distances and then died out, there being less accumulation of inflammable material then than now. It is reported that old-time hunters used to set fires on purpose. These older residents report that under the burning practice then in vogue the 'brush' (chaparral) was of more open stand and of lower stature, making it possible for a person or large animal to go anywhere on hillsides which now, since burning is restricted, are covered with impenetrable growths of dense, tall chaparral. With the earlier restriction of chaparral herbaceous vegetation was more plentiful, but since burning has been prohibited herbaceous vegetation and grasses are screened out by the growth of the chaparral. Earlier, deer are reported to have stayed on the chaparral slopes and not to have invaded cultivated lands, even when the latter were unfenced." (Storer, 1932:323.)

On the high prairie near Selmour, Illinois, "The total of animals other than ants was greater on the unburned area in both years." Since the ant nests are below ground they are not seriously disturbed by fire. (Rice, 1932:399.)

Speaking of the fear of fire—"No such fear seems to exist. I have seen deer in New Mexico feeding peacefully within half a mile of a big fire that had been filling the woods with smoke for a week. I have seen where deer went across a burn on which the snags were still smoking, when they could just as well have gone around it." (Leopold, 1933:347.)

Late season organized fires have been used in Tsetse Fly control in East Africa. "It will be asked whether these fires do not kill a lot of game and it is thought that the answer is definitely in the negative. It is quite certain that all forms of buck have plenty of warning and their speed will carry them well in front of the fire. Small ground animals undoubtedly perish in large numbers as probably do snakes, lizards, etc.

But it is not thought that the so-called 'game' suffer at all seriously." (Swynnerton, 1934:3.)

"We would like it clearly understood that we are recommending controlled use of fire mainly on quail and wild turkey ground, where an abundance of these game birds is considered of first importance by owners of the land. We are also confining our discussion to the open pineland type of forest * * *."

"Nothing for instance, can be more destructive to ground nesting game birds than summer fires which destroy nests and young, together with growing food supply and cover, and all conservationists should combine against them." (Stoddard, 1935:347.)

"A thousand-acre experimental burn on the Lassen National Forest had the following effect upon wild life:

1. Deer left the area before the fire and returned in increasing numbers the first year, attracted no doubt by new sprouting shrubs, and increased annual vegetation.

2. Rabbits, chiefly cottontails, were completely killed out, or the few survivors moved off immediately after the fire. Many carcasses were found.

3. Chipmunks were markedly reduced but not eliminated. A breeding nucleus survived at some of the rocky outcrops.

4. Mice of the genus *Peromyscus* survived the hottest fire and were caught in the center of the burned area two days after the fire. Litters of mice were caught proving that the presence of mice was the result of survival rather than migration into the burns from adjacent areas." A good crop of ponderosa, jeffery and sugar pine seed was produced.

"Mice were numerous enough to pick up a large portion of their seed." Burns discouraged rabbits for several years. "Burning of manzanita, ceanothus brush fields of northern California would discourage rabbits and cut down the loss of planted pine stock." (Horne, 1938: 379-380.)

"If you ever go deer hunting or elk hunting or antelope hunting in a brush-covered area in the mountains and you want to find any of these animals grazing, if there is any burned area in that country you will find your wild game there, because the feed is so much better there."

"All the grazing areas where the deer and the antelope and the elk used to roam, with those millions of acres over which to roam and get good feed, have not been burned over and have all grown up to brush so there is no feed and those wild game animals are crowded down into the low areas and take the farmers' alfalfa, Sudan grass, Ladino clover and acorns, not because there are more deer, but because their grazing area has been cut down by 50 or 75 percent." (Ellenwood, 1939:2 and 6.)

"Tender sprouts from root crowns or burned perennials provided a source of food eagerly sought by deer. Where any cover at all was available, deer were found to work out into the burn. When flushed from the burn the deer invariably sought to retreat to the edge to get into cover. The burn at the debouchment of San Antonio Canyon into the valley had such scant cover that it is very sparsely occupied by deer. The burned area west of San Antonio Canyon, extending into Fern Canyon and Cow Canyon, contained about 35 percent of the deer found,

although this area comprises only about 12 percent of the study area." (Bartholomew, 1942:8.)

"There is a vigorous sprout growth in some species of the California chaparral when the plants are killed back to the ground level by cutting or burning. This is browsed eagerly by black-tailed deer through a good part of the year. The deer tend to concentrate on this brouse to such an extent that hunters consider burned or lopped areas of sprouting brush ideal for bagging their deer. If crown sprouts could be produced in sufficient amounts to favor deer populations on such areas without injury to other values, the economic status of these lands would be enhanced, as much of the region is clearly submarginal for agricultural purposes."

"These data show that succulent crown sprouts afford higher nutritive values than samples of the current but older, uncropped growth stages, having at least twice as much water, minerals, and crude protein per unit of total dry weight, besides a lower calcium: phosphorus ratio, and lower percentages of crude fiber. From the standpoint of animal nutrition these differences seem to be in favor of the browsed crown sprouts."

"It is problematical why deer favor areas of burned or slashed brushland, * * *. To offer speculation water is likely the first limiting factor in normal animal metabolism, so that the moisture content of young sprouts would favor their greater palatability to deer as compared with more mature plants of chamise or other chaparral. During the hot, dry summers in California chaparral, the succulent sprouts may be sought solely because of their higher moisture content. Associated with the high water content are, however, high levels of both organic and inorganic constituents important in animal nutrition." (Reynolds and Sampson, 1943:119-121.)

"Wild life 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." (Sampsou, 1944:133.)

Fire and overuse tend in the same direction. When only new shoots are eaten, the plants producing them are naturally weakened, since under these conditions it is stored food which is consumed and only a

small part of the carbohydrates and proteins is actually manufactured by the shoots themselves. Therefore while sprout browsing may return food to deer or livestock it is really the food manufactured by the plants before the burn or before they were cut. That is why grazing following fire is likely to cause the extirpation of many of the more palatable plants, and has been condemned by many investigators. It is difficult to segregate the two effects of fire and overgrazing. "Overuse is the mark of greed and it results in reduced total yield and even worse, a constantly decreasing capacity of the land to produce forage. * * * Scientific range appraisal is not easy but neither is it impossible. Surely it is the wise approach to improve big-game management. * * * Stockmen endanger their position on the public lands by a too-insistent attitude that they and they alone are the 'rightful' users." (Stoddard, 1945:24.)

"In summing up my statement I want to remind you that fire is not the total solution to the range problem. It is but a tool for dealing with one phase which must be energetically followed by proper range management of reseeding, proper stocking, etc." (Nelson, 1945:6.)

"The 'biological deserts' of Southern California are, all too often, man-made. Many of these dense brushfields that now cover thousands of acres in the foothill zone were once woodlands; that is oak and pine grew with a ground cover of weeds and grasses, a parkland that attracted deer and game birds by its edge-types. If one doubts this, select for yourself a patch of land unburned for many years and compare it with an equal acreage of brush on a burned hillside for evidence of game. Examine the shrubs in each, and you will find twice or more different species in the woodland or park than in the old burn now grown up into a brushfield of comparatively few species, and that is what a deer likes—variety, a nibble of ceanothus, and a bite of fillaree or clover, a browse off an oak and one from a buckthorn or Fremontia.

"Advocates of constant periodic burning would do well to count the cost 50 years after and not now. Why do deer flock into the fresh burns? For food, the variety of vegetation that nature provides so quickly to cover the bare soil, and also to graze freely. Why are so many new species of weeds found on a burn? Because seeds latent in the soil spring to life when dense shade is removed by cutting or burning. And why should one not keep up the cycle of burning off periodically and so provide the range feed so eagerly sought? Because inevitably the hardier shrubs that grew in scattered quantities before, chamise, manzanita, yerba santa, and the like, will return 10-fold and the effect of fire will, if repeated over a number of years, encourage the vigorous hardy species that grow on poor soils to the detriment of those shrubs and weeds more palatable to deer." (Fleute, 1946:5.)

In western Oregon black-tailed deer suffer from malnutrition. "Many of the favorite food species, like the hedge nettle, common white clover, and fireweed, may be preferred foods in midsummer, but they disappear entirely during the winter. Although commonly found on logged or burned-over lands, they are almost wholly absent from closed canopies or heavily grazed areas. Deer on such lands usually are physically handicapped in winter. On the burned or logged-over lands the browse plants, other than those mentioned, usually are richer in protein, are of more vigorous growth and, in midwinter, still carry sufficient nutriment to sustain deer.

"On over-grazed or closed-canopy areas in Oregon, malnutrition in black-tailed deer became critical following a long period of dull weather. * * * If, however, the weather became mild and new vegetation began to grow * * * a crisis was avoided."

"A chance occurred to test this theory in practice in the fall of 1939, when a large area of about 300,000 acres was designated by the Oregon State Game Commission as a temporary refuge in the 'Tillamook Burn.' A forest fire of unbelievable intensity and destructiveness swept through green timber and previously burned areas, mostly in Tillamook County and east of the city of that name, in late August. This was originally a rugged area covered by a heavy stand of giant spruce, hemlock, Douglas fir, and cedar. With the soil sterilized by the intense heat of the conflagration, it made an ideal study plot. As the result of two severe fires, in 1933 and 1939, less than 5 percent of the original vegetative stand remained on this vast area and the deer population was reduced to below one animal per section of land. A fortunate heavy rainfall during the last days of the 1939 fire eroded the soil to underlying gravel in many places, but stimulated immediate vegetative growth; in consequence, fireweed shoots, most tempting to deer, appeared within 10 days after the conflagration. The intense heat insured freedom from parasites and improved the areas as deer habitat. A few weeks after the fire, the establishment of the entire tract and a marginal buffer strip as a sanctuary protected the remnant animals. The area was closed to hunting until September 26, 1942, when about two-thirds of the refuge was opened for hunting male deer only. The remainder was opened in 1943 under the same restrictions.

"During the protection period, deer increased from an average of less than one to over 15 per section. Most of the population resulted from natural increase, but some deer moved in from adjacent areas of poorer forage, particularly in the southern part, where populations in 1943 were about 30 deer per section along the Trask watershed in the part closed for four breeding seasons." (Einarsen, 1946:56 and 57.) It is difficult to understand the statement * * * "deer increased from an average of less than one to over 15 per section. Most of the population resulted from natural increase, but some deer moved in from adjacent areas" since not more than one-fourth of that increase could at the highest possible rate have resulted from the one deer which occupied the section in 1939.

ON SUBSEQUENT FORAGE PRODUCTION

As previously pointed out, the shepherds of early days were accustomed to use fire in the belief that it benefited the forage for their flocks. Early discussions of range lands in California omit discussions of fire as a tool. (Davy, 1902 and Potter, 1905.) Speaking of the practices in the Mediterranean during the classic period "Burning improved the pasturage, because the ashes temporarily enriched the soil, and the abundant shoots from the old roots furnished better fodder." (Semple, 1931:290.)

On Spring and Fall Ranges in Utah

"Observations on promiscuously burned areas which have been subjected to both promiscuous burning and to heavy grazing show that a combination of these factors has seriously reduced the total density of

the plant cover, and has depleted the stand of perennial grasses nearly 85 percent." (Pickford, 1932:171.)

"For many years cattlemen have observed that their stock exhibited a particular preference for foraging on areas recently burned over. Similar observations have been reported for deer." (Storer, 1932:324.)

In the longleaf pine belt "the average gain of cattle on the unburned pasture for 11 years was 69 pounds per head and for the burned pasture the average gain was 101 pounds per head." (Greene, 1935[a]:338.)

"Studies of grass and legume growth on the areas for periods of eight and nine years respectively showed that the quantity of forage growth on the ungrazed burned areas at the end of the period was more than double that on the unburned areas." (Greene, 1935[a]:820 and 1935[b].)

At McNeil, Mississippi. "From Tables 2 and 3 it appears that the cumulative smothering effect of unburned plant debris not only reduced the grasses on the protected areas but also reduced the legumes to the extent that after nine years of fire protection they were less than half as numerous as on the area burned annually over the same period, where neither area had been grazed."

"*Andropogon scoparius* and *A. tener*, were taken in 1929 and again in 1931 after seven and nine years of burning and fire control, respectively." The result showed 10.15 percent crude protein and 7.92 percent ash when taken from the annually burned area, and 7.77 percent crude protein and 6,86 percent ash when taken from the unburned area. (Greene 1935[b].)

"Destruction or Deterioration of Vegetation

"Fire may act destructively because it destroys or impairs the value of a given plant community, and/or of the crop yielded by that community. At the same time, it may act harmfully in that it puts back to an earlier stage the ecological status of the community: A more advanced stage being replaced by a stage much, or somewhat, earlier in the plant succession. Again, it may bring about an undesirable change in the floristic and community structure of vegetation, by destroying or inhibiting development selectively, or by aiding germination, and growth from root-suckers and stump-coppice, in some species but not in others.

"While fire is used in sylvicultural practices with some forest species such as teak, it may be looked upon as generally detrimental in its effect upon South African native forest."

"In tree-and-grass savanna of various types, and in grass savanna of probable climax nature (that is, the vegetation will develop no farther than a grass stage, under present climatic conditions), it is becoming more evident as work is done upon the interrelations of fire and constitution of the grass flora, that fire may either destroy, retard, or accelerate the development of certain species. What is equally important, however, is that the season of the year and the frequency of firing over the years appear to play a fundamental role in this connection. Destruction of a species, or its appreciable reduction in extent may follow on firing at one season, whereas spread of the species may result from firing at another season."

" 'Fijnbos' (Macchia or Maquis of the southwest Cape) vegetation, in almost all of its types productive of some of the most beautiful flowers

of our flora, has suffered severely by annual ravages by fire." (Phillips, 1936:36-38.)

In a letter of March 3, 1938, Mr. Henry C. Hindley, one of the leading stockmen of Humboldt County, says: "In my case in particular, burning permits as approved by the State Board of Forestry issued to me have increased my range capacity by one-third, which seems incredible considering it is a ranch of 3,450 acres.

"If these permits were discontinued this same property would soon become so covered with brush and small fir trees that it would be useless as a grazing ground.

"I believe that fire over grass land is of a benefit for it kills a moss that grows in the open grass land that eventually chokes out the grasses." "* * * Even deer do far better and get fatter in burned over areas than in any place else even though it is not seeded. They eat the young sprouts and help keep the brush down, where in old brush they do little if any feeding." (Strickland, 1938: 5.)

"Whenever an area is burned over the feed will be at least ten times as much and as good on a burned-over area as it is on a nonburned area." (Ellenwood, 1939: 2.)

Grazing, following fire, is confined to young plants or new sprouts. A study at the San Joaquin Experimental Range showed: "Review of the literature here cited reveals the fact that much confusion exists relative to the changes in composition of forage species. The fact that there is a high percentage of crude protein, and a low percentage of crude fiber in the early growth stages, followed by gradual decline in the former and increase in the latter with advance in the season, has already been well established: * * *.

"In most of the graminaceous, grass like, and broad-leaved herbaceous species, there is a continuous and rather orderly decline in the crude protein, the silica-free ash, calcium phosphorus, and potassium from the earliest appearance of the leaf blades to plant maturity. The percentage of crude fiber in these plant groups, on the other hand, increases with the advance of the season."

"The crude protein in the foliage of the deciduous shrubs and trees declines in an orderly way from the earliest appearance of the leaves to their maturity. * * * The crude fiber * * * maintains nearly the same level throughout the season, * * * in silica-free ash, and in calcium content, * * * the trend is distinctly upward with advancement in the season, * * * the trend in potassium content * * * is distinctly downward with increasing age of the foliage. * * * The phosphorus content declines gradually from the early leaf stage to leaf maturity." (Gordon and Sampson, 1939: 89-90.)

The uncertainty of an annual grass crop is pointed out for the intermountain region and would apply wherever grazing is largely or entirely dependent upon it. "These acute shortages in the yield of downy chess, which may come without warning, introduce such a large element of uncertainty into the feed supply program of stockmen that it is extremely hazardous for them to use this plant as a basis on which to establish perennial grazing operations." (Stewart and Young, 1939:1015.)

At McNeil, Mississippi, "Annual winter burning maintained more favorable composition, quality, and quantity of forage than did exclusion of fire." (Wahlenberg, Greene and Reid, 1939:47.)

In the woodland chaparral of the Sierra Nevada foothills "With the repeated burning of the vegetation there was a continual decrease in both the growth-rate and density of the vegetation and in the proportion of grasses to weed-species until by 1938 approximately 90 percent of the mineral soil was exposed." (Rowe, 1941:92.)

"After the first burns on both the periodically and annually burned plots the herbaceous vegetation came in abundantly and showed excellent top growth. * * * The stimulus to the herbaceous growth was very short lived, for with repeated burning there was continual decrease in both growth and density of the vegetation and a comparatively rapid decrease in the proportion of grasses to weed species." (Rowe, 1941:101.)

Downy chess, an annual, has taken over much of the northern and intermountain areas. Studies in Nevada indicate "The length of time through which it remains green and palatable depends on the amount of soil moisture. Bronco grass is, therefore, not a reliable source of feed for any definite length of time year after year.

"Invasion by bronco grass is hastened by any soil or vegetative disturbance such as is caused by heavy grazing or by fire.

"It can withstand untimely and heavy grazing better than the perennial grasses.

"Is there any assurance that perennial grasses would withstand the hard conditions of early spring grazing as well as bronco grass if they could be restored?" (Flemming, Shipley and Miller, 1942:20-21.)

"Cattle, sheep, or deer will usually graze a burned-over area in preference to forage on the unburned land adjoining, at least during the first season following the fire.

"In 1930 the phosphorus content of the alfilaria from the burned area, at all stages of sampling except in the leached condition, was approximately double that from the unburned, and the Ca:P ratio in the latter was extremely wide. * * * In wild oats there was about 25 percent more phosphorus in the forage from the burned-over area during 1930.

"In the spring of 1932 opportunity was presented to collect forage samples from burned and unburned areas on the more fertile soils of ranch No. 1 and on the University Farm. This was done with three species of alfilaria and with bur clover. Sampling was limited to the months of March and April. No significant difference was observed in the phosphorus content in the samples on these places although the stock were observed to give definite preference to the forage on the burned area. This question of palatability, therefore, probably involves many factors." (Hart, Guilbert and Goss, 1932:31 and 33.)

"By means of chemical analyses of samples from burned and unburned areas an attempt was made to ascertain why the forage on burned areas is more palatable to livestock during the first year following the fire. In one area a decided increase in phosphorus was shown to exist in broadleaf alfilaria and to a less extent in wild oats on the burned area. This was not substantiated in a limited number of samples taken from two other areas with more fertile soil." (Hart Guilbert and Goss, 1932:52.)

"Only 16 percent of the species" of herbs and grasses "which become conspicuous after fires tend to persist in comparatively large numbers five years or more after burning; * * *. 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 not more abundant than on unburned brush-lands.

"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 * * *. (Sampson, 1944:30-31.)

"* * * 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 8,920 pounds, respectively." The second year after burning the dry weight was 2,760 pounds per acre, the third year 4,150, the fourth year 6,600, the sixth year 10,080, the seventh 10,840, the eighth 11,380 and on unusually dense unburned old stands 28,070. "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 consumption of soil moisture by sprouts and seedlings of the chaparral vegetation." (Sampson, 1944:32, 38, 40 and 37.)

"In all instances, sprouts of chamise, manzanita, poison oak, and frequently yerba santa, appeared early in the season of the first year after burning. The sprouts and brush seedlings continued to develop in subsequent years until little other vegetation remained; but in the interim the carrying capacity was increased on areas of productive soil, whereas on thin soils little or no improvement was obtained."

"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." (Sampson 1944:44 and 46.)

"After fire or logging and fire, pure ponderosa pine lands have largely passed to a deerbrush and white-leaf 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, * * * extension of chamise and various species of manzanita and ceanothus into the burned brush-bordered grassland was found to occur with rather marked regularity." A three-acre patch of chamise had 22-year-old plants in the center, 11-year-old plants around this area and four-year-old plants on the periphery. "Thus, the central portion of the stand showed an average age of 22 years and the effect of at least two heavy fires. Surrounding this, * * * the area averaged 11 years, and showed the effects of * * * one heavy fire. The outermost circle of young brush * * * indicating that the last fire had crossed the area about five years previously." (Sampson, 1944:56-59.)

A comparison of vegetation on burned and unburned areas shows the following chemical differences. "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. * * * In all species the levels of phosphorus and potassium are highest in the early growth stages. The percentage of calcium, on the other hand, increases in the

shrubs and decreases in the herbs with the march of the season." (Sampson, 1944:97.)

"Inspections of the 1944 burn on Cow Mountain covering different areas in the north and south ends of the mountain show * * * There is little or no herbaceous vegetation growth on the pure chamise type during 1945 and 1946. Chamise sprouts have not developed greatly here due to soil conditions probably and hence little forage for game has been produced. No deer were seen on any of the chamise burned in 1944 nor were any deer tracks seen on three different large areas on trips made to the mountain in 1945 or 1946. Both deer and numerous deer tracks were seen in the dense brush types and in the woodland types. No domestic stock or sign were seen on any of the area at any time and little forage suitable for cattle or sheep was produced in 1945 or 1946 on any of the chamise burn, but lower down in the woodland and mixed brush types that were burned, considerable herbaceous vegetation was found along draws and on northerly slopes." (Smith, 1944.)

"One objective should be to determine before brush removal what will be the character and density of the cover that will come in naturally."

"On the Pauba ranch in Riverside County, an area of range near a nursery was accidentally burned in the summer of 1941. * * * In 1942, pasturable forage on the burned area was estimated to be twice as great as on unburned areas adjacent: * * * The brush is wild buckwheat and chamise." (Jones and Love, 1945:35, 32 and 33.)

"Military use of the Hunter Liggett Reservation has resulted in a large number of accidental fires. Because some of these were so intense and difficult to control, the Army has adopted the policy of annual burning in the areas where shellfire and other military activities made a critical fire hazard. * * * Since careful records of all burns have been kept, the Reservation offers an unparalleled opportunity of observation of the effect of fire on vegetation, plant succession and erosion. It would be very desirable for a well trained ecologist, assisted by a soil scientist, to make a thorough study of this area." The results are briefly as follows:

"1. Annual Burning of Grasslands:

Shallow infertile hill soils showed a marked increase of broadleaved filaree at the expense of several other species, especially soft brome. An area of deeper more fertile hill soil showed little change in composition.

"2. Annual Burning of Oak-Grass Savannah: * * *

Annual burning has not injured the oaks (mostly valley white oak, *Quercus lobata*) of moderate size but has prevented all reproduction. It has also destroyed many of the over-mature oaks with basal rot that could be reached by fire. The acorn crop in many years has considerable forage value. * * *

"3. Brush and Forest Fires: * * *

"A. Steep South or Southwest Slopes with Thin Soils Overlying More or Less Fractured Rock. * * * As a result of a hot burn the following occurred: (a) moderate to very severe erosion still occurring after three years, although at reduced rate. (b) Crown sprouting of the following: chamise, eriodictyon, live oak and redberry. Sprouts of the last two have some forage value. (c) numerous seedlings appeared of chamise, eriodictyon, sometimes wild buckwheat, and buckbrush. * * * From a

forage production standpoint, the results are to make worse an already practically worthless type of vegetation.

"B. Steep North and East Slopes, with Moderately Deep Residual Soils: * * * The total results appeared to be on the average: Eventual increase in the percentage and density of unpalatable shrubs; preceded by, in most cases, an increase in palatable brush sprouts for the second, third and fourth years after the burn; an increase of available grasses and herbs on the second and third years after the burn. This appears to be a net profit for the burn. However, there was evidence that if a second burn occurred, say the fourth year, the replacement of desirable shrubs by unpalatable shrubs, especially chamise, would be even more marked. * * *

"C. Deep Soils, Mainly Alluvial on the Level or Gentle Slopes. The results of a hot burn are very similar to those discussed under 'B' except that all vegetation, both grass and shrubs, grew more vigorously. We obtained clear evidence that chamise and buckbrush, both worthless to cattle, seeded out several feet into an area occupied only by grass before the burn. * * *

"An area of purple needlegrass (Stipa pulchra) was severely damaged by a hot burn that occurred last summer." (Bond, McNutt and Johnson, 1946:1-5.)

THE EFFECT OF VEGETATION COVER ON SOIL EROSION AND RUNOFF

The reduction of plant cover can be brought about by fire, overgrazing, or by human actions such as cutting, lumbering, road building, or cultivation. The reduction of the perennial cover to an annual crop even of native grasses is an approach to agricultural practice. It is not easy to appreciate in advance what will be the ultimate result of human action. Speaking of the grassland of the Abilene section of Texas, "The pioneer stockman in the section thought he had 'struck it rich,' as he had, and that there was not a sufficient number of cows in Texas to eat all the grass he saw growing in what is now called the Abilene country. There was no one in the country asserting any special claims to any particular lands."

"The idea that any of these grasses would ever become extinct, or that this golden period of fatness and plenty would come to an end, never entered the minds of those who were reaping the harvest. At a meeting of stockmen recently held those present were questioned about the native grasses growing on their respective ranges. One of the best informed undertook to describe the habitat and the characteristics of certain varieties that were especially mentioned. * * * At last one stockman offered a resolution which was adopted without a dissenting voice and with a shout. It was in words as follows: 'Resolved, that none of us know, or care to know, anything about grasses, native or otherwise, outside of the fact that for the present there are lots of them, the best on record, and we are after getting the most out of them while they last'." (Bentley, 1898:7, 12-13.)

Discussing the stock ranges of northwestern California although not mentioning erosion as such the stages of deterioration of natural plant cover are discussed. "Range deterioration is traceable to the desire to make as much off the land as possible, coupled with two mistaken ideas: (1) That a range can continue to carry the maximum number of stock without deterioration year after year without any rest; (2) That in order to get the most out of a range in a given period of time it must be stocked to its maximum carrying capacity.

"By maximum carrying capacity is meant the highest possible number of stock that the range will turn off in good condition at selling time, without taking into account the condition of the range itself; * * *.

"Two factors are at work on range deterioration. One is the destruction of the choicest forage plants by selection; the other the introduction of uneatable weeds which, multiplying rapidly, crowd out the often less vigorous, useful species, and fill the spaces left vacant." (Davy, 1902:38 and 40.)

The weeds are, so to speak, nature's effort to maintain a plant cover when the natural plant cover has been removed. Weeds may or may not

be valuable as forage, but they are always valuable in protecting the surface soil and in preparing the habitat for more permanent species.

"In conclusion, it may be said that although forest may have, on the whole, but little appreciable effect in increasing the rainfall and the annual runoff its economic importance in regulating the flow of streams is beyond computation. The great indirect value of the forest is the effect which it has on preventing wind and water erosion, thus allowing the soil on hills and mountains to remain where it is formed, and in other ways providing an adequate absorbing medium at the sources of the water courses of the country. It is the amount of water that passes into the soil, not the amount of rainfall, that makes a region garden or desert." (Toumey, 1903:288.)

From a six-year record on one-eightieth acre plots the runoff was reduced by bluegrass to 23 percent the amount from bare soil uncultivated but with the weeds pulled. The loss of an inch of soil would have taken 29 years on the bare soil and 3,547 years on bluegrass sod. (Duley and Miller, 1923:17 and 31.)

"Erosion and siltation effects follow deforestation in southeast Australia. * * * Two inevitable conclusions arise from this examination. In the first place the summer runoff is diminishing in volume; and conversely, the winter runoff is increasing. This means that the natural regulators, i.e., the forest catchments, are failing to the extent of approximately 14 percent over a period of 50 years. Secondly the velocity of the runoff is being accelerated over the whole area. After heavy rain hill streams rise immediately and become very muddy. * * * There is an urgent necessity for more complete investigation of the dangers that threaten our water supply. * * * The grazing license, which is the root-cause of deforestation in the hill-sections should be abolished immediately." (Wood, 1928:134-138.)

On plots 6 x 96.8 feet with a 2 percent slope, buffalo grass cover with a rainfall of 27.99 inches in 1926 lost soil at the rate of 11.32 tons per acre and fallow not cultivated 38.65 tons. In 1927 with a rainfall of 10.12 buffalo grass lost nothing and bare soil 6.83 tons per acre. In 1928 with 16.79 inches rainfall buffalo grass lost 0.08 tons and bare soil 19.82. The totals for the three years was 60.90 inches of rainfall and loss from buffalo grass 11.40 tons of soil per acre and from bare soil not cultivated 65.30 tons of soil per acre. (Dickson, 1929:418.)

"The results indicate that vegetation cover is a contributing factor in controlling erosion.* * *" (Coner, Dickinson and Scoates, 1930:49.)

"A 40 percent vegetation cover as compared to one of 16 percent reduced the amount of erosion caused by each 1,000 cubic feet of runoff from melted snow by approximately 57 percent and the average annual quantity of erosion from summer rains by approximately 54 percent." (Forsling, 1931:61.)

"The rock skeletons of Mediterranean lands are everywhere prone to thrust through the meager envelope of soil."

"When the mountains were denuded of their forests, the violent autumn storms, with their sudden downpour of rain scoured off the thin covering of earth from the steep declivities. The shield of foliage was no longer there to break the impact of the rain; the network of roots no longer held the light humus to the slopes." (Semple, 1931:291.)

"After several centuries of forest management in France, Germany, Switzerland, Austria, and Italy, the principle is universally recognized that a complete mantle of forest, brush, or certain types of herbaceous vegetation produces maximum regulation of runoff and reduces erosion to a negligible degree." (Pardee, 1932:13.)

"Vegetative cover is probably the most important factor of all those influencing erosion."

"Its removal or alteration by man, or his influences, may be placed in four general categories: 1. Cultivation and preparation of land for agricultural purposes. 2. Pasturing of stock. 3. Lumbering and other nonagricultural land-clearing operations. 4. Fire."

"Plants have a three-fold influence as a protection to the soil against the destructive action of running water. The stems, leaves, and branches intercept the rainfall before it touches the soil, thus breaking up the force of its fall and the resulting pounding action which always takes place on bare hard surfaces. Raindrops, therefore, reach the surface of the soil at greatly reduced velocities. Vegetation tends to minimize the concentration of rain water on the surface and its collection into small streams or rivulets. The roots of vegetation hold the soil particles together." (Weir, 1932:10, 11.)

In northern Utah "It was strikingly evident that the floods originated on the barren or nearly barren areas of the upper zone.* * * The steep, well-vegetated intermediate side slopes of the canyons contributed practically no runoff to the floods which swept down the main-stream channels.* * * No gullies originating on the adjacent steep, brush-covered slopes led into the flood channel." (Bailey, Forsling and Becraft, 1934:16-18.)

"From the data yielded by the North Fork installation, it may be concluded that a mantle of undisturbed vegetation serves in heavy rain storms to maintain the soil at high rates of absorption of rainfall, and that baring the soil of its natural cover of vegetation under the conditions increases superficial runoff.

"With increase of superficial runoff soil erosion is increased or accelerated far above the rate which took place under the control of a mantle of natural vegetation of the woodland brush type.* * *" (Lowdermilk, and Rowe, 1934:515.)

At Bethany, Missouri, "Under alfalfa there was a loss of only .2 ton of soil per acre * * *. For the same period fallow land kept free of vegetation lost an average of 112 tons of soil * * *."

At Columbia, Missouri, "Soil loss from fallow land was at the rate of 41 tons per acre, * * * while land in continuous bluegrass lost only .3 ton of soil per acre per year." At Tyler, Texas, "very steep slopes (16.5 percent) lost scarcely no soil when in grass, while the loss ran as high as 35 tons per acre when in cotton." (Upland, 1935:117 and 120.)

At Indianola, Iowa, measurements showed runoff to vary with different vegetative cover from 0.46 gallons for hazel brush-bluegrass to 7.62 gallons for oats.

"The mean plot runoff for the season was hazel brush-bluegrass 0.46 gallon, second growth oak-hickory 0.76 gallon, sweet clover 0.90 gallon, wheat drilled across 1.41 gallons, barley (weeds) 1.81 gallons, timothy and clover 2.18 gallons, alfalfa 3.49 gallons, weeds on old field 4.24

gallons, sudan grass 4.64 gallons, ragweed 4.90 gallons, wheat drilled down 5.45 gallons, corn 5.52 gallons, soybeans 5.89 gallons, sorghum 7.58 gallons, oats 7.62 gallons." (Dodge 1935:193.)

At Hayes, Kansas "land has lost under a mean annual rainfall of 22.18 inches, an average annual soil loss from native grass of 0.09 tons per acre, * * * the losses from a field rotated to wheat, kaffir corn and fallow were 15.79 tons of soil per acre * * *." (Lowdermilk, 1935[a]:124.)

On the Colorado Plateau "The destruction and modification of the plant cover by over-grazing appear to be the dominant causes of the recent epicycle of erosion." (Bailey, 1935:355.)

"It is a well-recognized fact that close vegetation, such as bluegrass sod or alfalfa, has a pronounced effect in reducing erosion and a somewhat less effect in reducing runoff." (Musgrave and Free, 1936:735.)

A vegetation cover of less than 30 percent appears to have little appreciable effect on retarding erosion.

"Rodents appear to have been an important factor in contributing to accumulated erosion. These animals have partially depleted the vegetation and disturbed the soil over four-fifths of the area studied. In addition, their effect upon erosion has probably been increased by their habits of concentration on southerly exposures and other areas which are heavily grazed by livestock." (Renner, 1936:32.)

"Vegetation, with the accumulation of litter, tends to retard surface runoff on steep slopes like those of Pickens Canyon, and its removal may permit a great increase in the rapidity with which the water passes over the surface of the ground. As the capacity of flowing water to carry debris varies as about the 3.2 power of the velocity if the slope remains the same, the increase in the velocity caused by removal of the vegetative cover will greatly increase the transporting capacity." (Troxell and Peterson, 1937:94.)

On the upper Rio Grande "Historical evidence clearly shows that the recent general decline of the watershed lands and resources began during the 1880's following the impairment of the natural vegetation cover." (Cooperrider and Hendricks, 1937:86.)

"The forest is the most efficient element to protect the surface of the soil." (Enquete International, 1937:132.)

"The most obvious conclusion from this study is the unquestionable superiority of the wheatgrass range over other existing range types for controlling runoff and erosion."

"Little need be said concerning the place of the annual weed type in range-watershed management. It is of little or no value at best for grazing, and areas supporting it constitute an erosion hazard that requires immediate attention in the interest of protection of forage and soil resources." The weed type includes tarweed, lettuce, etc. (Craddock and Pearse, 1938:18 and 19.)

"The forest tends to mitigate the small and middle floods but its greatest value is in the lessening of erosion, and preventing or reducing the movement of material to the small streams, thereby preserving their water carrying capacities. The forest in effect is desired primarily to hold back the soil, not the water." (Wannamaker, 1938:48.)

"The natural, most effective, and most economically maintained protection is through vegetation." (Cooperrider and Sykes, 1938:64.)

"Utilization of the foothill lands by livestock with or without burning of the vegetation is likely to effect all of the foregoing objectives to the extent that the soil is exposed in the process. There is a considerable literature that seems to show that the depletion of vegetation and exposure of bare soil may have detrimental effects several ways. Erosion may be accelerated, surface runoff and resulting flood crests may be increased." (Kittridge, 1940[a].)

"The flood source areas are characterized by a recently developed gully system, disturbed soil-horizons, and remnants of the original plant cover. While numerous freshly cut gullies testify to rapid runoff from the depleted 'sore spots,' there was no indication of accelerated runoff from adjacent and interspersed well-vegetated areas."

"From this evidence it was concluded that the formerly stable plant and soil mantle had been disturbed sufficiently to change the runoff and erosion relationships on these areas giving rise to abnormal floods. * * * From the evidence presented it is concluded that certain watersheds in the semi-arid west have normally high rates of degradation; that others have relatively low rates of erosion and runoff due to the development of a plant and soil mantle, the binding power and infiltration rates of which are equal to or in excess of the physical forces of degradation; and the accelerated erosion and runoff have been induced on some areas by a reduction of the normal infiltration-rate and stability of the soil mantle by deterioration of the plant cover." (Bailey, 1941:245 and 250.)

"Erosion was found to be most rapid on the abandoned fields, intermediate on the mountain bunchgrass, and least on the valley bunchgrass type." (Johnson and Neiderhop, 1941:856.)

CONTROLLED AND LIGHT BURNING

The use of fire as a tool in the management of vegetation is a many-sided problem. In some cases only a light burning is desired, while again the fire must be intense and severe to accomplish the desired end. The immediate result may be favorable while the ultimate effect may be bad. On the other hand bad present effects may be followed later by desirable effects.

In India—"Firstly, the want of unanimity in matters of fact is forced on one's notice; secondly, it is evident that conditions differ so greatly even in neighboring localities, that it is very unsafe to generalize.

"One point must be conceded to the 'too much protection' school. In certain localities and under certain conditions fire protection appears to be inimical to natural regeneration.

"In all forests fire is harmful, both directly to the growing-stock and indirectly by the removal of the soil covering, leading to dessication, lack of aeration of the soil, erosion, loss of nitrogen, destruction of seeds, etc.

"In certain forests, however, fire protection unaided by other operations hinders the natural reproduction of the most valuable species, especially in the case of teak forests.

"Improved fellings and clearings on a sufficient scale suffice to establish natural regeneration in the forests referred to." (Fisher, 1912:218 and 221.)

"As I view it, protection may be essential in one locality, of little importance in a second, and disastrous in a third.

"In Burma teak has suffered under fire-protection." (Walker, 1912:438-439.)

"Destruction by Fire. It is probable that a large number of tsetses in any case fail to survive the hard conditions of the height of the dry season, and these conditions would be intensified by thorough burning." (Swynnerton, 1923:356.)

"The heavy growth of bracken which follows the removal of our large forest trees has always seemed to me one of the most serious after-effects of deforestation in our mountain areas."

"It is one of the greatest enemies to reforestation that I know in the mountain areas. Not only does its vigorous rooting system overpower the young seedling eucalyptus, but it is just food for forest fires." (Ritchie, 1923:90.)

"The theory of 'light burning' is based on three postulates: (1) That under favorable circumstances fire will run through the forest consuming dead needles and branches, but with little or no damage to living trees; (2) that the intensity of a fire depends largely on the amount of inflammable debris which has accumulated on the ground since the preceding fire on the same area; (3) that complete prevention of fire is impossible.

"Opponents to the theory reply: that even light fire always does some damage both to mature timber and more especially to reproduction;

(2) that on the one hand the accumulation of true 'debris' under a system of fire prevention ceases after five or six years by decay, while on the other hand the accumulation of inflammable reproduction is an essential to timber production; (3) that reasonably complete protection has been proven practicable by the experience of the United States Forest Service.

"The conclusions of this and previous seasons are as follows: (1) spring burning is dangerous because by the time the litter is sufficiently dry to burn satisfactorily the season is normally far advanced. No more rains can be counted on and smoldering logs and snags may hold fire well on into the fire season; (2) summer burning can be kept under control, but apparently only at an expense out of proportion to the benefits obtained; (3) fall burning is often impractical because while vegetation dries out slowly it may become saturated with water in a few hours. Not infrequently the most critical period of the fire season is terminated by heavy rains, after which the ground never again becomes dry enough for burning. This condition may not be universal, but it seems sufficiently frequent to make fall burning impracticable as a generally appreciable plan; (4) at any season the cost of light burning appears considerably greater than the benefits resulting; (5) down-hill burning is decidedly preferable to up-hill burning, but it seems impracticable to avoid some up-hill burning on large experiments, and even down-hill fires are not free from damage; (6) no burn yet observed failed to damage seriously reproduction; * * * (7) no burn yet studied critically failed to cause damage to mature timber * * * ; (9) under conditions where light burning seems most necessary it is too dangerous to be practical; (10) light burning on large areas at one time is impossible because the moisture conditions on slopes of different directions vary widely." (Bruce, 1923 :130-133.)

"Light or controlled burning may be defined as the intentional burning of the forest at intervals with the objective of consuming much of the inflammable material and of so reducing the general forest-fire hazard that accidental fires will be controlled with ease and will cause but minimum damage to merchantable timber.

"In order for it to satisfactorily and economically accomplish the specific purpose of reducing the general hazard, which is its main purpose, light burning should meet these three conditions: (1) the amount of inflammable material must be considerably reduced; (2) the direct money cost of burning must be kept within reasonable limits, particularly if frequent burning of an area is found essential to reduce hazard; (3) the indirect cost or damage, both in the form of merchantable timber and small trees, must be held to a low percentage of the total destructible value at stake.

"The whole question of grazing and fire can be summed up by saying that in California pine region timber production and forage production necessarily conflict; that what is beneficial to the one is usually a detriment to the other; and that if lands are to be handled for permanent production of timber, grazing will inevitably be relegated to minor position in forest management as the artificial aid of fire is eliminated.

"Fire in virgin forests in restocking brush fields, and on cut-over lands is important not only in the loss of timber resources it causes, but also because each fire paves the way for greater and more serious losses from subsequent fires * * * as a result of this process each fire, by allowing the invasion of inflammable brush species, and adding fuel in other

forms, makes future protection more costly, more difficult and more uncertain." (Show and Kotok, 1924:45, 59, 71, and 78.)

"Since preservation of advanced reproduction is so important in continuing the stand, it follows that broadcast burning of the virgin forest should be avoided, because even light surface fires destroy most if not all of the young growth." (Show, 1926:11.)

"Teak forests began to become evergreen in character and in other areas bamboo and evergreen oaks invaded so that teak had little chance of regenerating. Management plans now include rather severe burning but when a young crop has been obtained, fire is excluded for at least ten years." (Irwin, 1927.)

"Within comparatively recent years the deterioration of the pasturage in the native locations has made alarming strides, * * *. It has been roughly estimated that over 60 square miles of previously excellent pasturage has been more or less taken possession of by an everlasting, * * * locally known as the 'Helichrysum Weed,' which even a hungry goat will not touch.

"The fire had swept through a portion of the enclosure and about a quarter of it had been burned. I had then, both burned and unburned ground inside and outside the enclosure, * * *. The natives at once put their cattle, sheep, and goats to graze on the young shoots of grass as they were coming up on the burned ground outside the enclosure * * * about 17 months after burning the burned patches exhibited a fine dense stand of grass, chiefly consisting of rooigras, whereas outside the fence the Helichrysum was strongly in evidence again, and could already be noticed at a considerable distance. In between the cushions there were large empty spaces, and here and there grass nibbled to the ground." "* * * it is quite clear from our experience that where grass has a fair chance the Helichrysum has none at all." (Schönland, 1927:6-8.)

"Periodically, the forest protection policy of the United States Forest Service, which seeks (1) to prevent fires from starting, and (2) to suppress quickly those that may start, is attacked by people who hold that the deliberate and repeated burning of forest lands offers the best method of protecting these lands from the devastation of summer fires. The 'light burning' advocates base their contentions on the false premises that fire prevention is in the long run an impossibility, that controlled burning does protect the merchantable stands of timber, and that this can be done at a lower cost than by fire prevention methods. But they present no facts to prove the correctness of their theory.

"Periodic burning does at first increase the stand of forage plants, but extensive experiments have shown that if this practice is continued, the noxious weeds and shrubs, which are more hardy than the forage plants, will soon take possession of the range and turn it into a weed and brush patch.

"Light fires, even if it were possible to properly control them, cause serious damage to the most valuable veterans of the stand by burning them at the base and causing cat-faces—a loss that amounts to several dollars per acre in merchantable timber every time a fire runs through the forest. In addition, all the little trees and saplings, which are the basis of the next timber crop, are killed outright. No more effective method of sure and total forest destruction could be devised. 'Light

burning' causes the same sort of forest destruction it is claimed to prevent.

"Do we want brush fields or forests in the mountains of California? If we want brush, let us 'light burn' and deliberately destroy the great natural wealth of the State." (Show, 1928 :1-3.)

"The recent discussion over the question of the use of fire in removing brush from private lands in the North Coast counties is an effort on the part of landowners to improve the carrying capacity of some of their hillsides from a grazing point of view.

"At this meeting there was evidently a very strong demand for a policy of assistance to farmers and stockmen in the removal of brush from their lands in order that they would support the maximum number of grazing animals. I believe that Mr. Kotok presented arguments in opposition to any policy of burning, pointing out the danger of fire getting out of control, damaging the neighboring property and possibly even constituting a menace to adjacent lands in Federal ownership. He also stressed the potential value of much of the land involved for recreational purposes and emphasized the point that such recreational values would probably be far in excess of any value from grazing and that fire scars throughout the region would certainly detract from the scenic values.

"State Forester Pratt then discussed a tentative policy in connection with such controlled burning involving the following essential points: (1) Organization of owners of land in each district into an association for cooperative assistance to the state during the fire season in preventing and controlling fires. (2) Agreement by members of such associations that they would do no burning prior to September first and then only under permit from and with the supervision of a representative of the State Forester's Office * * *. (3) Agreement on the part of the State Forest Inspector and Ranger that assistance and direction would be given in burning of such privately-owned lands outside the national forests and where in the judgment of the State Forest Inspector that such burning could be carried out without damage to timber or watershed values. * * *

"It is my opinion that this policy will greatly strengthen the fire protective work of the State in the North Coast counties in the next two or three years and should eventually result in complete understanding and cooperation in the program by many of those who are now antagonistic to any supervised program of fire protection. I realize that there are dangers of misinterpretation involved and also that there is some likelihood that a few fires may escape and do some damage. However, the real test of the policy will be in the appearance of the country in the region after a series of years and I have full confidence that the net result will be a substantial decrease in burned area." (Metcalf, 1930 :1-2.)

"In the past it has been a common custom to set fire to brush lands during the hottest part of the summer in order that 'a good clean burn' could be secured. In the natural course of events many of these fires got out of control and burned over much more territory than was intended by those who set them. Much damage to timber stands, improvements, and to scenic and recreational values was done, but the average resident of the region frequently adopts a complacent attitude about such damage

and usually dismisses the subject with the significant remark that, 'Anyway, the fires are doing more good than harm.'

"It has been demonstrated on relatively few areas that burning followed by careful handling to insure revegetation will result in improved forage conditions. There are many other tracts where soil, topographic, climatic, or economic conditions do not warrant the expense and danger involved. The College of Agriculture is carrying on some tests on typical areas and the results obtained should be pointed out to the owner of similar soil types. He should be made to realize that other methods, such as cutting and piling brush, followed by close grazing by goats, has usually given much better results than the use of fire.

"Within the redwood timber-land area where natural and artificial reforestation are bringing new stands of timber to replace the old, protection of these cut-over lands is a very vital problem. Such lands are often interspersed with agricultural lands from which the owners desire to burn the cover. Under the controlled burning policy such burning will be carried on under such safeguards as will minimize the danger to near-by plantations and young natural second-growth stands. Where such fires are set out without such safeguards and supervision, they may result in the burning over of thousands of acres of second-growth even though they be set late in the fall after the fire season is presumably over. I have recently examined an area near Trinidad, Humboldt County, where such a fire in November, 1929, caused irreparable damage to a large area of fine young timber.

"The real measure of the worth of such a policy will be the appearance of the region after a series of years. If it results in range improvement and less damage from fire than now occurs, it will be a step toward the better economic handling of the resources of the region. If the result is more widespread damage from fire than is now occurring, the policy should be discarded or changed. Bad fire scars on lands valuable for timber, watershed or recreation cannot be tolerated and will not be popular among the serious minded people of the region itself for very long. I am firmly convinced that this policy of helpful assistance to the private owner in handling his problem safely and legally, coupled with good law enforcement of the fire laws, good organization and equipment for fire-fighting in each local community and a continuing program of education in the fundamental principles of land use whether it be for growing timber, for grazing or other agricultural use, will yield big dividends." (Metcalf, 1930[a]:2-5.)

"A system of plowed or plow-harrowed fire lanes that circle incipient thickets, and divide the preserve into small units that can be burned out in winter by light fires of the 'creeping' type in alternate years, or as needed, may be made to increase, diversify, and properly distribute the food supply, regulate density and extent of thicket and ground cover, and aid in safeguarding the nesting by bringing about more even distribution of nests as well as permitting sterilization against parasites and disease of limited areas of cover where birds concentrate. (Stoddard, 1931:413.)

"In the redwood region of California there is a very common apathy toward the prevention of fires on forest and cut-over lands. Many local residents believe that fires do no harm in the forest; some go so far as to claim that periodic burning of the forest is good for the trees and that

it stimulates their growth. Some believe that exclusion of fires invites the growth of 'undergrowth' or shrubs which 'sap the vitality' of the trees and cause 'spike-tops' and eventually death. 'Old-timers' believe that in the early days fires were not so destructive as they are today because the more frequent burning kept the woods open. They claim that all of the forest was burned deliberately in those days every few years. These beliefs are fallacious as can be easily proved by close observation and correct interpretation of what one sees. The virgin redwood forest has been irreparably damaged by past fires; current fires aggravate the damage and on cut-over land they materially reduce its ability to produce new tree growth." * * * (Fritz, 1932:1-2.)

"For the removal of brush and its replacement by grass, where grazing is the best use of the land, or by timber on sites more favorable for profit from timber growing, there is urgent need for methods which are effective and cheap and at the same time without damaging results.

"Fire has been used for this purpose mainly because it has been the cheapest means available and was at least immediately effective. In some cases it has resulted in converting chaparral to grass. In others it has only resulted in extending the brush area. Too little is yet known of the reasons for success or failure. If fire can be made a good servant without entailing damages, both public and private, larger than its benefits, much will have been gained. The difficulty with indiscriminate broadcast burning is the lack of control. There is always danger of the fire spreading into areas which should not be burned, such as those to be devoted to forest-growing or those important for watershed control. Broadcast burning has had three-quarters of a century of trial, from which the evidence is clear that it has resulted in a continuously increasing total brush area, which has invaded both upward into that formerly occupied by the forest and downward into that of the grass." (Weeks, Wieslander, and Hill, 1934:85.)

"Fire as a Good Servant. Controlled firing of vegetation, controlled in regard to season and frequency, for a given class of vegetation within a given climate or soil region, undoubtedly has much to be said in its favor.

"From my own experience in the fijnbos * * * I am strongly inclined to the view that experimental work relatively soon would show one season to be more suitable than another, so far as obtaining the best increase in browse or grazing, and the minimum development of poisonous Monocotyledons * * * " (Phillips, 1936:40-41.)

"The dry season activity of the Tsetse Research Department at their Field Station at Old Shinyanga culminates in the grass fires during August. These organized late fires have been one of the main features of the anti-tsetse campaign at Shinyanga for many years and have actually been the sole method of reclamation in one of the blocks of country into which the area is divided for experimental purposes." * * * (Swynnerton, 1934:1.)

Speaking of controlled burning "The policy has been over-promoted as a panacea for lack of productiveness of grazing lands in some parts of the region." (Metcalf, 1935[a]:1.)

"We do, however, consider that carefully controlled fire, used at the proper season, under proper weather conditions, for the definite purpose of regulating cover and increasing food supply of the game birds, is a

necessary tool over much southeastern game territory, and an essential feature of quail management in the region.

"When judgment indicates that each fire will die out through increasing dampness after it has burned a spot of the desired size, we start criss-crossing the block, setting fires about every 100 yards until several dozen are burning.

"If all goes as planned, the block is ideally 'spot burned' when fires die out late in the night, and approximately half of the acreage burned very lightly in well distributed spots, with equally well distributed cover remaining between.

"Now for the procedure to be followed the second and succeeding years, assuming again that we desire to burn about half the acreage. As the 'rough' spots left last year will burn with greater intensity than the one year cover, we will start our fires later in the night, and rather centrally in these spots by the method previously described." (Stoddard, 1935:347, 349-350.)

Fire in vegetation in South Africa is discussed as follows:

"A suggestion toward the solution of the national problem.

"While we would agree that the building up of an enlightened public opinion would be the best protection possible against abuse of fire, and indeed should be the aim of scientific workers, agriculturists, foresters and educationalists to attain in time, it is perfectly plain that we cannot await such a time as shall see the average farmer gifted with both knowledge and a sensitive conscience. Vegetation, soil, and water supply are annually being lost. Hence action is urgently necessary. I consider the rational procedure to be much as described below:

(I) We must make up our minds that, for present purposes, certain classes of locality demand protection from all kinds of grazing, browsing, and firing, and that certain other classes demand early application of controlled firing; the remainder of the country we must leave unattended until the more important portions have been dealt with satisfactorily. So far as complete protection from grazing, browsing and firing is concerned, I consider the classes of locality to embrace (1) all important catchment areas feeding water supplies utilized either for human consumption or for irrigation; in practice, such would be certain mountain tops and slopes, valleys and water-course ravines; (II) certain mountain and other areas unquestionably suitable for conservation and improvement of national forests, and for planting and proper management of suitable exotic trees required for timber or other purposes. Areas urgently calling for attention in terms of controlled grazing, browsing and firing include some of the more important coastal and inland mountain regions, and less important catchment areas generally." (Phillips, 1936:43.)

"The situation in reference to controlled burning we believe is in a very satisfactory condition, at least for the northern part of the state.

"You will recall the Annual Convention of the California Wool Growers Association held at San Francisco November 19 and 20, 1936, at which time representatives of the wool growers, cattlemen, lumbermen, United States Forest Service, State Division of Forestry and the Fish and Game organizations made an unsuccessful attempt to reach an agreement on a private land burning policy.

"The conference finally passed a resolution calling upon the California State Chamber of Commerce to appoint the personnel of its regular Forest Study Committee, charged with the responsibility of conducting hearings to the end that some agreeable policy concerning the use of fire on private lands might be arrived at. It is distinctly understood that the subject to be considered would deal only with a person's right to burn on his own land in a legal manner without undue jeopardy to the property of his neighbor.

"At the January 3d conference the stockmen stated that they felt in all fairness to the State Board of Forestry and the others in charge of control of fires that it should be a general policy of stockmen and other private land owners who desire to burn brush, that before securing a permit to burn brush they should in all cases consult with the State Division of Forestry officials in reference to their plans of burning brush on certain areas; secure the approval of the State Division of Forestry for such burnings; to do certain work of clearing trails and fire guards to assure that such fire when started would not get away and damage neighbors; work to secure cooperation of several ranchers of the same vicinity for a fire burning program; lay the plans for brush burning perhaps a year or two years in advance; consult with the State Division of Forestry as to the proper time to burn; not burn unless adequate means of protection were being taken to assure proper supervision and if possible have a representative of the State Division of Forestry supervise the actual work of burning." * * * (Wing, 1937:1 and 5.)

"The reason that more acreage was not burned in the upper Sacramento Valley area this year was due to the heavy growth of grass. The stockmen felt that they could not afford to take the chances of the possible losses in feed that might occur when endeavoring to burn brush lands prior to the first rains if the fire should happen to get away from them and burn more of an acreage than they had originally planned on.

"State Ranger Gum * * * quoted in part: * * * 'There seems to be a sticker in the permit that stops a lot of them; that is the clause that makes the land owner responsible for the fire to the extent of paying the suppression cost should the fire get beyond his control.'

"In the North Coast area a considerable more acreage was burned, * * *. About 20 or 25 property owners secured from the ranger burning permits with whom they arranged for the time of burning so that no two fires would be going at the same time.

"It seems to be the consensus of opinion of many of the large property owners that it will be necessary for them to arrange to burn prior to the first rains. They do not wish, however, to burn during July and August when a smoky atmosphere would impair the very valuable tourist travel.

"In Mendocino County * * * It is particularly interesting to observe that in this county while there were 11,000 acres of brush land burned over under permit and control, there were only 5,663 acres burned over from incendiary and accidentally caused fires.

"We have not advocated burning regardless of what our personal opinion may have been in the matter. We have, however, endeavored to comply with the wishes of the property owner and assist by advising him as how best to handle his range improvement. We have endeavored to assume the attitude that where a man owns his own property and pays

the taxes thereon, that he should have the right to handle it in a manner best suited for his personal advantage, providing it does not damage his neighbor or effect the general economic condition of the community wherein he lives. Therefore, if he wants to burn we endeavor to make arrangements so that he can do so at the right time and under the right conditions.

"It is the duty of researchers to determine fully and accurately the value and losses caused by fire, not only to present existing vegetation, animal life, soils, etc., but also to the future conditions of the burned area." (Strickland, 1938:2, 4, 6-7, 15-17.)

"I have discussed this matter with Mr. Pratt and Mr. Strickland after reading the latter's report of November 16, 1938, and my feelings in the matter are summed up about as follows: (1) It is evident that controlled burning on privately owned lands outside the timber zone is a worthwhile experiment in public relations. It has reduced the number of incendiary fires and brought about better cooperation by stockmen in county-wide fire protection during the danger season. (2) In view of the uncertainty of range reseeding as demonstrated in most of the experiments by B. J. Jones and of the effects of burning brush areas in depleting soil fertility, increasing the proportion of unpalatable species of brush plants, decreasing receptivity of soil for water percolation and strongly influencing the possibilities of erosion on many steep slopes—as emphasized by the work of A. W. Sampson, I believe it should be recognized that the ultimate results of such burning are still very much in the experimental stages * * *. (6) Emphasis should be placed on two points which are of major importance in connection with controlled burning. (a) Burning by itself will not solve the problem of increasing forage resources of brush land. It must be followed by seeding, cultivation or other constructive management and by intelligent and conservative handling of the grazing animals. (b) It is of little avail to burn sprouting types of vegetation such as tanbark oak, madrone, live oak, etc., as in the words of Ranger Hufford, 'It is impossible to convert these to grass anyway.'

"Experience to date with this program indicates that substantial results have been secured in cooperation by land owners. Some of them are apparently not anxious to burn their lands when given the opportunity to do so." (Metcalf, 1939:1-2.)

Drawing largely on the reports from the long-leaf pine forests of the East, where much of the experimental evidence is misleading due to the use of faulty experimental methods and where there is little agreement in the interpretation of results and applying their practices to California. "* * * I wish to prove to you that this present plan of conservation as practiced for over 30 years in the past by the United States Forest Service has produced results in almost every case, exactly opposite to those planned and work an exceedingly damaging effect to timber, livestock, wild game and water conservation.

"Now, we are all agreed on conservation; it is simply a method of arriving at the proper plan.

"All I can say is this: we believe the first thing is help nature do the job. Years ago nature took care of all this together with the assistance of the Indians and the timber men and the stockmen and the miners and the prospectors. They all set fires.

"When I was on the State Board of Forestry—and this man right here can verify this statement (indicating Mr. Pratt)—he was there then, too, 20 years ago or so—we had at least two occasions when fires broke out in Lake County and Shasta County. I believed that we shouldn't spend any money, that we shouldn't send any men over there. We didn't do a thing except let a couple of rangers watch these fires to see that no damage was done to farm buildings. In Shasta County the fire burned, I think it was 14 days, and the State never spent one nickel. All the livestock men and everyone in Northern California were glad to see it. The same thing was true in Lake County; the fire burned several days and everybody was glad to see it burn because it was doing untold thousands of dollars worth of good to everybody in the country." (Ellenwood, 1939:2 and 21.)

It is not surprising to find so large an area of chamise in these counties.

"From a woodland and forest, the owner has converted nearly all the cover to a condition varying from open range to dense chaparral. This ranch is considered by many proponents of burning to be a shining example of range improvement by that means.

"The process employed by the owner in clearing his land may be described as follows: The area selected to be burned for the first time is usually larger than that on which the follow-up burns are made. Year before last, for instance, a 3,000-acre piece which had reverted to brush, was burned over. * * *

"As a rule, a piece of land must be burned over at least three times before an open condition is obtained. The interval allowed to elapse between burns varies with the exposure. In order to get a clean burn, there must be a good growth of herbaceous vegetation on the ground to carry the fire. On north and east slopes it is often difficult, and sometimes impossible, to get an open condition by burning, since the brush grows back so quickly that herbaceous vegetation is shaded out. Yet it will be from six to ten years before the brush is thick enough to carry a fire sufficiently hot to result in a clean burn. On north and east exposures, then, the usual interval between burns is three years.

"On the southern and western exposures, a period of four years between burns is the usual rule. Here the growth of brush is slower and more herbaceous vegetation can be obtained which makes possible a cleaner burn than is usually possible on the north and east exposures.

"It can be seen that the operator must continue to burn his range land in order to stay in business. He would not have the carrying capacity he has now, inadequate as it is, had he not burned in the past.

"It is apparent from the foregoing that the land comprising this ranch, and thousands of acres in Mendocino County which are being treated in a like manner, is being put to an improper use. The solution of the problem cannot be found in the prohibition of burning. Enforcement would be impossible. Private lumber companies who lease their cut-over land to sheep men experience the greatest difficulty in preventing their lessees from burning to improve the forage.

"(1) The report is based on the study of a 7,700-acre ranch west of Cloverdale on which the practice of range improvement by burning has been carried on for the past 68 years. (2) In its virgin condition, this land produced very little forage. Estimated carrying capacity (based

on examination of areas still in woods) shows that 14 acres would be required to carry one sheep on a year-long basis. (3) An area must be burned at least three times to convert it from brush or woodland to relatively open range. The interval between burns is usually three years on north and east exposures and four years on the south and west exposures. (4) An area which had been burned for the second time a year ago had a total vegetative density of only 10 percent and a carrying capacity of 133 acres per sheep on a year-long basis. (5) On a similar area burned two years ago, 58 acres per sheep would be required. Here the total vegetative density was 20 percent. (6) The best range produced on the ranch, on slopes below 40 percent has a carrying capacity of two acres per sheep. This condition prevails on a very small percent of the total area. (7) Most of the better range land has a carrying capacity of three acres per sheep. Both this and the type of land described in the preceding paragraph have been cleared for about 20 years or more, but not more than .6 of the ranch area can be said to have a carrying capacity averaging three acres per sheep. (8) On a portion of a one-year-old burn, with slopes in excess of 80 percent both sides of a drainage have been washed nearly clean of all soil on a total area 120 feet wide and 500 feet long. Bare rock is exposed except for scattered pockets of soil held in place by chamise sprouts. (9) On an area burned two years ago, soil loss has been severe even on a 23 percent slope. On the 65 percent slopes, the loss of soil from around the brush stumps averages three to four inches and runs as high as six inches. (10) The owner states that severe floods are increasing in frequency. Direct losses from high waters include: (a) The washing out of fences. (b) The loss of most of the available hay land on the ranch both by bank cutting and by deposition of sand and gravel. (c) The drowning of sheep. The owner lost over half of his sheep this year. Most of this loss was during the February flood. (11) The average loss of soil during the process of clearing the land by burning can be conservatively placed at two inches over three-quarters of the ranch area. (12) Economic pressure forces ranchers on sub-marginal range land, such as that under discussion, to burn in order to keep sufficient forage for the number of sheep required to meet expenses. (13) Under present conditions, 3,200 sheep of all ages must be kept in order to gross $2,839 after taxes are paid. This sum must pay for all other expenses of the ranch including the living expenses of two men all year and the pay of extra help during certain times of the year. (14) If the correct number of stock were run on the ranch, the gross income, after paying the taxes, would be only $1,088 a year. (15) A possible solution of the burning problem is the acquisition of submarginal range land by state or federal agency. Following this acquisition, the land should be classified as to its capabilities and administered accordingly. Any revenues above administrative costs would be turned over to the county in lieu of taxes." (Grover, 1940: 2-3, 7-9.)

The danger of invasion of nonuseful plants and especially those which thrive when repeatedly burned is not emphasized above but is a very real danger everywhere in the Redwood and Douglas fir belt. In the Douglas fir region. * * * "When brush species are held in check by successive fires and are replaced by herbaceous species, most of them run their course and disappear from the succession * * * but not so the bracken fern. It continues to build up and replaces other herbaceous

species as they fall out, and if the brush species continue to be held in check by occasional fires bracken will dominate the succession and take possession of the site. This accounts for the thousands of acres of bracken-covered stump land to be seen today from the highways of Western Washington and Oregon. On the better sites bracken develops such height and density that only the most vigorous species can compete with it, and only by cultivation and continuous cutting are ranchers able to combat it. Bracken as it dries deposits a layer of highly inflammable material on the ground every autumn. This accumulation becomes a bad fire hazard with the first dry days of spring, which sometimes is months earlier than the ordinary brush will burn. Therefore, not only do fires favor bracken but bracken favors fire, creating a vicious cycle that tends to perpetuate the fern patch and eliminate other weed species, brush and coniferous seedlings that would eventually form a new forest." (Isaac, 1940: 720-721.) The entrance of bracken can be noted on most of the cleared ranch lands of the redwood region. Since bracken spores are so fine that they are dust particles in the air there is no way of protecting land from infection by this fern. It is useless as forage and is always favored by fire.

"Controlled Burning. The development of range on cut-over land appears to be dependent on the use of fire as a land-clearing agent. Much research must be conducted and factual material obtained before it can be stated with certainty the actual role that fire should play in the management of lands in Southwestern Oregon.

"This suggests that although the use of fire may be beneficial in the early development of cut-over land for grazing purposes, its continued and often-repeated use should be avoided." * * * (Hochmuth and Gorton, 1940: 11 and 12.)

"The aim of this study is to determine how much of a problem the foothills brush area in Tehama and Shasta Counties are to the stockmen and private land owners in these countries and to find out whether or not burning of these brushlands increase their grazing value enough to justify the cost of controlled burning.

Summary. "(1) The density of brush is increased after burning, and brush types are at times extended into adjacent grass types. (2) The herbaceous vegetation that comes in following fire is generally of lower value, and the more inferior forage species predominate. (3) Burning generally improves the browse forage for periods of from two to ten years. (4) Some species, particularly wedgeleaf ceanothus, manzanitas and chamise, germinate readily after fires, and burning seems to spread and increase the density of these species. (5) Burning of grasslands generally results in an increase of some species of lower value (annual fescue, nitgrass, rip gut) and a decrease in others of higher value (soft chess and wild oats). (6) Hot-burning fires seem to have more effect on the vegetation. It appears to recover slowly. This is quite evident when dense manzanita is burned. Few grasses and weeds come in on the sterilized soil. (7) The first year after a very hot burn there may be very little increase in forage values in most brush types. (8) It takes from four to five years for better forage grasses to come back on burned areas. (9) Burning opens up brush stands and makes them accessible for five to fifteen years. Soils, topography, the kind of brush, the nature of the brushfields, and the intensity of the fire all have a relationship

to the results secured. Conclusions in this respect follow: (a) The greatest increase in forage is secured on the better soils which are associated with more level lands on northerly slopes. (b) The steeper slopes (with which poor soil is usually associated) yield low returns. (c) North slopes yield better than south slopes because of better soil and more favorable climate. (d) Open brush with intermingled grass and weeds usually give higher returns than dense brush. (e) Mixed brush yields more usable forage than stands composed of single species. (f) Light, slow moving fires yield more and better forage, particularly in the years following the burn, than the very hot fires.'' * * * (Fausett 1943: 1, 18-19.)

''The committee has in progress of preparation a summary statement of the problems relating to brush burning, the difficulties involved, the various and divergent views which have been expressed relative to their use and management, and the results of the studies of the committee up to the present time.

''In the Tehama-Shasta area a number of small plots have been established to secure information on the effect of brush removal, on water penetration, runoff, and erosion. These plots represent the major soil and cover types of that area.

''The findings of the committee to date may be summarized as follows: (1) That controlled burning is a practical means for the removal of brush from the foothill areas where such removal is desired. (2) That the production of forage for livestock and wild life is materially increased for two or more years following the removal of the brush by burning. (3) Soil sampling for the past three years on the several paired test plots in Tehama and Shasta counties have definitely shown that denudation does not produce undesirable change in the infiltration capacity of the soil. The results from these plots also seem to indicate that removal of the vegetation is not harmful so far as runoff and erosion are concerned.'' * * * (Madson, 1943:1 and 5.)

Woodland-Chaparral and other brushfields. ''They form a part of the important range area of the state and have been a problem with the stockmen ever since the livestock business became a major industry. The dense evergreen broad-leaved shrubs and trees prevented the growth of desirable forage species, interfered with the handling or gathering of livestock, impeded travel, and presented a high fire hazard. As a result, such areas were frequently burned. Herbaceous vegetation increased temporarily in the burns, and succulent sprouts provided additional forage for a few years. In addition the sprouts partly remedied a diet deficiency, particularly during the summer period when the herbaceous vegetation was low in proteins and vitamin A and otherwise unsatisfactory for the maintenance of grazing animals.

''With the recognition of forest values on the adjoining timberlands, and structural development of the range area with fences, buildings, etc., and the breaking up of the lands into smaller ownerships, the problem of handling fire became increasingly difficult. The resulting damage to improvements and timber, the difficulty of confining fires to the lands owned or controlled, and the governmental requirements in regard to the use of fire as an agricultural tool made burning uneconomic in many areas. In parts of the area, erosion was significant, resulting in damage to watersheds, developed agricultural lands, roads, railroads,

reservoirs, and urban reas, with the result that public pressures eliminated the use of fire on range lands in many areas.

"From time to time certain individuals tried and developed methods of handling such lands in a manner that would convert them from brush areas to grassland or woodland-grass areas in a single step. This consisted of clearing by hand or machinery, followed by goat grazing, which controlled resprouting, and was continued until the undesirable woody species were killed, leaving a grassland often dotted with deciduous oaks which were left intentionally. This was economic only on the better soils and where there was a ready market for the fuel wood which was harvested in considerable quantity on the woodland-chaparral areas.

"In the first growing season following cutting, the area is immediately invaded by annual grasses and weeds, but during the first two or three years these are usually of poor quality and low density, consisting of annual fescues and grasses of similar character, popcorn-flower, and other low value weeds. The third year smooth brome shows up in appreciable quantities, and by the fifth year there is a good density, with smooth brome and alfilaria predominating and with some burclover in the swales. The job is then complete and permanent. The grazing capacity and value of land as well, is increased several fold.

"The true brushfields of the Sierra foothills and elsewhere are a more difficult problem. In areas with better soils, small acreages have been hand-cleared and plowed for agricultural purposes. Some of these were dry-farmed but are now mostly in permanent grasslands." (Cronemiller, 1943 :1-6.)

"Some excellent work has been done by committeemen representing agronomy, irrigation and animal husbandry * * *. Unbiased research is badly needed to define the areas that can be profitably treated and those where brush depletion or removal is not profitable and may be detrimental or destructive:

"In all the years of controversy no fair-minded man has argued that burning or removal should be applied to merchantable timber or stands that may become merchantable timber * * *." (Ellenwood, 1943.) (Compare Ellenwood, 1939.)

"*Resolved,* That the California Cattlemen's Association express their appreciation for the progressive attitude taken by the State Forester and State Board of Forestry. That the association urge the continuance and enlargement of the brush-burning program and that said program be in keeping with good range management practices." * * * (McKinney, 1944[a].)

In a letter to the Los Angeles Chamber of Commerce "we would like to suggest that the endorsement by the chamber of the principle of controlled brush-burning would be greatly appreciated by the cattlemen of the State as well as all others who see in this method the means whereby vast areas of range lands can be restored for the use of sheep, cattle and big game. Further by this method fire hazards to range, timber and watershed areas are unquestionably reduced materially. By controlled and systematic burning of brush lands and the consequent avoidance of great uncontrolled fires, most erosion resulting from unseasonal denudation of steep slopes can be prevented. (See "Common-Sense Con-

servation" by Fred A. Ellenwood, former Chairman, California State Board of Forestry.)

"The encroachment of brush upon the higher ranges has crowded the deer into the farming areas and presented a very grave problem of crop damage of which we hear so much of late years. A spokesman from the Division of Fish and Game at a recent meeting of cattlemen in Salinas stated that experiments conducted by the division proved beyond doubt that controlled burning of the brush which had destroyed the former ranges of the deer resulted in restoration of these ranges and the return of the deer to them. He stated, that the division was convinced that this was definitely at least a partial answer to the crop damage problem.

"The story behind the brush problem is written on the lands of this state in visual language that cannot be misinterpreted by eyes which have observed the writing of it. The balance of nature is upset the moment man begins civilized utilization of the land by the grazing of livestock or any other means. The natural competitive position of various kinds and species of vegetation is thrown out of balance. Grasses in many cases are handicapped and brush plants given an advantage never enjoyed in nature as evidenced by the presence of grasses and the absence of brush in the virgin state on these areas where grasses were the best fitted to survive; the opposite being true where conditions were reversed. Each species of plant life carried on its competitive struggle for survival just as did the various species of animals. Our arbitrary control of the brush is necessary to offset our control through usage of competitive plants upon which we have placed a handicap." (McKinley, 1944.)

"The controversy over brush burning on California ranges has been vigorously waged over a considerable span of years. * * * it seems evident that there are areas in which brush removal is fully justified in the end results attained. On the other hand, there are areas in which the injurious effects of brush removal far outweigh any benefits that are derived from it.

"The following general principles may be laid down as a starting point. Future work should be calculated to demonstrate the areas on which any or all of them may apply for or against this practice:

"1. Soils and slopes that are known to be erodible should not be denuded of their native cover unless adequate provision can be made to prevent sheet or gully erosion.

"2. Some soils and slopes are not naturally adapted to the production of good forage after the brush is removed. On such sites it is not economic to attempt to remove the cover that holds the soils in place.

"3. In general the soils of steep south and southwest exposures are too shallow and too much exposed to weathering to justify burning the brush from them. In El Dorado County and some other foothill areas the burning and reseeding of such areas has not generally resulted in any improvement in feed conditions. On the northerly slopes and deeper soils such burning has often resulted in a marked improvement and increase in pasturable plants. On the other hand many south slopes in the north coast counties have been burned and have produced good feed—with or without artificial seeding. That is a country of higher rainfall, higher summer humidity and more stable and productive soils.

"4. Even under the most favorable conditions maximum results cannot be achieved unless the areas burned each year are restricted to

an acreage that can be properly managed with respect to the grazing of browse shrub sprouts, at the same time encouraging and preserving seeded or natural forage grasses that grow within the area.

"5. Burning of brush, or grass, does not kill out any considerable percent of the perennial grasses that may be growing within the burned area.

"6. In some areas of the north coast seeding in a burn tends to reduce the amount of brush that returns after burning.

"7. If artificial seeding is done after burning, it should be done immediately—or before the fall rains. The ash is useful as a cover for the seed and early germination helps the seeded species to compete with natural growth.

"8. Brush removal should not be encouraged unless local experience has previously demonstrated that serious erosion will not follow and that natural vegetation or reseeding will increase the livestock carrying capacity.

"9. Accidental burns should be used for experimental or test plot areas to determine these facts." (Jones, 1944.)

"The use of fire to remove brush that interferes with the production of forage and the handling of livestock on Western range lands has long been a controversial subject. It has been condemned because of the harmful, often disastrous, consequences of widespread haphazard or accidental burning. Promiscuous burning of sagebrush has played havoc on literally millions of acres of range land, removing the sagebrush but leaving the soil exposed to erosion by wind and water, because the burning was done in places or in a manner which discouraged the immediate reestablishment of grass and other forage cover. * * *

"Carefully planned burning, when properly carried out, is an effective means of increasing forage production, a matter of immediate importance at this time in the food production program. * * *

"Burning is like a fine tool or intricate machine; if it is to be used with any success it must be used skillfully, and that use must follow an intelligent plan. The simple, practical rules and guides set forth here on where, when and how to burn, and the grazing management to be used after burning, if followed carefully, will afford a reasonable chance for improvement of the range and help to avoid the damage that so frequently follows haphazard or promiscuous burning." (Watts, 1944.)

"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 * * * . In Lake, Mendocino, Humboldt, Shasta, Tehama and Colusa Counties, 85 operators were consulted."

"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.'

"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 six stated that the condition was 'poor.'

"Of the 85 men consulted, only 58 reported, and 28 of these would make no grazing-capacity estimates.

"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. * * * Only one man out of 76 answering believed that the increase amounted to as much as 75 to 100 percent for a considerable period of time after burning, while several men believed that there was a definite decrease.

"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.

"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.

"About one-third of the answers favored burning every two or three years if it were possible, while another third favored burning at intervals of four or five years. Smaller numbers believed that burning should take place at intervals of 8 to 15 years. A relatively small group of men had been convinced by experience that burning on their land was never desirable." (Sampson, 1944:23 and 25.)

"Summary of Field Observations on Burns. Of the 34 ranches examined, 29 showed rapid reoccupation of the original brush. On seven 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 percent. The tabulated records revealed that 30 of the burns had slight or no soil slippage, whereas on four areas soil slippage had been severe. Twenty-two burns had little or no gully erosion, whereas on four burns, soil erosion of a general nature was severe, and on eight burns, soil erosion was moderate. The four severely eroded areas had an average slope of approximately 44 percent, whereas those classed as moderately eroded had an average slope of about 32 percent.

"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." (Sampson, 1944:108.)

"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 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." (Sampson, 1944:134-135.)

Resolution No. 11, "adopted by vote of the members of the California Cattlemen's Association in their Twenty-Ninth Annual Meeting at San Francisco, California, December 14-15, 1945:

"WHEREAS, The annual losses from forest fires in California are estimated at several million dollars, and

"WHEREAS, The entire state is vulnerable to attack by fire during the dry season, with possibilities of enormous losses, and besides the initial loss of property (timber, feed, improvements, etc.,) vast amounts of money, man power and equipment are used in combating these fires, the cause and spread of which is due largely to accumulations of fire hazards; and

"WHEREAS, In Calaveras County the operation of the control burning program has proved to be a practical answer for fire prevention, for range improvement, from cleanup work reducing fire hazards, and for the reduction of wild fires; therefore, be it

"RESOLVED, That we recommend that in all areas of California where brush burning programs are inaugurated in cooperation with the State Board of Forestry, that the stockmen of each of said areas select local committees to advise and cooperate with the administrative officers of the State Board of Forestry." (McKinney, 1945.)

In the southwestern cape of South Africa "Total protection from burning appears to be needed to conserve water and soil, but if this treatment were carried out universally the cost would be prohibitive, and there is doubt as to whether total protection everywhere is a practical possibility.

"Evidence exists in favor of controlled burning in order to reduce the inflammability of the vegetation and to promote lavish displays of flowering geophytic plants in selected areas, but such burning should never be followed by sustained pasturing. Pasturing on the steep, acid, mountain lands of the cape is barely profitable, and invariably leads to destruction of vegetation and serious erosion. (Wicht, 1945:52.)

"Even in the Spanish era, the raising of livestock was an important California industry." (California Forestry Study Committee, 1945:98.) One might add that in no country in the world were the sheepmen so thoroughly in control of the economic and political life of a country as in Spain. (Klein, 1920.) "Briefly the range-forestry issue may be described thus: As grazing continues, brush invasion becomes more general and more serious on certain lands. To survive against such invasion stockmen must clear off the brush. The values per acre are so low that manual or mechanical clearing is too expensive, therefore fire is used as the tool. Stockmen felt that they should be permitted rather broad freedom to burn their ranges however and whenever it is possible. Unfortunately, some graziers, in the past, permitted their fires to go beyond their own lands and into cut-over or natural brush lands of others with the expectation that such burning would extend their feeding grounds. It has been and still is the case that some stockmen own more sheep or cattle than could be grazed on their own lands. Some stockmen have complained that while the brush is driving them out of business they are prohibited by law from burning. As far as the committee knows, no law was ever passed in California prohibiting burning, the only requirement being that burning shall be under control.

"The committee is sympathetic toward the stockmen's brush encroachment problem and wants to help them maintain the carrying capacity of their range lands. It feels however that stockmen should cooperate by making their plans for burning well in advance of the burning season; by installing the precautionary measures the ranger recommends; by burning only when a permit is granted and only at a time not declared to be 'fire weather' intensity; by doing all in their power, through self regulation, and to control the illegal setting of fires. Livestock ranges, as well as timberlands, must be kept productive." (California Forestry Study Committee, 1945:98-99.)

"On one range in Lake County a program of controlled burning has been underway for five years. This is a typical chamise area with steep slopes and a thin, poor soil. Designated areas are burned each year, and domestic rye grass is seeded in the fresh ash. At the end of five years the stand of rye grass is still very good, and there has been no appreciable erosion. Sheep are pastured on this range in June, July, and September. They browse the young sprouts of chamise and crop the matured rye grass, trampling the grass seed into the soil. Although this browsing is materially retarding the chamise sprouts, the brush may perhaps eventually retake the land unless it is reburned. Such burning will destroy the grass litter that has improved the soil somewhat. It is impossible to predict what the end product will be.

"Soils and slopes known to be erodible should not be denuded of their native cover unless adequate provision can be made to prevent sheet or gully erosion.

"Some soils and slopes are not adapted to the production of good forage after the brush is removed. Detailed surveys to delineate these areas are needed.

"In general, the soils of steep south and southwest exposures are too shallow and too much exposed to weathering to justify burning the brush from them." (Jones and Love, 1945:31 and 43.)

"Control burning is the 'deliberate use of fire on land whereby burning is restricted to a predetermined area and intensity'; * * * there are four broad categories of land classification concerned with this subject, three of which I am placing outside the limits of my discussion. These three are (1) timber lands, (2) primary watershed lands which, if we are to secure their greatest economic values to the state in the opinion of the State Board of Forestry, must be protected from fire in the form it is being discussed today, and (3) our open grass ranges which you want protected from fire for personal economic reasons.

"The fourth category and the one to which I wish to limit my discussion is the great intermediate area of brush land which has relatively low range value and secondary watershed value and no timber value. In this category there are several millions of acres ranging from the poorest of soils on steep slopes supporting thin stands of chamise to relatively good soils supporting heavy stands of chaparral composed of the various oaks, manzanita, ceanothus, etc. It is possible under proper treatment and range management that a goodly part of this area may be made to produce greater economic returns to the livestock industry and the State.

"To this end the State Board of Forestry is committed to a type of land management that will produce the maximum economic benefits to

the State on a long term or sustained yield basis. This policy applies to the production of timber, water and range alike, since all three are natural resources harvested from our so-called wild lands and each is essential to California's economy.

" * * * this is not a single problem but a composite problem with many complexities. To name a few we find (1) selfish interests seeking special privileges and services; (2) people and groups of people wishing to burn someone else's land for their own benefit; (3) large numbers of people who are unwilling to assume the responsibility and obligation that goes with the privilege of using fire as a tool in their land management as legally authorized by the Legislature; (4) people confronted with a bread and butter economy on admittedly poor range lands; (5) lack of sufficient knowledge to make prior determination of the economic benefits from burning on many soils, slopes, sites and types; (6) lack of knowledge as to best reseeding methods and species as well as an unwillingness on the part of many to make the necessary cash outlay; (7) lack of a land classification defining the areas within which control burns may be used profitably and, (8) inability of the Division of Forestry to cooperate on control burns and at the same time cope with critical wild fire situations. These are but some of the problems which interlace and overlap to form a complex pattern. The solution to these problems will not be found by any simple formula or in any short period." (Nelson, 1945:1-3.)

"Ranchers of Madera County have long been interested in the use of control burning as a means of brush removal. * * *

"The object of the Control Burning Program in Madera County is to set up a plan which will enable owners and operators of brush covered lands to remove their brush by control burning or otherwise under the supervision of the State Division of Forestry, as provided by law. The program sets up district and county control burning committees which will provide leadership in encouraging individual ranchers to draw up and carry through detailed plans for control burning and land use, and in coordinating these plans into district and county programs.

"That there are many unsolved problems connected with brush removal is well known. Brush can be removed by a number of different methods, including mechanical means, burning and reburning, and by various combinations of mechanical means, burning and use of livestock. No one method will suit all conditions even in a single community. The proper procedure to follow on each ranch will take the combined best judgment of the rancher, the district committee, and the state or federal forest ranger. Because of the difficulties and dangers involved, it is important that a well thought out plan be drawn up for each ranch. * * *" (Madera Co., 1946:1.)

"There are large areas of fertile range soil in the Western States upon which a dense stand of sagebrush, undesirable shrubs and inaccessible and noncommercial timber render the soil unproductive for usable forage. The removal of this cover would materially enhance productivity of forage, remove overcrowded tree growth, reduce fire-hazard, preserve moisture and protect private resources. Scientific experimentation has demonstrated that controlled burning and other methods can be applied advantageously to remove such cover.

"We recommend that landowners and land-managing agencies use supervised and controlled burning as one of the methods to accomplish

this result. In making this recommendation we are cognizant of the fact that there has been some careless and unsupervised burning in the past, and such methods have diminished forage and damaged property. We, therefore, explicity urge that full control of fire be exercised at all times to the end that damage to any and all lands or property be avoided; and that such burning be done in strict accordance with law and regulation.

"We further recommend that proper reseeding be carried out in connection with burning. * * * " (National Wool Growers, 1946.)

"It seems high time for those whose fear of fire amounts to no less than panic to pause for a moment and analyze their methods of control and prevention. This panic has resulted in an extreme policy which considers fire as strictly a destructive agent and refuses to recognize its possibilities for constructive purposes. Under this narrow policy the prevention of all fire, at any cost, becomes the primary purpose to be served. All other uses of the land must be subordinated to fire prevention. We must realize that, assuming the most effective prevention imaginable involving the complete removal of livestock, closing of the areas to hunting and recreation and all other human uses, natural causes still remain to start unpreventable fires. Our encouragement of the growth of brush and the accumulation of debris makes such fires inevitable and extremely disastrous when they occur.

"There are areas, particularly in Southern California, which probably never grew anything but a dense stand of brush and where, to eliminate this fire hazard it would be necessary to eliminate the land. I refer to the brush itself as the hazard, not the risk of its burning for the latter risk only exists because of the former. Now, there are other areas which were once free of brush and, therefore, free of this hazard which, with intelligent management could have been prevented from overrunning them." (McKinney, 1946:1-2.)

In Oklahoma "June is the ideal time to mow sagebrush for best control of brush and maximum improvement of grass * * * ."

"It is extremely important to defer grazing—exclude livestock from a pasture—from June to September of the mowed years. This protection enables the grass to recover, develop a deeper and more extensive root system, and compete to better advantage with the weakened sagebrush. All of the mowed brush should be left on the land to provide a protective mulch for natural reseeding." * * * (Savage, 1946:68-69.)

"* * * I do not believe in any fires that are not controlled.

"So here is the way I sum up this problem: (1) Continue the fire permit system. (2) Pass laws to give the Division of Forestry some money for the prevention of fires so they can burn out some of the hazardous places before the hot weather comes. It will help the ranges, protect the timber and make it possible to control some of the fires. (3) And I consider this most necessary: Keep up a steady educational campaign. Meet as often as advisable and above all things, this Range and Land Clearing Committee and the Division of Forestry *must* cooperate." (Elliott, 1946:5.)

"Due to the encroachment of brush, many thousands of acres of land which were formerly capable of carrying large numbers of grazing livestock have been rendered practically useless for this purpose. Owners of these lands nevertheless pay taxes and endeavor to earn a livelihood. Furthermore, this brush utilizes large amounts of water which would

otherwise percolate down through the soils and streams to be used by irrigationists in the valley floors. A proper cooperative program for the control burning of this brush would enable owners of this land to utilize it for grazing purposes, thereby increasing their income.

"According to the results of experiments conducted by the University of California under Professor F. J. Veihmeyer, the burning of brush resulted in the saving of water and, at the same time, increased production of forage; furthermore, runoff and erosion were not greater on the burn plots as compared with the unburned plots in the area where the experiments were conducted.

"The Madera County Brush Burning Committee recognizes that there are many brush covered areas which should not be burned. These include lands that are so steep that erosion would be a serious factor. There are soils so thin and poor that probably their best use is to remain in brush cover. There are brush covered areas which include valuable stands of timber or grass which should not be burned. In any control brush burning program, it is of course important that such areas be not burned. We believe that local committees of farmers, land owners and operators, should be the best judges of which areas should be and should not be burned.

"Suggestions for fire prevention and control burning program. * * * (1) A bill should be enacted by the State Legislature enabling the use of State Division of Forestry equipment for fire prevention purposes in counties which are organized for fire prevention and brush burning, whether such equipment is used on public or private lands. (2) A bill should be enacted in Congress or change made in certain United States Forest regulations exempting an operator of privately-owned lands from a damage suit by the Federal Government, if a fire which he started causes damage to national forest lands, provided such operator has complied with all regulations of the United States Forest Service pertaining to the safeguarding of adjacent lands from damage from a control burning fire. (3) The State Division of Forestry should be provided with sufficient funds to enable it to employ all of its foremen and truck drivers on a year round basis. At present, only a small proportion of these men are employed on a year round basis. During the fire season, they are used exclusively on fire suppression; during the nonfire season, the few carryovers are kept busy on essential maintenance work, leaving no time for fire prevention activities. A large number of foremen and truck drivers are now employed during the fire season from May to November 30th and are then laid off. * * * (4) The State Division of Forestry should be provided with sufficient funds to enable it to purchase adequate equipment, * * * (5) The State Division of Forestry should be provided with sufficient funds to enable it to assign an Assistant State Forest Ranger to each county that is properly organized for a control burning program. * * * (6) The State Division of Forestry should be supplied with sufficient funds to provide in each county that is properly organized for control burning, suitable fire fighting equipment and a standard nine-man crew to be assigned to the control burning program from the season May 1st to November 1st." (Crooks, 1946:1,3-4.)

"To summarize, burning is practiced in parts of Australia, New Zealand, South America and in various tropical jungles chiefly to suppress or dispose of tree and brush growth, and of coarse grass. Every-

where the practice is challenged by some landowners, and by various scientific groups and individuals. In some localities, grazing lands have been irreparably damaged by too frequent and unseasonable burning, whereas in other localities rational burning has proved beneficial, and even necessary. In all habitats burning results in throwing back the succession; in some localities the subclimax vegetation affords the best grazing values. Most investigators agree that the ranges are 'fired' too frequently. (Sampson, 1946*:18.)

"The Barnwell Ranch, which was originally about 900 acres, has been enlarged by purchase to around 10,000 acres and he leases 9,000 acres. This ranch has not been burned over. Only a few acres have been burned in late season, or at a time when fire would not run, to get rid of an accumulation of debris. The father of William Barnwell did not believe in fire and kept reproduction down to a fair degree by pulling up seedlings himself as he went around, and having his boys do the same. He also practiced girdling trees that were of no commercial value and employing his sons at a small sum per tree to girdle a large number of fir poles and trees with the idea of keeping such timber type open. Over a period of years falling limbs and twigs broke up and rotted and went toward building up the soil. Today the soil is loose and crumbly, and not only deep but has a good depth of humus on top, and this black loam shows no erosion characteristics.

"The condition of the soil is generally remarkable when compared with soils on other ranches that have had the usual burning treatment.

"Mr. Barnwell has sowed grass seed of a number of species. * * * These grasses under the shade of the girdled trees attains a density of 7/10 to 8/10 with an estimated palatability of 70 to 80 percent, and an estimated carrying capacity of a sheep to the acre or 1¼ acres which is quite high even for this country.

"The next ranch visited was the W. Perry place east of Barnwell's place. Here Perry has land on both north and south slopes similar to Barnwell's and has gone in for girdling recently to some extent. He has fair feed on north slopes and a rather poor stand of annual vegetation on south slopes, both on open glades and under dead timber. Soils, elevation and degree of slopes are comparable with Barnwell's, but with this difference. Perry has done considerable burning. It is quote noticeable that on the open slopes the soil is quite hard and light colored. A preponderance of low Hair grass, fescue, low soft Chess and some sparse clumps of other grasses, while on burned or girdled and burned timbered sites—slopes and benches—the soil is hard with little humus, and the grasses are neither so luxuriant nor as valuable as found on unburned slopes on the Barnwell ranch. On both south and north slopes where fire has run in the past, evidence of sheet erosion is to be seen and the results of such erosion, or loss of the valuable top soil layers, is shown by reduced growth of all vegetation and relative abundance of the less valuable species of weeds and grasses.

"It is not thought that such practices as those of Mr. Barnwell can be held up as examples for all to follow, nor are practices followed by Mr. Perry to be frowned upon and held up to ridicule, but it is believed much can be learned from these two examples. (Smith, 1946:1-3.)

"The Humboldt ranchers quite definitely have a land clearing problem. Brush and ferns quickly take over open land, the reversion being to

the original type, unless constant work is devoted to keeping down such species. This is expensive on originally timbered sites when brush came in after logging or burning. On the shore facing grassland, fern, both Bracken and other coastal species of ferns, *Rubus* spp., *Ceanothus* spp. and other coastal species of brush, are invading all areas and, as in Mendocino coastal ranches, bid fair to take over in time and render much area valueless for grazing. Fire does not kill out such species, but seems to spread them.

"It seems to me from the observations made around Mattole, Bear River and Van Duzen River drainages, and talks with the ranchers, that we should continue to work with the ranchers to secure small adequately controlled burns on such types, slopes and soils that will clearly produce sufficient forage to justify the expense of control and try to persuade them to refrain from burning such slopes as will quite certainly not produce forage." (Smith, 1946 :4.)

"On the Cow Mountain burn of 1944 there is a vast area that produced little or no herbaceous vegetation in 1945 and very sparse stand of low weeds and annual grasses in 1946 with a very sparse stand of chamise sprouts. Lower down, on what appears to be somewhat better soil conditions, but still an almost pure chamise stand, there is a very good stand of annual weeds and grasses together with a considerable percentage of perennials such as stipa.

"In Lake County, but still on east slopes of Cow Mountain some 1944 and 1945 burns were gone over. Here the same conditions were observed. Some areas with same degree of slope and exposure have a fine stand of herbaceous vegetation while nearby areas will be almost bare of vegetation and have very small growth of sprouts. * * *

"On another area in Lake County, but on the Cache Creek drainage, a fire that burned with great intensity in August, 1945, cleaned off most of the chamise and left the slopes practically bare. At this time (May, 1946), some of the slope is still practically bare but with a lot of chamise sprouts, there is a fair stand of weeds. These weeds are mostly of no value or actually poisonous plants such as an abundance of Death Camas. On other areas an abundance of soap root is found.

"These observations demonstrate that we need to know more about the soil and its potential capacity to support other vegetation than chamise.

"Instead of broadcast burning of such areas it is suggested that better returns can be secured if small drainages be burned under proper control leaving some areas unburned for shelter for game. It is evident that large, cleared out areas are not suitable for deer, as no shelter is left and deer will not remain there but will seek forage and shelter elsewhere.

"Cow Mountain has been repeatedly burned and the condition of the slopes shows that there has been a heavy soil loss, a decrease in amount of forage produced, a reduction in size and density of brush growing on such depleted sites, and a measurable loss in grazing value.

" * * * only on favorable sites does he get much forage and not on sites when chamise is the climax type, but rather when chamise is found on sites where oak and other mixed brush species would and should grow if given a chance.

"The returns—on the pure chamise type, on the upper slopes and top of ridges, do not warrant continued burning, or any burning. Therefore, burning should not be tolerated." (Smith, 1946:2-5.)

The present California state law (Statutes 1945) says in part:

Chapter 1018—Section 1

CHAPTER 8

"SECTION 4871. The people of the State have a direct interest in the protection and improvement of public and private lands which are principally used or useful for range or forage purposes for domestic livestock and wild life. This chapter is enacted in furtherance of that interest to provide not only for controlled land clearance and revegetation of such lands but also having as its objective fire prevention and protection, watershed protection and conservation, and the prevention of soil erosion.

"SECTION 4873. The division may enter into contracts or cooperative agreements with any person, firm, public or private corporation, district or municipal corporation, or other political subdivision of the State, or any group or combination thereof, owning or controlling brush covered land within the area the fire protection of which is primarily state responsibility for the purpose of engaging in controlled land clearance and revegetation, including the burning of brush from such lands, or portions thereof, under the supervision of the division or by the division.

"SECTION 4874. In furtherance of such contracts and agreements, and also independently thereof, the division shall engage in experimental land clearance and revegetation of such lands in the interests of protection and improvement of range and forage lands and shall also engage in such research in connection with it as will enable it to determine the value of such methods in relation to the several purposes and interests of the people of the State as set forth in this chapter.

CHAPTER 1420

"SECTION 1. The purpose of this Act is to promote the public security by eliminating fire hazards and to reduce the risk of uncontrolled fires which result in great annual financial losses to the people of the State, to increase range forage, to return waste lands to production and to reduce the danger of incendiarism.

"It is also the purpose of this act to provide means and facilities to determine the effects of controlled clearing and revegetation and burning of brush covered lands which are primarily valuable for range or forage purposes as a part of the legislative policy of providing for and carrying on a continued study of range improvement."

SECTION 2. The Division of Forestry in the Department of Natural Resources is hereby directed to engage in a program of experimental controlled land clearance and the revegetation thereof with respect to lands which are principally used or useful for range or forage purposes and which lie within that area the fire protection of which is primarily State responsibility. Such program shall also include such research as may be necessary before and after such clearance of lands in order to determine the value of the methods used in relation to the purposes of this act.

The division shall determine the effects of such clearance and the value of such methods with reference to fire protection and prevention, watershed protection and conservation, the prevention of soil erosion, and the increased economic value of such cleared lands insofar as they may be so made available for range and forage purposes. (Statutes of 1945.)

"In general, this policy has worked quite satisfactorily, the primary difficulties being that

"1. Too often the applicant does not want to expend money to put in the necessary control lines prior to the burning in order that the fire may be properly confined to the prescribed limits.

"2. Too often the applicant wants to burn a larger area than can be reasonably held under control. Under normal conditions it is difficult and often impossible to properly control a fire burning more than 300 or 400 acres.

"3. The applicants are often unwilling to assume the responsibilities and liabilities that are required by law if their fires escape and do damage to property of another.

"I believe some of the reasons for the unwillingness on the part of applicants to expend sufficient money on this program and assume their legal responsibilities rests on the facts that many of them are endeavoring to eke out a 'bread and butter' economy from submarginal lands which do not justify any material expenditure even when burned over. Too often many of our ranchers think that the answer to their economic prayers is to burn the country over and next year turn the livestock on the burned-over area and hope they get fat." * * * (Nelson, 1946.)

LAND PLANNING

"Broadly defined, land utilization is the science and art of achieving the most effective use of land." * * *

"The conception of efficient utilization includes the concept of conservation of natural resources. The emphasis in land utilization is on the mode of use and the essential adjustments involved; but the conservation of soil fertility, timber, water, wild life, recreational, and scenic resources is a basic consideration in the determination of effective present use. In the long run the determination of most effective use becomes a matter of regional or local planning which will take account of important public considerations and necessary adjustments." * * * (National Land-Use Planning Committee, 1932.)

Such work demands the best available technical judgment and experience. It seems the only safe means of bringing into harmony the many demands of the different interests to exclusive or nearly exclusive use of these lands. The long view is seldom taken by those who derive present benefit by improper land use.

Years ago many plans were proposed for the management of public grazing lands (Coville, 1905) and years later, "Conservation of the Grazing Resources of the Remaining Public Domain" was issued as publication No. IV, Washington, March, 1933, by the National Land-Use Planning Committee.

"On the Siskiyou National Forest there are approximately 327,000 acres, exclusive of the Smith River watershed, out of 1,302,393 acres that are covered with chaparral of many species. The cause of their existence, however, is not difficult to ascertain, and is seen on every hand. The charred stump, tree trunk and fallen log tell plainly that fire was the cause, and has done its work."

"The old story of burning over these brush areas yearly, so that a large fire could not occur because of available material sufficient for a large fire has been told again and again."

"Could a man have seen this Southern Oregon country before the original fires along the coast occurred, he would have seen a forest practically continuous." * * * (Haefner, 1912:82 and 83.)

Fire is being used in the redwood belt to reduce the land to agricultural or grazing land.

"The redwood thrives on many different kinds of soil * * * soil conditions vary greatly within limited areas and no large section of a uniform soil type is to be found in the valleys and slopes of the cut-over regions. * * * This great diversity of soils, however, offers a grave problem to the would-be farmer.

"These preliminary operations clear the land of marketable forest material but do not remove the larger waste limbs, defective logs, small trees and stumps. The firing that has occurred does not usually affect the large redwood waste and stumps. The redwood is extremely resistant to fire and only such portions of the trees as may be broken and splintered burn, together with the limbs and occasional defective logs.

"The comparison with other conifers strongly emphasizes the remarkable reproductive power of the redwood. * * * The fire menace which is always present in the forest is being guarded against. * * *

"It is well to recognize the difficulties of real agriculture in the redwood belt. The farmer of such lands will meet many extraordinary difficulties not present in ordinary unforested agricultural sections. Further there seems to be no doubt that the splendid heritage of our redwood forest should remain, through reforestation, an asset to the State, not only financially but in grandeur and beauty." * * * (Clarke, 1922:168, 173 and 186.)

"The six counties of California lying north along the coast between San Francisco Bay and the Oregon line present some interesting problems in land utilization and in administration of the fire laws. Something less than one million acres are included in the redwood timber belt and these are lands of very high productivity from a timber point of view. Tanbark oak which occupies a belt within and adjacent to the redwood area, is also an important forest resource because of its bark, which is used in the tanning industry. Mixed with the redwood and tanbark oak, and stretching over many thousands of acres to the eastward, are stands of Douglas fir and oak of several species which have practically no present value except for firewood, for which there is only a limited demand, and for Christmas trees from young stands of fir. There are many large areas of brush fields of greater or less density, made up of several varieties of manzanita and ceanothus, scrub oak, chamise, and other shrubs. These brush fields are often so dense as to be almost impenetrable and while they have some value as deer cover, they have very little utility for grazing domestic animals. There are also many thousands of acres of grassland with scattered trees which furnish good grazing for cattle and sheep and as grazing is one of the principal agricultural industries of the region, there is constant pressure to increase the forage resources by getting rid of unpalatable plants and dense stands of brush and young reproduction which are coming in on private lands.

"The value of much of this land for grazing is not high, but it is also true that these areas have little value for other purposes. The market for firewood or Christmas trees is very limited and only a few owners of favorably situated lands are able to obtain some return by leasing the deer hunting privileges to some club. The raising of sheep or cattle is therefore about the only way in which the private owner can manage these lands to secure an immediate revenue." (Metcalf, 1930[a]:1.)

"Agriculture has made continual inroads upon land areas often little suited for other uses. The forest area has been reduced more than 30 percent in the past 60 years and brush has been replacing trees on the mountain sides. The utilization of the deforested land is a question of vital importance to the State—what areas might profitably be retained in brush for purposes of watershed protection, what areas might profitably be returned to forestry, and how much can and should be converted to grassland. Since California livestock consumes a large amount of the products of crop land, the improvement of the range is of importance to all farmers. It is vital that the various opportunities for a better utilization of California land be coordinated." * * * (Sproul, 1930:42-43.)

"While a maximum crop of timber and a maximum crop of quail can seldom, if ever, be produced on the same ground, some timber can be pro-

duced on lands handled primarily for quail, and some quail can be produced on lands handled primarily for timber." (Stoddard, 1931:143.) Here it may be desirable to use the land for a dual purpose, or it may be found best to limit it to one use, either that of timber production, or, as on the lands of the sporting clubs, largely to quail production.

"Forest Supervisor Jones made an excellent presentation of essential points in management of lands for timber and forage production and pointed out that these two objects did not always go hand in hand. He emphasized land classification and stated that when certain lands were classified as more valuable for grazing fire might be used in their management, but could not be used until additional protective facilities and improvements such as roads, trails, motorways, and fire-breaks were available." * * * (Metcalf, 1932:4.)

"This bulletin is a report of the results of the first large-scale study, in California, of land utilization and of the complex problems arising out of its relations to the economic and social structure.

"The general objectives assumed by the writers of this bulletin are to coordinate and harmonize land uses so as: (1) To obtain for the owners of the land and for the community and the local government the greatest possible return in proportion to the amount of energy and capital applied. (2) To protect farmers from the results of unwise expansion and to give such assistance as may be possible in the efforts being made throughout the country to balance production and consumption. (3) To assist residents in the area to adjust their economic programs to changing conditions. (4) To conserve for the general public of this and future generations the natural resources, including the soil and its fertility. In the maintenance of these resources in unimpaired productivity the public has an interest superior to that of private exploitation. (5) To provide information concerning adaptations and probable future utilization of land which will make possible progressively greater efficiency both in land use and in the administration and financing of the several functions of government and public-service agencies. (Weeks, Weislander and Hill, 1934:3 and 7.)

In order to carry out a program of this type the physical basis of land, climate, and vegetation cover must be clearly understood. It is unfortunate that most of the lands under chaparral lie outside of the limits of our state and national soil maps and are generally referred to as "rough and stony lands." Moreover, the vegetation, although mapped in general terms, must be studied in far greater detail. The natural trends of vegetation development, or in more technical terms the details of succession, must be known before the presence of a vegetation type can mean much as to its response to any treatment whether cutting, grubbing, or burning. This is essential to the ultimate solution of the brush problem in any local area. Too often it is just "brush" and "good" or "poor soil.

"The status of fire protection efforts in the north coast region of California is in a very unsatisfactory condition in spite of rather strenuous efforts to better the situation. I believe the important elements in this situation may be stated about as follows:

1. The preponderance of acreage used for grazing. Two and one-third million acres owned by farmers in the region are so used besides a large area of public-domain which is also grazed. Much of the privately-owned area is of low quality but the owners are paying taxes on it and

wish to get at least some revenue from it. Lands covered with brush, woodland or even fairly good stands of Douglas fir have no value to the man who wishes to graze them. 2. Exemption of redwood timberland from the provisions of the fire laws and the desire of logging operators to carry on burning at any time during the fire season. Owners of adjacent lands see no reason why they should not be allowed to burn their lands as well without penalty. 3. Lack of a definite management policy for cut-over lands held by large lumber companies. The forestry branch wishes them protected to secure a second stand of timber while the grazing department of the company wishes to see them burn to open them up for grazing. 4. Slight importance of vegetative cover for watershed protection from a state-wide or regional point of view. Watersheds are short and irrigation or other water supplies are not deemed of much importance. 5. Recreational use is important in a few rather small and concentrated areas but does not bulk very large in influencing public sentiment against fires. 6. Failure of the educational campaign to convince many of the land owners that fires are not a good thing for their lands." * * * (Metcalf, 1935.)

Highly important, if a land planning program is contemplated, is a knowledge of the distribution of vegetation types. "The survey not only provides information about the present vegetation cover, but also discloses that in many localities its character has been profoundly changed since the advent of the white man. The most striking and significant of such changes are those representing a progressive deterioration from higher and more valuable to lower and less valuable types of vegetation as a result of such land abuse as destructive logging, accidental and wilful summer fires, the practice of annual burning in many foothill and mountain localities, and excessive grazing. As a consequence of such treatment, there have been extensive replacements of commercial timber stands by woodland, chaparral, or sagebrush; of big-cone spruce and Coulter pine by chaparral or woodland; of piñon by chaparral; or sagebrush; of chaparral by sagebrush." * * * (Weislander, 1935: 142.)

It is evident that, with this information at hand, nature protected or aided would return the more desirable types in a suitable time. Moreover, the site may be much better than would at first appear since the land may not be occupied by a climax plant cover but by one of the early stages which is probably the climax type on poorer soil and in a dryer climate.

In land classification it is important that a detailed soil survey be extended to all lands including those on the brush-covered lands. An advance in the use of soil maps is that used in "A Rating of California Soils." (Weir and Storie, 1936.)

Undoubtedly by a careful application of the principles used in this work and by careful coordination of soil and brush types, a much safer prediction of the probable success of any land treatment could be made and much costly work by the trial and error method avoided.

As an argument against the control of the intensity of grazing and the reports of deterioration of range lands, "If and When it Rains" (Mollin, 1938) merely echoes the statement of Theophrastus, "It is the weather rather than the soil that determines the harvest." (Semple, 1931: 297.) Throughout man's history he has looked largely to his gods

to provide feed for his flocks. This was probably emphasized by the fact that so much of our written history comes from semi-arid lands where the shepherd furnished much of man's sustenance. Droughts caused the great famines of Biblical and classic literature. When rainfall is abundant grass will grow almost anywhere. However, even rainfall on a soil with no living plants cannot produce forage and the returns from rainfall are tremendously effected by two factors, (1) the number of live grasses or seeds in the soil and (2) the penetrability, depth and fertility of the soil on which the rain falls. A very deceptive recovery on badly over-grazed range results, since if only one-tenth the full number of plants have survived those that remain have 10 times as much water and soil as would those of a full stand and the larger individual plants are mistaken for range recovery. It is easy to infer wrongly that since erosion is a natural process there is no induced erosion, since range grasses grow tall after drought when rains fall, there is no permanent damage done to the plant cover by the drought, and that since grazing is good in wet years there is no over-grazing during drought years. Rain without soil will produce little. Rain and soil without a living plant-cover or seeds will produce no forage.

"Wise use of farm lands, coupled with intelligent conservation and use of our forests and with progressive development of our scenic and recreational mountains and beaches will maintain California as a state of unexcelled possibilities for health, security and happiness." (Commonwealth Club of California, 1938: 1.)

"Whether brush-cover can be returned to grass-cover by repeated burning and if so, whether or not too much erosion will occur in the interim to make the procedure practical are still unsolved problems that undoubtedly differ in different localities.

"Livestock and game-animals constitute very important means of realizing the great potential values of our natural vegetation on uncultivated lands.

"Domestic animals should be fitted into the forest-and-range picture on public lands to the best advantage of all factors concerned." * * * (Hart, 1938: 639-640.)

"In this system of classification the land is broken first into five broad physiographic groups lettered A, B, C, D, and E: * * * E, the upland or mountainous land.

"Within each broad physiographic group are found the *natural land divisions*, each of which is a land unit having a particular set of natural characteristics, such as topography, soil, drainage, erosion, and climate. These characteristics of the natural land divisions also define the natural productivity of land for plant growth whether it be cultivated crops, grass, or timber." (Storie, 1940: 4-5.)

"The upland and mountainous land which occupies 73.8 percent of the land area in Santa Cruz County contains only 26.4 percent of the total cultivated land but contains 96 percent of the timber land, 92.4 percent of the woodland, 86.1 percent of the brush, 68.9 percent of the grass and 80.4 percent of the Recreational land." (Storie, 1940: 42.)

"The present forest resources of the foothill zone around the Central Valley are largely limited to the strip of second-growth ponderosa pine of the Sierra slope at elevations between 1,500 and 3,000 feet from the upper San Joaquin to the Pitt River. This strip averages perhaps 10

miles wide and contains something over 700,000 acres. The stands are almost pure ponderosa pine, most of them between 70 and 80 years old * * *. At a conservative value of $1.50 per thousand board feet on the stump, this would be the equivalent of a monetary return of $1.35 per acre per annum. These stands are reaching a size at which the larger trees are already merchantable.

"The lower limit of the Ponderosa pine has been pushed east 5 to 20 miles and the pine has been replaced almost completely by brush and Digger pine as a result of fires and heavy grazing.

"The foothills in the northwestern part of the State in the redwood belt and adjacent territory to the east represents a different set of conditions. Both redwood and Douglas fir formed extensive forests of large timber in this region down to the valley floor. Some old growth remains and parts of it are being logged currently. It is possible to reforest the cut-over lands either naturally or artificially if fires are controlled. The growth rate of second growth redwood is the most rapid of any timber species in the country.

"In a considerable area somewhat back from the coast, Douglas fir is aggressively reseeding cut-over and open areas, and these natural second growth stands promise to yield increasing returns in marketable products in the future." * * * (Kittridge, 1940:1 and 3.)

"At the outset of the initial research in El Dorado County, the central objective was the 'delineation of the boundaries of areas best suited for agriculture, forestry, recreation, water conservation, grazing and other major uses.' As a means by which this primary objective was to be attained, a group of secondary objectives was set up. These secondary objectives were: (1) A general classification of land on the basis of its physical characteristics; (2) A statement of the way in which the different classes of land are utilized; (3) An analysis of farm income under prevailing conditions and present utilization of the different classes of land; (4) A consideration of alternative uses for the land and alternative employment for the people on the land; (5) The determination of the extent to which local areas are capable of yielding sufficient returns to justify the expenditure of public funds required for their maintenance on the basis of their present utilization; and (6) A statement of the conditions under which land is submarginal for agricultural use." (Weeks, 1943:154.)

"In outlining the land-character types * * * detailed data on climate, soils, topography, natural vegetation, and timbersite quality were recorded on maps, each having the same base. * * * For some purposes, such as detailed planning of the use of individual tracts, a more detailed classification * * * might be required.

"A large portion of the area covered by conifer and chaparral types comprising * * * about 25 percent of the total area of natural vegetation in the foothills offers only limited inducement for clearing because of persistence of the brush, shallowness of the soil, unfavorableness of location, and low returns compared with costs of clearing. On the other hand, foothill vegetation types comprising about 45 percent of the total, offer considerable possibilities for land clearing. These types include brushy grasslands, woodland, and chaparral. They are chiefly located on fairly productive soils and can be cleared by various methods.

"Opinions as to methods of improving land utilization vary from a belief that adjustments should be allowed to take their own course through the results of economic pressure, trial and error, to the opposite belief of those who maintain that the government should determine an ideal social and economic pattern of land utilization and then take steps to bring that plan into effect. Intermediate between these extremes lie many possible courses." (Weeks, Weislander, Josephson and Hill, 1943:12, 118, and 122.) This is an excellent example of study and analysis of a large area and should point the way to a better management by private landowners within the various zones. When it comes to the application of fire to a type of vegetation far greater detail of soil conditions and an intimate knowledge of every important plant and its reaction to fire will be necessary if the burn is to be more than one of trial and error.

In land planning and especially in the use of fire as a tool to establish a brush stand or secure a grass cover, it is essential to understand clearly what will follow the fire, and whether the desirable plants will be favored or whether, on the other hand, the undesirable ones will survive or follow the fire.

"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.

"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.

"Few plants of sprouting forms of chaparral were killed, and few such stands were destroyed or materially thinned out by periodic burning * * *.

"Invasion 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 brush fields leeward to the prevailing winds, where abundant seed had lodged." * * * (Sampson, 1944:26, 129 and 130.)

"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 20 to 25 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 under-story vegetation occupies 20 to 30 percent 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." (Sampson, 1944:60.)

"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 localities of heavy deer population, close browsing by these animals is effective in eliminating sprouting brush from small burns.

"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. In 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. In 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 or 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 non-sprouting brush areas a two-year burning plan, with little or no grazing during the 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 * * * is useful, as the brush is immediately and almost completely eliminated, and is followed by strong successions of grasses of fairly high carrying capacity." (Sampson, 1944:118-120.)

"The state should furnish fire protection for cutover lands in non-operating areas. In this respect, fire protection cannot be too greatly stressed. While not belittling other efforts, operators experienced in Douglas fir, pines, and redwood areas are of the firm opinion that keeping regrowing areas free from fire damage is by far the major consideration in producing a second crop of timber." (California Redwood Association, 1944:156.)

The amount of growth of redwood is phenomenal in forestry. "A one-acre plot of second-growth redwood on a high Site I on Big River in Mendocino County, California, was measured for the third time in 20 years. At 65 years it produced 139,939 board feet of second-growth redwood and 1,476 board feet of alder plus 11,000 board feet that was added to five old-growth residual trees after the logging. Twenty years later, at 85 years, the figures stood at 223,034 board feet of second-growth redwood, 540 feet of alder, and 21,400 feet added to the five residuals for a grand total growth in 85 years of 244,974 board feet per acre or 2,878 board feet per acre per year." * * * (Fritz, 1945:36.)

"The control burning problem in the State and in Mendocino County particularly, is not a single problem but a composite of a number of com-

plex problems each of which must be studied and conclusions drawn separately before an over-all conclusion can be made as to success or failure of the program.

"On the coastal belt, because of high humidity, it is said to be impossible to burn clear land except for a few days in the fall, usually September, when the humidity goes down and there is a land breeze. Some years, because of the sudden changes in humidity, the ranchers have not been able to burn at all, or secured only a partial burn, leaving fingers of green brush with dry grass gone. Unburned, dead snags and limbs present difficulties in utilization of any new forage that may come in under such conditions. A reburn to clean up the area is not possible for several years or until new fuel accumulates. For this reason encroachment of brush (Blue Blossom, Madrone, Tan Oak) Redwood suckers and fir reproduction has been rapid.

"Ranch clearings in many instances have gone back to brush and are not usable by stock. Some ranchers have been forced to reduce their number of stock or have sold out entirely. Others are trying to run a few stock while working for the lumber company or in town earning money to support the ranch.

"Capacities are greatly reduced, even on the better places and the quality of forage produced is low. A. Gray Ranch, A. Luce Ranch, Ross Ranch and F. Vierra Farm as well as numerous others are good examples of this reversion to forest. Therefore, unless something is done to change the picture, grazing of domestic stock will become uneconomic and will cease to be an industry in that locality.

"On the eastern side of the county under different climatic conditions, timber is not holding its own. Areas that were formerly producing pine or fir and pine mixture are now either poor to fair grassland or dense brush fields.

"Repeated burns, which probably do not date back farther than 50 years, have so reduced the growing capacity of the soil that many of the slopes and ridges now support mainly a stunted form of chamise which has a very minor value for forage at any time. Nevertheless the landowner still tries to run an economic number of stock with steadily dwindling capacity which results in ever recurring attempts to increase his feed even for a year or two, by clearing his land of the encroaching brush by the use of fire.

"This attempted land clearing program is a never ceasing job if the rancher is to keep up with the growth, for as soon as he lets up in his endeavors, nature moves in and takes over. Inspection of a number of the ranches—Comptche, Redwood Valley, and elsewhere—seems to demonstrate that the area of good pasture is less now than it was when the ranch was first occupied. This is evidenced by even aged stands of reproduction or brush that shows invasion characteristics Only seven to ten years seems to be the period necessary for reversion to the original type. This means that a cleared area in sprouting types at least, must be reburnt every ten years, and some areas inspected every three to five years in order to retain the acreage in pasture. This procedure takes no account of loss in quality of forage thus secured.

"The overall problem is one of land use—proper use of each soil and climatic type. It is a problem to be attacked from the standpoint of what is in the best interest of the people in which county, state and fed-

eral government must work with the landowner on his individual economic problem if there is to be an assurance of an adequate timber supply.

"The situation confronting us here and elsewhere throughout the State, clearly indicates the need for a land-use planning program with land zoning set up as a primary objective whereby it can be set down and enforced that certain lands are best suited to certain uses and shall be only so used.

"Mendocino County has been farmed or used as stock raising country for many years. Lumber companies have logged the timber off and are still doing so, selling such cut-over timber producing land to former and present employees as well as other individuals, for farming and stock raising. Little or no concern is given as to whether such an operation will be successful or not. The consequence is that large areas of the finest redwood growing land in the State is being cut up into very poor quality farms and ranches which instead should be growing timber. These recently cut-over lands possess excellent uneroded soil, and growth of forage plants is rapid.

"On the coast ranches a large percentage of the areas in pasture inspected during the past summer is rapidly being taken over by bracken ferns, iris, rhododendron, bush monkey flower, and other shrubs peculiar to the coastal fog belt. This condition seems to be present regardless of whether area is heavily grazed or not. There is no doubt that some of these open slopes were grazed much heavier in the past than now, but it is noticeable on areas that are not being grazed at all. This condition has reached a point where the ranchers are worried over the prospect of continuation of the stock industry. Burning is not, and evidently has not been the answer here, as these forms of vegetation come back more densely than before. This being the case for these coast ranches which are better than average, how much greater is the problem of those trying to ranch on the better timber growing lands which quickly revert to brush and timber?

"The conditions on the east side of the county are somewhat different. Here we find ranches, outside of the strictly fruit growing bottom lands in the Hopland-Ukiah Valley that are and will continue to be economic ranches in the future, but even here some of the range lands have been so severely burned and over-grazed that their carrying capacity is greatly reduced.

"Burning of such brush ranges is the only economic clearing method possible according to a number of investigators. Some ranchers agree although a number admit such land clearing methods have been ruinous to the soil * * *." (Smith, 1945:1-5.)

"Only 29 percent of privately-owned land in Mendocino County grows grass, we pay taxes on the balance but derive no income from it. It is simply brush. Today we find our grazing areas reduced 50 percent as compared with 50 years ago, due to brush encroachment." (Mendocino Co., 1945.)

It is necessary to know the successional history of every important brush species before a safe prediction can be made of the effect of brush burning.

"Control burning is the 'deliberate use of fire on land whereby burning is restricted to a predetermined area and intensity'. * * * There are four broad categories of land classification concerned with this

subject, three of which I am placing outside the limits of my discussion. These three are (1) timber lands, (2) primary watershed lands which, if we are to secure their greatest economic values to the state in the opinion of the State Board of Forestry, must be protected from fire in the form it is being discussed today, and (3) our open grass ranges which you want protected from fire for personal economic reasons." (Nelson, 1945:1.)

In the redwood region "Fire alone is responsible here for more deforested and non-stocking forest land than all the socalled improper logging practices." * * * (Reveal, 1946.)

"Just today * * * forest technician with the Division of Forestry, came in with the unbelievable news that * * * was burning 20- to 30-year old second-growth redwood along the Eel River between Pepperwood and Elenor flats and was reburning the 'range' along the east bank of the Eel as far up as Dyerville. About eight miles of fire in some of the best redwood producing lands in Humboldt County." (Reveal, 1946[a].)

"The Madera County Brush Burning Committee recognizes that there are many brush areas which should not be burned. These include lands that are so steep that erosion would be a serious factor. There are soils so thin and poor that probably their best use is to remain in brush cover. There are brush-covered areas which include valuable stands of timber or grass which should not be burned. In any control brush burning program it is of course important that such areas be not burned." (Crooks 1946:1.)

"The foothill and steeper upland areas in the mountains of California are generally referred to as 'wild lands'. These lands comprise about 60 percent of the total area of the state and constitute an important natural resource of forests and grass. Timber trees are recognized as a crop—a product of the soil like lettuce, alfalfa or peaches. To date only a small portion of these lands has been covered by organized detailed soil surveys. Recent soil surveys on 'wild lands' have been completed in Santa Cruz County, in Santa Clara County, in Santa Barbara County and in Colusa County. A soil survey now in progress in Madera County is planned to cover the entire county which will include a considerable area of foothill range land and the high mountainous land.

"Such important factors as profile depth to bedrock, nature of the parent bedrock, texture of the soil, compactness, reaction, and porosity of the various soil horizons are recorded and studied * * *.

"All of the factors have a direct bearing upon the nutrient level of the soil, the water storage capacity of the soil, and the general behavior of water and root penetration into the subsoil.

"The surface features of the region such as general slope, drainage pattern, and degree of man-induced as well as geological erosion is observed and recorded * * *.

"A few key soils never can be secured within the first year if the soil survey of 'wild lands' program is initiated. An adequate number of trained soils personnel for maximum production and efficiency will be available in about three years." (Storie and Harradine, 1946:1, 2 and 5.)

"As early as possible the State should undertake a study of land classification to determine factually which lands should be dedicated to timber growing, which to livestock raising, and which are too poor or unsatisfactory for either pursuit." (Biggar, 1945:100.)

SUMMARY

The plant cover or vegetation is in adjustment with or tends to become adjusted to the climatic and soil conditions. Many factors can destroy or partially destroy this balance and throw the vegetation back to an earlier stage from which it will tend to recover and establish ultimately the fully developed stage referred to as the climax.

By lumbering, grazing and clearing for cultivation man has brought about great changes in the natural plant cover. Much of this was essential to his well-being. Much of the earth's surface still remains as wild land where man is served directly by the natural cover. He is especially conscious at this time of his responsibility to conserve the earth's mantle of vegetation and soil. All food for man and beast must come from the earth's plant cover of natural and cultivated plants.

The reason for the present interest in conservation is found in the history of man's use of these resources in earlier times and other regions. Man has changed many regions from productive forests and grasslands to deserts, from brushlands to nearly bare rock areas. History is filled with a succession of failures to conserve the earth's mantle, which failures have forced him again and again to migrate to new lands not yet despoiled. These changes were brought about by unlimited cutting, grazing and burning, and always the change in the mantle is toward a more desert type.

One of the most productive areas on the earth is an exception to this rule. The Nile Valley is as productive today as it was 6,000 years ago. The reason seems evident. In other areas, as in Italy and most of the Mediterranean country, as well as on the Tigris and Euphrates, the pressure of populations resulted in the over-use of the mountains which fed the streams on which the people of the lowlands were dependent for water supplies. The heavy populations of the Nile Valley impinged in no way on the headwaters which lay thousands of miles inland, and which are today in as good condition as they were 6,000 years ago. This emphasizes the need of protection of watersheds from the destruction of the soil and vegetation.

Movements in the direction of dessication may not indicate a lowering of the rainfall, but may be brought about by the partial destruction of the plant cover, followed almost immediately by the loss of the soil mantle. These effects are confined largely to man's use of wild land and the result is always that of throwing the vegetation to a more desert type. Nature struggles continuously to move the other way. A bare area is soon weed covered. The weeds are soon replaced by perennials, and these in turn by still more luxuriant types until each area has reached the highest type that it is capable of producing.

Man's destruction is sometimes justifiable and sometimes unjustifiable. Land must be cleared to produce crop land and pasture land, but on wild land, land not to be cultivated, trees and forage must be harvested on a sustained yield basis. Timberland cut out and burned deteriorates very rapidly, likewise grazing land if so heavily grazed that the

more palatable plants are eaten out and only the unpalatable ones left in complete control also deteriorates rapidly. Weeds do not drive out the palatable grasses but merely move in to take the place of those eaten out. Fire, although not selective, where immediately followed by grazing, very greatly fosters the elimination of the more palatable forms.

The earth cover has through all time been subjected to fires from natural causes. There are great fire belts among which should be mentioned the tropical grasslands, the monsoon forests, and the prairie type of temperate grasslands. Some of the temperate forests are on poor soils, soils which have not developed because of fires which have held the vegetation back to an early stage and likewise kept the soils from coming into balance with the climate.

In the tropics the natives developed the Fang—a method of destroying a fully developed forest area in order to produce a few years of crop. This area was then left and the tribe moved on to a new forest area. This progressively destroyed the climax tropical forest.

The expansion of the live stock industry has as a rule been dependent upon extensive areas of wild land, and these have received little or no constructive or conservation effort. Most of the range improvement has consisted of building drift fences and establishing watering places to increase the consumption, rather than the production of forage. Ranges were often burned and over-grazed, the main object being present results with little thought of ultimate effects. In West Asia, North Africa and Southern Europe, such areas are often devoid of any part of the perennial grass or forest cover, which has been reduced to a crop of annual weeds or a degenerate garigue, a poor substitute for the original type.

In regions of relatively heavy rainfall, such as the Pacific North West and the temperate rain forests of Central Africa and New Zealand, clearing off the forests by cutting and fire reduces them often to useless fields of bracken. Bracken thrives on fire and fire thrives on bracken. When once well established bracken not only has no grazing value, but makes reforestation and even clearing for agriculture a tedious and costly process.

A third of the natural vegetation of the earth's surface was effected by fire. In each case the vegetation is thrown back to a less luxuriant type, a dryer or less productive type. However, many of these areas have been accepted by man as natural. In a scientific age, man need not continue to use a third of the earth's surface in a fire stage, unless that stage is more useful to him than the better developed stage. Except for pinelands and monsoon forests, and the Mediterranean type, which includes the chaparral of California, the forests of the world are not fire types. The heavy coarse grasslands of the tropics and moist prairies are fire types, but not especially good grazing lands. Civilized man need not accept either natural conflagrations or the fires of primitive peoples as a necessarily safe guide to present day practices. A few cases may make this clear. The choice lies between hardwoods and a good soil, and pinelands and a relatively poor soil in the southeast; between white pine and the jack pine or ericaceous brush in the Lake States; between Douglas fir and bracken fields in the northwest; between redwoods and bracken fields, or nitgrass, moss and soil lichens in the redwood belt; and in New Zealand and Central Africa, between temperate rain forests and

bracken fields. Fire in all these cases is the one factor that will shift the vegetation rapidly down to an earlier stage in a long succession.

The brush lands of California present a very complex problem. Similar in their ecological aspects and uses to the Mediterranean type the world over, the experiences of other lands apply to our problems in a very direct way.

In the Mediterranean, fire necessary to provide a few grasses and weeds for sheep and goats continually moved the once forested, or nearly forested, areas toward a useless bare rock, and a low garigue of mints and cistus which as Rübel says "cows detest." In South Africa, much of the once luxuriant fijnbos is now down to a near useless heath-like cover, which has been given up even by the sheep men. Where they have successfully cleared off the brush for farm land, it was accomplished by keeping fire out of the brush, and by using mechanical methods. Even then fire cannot be used to destroy the grubbed out brush without reestablishing a seedling stand of brush where the land is burned. A fire on land which has been cleared for as much as 30 years will cause dormant brush seeds to germinate.

The brush problem in California is one of very great importance. Everyone wants to stop the encroachment of chaparral upon both agricultural and grazing lands. With a proper approach this probably can be acomplished. However, it seems to be true that the broadcast burning is the main cause of so large an area being now occupied by the nearly useless chamise. The problem is likewise complicated by the fact that the brushland abuts upon one of the finest forest areas of the world, the Redwood area. Following cutting and burning the brush here is mostly forest reproduction and consequently no part of the chaparral. After repeated burns a soft brush may develop and on the dryer types and poorer sites broad-leafed chaparral and ultimately even chamise. More likely the land will be reduced to poison oak and bracken, and on the bald hills, it will pass from annual grasses to nitgrass and mosses and soil lichens. This is the lowest stage it can reach above bare soil.

Brush is of many types and in order to deal intelligently with its eradication or control, it must be broken down into broad types such as redwood, Douglas fir and tan oak or pine reproduction; into soft brush, broadleafed, chaparral, oak-chaparral and chamise chaparral, and these also into much smaller communities, which represent local adjustments to soil and also to stages in development following fire. The work of Weislander, Sampson, Horton and others are excellent examples of attempts to understand and interpret the many plant communities which make up the brush cover. With this knowledge one should be able to predict with some certainty just what could be accomplished by burning any of the area. Still the problem is more complex than this would indicate. To take a single example:

Chamise grows on a great variety of soils and sites and with considerable variation in climate, not only sprouts when burned but reseeds very rapidly in the ashes and is spread and thickened by burning. This type is carried far above its natural climatic zone by fire and by unfavorable soil or both. It is carried down into the grasslands by soils unfavorable to grass. On soil good enough to produce good grass cover, it may also be established by fire, overuse or bad practices. Because of the fact that it can indicate several types of soil and several types of climate,

a land classification should combine both the condition of the chamise as to age and vigor and the soil and climate conditions. In other words, chamise might be established on good soils by bad practices of overgrazing or fire and likewise, by fire and denudation of forests, carried far above its natural range. However, there are areas where it is the natural cover and may hold the land for so many years that it may become practically a climax type, one which will not be naturally replaced by any other type until the soil or environment is changed.

When we consider that the brushlands are made up of dozens of different plants, each of which alone or in combination can form a dominant community and indicate different environmental conditions, and which can be carried above or below its climatic area by fire or more favorable or less favorable soil conditions, it is not surprising that there are conflicting results following the experiments of the various workers. Added also to this difficulty is the different approach and the lack of complete accord in the terms and meanings of words. Usually a worker fully qualified for one type of work is not fully qualified in other fields, and this may lead to confusion in applying and interpreting results. Even the word fire is a conjure word. To one man it means uncontrolled destruction, to another merely the removal of the brush cover.

Until the chaparral is broken down into dominant species and the many communities recognized and placed in their successional relationship, and the life history, physiology, ecological and soil relations understood, two men cannot well discuss understandingly the advisability of the removal of the chaparral even if a definite plant and a definite environment are under discussion.

It is equally important that we have a soil survey backed, of course, by soil studies which give for the "rough and stony land" as careful interpretation as has heretofore been given to agricultural land. This study should not only classify the land as to depth and character of the soil, but the character of the underlying rock and all conditions of topography and slope that are needed to properly supplement the study of the vegetation and to aid the interpretation of present conditions, and serve as a guide to future management. Storie and his associates have already shown the way.

As shown by many papers the plant cover is the most important factor in keeping soil in place on slopes and preventing erosion. Whenever the vegetation is removed by any means the soils soon give way and are either washed away slowly or rapidly, or even where they hold in place the soil surface becomes so altered that most of the water runs off and is useless in producing plant growth. Some of the most desert areas in the world lie in a region of ample rainfall. The clay hills with little or no water penetration at the same time show comparatively little erosion, but practically all the rainfall runs off. Too little attention has been given to the surface phenomena of soils. A plant cover, a duff cover, accompanied as it is by a myriad of animal forms, and an equally rich fungal and bacterial flora keeps the surface in a constant stage of biological activity. This is tremendously important, not only in keeping the surface loose and preventing "baking" but also in providing an agency to digest the mineral elements and make them available as plant food. This activity involving the upper inch or more of soil, and the inch or inches of animal and plant cover is totally

destroyed by fire. That fire enriches the soil chemically might be true, by reducing these plants and animals to dead matter, and yet be harmful. But there is little evidence that the soil is enriched through a series of burnings and considerable evidence that it is not. Too many conclusions have been based on the determination of organic matter by "loss on ignition," a totally unreliable method when inorganic soils are used, especially in the warmer regions with high rainfall.

Another effect of removal of the vegetation by fire is that the duff and the mycorrhizal content so necessary for many of the forest trees is largely destroyed and it may take years to bring them back to normal activity.

Fire destroys the vegetation which under normal conditions is utilizing much of the sun's heat in the transformation of water. With this stopped the earth's surface would be appreciably warmer, and any plants growing or beginning growth would use a greater amount of water. That forests or the condition of the soil surface influences rainfall is unlikely, but they profoundly influence the micro-climate and that is what immediately affects the growing plant, and the animals and people that live in a region.

With regard to wildlife, fire of the spot variety has benefited wildlife of certain types, especially deer, quail and turkey. Small fires with edge effects and firebreaks are favorite feeding grounds. But large broadcast fires might either destroy outright or starve seriously many types of game including deer, quail and turkey, as well as most of the other wildlife forms except mice and ants and probably the larger predators.

By changing mixed types of vegetation to chamise, whole areas are made unfavorable for deer and other wildlife, and such is the tendency in most of the brush ranges. From a management point of view wildlife is still in the panacea stage. Careful brush management could probably make the brushlands far more valuable than they are now. But here as elsewhere the present quick returns should not blind us to a sane long range policy of game management. The ultimate dominance of chamise on the brushlands of California which is almost certainly predictable if burning still persists does not argue well for the future of either quail or deer.

There is every reason to believe that the valleys and hills where now only an annual grass cover is found, were once covered with bunch grass. Under natural conditions, bunch grass can compete with and replace brush and annual grasses on many areas. When fire passes over an area burning off the brush, both bunch grass and sprouting chaparral begin to grow. The bunch grasses will grow at once, but almost entirely from the previously stored food. Experiments in many places emphasize the necessity of protection from grazing after the burning until the more palatable plants have time to get a footing. Grazing immediately after a burn has in many cases extinguished the most valuable forage plants, and left the nonpalatable a free hand with no competition. The annual grasses cannot be expected to compete with perennial shrubs. Perennial or bunch grasses on the other hand when not subjected to the handicap of grazing often are completely successful with shrubs. If we wish to have grasses we must give them at least a fair chance in their competition with the shrubs.

Repeated burnings alone are usually effective in eliminating the better bunch grasses. When brush is burned, there is produced a flash of annual vegetation, if seeds and a suitable soil are present, and often a release of death camas fatal to livestock, and a sprout growth somewhat more palatable for a time than the old growth. This is accompanied however, by a shift toward the less palatable plants. Young growth is more palatable than old. As plants become older the amount of crude fiber increases which causes, in all analyses expressed on the basis of percentage, a decline in most of the food constituents. Although there is much difference of opinion, there is surprisingly little evidence that forage production is increased as a result of a burn, whereas there is some evidence to show that production is reduced.

It is difficult to understand fully the many references to the elimination of chamise and other chaparral by the use of fire when there is so much evidence and almost complete agreement by students of vegetation and succession that, although the fire may destroy the stand of above ground shrubs, it only insures the continuance of these forms after the burning. Not only do most of the species which burn down sprout after fire, but thousands of seedlings begin to develop additional stands of sprouting and nonsprouting chaparral. There is abundant evidence that burning is responsible for the chamise chaparral which is so dominant in the chaparral areas and in the Ponderosa Pine belt. Fire to many is a panacea for all their troubles, an anodyne to lull them by giving them something to do while nature speeds up the process of expansion of chaparral over some of Californias' best timber, grazing and even agricultural land. Possibly the expression "burn off the brush" is used only to apply to the brush above the ground. That each of the sprouting species may put up 10 times as many new shoots and also hundreds of seedlings will start and that the nonsprouting plants burned to death, will leave several hundred of its seedlings to "avenge its death" is not taken fully into account.

The destruction of vegetation either by fire or other methods is generally accompanied by erosion resulting from increased runoff. The effect of fire on the soil surface is probably cumulative since with no protection and devoid of the extra micro- and macro-fauna and flora, the surface is profoundly changed. The soil loses friability and becomes mechanically hard.

In this phase some excellent plot studies have presented convincing evidence of the increased loss of soil by erosion and of water by runoff due to fire. It would be unreasonable to conclude that there are no exceptions where erosion and runoff are not accelerated by fire. Indeed, if such conditions can be found, it is possible that this method may provide a means of determining which land can be safely cleared for agricultural purposes and which should be left for watershed protection. Extensive experiments on the foothills of the Sierra Nevada and at San Dimas show consistent loss due to fire and due to denudation.

An intensive investigation covering all European countries made by the International Institute of Agriculture in Rome, concludes that "forest is the most efficient element to protect the surface of the soil."

Fire can be used as a tool in many cases of wild life management. However, it is often impossible to confine it, or use it in such a way, as to secure only desirable results, and avoid the bad results. Also present

gains may mean future losses. Conflicts in land use almost always enter. When forest reproduction is destroyed to favor forage, it is a matter of adjusting conflicting interests. The destructive phases are all too evident. Forests and grass land are destroyed, habitat of both plants and animals caused to deteriorate, the soil surface is changed, forage and timber destroyed, erosion and floods cause secondary damage, and esthetic features are damaged. All of these results point to fire as a bad master. As a good servant its use must be strictly controlled and applied only when good results can be accomplished. It is not possible in dealing with so dangerous and uncontrollable a tool to allow each man to be his own judge, as to how it shall be used, at least until he has assumed any and all responsibility for damage done beyond the boundaries of his own land. He should have all the advice science can give in the proper management of his land, and if fire can be used as a useful tool, it should be used. Unfortunately many look upon fire as a cure for all their troubles. Often with no sure knowledge of what the fire will do to the range they are still convinced that it will be improved by burning. "Uncontrolled firing is costing this country untold millions and is creating for posterity a most serious state of affairs which no amount of money would ever be capable of putting right."

It is evident that land is not equally suited for all uses, some uses are more exacting as to the physical base of soil and climate than other uses. Some uses are more urgently needed from an economic and social point of view than others. Naturally the most productive land offers the greatest variety of profitable uses, but road ways, air fields and lands for industrial plants do not require a fertile soil. Orchard land could become good grazing land. Good timber land might be reduced to good grazing land, and still the demand for timber take first rank. Redwood land generally recognized as the world's finest timber land, can be reduced to relatively inferior agricultural or grazing land. From a national or state point of view, and the general welfare, and from the standpoint of the landowner, the proper use of land must be recognized. This need not involve administrative control, but the federal and state agencies especially those in the educational and extension phases should have this clearly in mind in advising local land users. Agricultural agencies do not hesitate to advocate good cultural practices and to discourage bad cultural practices, neither should they hesitate to advocate sound long range land use practices, and condemn bad land use practices. Often there is danger in too narrow a view, and an attempt to bolster bad land use by various devices and practices, which should be unnecessary if the proper program of use were first outlined. It is not a good economic or social policy to attempt to gather "figs from thistles."

The proper management of brush land will demand an expansion of our present knowledge of the ecology of brush communities, a thorough understanding of the secondary successions initiated by burning and the effects of heavy grazing and fire. This will also have to be supported by a study and classification and evaluation of the soil upon which brush grows, and a knowledge of what the effect of the removal of the brush will be on soil erosion and the loss or conservation of water. We should determine the role of fire in the extension of brush areas and also the role of fire in destroying brush, and the most feasible and economic

methods of clearing potential agricultural land from brush. There is little evidence that fire alone can accomplish this result.

Studies in land use will, when the physical base is known, consider the economic and social problems, determine which areas can be most successfully devoted to agriculture, forestry, recreation, water conservation, grazing and other major uses, analyze present use and income, consider alternative uses and make other studies needed to give sound advice to landowners.

The conflict of interests for the use of the land can only be solved by proper land use studies. These should aid each landowner to avoid the pitfalls and needless expense and futility of attempting to make land perform unreasonable tasks.

We must work with nature to accomplish possible ends. If our desires run in the opposite direction, expense and disappointment are likely to result.

"As soon as possible the State should undertake a study of land classification to determine factually which lands should be dedicated to timber growing, which to live stock raising, and which are too poor or unsatisfactory for either pursuit."

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