Forest Fire in Perspective

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WILDFIRE is man's worst enemy, in his efforts toward good forest protection and management. But has it always been, and need it continue to be? In an attempt to answer this question, it may be worthwhile to consider some of the historical aspects of forest fires and to examine our present policies.

FIRES IN PRIMITIVE FORESTS

Along with climate, soils, and topography, fires set by lightning and by Indians were also of great biological significance in California's primitive forests. John Muir (1894) referred to fire as the master controller of the distribution of trees. Jepson (1921), an early botanist at the University of California, Berkeley, concluded that the Sierra Nevada forests were clearly the result of periodic or irregular fires occurring over thousands of years. Kotok (1930), silviculturist, and for many years director of the California Forest and Range Experiment Station, stated that in some regions fire was the major force that molded and shaped the character of the forest. More recently, Reynolds (1959), a geographer and naturalist, suggested that many forests in which the Indians lived were in dynamic relation to the periodic fires which ran through them.

It is probable that fires burned over California's landscape for thousands of years, and swept through virtually every forest in which there was anything to burn. Tree trunks in forested areas contain a record of past fires, at least as far back as the oldest trees. A moderate or light fire burning a log or other heavy debris next to a tree will often kill the tree's cambium on one side, leaving the other side unharmed. A new layer of wood then starts to grow around the scar, which in turn may be injured by another fire. By looking at the scars and counting growth rings, it has been possible to date fires even centuries after they occurred. Scientists had an opportunity for large-scale dating of fires in primitive forests of California when they conducted a study of dryrot in incense-cedar. In this study, more than a thousand trees of incense-cedar were cut in six different areas extending from Sloat, on the Plumas National Forest, Plumas County to the Sierra National Forest in Fresno County. All the trees were in mixed-conifer forests at elevations of 4,300 to 5,600 feet. The evidence showed that fires occurred throughout this region on an average of every eight years, from 1685 to 1899. A more detailed study on 74 acres in the Stanislaus National Forest in the Sierra Nevada showed 221 distinct fires between 1454 and 1912, or one about every two years (Kotok, 1930; Wagener, 1961).

The history of forest fire in giant sequoia has been determined to a very early date by means of the fire-scar method of dating. Sequoia trees live to be 3,500 years old or so, and thus retain the tell-tale burns for centuries. In the Mariposa grove, in Yosemite Park, 15 fires were dated for the period 450 A.D. to 1862. Jepson speculated that probably every old giant sequoia tree had been struck by lightning. He regarded as one of the most remarkable forest experiences the sight of a fire burning at night, 150 or 200 feet in the air in the top of a giant sequoia.

In view of the large number of fires in primitive times, I decided to check the number and distribution of lightning fires in the Sierra Nevada for more recent years. It is reasonable to assume that the pattern today is similar to that of very early times, the main difference being that lightning fires now are quickly suppressed. For the study I selected two townships in Yosemite National Park, one at the Tuolumne Grove of big trees, the other near the Mariposa Grove. In the township at Tuolumne, 39 lightning fires were suppressed in the nine years 1951 to 1959, inclusive; in the Mariposa Grove, 36. Similar data were obtained for a township at Sloat, in the mountains east of Chico, and for one at Pinecrest. At Sloat, 24 lightning fires were suppressed, and at Pinecrest, 18. Lightning fires were also recorded for all four townships in every year except 1954. Records were also obtained for the Plumas, Stanislaus, Sierra, and Sequoia national forests in the Sierra Nevada. Lightning fires occurred in all four forests in every year except 1954, when there were none in the Stanislaus forest, as indicated below.

Number of lightning fires in:

Year	*Plumas*	*Stanislaus*	*Sierra*	*Sequoia*
1951	268	11	36	18
1952	164	61	114	86
1953	85	73	66	106
1954	14	—	15	14
1955	155	30	18	18
1956	186	85	109	125
1957	36	19	33	25
1958	101	54	120	124
1959	78	51	95	85

Many other investigators have studied the occurrence of lightning fires in California forests. Komarek (1967) has given us a good account of the incidence of lightning fires on Forest Service lands. His data show not only that such fires are numerous, but also that they have increased slightly over the years. Court (1959) reported that in an area of about 5,000,000 acres of forest and bushland from Yosemite Park north to the Feather River, the number of annual lightning fires between 1948-1958 varied from 50 to 300, and averaged over 100 per year; 200 or more lightning fires in a season, in this area, seemed to come at intervals of 5 to 10 years.

Fires in primitive forests were set by Indians as well as by lightning. This is borne out by various explorers and naturalists who observed the results at first-hand—for example, Galen Clark, for many years the guardian of Yosemite; Dr. L. H. Bunnell, a member of the 1851 Yosemite discovery party; and Joaquin Miller (1887), who wrote,

> In the spring . . . the old squaws began to look about for the little dry spots of headland or sunny valley, and as fast as dry spots appeared, they would be burned. In this way the fire was always the servant, never the master. . . . By this means, the Indians always kept their forests open, pure and fruitful, and conflagrations were unknown.

On the basis of this hypothesis, much has been said and written about the Indian as the original forester and guardian of our forest resources.

Why did the Indians burn? Sauer (1950), Stewart (1956), Jepson (1921), and others have reported that they did it to improve both browse for deer and hunting conditions, and to clear the brush and undergrowth. Since the Indian has been here for at least 15,000 years, and perhaps 200,000 or 300,000 years, it is conceivable that some areas in the pine forests of the Sierra Nevada were burned hundreds of times by his fires, to say nothing about the thousands caused by lightning.

Descriptions of fires in primitive forests are almost nonexistent. However, John Muir, in 1875, described a fire as it entered a grove of giant sequoia. This was in September, the driest time of the year. John Muir could not be considered a fire expert, of course, but he was a keen observer and his description is interesting and worthwhile:

> The fire came racing up the steep chaparral-covered slopes of the East Fork canyon with passionate enthusiasm in a broad cataract of flames. . . . But as soon as the deep forest was reached, the ungovernable flood became calm like a torrent entering a lake, creeping and spreading beneath the trees. . . . There was no danger of being chased and hemmed in, for in the main forest belt of the Sierra, even when swift winds are blowing, fires seldom or never sweep over the trees in broad all-embracing sheets as they do in the dense Rocky Mountain woods and in those of the Cascade Mountains of Oregon and Washington. Here they creep from tree to tree with tranquil deliberation, allowing close observation.

From the above statement, one might question whether John Muir knew of a single case of crown fire in the Sierra Nevada. It is clear,

FIG. 2. Open, parklike ponderosa pine where wildfire danger is very low.

however, that he knew about such fires in the Rocky Mountain woods and the Cascade Mountains of Oregon and Washington.

In the primitive forests, fires were a *natural* feature of the environment. Not only were recurrent fires essential for the forest, but the evolutionary development of the forests and the trees themselves was related to fire. We cannot, of course, permit fires to burn at random, as they did in the primitive forests. Nevertheless, a knowledge of the interrelationships between fire and forests can be of great practical importance to the modern-day forester in developing sound management practices. Frequent fires in the primitive forests served as a negative feedback mechanism to prevent complete destruction of the forests by a runaway fire at some later date (Schultz, 1967). In the natural forest, a small fuel accumulation resulted from normal forest development, then a light fire reduced the fuel to a "tolerable" level. In this way, the primitive forests found stability and protection against holocausts.

The primitive forests were open and park-like. In John Muir's book (1894) we find this statement:

> The inviting openness of the Sierra Woods is one of their most distinguishing characteristics. The trees of all of the species stand more or less apart in groves, or in small irregular groups, enabling one to find a way nearly everywhere, along sunny colonnades and through openings that have a smooth, park-like surface, strewn with brown needles and burrs. . . . One would experience but little difficulty in riding on horseback through the successive belts all the way up to the storm-beaten fringes of the icy peaks.

Clarence King (1871), a brilliant young geologist in Brewer's geological survey party, wrote of his going into the Sierra Nevada:

> Passing from the glare of the open country into the dusky forest, one seems to enter a door, and ride into a vast covered hall. The whole sensation is of being roofed and enclosed. You are never tired of gazing down long vistas, where, in stately groups, stand tall shafts of pine. Columns they are, each with its own characteristic tinting and finish, yet all standing together with the air of relationship and harmony. . . . Here and there are wide open spaces around which the trees group themselves in majestic ranks.

And in another passage:

> Whenever the ground opened level before us, we gave our horses the reins, and went at a free gallop through the forest; the animals realized that they were going home and pressed forward with the greatest spirit. A good-sized log across our route seemed to be an object of special amusement to Kaweah, who seized the bits in his teeth and, dancing up, crouched, and cleared it with the impression that one was enough of that sort of thing.

Jepson stated that the forest stand was open, with broad spacings of the trees and a forest floor destitute of a ground story or carrying only scattered or somewhat scattered shrubs or a carpet-like ground-cover. This spacing, he thought, undoubtedly represented an adaptation to fire conditions. Jepson also mentioned that nearly all forest species in the Sierra Nevada mountains had developed a trunk bark of marked thickness, which served as a protection for the cambium.

Fires in the primitive forests also played an important role in the succession of species. The trees most resistant to fire had the best chance of surviving and dominating. For example, in areas where pines, white fir and incense-cedar normally grow, the pines dominated because the white fir and incense-cedar, with their less protected buds and more flammable foliage, were more easily killed. Furthermore, the latter two species, normally growing in the understory of larger trees, were more exposed to fire.

Frequent fires in the primitive forests resulted in a mosaic of even-aged stands. Each even-aged group sprang up in an opening left by the death of a mature tree or group of trees. The first fire or two that passed through consumed the dead trees, and left a good seedbed for new seedlings. New seedlings cannot withstand light surface fires, but they are protected by the lack of dry pine needles, which carry such fires. After 10 or 12 years, the new seedlings or saplings drop enough needles to carry surface fires under the new canopy. The first fire thins by killing many of the smaller trees, but the larger ones survive to form another even-aged group. In some cases, a group may not consist of more than three to five trees, but usually there will be more (Cooper, 1961). New seedlings continually spring up under the older trees, but as fast as they appear they are killed by the next surface fire. In this way, forests are kept open and park-like, and the older trees are free of under-story competition.

Frequent surface fires in the primitive forests continually acted as a thinning agent. In the young and pole-sized stands, the fires killed the suppressed trees because of their thinner drier bark. In the older stands, the trees killed were those with fire scars. With each surface fire, a few scarred trees were burned enough to topple over. Show and Kotok (1924) found this to be about one tree on each 11 acres. In my own work, I found that old fire scars do catch fire easily when surrounded with pine needles, but only about 1% of them burn enough to topple over. When a tree is killed, the roots of the survivors quickly appropriate the soil made vacant, and their growth is stimulated. In the primitive forests many of the trees became very large indeed.

DESTRUCTIVE BURNING BY EARLY SETTLERS

Early European settlers in California used fire carelessly and destructively. Their fires caused much concern to thoughtful observers, and no doubt helped stimulate the conservation movement which followed around the beginning of the twentieth century. The early miner used fire to clear the landscape and facilitate prospecting. The more plant cover he could destroy, the better, because then he could see the gold-bearing out-crops. He also used fire carelessly to remove slash after timber cutting for mining props and fuels. Although these fires in slash must have been intense, fortunately they did not kill all trees, and many remained to reseed the landscape. Today some of the best pine stands in California are found in the areas where miners did heavy burning.

Early-day lumbermen also used fire destructively. They had little or no concept of sustained-yield forestry. Their idea was to cut and get out. Very often, therefore, they cut all the salable trees on an area and then burned to get rid of the slash, which gave an intense fire. Usually, most of the unsaleable trees that remained after logging were killed. Many of the areas that were heavily cut and burned turned to brush fields (Show and Kotok, 1924).

Sheepmen were a third group that did destructive burning. Usually the sheep were taken to the mountains for summer grazing. When they were brought out in late summer, at the driest time of the year, the shepherds set the forest afire to get rid of new forest growth, logs, pine needles and other debris that hampered grazing. They probably observed that the best forage was in open areas; therefore, it was to their advantage to prevent as much reproduction as possible. However, because the fires were frequent, it is difficult to see how they might have been very intense. Some of the reported damage by shepherds fires may have been from the grazing and trampling that followed the burning. John Muir and others noted that the sheep ate every green sprig they could reach, and the millions of hoof prints trampled and packed the soil, making it subject to runoff and erosion.

Although there was much destructive burning by early settlers, Wagener (1961), reporting on the change in fire-frequency pattern after the coming of the white man suggests, on the basis of fire-scar data, that no major change occurred until after 1900. That date corresponds roughly with the establishment of the national forests, and at that time fire frequency declined.

FIRE EXCLUSION POLICY

We know, of course, that wildfire prevention and suppression are essential in the management of today's forests, with their many uses. There should be no doubt about this.

The policy of fire exclusion on Forest Service lands in California was initiated about 1905, almost simultaneously with establishment of the forest reserves. The policy of the California Division of Forestry was not finally adopted until about 1924. Between those dates, there was vigorous controversy about the wisdom of complete fire exclusion (Clar, 1959). Two groups emerged. The first advocated light burning in the spring and fall as a means of hazard reduction. Such fires would do about what the lightning fires and Indian burning had done in nature. The theory was that without light burning, the fuels would eventually build up to a point at which a wildfire could not be stopped. Later on, the wildfires would be so intense that all trees would be killed over any areas burned. Furthermore, the group suggested that light burning might be useful for insect control by keeping down understory competition and removing debris. The second group maintained that wildfires could be stopped without much difficulty, and theorized that virtual fire exclusion must be the procedure in forest practice. For many years no research was reported to confirm or deny the opinions of either group.

Among the strong advocates of light burning were members of the Walker family of the Red River Lumber Company in Shasta County. From 1909 to 1913, inclusive, the Walkers made a thorough test of light burning on nearly one million acres of pinelands under their management. Thirty-five men from Redding were hired to do light burning over these lands throughout the year, when conditions were suitable. This group became known as the "needle scratchers." When they could not burn, they piled rocks in the cavities of fire-scarred trees and then threw in dirt to keep those trees from catching fire. They also removed fallen logs from near the trunks of trees and did other things to lessen the damaging effects of light fires. They reported that the cost of burning was about 30 cents per acre. This project was given up in 1913 because of outside pressures.

In 1919, the light-burning controversy reached a new peak. It appeared that cooperative fire protection between the Forest Service and lumbermen might be endangered. Accordingly, the Society of American Foresters intervened, and the California Forestry Committee was organized in 1920 to look into the particular problem. Committee members were: P. G. Redington, District Forester, representing the U. S. Forest Service; M. B. Pratt, State Forester; R. F. Danaher, Manager of the Michigan-California Lumber Co.; C. R. Johnson, President of the Union Lumber Co.; B. A. McAllester, Land Commissioner, Southern Pacific Railway Co.; and Donald Bruce, Professor of Forest Engineering, University of California, Berkeley, Chairman.

The Forestry Committee did meager research over a period of three years, but from this it concluded that the light-burning theory was neither more practical nor more economical than the fire-exclusion theory of the Forest Service (Bruce, 1923). Therefore, the study was concluded. Official recognition was taken of this by the State Board of Forestry in August, 1924.

At about that time, two brilliant young foresters, S. B. Show and E. I. Kotok, had studied the history and role of fire in California forests and published several articles jointly between 1923 and 1930. Show was clearly the authority on fire damage and fire exclusion. Later he became Regional Forester for California and served in that capacity for about 20 years. Soon thereafter, Kotok became director of the California Forest and Range Experiment Station, where he served for many years. It is obvious, then, that these two men together had tremendous influence in establishing forest fire protection policies in California. From the time of their appointments until 1945 there was not much attention given to the use of fire in wildland management except for bunching and burning of logging slash. However, in 1945 the State Legislature authorized the California Division of Forestry to issue burning permits for purposes of range improvement and a new interest in the use of fire was stimulated.

If any one person could be named as the leader of the light-burning theory, it was probably Stewart Edward White, popular writer and large-scale timber owner. He was a strong advocate of light burning for both hazard reduction and insect control.

FIG. 3. A dangerous fuel situation in second-growth *Sequoia gigantea*, mixed-conifer at Whitaker's Forest. It is dangerous to prescribe burn in such areas without ponderosa pine needles to carry surface fire. Therefore, the excess fuels are cut and burned in small piles. On test plots, an average of 44,040 pounds of dead material was removed. In addition, 550 standing dead incense-cedar, together with 945 understory white fir and incense-cedar between 1 and 11 feet tall were removed.

THE WILDFIRE PROBLEM

Fire control proved easy in the primitive-like forests, and there was much evidence that wildfires could be stopped without difficulty. But the fire-exclusion policy proved all too successful in many places, and great fuel hazards have developed over the years. Part of the increase in hazards has resulted from fire protection itself, for protection permits understory trees and brush to grow and debris to accumulate. However, slash from timber cutting, and dense second-growth forests have contributed much to the increasing hazards. This was first pointed out by Show and Kotok in 1924.

> The virgin forest is uneven-aged, or at best even-aged by small groups, and is patchy and broken; hence it is fairly immune from extensive crown fires. Extensive crown fires, though common in the forests of the western pine region, are almost unknown in the California pine region. Local crown fires may extend over a few hundred acres, but the stands in general are so uneven-aged and broken and have such a varied cover type that a continuous crown fire is practically impossible. A rare exception was the Egg Lake fire on the Modoc National Forest, where one area of 92 acres was destroyed. In general such stands are immune, but immunity to crown fires does not extend to second-growth stands, cut-over areas, or restocking brush fields.

The changing scene in the forested areas of California resulting from fire exclusion, timber cutting and other activities of the white man was aptly described in the Leopold Committee Report, "Wildlife Management in the National Parks," 1963:

> When the forty-niners poured over the Sierra Nevada into California, those that kept diaries spoke almost to a man of the widespread columns of mature trees that grew on the western slope in gigantic magnificance. The ground was a grass parkland, in springtime carpeted with wildflowers. Deer and bear were abundant. Today, much of the west slope, is a dog-hair thicket of young pines, white fir, incense-cedar, and mature brush—a direct function of over-protection from natural ground fires. Within the four National Parks—Lassen, Yosemite, Sequoia, and Kings Canyon —the thickets are even more impenetrable than elsewhere. Not only is this accumulation of fuel dangerous to the giant sequoias and other mature trees, but the animal life is meager, wildflowers are sparse, and to some at least the vegetation is depressing, not uplifting. Is it possible that the primitive open forests could be restored, at least on a local scale? And if so, how? . . .

Changes in the parks and in other places where there was no timber cutting have taken place at an almost imperceptible pace. The young trees and brush plants grew slowly because they were competing with the older trees, and mortality was gradual. The debris also built up slowly as the mature trees continued to die, and small trees succumbed to natural competition as the forests developed. Because of dry summers and cold winters, wood-rotting organisms have not removed the debris as fast as it formed—thus it has accumulated over long periods. The understory trees and debris serve as a tinderbox ready to burst into flames of uncontrollable intensity. It is paradoxical, then, that modern man with his knowledge, skills, and tools has helped create the thing he fears most in forest land management, that is, destructive wildfires.

In recent years, wildfires have destroyed a wealth of forest resources. Even though we have an excellent fire prevention program with "Smokey the Bear," and the best firefighting forces in the world, doing excellent work, a few of the wildfires become big and nearly impossible to stop until the weather changes. Under difficult circumstances, the firefighters are doing the best possible job, but they appear to be battling increasingly serious odds as the dangerous fuel build-up continues, especially in second-growth forests, and more use is made of forested lands. The big fires in forested areas usually occur at or near the end of long dry periods when the humidity is low, and the wind may be blowing. But such periods must be considered *normal* for California. The last really big siege of wildfires in timbered lands in California occurred in 1955, when 141,222 acres were destroyed between August 27 and September 13 (USFS, 1955).

The magnitude of the wildfire problem in general can be illustrated from a recent report covering the year 1966 (Cameron, 1967). During that year, 285,000 acres were burned in 7,500 fires. The report stated, "Each year forest and range fires cost Californians an estimated $250 million in lost wages, lost taxes, fire fighting expenses, timber destroyed, flood damage due to burned watersheds, destruction of private property, farm lands put out of production, and recreation facilities damaged. And it takes about 100 years for a forest to replace itself after being destroyed by fire."

The costs of fire suppression and damage have sky-rocketed. Only 12 years ago, suppression costs and damage were estimated at $25 million each — a total of $50 million, compared with the $250 million for 1966. There is every expectation that the cost and damage figures will continue upward at a fast pace as the population increases, as there is more property to be damaged, and dangerous fuel accumulations become more widespread. Is it, therefore, desirable to let the fuels build up to such dangerous levels in so many places?

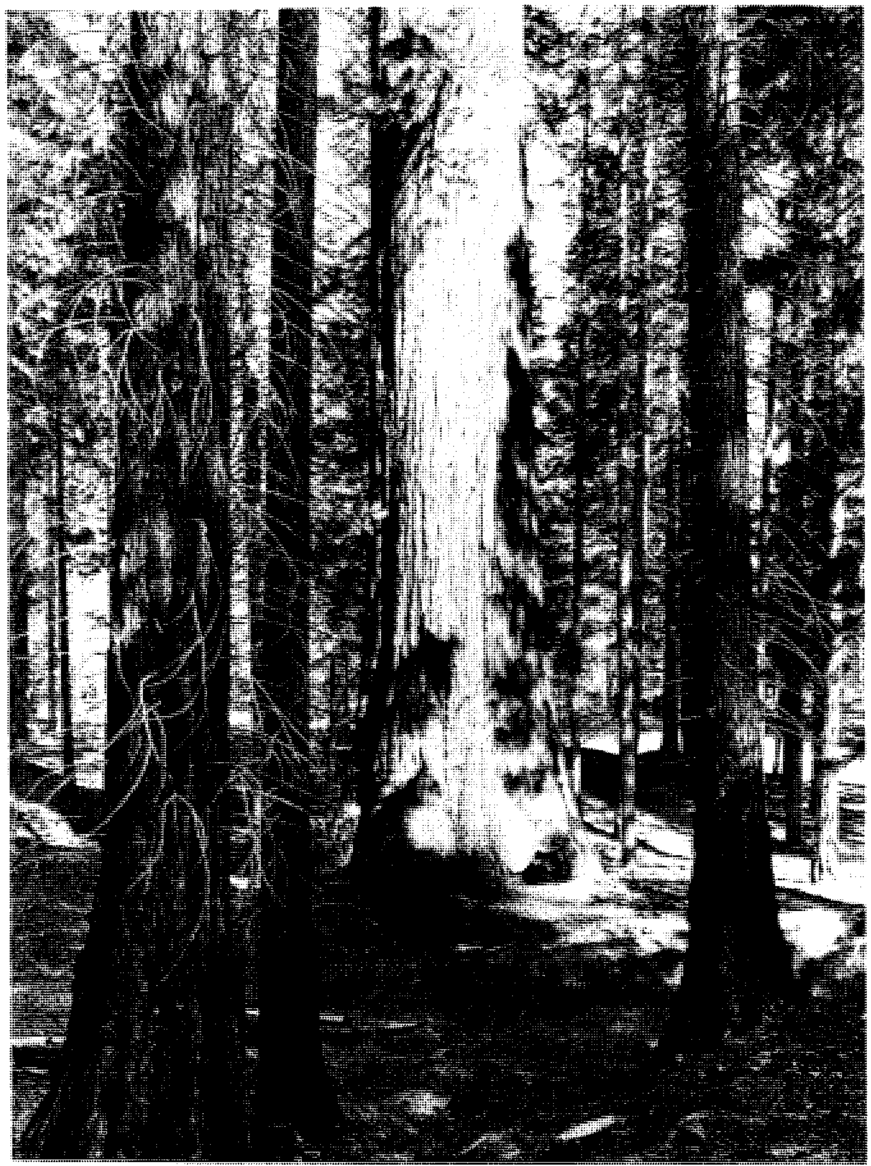

Fig. 4. Open, parklike conditions in giant sequoia Whitaker's forest. No-pruning practice results in a "natural" appearance. Later on, studies will be made of prescribed burning as a means of maintaining low fire hazards.

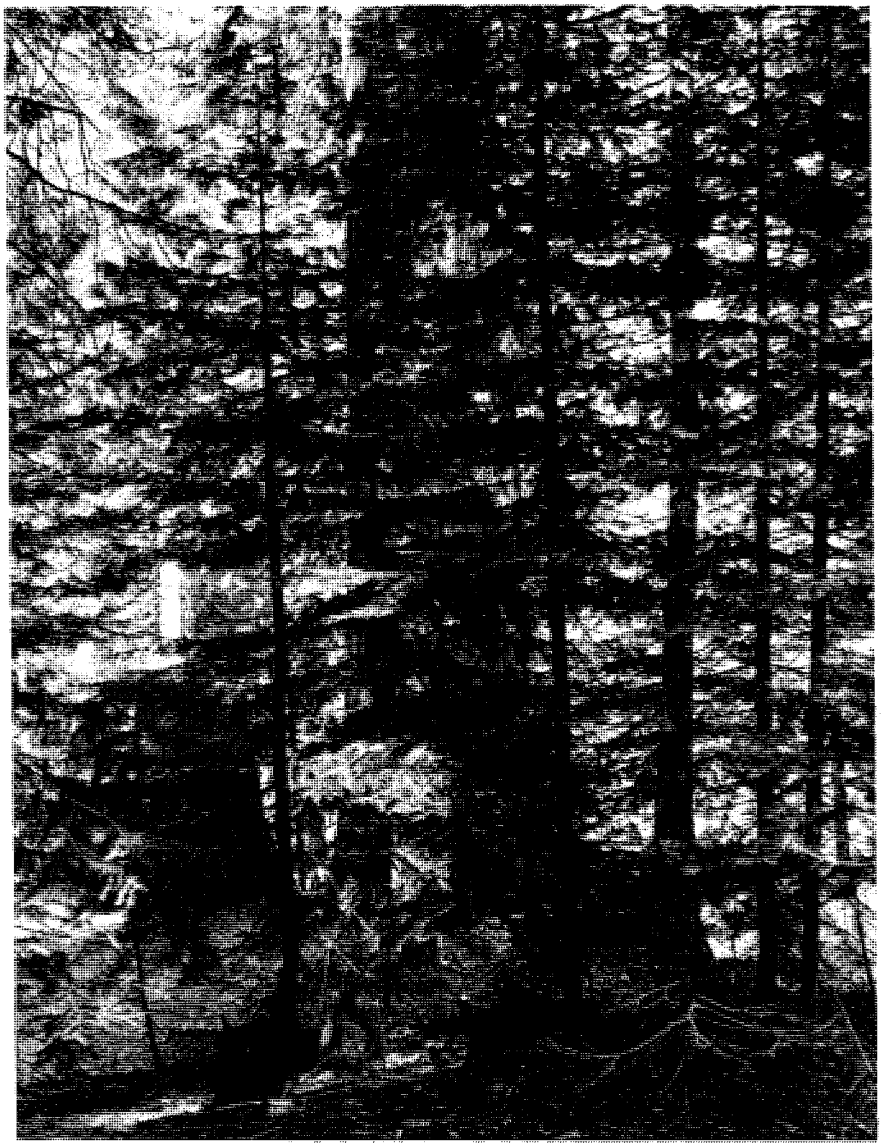

FIG. 5. A giant sequoia tree can scarcely be seen from 50 feet away because of the understory of shade-tolerant trees.

PRESCRIBED-BURNING EXPERIMENTS

Prescribed burning, also known as control burning, is the judicious use of fire for a constructive purpose. It involves such questions as why, where, when and how to burn. It is defined in the glossary of forestry terminology as the "skillful application of fire to natural fuels under conditions of weather, fuel moisture, soil moisture, etc., that will allow confinement of the fire to a pre-determined area and at the same time will produce the intensity of heat and rate of spread required to accomplish certain planned benefits to one or more objectives of silviculture, wildlife management, grazing, hazard reduction, etc. Its objective is to employ fire scientifically to realize maximum net benefits at minimum damage and acceptable cost." This term should not be confused with debris burning. The term *prescribed burning* was first used in connection with use of fire in the understory of trees. Later, the term was employed synonymously with control burning as applied to brushlands.

Back in the late forties, after I had studied the ecology of the primitive forests and observed our present high fire-hazard conditions and the great damage being done by wildfires in California, it appeared that new ways must be sought to modify forest fuels, and new management practices developed to avert the mounting danger and suppression costs of great wildfires. Since surface fires were so effective in nature in creating and maintaining open, park-like forest conditions with low fire hazards, I thought it worthwhile to do some research and testing of this phenomenon. The prospect of using such fires in the ponderosa pine forest type seemed so good that my associates and I started experiments in prescribed burning on the Teaford Forest in the central Sierra Nevada near North Fork in April of 1951, and at Hoberg's in the North Coast Range in the fall of 1951. The results have been published in several places (Biswell, 1959, 1961, 1963, 1967). Before that time, I had just finished six years of study of prescribed burning in the pine forests of the southeastern United States, and had been most favorably impressed with the results. Only a small amount of prescribed burning was being done in the southeastern United States at that time, but now it is a regular part of most forest management programs, and is widely

Fig. 6. Proud owner, Otis Teaford, after extreme wildfire hazards have been removed from his forest and grazing lands. Earlier, he had thought it would be just a matter of time until his forest would be destroyed by wildfire.

used. A survey in 1964 showed 2,500,000 acres burned annually; in 1954 it had been only 1,250,000, thus the practice is moving forward rapidly (Robert W. Cooper, personal communication).

The main purpose of prescribed burning at Teaford's and Hoberg's was fire-hazard reduction, the intention being to restore the forests to open, park-like conditions. From this research an idealized management plan has been developed. The trees are managed in a mosaic of even-aged groups at about ideal stocking. When a small area is harvested by clear cutting, new reproduction is obtained in adequate amounts. This is then protected against fire for 10 to 15 years, or until enough pine needles have fallen to the ground to carry surface fires. After that, the area is burned periodically to keep it free of understory trees and to eliminate debris. From this point on, the even-aged groups can be commercially thinned periodically to keep the stands healthy, vigorous, and productive. A long rotation—for example, 150 years—permits some trees to become large, so that the forest as a whole is broken by many even-aged groups. This makes the forest particularly resistant to crown fires. The debris is burned after each thinning or final harvesting of trees. Managed in this fashion, a forest can apparently be kept almost immune to extensive crown fires.

As I visualize this management plan, it is almost identical with the way the forest reproduced itself and developed during primitive times when nature's fires were free to operate in their own fashion. During those times, the forest cover and surface fires must have been in nearly perfect balance—nature's balance.

Sixteen years have elapsed since the studies began, and the pine trees seem to prune themselvs and do better with periodic surface fires than they do with complete protection. But how could this be? Is it that the pines are so well adapted to surface fires through evolutionary development that they do less well with complete protection? Is it due to more available nitrogen and more rapid cycling of nutrients? Is it that the roots are more firmly established in the soil? Is it due to the destruction, by fire, of growth inhibitors in the duff? Is it less competition from the understory, or a combination of all of these factors and perhaps others? Certainly, here is a fertile field for research.

The most extensive studies on prescribed burning in California have been conducted at Teaford's and Hoberg's. However, in the Western ponderosa pine zone, Weaver (1955, 1957, 1964) has done extensive work. His results and conclusions and those presented here are in nearly perfect accord.

In 1964, studies of fuel reduction and modification were started in giant sequoia-mixed conifer at Whitaker's Forest (Larson, 1966). This forest is on the western slope of Redwood Mountain, where John Muir explored in the summer of 1875. He found this mountain covered with a superb growth of Big Trees. The fuel build-up on the lower fringes of Redwood Mountain is now so great that some day this same superb growth of Big Trees may be destroyed by a huge wildfire. This mountain has been recognized as a "powder keg" for some time, and although certain measures have been taken to aid protection, not enough is being done to modify the fuels to bring the fire danger down to "tolerable" levels.

Prescribed burning will be more difficult in this type than in ponderosa pine. Whereas prescribed fires burn gently through pine needles, the debris under giant sequoia and white fir will not burn under the same moist conditions that fires burn through pine needles. In the latter case it is more dangerous to use fire in heavy accumulations of fuels and abundant understory trees. Accordingly, in experimental work at Whitaker's Forest, the fuels are first reduced by cutting and piling small, crowded understory trees, and burning the material, together with debris accumulated on the forest floor. No pruning is done, so that the end result is one of natural appearance. On test plots, 44,040 pounds of dead material were removed; 550 standing, dead incense-cedars killed by natural competition were cut, together with 945 understory, shade-tolerant white firs and incense-cedars between 1 and 11 feet tall. Portions of the forest are now open and park-like. Not only have fire hazards been decreased, but vistas of giant sequoias have also been created, competition for soil moisture and nutrients has been reduced, and conditions for wildlife—an integral part of a wildland scene—have been improved. Such a program is expensive, but how much is it worth to save centuries-old giant sequoia trees from wildfire? These trees should be considered a priceless heritage to be preserved at any cost. At a later date, prescribed burning will be tested as a means of keeping the sequoia groves open and park-like and relatively free of dangerous fuels.

SUMMARY

California's primitive forests were kept open and park-like by frequent surface fires set by lightning and by the Indians. The forests were in a stable equilibrium, immune to extensive crown fires.

Early European settlers used fire destructively in mining operations, lumbering, and grazing. This caused concern to many interested observers and helped bring on the conservation movement. A policy of fire exclusion based on prevention and on suppression of all going fires has worked all too well in many instances. Dangerous fuel situations have built up as a result of fire exclusion, timber cutting, and other land-management practices. Wildfires are now destroying a wealth of resources.

There is no place for indiscriminate burning, and intense fire prevention and suppression are essential in forest-land management. However, prescribed burning, more or less simulating nature's surface fires, and management for a mosaic of even-aged groups, with open, park-like conditions, offer a means of diminishing the wildfire problem. At the same time, such measures can become a step in efficient management for timber, forage, wildlife, water and recreation. Prevention, suppression and fuel reduction are the three essentials in adequate fire protection. Reducing fuels to a "tolerable" level by prescribed burning comes closest to nature's way of stablizing forests and helping protect them against holocausts.

BIBLIOGRAPHY

Biswell, H. H. 1959. Man and fire in ponderosa pine. Sierra Club Bulletin 44(7): 44–53.

———. 1961. The big trees and fire. National Parks Magazine. April.

———. 1963. Research in wildland fire ecology in California. Second Tall Timbers Fire Ecology Conference, Tallahassee, Florida. pp. 63–98.

———. 1967. The use of fire in wildland management. *In* Natural resources, quality and quantity, by S. V. Wantrup and James J. Parsons, U. of C. Press, Berkeley.

Cameron, J. 1967. Did heavy rains ease the forest fire threat? P. G. & E. Progress, San Francisco. July.

Clar, C. Raymond. 1959. California Government and Forestry. Calif. Div. Forestry, Sacramento, California. 623 pp.

Cooper, Charles F. 1961. Pattern in ponderosa pine. Ecology 42(3):483–499.

Court, Arnold. 1957. On incidence of lightning fires. Studies conducted by the Pacific Southwest Forest and Range Exp. Sta. Berkeley, Calif. for the Calif. Div. of Forestry (unpublished data).

Jepson, W. L. 1921. The fire-type forest of the Sierra Nevada. The Intercollegiate Forestry Club Annual. 1(1):7–10.

———. 1923. The trees of California. (Second edition). Sather Gate Book Shop, Berkeley, California. 240 pp.

King, Clarence. 1871. Mountaineering in California. Reprinted, with preface and notes, by Francis P. Farquhar.

Komarek, E. V. 1967. The nature of lightning fires. Proc. Seventh Tall Timber Fire Ecology Conf. Tallahassee, Florida.

Kotok, E. I. 1930. Fire, a problem in American forestry. Scientific Monthly. XXXI: 450–452.

Kotok, E. I. 1934. Fire, a major ecological factor in the pine region of California. *In:* Proc. Fifth Pacific Science Congress, Canada. Univ. of Toronto Press.

Larson, G. B. 1966. Whitaker's Forest. American Forests. 72(9):22–25, 40–42.

Leopold, A. S., S. A. Cain, C. M. Cottam, I. N. Gabrielson, and T. L. Kimball. 1963. Wildlife management in the national parks. Rept. Advisory Board on Wildlife Management by Secretary of the Interior Udall (Mimeo) pp. 23.

Miller, Joaquin. 1887. Paper read before American Forestry Congress. Rept. Amer. For. Congress. pp. 25–26.

Muir, John. 1894. The mountains of California. Doubleday and Co., Inc., Garden City, New York.

Reynolds, Richard. 1959. Effects upon the forest of natural fires and aboriginal burning in the Sierra Nevada. Master's thesis. Dept. of Geography, Univ. of Calif., Berkeley.

Sauer, Carl O. 1950. Grassland climax, fire, and man. Jour. Range Management 3: 16–21.

Schultz, A. M. 1967. The ecosystem as a conceptual tool in the management of natural resources. *In:* Natural resources, quality and quantity, by S. V. Wantrup and J. J. Parsons. U. of C. Press, Berkeley and Los Angeles. pp. 139–161.

Show, S. B., and E. I. Kotok. 1924. The role of fire in the California pine forests. USDA Bull. 1294, pp. 1–80. Washington, D. C.

Show, S. B., and E. I. Kotok. 1925. Fire and the forest, USDA Cir. 358. Washington, D. C.

Stewart, Omer C. 1956. Fire as the first great force employed by man. *In:* Man's role in changing the face of the earth. U. Chicago Press. pp. 115–133.

Sweeney, J. R., and H. H. Biswell. 1961. Quantitative studies of the removal of litter and duff by fire under controlled conditions. Ecology 42(3):572–575.

Teale, Edwin W. 1954. The wilderness world of John Muir. Houghton Mifflin Co., Boston.

U. S. Forest Service. 1955. California aflame. San Francisco, California.

Wagener, Willis W. 1961. Past fire incidence in the Sierra Nevada forests. J. Forestry 59:734:747.

Weaver, Harold. 1955. Fire as an enemy, friend and tool in forest management. J. Forestry 53:499–504.

Weaver, Harold. 1957. Effects of prescribed burning in ponderosa pine. J. Forestry 55:133–138.

Weaver, Harold. 1964. Fire and management problems in ponderosa pine. Third Tall Timbers Fire Ecology Conference, Tallahassee, Florida. pp. 61–79.