UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1294

Washington, D. C. ▼ December, 1924

THE RÔLE OF FIRE IN THE CALIFORNIA PINE FORESTS

By

S. B. SHOW, Silviculturist, and
E. I. KOTOK, National Forest Inspector, Forest Service

CONTENTS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1924

CONTENTS

F-159910

THE RETURN OF THE FOREST—WHEN FIRE IS KEPT OUT

This area was logged 20 years ago and has since been protected from fire. As a result of this protection the new stand of second growth that is coming up will far surpass the virgin stand in board feet per acre. Such growth a single slash fire, a "light burn," or a so-called "harmless" surface fire renders impossible; but with adequate protection for the future, costing only a fraction of the value already at stake here, the new forest will be assured

UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1294

Washington, D. C. ▼ December, 1924

THE RÔLE OF FIRE IN THE CALIFORNIA PINE FORESTS[1]

By S. B. Show, *Silviculturist, and* E. I. Kotok, *National Forest Inspector, Forest Service*

INTRODUCTION

In forest regions where fire commonly results in complete destruction of the standing timber the rôle played by fire is definitely recognized and serious efforts are made to control this menace.

In the California pine region, however, and in other localities where fires run through the forest comparatively lightly and only occasionally assume the dimensions of a crown fire, injury is less obvious and the consequences of fire both in mature and in growing timber often go unrecognized.

Physical conditions in the pine forests of California have led to the frequent recurrence of fires for centuries, but the fact that magnificent forests still cover large areas and give the appearance of well-stocked, vigorous stands has blinded the public to the harm that fires have done and are steadily working throughout the whole region.

Were it possible for the observer to visualize the entire area upon which pine has grown, and to behold it truly fully stocked, he would then see by comparison that the present California pine forests represent broken, patchy, understocked stands, worn down by the attrition of repeated light fires.

The true rôle fire has played in this region can be appreciated to-day only by careful scrutiny of the less obvious forms of damage. True, the thousands of acres of waste land or unproductive brush fields, the small stands of mature timber so isolated by brush as to be inaccessible for logging, the areas on which the forest type is changing to less valuable species, the failure of cut-over lands to reproduce—all these are apparent enough, and tell an eloquent tale

[1] The pine region of California includes the timbered parts of the Sierras, the timbered parts of the northern Coast Ranges that are away from the influence of the Pacific Ocean, and the timbered parts of the mountains of southern California. It includes the yellow-pine type, of which western yellow pine (*Pinus ponderosa*) is the principal tree, and the yellow pine-sugar pine type, in which western yellow pine grows in mixture with sugar pine (*P. lambertiana*) and in which Douglas fir (*Pseudotsuga taxifolia*), incense cedar (*Libocedrus decurrens*), and white fir (*Abies concolor*) occur as associate trees in varying proportions. This type is often called the mixed conifer type. The pine region also includes the sugar pine-fir type where the two firs (*A. concolor* and *A. magnifica*) grow in mixture with the sugar pine. In some places the Jeffrey pine (*Pinus jeffreyi*) takes the place of the yellow pine in the stands or may grow with it in mixture with other species. Other types include the yellow pine-white fir type and the lodgepole pine type, where the lodgepole (*P. contorta*) grows in almost pure stands. A number of minor types are also recognized.

of the ultimate work of fire; but the connecting links between these conditions and the "harmless" forest fire are usually not known or are overlooked, so gradual is the cumulative effect.

Fire scars and heat killing begin the destructive work and lead directly to burning down of trees or susceptibility to wind throw, to insect infestation, to decay from fungous diseases. Each fire accelerates the progress and effects of the next; each successive fire adds its often imperceptible weight to the force of attrition that thins the stand, weeds out the finest individual trees, and gradually reduces the forest in quality and quantity to the point where the returns will not justify the cost of logging. Where logging has been in progress, the broadcast slash fire sweeps over with perhaps little apparent permanent damage; but in its path reproduction, the basis of the new forest, is gone and will return only after many decades. The few seed trees left are weakened and are prey to the first strong wind. Brush sprouts from the unburned roots and gains the mastery. The next fire will blaze as fiercely as the slash burn. If any tree seedlings are still striving to regain the land for timber, they will be wiped out completely. At the borders of the brush field, the skirmish line of timber and brush, the fire will attack the vanguard of the forest with all the strength of a crown fire, and the forest will give way again before it.

These are the links in the chain. Once they are seen and understood, fire in the California pine region can no longer be regarded as the friend of man or a negligible foe. Its rôle of destroyer is as unmistakable here as elsewhere.

The habit of thinking of the forest as an inexhaustible source of material, to be mined rather than grown as a crop, has been an obstacle to a general appreciation of the destructiveness of fire.

Another obstacle has been the difficulty of obtaining the facts regarding damage, and the consequent ease with which the case could be overstated or understated. Although the importance of fire damage was recognized by the earliest administrative and investigative officers of the Forest Service working in California, and although estimates of fire damage have been made a part of each report ever since systematic fire protection was begun in that State, the figures compiled have proved to be in general very much below the actual damage (*23*).[2]

How seriously misleading these figures may be is shown by a cruise of five large fires made after a considerable lapse of time. This critical survey disclosed a direct loss of 2,000 board feet to the acre, in contrast with the orginal estimates, made directly after the fire, of only 525 board feet to the acre. Thus with few definite facts to work with, much misstatement of the situation, and in some cases unreliable data, it has in the past been difficult to bring out any reliable and convincing estimate of fire damage.

The object of this bulletin is to present the available facts of fire damage. This is attempted by means of a careful examination of the various forms of damage, both direct and secondary; by an estimate of the seriousness of each form of injury, of the immediate loss and also of the indirect cost; and by a survey of the effect of such

[2] Numbers in italics in parentheses refer to "Literature citied" on p. 80.

losses on the future timber supply and on the problem of forest management. An intensive study of "light-burning" experiments and some discussion of possible beneficial uses of fire apart from light burning is included. On the basis of these observations the effort is made to present a workable theory of fire protection in relation to forest policy.

The need for study of the actual physical action of fire was early recognized, and by 1911 studies of the fundamental facts of fire damage were begun. Some of these investigations have been continued up to the present, and include the effect of surface fires in reducing hazard, the relation of crown injury to rate of growth, the effect of repeated fires on the enlargement of fire scars, the influence of fire on the forest type, and the relation of fires to insect epidemics. Supplementary to these studies, careful cruises on many large fires have been made in the attempt to supply more general figures of the average rate of loss by the acre on such fires. As these figures were gathered a sufficient length of time after the fire to permit determining the actual extent of damage, they have been used in this bulletin in preference to those in the original fire reports. The writers have also had the advantage of observational data collected by themselves and other forest officers in this region during the past 12 years, and have used freely the material of many others who have made special investigations of fire in relation to forest insects, tree diseases, and related problems.[3]

The result is not claimed to be the final word on this important subject. Detailed study by many men for more than a decade, however, now permits the drawing of a reasonably complete, accurate, and well-balanced picture of the part fire plays.

FIRE HISTORY OF THE CALIFORNIA PINE REGION

DATA FROM FIRE SCARS

The history of the periodic fires in the virgin forests of California throughout the past centuries—fires which have largely determined the present condition of our forests—is derived in some measure from written historical evidence, but mainly from the careful study of fire scars on the trees themselves. Fires record themselves on living trees by killing or burning away part of the outer bark, the inner bark, and the wood of the bole. When such scars are formed, an immediate attempt is made by the tree to cover them over with new wood which grows from the living edges of the inner bark toward the center of the wound. With no further reopening, the wound will eventually heal completely over with wood and bark and become a concealed scar. The date of such an injury can years afterwards be accurately determined by counting the number of annual rings that have formed in the callous growing over the scar, plus any rings that may uninterruptedly cover the scar after complete healing has taken place. Furthermore, because the face of the wound is charred, a scar caused by fire can be distinguished with certainty from scars of injuries caused by lightning or mechanical agencies.

[3] In this connection the writers desire to make specific acknowledgment to Swift Berry, Ralph Hopping, Duncan Dunning, F. D. Douthitt, and D. K. Noyes.

Repeated fires in a scar, resulting as they generally do in enlarging the wound, often obliterate the successive callouses and render impossible a precise determination of the number of fires that have caused it. Nevertheless, if a sufficient number of scarred trees can be studied in detail, it is generally possible to reconstruct with essential completeness the fire history of a given area.

The most complete records bearing on fire scars for California were obtained by Boyce (*3*) in his study of dry rot in incense cedar. For each tree studied the dates of all injuries were determined with unusual care, since it was essential to know how long the decay had been working in a particular tree in order to determine the age of infection, the rate of growth, and the rate of spread of the fungus. This study was conducted on six areas extending from the Klamath National Forest near the Oregon line through the Sierras to the Sierra National Forest near the southern end of the great belt of the California pine region. It was to be anticipated that these investigations would disclose with reasonable completeness the fire history of the pine region within the period represented by the age of the trees studied.

RECURRENCE OF FIRE YEARS

In analyzing the data from fire scars each area was treated as a unit and the dates of all fire injuries were plotted on cross-section paper. From these charts it was at once evident that certain years in the record were characterized by a large number of scars and might safely be considered fire years. Even with the slight errors that are likely to occur in counting the rings—errors that no doubt account in part for a sprinkling of fire scars in the years between the principal peaks—there was no reason to doubt that in the past the forests have been subjected to periodically recurring fires.

The earliest date of past fires found on any of the trees studied was 1530, and for more than a century after that date comparatively few scars were observed, for the reason, no doubt, that of the trees growing in the sixteenth and seventeenth centuries only a few have survived to the present. There is the further fact, already explained, that repeated fires in a particular wound tend to obliterate the evidence of earlier fires, even if they do not destroy the tree. From about the year 1700 on the frequency of the scars is such that the fire history of most of the areas studied can be stated with a fair degree of precision.

During the past three centuries the years 1685, 1690, 1699, 1702, 1708, 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 cleary as years of extensive fires. Naturally enough the latter part of the record is marked by a greater number of scars than the earlier part, owing to the gradual elimination of the older and more heavily scarred trees.

During the two centuries for which the data can be regarded as fairly complete 25 clearly marked fire years are found and it is a fact of high significance that this general average periodicity of eight years holds true for all areas studied. The shortest period between fire years is 3 years and the longest 11 years.

Huntington's investigations (*13*) of big trees (*Sequoia washingtoniana*) enable us to carry the fire history even further into the past than the study of the relatively short-lived pines, firs, and cedars. Although the fire history depicted by the big trees is fragmentary indeed, it is shown that back as far as 245 A.D. fires occurred in the pine region in restricted localities in which the big tree is found.

Whether these early fires were light or heavy there is no way of determining, the records on surviving trees merely indicating that fires occurred. The fact that a forest of a sort was able to survive these frequently recurring fires would indicate that most of them were in all probability light surface fires.

CAUSES OF EARLIEST FIRES

The causes of the fires of the past are, in most cases, not known. Fire records for 10 years in the California pine region show an average of 350 lightning fires every year, and show also that even under systematic fire protection some have attained enormous size (*23*). For the 10-year period ended 1920 an area of 415,000 acres was burned over by fires from that cause. The zone in which lightning fires are known to occur embraces an area of nearly 11,000,000 acres, and coincides in general with the commercially important portions of the California pine region. It seems evident that lightning must have been an important cause of forest fires in the past as it is to-day. Examination of felled trees discloses lightning scars dating back as far as the occurrence of fire scars themselves. Natural agencies, therefore, have been a big factor in the occurrence of fires and in molding the condition of the present virgin forests.

The forests were long inhabited by the Indian, a user of fire, and he also has been a cause of forest fires. A persistent tradition, much discussed in the last quarter century, holds that it was the regular practice of the Indian to fire the forests as frequently as fire would run through them (*18*). On this hypothesis much has been said and written extolling this primitive race as the original foresters and guardians of our forest resources. Without reciting in detail the conflicting statements of fact and surmise on the Indian as an agency responsible for forest fires, it may be said that in some parts of the pine region he undoubtedly fired the forests or at least regarded forest fires with equanimity, while in other parts of the region the evidence is just as conclusive that he regarded forest fires with fear and did not deliberately set them. In any event, his motive had nothing to do with the forest as a growing timber crop. It was to his interest to prevent the growth of brush and reproduction which would hinder him in hunting, and this purpose was admirably served by the use of fire.

The advent of the white man, particularly the influx during the forty-nine gold rush, brought an additional risk. The written historical records of the period, though extraordinarily meager on this question, indicate that the early miner was the cause of many forest fires. He, like the Indian, had little interest in the forest as a growing crop. Along the Mother Lode, where the camps were located at the lower edge of the yellow-pine belt, the supply of virgin timber was completely removed for mining purposes, and mostly during the sixties.

As the early placer diggings were worked out and quartz and hydraulic mining became an important pursuit, prospecting extended in all directions. There is evidence that these early prospectors found themselves hampered by brush and young growth, and adopted the practice of setting fire to the woods in order to facilitate their search for gold-bearing outcrops. Whether or not the early miners did actually set fires, it is certain that they had little interest in controlling fires.

Certainly, the earliest reports of forest fires in California, those by Hough (*12*) and the California State Board of Forestry (*5*), make it clear that fires caused by white men were both common and extensive, and even in the eighties gave much concern to thoughtful observers. In the scanty forestry literature of the last quarter of the nineteenth century, comparatively little mention is made of the red men as being responsible for fires. Later history points to successive industrial developments such as grazing, railroading, and lumbering as causative agents in forest fires.

It is clear that fires have occurred periodically as far back as the record is traceable. The pine forests of California have thus been subjected to a cumulative process of attrition by fire, a process that is still at work in the forests and which is examined in detail in this study.

FIRES IN THE VIRGIN FOREST

INJURY FROM FIRE SCARS

The virgin forest is characterized by the prevalence of fire-scarred trees, including particularly the oldest and largest individuals which have been longest exposed to fires. How such scars are started is easily explained by examining any forest area. On slopes the fire scars are invariably on the uphill side of the trees, where masses of litter, twigs, limbs, and similar material naturally accumulate, showing that fire scars originate usually from the burning of a mass of material against the bole of the tree. Nor does the amount of material necessary to start a scar need to be very great.

FORMATION OF SCARS

Study has shown (*15*) that the first stage in the formation of a scar is frequently no more than the killing of the living inner bark without burning away the outer bark, which at first remains closely adhering to the sapwood. Such a hidden scar, as shown in Plate I, may give no surface indications of its existence for many years. In the healing process, however, callouses form beneath the bark around the edges of the killed area of inner bark and, gradually growing in from the sides, force the bark away from the dead sapwood. This bulging growth of the callouses causes the dried bark to crack and split, and to drop away in pieces until finally the sapwood is exposed. Subsequent fires have direct access to the wood and are enabled to burn into the base of the tree, forming cavities in the butt.

On an experimental light-burning plot[4] on Snake Lake 321 trees were tagged and described in detail before the area was burned

[4] "Light burning," as advocated by certain timberland owners, is a method of intentional, supposedly controlled burning of forest litter at comparatively safe seasons, with the object of reducing fire danger by decreasing the quantity of fuel on the forest floor.

in 1919, in order to follow the formation of new scars and the extension of old ones. In 1923, as a result of two successive burns 8 of the 72 originally unscarred trees (or 11 per cent of the total trees in this class) had developed new fire scars. A study of the detailed notes of each tree shows that in most cases the new scars were formed where a down log or a heavy accumulation of débris against a tree had burned. While these figures are not to be regarded as conclusive in showing the average rate of formation of new scars, they are significant in proving that even the very lightest fire, such as this was, may result in the formation of new scars because of intense heat developed locally in the course of the burning.

Of the trees on this area originally scarred and reached subsequently by fire, 5 per cent were burned down, 8 per cent were killed by other causes, 5 per cent formed new scars without enlarging the old ones, 71 per cent showed extensions of the original scars, and only 11 per cent showed no extension of the old scars. On only 13 per cent of the scarred trees which survived the fires were the scars not enlarged.

This light-burning study showed the average dimensions of the original scars on 95 of the trees to have been: Width, 2.01 feet; height 4.5 feet; area 4.52 square feet.

As might be supposed, the extension of the scars after the two fires was mainly upward. This is shown by the new measurements, which were: Width, 2.56 feet; height, 5.25 feet; area, 6.72 square feet.

The average increase in scar area thus amounted to 48 per cent, as shown in the following extension figures: Width, 0.55 foot; height, 0.75 foot; area, 2.2 square feet.

The magnitude of the extension of a scar depends in the main on the size of the original scar, for the larger the surface area burned the longer continued and more intense will be the heat released in the new burn. The tendency toward acceleration in this form of fire damage points to a law that will be found true in most forms of fire damage. That is, a process of loss from fire once started gathers momentum with each succeeding fire and finally results in total loss of the individual tree or of the stand.

SUSCEPTIBILITY OF VARIOUS SPECIES TO FIRE SCARRING

The following percentage figures, based on open fire scars and reported by Lachmund (*15*), give an indication of the relative susceptibility of the important species to fire scarring: Incense cedar 61.5 per cent, western yellow pine 42.7 per cent, sugar pine not given, white fir 25 per cent, and Douglas fir 17.2 per cent.

On the Snake Lake plot the figures are: Incense cedar 72.2 per cent, western yellow pine 51.2 per cent, sugar pine 54.5 per cent, Douglas fir 40.5 per cent, and white fir 15.1 per cent.

The two sets of data agree in a general way in showing incense cedar to be the most susceptible species, the two firs the least susceptible, and the pines intermediate. On the Snake Lake area the low rate of scarring on the firs is due largely to the fact that these species generally grow on the northerly slopes where fires have been less frequent than on the drier aspects where the pines and cedars are more abundant. The inflammability of incense cedar bark is largely responsible for the susceptibility of this species, the bark of the firs and pines burning very much less readily.

Similar evidence has been obtained from 12 acres of mature timber, comprising 445 trees of 12 inches diameter breast high, in what is known as the Moffitt Creek area. Fires are known to have occurred here in 1822 and 1850, with present day results as follows:

Of 353 yellow pines 76 are scarred, or 21.5 per cent.
Of 10 sugar pines 4 are scarred, or 40 per cent.
Of 65 Douglas firs 4 are scarred, or 6.2 per cent.
Of 17 incense cedars 4 are scarred, or 23.5 per cent.

Of the 445 trees, 88 in all were scarred, or 19.8 per cent, and the distribution of this injury indicates again that Douglas fir is less susceptible than yellow pine to fire scarring.

BURNING DOWN OF SCARRED TREES

In studying the action of present day fires a careful observer can not fail to note that one inevitable result is the burning down of previously scarred trees. Nearly everywhere in the virgin forest these scarred trees, usually the oldest and largest individuals in the stand, are evidence that fires have taken their toll, and that the forests of the present have been markedly influenced by the action of centuries of repeated fires.

The final step in burning down is a purely mechanical process. The repeated fires, gradually eating into the base of the tree, destroy so much wood that the tree is unable to withstand mechanical strain placed upon it. This in part explains why the very large trees, which contain a high percentage of upper grades of lumber, are so susceptible to this form of loss, though they are ordinarily fairly immune to other forms of heat injury. Table 1 shows that this kind of loss has occurred in every one of the large timber fires in this region of which an accurate appraisal of damage has been made. (Pl. II, figs. 1 and 2.)

The prevalence of burning down is perhaps the most striking feature of this table, but a point of almost equal interest is the relatively constant amount of loss that has occurred on burned areas where the fires were of widely varying intensity. For example, in comparing a fire with an extremely high intensity of heat, such as the Howard fire, to one of only a moderate intensity, as the White Horse fire, it is found that loss from burning down is less variable than might be expected. Likewise, on the Snake Lake fire, which is an experimental, early spring light burn of as low intensity as possible, the loss per acre from burning down is of about the same magnitude as on the Ham Station fire, which was a hot and destructive fall fire.

Without intimate knowledge of the forests of the California pine region and of the nature of forest fires, the reason for the striking uniformity of the damage from burning down and the prevalence of this form of loss might be difficult to isolate. On trees of several of the important species in this region, such as western yellow pine, sugar pine, and Douglas fir, once an open scar is started a heavy flow of pitch is put forth which covers the surface of the wound. With this highly inflammable coating, it is only necessary for a fire to reach the base of the tree to cause an enlargement of the scar, since the pitch on the surface and the pitch-impregnated wood of the wound burn fiercely for minutes and often hours after the main fire traveling on the forest floor has passed.

F-46119-A

FIG. 1.—A HIDDEN FIRE SCAR

F-46119-A

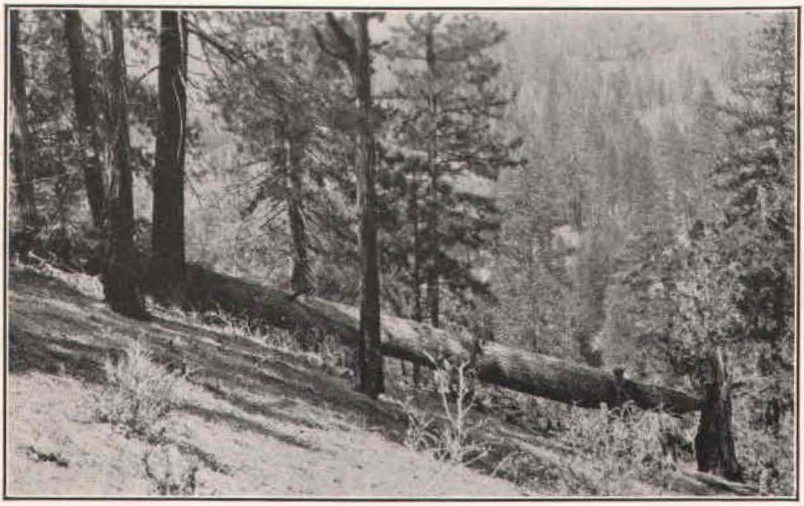
FIG. 2.—THE DEAD AREA OF THE SCAR

A 48-inch western yellow pine scorched by fire 21 years previously has kept its bark on over the dead wood. Such hidden wounds, no less harmful to the tree than the open scar, are often overlooked entirely in hasty estimates of fire injury. Decay has already set in, with a heavy loss of valuable lumber, as shown at the base of the tree

F-46115-A

FIG. 1.—A RESULT OF REPEATED FIRES IS THE ENLARGEMENT OF FIRE SCARS

The final stage is the falling of the tree, unable longer to support its own weight



F-166246

FIG. 2.—BURNING DOWN AS A RESULT OF REPEATED LIGHT FIRES REDUCES THE QUALITY AS WELL AS THE VOLUME OF THE FOREST, FOR THE BIGGEST AND FINEST TREES USUALLY SUCCUMB TO THIS FORM OF FIRE INJURY

Every tree in the foreground of this picture has a fire scar

TABLE 1.—*Burning down of scarred trees*

Name of fire	Area	Extent of damage, by species					Total damage per acre	
		Western yellow pine	Sugar pine	Douglas fir	White fir	Incense cedar	Volume	Value
	Acres						*Bd. ft.*	
Ham Station	9,485	1 tree 42", 7-log, per 11 acres; 336 bd. ft. per acre.	1 tree 40", 7-log, per 40 acres; 70 bd. ft. per acre.	Trace	Trace	1 tree 36", 5-log, per 15 acres; 70 bd. ft. per acre.	476	$1.12
Bear River	500	1 tree 44", 7-log, per 17 acres; 240 bd. ft. per acre.	None	None	None	Trace	240	.60
Slate Mountain.	350	1 tree 36", 7-log, per 32 acres; 90 bd. ft. per acre.	Trace	1 tree 40", 8-log, per 25 acres; 113 bd. ft. per acre.	None	Trace	203	.34
Butler Meadow.	1,120	1 tree 44", 7-log, per 30 acres; 137 bd. ft. per acre.	1 tree 46", 7-log, per 38 acres; 106 bd. ft. per acre.	Trace	1 tree 40", 8-log, per 24 acres; 160 bd. ft. per acre.	1 tree 36", 5-log, per 11 acres; 95 bd. ft. per acre.	498	.84
Pilot Creek	380	1 tree 52", 9-log, per 7 acres; 1,043 bd. ft. per acre.	Trace	1 tree 47", 9-log, per 1.7 acres; 2,645 bd. ft. per acre.	1 tree 51", 8-log, per 21 acres; 265 bd. ft. per acre.	1 tree 43", 6-log, per 8.4 acres; 208 bd. ft. per acre.	4,161	5.49
Howard	700	1 tree 36", 6-log, per 5 acres; 460 bd. ft. per acre.	1 tree 42", 7-log, per 20 acres; 160 bd. ft. per acre.	None	1 tree 34", 6-log, per 20 acres; 90 bd. ft. per acre.	1 tree 38", 5-log, per 2.5 acres; 800 bd. ft. per acre.	1,510	2.20
White Horse	20,500	508 bd. ft. per acre	16 bd. ft. per acre		10 bd. ft. per acre	86 bd. ft. per acre	620	1.60
Soda Creek	1,200	247 bd. ft. per acre	83 bd. ft. per acre	361 bd. ft. per acre		24 bd. ft. per acre	715	1.60
Moffitt Creek	10,000	1,250 bd. ft. per acre	None	715 bd. ft. per acre	None		1,965	3.84
Total	44,235						[1] 930	

[1] Weighted average.

The latter part of Table 1 shows the manner in which this relatively even loss occurs. On the Ham Station fire, for example, the trees burned down averaged one 42-inch 7-log yellow pine on every 11 acres burned over; one 40-inch 7-log sugar pine to every 40 acres burned over; one 36-inch 5-log incense cedar to every 15 acres burned over; and an occasional Douglas fir and white fir tree. The loss on the other fires studied in detail was of the same general nature; that is, only an occasional large tree succumbed to the flames, and on only one of these fires did this loss exceed one tree to the acre.

Of certain conspicuous exceptions involving unusually heavy losses, the most outstanding in this table, both as regards actual board-foot loss and destruction of trees per acre, are the Moffitt Creek and the Pilot Creek fires. These exceptional losses are traceable to the previous fires in the stand. Examination on the ground made it quite certain that fires have been more frequent on these two areas than on the other areas of virgin forest studied, or for that matter, more frequent than the average for the pine region of California. The Moffitt Creek area represents the maximum damage so far encountered in number of trees down. The loss recorded amounts to more than one tree to the acre, or very nearly 10 per cent of the total merchantable stand.

Once fire reaches the base of the trees the main factor which determines the amount of loss from burning down is the prevalence of scars from previous fires. In the California pine forests, the amount of inflammable material, general intensity of the fire, season of burning, rate of spread, and similar factors are only secondarily important in the final outcome.

This loss for any particular area, therefore, must be anticipated, whether the fire is light or heavy, and whether it burns in the spring, summer, or fall. Although the elimination of an occasional tree is ordinarily inconspicuous and a loss easily overlooked, nevertheless it averages 930 board feet per acre, a factor to be reckoned with.

Furthermore, the process of attrition, which results in the burning down of an occasional tree, speeds up when fires on a particular area are frequent, for the scarred trees then have little opportunity to cover over the wounds with a new layer of wood, and each new fire capitalizes in full the effects of previous fires.

In any case, the resultant loss is peculiarly unfortunate because of the very large and high-grade trees that succumb. Stumpage appraisals on the Ham Station fire, for example, show that while the average percentage of upper grades in the entire stand of yellow pine and sugar pine is 40 per cent, for the trees of these species burned down it is more than 60 per cent. Thus, aside from the loss of actual material, burning down results in a lowering of the quality of the stand.

DIRECT LOSS OF WOOD AND REDUCTION IN GRADE

So far fire scars in standing, merchantable trees have been considered only to the extent that they may ultimately result in the loss of the tree through burning down. In many cases, however, a single fire does not result in the loss of a tree but does burn out a certain amount of wood in the butt log, and, in the case of the two pines and Douglas fir, causes the wood surrounding the fire scar to become very pitchy. Although this direct loss of wood is not a high percentage of the total tree volume, it includes that part from which the clear grades of lumber, the highest quality of material in the tree, are obtained.

A study made in 1911, covering 155 sample trees in the yellow pine region of eastern Oregon, an extension of the California pine region, disclosed the fact that 42 per cent of the merchantable trees were fire scarred. On 1,184 representative trees in Grant County, Oreg., 23 per cent of the butt logs were fire scarred, not counting stumps from which the trees had been cut high enough to avoid the scars (*19*). Of these logs 18.6 per cent were so badly scarred that an average of 46 board feet, or 14 per cent of the full scale, had to be deducted from the total log scale. A typical scar of this sort is shown in Plate III.

A study of cause of cull for a typical mill in the Sierra region showed that more than 50 per cent of the total cull was due directly to fire and that this loss amounted to 9 per cent of the total scale of defective logs. Table 2, covering this study, shows, beside the direct loss of wood from fire, the total loss due not directly to fire but to decay, entrance of which is generally through fire scars.[5]

No detailed figures are available showing the reduction in lumber grade on account of the increased amount of pitch surrounding fire scars. That there is such a reduction is a well accepted fact. This reduction is of particular importance because it affects those species which furnish the most valuable pine lumber.

TABLE 2.—*Comparison of cull due to fire and other causes in western yellow pine logs*[1]

Kind of defect	Average diameter of log	Gross scale	Net scale	Reduction	
				In class	Total
	Inches	*Board feet*	*Board feet*	*Per cent*	*Per cent*
Fire scar	24	11,490	9,732	15.3	4.72
Cat face	20	660	400	39.4	0.70
Burned butt	25	460	428	7.0	0.09
Fire scar and pitch	23	1,880	1,204	36.0	1.82
Fire scar and center rot	28	580	517	10.9	0.17
Fire scar and stump rot	29	3,040	2,485	18.3	1.49
Total due to fire		18,110	14,766	18.5	8.98
Cull not due to fire		19,110	16,043	16.0	8.24
Total, all causes		37,220	30,809	17.2	17.22

[1] Basis, 106 defective logs, on Plumas National Forest; Delleker Mill scale.

DIRECT HEAT KILLING

An always obvious form of damage to merchantable timber is direct heat killing. This occurs when fire has swept through the crowns of the trees, burning up the foliage completely, or when fire on the forest floor has developed such heat that the foliage and buds are killed without being consumed. Occasionally the inner, living bark on the trunks or on the roots near the surface of the ground is killed by long-continued intense heat from burning logs or deep layers of litter and duff.

[5] The influence of fire on decay is treated more in detail later. It is sufficient here to note that decay is one of the invariable secondary causes of loss of timber directly chargeable to fire.

This form of damage is always strikingly apparent immediately after a fire, for the fire-blackened trees or those with brown foliage stand out in strong contrast to the living forest.

CONTROLLING FACTORS

In the virgin forests of California, the severity and extent of heat killing varies greatly, depending on a wide range of factors. In the field study of direct damage to merchantable timber, 15 large fires with an aggregate area of 52,100 acres were carefully cruised long enough after the fire so that the amount of fuel and the extent of damage could be accurately related. The facts are given briefly in Table 3.

TABLE 3.—*Direct damage to merchantable timber by heat killing*

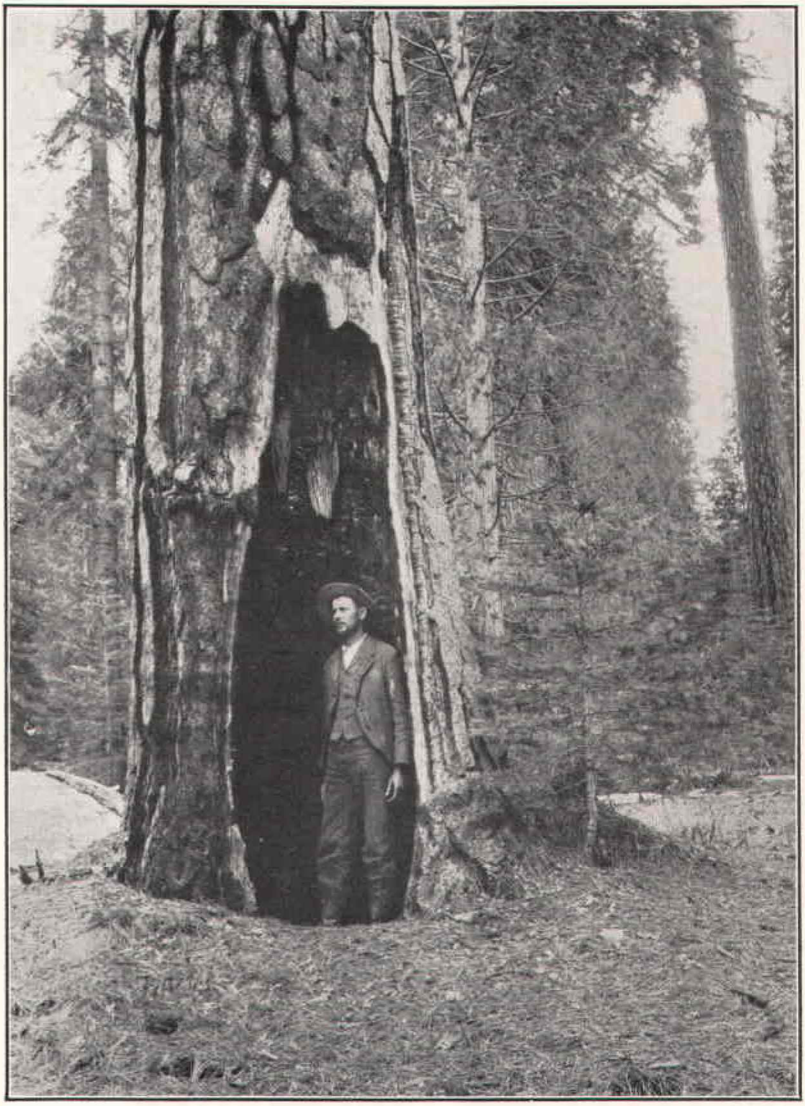
Name of fire and type of cover	Area	Area heavily damaged		Quantity killed per acre on total area	Value of loss per acre [1]
	Acres	*Acres*	*Per cent*	*Board feet*	
Ham Station—Bear clover, and brush	9,485	310	3.3	550	$0.54
Bear River—Bear clover	500	7	1.4	38	.08
Slate Mountain—Bear clover	350			50	.10
Butler Meadows—Some brush	1,120	18	1.6	230	.66
Pilot Creek—Some brush	380	10	2.6	250	.25
White Horse—Some brush	20,500	2,300	11.2	1,590	3.90
Howard—Heavy brush	700	700	100.0	10,900	16.40
Hoey—Heavy brush	410	410	100.0	2,820	8.50
Soda Creek—Heavy brush	1,200	480	40.0	2,340	5.50
Ferris Creek—Heavy brush	4,635	2,220	47.9	3,360	6.90
Weed—Little brush	2,000	30	1.5	220	.66
Quincy Junction—Medium brush	200	30	15.0	2,100	4.50
Moffitt Creek—Medium brush	10,000	1,210	12.1	1,425	2.90
Lassen-Walker—Heavy brush	220	220	100.0	3,350	5.50
Boardman Ridge—Medium brush	400	40	10.0	1,390	2.03
Average (weighted)			15.3	1,570	3.32
Total	52,100	7,985			

[1] Based on the average minimum stumpage prices of the Forest Service for this district, which for the five species concerned are: Sugar pine, $2.75; western yellow pine, $1.75; Douglas fir, $0.75; white fir and incense cedar, $0.50.

By far the most important factor in heat killing is the amount of inflammable material on the forest floor, such as litter and duff, and the understory of grass, weeds, undergrowth, and reproduction. If the individual fires are examined in detail, it is seen that the most serious damage has resulted where a large amount of brush was present under the timber stand. The least damage was found where the inflammable material consisted of needles, twigs, and bear clover.[6]

Topography is a factor of great importance. Fires starting near the bottom of a slope gather momentum as they travel uphill, and the timber on the upper slopes and ridges must bear the brunt of the increased intensity of the flames. Gulches and saddles often tend to act as funnels for the wind, developing intense heat and causing great damage to standing timber. On large plateaus where there is no topographic interference to the uninterrupted sweep of the wind, fires are often fanned to intense heat over a wide front, resulting in heavy damage to timber.

[6] Bear Clover (*Chamaebatia foliolosa*) is a low-spreading shrub which burns very rapidly, but has only a little fuel substance, and therefore burns and retains heat for only a short time.



F-54661

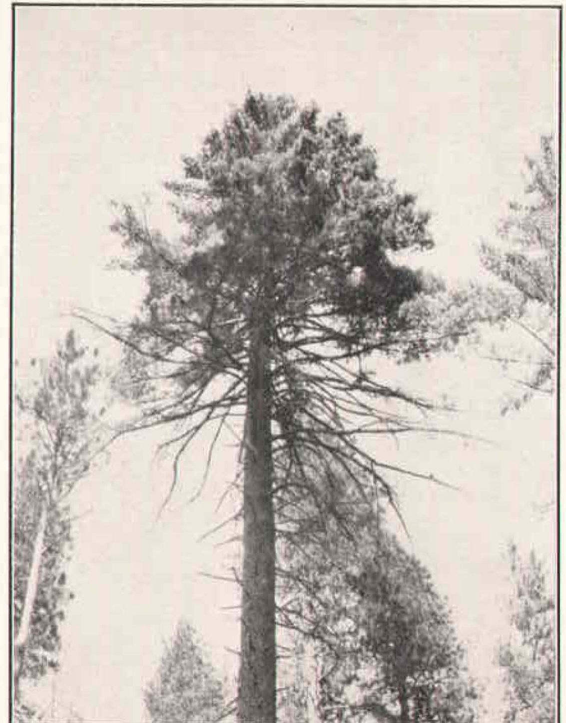
A RESULT OF REPEATED FIRES THROUGH PAST CENTURIES

The highest grades of lumber are obtained from the first, or butt log. This is the point of attack of every fire scar, which, as it is enlarged, not only burns its way into the heartwood but permits the entrance of fungi, a very destructive agent. Fire protection can not save this big fellow, but its results are clearly seen in the amount of reproduction already established near by

F-156400

FIG. 1.—HEAT-KILLING OF LARGE TREES FROM LIGHT FIRES

The damage in this burn in northern California amounted to a loss of 220 board feet an acre from heat-killing alone



F-24604-A

FIG. 2.—THE CROWN OF A SUGAR PINE, SHOWING THE LOWER BRANCHES KILLED BY HEAT FROM A GROUND FIRE

Such crown injuries mean a corresponding reduction in the rate of growth of the trees affected

Climatic factors also exert an important influence in determining the damage that fires will do in a particular stand of timber. Excessive dryness and high winds favor rapid spreading and intensity of fires. Normally, summer fires occur under drier conditions than those of spring and late fall.

The stage of growth of the forest at different seasons is also a factor in damage. In spring or early summer when the tree is growing actively, a tree is more likely to be killed by a given volume of heat than during late summer or fall when the tree is less active and the heavily protected winter buds have been formed.

The density of the stand itself is a factor which must not be overlooked. Open stands not only offer less interference to the sweep of wind than do dense stands, but usually have an understory of highly inflammable grass, brush, or reproduction which utilizes the space and moisture. A dense, closed stand of timber, on the other hand, will more readily develop a true crown fire. Such fires are the rule in dense, even-aged, second-growth stands where there is an uninterrupted tree canopy.

PREVALENCE OF HEAT KILLING

One of the most striking features brought out in Table 3 is that in every fire but one a certain percentage of the burned area shows heavy loss from heat killing, heavy loss here being defined as the outright death of 50 per cent or more of the merchantable timber on any area. Heavy damage was found on as little as 1.4 per cent and as much as 100 per cent of the total burned area of the different fires studied, with a general (weighted) average for all of 15.3 per cent. Table 3 thus shows that no large fires occur without a certain amount of heat killing. What will happen in any particular stand is a question of degree rather than of kind.

The average (weighted) loss of merchantable material for the areas studied is 1,570 board feet to the acre. This loss, it should be noted, represents the complete or nearly complete wiping out of small patches of the stand rather than a uniformly distributed loss over the entire area.

SUSCEPTIBILITY OF VARIOUS SPECIES

Though heat killing has been considered for the forest as a whole, without distinction between different species, it is only where true crown fires sweep through a mixed stand that complete destruction results.

In studying the effects of ground fires it is important to note to what extent the species differ in their resistance to injury. Percentages from two sample plots in heavily burned areas are given in Table 4 for the mixed conifer type. It will be observed that the loss of both western yellow and sugar pines is strikingly less, in volume and in number of trees, than is the loss of either white fir or incense cedar. In both these mixed stands the trees of different species grew in close contact with each other, so that these figures give a very fair picture of the relative susceptibility of the different species to hot surface fires.

TABLE 4.—*Relative susceptibility of species to direct heat killing*

Species	Ham Station fire		Howard fire	
	Volume killed	Trees killed	Volume killed	Trees killed
	Per cent	*Per cent*	*Per cent*	*Per cent*
Western yellow pine	54.0	72.0	45.0	62.0
Sugar pine	56.3	70.0	60.0	64.0
White fir	75.8	92.0	72.0	78.0
Incense cedar	97.0	85.0	81.0	78.0

The reason for the greater resistance of the pines to heat, as compared with the fir and cedar, is not difficult to find. White fir, though it averages a greater height than the pines, has very inflammable foliage, and its needles are unable to endure as high a degree of heat as the needles of the pine. The needles on the pines cluster around and enfold the terminal buds and protect them from the heat. These buds, too, have thick scales. But the buds of the fir have thin scales and are only slightly protected by the needles. The crowns of white fir and cedar, the two most tolerant species[7] in the mixed conifer forest, are both longer and denser than those of the relatively intolerant pines, for the lower branches, being able to withstand the shade of those above, continue to live, whereas the lower branches of the pines are shaded off. Therefore, the possibility of a hot surface fire setting the crowns afire and then being able to spread from branch to branch and finally to strip the foliage is much greater in fir and cedar than in the pines. A further condition influencing the relatively high susceptibility of the cedar is its smaller stature. In the areas under consideration, the average merchantable height of mature cedars killed was only 65 feet, as compared with 104 feet for white fir and 94 feet for the pines.

The factor of susceptibility thus plays an important part in the succession of species in the pine region where there are repeated fires For example, on the east side of the Sierras in the yellow pine-white fir type, where enormous areas have been subjected in the past to repeated surface fires, the present merchantable stand is almost pure western yellow pine, but the reproduction that is appearing abundantly since the inauguration of systematic fire protection is predominatingly white fir. In an undisturbed state of nature in this type the inevitable tendency is for the tolerant species (white fir) ultimately to dominate the stand to the exclusion of the intolerant species (western yellow pine), because the tolerant fir will reproduce in the shade of the mature forest and thus get a start on the pine. The recurrence of fires is responsible for interrupting the normal succession so generally.

The most important conclusion concerning relative susceptibility to heat killing is that the more tolerant the species the higher its degree of susceptibility to a fire of given intensity.

RELATION TO SITE QUALITY

Not only is specific susceptibility an exceedingly important factor in determining changes of composition within a given mixed forest, but it also furnishes a clue to the relative amount of damage in

[7] "Tolerance" is the ability to endure shade. White fir is spoken of as a tolerant species because it can grow under heavier shade than, for instance, western yellow pine, an intolerant species.

different forest types. Only with an enormous mass of data would it be possible to prove statistically the relative rate of loss in different types, because of the great difficulty in finding comparable stands, fires of comparable intensity, and comparable sites. But, given fires satisfying these conditions, it would probably be found that the fir types show higher rates of loss than the pine types. An example of maximum damage from heat killing is shown in Plate IV, Figure 1.

In a many-aged forest the susceptibility of the individual trees to heat killing by the burning of the litter, undergrowth, and reproduction would appear to vary inversely as the quality of the site, which is to say, as the height of the trees, a good site having a greater proportion of trees whose crowns are safe from ground fires. With fires of equal intensity, other than crown fires, the percentage of the stand killed should be greater on poor sites and less on good sites.

It is impossible to give rigid statistical proof that liability to heat killing is in inverse ratio to the excellence of the site; nor is it possible to state the exact magnitude of the losses caused by fires of given intensity on poor sites and on good ones. With the exception of second-growth stands, our forests are so broken, so variable, and so patchy, and the technical difficulties of measuring intensity of fire are so great, that no exactly comparable data have been obtained.

The only method so far developed for measuring with reasonable precision the effect of a given fire on individual trees was evolved in the examination of certain of the large burns of 1917 on the Eldorado National Forest. Considering only one species, western yellow pine, and fire for one season of the year, namely, fall, it was found that the crown of a tree was killed for an average distance of 20 feet above the highess point of actual burning by the flames. If, for example, a yellow pine had a 40-foot crown and the fire had actually scorched the trunk up to the base of the crown, then 20 feet of the crown succumbed. (Pl. IV, fig. 2.) Naturally, the level to which the flames tended to reach depended on the amount of fuel on the ground. With only bear clover, a low-spreading shrub, for example, it was found that the flames reached only 10 to 15 feet, but with manzanita, a much taller undercover, they reached 40 to 60 feet. The observations indicate that more trees would be killed in low stands than in tall ones, other things being equal.

CROWN INJURIES AND RATE OF GROWTH

In addition to the direct or primary physical damage to merchantable timber which is evident from even a casual examination of burned areas, fire in the virgin forests of California may and often does start a less conspicuous train of events which is reflected in the condition of the stand for many years afterwards. These influences ordinarily show themselves either in a reduction of growth or in decay that injures the trees without actually killing them.

EFFECT OF CROWN INJURIES ON GROWTH

One of the important secondary injuries resulting from fires is the reduction of the rate of growth as a result of crown injuries. On the Klamath National Forest a study of the effect of surface fires on rate of growth was very instructive. In 1910 a fire ran through a mixed stand of western yellow pine, sugar pine, and Douglas fir, partially killing the crowns of nearly all trees but failing to kill any tree outright. In the fall of 1915, when the rate of growth for the previous decade was determined by measuring the annual rings, the stand failed to show noticeable external damage from fire. Many trees which had badly scorched crowns in 1910 had recovered, and only one tree had succumbed to fire injuries during the five years.

The growth at breastheight was measured separately for the five-year periods before and after the fire. It was found that 16 per cent of all the trees measured grew at the same rate for both periods, while 68 per cent grew more slowly and 16 per cent grew more rapidly after the fire. The growth of one tree fell off 69 per cent, while none of those increasing made a greater gain than 14 per cent. Averaging all trees, the growth in basal area after the fire was only 83.6 per cent of the growth before the fire, while the volume growth was correspondingly reduced by about 25 per cent. The stand on this particular plot was 43,230 board feet to the acre, and the volume growth for the five-year period before the fire was 1,945 board feet to the acre, or 390 board feet each year. The reduction of 25 per cent means a loss of nearly 500 board feet per acre for the five-year period. Checks on adjoining unburned areas showed no change in rate for the two half decades.

In 1919 a similar study was made on the Shasta National Forest of an area burned in 1914. Growth figures were obtained by taking increment borings on a number of trees of different species, selecting only those individuals whose growth had not been affected by the death of near-by trees. For each tree were recorded the species, diameter, total height, percentage of crown killed by fire, growth for five years before the fire, and growth for five years after the fire. Table 5 shows that a reduction of growth of 30.8 per cent occurred on the trees studied, which on the poor site represented amounted to 50 board feet to the acre each year.

TABLE 5.—*Effect of crown injury on current rate of growth*[1]

Amount of crown killed	Reduction of diameter growth	Basis	
		Number of trees	Average height
Per cent	*Per cent*		*Feet*
17	11.0	9	68
25	28.5	12	71
33	32.0	19	68
50	39.0	10	58
67	56.5	4	57
	[2] 30.8		

[1] Data obtained 5 years after burn, for all species; Shasta National Forest.
[2] Average (weighted).

The table further brings out clearly that the degree of reduction of diameter growth varies directly with the percentage of the crown killed by the fire. With only 54 trees as a basis, perhaps it can not be stated without qualification that this relation generally exists; but such a relation agrees with what is known of the function of the crown in the growth of the tree.

CONTROLLING FACTORS

As one might expect, the degree of crown injury appears greatest in the shortest trees and least in the tallest trees. That this relation exists on the particular area studied is evident from the height column of Table 5 though the relation is far from perfect. Similar figures, as shown in Table 6 were obtained from two plots laid out in a fire-damaged area of pure western yellow pine on the Modoc National Forest.

TABLE 6.—*Influence of height on crown injury*

[Western yellow pine; Modoc National Forest]

Plot 1				Plot 2			
Height	Diameter breast high	Crown injury	Trees measured	Height	Diameter breast high	Crown injury	Trees measured
Feet	*Inches*	*Per cent*	*Number*	*Feet*	*Inches*	*Per cent*	*Number*
85	18	47	2	80	16	44	1
86	14	49	2	85	18	62	1
90	16	55	6	95	20	37	3
97	22	26	3	107	22	10	5
102	20	48	2	112	28	20	4
106	24	26	1	115	24	19	5
115	26	24	5	118	34	17	3
122	28	31	2	122	26	7	5
123	34	41	1	127	30	23	4
125	40	11	1	130	32	0	1
130	38	37	1	135	38	0	1
140	32	27	2	140	36	17	1
----------	----------	----------	----------	150	40	20	2

Though the progression is not entirely regular, it is evident that the degree of crown injury varies inversely with the total height of the trees. This relative susceptibility to crown injury is of great importance not only in its influence on relative damage to different species in mixed stands, but because it confirms what has already been shown, that the poorer the quality of the site, and consequently the shorter the trees, the greater is the susceptibility of the forest to crown injury, and to retarded growth or even outright death directly from heat. If the scale of protection is based on the value of the resources, it will obviously be less intensive on poor sites than on good ones, in young stands than mature ones. The likelihood of heavy damage, and consequently the need for intensive protection, are greater on the poorer sites and in the younger forests.

EFFECT ON VARIOUS SPECIES

The relative resistance to heat killing of the crowns of several of the important California conifers has been noted. The experimental plot on the Shasta National Forest discussed in connection with Table 5 affords some very interesting side lights on this point, particularly in those cases in which the intensity of the fire is not sufficient to destroy the crowns completely. By determining the average percentage of crown killed for each species, the result, as shown in Table 7, is an excellent index of the relative susceptibility, since in none of the trees studied did the fire actually consume the crowns.

TABLE 7.—*Relative susceptibility of species to crown injury*

[Shasta National Forest]

Species	Average height	Amount of crown killed	Average growth reduction	Growth-reduction index [1]
	Feet	*Per cent*	*Per cent*	
Western yellow pine	64.9	30.6	21.7	1.00
Sugar pine	78.0	31.3	38.9	1.75
Douglas fir	64.5	38.7	43.3	1.58
Incense cedar	61.5	40.2	39.7	1.39
Average		35.2	35.9	1.43

[1] On basis of crown injury, and taking western yellow pine at unity.

Of the four important species represented on the plot, all but sugar pine had practically identical heights. Western yellow pine showed the lowest percentage of crown injury, Douglas fir the next lowest, and incense cedar the greatest. The sugar pine, with practically the same degree of crown injury as western yellow pine, but with a considerably greater total height, apparently is intermediate in resistance to injury between western yellow pine and Douglas fir. Table 7 further supports the conclusion that resistance to heat killing varies inversely with the tolerance of the species.

The last column of the table, showing the relative response of the four important species to a given degree of crown injury, indicates that western yellow pine suffers least and sugar pine most, while Douglas fir and incense cedar are intermediate. Of all the species studied western yellow pine is not only the most resistant to crown injury from heat but is the least responsive in reduction of growth to such injuries as are received.

INDIRECT PHYSICAL DAMAGE TO MATURE TIMBER

INSECT INJURY

Certain other secondary injuries from fire are not immediately evident or simple of proof and, indeed, can be exactly determined only after detailed study over a period of years. Chief among these are losses from insects and wood-destroying fungi.

Of the insects which cause the greatest losses to pines the genus *Dendroctonus* is the most important and most prevalent. Though a light infestation is practically always present in the pine forests, lumbermen and foresters are chiefly concerned with this and other forest insects only when an epidemic develops. Insect epidemics have been known for many years, but the reasons for the sudden outbreaks have been exceedingly obscure. Only recently has it been discovered that insect epidemics are frequently precipitated or intensified by forest fires.

One of the first large burns to be studied with this probability in mind was the Mormon Hill fire, in the Sierra National Forest, which occurred October 15, 1916, covering about 640 acres in the western yellow-pine type. The direct loss due to the fire was comparatively light, though many trees were injured. The history of the area was followed in detail by one observer for the seasons 1916 to 1919, inclusive. Besides the area covered by the fire, an adjoining area of similar type and topography was used as a control plot and examined during the same period. On both of these plots a hundred per cent cruise of all insect damage was made. Fortunately, in connection with other studies, the cruise for 1916 had been made before the occurrence of the fire and the records for that year, covering as they do a large area long undisturbed by fire, may be accepted as showing the stage of infestation of the area before the fire. Table 8 presents data of this study.

TABLE 8.—*Relation of fire and insect damage*

[Mormon Hill burn, Sierra National Forest, October 15, 1916]

Year of observation	Insect damage on burned area			Insect damage on unburned area [1]		
	Trees lost	Total loss	Loss per acre	Trees lost	Total loss	Loss per acre
		Board feet	*Board feet*		*Board feet*	*Board feet*
1916 [2]	47	32,745	51	17	22,695	11
1917	97	129,970	203	21	30,700	15
1918	116	120,690	189	37	47,083	24
1919	40	33,370	52	43	51,600	26
Total	300	316,775	495	118	152,028	76

[1] Unburned control area of 2,000 acres, adjoining Mormon Hill burn.
[2] Data for this year gathered before the burn, over a territory of 640 acres long undisturbed by fire.

On the control plot the infestation during the period of observation was relatively constant, both as to number of trees killed each year and the actual volume lost. There was a slight tendency to increase from the beginning to the end of the observation period; but the maximum loss in any one year did not exceed 26 board feet an acre, or one tree to 50 acres, which is well within the limits considered as normal infestation.

On the burned area the loss during the year before the fire was somewhat greater than for the control plot. As indicated by the control plot, the normal infestation was increasing slightly during the period of the study, but the increase on the burned area was far more rapid than the normal rate. In the year following the fire a sudden and sharp increase in loss from insects was reported. In 1918 the number of trees lost was still larger. In 1919, the third year after the fire, the infestation subsided to about the same level as before the fire.

Other evidence confirming these investigations has been obtained in the study of the Snake Lake experimental burn. The figures on insect damage on this area, shown in Table 9, were obtained by a hundred per cent cruise which covered 105 acres burned in 1919 and again in 1920; also from an unburned control plot adjoining the burned area. As has been explained, the Snake Lake plot is an area burned over lightly for experimental purposes. All the fires here have been very slow in spreading and light in character, the burning being done at the earliest possible date in the spring and the fires set to burn downhill under control.

TABLE 9.—*Losses due to insects following fire*

[Snake Lake experimental area]

BURNED AREA: FIRST FIRE (1919), 105 ACRES; SECOND FIRE (1920), 126 ACRES

Species	Loss in 1919		Loss in 1920		Loss in 1921		Loss in 1922	
	Trees	Volume	Trees	Volume	Trees	Volume	Trees	Volume
		Board feet		*Board feet*		*Board feet*		*Board feet*
Western yellow pine	5	4,240	11	6,680	17	10,200	2	2,660
Sugar pine	38	70,600	17	32,520	2	2,900	2	2,920
Douglas fir	3	3,440	2	1,930	1	750	2	5,600
White fir	2	3,800	6	8,450	3	2,420	3	920
Incense cedar	----	----	----	----	----	----	----	----
Total loss	48	82,080	36	49,580	23	16,270	9	12,100
Loss per acre	0.46	782	0.29	393	0.18	129	0.07	96

UNBURNED CONTROL AREA, 200 ACRES

Species	Trees (1919)	Volume (1919)	Trees (1920)	Volume (1920)	Trees (1921)	Volume (1921)	Trees (1922)	Volume (1922)
Western yellow pine	4	3,200	3	2,090	2	1,200	6	5,690
Sugar pine	4	3,600	1	80	2	1,600	----	----
Douglas fir	1	450	----	----	----	----	1	2,610
White fir	----	----	4	2,870	3	1,700	2	940
Incense cedar	----	----	----	----	----	----	----	----
Total loss	9	7,250	8	5,040	7	4,500	9	9,240
Loss per acre	0.04	36	0.04	25	0.04	22	0.04	46

Comparative losses on burned and unburned areas.—Considering first the control plot for the Snake Lake burn, it will be observed that the loss for each acre is comparatively small and has shown no conspicuous tendency to increase since the experiment was begun. On the burned area the contrast is striking. In the first year following the initial burn, 48 trees were killed by insects on 105 acres, which is at the rate of 293 trees to the section (640 acres), compared to the rate on the control plot for the same year of 29 trees to the section. In the second year, following the second burn, which covered 126 acres, the loss was at the rate of 183 trees to the section. In the third year the rate of loss was 117 trees to the section. Averaging the results of the three years, it is found that the rate for the control plot is 26 trees a section each year and the equivalent board-foot loss is 17,900; whereas, on the burned area, the corresponding values on a section basis are, in round numbers, 200 trees and 275,000 board feet. Definite proof that the insects entered the trees on the burned area after the fire, was found in the fact that the pitch tubes overlaid the scorched and blackened bark.

These results from two independent observations are strikingly similar, although the two areas are far apart and in different timber types, and the time and intensity of fires were dissimilar.

The Crane Valley fire in the Sierra National Forest is also of interest in studying relation of burning to insect infestation. The fire occurred in October, 1916, and spread rapidly uphill through an excellent stand of thrifty western yellow pine, killing many trees outright and scorching the bark and destroying part of the crown of nearly every individual in the stand. In the spring of 1917, six months after the fire, an insect-control crew employed by the owner of the land worked the area covered by the fire, as well as the surrounding unburned land. On the burn the infestation was found to be excessive. On one 40-acre tract, a total of 55 trees, both western yellow and sugar pines, were peeled by the crews. Over the entire burn the infestation was strikingly heavy; and on one acre 7 infested trees were found and peeled. That the insects had entered the trees after the fire, was definitely established by the presence of fresh pitch tubes overlying the burned bark. The adjacent unburned area had nothing like the same degree of infestation. A cruise of one 40 showed 3 infested trees, while another 40 had 5. This striking contrast between the burned and unburned forest is still further heightened by the data obtained in a later inspection made in July, 1917, about three months after the completion of the control work. At that time it was found that on the 40-acre tract where the 55 trees had been treated 10 additional trees were infested.

That these examples are not exceptional is shown by the results of fire-damage studies on many other large burns. An increase in infestation on all the areas studied has been found without exception, the only variation being in the relative intensity of the attack. It appears to be established beyond contradiction that serious loss from insects is a corollary of fire, whether that fire be light, as in the case of the Snake Lake and Mormon Hill burns, or heavy, as on the Crane Valley burn. The indications are that the extent of this damage is likely to be from 8 to 12 times as great as that existing before the fire, and that heavy loss from insects will continue for about two years after the fire. Without attempting to state an absolute average figure of loss for insect damage after fires, it may be pointed out that on the areas studied the stand suffered to the extent of about 1,000 board feet an acre. This form of loss, therefore, is serious.

Loss from insects following fires is one of the several factors which normally result in the gradual depletion of the forest stand. None of these factors, except occasionally heat killing, results in wiping out the forest at one stroke; but all combine to make any extensive fire in the virgin forest the starting point of a train of circumstances the full effects of which do not become apparent for years.

Why insect attacks follow fire.—Just how insect infestations take hold in a forest so rapidly immediately after a fire is difficult to explain. A study conducted at the Feather River Experiment Station throws some light on this question. In the fall of 1916 a fire burned a strip through a dense stand of western yellow pine poles, injuring many of the trees, chiefly by partially killing the crowns. A year after the fire a detailed study was made of many of these trees to determine, if possible, what influence the fire had had on insect infestation. Of the trees uninjured by fire, 1.5 per cent had been heavily attacked by *Dendroctonus brevicomis*, but an abundant flow of pitch repelled the beetles. Of the trees injured by the fire, 60 per cent had been successfully attacked and had succumbed. This is the more remarkable since thrifty young trees are practically immune to attack. Trees whose vigor had been lowered through crown injury were prominent among those successfully attacked, and this fact indicates clearly that any serious reduction in the vigor of a tree predisposes it to attack by insects.

Loss of vigor by partial killing of the crown is not the only form of injury that invites insects. Fire scars on the trunk are a favorite place for attack. A detailed examination of the injured trees showed that even scorching of the bark appeared to invite rather than to repel attack. In detailed examination of the 134 fire-scarred trees on the Snake Lake burn it was found that large areas of inner bark surrounding the fire scar may be killed by a fire that does not consume the outer bark or leave any external evidence of injury. It seems not improbable that such fire-injured trees should be peculiarly susceptible to attack in view of the apparent preference of forest insects for weakened trees. On these trees it was found that pitch tubes were far more numerous on the blackened bark which had been subjected to intense heat than they were on the unscorched or lightly scorched bark of the same tree. On a number of trees a count of the number of pitch tubes showed that the number on the badly scorched portions was more than twice as great per unit of surface as on the unscorched.

Though not conclusive, this study confirms the deduction that insects successfully attack those trees and those portions of trees that have been most seriously affected by fire. This conclusion is in harmony with the known biological facts governing the resistance of organisms to disease or attack by their enemies.

FUNGI

The virgin forest, subjected to repeated surface fires for centuries, has been exposed to what has been aptly called cumulative risk. That is, the older the stand the more opportunities there have been for the trees to be injured, and the more serious subsequent injuries have proved. One serious result of cumulative risk has been the susceptibility of the damaged trees to ravages of wood-destroying fungi, which have gained entrance to the trees through open fire scars, and have caused a serious loss of merchantable timber.

Decay in white fir.—In the detailed studies of white fir (*Abies concolor*) by Meinecke (*17*) it has been shown that only in very rare cases did the Indian paint fungus (*Echinodontium tinctorum*) obtain a foothold in uninjured trees. Of 59 firs wounded by fire, he states that only 11 had decay not traceable to the fire wound. Out of a total of 109 cases of decay, the causes of which were definitely determined, 48 were due to fire, 25 to frost, 23 to lightning, and 13 to other causes.

The seriousness of decay from infection by various causes was rated by Meinecke as follows: Lightning least, fire and minor causes next, and frost most serious. By combining the factors of frequency of infection by different causes and the seriousness of the decay, Meinecke obtained the following relative ratings: Fire 144, frost 100, lightning 23, others 39. A major conclusion reached is that fire, chiefly through the formation of basal wounds, is the most important single factor resulting in the prevalent unsoundness of white fir in the virgin forest.

Decay in incense cedar.—Boyce's studies (*2*) of dry rot in incense cedar caused by *Polyporus amarus* are equally conclusive in demonstrating the effect of cumulative risk on the merchantability of this species. Surface fires start a train of circumstances the effects of which can not be fully determined until many years afterwards. That incense cedar with advancing age is subject to cumulative risk from dry rot is strikingly shown in Table 10. Indirectly, the same figures further emphasize the cumulative risk in fire scarring, for fire scars are by far the most important point of entry of fungus.

TABLE 10.—*Cumulative risk to incense cedar from dry rot*

[From U. S. Dept. Agric. Bulletin 871, "The Dry Rot of Incense Cedar," by J. S. Boyce]

Basis			Percentage of injury			
Age class	Average age	Trees	Dry rot volume	Severe cull	Cull	Infections
	Years	*Number*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1 to 40 years	40	1	0	0	0	0
41 to 80 years	60	51	1	0	4	6
81 to 120 years	105	185	3	3	20	38
121 to 160 years	141	284	4	2	29	46
161 to 200 years	180	233	10	12	42	61
201 to 240 years	223	118	22	30	61	73
241 to 280 years	259	94	44	52	79	83
281 to 320 years	296	49	62	67	88	92
321 to 360 years	334	19	67	79	90	90
361 to 400 years	370	4	82	75	100	100
401 to 440 years	436	2	5	0	100	100
Total		1,040				
Average	172		15	17	42	56

This study further showed that of 1,075 typical trees dissected and examined 60.1 per cent had fire scars. On fully half of these trees the scars had not healed over. Of 656 trees infected with dry rot 67.1 per cent had been infected through fire scars. The importance of these wounds as a point of entrance for the fungus is illustrated by the fact that 67 per cent of all trees with fire scars were infected. Of the cases which resulted in serious cull, defined by Boyce as loss of one-third or more of merchantable volume, fire was responsible for the entrance of the fungus in 84 per cent. Thus all other causes combined resulted in only 16 per cent of the instances of serious cull.

The tendency to decay through new fire scars or through old wounds enlarged by fire is likely to be more serious in the older stands than it is in young stands, as the studies already cited show; for, although infection of trees may take place at a comparatively early age, serious destruction of the heart wood seldom appears at an age below 160 years.

While the actual amount of loss from decay induced by fire is not given by either author quoted, it is clearly shown that fire is the principal indirect agent causing cull in white fir and incense cedar in the virgin forest. This is of special interest in view of the fact that these two trees, which form an appreciable part of the timber stand in the pine region of California, have come to be classed as inferior both by lumbermen and by foresters, and not because of inferior technical qualities of the wood, but rather because of the greater frequency of cull.

The relation of decay to fire injuries is not, however, of significance only for the species regarded as inferior. Fire scars on the more valuable pine are an important source of infection, and though the degree of decay here is very much less than in white fir and incense cedar, in one typical instance in western yellow pine it has amounted to a cull of 1.7 per cent, due to rot directly traceable to fire scars. Table 11 shows a similar case. This table gives the actual commercial loss of volume from decay for all five of the principal species, as this appeared on extensive Government timber sales.

The cull percentage, it will be noted, is, as usual, much higher in the two inferior species than in the pines; but even in the pines it must not be disregarded. It is not implied that all the decay was chargeable to fire, but the greater part of it can be directly traced to fire.

TABLE 11.—*Percentage of cull in important species*

[National forest timber sales]

Species	Average cull	Maximum cull	Minimum cull	Basis	
				Sales	Total
	Per cent	*Per cent*	*Per cent*		*Board feet*
Western yellow pine	3.4	8.2	1.2	10	13,649,000
Sugar pine	10.1	13.3	2.5	8	10,605,000
Douglas fir	14.5	22.0	3.0	5	3,738,000
White fir	13.2	30.1	3.5	9	7,197,000
Incense cedar	26.5	46.3	7.8	7	2,286,000

FIRE DAMAGE TO YOUNG GROWTH

Within the past 15 or 20 years, or since fire protection has been attempted, conditions in the virgin forest have changed radically from the time when fires ran unchecked. The most outstanding of these changes is the enormous number of young forest trees that have appeared as individuals and in groups, or, in the more open virgin stand, as a veritable blanket under the mature timber. This remarkable change is in itself proof that the virgin forest as we find it does not represent the productive capacity of the land, for if an area of ground is fully occupied by a mature crop of timber the young individuals can not obtain a foothold because the available moisture and light are already fully utilized. That this alteration is due solely to fire protection is clearly evident from the descriptions of the virgin forest of a half century ago by historians and early settlers. In this picture the dominant note is the openness of the forest, emphasized in the oft-repeated statement that one could ride anywhere or could see for long distances through the timber. The general occurrence of young growth or advance reproduction in the virgin forest to-day is the effort of nature, in response to fire protection, to utilize the full growing power of the land, and to restore the broken and understocked forest to a more normal condition.

Even a light fire is sufficient to destroy the seedlings and saplings in a stand; that is, the young trees which must become established if forests are to persist indefinitely. Unless some reproduction is able to become established and survive, it requires little imagination to see that, with fires occurring on the average about eight years apart, and even with the very lowest rate of loss to the largest trees that has been found on any of the fires studied in detail, the forest must eventually disappear. The presence and history of brush fields well illustrate this. On the other hand, repeatedly burned-over timber stands prove that in many cases the forest has been able to reproduce itself about as rapidly as fire has eliminated individual old trees and the smaller, younger trees. Perhaps the most remarkable thing in this entire survey of the cumulative effects of fire is the fact that so large a percentage of the forest has persisted.

FUNCTIONS OF ADVANCE REPRODUCTION

Two general functions of advance reproduction in the virgin forest are to be noted. First, in timber that will not be cut over for many years to come, the advance reproduction will fill in the blanks of the present forest and will in many cases attain sufficient size to increase the yield of the stand when it is cut. Even in comparatively fully stocked stands under protection, gaps may thus be filled, as single mature or overmature individuals succumb. Reproduction is assurance that the growing capacity of the land will not lie idle. In other words, the virgin forest is not in a static condition; changes are taking place constantly, giving constant opportunity to new growth.

The second function is in evidence when the virgin forest is to be harvested within a reasonably short period and some provisions must be made for continuing the forest without resorting to planting. Dunning's investigation (*8*) shows clearly that by far the most certain, safest, and quickest method of getting a new stand in the California pine region is to preserve the advance reproduction in the logging operations. Depending on seed trees alone is likely to lead to a serious delay in obtaining a new crop. On cuttings on private land where no provision is made for seed trees and where the land is practically clear cut, advance reproduction is the only assurance that a new forest will follow the old.

What effect even a single surface fire will have on young growth in the virgin forest is therefore not merely of academic interest, but is of truly momentous importance.

ACTION OF FIRE

There has been a great diversity of opinion regarding the physical effects of fire on reproduction in the virgin forest. Some who have wished to emphasize the destructiveness of fire have assumed that the mere occurrence of even a light fire resulted in complete obliteration of the young trees over large areas, although the very persistence of the virgin forest in the pine region in spite of repeated burns is prima facie evidence that such is not the case. On the other hand, those who have desired to minimize the damage to reproduction from fire have taken the position that fire is a positive benefit through its alleged action in thinning the weaker and smaller individuals out of the dense thickets. The present investigations indicate that the truth lies between two extremes, and a fire of this nature is neither a catastrophe nor a blessing.

In the examination of the Ham Station fire, reproduction plots were tallied at intervals along a cruise line. It was found that on an average the reproduction before the fire was 66 per cent complete and that after the one fire the degree of stocking had been reduced to 40 per cent. Using only this one illustration for the present, it may be pointed out that even fires that result in material damage to merchantable timber, as this one did, fortunately do not entirely wipe out advance reproduction, even that of small size, over extensive areas. On this 9,000-acre burn the effect of the fire on advance reproduction was very similar to the effect on large timber; that is intense damage on many plots of a few acres each, where the young growth had been completely destroyed, coincided with areas of heavy heat killing of merchantable timber; while over the greater portion of the burn the damage took the form of reduction of the stand. Since the young growth was smaller and more susceptible to fire than the merchantable timber, the percentage of such reduction was naturally greater.

A study was made of a large area in the east side western yellow pine type burned over in the summer of 1920. Cruise lines were run through the burn and each one-tenth acre square on each side of the line was classified as to the degree of stocking of the reproduction before the fire, the percentage of the ground burned over, and the percentage of the reproduction killed. The survey covered a total of 379 sample plots, almost 38 acres, along a mechanically located strip, fairly sampling a burned area of approximately 2,000 acres.

This study showed that, in general, the heavier the original stocking on the plots the higher was the percentage of the area burned; that is, very open and scattered stands of reproduction had a better chance of escaping the fire than did the denser stands. The proportion of reproduction killed followed closely the proportion of the area burned. Considering only the grand average of all the data, 69 per cent of the plot area was burned, and 64 per cent of the reproduction was killed.

It is shown that instead of uniformly thinning the stands of seedlings and saplings, a surface fire wipes out a certain portion of the stand wherever it runs. Outside the area actually burned, and yet within the boundary of the burn as a whole, there will be a certain amount of reproduction, even though small, that is able to survive. This is exceedingly important, for it means that fire creates a patchy, scattered distribution of reproduction, with many areas denuded but others left intact. On the more intense burns, such as the Howard and Soda Creek fires and on the more heavily burned parts of the other areas, not even occasional patches of unburned reproduction are left, but complete destruction of reproduction is the rule.

RARE INSTANCES OF BENEFICIAL EFFECTS

Fires in the early spring, or late fall after the first rains, are naturally less destructive than in the summer, because of the more moist condition of the litter. Studies on the Castle Rock, Red River, Snake Lake, and Sierra Iron Co's burns show that with very light fires the stands of large reproduction, especially in the sapling and pole stages, may sometimes be thinned by fire without complete destruction of the entire stand. As an example of the way in which a fire acts under such circumstances, an area of slightly more than one-third of an acre, with reproduction ranging from seedlings to poles 12 inches in diameter, was studied. As shown in Table 12, only a very low percentage of seedlings escaped death; but the larger the trees the larger the percentage that lived. Though only 20 per cent of all the young trees survived, they represented a total of 480 trees to the acre consisting chiefly of the larger individuals, and were quite sufficient to give a reasonable degree of stocking. As the surviving trees were uniformly distributed, there is no concern in this particular case over the heavy loss of seedlings and saplings.

TABLE 12.—*Effects of light fire on young growth*

[Sample plots covering 14,725 square feet (0.338 acre), Sierra County, 1921]

Diameter of trees breast high	Total killed		Total alive	
	Number	*Per cent*	*Number*	*Per cent*
Under 2 inches (seedlings)	427	97	14	1
2 inches	163	88	23	37
3 inches	38	63	22	36
4 inches	22	37	38	67
5 inches	10	33	20	23
6 inches	3	18	14	82
7 inches	0	0	7	100
8 inches	2	33	4	67
9 inches	0	0	9	100
10 inches	0	0	4	100
11 inches	0	0	2	100
12 inches	0	0	6	100
Total	665	80	163	20

A similar condition was found on the Red River burn. Here, as shown in Table 13, the seedlings were almost completely wiped out; but a greater and greater percentage of the trees survived as the size increased. On the area of the plots, covering a little more than a fifth of an acre, 22 per cent of the young trees lived, an equivalent of 676 to the acre. Because of the good distribution and the fair amount of living reproduction, the fire had been beneficial or at least neutral in its effect on reproduction. On this, as on the area previously described, not all the land within the exterior boundaries of the fire was covered by the flames.

TABLE 13.—*Effect of light fire on young growth of western yellow pine*

[Sample plots totaling 9,000 square feet (0.207 acre) in area, Lassen County]

Diameter of trees breast high	Total killed		Total alive	
	Number	*Per cent*	*Number*	*Per cent*
Under 2 inches (seedlings)	222	97	8	3
2 inches	188	78	53	22
3 inches	53	55	43	45
4 inches	14	45	17	55
5 inches	7	44	9	56
6 inches	1	25	3	75
7 inches	3	43	4	57
8 inches	0	0	3	100
Total	488	78	140	22

With summer fires, these dense groups of reproduction, even in the sapling and pole stages, are peculiarly susceptible to crown fires, just as the larger second-growth stands are. Even where the thinning effect of a light fire is apparently beneficial, basal scars are formed on many of the surviving trees, as shown on the areas already cited. There can be little doubt that these scars are likely to prove a source of weakness during the life of the trees.

RELATIVE SUSCEPTIBILITY OF VARIOUS SPECIES

In a plot on the White Horse burn, Modoc National Forest, in a mixed stand of reproduction, all the species were intermingled, and the trees were less than 4 inches in diameter. The data given in

Table 14, taken from this area, illustrate this relative resistance of the principal species to light fires. In short, the western yellow pine is found to be the most fire-resistant species, cedar and fir highly susceptible, and sugar pine probably close to western yellow pine in its resistance. The relative order of the species is found to be similar to that for mature timber in resistance to crown injury.

TABLE 14.—*Relative susceptibility to fire injury of different species of young growth less than 4 inches in diameter*

[White Horse fire, 1920, Modoc National Forest]

Species	Number (basis)	Total killed		Total alive	
		Number	Per cent	Number	Per cent
Western yellow pine	485	363	75	122	25
Sugar pine	5	4	80	1	20
White fir	126	123	98	3	2
Incense cedar	54	54	100	0	0

A similar study, the Castle Rock light burning, was started in 1911 in the Shasta National Forest and continued for several years. On this area Douglas fir is the associated species in place of white fir. The results of the investigation showed western yellow pine to be the least susceptible, incense cedar the most susceptible, and Douglas fir intermediate. It is noteworthy that these results are in line with the results obtained by the California Forestry Committee (*6*) in their hundred per cent survey of light burning on the Moffitt Creek area in the Klamath National Forest, as shown in Table 15.

TABLE 15.—*Relative susceptibility of young growth to fire injury*

[Strip, 2.6 acres; Moffitt Creek light-burning area, Klamath National Forest; burn of June, 1922]

Species	Surviving trees, by height groups									
	½ to 3 feet		4 to 6 feet		7 to 8 feet		Over 8 feet		Total	
	No.	*P. ct.*	*No.*	*P. ct.*	*No.*	*P. ct.*	*No.*	*P. ct.*	*No.*	*P. ct.*
Western yellow pine	215	1.9	184	3.3	33	12.1	62	42.0	494	8.1
Sugar pine	4		2						6	5.0
Douglas fir	12		8				4	25.0	24	4.2
Incense cedar	148		54	3.7	3		6	16.7	211	1.4
Total, all species	379	1.1	248	3.3	36	11.1	72	38.9	735	6.0

EFFECT OF FIRE ON FOREST COMPOSITION

The investigations of Hoffman (*10*) and others have shown that fire has been the dominant factor in the Douglas fir and western white pine regions in controlling the present composition of the virgin forests. Douglas fir and white pine, the intolerant species in their respective regions, are perpetuated in the mixed virgin forests by the elimination of the other species through crown fires. If the forest were allowed to develop uninterrupted by fire, it would finally consist of the tolerant hemlock, cedar, and white fir, which are able to reproduce in the shade of the old forest. Douglas fir and western white pine would be relegated to very minor positions in the stand.

F-156401

FIG. 1.—THE VIRGIN FOREST

The California pine forests have been reduced both in volume and in number of trees by successive light fires that have run through them for centuries. An old and open stand such as this can not compare in volume with fully stocked second-growth stands. However, reproduction is gradually taking possession of the openings, encouraged by fire protection in recent years

F-94718

FIG. 2.—THE RESULT OF A CROWN FIRE IN SECOND GROWTH

Although crown fires are rare in old stands, in the California pine region, they often develop from light burns in second growth. When this occurs, the result, as in this case, is disastrous

F-160194

FIG. 1.—BEFORE BROADCAST BURNING OF SLASH

A small area in northern California as it appeared before the slash was burned off by the broadcast method

F-161208

FIG. 2.—THE RESULT OF BURNING BROADCAST

The same view as that above, after the burn. The young trees have been fire-killed and the area devastated, showing conclusively the undesirability of such methods of slash disposal

The influence of fire in the California pine region, in interrupting the normal development of the forest and in perpetuating the intolerant species through its selective action, is fundamentally the same as in the Pacific Northwest, though the species are different. The result in California is attained not by occasional catastrophes, as in the Northwest, but by the gradual diminution of the tolerant white fir and incense cedar, which are easily killed by fire. The intolerant pines, with their ability to resist fire, are established under conditions unfavorable to their competitors.

Similar manifestations of the importance of recurring surface fires in controlling the composition of forests are plainly evident in many parts of the western yellow pine belt on the western flanks of the Sierras. Since fire protection became effective, white fir and incense cedar are appearing in increasing proportion in what, from a mere tally of mature timber, would seem to be a western yellow pine type.

Although in the study of plant environment little weight has been given to fire, even in an uninterrupted state of nature, it has, in the California pine region, been a primary force in determining the succession of forest types.

TABLE 16.—*Changes in type as a result of protection against fire, as shown by comparisons of merchantable stands and advance reproduction*

Species	Merchantable stand		Advance reproduction	
	Acres	*Per cent*	*Acres*	*Per cent*
Lassen National Forest:				
Western yellow pine	199,600		127,500	64
Fir	32,800		[1] 115,000	351
Lodgepole pine	6,500		6,500	100
Brush	10,100			
Plumas National Forest:				
Western yellow pine		[2] 22		9.9
Sugar pine		11		5
Douglas fir		18		25.2
White fir		18		20.8
Incense cedar		31		39.1
(Basis, 51.2 acres.)				
Tahoe National Forest:				
Western yellow pine		76		36
White fir		24		64
(Basis, 10 acres.)				

[1] Fifty per cent or more fir in reproduction determines fir type.
[2] Percentages by number of trees. Percentages by volume of merchantable timber are, for these species, reading down: 35, 17, 23, 15, and 12.

THE PROCESS OF ATTRITION

The most significant relation between fire damage and site quality has been referred to as attrition, that important but often unnoticed process that has been going on for centuries in the virgin forest. On such a burn as the Ham Station fire, mentioned in connection with Table 4, not only was a certain percentage stripped of timber, but this area as a whole is reverting to brush, and the brush will in turn increase the intensity of subsequent fires. Another example already mentioned is the Howard fire, which occurred on an area the fire history of which is known with a reasonable degree of certainty. This area has been subject for many years to repeated forest fires and by this process of attrition has been reduced in density, thereby increasing the amount of undergrowth. The latest fire on this area, which has caused tremendous damage, is the logical and inevitable result of the previous fire history. All such examples lead to the same conclusion: *Fire in forest areas invariably breeds still more serious fires.*

Because of attrition, exerted in these and other ways, the present virgin forest, however splendidly complete and magnificent it may appear, is not fully stocked and represents but a part of the productive power of the land. The volume per acre in virgin forests repeatedly subjected to fire is not comparable to the volume per acre in fully stocked second-growth forests on sites of the same quality, but from which fire has been excluded. One instructive example is illustrated in Table 17. From this table it is evident that for extensive areas of virgin forests the average yield to the acre of stands 200 to 300 years old is very much less than the yield obtained from the more fully stocked stands of 50 or 60 years of age. (Pl. V, fig. 1.)

TABLE 17.—*Yield of virgin forest and fully stocked second-growth forest, by sites*

[Lassen National Forest]

Site	Area of virgin forest	Yield of virgin forest	Yield of second-growth forest [1]	Degree of normal stocking in virgin forest
	Acres	*M bd. ft.*	*M bd. ft.*	*Per cent*
1	2,149	34.2	74.0	46
2	20,277	24.0	56.0	43
3	129,767	16.7	40.7	41
4	118,349	7.5	26.0	29

[1] Second-growth yields are determined by analysis of 130 measured plots in fully stocked stands, second growth, 50 to 60 years old.

It is unnecessary to insist either that the discrepancies shown above are due solely to fire or that the actual figures in this table are representative for the entire forest region. The inference is plain that even where the virgin forest has persisted fairly well in spite of repeated fires, the yield is naturally lower than if the area had escaped from fires. A second illustration of the same truth is found in an estimate of the yields of virgin and fully stocked second-growth tracts in the Plumas National Forest. On second-quality sites the mature virgin stands show a present yield per acre of 28,800 board feet, estimating on a basis of 33,033 acres, while fully stocked second growth aged 50 years, on similiar sites, shows already 27,130 board feet.

From this it is seen that, for the mixed conifer forests of the west slope of the Sierras, the average present stand of virgin timber can not compare favorably in yield per acre with fully stocked young growth, which is already nearly equal in yield. In the rare patches of fully stocked virgin forest, carefully measured sample plots showed an average yield of 110,000 board feet to the acre, compared to 42,000 board feet for even the average best of the typical virgin forest. These illustrations make it clear that the present yields of even our best virgin forests probably represent less than half the timber-producing capacity of the land.

The last step in the process of attrition, the ultimate effect of repeated fires, is the complete destruction of the productive capacity of the site. This ultimate result will be discussed later in considering the effects of fire in the brush fields.

FIRE IN SECOND-GROWTH STANDS

In discussing the fire damage to second-growth stands, only those are selected for study that have followed the cutting of virgin timber and have attained a size sufficient to justify their exploitation for saw timber. This rather restricted selection is advisable because in the California pine region there are extensive areas of such second growth, which followed the cutting of the virgin forest in the early mining days from about 1850 to 1870, and these stands are now being logged. Of the total forest area of the region these stands form but a minor portion; but they have a significance very much greater than their area alone would indicate, for they represent the type and kind of forest that will become increasingly abundant as the virgin forest is removed and new stands take its place. These stands differ profoundly in many ways from the virgin forests, and in no way more than in their reaction to forest fires.

THE CROWN-FIRE HAZARD

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, devasting crown fires. Extensive crown fires, though common in the forests of the western white pine region,[8] 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.

Existing second-growth stands are typically even-aged and fully stocked, have a continuous, unbroken canopy, and are consequently susceptible to the most destructive type of forest fire. To those familiar with the occurrence of crown fires in the dense even-aged forests of western white pine and Douglas fir in the Pacific Northwest a field examination of the second-growth western yellow pine forests of California would be immediately convincing that these stands also represent an exceedingly high inherent hazard, and that this hazard differs from that of the virgin forest. (Pl. V, fig. 2.)

The most extensive second-growth stands are in the Mother Lode region of the Sierras, centering around Nevada City.[9] It is in this vicinity that the result of fires has been most carefully studied. For many years the practice on some of the private lands has been to allow light fires to run through the second-growth forest, either

[8] The western white pine region includes northern Idaho and northwestern Montana, where the western white pine (*Pinus monticola*) grows in dense, uniform stands over large areas.

[9] The Mother Lode region is the rather narrow belt lying along the edge of the central Sierras, where gold has been extensively mined.

in the spring or in the fall after the first heavy rains. Fires of this character, far from protecting the stand from fire damage, rather increase the hazard. What this hazard is, is shown by several examples of just such areas where crown fires have developed with disastrous results.

The largest burn in second growth of this sort which was studied was the Rock Creek fire near Nevada City, Calif., which burned from September 1 to 6, 1910 (*8*). The following sample plot is representative of conditions on this area:

SAMPLE PLOT OF ROCK CREEK FIRE, 1910

(SW. ¼ NE. ¼ sec. 32, T. 17 N., R. 9 E., M. D. M., near Nevada City)

Area.—1 acre.
Slope.—3 to 5 per cent, north exposure.
Condition at time of examination, December, 1919:
Timber—
172 western yellow pines, 5 to 18 inches diameter breast high, killed.
28 incense cedars 5 to 8 inches diameter breast high, killed.
3 yellow pines 12 inches diameter breast high, alive.
2 incense cedars, 7 to 9 inches diameter breast-high, alive.
Reproduction—
1 western yellow pine seedling, alive.
8 Black oak coppice sprouts, alive.
Cover.—Abundant stand of manzanita (*Arctostaphylos patula*) 3 to 5 feet high, deer brush and buck brush (*Ceanothus integerrimus* and *C. cordulatus*) 2 to 3 feet high, dense mat bear clover (*Chamaebatia foliolosa*) ½ to 1 foot high.
Hazard.—All trees killed, except two cedars, had rotted and fallen, covering the ground with a tangle of logs, bark, and limbs. A summer fire would spread rapidly.

This fire burned a strip, 3½ miles long and 1¼ miles wide through the center of a practically continuous tract of 40-year old second-growth western yellow pine which had been regularly light burned. The total burned area was 2,840 acres, of which 2,160 acres were timbered with this splendid second growth that averaged as high as 20 cords of wood to the acre. A cruise of the burn showed that on more than 75 per cent of the total area all trees were killed, except occasional isolated clumps. This fire spread through the crowns, utterly destroying the timber on all slopes and exposures, and resulted in the reversion of the burn to a worthless brushfield. At the present time the area is occupied exclusively by a dense stand of a number of brush species (*Arctostaphylos patula*, *Ceanothus integerrimus*, *C. cordulatus*, *Arbutus menziesii*, etc.), and hidden by this brush is a tangle of rotting logs and chunks of trees, the remains of the former forest. The destruction by this single fire was almost complete and far exceeds anything known in the virgin forests either in this particular locality or any other part of the pine region.

Another destructive fire in a second-growth western yellow pine stand occurred near Groveland in 1917. This crown fire destroyed the stand on an area of 100 acres. Another similar crown fire during early May, near the Pilgrim Creek nursery on the Shasta National Forest, wiped out the stand on 150 acres, although banks of snow were still present.

The Cement Hill fire on the Tahoe National Forest on November 26, 1919, covered an area of over 600 acres. In spite of the fact that the fire was far past the time when fires ordinarily burn at all, it developed into a crown fire on many southerly slopes and obliterated the stand on many patches of 2 to 4 acres.

SAMPLE PLOT OF CEMENT HILL FIRE, 1919

(Sec. 35, T. 17 N., R. 8 E., M. D. M.)

Area.—0.6 acre.
Fire history.—No fires since 1881, except a small blaze confined to two trees in area showing scars 3 years old. Following light rain on November 4 and soaking rain on November 7, 1919, fire burned on November 24 and 25, 1919.
Original stand.—50 years old, western yellow pine; 228 pines per acre, 5 to 22 inches diameter breast high, 50 to 60 feet; 180 pines per acre under 5 inches diameter breast high.
Slope.—Gentle, not over 5 per cent, in a shallow swale, northerly exposure.
Cover prior to fire.—Very little brush, few old manzanita bushes dead from shading of trees; some bear clover.
Litter.—Probably 1 to 1¼ inches thick, as judged from adjacent unburned areas.
Reproduction.—Absent.
Results of 1919 fire.—Every tree killed on area; litter consumed to soil; bear clover scorched off; dead brush not all consumed.

An enumeration in detail of all destructive fires in second-growth stands would merely be a repetition and amplification of the examples already given. Stands of this character represent an extreme hazard. Destruction of the forest on wide areas is to be anticipated at any time of the year when fires will burn at all, if fire occurs when weather conditions favorable to spread of fire, particularly high winds, prevail.

As in the Pacific Northwest, not all fires in second-growth stands develop into disastrous crown fires, many either being controlled while yet small or protected by climatic and topographic conditions. Another reason that more extensive fires have not occurred in merchantable second growth in California is that most of the existing stands are in the foothill regions and are broken up into small tracts by agricultural clearings.

ANNIHILATION OF STANDS

The hazard in second-growth stands has been compared to that in the Pacific Northwest, but there is one vital difference of great importance. Serious as the loss of merchantable material is in the Douglas fir and western white pine crown fires, investigation has proved that destruction of the stand does not reduce the burned-over area to a nonproductive state. Reproduction of these valuable species ordinarily appears promptly after such a fire, either from dormant seed in the forest floor or from seed on the trees at the time of their death. Regeneration in these regions is also readily obtained because of the favorable amount and distribution of moisture, and because of the earlier seed-bearing age of the important conifers.

In striking contrast, crown fires in second-growth pine stands in California inevitably reduce the areas to sterility and establish a permanent brush cover. This is explained by the fact that dormant seed is not an important factor in the regeneration of these stands.

Moreover, seed is not borne in appreciable amounts until the stand is at least 60 years old, and climatic conditions for the establishment of reproduction are critical at best. The reestablishment of a forest in a brush field is a long, slow process, for seed is scarce, rodents are abundant, and seedlings must compete for moisture with established vegetation during a long drawn out dry season. Crown fires in California are serious, therefore, even more because they render forest land nonproductive than because they result in great destruction of merchantable material. As the cutting of the virgin forest proceeds and the area of second-growth stands is correspondingly increased, the problem of preventing serious damage by forest fires and, more important, of preventing devastation of forest lands, will be infinitely more difficult than it is in the present virgin forests. Only more intensive management of the second-growth forests can minimize the chance for extenisve conflagration.

EFFECT OF REPEATED SURFACE FIRES

While it is true that heat killing is the outstanding form of damage in second-growth stands, there are other losses which can not be overlooked.

Studies of the effect of repeated surface fires in second-growth stands show strikingly the same process of attrition that is known to have taken place in the virgin forest. Results of studies of several sample plots on private land are tabulated below:

Graham Ranch Plot, Tahoe National Forest (Area 0.3 Acre)

History.—This area has been regularly "light burned," the last fire being in 1918.
Slope.—30 to 40 per cent, eastern exposure.
Stand.—73 live western yellow pines 5 to 24 inches in diameter (average 12 inches diameter 50 feet in height); age about 50 years; base of crowns 15 to 20 feet; one old western yellow pine 42 inches in diameter; 50 trees killed by fire were 3 to 5 inches in diameter, mostly suppressed and intermediate; charred stubs of limbs to within 6 feet of ground.
Litter.—The average of the measurements showed 1.3 inches depth. The upper layer was of newly fallen needles; the lower mat of partly decayed needles had not been burned by last fire.
Ground cover.—80 per cent of the area was covered by bear clover averaging 6 inches in height, 6 to 8 years old, which had only been scorched by the latest fires.
Brush.—Manzanita 6 to 10 feet high, mostly dead, is found in all openings. These old bushes had not often sprouted, but abundant new manzanita from seed, 6 to 8 years old, and 3 feet high, had come in where there was sufficient light. There was also an abundant mixture of deer brush 1 to 2 feet high, originating mostly from seed and dwarfed by grazing. The brush was only slightly scorched by later fire.
Reproduction.—There were no tree seedlings even in the openings, although the young trees were bearing seed, and a 42-inch western yellow pine was near.
Scars.—11 trees, or 14 per cent of those alive, had five scars, many of them long ones, made largely by the fires of 1910, 1913, and 1918. Many of these scars were still hidden by bark and were not noticeable unless the bark was knocked off. Woodpeckers have chipped off some of the bark around scars, indicating insect work.

Kitt's Area No. 1, Tahoe National Forest (Area 1 Acre)

History.—Intermittently "light burned"; last burns, in 1919, very light and patchy; limbs left from wood cutting were not removed from the trees, and patches of inner bark had been killed at the base.

Slope.—Uniform, about 30 per cent, exposure west.
Stand.—113 live western yellow pines 55 years old, 6 to 24 inches in diameter, and from 60 to 80 feet in height, 12 live incense cedars.
Scars.—10 of the 125 living trees, or 8 per cent, had visible fire scars.
Insect damage.—5 trees, 11 to 14 inches in diameter, were killed by insects; 4 live trees showed new pitch tubes of the red turpentine beetle (*Dendroctonus valens*).

KITT'S AREA NO. 2 (AREA 0.3 ACRE)

History.—Area intermittently light burned, latest fire in the spring of 1919, which was light and did not spread beyond pine needles, hazard at the present time very high, due to great amount of inflammable material.
Slope.—50 per cent, northern exposure.
Stand.—45 live western yellow pines, 6 to 20 inches in diameter by 40 to 80 feet in height, 50 to 55 years old; 20 dead trees, the largest 8 inches in diameter and 40 feet in height, had been killed by the 1919 and former fires; base of crowns 25 to 30 feet from ground, and dead limbs extend to ground.
Brush.—Abundant stand of old deer brush 10 to 12 feet in height, curled over and festooned with needles, dead from shading by trees; a few dead manzanitas also occur.
Litter.—1 to 1½ inches deep, ½ inch of the upper layer of this autumn's needles—beneath this a mat ½ to 1 inch thick of partly decayed needles limbs and rotted parts of trees on the ground.
Scars.—13 trees, or 20 per cent, had visible fire scars.

(KITT'S AREA NO. 3 (AREA 0.3 ACRE)

History.—Area intermittently light burned; last fire was in the spring of 1919; no appreciable reduction in inflammable material.
Slope.—5 per cent, northern exposure.
Stand.—16 live western yellow pines, averaging 16 inches diameter and 75 feet in height; 12 live incense cedars, averaging 12 inches diameter; trunks free of limbs up to 10 to 15 feet, and base of crowns 25 to 30 feet from ground.
Brush.—Practically absent.
Litter.—1½ inches deep, upper layer fallen since spring fire.
Reproduction.—No small seedlings are present, except along a ditch where protection from past fires was afforded, and here are to be found several western yellow pine seedlings 2 to 3 years old. A few incense cedar seedlings had germinated since the last spring burn.
Scars.—13 out of 16 western yellow pines and 7 of the 12 cedars were fire scarred; 6 of the trees had fire scars 4 to 10 feet high.

The repeated fires in these areas have undoubtedly been more concentrated in time than have the fires in the virgin forest. There is no exact information as to the date when light surface fires began in the second-growth stands, but it is quite probable that most of them have occurred in the last 20 years. Some of the plots show that the fires, though of insufficient intensity to develop as crown fires, were nevertheless hot enough to destroy the intermediate and suppressed trees from 3 to 5 inches in diameter. In spite of their vigorous growth the young trees, through repeated burning of fire scars, are eventually burned down, just as in the case of mature timber in the virgin forest.

A half-acre plot of second growth examined is of particular interest. On this area were 42 western yellow pine trees 50 years old and from 8 to 20 inches in diameter which had survived a severe fire in 1898, the Rock Creek fire of 1910, and numerous light surface fires, including the last one, in 1918. As a result of a heavy windstorm on November 26, 1919, 20 of these trees bearing large scars formed originally by the 1898 fire and subsequently enlarged by the succeeding fires were broken off at the scarred places. None of the 22 unscarred trees was thrown during this windstorm. Additional examples could be cited, but they would merely confirm the conclusion that repeated surface fires deplete second-growth stands in the same manner as they do the virgin forest. Further, the gradual thinning of the forest allows the invasion of brush and other inflammable cover so that succeeding surface fires more readily develop into disastrous crown fires.

OTHER FORMS OF FIRE DAMAGE

In general, the secondary and indirect forms of damage resulting from surface fires are similar to these forms of damage in the virgin forest. Destructive insect attacks in timber of this character are almost invariably associated with fire, since second-growth stands are normally immune to ravages of forest insects.

The reduction in the rate of growth as the result of crown injuries by fire has been little studied, but there is no reason to doubt that it is a weighty factor in reducing the yield.

The study of fire damage in second-growth forests thus reveals two major conclusions: (1) that the danger from extensive crown fires is very much more serious than in the virgin forest; and (2) that the other forms of loss found in the virgin forest occur on and are equally inimical to second-growth stands.

OCCASIONAL BENEFITS

Occasionally a single surface fire in second-growth stands may be beneficial rather than harmful. This is true when a very light ground fire occurs in a stand so heavily stocked that growth is seriously retarded by the very denseness of the cover. If a fire of exactly the right intensity runs through such a stand it will result in killing many of the intermediate and suppressed trees, without seriously injuring the principal individuals of the stand, consisting of the dominant and codominant trees. This possible use of fire is treated in greater detail later in examining the proper field for employing fire in forest management. At this point it is only necessary to note that benefits from a single fire occur under an exceedingly narrow range of conditions, and that serious dangers are inherent in the employment of fire in the promiscuous thinning of forest stands.

FIRE DAMAGE ON CUT-OVER AREAS

In most forest regions, fires in cut-over areas are more intense and destructive than in virgin timber. An accumulation of inflammable slash is present, the openness of the remaining stand offers no barrier to the sweep of the wind, and standing snags scatter sparks broadcast in advance of the main fire. Detailed studies in recent years of many such areas in practically all parts of the pine region disclose the fact that the action of fires on cut-over land is generally about the same as that of fires in brush fields. That is, wherever the fire burns, except in rare cases among spring or fall fires, the new growth which survived logging is wiped out and the number of remaining seed trees is seriously reduced.

Next only to fires in restocking brush fields, fires in cut-over lands present the most serious problem both in the completeness of destruction and in difficulty of control. This problem will become increasingly important as the cutting of the virgin forest progresses and the nature of fires on cut-over areas makes adequate attention imperative.

Of the total of nearly 1,500,000 acres cut over in the pine region, 564,000 acres are estimated to be in a nonproductive condition, mainly because of fire. These 564,000 acres are either completely denuded of tree growth, or are depleted to the extent that less than a third of the stand has survived. Table 18 shows by classes of owners the amount of cut-over land and the amount of nonproductive land. The figures are approximate, being based on extensive field examination of the larger areas, and representative samples of the smaller.

TABLE 18.—*Proportion of denuded areas on cut-over land in private ownership to 1922*

Class of ownership	Number	Total cut-over land [1] (acres)	Area denuded	
			Acres	Per cent
Large operators	24	636, 430	271, 970	34
Small operators	270	100, 000	20, 000	20
Large nonoperators	34	121, 050	46, 550	38
Small nonoperators	76	75, 000	25, 000	33
Water and power companies	5	34, 800	8, 900	26
Graziers	2	31, 000	12, 000	39
Railroads	2	94, 000	32, 300	34
Pulp and paper companies	1	14, 300	4, 300	30
Mining companies	9	6, 470	2, 870	44
Others	2, 982	355, 950	140, 110	39
	3, 405	1, 469, 000	564, 000	38. 4

[1] Data from owners, county assessors, and Forest Service records.

EFFECTS OF SLASH FIRES

On one area in the east side western yellow pine type, experiments were conducted by an operating company to determine both the feasibility of broadcast summer burning of slash on small areas of 5 to 25 acres and the damage resulting therefrom. The particular interest of this company was the protection of adjacent timber and the removal of slash in the hope of decreasing insect infestation. Plate VI shows views of this area before and after burning. While the particular object of the operator was attained in this case, the burning has left the area in such shape that it will require years for the forest to reclaim it. This is no exceptional instance, but is the inevitable result of such practices.

On another typical area studied in detail a cruise of the reproduction surviving logging was made and exactly the same area was reexamined after the slash burning. In spite of the fact that the fire was confined to a small area and the burning was done at night, with consequently none of the rapid spread characteristic of slash fires, the results were as follows:

Before the fire.—705 small trees; 80 per cent of plots with reproduction.
After the fire.—86 small trees; 31 per cent of plots with reproduction.
Effect of fire.—12 per cent of small trees remaining; 39 per cent of reproductive area remaining.

The area can not be classed as devastated, but the figures give evidence that the new stand will be but a fractional part of the capacity of the land.

On one part of an area logged in 1917 fire escaped and burned the slash, while from the other the fire was excluded. The burned area was, for all practical purposes, completely devastated. The advance reproduction and even the remaining seed trees were killed. Brush is now in possession of the ground, and the return of a reasonably good forest cover will be a matter of decades at best. A cruise strip on the area showed no living reproduction or larger trees for a distance of more than half a mile. The unburned area in contrast is in very fair condition, with a reasonable amount of advance growth and seed trees.

Fires on cut-over lands destroy the great bulk of advance reproduction, even though seed trees may survive. Where minimum damage occurs, however, as is the case with uncontrolled spring or fall slash fires, the slash itself is incompletely consumed and the dead reproduction adds to the fuel for another fire.

Under rare circumstances, representing much less than 1 per cent of the total cut-over area, excellent stands of reproduction have come in after an exceedingly hot summer slash fire. This has occurrred on small areas where the fire in the early fall followed so closely upon cutting that the seed crop was still in the cones and was thus protected from fire. In nearly all such instances, also, the following growing season was distinctly favorable to the establishment of reproduction.

Slash fires in most cases result in devastation and the occupancy of the land by brush. At the very least they destroy or seriously reduce the advance growth. Only under the most exceptional circumstances does a new stand of reproduction follow a typical slash fires.

EFFECT ON REPRODUCING AREAS

It should be noticed that slash fires in the pine region are as likely to result in a partly stocked, patchy forest, damaged by fire and disease, as they are to denude cut-over lands completely. While the complete devastation of a third out of large areas of cut-over land is perhaps the most serious outcome, the fact that thousands of acres are producing wood at only a fractional part of their capacity is of almost equal importance.

This aspect of slash fires is admirably illustrated by the results of an intensive cruise (*1*) made by one of the large operating companies on its own lands. This cruise was made in order to ascertain the amount and distribution of seed trees and of reproduction accumulated on the cut-over areas during 20 years. These areas were themselves representative of the laissez-faire policy, under which fires were suppressed only when damage to merchantable timber or improvements was threatened. The relatively poor stocking which the cruise disclosed may unhesitatingly be charged to the widespread slash fires resulting from this policy, as indeed is recognized by the company itself.

The results of the examination that was made show that on 16.7 per cent of the total area the stocking of young trees was 60 per cent or better, averaging 72 per cent; on an additional 52.4 per cent of the area the stocking was from 10 to 60 per cent complete, averaging 28.5 per cent; and on the remaining 30.9 per cent the stocking was under 10 per cent, or practically nonexistent.

A curve drawn through the plotting of these generalized figures indicates that 50 per cent stocking or better appeared on only 22 per cent stock of the area. Nearly a third of the area is entirely denuded, while two-thirds show only 33⅓ per cent stocking. Only one-twentieth of the entire area boasts more than 83 per cent of normal density of young growth.

It has already been shown that in many places repeated fires ultimately either deteriorate the site to a point where timber will no longer grow, or change the type from a desirable to a very inferior one. Fires on cut-over lands often duplicate at a single stroke these profound changes of site and type that in the virgin forest may require decades. An example of site deterioration is illustrated in Plate VII, Figure 1, by a photograph taken seven years after logging operations that were followed the next summer by a severe slash fire. A cruise line on the cut-over area showed in 1½ miles only two living seedlings and no seed trees. In addition, the rabbit brush (*Chrysothamnus*) that has occupied the area is indicative of reversion to a non-timber site and it is certain that the forest will not return naturally to this area for many tree generations.

Sometimes the change is from commercial timber to an inferior type. One area, originally a western yellow-pine white-fir type, was logged in 1913 and a slash fire followed the logging. A large amount of lodgepole pine reproduction has come in, and it seems evident that the future forest on the area will be composed principally of this less desirable species.

FIRE IN BRUSH FIELDS

SITE DETERIORATION

The cumulative effects of repeated fires in forming brush fields and reducing the yield of timber are but different phases and stages of the general process of attrition. The end of this process is destruction of all merchantable timber. The history of forests throughout the world teaches this one lesson of outstanding significance: Continued abuse of the forest, through either excessive cutting, burning, grazing, or other agency, results in the final obliteration of the forest cover and such deterioration of the site that timber will no longer grow there. In extreme cases, no cover at all will grow. One of the principal results of continued burning in parts of the California pine region has been the repetition of this process of site retrogression. The forest has been more 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. The same climatic factors which make reproduction of the forest more difficult also create critical fire conditions, so that fires are not only more frequent, but burn with greater intensity and destructiveness. It is therefore not surprising to find that at these lower limits the forest itself has been pushed back and the potentiality of the land to sustain timber has been destroyed, for many years at least. The ravages of successive fires, followed by erosion and leaching, have here critically reduced the fertility and the amount of the soil. (Pl. VII. fig. 2.)

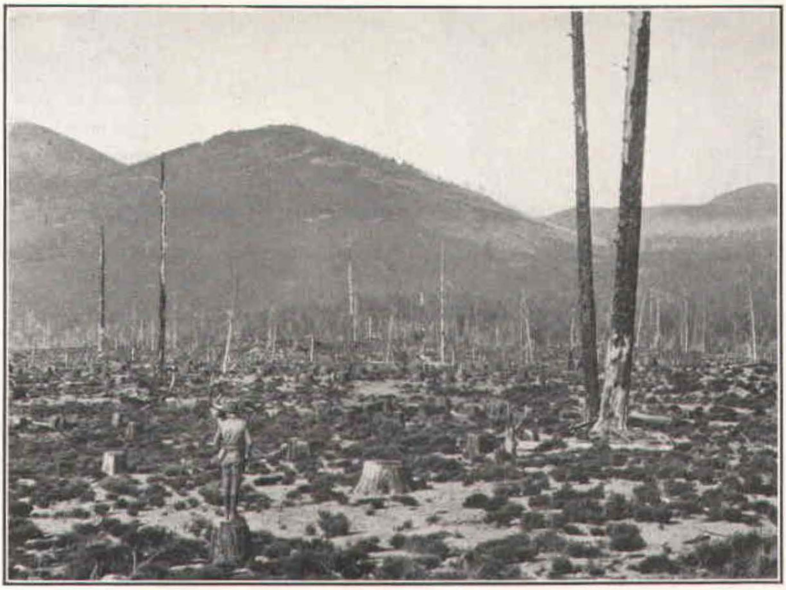
The results of the process have been very clearly worked out in parts of the Mother Lode region along the lower edge of the western yellow-pine forest. The process of retrogession was particularly rapid in this region, not only because of the unfavorable climatic factors, but because of the indiscriminate cutting and burning of the forest following the discovery of gold. There are still to be seen in this region the most striking contrasts of excellent second-growth western yellow pine in the closest proximity to nontimber producing areas occupied only by chamise, the characteristic plant of the true chaparral[10] type (*7*). Illustrations showing the original forested lands contrasted with present conditions, are abundant proof that the ultimate results of continued mistreatment of forest lands are the same in California as elsewhere. The various steps in the retrogression from standing timber to chaparral can be found on the ground within a comparatively restricted scope. Although the extent of this retrogression is not known exactly, the retreat of the western yellow pine from the lower to the upper foothills in certain portions of the Sierra region has certainly amounted to several miles within the past half century, and for the State as a whole an area of many hundreds of square miles has been taken from the timber-producing zone.

In the deterioration of the site as the result of fire, the first step is the destruction of the organic material and microorganisms in the humus of the upper soil layer. After the destruction of the vegetative cover, erosion begins and the surface soil is carried away. Finally, the leaching of the important soluble organic salts in the soil reduces fertility to a minimum (*20*). The moisture-holding capacity of the soil is also reduced and the more drought-resisting plants take possession of the soil.

Whether a particular area subjected to many fires becomes a brush field or remains in timber depends on a number of factors, some of which are purely accidental. Probably the most important factors determining the local distribution of brush fields are topographic. Brush fields are far more common on upper slopes or ridges, because, as already explained, fires traveling uphill become more destructive as they go and the timber at higher elevations is exposed to a devastating heat. A second factor of major importance is the direction of slope, or aspect. A careful examination of the local distribution of brush fields shows that the relative proportion of brush areas on various aspects is approximately as follows: South, 100; west, 75; east, 55; and north, 30. Aspect is not only important as it influences the intensity and severity of fires, but also as it effects regeneration on the drier and hotter slopes. The largest brush fields are found on broad slopes with an absence of topographic interference to the sweep of prevailing winds.

If a present-day surface fire is examined in detail, it is found that by no means all the surface within the exterior boundaries of the burn was actually covered by the fire. Minor natural barriers of various sorts, such as outcrops of rocks, moist spots, patches of noninflammable material, and certain plants such as squaw carpet (*Ceanothus prostratus*) that resist slow, creeping fires, unite to make it possible for a certain amount of reproduction, even small seedlings, to survive fires. Other influences affecting the completeness of a burn

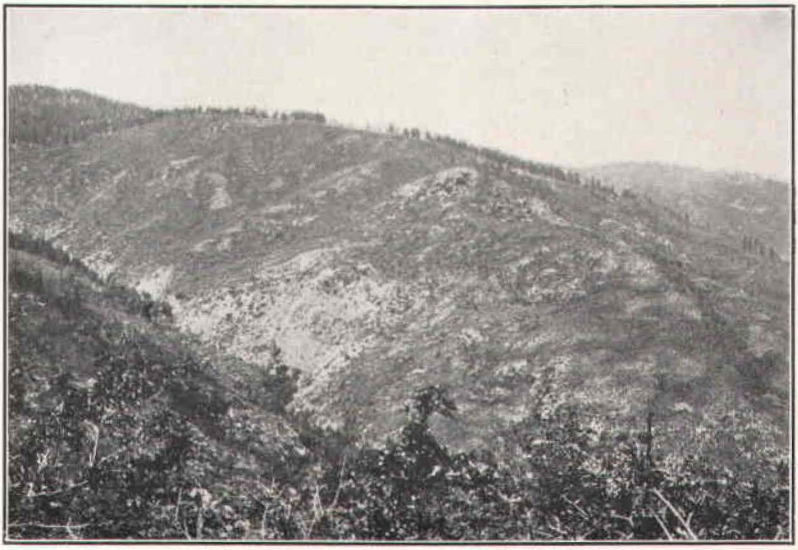
[10] Chaparral is the term applied to the brush cover growing on lands which are incapable of supporting a commercial forest for the time being.



F-156404

FIG. 1.—FROM FOREST TO WASTE LAND AT ONE STRIDE

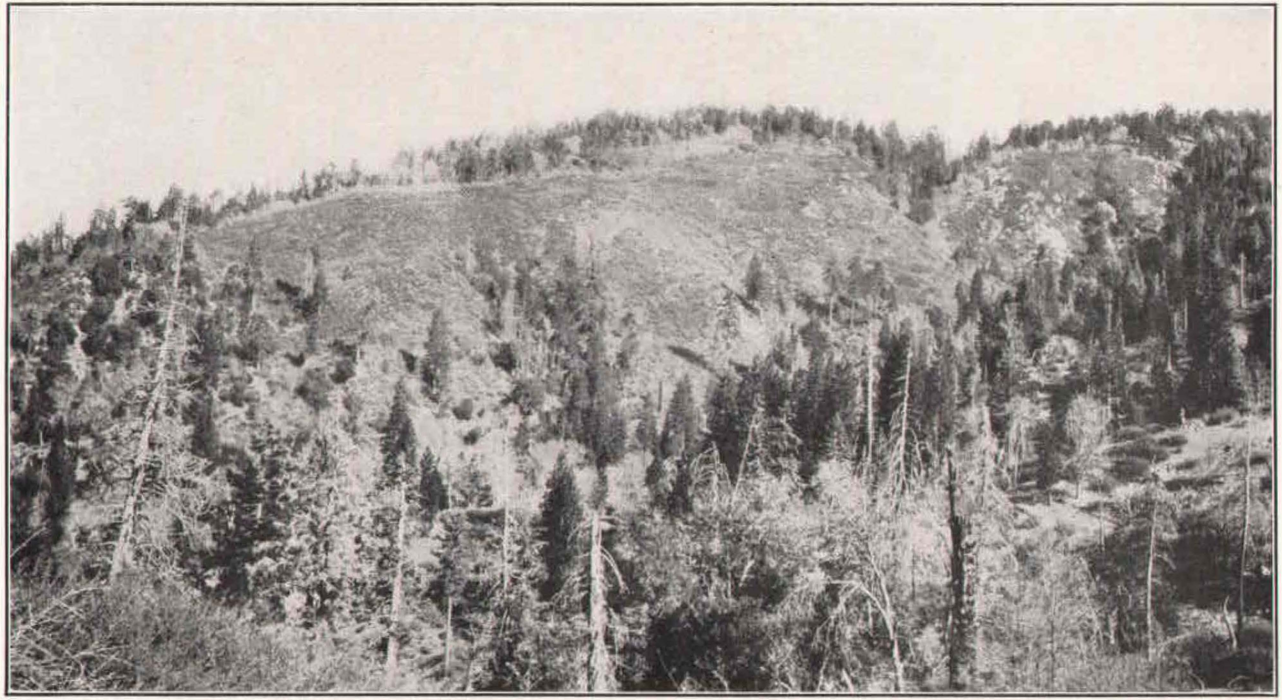
Only a single severe summer fire in the slash left from logging was needed to reduce this high-grade forest land to an unproductive waste but one step removed from the desert. Centuries would perhaps be required to reestablish by natural means a complete forest cover



F-18478-A

FIG. 2.—THE SLOWER PROCESS OF REDUCING FOREST TO BRUSH LAND

On the steeper slopes the timber has first been killed and then consumed by repeated fires, which have at the same time impoverished the soil and left it in many places bare and subject to erosion. The forest has been largely replaced by dense brush fields, which, with their high fire hazard, are a standing menace to the remaining forest as well as to the young trees that get a foothold in the brush. Reclaiming a site like this is slow, difficult, and expensive



F-52350

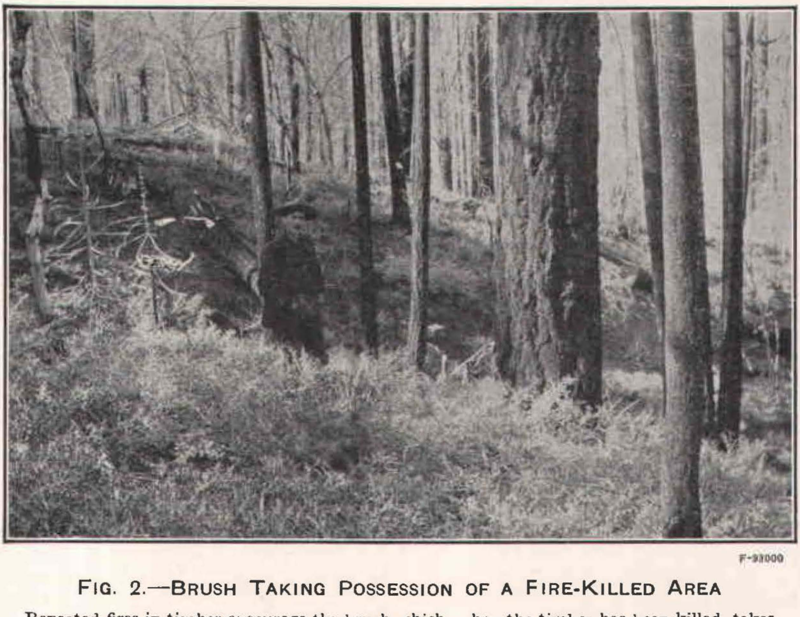
EVIDENCE THAT BRUSH FIELDS ARE THE RESULT OF REPEATED FIRES

The brush field is surrounded by virgin forest, small islands of which occur in protected spots where fires are less destructive. Even in the brush, scattered fire-scarred trees and recently killed snags attest to the havoc wrought by the attrition of repeated fires. This is but the last stage of the attritive process now going on in the forest where fire exclusion is not practiced. A south slope, as shown here, turns more readily to brush, and such brush fields are more extensive, owing to the more destructive fires on south than on other slopes

F-152447

FIG. 1.—WHERE FIRES RECUR BRUSH HAS THE ADVANTAGE

Without fire protection, the forest gives way to the brush field; for sprouts from the stumps and roots of the brush quickly reclaim the area, whereas timber invasion is a long-time process



F-93000

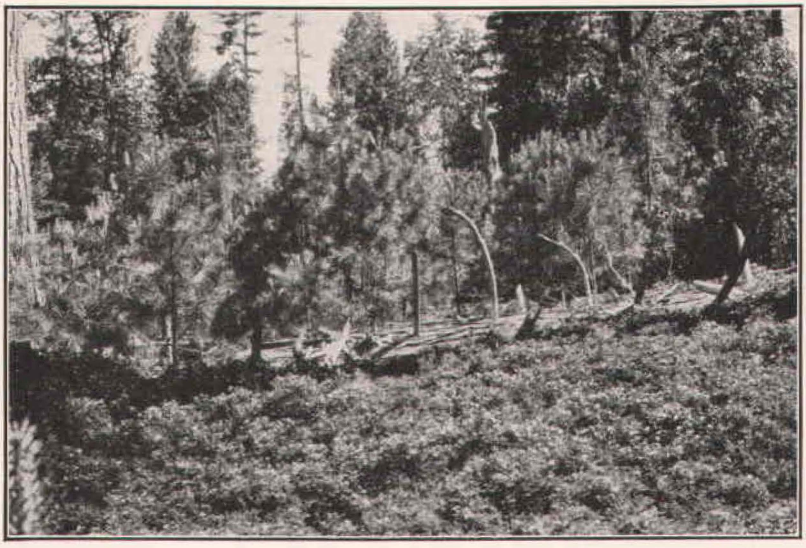
FIG. 2.—BRUSH TAKING POSSESSION OF A FIRE-KILLED AREA

Repeated fires in timber encourage the brush which, when the timber has been killed, takes complete possession. In a few years these snags will fall and a nonrestocking brush field will take the place of the former productive forest

F-50819

FIG. 1.—REPRODUCTION ESTABLISHED THROUGH PROTECTION

This is the response to the exclusion of fire from the brush fields. The young growth has been able to establish itself and will eventually, if fire is kept out, reclaim the brush to the forest type



F-34650-A

FIG. 2.—THE RESULT OF FIRE PROTECTION ON CUT-OVER LAND

Ten years after cutting, as a result of fire protection, the nucleus of a new forest is appearing. With protection continued, the brush will give way to a second growth of young pines are the season when the fire occurs and the direction of wind, the latter largely determining whether fire burns up or down hill.

One major result of past fires has been the stripping of the merchantable timber from nearly 1 acre out of every 7 of timber-producing land. At a very conservative estimate, this represents a loss 36,000,000,000 board feet of timber or, at the present rate of cutting in the pine region, enough to run all of the mills in the region for nearly half a century.

In a comprehensive survey of the pine region of California, perhaps the most striking feature is the vast area of land within the timber belt proper that brush occupies. Disregarding entirely the chaparral, still no careful observer can fail to be impressed with the unproductiveness of what was once timber-producing land.

Out of a total area of 13,625,000 acres in 10 of the important national forests in the central and northern parts of California, there are estimated to be 1,862,000 acres of brush fields. This total area, comprising the Sierra Nevada, the Coast ranges north of Clear Lake, and the cross ranges of northern California, embraces by far the largest part of the California pine region. Table 19 shows both the total extent and the relative importance of the brush fields in the different parts of this region.

TABLE 19.—*Brush-field areas in 10 of the national forests of California*

National forest	Total area[1]	Area of brush fields	
	Acres	*Acres*	*Per cent*
Klamath	1,734,665	254,550	14.7
Trinity	1,724,125	246,200	14.3
Shasta	1,630,000	318,000	19.5
California	1,062,572	201,000	18.9
Lassen	1,306,287	154,490	11.8
Plumas	1,458,140	170,000	11.7
Tahoe	1,106,137	95,000	8.6
Eldorado	835,800	58,200	7.0
Stanislaus	1,104,412	179,230	16.2
Sierra	1,662,560	185,000	11.1
Total	13,624,698	1,861,670	13.7

[1] Includes Government and private land within national forest boundaries.

RECLAIMING THE BRUSH FIELDS

The history of such recent burns as the Howard fire proves that timber stands may be destroyed by repeated fires and that brush then occupies the ground. But just as the fire scars in the timber stands show that the forests have been subjected to repeated fires, so do the older brush fields themselves furnish convincing evidence that they are the result of fires. Although brush fields are spoken of as nonproducing areas, it should not be inferred that forest trees have been completely eliminated from the areas now occupied by brush. The most convincing proof that the brush fields are the result of fire is that within a comparatively short distance there may be found all the gradations from a stand of merchantable virgin timber to a stand of brush with no living trees. (Pl. VIII.) Other evidence that the brush fields were formerly timberland, and have reverted to their present condition chiefly through fires, may be summarized as follows:

1. In the largest brush fields occur scattered patches or islands of virgin forest in naturally protected spots, where our knowledge of present fires shows that timber would be least susceptible to complete destruction. Also living stands of old-growth virgin timber are found immediately adjacent to brush fields and occupying similar sites.

2. Scattered living trees and snags, bearing the evidence of many fires, are not unusual in even the largest brush fields. Even in brush fields with no standing trees or snags a careful search nearly always reveals burnt remnants of tree trunks, stumps, or hollows formed by the complete burning out of stumps.

3. Repeated burnings are shown in charred remains of brush found in brush fields.

4. The woody species occurring as underbrush in the virgin forest are the same as those constituting the cover of adjacent brush fields, and brush is known to sprout after fires in which conifers have been destroyed.

5. Reproduction of coniferous species becomes established in the brush fields wherever seed trees are present and fires are absent.

The composition of the brush fields in various regions and on different sites and elevations varies even more than does the composition of the forest, the climax type. In the same way the timber species that are so generally invading the brush fields vary. One common characteristic of brush fields, however, is that they are themselves due to fire, and that with the exclusion of fire they are being replaced with the climax type, the forest.

Thus, although the gradual process of attrition or wearing down of the forest through repeated fires results in what may prove to be the final victory of the brush over timber species, forest reproduction still attempts to regain a foothold in the brush fields, an attempt to which fire has an important relation.[11] (Pl. IX.)

Estimates made after years of study of brush fields indicate that about two-thirds of their area is reproducing sufficiently to establish eventually a commercial forest. The extent to which tree reproduction is taking place depends naturally on the number and distribution of seed trees available, for regeneration can be counted on to a distance of only a few hundred feet from seed trees. Smaller brush fields, generally speaking, are restocking in a satisfactory manner. It is chiefly in the very large brush areas of 5,000 acres or more, as

[11] In this connection, one fact of outstanding importance should be observed, namely, that conifers in the pine region, unlike the redwood, do not reproduce by sprouting, and that the various species of competing woody plants, ordinarily given the collective name of brush, do so prolifically.

Hoffman's study of the Kinney Creek fire, Crater National Forest, gives the sprouting propensity of manzanita as follows:

Bush number	Main branches of old stump	Burned sub-branches	New shoots
1	3	25	48
2	2	10	32
3	3	15	95

On the Swartz Creek fire, Crater National Forest, Hoffman reports that manzanita established 91 seedlings per square yard after the fire, and that the number of individuals increased 918 times in this instance.

on the slopes of Mount Shasta and Mount Lassen, that complete restocking will be a matter of several tree generations, or of planting.

The very nature of brush fields, with their dense uninterrupted canopy of inflammable material and their heavy accumulation of ground litter, makes them strikingly susceptible to crown fires. Although not all brush fires develop into crown fires, a high percentage of them do. A crown fire in brush will destroy the young coniferous trees that may be present. Many investigations of fire damage in restocking brush fields have been made and all show convincingly that the survival of any tree growth on the area burned is the rare exception. Brush fires, like those in timber, are frequently patchy and do not cover all the area within their boundaries. On most large fires islands and patches escape, but they represent only a small fraction of the total area.

Fires in virgin forests may destroy valuable merchantable timber, the capital stock, and may indeed wipe it out on a small area. Unless, however, fire is repeated a number of times, which is becoming less and less likely as fire protection improves, the forest suffers merely a reduction in density and the area remains in the productive class. Fires in the brush fields, on the contrary, are of serious moment, not because they destroy merchantable timber, but because at one stroke they may sweep the new forest from thousands of acres and even destroy the scattered seed trees that are necessary to maintain the forest type.

The amount of reproduction present in the brush fields to-day is very much greater than would seem on superficial examination, for in many places the young trees are just beginning to break through the brush canopy and to become easily visible. This condition is wholly the result of 15 to 20 or 25 years of fire exclusion. Fire in restocking brush fields now is little less than a calamity. (Pl. X.)

Serious as are the tremendous losses where virgin stands have been converted by fire into brush fields, or where fire has swept the restocking brush fields, they can not be compared with the colossal difficulties the brush fields present in the management and protection of the remaining forests and in the reclamation of these waste areas themselves. Nor, with our present protective system, is the problem even approaching solution. Table 20 shows for a period of years the comparative size of fires in timber and in brush and the relative area of each type burned compared to the total area of each class. Not only do fires in brush attain a greater average size than in timber, but for equal areas of timber land and brush land nearly seven times as many acres of brush land are being burned each year as of timber.

TABLE 20.—*Relative size of timber and brush fires in California, 1916 to 1918, inclusive*

	Timber	Brush
Total area [1] ... acres	10,000,000	5,000,000
Number of fires	1,757	1,878
Total area burned annually ... acres	66,690	204,702
Total area burned annually ... per cent	0.7	4.1
Average size of fire ... acres	114	327
Proportion of fires over 10 acres in size ... per cent	18.3	42.4
Average cost per fire	$25.75	$98.40

[1] Estimated—no absolute figures available.

Recent studies have shown (*23*) that fires in brush are far more difficult to control than those in virgin forest, and attain a much larger average size. Once started, also, they are likely to sweep into adjoining timber stands with an intensity that results in wiping out the immediately adjacent timber belt, thus extending the brush fields themselves.

Fires in brush fields are typically crown fires and partake of the nature of crown fires in timber. The conclusion already pointed out that one fire paves the way for greater intensity and damage by succeeding fires applies in the highest degree to fires in brush. Without exaggeration, it may be said that the ultimate productivity of the pine region and the success of systematic forest management in California depend in large measure on the reclamation of the brush fields.

This is not merely because the productive capacity of the brush lands is essential for our timber requirements, but for the more important reason that it will be impossible to guarantee success in protecting either the virgin forests or cut-over lands as long as the threat of disastrous crown fires in brush exists.

DAMAGE TO WATERSHEDS

In some of the older countries, where the effect of destructive agencies is most thoroughly understood, the secondary or indirect influences of the forest are given as much consideration as its value in producing a wood crop.

In California, Munns's investigations (*20*) have shown clearly the influence of fire not only on the site itself, but on erosion and run-off. Fires seriously reduce the mechanical interference with erosion afforded by the forest or brush cover, and also destroy the fertile vegetable mold or humus of the top layers of soil. This reduction is in itself a lowering of site quality, since the nitrogenous material derived from humus is essential for a vigorous growth of forests. It also adversely affects the moisture-holding capacity of the soil, so that less water is held per cubic foot of soil after the fire than before.[12] Experiments over a period of years show that run-off is more rapid on burned than on unburned areas, and that erosion is more likely to start and to reach more disastrous proportions, and that the flow during the dry period is much less in streams heading in burned watersheds than in those in the forested areas.

In so far as a single fire is concerned, even a very intense or destructive one, the period of heavy erosion does not continue indefinitely; but particularly on brush fields and cut-over areas, where fires are ordinarily severe, site deterioration and erosion after fire have been shown to follow most readily. These secondary forms of damage—site deterioration, erosion, and changes in stream flow—have proved to be very difficult to evaluate, since their effects are not so immediate or so readily discernible as direct damage to virgin timber.

Serious as are the results of fire and subsequent erosion on the forested lands of the mountains, it is at least an open question whether the tributary valley lands are not in the long run affected equally.

[12] Cooper's studies (7) show that the soil of the forest has more humus and consequently a greater moisture holding capacity than the soil of the brush field.

As a change from extensive grain growing to intensive agriculture develops further in the great California valleys, the importance of an adequate and sustained supply of water for irrigation becomes more and more imperative. In some places, irrigation is the very essence of intensive agriculture, as in the citrus belt of southern California. As the valleys of the Sacramento and San Joaquin Rivers are more intensively used, the need for a conservation of irrigation water will become more and more apparent.

The ways in which destruction of the mountain cover damages agriculture are the same in California as in other parts of the world, as many thorough investigations have shown. Reduction of the low-water stage of streams, the lowering of the water table, and the silting up of valley agricultural lands, reservoirs, and ditches are principal effects of forest destruction and are particularly important in regions dependent upon irrigation.

The great hydroelectric development now under way in the California mountains may also be adversely affected by the removal of the forest cover, as silting of reservoirs and the disturbance of run-off reduce the amount of power developed.

The tendency to ignore or undervalue the intimate relation between forest and brush cover on the one hand and agriculture and power development on the other has resulted from two principal conditions: (1) The supply of water for relatively extensive agriculture has been so abundant that there has been no need to take thought of the conservation of the supply. (2) The present point of use of water has been so far removed from the watersheds themselves that the water users generally have failed to recognize that what may affect a far distant forest or brush cover is of vital importance to them. The interests of the valley agriculturists are sharply in conflict with those of the farmer or grazier in the brushy foothill region who shortsightedly desires the wholesale removal of cover by burning.

In short, although water may be used at a point far removed from an area suffering from forest destruction and the effects of forest destruction may not be immediately evident in their relation to the water supply, it can not be doubted that this secondary value of the forests is an important consideration in California as elsewhere.

LIGHT BURNING

TECHNIQUE

Light or controlled burning may be defined as the intentional burning of the forest at intervals, with the object 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. We must, then, distinguish between light or controlled burning proper, which has the specific objective of protecting forests, and general or promiscuous forest burning, which disregards forest values and aims to improve grazing, facilitate prospecting, and render the forest more accessible.

The technique of light burning has varied somewhat during the last 15 years. Different practitioners have evolved different methods, both for controlling the fires themselves and their effect on merchantable timber. In general, however, the fires are set either in spring or late fall, at a time when only the top layers of litter are dry and the fire will burn slowly. (Pl. XI, fig. 1.) The ordinary practice is to set the fires along ridges so that they will spread downhill and thus avoid the damage frequently resulting from fires that run up the slopes. The most elaborate of the plans followed includes scraping away the litter from most of the merchantable trees and even cutting brush and reproduction that stand close to the trees. Another plan, extensively used in flat country, involves constructing cleared fire lines around each 160 or 640 acre tract, felling of snags by hand near these lines, and burning in toward the center from the lines. Following these preparations, burning is practiced in the summer at night.

Others who have employed light burning have merely set fire to the forest litter without any special preparatory measures to protect the trees or control the fire, allowing the fire to run at will unless improvements were in jeopardy.

An elaborate plan proposed, but never put in practice, contemplated first the burning of snags, down logs, and extra large accumulations of débris, followed by a second treatment of the same area, in which ridge tops were burned, and a third treatment of upper slopes and minor ridges; finally came the burning of the gulches lower slopes and other unburned portions. A rotation of from 5 to 25 years was planned, depending on the degree of cleaning up accomplished by the first treatment and the rate of accumulation of new inflammable material. This scheme (*14*) received wide publicity, but was never actually put into effect, and remains merely as one of the few published complete expositions of the light-burning technique.

HISTORY OF GROWTH AND PRACTICE

At the time the large private holdings of timberland were acquired in California 20 to 30 years ago, public opinion in the pine region regarded fire as a benefit rather than a detriment. Tradition credited the Indians with periodic burning of the forest; the crude forms of agriculture, such as grazing, employed fire to induce the growth of forage; in fact, nearly every industry of the early days used fire promiscuously. The simple needs of the population for wood were not seriously affected by forest burning, and forest lands as a source of timber were in people's minds to only a very limited extent. It can hardly be doubted that the public point of view which the early lumberman and timber owner found colored their own ideas and approved general forest burning as an accepted practice of forest-fire protection.

With evidence of past fires in the forests, and the fact that splendid forests had persisted through these fires, it was logical for the timber owner also to argue that periodic burning was not only desirable but necessary as a protective measure against the terrifically destructive crown fire which many of these lumbermen had learned to fear in the Lake States. Any measure that might prevent or mitigate such catastrophes in their new possessions was grasped eagerly. Deeply concerned with maintaining the integrity of their investment, it seemed to the owners of large areas of timberland that to reduce the amount of inflammable material in the forest was absolutely essential; and that if this reduction could be accomplished, the safety of their investment, the merchantable timber, would be assured.

Advance reproduction, as well as brush and litter, they regarded simply as additional fuel. Because the only concern was for the merchantable timber, no value was attached to the destruction of small trees or reproduction.

Thus the practice of forest burning, originally employed by graziers, miners, and others who had no particular concern with the forest as such, was accepted and employed by timber owners who had every possible interest in the preservation of the existing forest.

The establishment of the national forests in California, beginning as early as 1891, thus found forest burning an established practice. The idea that fires could be excluded entirely from millions of acres was generally regarded as preposterous and the most gloomy pictures were drawn of any such attempt. It was claimed that the uncontrollable crown fire was to be expected as the inevitable consequence of allowing ground cover and litter to accumulate. Thus, in the early years of protection of the national forests, the forests were still open as a result of the repeated fires of the past. The great outbreak of incendiarism and agitation for light burning did not come until later. As fire protection became an accomplished fact and the young growth began to fill up the open forest, the amount of inflammable material in the forests increased greatly. Thereupon renewed efforts were made to return to the unrestricted use of fire. The incendiary who desired an open forest and had no concern for the forest itself, and the light burner who honestly desired to protect the merchantable timber with fire, now became two of the most serious obstacles to successful protection, not only because of their direct action, but even more so because of their open preaching of fire. No attempts to suppress the activities of the one or to convert the other could, however, well be successful without facts of fire injury at hand, and these for many years were not available.

RESULTS OF LIGHT BURNING

There has been much discussion of the relative merits of light burning and fire exclusion as methods of protection. The issue had to be met in national forest administration, and it was met by a careful study of the value of light burning for reducing hazards, the direct money cost in its application, and the indirect damage costs. In considering the use of fire for reducing special hazards, answers were sought to three principal questions: (1) Were the objects sought accomplished; (2), what were the costs, direct and indirect; (3) how do the benefits and costs balance? The results of these studies are worth examining in detail.

WITH MAXIMUM PROTECTION—LASSEN COUNTY

The first extensive, deliberate light burning of recent years (*24*) was carried out in the western yellow pine and western yellow pine-white fir forests of Lassen County in the fall of 1910. The operator who carried out this project recognized clearly that even light fires damage merchantable timber and therefore took elaborate precautions to prevent the fire from even reaching the trees he was attempting to protect. The litter and twigs were raked from around the individual trees to a distance of several feet, brush and reproduction were cut and thrown away from the trees, down logs and other débris were carefully removed from standing timber. These precautions were taken even in the case of unscarred trees. In anticipation of a second burning of the area, earth was banked to a height of 6 inches around the largest and most valuable trees, the idea being that needles and twigs would be shed by this bank of earth from the immediate base of the tree, and that subsequent protective measures for the individual tree would be unnecessary. (Pl. XI, fig. 2.) The operator recognized also the extra danger to trees already fire scarred. On such trees the additional precaution was taken of filling in the wounds with rock and earth, with the object of preventing fire from reaching the pitchy scars.

This operation covered an area of 3,000 acres, all level or very gently rolling land with uniform dense stand of timber distinctly above the average for this region. Unusual care was exercised in the burning operation itself. The firing was done in late October after heavy rains had fallen, and it was only between the hours of 10 a. m. and 3 p. m. that the fire would spread at all. Officers of the Forest Service who were present during the burning agreed that the greatest possible care had been taken in protecting mature timber. These men reported that the use of this method was undesirable because of damage to small trees and because of the high cost of the work.

Although exact cost figures were never published by the operator, it was agreed at the time of the burning that the operation had cost approximately 50 cents an acre (*21*). This figure was used publicly in 1910 and 1911 without challenge, although 10 years after the burning it was claimed that the cost was very much lower. But any figure from 8 to 75 cents an acre would represent an enormous expenditure if the practice were applied to even a single national forest of 1,000,000 acres.

In October, 1915, just five years after this burning, careful study was made of this area to determine the reduction, if any, in hazard, and the indirect costs and damages that had resulted. Much of the area looked, superficially, as though it had been untouched by fire for many years. The burn had been patchy, covering not over 50 per cent of the ground. The only positive way of telling whether a particular area had been burned was the presence or absence of fire-killed reproduction or brush. No radical change in the condition of the forest had resulted from the burning.

Assuming that cover conditions on unburned spots had remained constant during the period since the fire, a series of 300 measurements of litter depth, practically equally apportioned to burned and unburned areas, was made. As a result of the fire, the litter depth on burned and unburned areas showed an increase of 50 per cent on the former, or as follows:

	Average (inches)	Maximum (inches)	Minimum (inches)
Burned areas	0.72	1.44	0
Unburned areas	.38	1.44	0

This increase in the inflamable material is closely associated with the practice of light burning, and is explained by the fact that in consuming existing litter a new and often larger source of the same material is created in the shape of needles, twigs, bark, and stems of killed

F-41638-A

FIG. 1.—LIGHT BURNING UPHILL AGAINST THE WIND: EARLY MORNING

On this project the loss due to the fire here shown amounted to 972 board feet an acre. Snake Lake, Plumas National Forest

F-98912

FIG. 2.—MAXIMUM PROTECTION AGAINST INJURY FROM LIGHT BURNING

The earth is banked about the base of the larger trees to afford direct protection to the tree and also to shed falling needles and twigs that would bring the next fire too close. This method has proved both expensive and ineffective, and is impracticable on an extensive scale

F-46061-A

FIG. 1.—FUEL FOR THE NEXT FIRE

This area has been light-burned annually. Each succeeding fire creates fuel for the next one

F-156398

FIG. 2.—A TYPICAL LIGHT-BURNING AREA IN SISKIYOU COUNTY

The general type of country light-burned in northern California. Although the fire in this instance was patchy, much reproduction was killed and not consumed. A large western yellow pine in the foreground has been burned down seedlings, saplings, poles, and brush. Where this increase does not occur, fires must be intense enough to consume entirely the plants killed. The considerable damage to merchantable trees by such fires takes the burns quite out of the class of light fires.

An additional source of increased fuel is the brush which sprouts soon after the parent stock is killed. On the area mentioned not only had practically all the stools sprouted after the fire, but the area occupied by brush had increased approximately 10 per cent. The sprouts had attained an average height of from 3 to 5 feet within five years, so that the amount of this new material was fully as great as before the fire.

As was to be anticipated, this light burning, with all the costly precautionary measures, resulted in no appreciable damage to merchantable timber, for only one mature western yellow pine tree was found burned down. The fire was so light and so patchy that in few spots had damage to any reproduction other than seedlings taken place. Where small seedlings alone occupied burnt areas, they were almost entirely killed; but in some of the dense pole and sapling thickets the fire had beneficially thinned out the smaller and weaker trees. Considering the effects of the fire over the entire area, the data collected showed clearly that the degree of damage was not serious.

The most important conclusions to be derived from the study of this operation may be summarized thus: This area had not been subjected to fire for at least 20 years before the light burn, and therefore represented a typical degree of hazard under protection: Five years after this operation, which, though it caused a minimum of damage, probably cost at present wage scales as much as $1 an acre, the amount of inflammable material on the tract was actually greater than before the fire.

INFLUENCE OF TOPOGRAPHY—SIERRA COUNTY

An area in Sierra County, covering parts of a 2,000-acre tract, was burned in the spring of 1912. Two distinct types existed here. The western yellow pine-Jeffery pine type, with a slight admixture of white fir, very similar to the Lassen County area, occupied the flat or very gently rolling lands. Much reproduction had come in since the inauguration of systematic fire protection, squaw carpet covered a large part of the ground, and the hazard was low. Scattered brush, mostly in isolated clumps, was present, but nowhere made a continuous understory over on extensive area. The rest of the stand, a mixed coniferous type, in which the Douglas and white firs were heavily represented, occupied north and east exposures ranging from 20° to 25° in slope. Large amounts of reproduction were present here, and with distinctly more brush than on the flats.

The area was carefully studied in the fall of 1915, four growing seasons after the fire. No particular measures had been taken to protect the individual trees, and the fire had been allowed to spread until it burned out at roads and other natural barriers. But that this had been a light burn was evident from the fact that in most places where the fire had spread it had consumed only the top layer of litter and left untouched or merely charred the lower and deeper accumulation. Cost figures were never made available by the operator; but the expense per acre must have been extremely low, as the only cash outlay was in the setting of fire.

The first striking feature disclosed was that the fire spread freely through the western yellow pine-Jeffrey pine type, but entirely failed to cover the ground in the mixed conifer type. Dozens of fires had been set on the slopes, often by collecting dry material, but these fires invariably went out after covering a spot a few feet in diameter. This experiment, therefore, went to prove that in a country of diversified topography the flats and warm slopes will be burnable before the cooler and moister exposures.

The value of the burning in reducing hazard was studied in detail by locating sample plots on adjacent unburned portions. The details of a representative sample and check plot are given below:

Plot 2—Burned

Slope.—20° N., 45° E., near bottom of slope.
Elevation.—4,750 feet.
Depth of litter.—Maximum, 0.07 foot; minimum, 0.00 foot; average of 20 measurements, 0.05 foot.
Underbrush.—Whitethorn clumps now cover 30 per cent of the plot, though before the fire not more than 10 per cent was covered.
Reproduction.—Heavy stand of reproduction killed; only one live seedling found.
Hazard.—The trampling by sheep has reduced the danger temporarily, but fire could run over most of the plot.

Plot 2_A—Unburned

(Adjoining area with same conditions of slope, elevation, and exposure)

Depth of litter.—Maximum, 0.09 foot, minimum, 0.00 foot, average of 20 measurements, 0.04 foot. Distributed more uniformly than on plot 2.
Underbrush.—Only one whitethorn alive; several killed by suppression; small amount of grass and weeds.
Reproduction.—Area uniformly covered with dense thickets of seedlings, and small saplings of incense cedar.
Hazard.—Fire danger higher than on plot 2, because crowns of reproduction reach to the ground; no greater, if only litter is considered.

On the burned plots studied in detail the average depth of litter was 0.075 foot and the corresponding check plots 0.058 foot. The actual increase in amount of inflammable material as a result of the fire is further evidence that the practice of light burning gives, at the most, only an ephemeral reduction of hazard. Furthermore, on the burned plots the area occupied by brush increased about 30 per cent within the three years following the fire, due in part to the removal of the competing coniferous advance growth.

A summary of the effect of the fire on the various classes of inflammable material runs as follows, considering the effect first as it appeared immediately after the fire and then as it showed up three years later:

UPPER LITTER

(Needles, etc.)

Immediate effect.—Burned fairly completely.
Subsequent effect.—Renewed by natural fall from timber, from reproduction, and from brush killed; a noticeable increase over that before the fire.

LOWER LITTER

(Compact partly decomposed)

Immediate effect.—Partially burned, charred, or untouched.
Subsequent effect.—Roughed up by wind and storm; more readily inflammable than before.

BRUSH

(Whitehorn, rabbit brush, bitter brush, and sage)

Immediate effect.—Killed but not consumed.
Subsequent effect.—New growth from seeds and sprouts more dense than befoe; areas invaded that were held before by reproduction; litter increased by dead brush.

SEEDLING REPRODUCTION

Immediate effect.—Killed, but mostly not consumed by fire.
Subsequent effect.—No new reproduction; litter from dead seedlings added to that from other sources.

SAPLING REPRODUCTION

Immediate effect.—Killed, 75 per cent; not consumed.
Subsequent effect.—No new reproduction; dead saplings additional source of inflammable material.

POLE REPRODUCTION

Immediate effect.—Some killed; lower limbs on all poles killed.
Subsequent effect.—Dead poles and limbs add to hazard.

MERCHANTABLE TIMBER

Immediate effect.—Occasional large trees killed.
Subsequent effect.—Fall of needles and large quantities of cones and bark from killed trees form the main source of litter on the ground where these trees stand.

SQUAW CARPET

Immediate effect.—In general, not killed or injured, but checked fire and protected seedlings.
Subsequent effect.—Same as before the fire.

SNAGS AND DOWN LOGS

Immediate effect.—None completely consumed, many untouched; evidently developed heat enough to kill large poles near by.
Subsequent effect.—Still as great a source of danger as ever.

Although on most of this area only the top layers of litter were consumed, on at least one small portion intense damage resulted, showing once more that the lightest surface burn, unless extraordinary precautions are taken, will develop sufficient heat locally to destroy merchantable timber. The damage in this case occurred on a low ridge where the fire had simultaneously run up opposite sides and met at the top. Here, within about 2 acres, a total of 26 western yellow pine trees, ranging from 12 to 59 inches in diameter, and with a total volume of 59,000 board feet, were killed outright. Although this loss is not in itself particularly impressive, it points to one of the inherent dangers in light burning, the occasional flare-up of extensive surface fires. The amount of loss from burning down was not recorded in detail. Damage from this source, however, was present over the entire burned area, exceeding in amount the loss from heat killing.

Sample plots on burned ground showed that trees up to 6 feet in height were uniformly destroyed, and the reproduction, considering the area as a whole, is more patchy in its distribution as a result of this fire. The thinning of the smaller individuals is not of itself undesirable and may at times even be a benefit, but it was in these dense stands that the increase in the amount of litter since the fire was most striking.

This fire reemphasized the conclusion previously reached on the Lassen County burn that reproduction standing in squaw carpet is practically immune to light surface fires, because this low-spreading plant is sufficiently fire resistant to stop the progress of such fires.

The most striking contrast between the Lassen County and Sierra County burns is in the direct and indirect costs. On one area, heavy cash investments in protecting merchantable timber were completely successful in eliminating damage to this class of material. On the other area, with no investment in protection of merchantable timber, material loss to mature trees resulted.

DETAILED STUDIES OF HAZARD REDUCTION—SHASTA AND SISKIYOU COUNTIES

An experimental light-burning area in Shasta County, in the mixed conifer type, was burned in March, 1911, with an exceptionally light fire, burning only the top layer of the litter and killing much of the reproduction without consuming it (*22*). The clumps of brush in the burned area were also killed by the fire, but again without consuming the stems, twigs, or even the foliage. This experiment covered only a few acres and was so small that no effort was made to study the effect of the burn on merchantable timber. Instead, efforts were concentrated in determining the effects on reproduction and in reducing inflammable material. Periodic examinations were made of the condition of litter, brush, and general inflammability on a number of detailed plots set out on the burn, the results of which are given in the following paragraphs: Within a year following this light surface fire the inflammable material had reached its original amount and it continued to increase during the period of the experiment. This feature of light burning has appeared so uniformly that it can only be regarded as an inherent result of a surface fire.

Examination of March, 1911, directly after the fire

Condition of litter.—Where less than one-half inch deep, all the litter was consumed, but where deeper only the top layer burned.

Condition of brush.—Killed and partly consumed, but much of it retaining scorched leaves.

Degree of hazard.—Amount of inflammable material much reduced, to the extent that fire could not have spread again at this time.

Examination of October, 1911, six months after the fire

Condition of litter.—Amount now equal to that on adjoining areas, produced by dead vegetation, mainly fire killed.

Condition of brush.—New sprouts varying from 10 to 20 inches.

Degree of hazard.—Amount of inflammable material now equal to that before fire.

Examination of August, 1912, approximately 18 months after the fire

Condition of litter.—Very heavy under dense sapling stands; moderately heavy elsewhere.

Condition of brush.—Sprouts now 24 to 36 inches long.

Degree of hazard.—As before, or slightly increased, with half of needles still hanging on fire-killed reproduction.

Examination of September, 1913, less than three years after fire

Litter still increased by falling leaves; *brush* sprouts increasing; *hazard* greater than before fire, part of needles still on trees, bark and twigs still falling.

More recently an opportunity on a larger scale has been afforded for a conclusive study of the costs and results of light burning as a means of reducing hazard in California pine region.

From early July until the latter part of August, 1920, a fire burned in the Moffitt Creek watershed in Siskiyou County, covering an area of about 11 square miles and causing a heavy loss in merchantable timber both by heat killing and by burning down, averaging 3,390 board feet per acre. The land was privately owned, largely by the Central Pacific Railway Co. The California Forestry Committee, on the request of the principal owner, decided to conduct experiments in light burning here, primarily with the idea of keeping the hazard at a low point and to determine the costs of large-scale operations (*4, 6*).

The first attempt to carry out this project was made in the spring of 1921. After more than a month's efforts only a very small part had been burned. Most of the time rains prevented burning at all, and a few days after the last rain the forest floor became so dry that it was considered dangerous to set fires. In the fall of 1921 slight progress was made in reburning the area. Weather conditions continued uniformly dangerous up to the time of the first fall rains, after which fire would not spread.

Similar climatic difficulties were again encountered in the spring of 1922 when a crew of men tried for 13 days to fire the area and were able to burn only 32 acres. Frequent rains made it impossible to obtain burns even on southerly slopes during the first 10 days, after which the weather suddenly became dry and hot. On the thirteenth day fires spread so rapidly that the work had to be abandoned.

One area of 12 acres, burned in June, 1922, just before the abandonment of the work, the fire being generally light and spreading downhill, was examined in detail in October, 1922. It was found that 6 western yellow pines and 4 Douglas firs, totaling 5,470 board feet, had been burned down, while 4 western yellow pines and 3 Douglas firs, totaling 3,710 board feet, had succumbed to heat killing. The average direct loss from both these causes equaled 765 board feet per acre. Even this small area shows in an epitomized form the results observed on other light burns, that unless trees are individually protected material loss to merchantable timber may be anticipated.

The effect of the light-burning operation on reproduction as shown by a detailed survey on 2.6 acres, was such that of the original stand of 280 seedlings and saplings per acre only 5.7 per cent survived. The area was thus left practically denuded of advance reproduction.

REPEATED LIGHT BURNS—NEVADA AND PLUMAS COUNTIES

It is important to determine whether repeated surface fires actually reduce the inflammable material to the point where forests are immunized against serious damage from subsequent fires.

The only areas on which there are definite facts as to the cumulative effect of several controlled fires, either on the forest itself or in reducing hazard, are the second-growth stands of western yellow pine on private lands in the Mother Lode region. It is known that certain of these stands in Nevada County have been light burned more or less regularly for many years. Some of the results have already been noted in considering the influence of fire on second-growth forests. From these results it is clear that, as with uncontrolled fires in the virgin forest, repeated light surface burns not only do not permanently reduce the amount of inflammable material but actually tend to increase it. (Pl. XII fig. 1.) A splendid illustration of the dubious value of light burning as a reducer of hazard is afforded by a study of the Cement Hill fire of November 26, 1919. This fire, which had been set on one of the periodically light-burned areas, became suddenly accelerated by a heavy wind and covered 600 acres, developing into localized crown fires on several exposed slopes and wiping out every tree on areas of 2 to 4 acres.

It is noteworthy that although the fire occurred late in the fall, the damage was as heavy on the areas where light burning had been practiced regularly as it was in the stands where fire exclusion has been maintained. Nor is this an isolated example of the harmful results from light burning, for it is a fact that summer fires in these light-burned forests are of not infrequent occurrence and are gradually wiping out the stand. As far as second-growth forests are concerned, the data prove that even repeated surface fires under the most favorable conditions do not reduce hazard sufficiently to prevent crown fires.

In all the virgin forests in which light burning had been started from 1910 to 1917 the practice was dropped after the initial burn. This cessation made it impossible to study the effects of repeated burns in reducing hazard except by depending on chance fires or on an experimental burn. Therefore an area on the Plumas National Forest was selected and an experimental light burn stated by the Forest Service in the spring of 1919.

Some 200 acres in the mixed conifer type with wide variations of slope, aspect, forest types and site quality were selected. Before the burning was begun a careful cruise of the original stand was made. In addition, a number of sample plots were established to determine depth of litter, density of reproduction, number of fire-scarred trees, size of scars, and character and distribution of underbrush. A fire line was then constructed around the area and burning was done at night from this line toward the center. Fires were set also along the ridges in an effort to force downhill burning rather than uphill. The area has been burned twice—once in May, 1919, and again in May, 1920.

Fires burned freely but lightly on the warmer and drier aspects. Because of the abundance of squaw carpet, they did not cover all the ground, although a reasonably complete burn was obtained. Simultaneously, fires were set on the cooler aspects; but in spite of repeated efforts, only small patches could be burned. This difficulty of burning has been experienced both times the burning was done, and of the 200 acres within the area only 126 have been burned over to date. As on the Sierra County area, the largest amount of inflammable material exists on the coolest slopes, where the amount of undergrowth and reproduction is materially greater than on the dry southerly slopes. Even at the same elevation, a period of at least two weeks must elapse after south slopes burn freely before fire will spread on north slopes. If burning is postponed until north slopes will carry fire, the south slopes are then so dry that the fire partakes of the nature of a summer burn.

Broadly speaking, this area was divided into two inflammability types before the burning was started.

TYPE 1

Ground cover.—Needles, short herbaceous material, occasional clumps of brush, scattered squaw carpet.
Soil.—Varying from fine to very rocky.
Fire-line construction.—From easy, where soil is not rocky, to moderately difficult where much rock occurs and slopes are steep.

TYPE 2

Ground cover.—Open to medium brush, heavy squaw carpet, bear grass.
Soil.—Generally rocky.
Fire-line construction.—Medium difficult, due to brush and rocky soil.

The first fire covered most of the ground classed under type 1 and little of that under type 2. The second fire again covered most of type 1 and crept in patches over part of type 2. The effect of the two fires on type 1 has been to reduce the amount of litter, but the natural replacement, plus the fuel created by the fires themselves, has made a third fire entirely possible. The effect on type 2 has been negligible. Relatively little of the rather heavy litter was consumed. What brush was killed has resprouted, and the dead material will furnish fuel for the next fire.

As far as can now be forecasted, several more burns will be necessary to reduce type 2 areas to a condition of inflammability comparable to that attained on type 1 to date. The latter probably can not be brought much lower than now; so long as timber is on the area, the natural fall of material will replace annually whatever is burned. On type 2 it may be possible by repeated efforts to reduce the brush to the form of low 1-year-old sprouts and to reduce the accumulation of litter. On such areas, however, fires are dangerous, especially during the preliminary reduction of inflammable material, when a sudden gust of wind may convert an innocuous creeping fire into a hot and damaging one, even in the early spring or late fall.

From the standpoint of reducing hazard, it can not be said that much progress has been made. The more important and difficult of the two inflammability classes has scarcely been touched, and this general type of course is the one that light burning should reach if it is to have any success.

In disposing of standing snags and down logs, the burning so far has been far from successful. Not more than 20 per cent of the standing snags have gone down, and not more than 45 per cent of the down logs have been reasonably completely consumed on the area burned over. The killing of trees by insects has more than offset the reduction of snags existing before the fire.

Light fires may actually increase the amount of inflammable material by creating new sources of fuel. This increase occurs not only in the smaller material but also in large dead trees. On the area under discussion the first fire resulted in burning down a number of large trees. Some of these in falling came into close contact with other trees and clumps of advance growth and reproduction. The second fire fed on and partially consumed some of these down trees, the resultant intense heat killing the standing trees against which they had lodged. Where the down trees had fallen among young trees the latter were wiped out. This area, in this manner, again proves the principle that one fire paves the way for more destruction by subsequent fires.

Table 21 gives the data on damage to mature timber for both fires. The first noteworthy feature is that the loss from burning down is greater in the second fire than in the first. In other words, repeated light surface fires over a given area continue the process of attrition or even accelerate it.

TABLE 21.—*Damage to merchantable timber*

[Snake Lake experimental light burning area. First fire, 105 acres; second fire, 126 acres]

Nature of damage	Loss in trees, by species											
	Western yellow pine		Sugar pine		Douglas fir		White fir		Incense cedar		Total	
	No.	*Bd. ft.*	*No.*	*Bd. ft.*	*No.*	*Bd. ft.*	*No.*	*Bd. ft.*	*No.*	*Bd. ft.*	*No.*	*Bd. ft.*
BURNED DOWN												
First fire	5	13,190	1	120	3	6,010	0	--------	3	770	12	20,090
Second fire	5	17,740	5	14,980	7	9,120	1	170	6	1,790	24	43,800
Total	10	30,930	6	15,100	10	15,130	1	170	9	2,560	36	63,890
HEAT KILLED												
Second fire only	2	170	0	--------	1	100	0	--------	6	1,360	9	1,630
INSECT KILLED												
First fire	5	4,240	38	70,600	3	3,440	2	3,800	0	--------	48	82,080
Second fire	11	6,680	17	32,520	2	1,930	6	8,450	0	--------	36	49,580
Total	16	10,920	55	103,120	5	5,370	8	12,250	0	--------	84	131,660
TOTAL KILLED												
First fire	10	17,430	39	70,720	6	9,450	2	3,800	3	770	60	102,170
Second fire	18	24,590	22	47,500	10	11,150	7	8,620	12	3,150	69	95,010
Total	28	42,020	61	118,220	16	20,600	9	12,420	15	3,920	129	197,180
AVERAGE KILLED PER ACRE												
First fire	----	166	----	673	----	90	----	36	----	7	-----	972
Second fire	----	195	----	377	----	89	----	68	----	25	-----	754
Average	----	182	----	512	----	89	----	54	----	17	-----	854

Another important feature is that direct heat killing did not result from the first fire but from the second, occurring where trees burned down in 1919 lodged against standing living trees and were consumed in the 1920 fire. The actual amount of loss from heat killing is not particularly striking. It does, however, point to the conclusion that some damage of this sort is to be expected if surface fires run over an area repeatedly.

The serious loss from insect attacks, induced by the two fires, has already been noted in connection with that subject, as have the enlargement of fire scars and the formation of new ones. The direct loss to merchantable timber from all causes has averaged about 900 board feet per acre for the two burns.

None of the forms of loss which appear to be inseparable from the practice of light burning are in themselves catastrophes and all are relatively inconspicuous. The cumulative effects of repeated fires inevitably tend, however, toward the gradual reduction of the stand.

The cost of burning on a relatively small area such as this can not be considered as representing what the cost of treating large areas might be, but does indicate that costs can not be ignored.

	Man days
Costs for 1919 burn:	
Fire-line construction	$2\frac{1}{2}$
Setting and control of fires	5
Total	$7\frac{1}{2}$
Costs for 1920 burn:	
Fire-line construction	$1\frac{1}{2}$
Setting and control of fires	7
Total	$8\frac{1}{2}$

Length of fire line, $2\frac{1}{2}$ miles.
Area burned, 105 and 126 acres, respectively.

At average wages this would amount to at least 28 cents an acre for each burning. At average stumpage rates $3 a thousand board feet the indirect cost or damage to merchantable timber would average about $2.75 per acre for each burning.

The effect of the burning so far has been but a very slight reduction in hazard, which has been accomplished at a cost disproportionately great compared to the value of the results.

USE IN INSECT CONTROL—SISKIYOU COUNTY

In recent years, as the value of merchantable stumpage has increased and as every form of loss has been scrutinized more and more closely, owners of timberland have felt grave concern over the serious losses from tree-destroying insects.

The methods of direct control developed by the Bureau of Entomology, United States Department of Agriculture (*11*, *26*), require a considerable outlay of cash, can not be applied over a large area at one time without a highly specialized and trained organization, and are especially adapted to acute infestations. Therefore, in searching for a quick and inexpensive means to control forest insects it was natural that owners of pine timber should be willing to consider the practice of extensive light surface burning of the forest as a possible means of control. The view that light burning not only would control existing insect epidemics but would prevent new ones from starting was first given publicity in 1916 by Stewart Edward White (*27*). As a basis for the theory, the statement was made that serious insect depredations were unknown when surface fires ran frequently through the forests. Entomologists have, however, shown conclusively that losses from insects were prevalent in the past as they are now. That these losses should have been overlooked or ignored by timber owners is not surprising, for they knew little of forest entomology and the loss of a small part of the stand occasioned no trepidation even to owners of pine stumpage.

In late years, therefore, the proponents of light burning have claimed not only that it is an excellent measure to reduce fire hazard but that it is the best, cheapest, and most certain method for controlling tree-destroying insects. The evidence available at the time this theory was most widely announced indicated clearly that light burning was of little value in reducing hazard, and indeed that it tended to increase rather than decrease insect attacks. In spite of these facts, one of the large lumber companies felt justified in initiating some large-scale experiments to test anew the cost and value of the practice.

In 1920 an area was selected in the pure western yellow-pine type of Siskiyou County, located on the level or gently rolling plateau surrounding Mount Shasta. The experiment, judging by the manner of its execution, was based on the following assumptions:

1. That light surface fires caused negligible loss to merchantable trees; and that, therefore, no protection of individual trees was required.

2. That reasonably complete covering of the surface by the fire was necessary, and therefore the burning should be done in summer, when fires were certain to cover most of the ground.

3. That to control the fire it was necessary to divide the area into small burns, each of which could be completed in one night; and that, therefore, the area must be blocked by fire lines.

4. That by burning at night the fires could be controlled and damage to merchantable timber avoided.

5. That the cost of burning plus direct damage to merchantable timber would be less than the cost of intensive systematic fire control until the timber was harvested one to five years from date of burning, plus the cost of controlling a serious epidemic of insects then prevalent on the area.

In the actual burning the area was divided by fire lines into blocks of 160 and later 640 acres. Snags near the line were felled by the saw and fires were set in the evening at the edge of the fire line and allowed to burn toward the center.

The operation was carried out in the summer of 1920, and no additional work was done in subsequent years. An examination by forest officers of the California district was made in July, 1921, by running 4¾ miles of mechanically located cruise lines in cardinal directions and sampling the area sufficiently to give a representative basis for conclusions, or 76 acres in all. Losses were found to be as follows:

Trees burned down, 0.237 per acre, or 425 board feet per acre killed.
Trees heat killed, 0.167 per acre, or 220 board feet per acre killed.
Trees insect infested following fire, 0.334 per acre, or 440 board feet per acre killed.
Trees affected by fire, in all, 0.738 per acre, or 1,085 board feet per acre killed.

The most serious losses were in trees attacked and killed by insects following the fire. Subtracting the average rate of annual loss for this region, where fires have been excluded, which is estimated at 40 board feet to the acre, we have as the amount of loss that can safely be charged directly to the fire 400 board feet to the acre.

As on other areas, an appreciable loss of merchantable timber due to the burning down of previously scarred trees was noted; and again, as previously shown, trees lost by this process were almost invariably the largest individuals with the highest quality of timber, so that not only was the total stand reduced but the average quality of the stand as well. (Pl. XII, fig. 2.) Reproduction was destroyed on about two-thirds of the total area, which was the portion actually covered by the fire.

That the insect epidemic was not lessened but actually accelerated was proved by the fact that the owner in the year following the fire concentrated insect-control operations on the burned area, practically following the methods used by the Bureau of Entomolgy. The trees burned down by the light-burning operation became a center of infestation. The next year the insect-control crews of the company found it necessary to treat these very trees to protect the remaining standing timber. In other words, the burning operation did not accomplish its major purpose, the control of the insect infestation.

At the time of the 1921 examination a practically continuous layer of new litter had formed on the burned area and fire would again have covered essentially the same ground as before. The California Forestry Committee in an examination of the area at the time of burning (*4*) reached the unanimous conclusion that there had been only slight reduction of hazard, which, as a matter of fact, was originally low, as proved by the fact that the burning could be done during the summer months with only occasional flare-ups and without losing control of the fires. This operation demonstrates further that light burning, even when carried out on an extensive scale, under controlled methods, is an expensive practice. The burning done by 160-acre blocks was reported by the California Forestry Committee as costing $1 per acre. Later, when burning was done by 640-acre units, the company reported that the cost was reduced to 37½ cents per acre.

SUMMARY OF LIGHT-BURNING OBSERVATIONS

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 the hazard.
3. The indirect costs or damage, both in the form of merchantable timber and small trees, must be held to a low percentage of the total destructible values at stake.

From the foregoing experiments and studies, the following main conclusions may be drawn.

DIFFICULTIES OF OPERATION

The difficulties of actually carrying out burning under any form of control are very great. In the spring, weather conditions may change so rapidly that, within a very few days after a period when fire will not spread at all, the danger of destructive fires may suddenly become formidable.

If burning is done in spring or fall, the only time when fires can be handled easily and minimum damage can be expected, it is impossible to burn the more moist slopes. Even at these seasons a sudden rainstorm or a sudden hot, dry period may make it impossible either to burn at all or to handle fires except with high expenditures and the likelihood of heavy damage.

When it comes to carrying out light burning in country of broken topography the difficulties are tremendous, due to the variable moisture content of the litter. While it is fairly easy to burn in stands where reproduction and brush is scanty and hazard low, it is extremely difficult to secure a burn where brush and reproduction, which it is desired to remove, are abundant and hazard is relatively high.

RESULTANT HAZARD REDUCTION

A single surface fire reduces hazard only temporarily. In one or two years the amount of inflammable material on the burned area is generally greater than before the fire. Light fires consume but a small portion of the inflammable material, and this material is soon replaced or even increased by the fall of needles and twigs from trees and brush killed but not consumed by the fire.

It has, indeed, been shown, in the Lassen County fire, that five years after the fire the amount of inflammable material was decidedly greater than before the fire. The value of banking trees with earth, which had so carefully been undertaken, had been lost, for the rain had meanwhile leveled these mounds and litter again reached the base of the trees.

What is unavailing in virgin forest is even less advantageous in second-growth stands where even repeated surface fires at frequent intervals do not immunize the stand from devastating crown fires.

Light burning has been carried out successfully only where the inflammable material consisted mainly of litter, with only scattered brush and reproduction. It has not been successful where large amounts of brush and reproduction are present and where the hazard is consequently high. The practice, therefore, has temporarily reduced the hazard only where it is already low.

INDIRECT COST IN DAMAGE INCURRED

A light-burning operation may be regarded, at best, as negatively successful when no damage results to mature timber and only moderate damage to small timber. Unless damage to merchantable timber can be prevented by special protection of the individual trees, the minimum damage to mature timber is of the same nature and magnitude as that from summer fires, namely, the burning down of some fire-scarred trees, usually the largest and most valuable in the stand. In addition, an occasional flare-up on even the lightest fire may be expected to result in a small amount of heat killing of merchantable timber. The enlargement of old fire scars and the creation of new ones inevitably occur where fire reaches the trees. Each fire over a given area must thus be counted on to take its toll of large trees.

Light surface fires, like any other, may induce sudden and intensive epidemics of tree-destroying insects, during which a rate of loss from 8 to 12 times as much as the normal rate may be incurred for a period of at least two years.

Surface fires during any season of the year, under any method of control, destroy practically all seedling reproduction up to 6 feet high on areas actually burned. Since these fires are normally patchy, however, a single or even a series of light fires does not necessarily result in wiping out completely all small reproduction within the exterior boundaries of the burned area. Sapling and pole reproduction suffer less seriously. In exceptional cases dense thickets may even be accidentally benefited by fire through thinning out the smaller competing individuals.

In general, surface fires, even light ones, cause material loss to merchantable timber and excessive loss to reproduction.

COUNTING THE DIRECT COST

The direct cost of light burning, either where individual trees are protected or where the fire is controlled by the previously prepared lines, can not be set at less than 30 cents per acre. On the Lassen County area, as has been shown, the cost, on the basis of present wages, probably would amount to at least $1 an acre, a sum sufficient to give 10 years of intensive fire protection. Since this cost must be repeated indefinitely to obtain a permanent reduction of hazard, the cost to any owner of a large acreage would soon become impossibly high.

The yearly cost per acre of the Forest Service fire-exclusion plan in California has averaged between 1½ and 3 cents, depending upon the degree of hazard. This protection has reduced the total timbered area burned over each year to an average of only 0.6 per cent. If the potential timberlands in the brush fields were included in the computation, the rate of annual loss would be higher; but as light burning proper has not even been proposed for use as a protective measure in this type, it need not be considered. Therefore, the average annual cost of protection, plus loss under a fire-exclusion policy, even with the present moderate degree of protection, is far less than the average cost plus loss of controlled burning.

Wherever light burning has been practiced, material loss has resulted. The best that can be expected, unless expensive protection is given to the individual trees, is the burning down of previously scarred trees. Occasional flare-ups also may be expected which result in heat killing. Insect epidemics are as prone to appear on lightly burned as on heavily burned areas. The immediate value of trees killed in any case is many times as great as the cost of fire prevention would have been.

In short, no light-burned area thus far studied has failed to exhibit the same evil effects of fires that the practice itself is designed to prevent. The magnitude of loss differs from that caused by summer fires in degree rather than in kind. Even if forests are handled only for the merchantable timber they contain, the loss caused by repeated surface fires is large enough to be reckoned with.

If forests are to be handled not only for harvesting the mature timber but for the protection of repeated crops of timber as well, general burning, whatever its intensity, then adds to the loss of merchantable timber the still more serious loss of the advance reproduction that must form the basis of the succeeding crop.

POSSIBLE BENEFICIAL USES OF FIRE

The possible beneficial use of fire must naturally be such as will lie without the range of acceleration of damage, attrition, and site deterioration, or it must take these into account and outweigh them with superior advantages in the particular results for which it is employed.

All such possible uses of fire must be examined with certain specific questions in mind in order that a correct and balanced picture of the benefits and costs may be obtained. (1) Is the specific purpose of the burning attained, and what is its value? (2) What is the money cost of the burning operation, and can the operation be carried out with certainty that the desired results will be obtained? (3) What are the indirect costs of burning, such as damage to merchantable timber or to reproduction? (4) How do the total costs and gains compare?

USE IN SLASH DISPOSAL

The first and most obvious field for the use of fire as a means of forest protection lies in the disposal of slash following cutting. As long as slash exists on cut-over areas, it constitutes a menace to the adjacent timber as well as to the seed trees or young growth. Until it has been mashed down and disintegrated by winter snows and the action of fungi, it is tinder for fires of unsurpassed intensity and capable of great damage. Such fires, as has been pointed out in the discussion on cut-over lands, always leave the burned-over areas in a devastated condition and pave the way for a prompt invasion of brush.

Efforts to reduce this danger and thus remove the likelihood of rapid spread of fire have naturally taken the form of efforts to substitute deliberate, controlled burning for the more dangerous accidental burn. No method of slash burning can be said to be free from some damage to young growth and seed trees. The methods generally practiced strive to reconcile maximum effectiveness, minimum burn, and economy of operation. These aims tend to be mutually exclusive, and the result is that now one and now another is favored at the expense of the others. The three most clearly defined methods in use are broadcast burning, burning in place, and piling and burning.

BROADCAST BURNING

The usual result of broadcast burning of slash as it lies, such as has been common on private lands for the past few years, is that the fire not only removes the slash itself but covers the rest of the ground, at the very least destroying the advance reproduction which is so essential for full productivity of the area. (Pl. XIII.) Broadcast burning on a large scale has been employed in spring, in summer, and in fall from the earliest time when fires will burn until the storms of early winter make burning impossible. The conviction of those who have studied the method, as well as those who have used it, is that it is so uncertain, both in getting the results desired and in indirect cost or damage, that it can not be accepted. It is, at best, but of minor value in affording protection to adjacent bodies of timber.

The previous discussion of the effect of fire on cut-over lands has made it clear that with conspicuously few exceptions the effects are disastrous. Broadcast burnings of slash in the pine region may be dismissed with the statement that the indirect costs or damages to the remaining timber and young growth are excessively high, and that the broadcast use of fire induces occupation of the burned area by brush.

BURNING IN PLACE

A second way in which slash may be disposed of by fire is to burn the separate piles and windrows just as they lie after the logging operation is completed. This method must be employed when the slash itself will burn but the surface between piles will not. In practice, these exact conditions have proved extraordinarily difficult either to forecast or to recognize. The grave danger of burning in place is that conditions may be misjudged and a broadcast burn result. Another disadvantage is that with either animal or machine logging, both of which make trails cleared of reproduction, the slash is left in the strips between trails mingled with the reproduction which has survived from the logging operation. Burning of the slash in place by spot firing has resulted, even under the best conditions, in very heavy loss to young growth. This method is generally less destructive than the broadcast burn, but the cost is materially higher, since the fire must be set to individual piles.

Burning in place has, however, been skillfully and successfully used in some mixed stands of western yellow pine and white fir where only the pine has been logged and where the amount of slash was consequently small, and the trees left were generally large. But with the ordinary type of clear cutting of the forest, this practice can not be considered desirable because it is so uncertain and is frequently accompanied by serious losses. Both broadcast burning and burning in place may result in a complete clean-up of the slash itself, but only at the sacrifice of the major purpose of slash disposal, the preservation of reproduction and seed trees from accidental fire.

PILING AND BURNING

A third method in which fire may be employed in removing slash is that generally used in national forest sales, known as "piling and burning." In this method, as logging progresses the slash is placed in compact piles in openings away from the bulk of the reproduction and seed trees. (Pl. XIV, fig. 1.) The piles are then burned, usually in the late fall at a time when a minimum of damage will be caused to advance growth and seed trees. Constant study and application by many men over a long period of years have developed the technique of this method to a high point and with close supervision its results in actual practice are generally good. Properly used the system cleans up from 75 to 90 per cent of the slash with a negligible percentage of damage to advance reproduction and seed trees.

The necessity for skill and care in these operations may be made very clear by pointing out the following dangers:

1. Misjudging climatic conditions, and burning at a time when fire will spread, with the result of wiping out or seriously damaging advance reproduction and seed trees.

2. Sudden change in weather while burning is in progress, so that fires spread before they can be stopped, with the same result as noted above. Occasionally a heavy rain or snow in the first fall storm may prevent burning for a season.

3. Touching off at one time too many piles that are close together, and thus drying out the litter and spreading the fire.

4. Piles mixed in with advance reproduction, instead of being placed in open spots or on skid trails. This usually follows where supervision

is not close. In this case the piles must either be left unburned or be repiled, otherwise advance reproduction will be destroyed.

5. Making piles too large, too small, or too loose, resulting in any case in serious damage to advance reproduction.

6. Failure to carry on piling progressively with logging, with the result that slash dries out, leaves and twigs fall off, and slash is incompletely cleaned up.

The particular object of this method of slash disposal is the reduction of hazard on cut-over areas, with the minimum damage to advance reproduction and seed trees. Is this object accomplished and to what extent?

At its best, as illustrated on many Government sale areas, piling and burning results in an excellent clean-up of the cut-over lands, with slight damage to reproduction. At its worst, where slash has been carelessly piled and burned it approximates broadcast burning in its effect. Studies on Government sale areas where a good job of piling and burning has been done show that from 6 to 17 per cent of the total ground area is covered by the burned slash piles, depending on the density of the stand and the amount of timber cut. This indicates conclusively that the method can be safely employed in reducing hazard. Cruises of such land show, moreover, that from 75 to 90 per cent of the slash is actually consumed and that the remainder is so scattered as to have no material bearing on the difficulty of fire suppression. To that extent the method represents a legitimate use of fire in forest management. Under present conditions, it is the maximum that can be done toward cleaning up the forest, and the dangers in its employment are controllable.

Does piling and burning insure that any fire that may start can be suppressed within a reasonably small area?

The effectiveness of this measure is shown by the figures obtained on cut-over areas where slash has been piled and burned, showing that the average size of 45 subsequent fires was held to the very low figure of 0.4 acre, as against 9.7 acres for the average of 37 fires on adjacent unburned slash areas (Table 22). The blanket protection afforded all these classes of land had been the same, and the conclusion is logical that piling and burning of slash is an effective means of reducing hazard.

Another point to be considered is whether fires within areas where slash has been piled and burned do as much damage as in areas where the slash has not been so disposed of. Field studies of comparable areas indicate conclusively that while heavy loss of reproduction results from fires even where the slash has been piled and burned, seed trees ordinarily escape, and the fires burn but a small percentage of the entire area. These losses, though severe, are nowhere near as complete or as irreparable as those resulting from slash fires.

It may therefore be accepted that piling and burning slash is a beneficial use of fire and that the indirect costs or damages are not serious if the burning is properly and carefully done.

The outstanding objection to piling and burning is its direct cost. With present wage scales, the expenditure can not be set at less than 35 cents a thousand feet cut, and on many areas it may be as high as 50 cents a thousand feet. Of this cost, at least 85 per cent is taken up by the charge for piling, the burning usually costing only about 5 cents a thousand. If this cost is converted into terms of

F-157079

FIG. 1.—ADVANCE REPRODUCTION BEFORE BROADCAST SLASH BURNING

Such reproduction is the result of fire protection, and means that the new crop of timber on this land is by so many years nearer maturity

F-167515

FIG. 2.—SEED TREES KILLED AND REPRODUCTION WIPED OUT

The same view as that above, after broadcast slash burning, tells the story of a practice that has made many thousands of acres in the California pine region unproductive, a loss to the owner, the State, and the Nation

F-172754

FIG. 1.—SLASH PILED READY FOR BURNING

Where slash is skillfully piled, no more than 6 to 17 per cent of the total area is burned, with but little damage to seed trees or reproduction

F-163546

FIG. 2.—WINTER WORK IN FIRE PROTECTION

A feasible, economical, and safe way to get rid of standing snags, combining safety with economy in that it gives work in the slack season

TABLE 22.—*Effect of piling and burning slash on size of subsequent fires, for a representative operation*

Number and size of subsequent fires	No slash disposal	Piling and burning disposal
Number of fires	37	45
Average size ... acres	9.7	0.4
"A" fires (less than ¼ acre) ... per cent	49	76
"B" fire (from ¼ to 10 acres) ... do	29	24
"C" fires (over 10 acres) ... do	22	0
Largest fire ... acres	165	3

acres, with an average cut for the region of about 20,000 feet to the acre, the impressive figure of $7 is arrived at. Furthermore, this must be considered an investment merely to reduce the likelihood of damage after fires start; it does not eliminate the likelihood of fires starting.

In summarizing, it may be stated that with our present degree of protection, the use of the piling and burning method is a warranted safeguard even at present costs. As our protection becomes more certain in its results, the extensive use of this method may advantageously be modified and in many areas entirely eliminated in favor of more intensive patrol of cut-over areas.

USE IN OTHER PROTECTIVE MEASURES

REMOVAL OF RISK

The reduction or elimination of risk is in some instances a very necessary protective measure, and one which warrants partial sacrifices in the form of fire injury on restricted area. In certain circumstances the elimination of any possibility of fires starting is of such importance that burning off every vestige of vegetation within the specified tract is justified. In general practice, it may be said, the risk can only be reduced and not entirely removed.

The most obvious occasions for this use are at donkey settings, along lines of highways and railroads, and at public camp grounds. Beyond these, the legitimate use of fire in reducing risk is a limited one. The only permanent reduction of risk must be accomplished by eliminating the causes of fire, rather than by reducing the amount of inflammable material.

CONSTRUCTION OF FIRE LINES

The use of fire lines or fire breaks of one sort or another is so common in all forest regions that an extended description of their purpose or effectiveness is not necessary. We are concerned for the present with fire lines only to the extent that they may be constructed by the use of fire.

Perhaps the best recent example is that furnished by a large operator in the California pine region (*16*). Narrow strips were cleared by hand round the outer edges of lines averaging 100 feet on both sides of railroad right of ways, highways, and camps. Fire was then applied along these cleared strips and allowed to burn out the intervening territory. The purpose of these fire lines was twofold—to reduce the inflammable material so that fewer fires would start within the risk area and to make it easier to control fires if they should start. In practice this work has proved to be a pronounced success. Before the systematic attempt at reducing special dangers, the company had spent $10,000 a year in 1919 and 1920 for suppressing fires originating on these risk areas. For 1921 the cost of constructing lines along 6 miles of right of ways, of patrol following trains, and of fire suppression, totaled but $3,600, and damage to cut-over land was reduced to a small fraction of that for either of the two preceding years. The work was continued by the company in 1922. That year 186 fires starting within the risk area resulted in burns totaling only 50 acres.

The point of particular importance is that the method is effective and not excessive in cost. It is now being adopted more and more by railroad and lumbering companies throughout the California pine region. If proper care is used in burning the strips there is little danger of fire escaping to adjoining lands and, once constructed, the effectiveness of the breaks in reducing special dangers is thoroughly proved. Burning of the strips is required periodically, but only for as long as the risk exists, and not so as to involve the permanent relinquishment of the land for forest purposes.

Although the use of fire on forest lands during the period of growth is a violation of the principles so far deduced in this bulletin, and although it naturally results in severe damage to reproduction within the burned strip, the practice is amply justified on the basis of sacrificing a small portion of an area in order to secure better protection on the remainder. If, however, the general scale of fire protection were intensive enough to guarantee success on cut-over lands, the practice would be of doubtful expediency.

CLEANING OF BARRIERS

One of the chief results of repeated fires which has already been noted has been the creation of an almost continuous area of brush along the lower edge of the timber zone, part of which is restocking with forest trees and part of which has reverted to a nontimber type, or chaparral. This area is one of extreme hazard. Fires originating in the brush type are a serious menace to adjacent standing timber, and the problem of insulating the timber zone proper from the adjoining nontimber type is critical in many parts of the region.

A complicating factor in the problem is that the numerous fires in the chaparral areas definitely reflect the state of mind of a minority of the settlers living within this zone. A small amount of forage is available on these areas for a short time after they are burned, while dense unburned fields of chaparral are totally inaccessible to stock. Firing of these areas for low-grade, temporary agricultural use is a common practice and is the most serious handicap, not only in the protection of the chaparral areas themselves but of the adjoining timberlands. Until this practice ceases, protective burns are largely defensive.

An attempt has been made to solve this problem by deliberately burning belts of from one-half to 2 miles in width near the upper edge of the chaparral, or permitting fires to burn here, with the idea that these barriers would automatically stop the run of fires toward the timber zone. The cost of these protective burns has run from 10 to 25 cents for each acre burned.

A serious difficulty has been encountered in making this barrier. If conditions were right for securing a clean burn of the brush, the fires have been difficult to confine within the desired belt; and if the fires were readily controlled, a complete burn was not obtained, thus reducing the value of the barrier.

Although the effectiveness of these protective burns in stopping large fires has not been completely established, experience so far shows that they are of some value in preventing fires originating in the chaparral from reaching the timber belt. The money cost of the burns is not excessive, but even with the best possible control some fires escape either into the adjoining brush fields that are restocking to timber or into the timber itself, so that this secondary cost or damage is therefore not to be overlooked entirely. By far the most important secondary loss, even if the protective burns are confined solely to the chaparral type, is from erosion, which in the section on watershed protection has been shown to be a corollary of heavy burns in this type.

The use of fire for cleaning barriers must in the final analysis be legarded merely as a temporary and undesirable expedient justified rolely because effective protection of the chaparral belt, which is sargely outside the national forests, has not yet been attained.

DISPOSAL OF SNAGS AND DOWN LOGS

Standing snags in the coniferous forest are recognized as an extra fire hazard (*23*), not only because they are often struck by lightning, but also because going fires are spread by sparks flying from them. Their danger is recognized by the universal practice of requiring that they be cut on Government timber-sale areas. That fire can be used advantageously in felling and disposing of them has recently been demonstrated on a large scale in the western yellow pine forests of northeastern California (*25*). Details of this work, in which both standing snags and down logs as well were successfully burned, will be found in the following figures:

Observations made on the Modoc National Forest in 1920

Area covered ______ acres__	2,000
Trees set on fire ______	4,600
Trees burned per man per day ______	115
Average number burned per acre ______	2.3
Total volume of trees ignited ______ ft. b. m.__	5,530,000
Average volume per acre burned ______ do____	2,765
Average time to fire a tree ______ minutes__	4.1
Cost of the operation:	
Labor ______	$218.78
Subsistence ______	30.75
Automobile travel (416 miles at 7 cents a mile) ______	29.12
Kerosene and matches ______	2.30
Total ______	280.95

Not only was the cost of this work, averaging 6 cents a tree or 14 cents an acre, far less than if the trees had been cut with the saw in the usual manner at an average figure of 60 cents a tree, but in addition, because the burning was done in winter, the fires did not spread on the ground and there was practically no damage to reproduction. Considerable additional work has been done with species other than western yellow pine, notably white fir, Douglas fir, and incense cedar, all of which are proverbially difficult to burn after the wood has become at all moist. The success attained with these species is evidenced by the fact that out of 319 snags ignited, 82 per cent burned down and ceased to be a special danger.

These experiments indicate conclusively that this method of ridding the forest of standing snags and down trees is feasible, economical, and safe. It has the additional virtue of being possible to carry on when many other forms of forest work can not be done. (Pl. XIV, fig. 2.)

This method would be highly desirable on timber-sale areas, instead of the more costly falling by the saw method; on areas of high risk, such as along roads, railroad right of ways, and around camps; along natural or artificial fire barriers, as ridges; and along probable lines of defense in fire suppression, such as roads and streams.

USE IN SILVICULTURAL PRACTICE

Quite distinct from the use of fire in fire protection is its use in silvicultural practice. Here as elsewhere the questions as to the value of the operation, the certainty of results, the direct and indirect costs, and the net advantage gained must be pertinently put and answered, before such use can be regarded as legitimate. Three uses in silvicultural practice are presented below, somewhat tentatively, but with evidence to show that the results to be obtained by their careful and intelligent application may more than outweigh the dangers or losses involved.

RELEASING REPRODUCTION

The reproduction of the California pine forest is difficult if a compacted layer of litter covers the ground, for the roots of the germinating seedlings may be unable to penetrate this. The white fir and incense cedar are much less affected than the pines. Consequently under a fire-exclusion policy the tendency is for the reproduction which starts in the mixed virgin forests to be predominantly fir and cedar.

Sample counts of the Snake Lake area on the Plumas National Forest, both on the light-burned and unburned portions, showed in brief that not only is the amount of reproduction greater when the litter is removed than when it is in place, but also that the pines are favored over the firs and cedars. (Table 23.)

TABLE 23.—*Influence of heavy litter on germination*

[Snake Lake burning area, Plumas National Forest]

Species	Number of seedlings to each 100 square feet		
	Litter undisturbed	Litter removed	Percentage increase
Western yellow pine	6	29	383
Sugar pine	2	7	250
Douglas fir	8	15	88
White fir	19	34	79
Incense cedar	25	37	48
Total	60	122	103

Another striking illustration of the influence of heavy litter in preventing successful reproduction was found in the Butler Meadow fire on the Eldorado National Forest. A part of this burn was a very light surface fire which crept through a dense stand of mature white fir. One year after the burn it was found that seedlings had come in at the enormous rate of 20,000 per acre where the litter had been removed by the fire, while in undisturbed litter no seedlings were found, even of white fir.

These illustrations merely prove that fire has a possible use in obtaining regeneration, Obviously, its usefulness must be limited to areas where heavy accumulations of litter in the dense virgin forest have prevented reproduction. Further, burning must be done only where the mature crop is about to be harvested. This will at the same time secure the establishment of reproduction in advance of logging, and insure the possibility of salvaging such timber as is damaged by the fire. The necessity for permitting time for the new growth to become established before logging is evident in the fact that cutting can not be depended upon to be undertaken at the proper time to insure an ample supply of seed, nor can any reliance be placed upon seed in the forest floor where litter is so deep and compact. Also care must be exercised to confine the burn to the specific areas on which the reduction of litter is desired and nothing approaching broadcast burning will be possible.

Where logging is under way, the breaking up of the litter is ordinarily accomplished sufficiently by the logging operation itself. The most serious impediment to reproduction is then competing vegetation, which can not be removed by fire.

CONTROLLING COMPOSITION

The data previously given regarding the relative susceptibility of species to heat killing point to the possible use of fire in controlling the composition of established stands of reproduction. Light fires in mixed stands tend to favor the fire-resistant pines by eliminating the relatively susceptible firs. This differential action of fire thus suggests the possibility of future usefulness, but at present the most important point in regenerating our forests is rather to utilize completely the productive power of the land than to attempt refinements in controlling composition. Furthermore, we can accept established reproduction whether there is as much pine as might be desired or not, and depend on thinning and on silvicultural methods of marking to leave sufficient seed trees to increase the pines in the future stands.

PREPARING GROUND FOR PLANTING

Another special use of fire that has been developed in this region is in burning over dense, nonrestocking brush fields as a preliminary to planting. This has been done with two main purposes, to reduce the physicial difficulties encountered in planting in dense brush, and to give the young trees a fairly even start with the brush during the first few years of the growth, rather than to force competition with a dense overstory already established.

The plan has involved constructing a cleared line surrounding the area to be burned, followed by spring burning, in which fires set along the fire lines are permitted to spread toward the center of the area. Burning in the spring results in complete destruction of the foliage and smaller twigs of the brush. Only the top layers of the litter are consumed, leaving the lower layers and the soil itself unaffected.

The cost on a burn of about 2,000 acres on the Shasta National Forest was 30 cents an acre, including the preparation of lines. Comparative costs of planting in unburned and burned brush fields were $11.50 an acre for the former and $7.08 an acre for the latter. This difference in cost is explained by the much greater ease with which areas on which the brush cover has been removed can be planted. Also, on burned areas, a much closer and more effective supervision of labor is possible. The results obtained, as has been intimated, are correspondingly in favor of preparing dense brush fields for planting in this manner, and when computed on a basis of labor expended greatly reduce the total cost of the whole operation.

USE AS AN AID IN GRAZING

In discussing the historical development of the light-burning theory, it was shown that two separate motives have actuated the proponents of forest burning. Lumbermen and others, interested in the safety and the preservation of the merchantable timber, regarded fire as an active agency of protection. By far the larger number, however, have regarded fire solely from its effect on secondary products and uses of forests, such as grazing, prospecting, hunting, and ease of travel. Although these two ideas have been greatly confused in what has been said and written concerning the use of fire in our forests, the two ideas are fundamentally different. Light burning, nevertheless, has the perfectly legitimate purpose of protecting merchantable timber. Some of the lumbermen who have practiced light burning regard destructive fires in the forests with as much abhorrence as foresters. It is with the hope of preventing just such destructive fires that the practice of light burning has been employed, even if mistakenly.

The other group of forest burners is not interested in the timber, but in purely secondary uses of the land. Of this group, unquestionably, the grazier has been the most active both in actual burning and in preaching the active use of fire. From the standpoint of his desires, the object of fire is not to protect but to destroy the forest, since the types of vegetation in which he is interested occur but sparingly in a dense forest and abundantly after the forest is partially or wholly removed. The best fire for his purpose is the most destructive, and though his purposes have frequently masqueraded under the euphemism of light or protective burning, they are, in reality, wholly inimical to the objectives of even the true light burner.

This group has not only burned forests until they ceased to be forests, but have continued the burning of the brush fields that have followed the forests, until in some cases a true chaparral type with little value even for forage has finally become established as a result of site deterioration.

The facts concerning grazing and the use of fires may be stated briefly, without attempting to recite in detail the specific available proofs.

Fully stocked forest, whether even-aged or uneven-aged, with abundant reproduction, contain little forage, because the trees occupy the space to the practical exclusion of other plants. Fires in this type, in so far as they remove the timber cover, allow the entrance of other plants including those of value for grazing. The present extensive use of the virgin forests for grazing is possible only because, as a result of past fires, these forests are not fully stocked with timber. Therefore the use of fire in timber stands as an aid to grazing is permissible only if the highest value is for grazing and not for timber. The annual value of the forage crop on an average acre in the California mountains is, as a matter of fact, but a fractional part of the value of the potential yearly timber growth.

Fires in the brush fields, themselves the result of fire, make it possible for stock to graze areas which would otherwise remain unutilized. Many of the forage brush species, if not burned frequently, attain such a stature that stock can not readily browse them; and in certain types of brush the succulent sprouts which appear after a fire are palatable while the older and tougher shoots are not. In brief, heavy burning in brush fields is evidently beneficial to grazing. It is not, however, beneficial to the reclamation of the brush land by forest.

The use of fire in brush fields within the timber zone therefore depends upon the use to which the land is to be put. This should in turn be determined by the values represented by these uses. That the highest use is for forest in most cases is well shown by the fact that the average annual growth to every acre given protection will be at least 300 board feet, which, though far less than fully stocked stands will produce, is worth at the very lowest estimate 50 cents an acre a year, while the average annual returns from grazing on the best of these areas does not exceed 15 cents an acre a year and are usually much less.

A third class of land upon which fire has been employed to improve grazing is that loosely spoken of as chaparral and already defined as land which, either because of adverse site or because of past abuse by fire, is no longer capable of producing timber in commercial quantities. An enormous area, estimated (*20*) at 9,000,000 acres for the entire State, largely outside the national forests, is still being subjected to repeated burnings, both to increase the amount of palatable feed and to render accessible the feed which already exists.

It has been found that burning of this type of land results in a large temporary increase in forage, particularly grasses. A study of this development, covering a burning in chamise in 1915, and followed closely for six years, showed that while the fire was a pronouned success in increasing grazing values, it encroached to some extent on the present timber belt and caused severe erosion on the burned area. Cooper indicates (*7*) that such repeated fires have extended the chaparral type into the forests and have also resulted in the final reversion of chamise types to grassland.

It appears incontrovertible that one or more fires in the chaparral belt are at least a temporary benefit to grazing. But it has already been noted that erosion is a matter of such serious moment on lands of this type as probably to far outweigh in importance the relatively small increase in the grazing value. Also, as already pointed out on those chaparral areas that were once forested, the gradual restoration of site quality necessary before forests can again occupy the land can not possibly take place while even occasional fires occur.

The whole question of grazing and fire can be summed up by saying that in the California pine region timber production and forage production necessarily conflict; that what is a benefit to 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.

THE RELATION OF DAMAGE TO FOREST MANAGEMENT

The preceding definition and discussion of the various ways in which fires cause physical damage to the forests of the California pine region have shown that the present condition of the forests is in itself the cumulative result of centuries of repeated fires, and that even a single fire contributes perceptibly to this process of deterioration.

The discussion of the effect of fire would, however, be incomplete if it were confined to the present physical condition of the forest. We are at the point in the silvical and economic history of this country where the effort to preserve forest land for future forests and to obtain the highest permanent yield from such forest areas is of prime importance in the Nation's welfare. The rôle of fire is consequently nowhere more significant than in the sphere of forest management, or in determining what can and what can not be done in managing our forest properties more intensively in the future.

EFFECTS ON LOGGING COSTS

Loss from fire must always be considered in terms of both quality reduction and quantity reduction. Both these forms of attrition affect the merchantability of timber and the cost of logging.

Quality reduction is effected in the destruction of the largest and most valuable individual trees, and in direct loss of the best quality of wood in standing trees. One of the principal agencies of this form of loss is the fire scar, which destroys the wood of the butt and leads to burning down, windfall, and the entrance of insects and fungi. In the virgin pine forest, the trend of all fire damage, save heat killing and the rare crown fire, is to eliminate the oldest, the largest, and therefore the most valuable individuals from the stand.

Quantity reduction, or the work of attrition in thinning out the maturing stand, is a direct tax on what in logging costs is called the fixed investment. In modern logging the fixed investment is heavy, especially in railroad construction, and must be charged against the crop or the product derived from the specific area. If a body of timber is reduced in volume by even 10 per cent, the construction charge for each thousand board feet is correspondingly increased for the remaining 90 per cent. The increase in yarding costs brought about by quantity reduction is, within small limits, of minor moment, since it proceeds principally from the increased frequency with which donkey engines must be moved, an operation that ordinarily costs not more than 10 cents a thousand board feet cut. On poor sites, however, and often such as barely justify logging at all, a loss of even 1,000 or 2,000 feet an acre may remove the stand entirely from the exploitable class. How this is worked out in practice is shown below.

In the first area, representing 300,000,000 board feet of annual cut, located on the west slope of the Sierras, in a mixed conifer type, the average stand per acre is reckoned at 28,000 board feet. Railroad cost per thousand board feet is $1.80; yarding cost, which involves moving of outfits from landing to landing, is $0.51 per thousand; a total of $2.31 per thousand board feet. Both these factors of cost are affected by density of stand. To what extent the total cost is affected by reduction in stand per acre is apparent in the following figures:

Reduction of 500 board feet increases cost $0.04 per 1,000, or $1.12 per acre.
Reduction of 1,000 board feet increases cost $0.085 per 1,000, or $2.38 per acre.
Reduction of 1,500 board feet increases cost $0.13 per 1,000, or $3.64 per acre.
Reduction of 2,000 board feet increases cost $0.18 per 1,000, or $5.04 per acre.

Similarly, on an area on the east slope of the Sierras, in the western yellow pine type, representing an annual cut of 265,000,000 board feet, where the average stand per acre is 18,000 feet and the railroad and yarding costs are respectively $1.50 and $0.51 per thousand, the following increases of cost in inverse ratio to reductions in stand per acre would be met:

Reduction of 500 board feet increases cost $0.06 per 1,000, or $1.08 per acre.
Reduction of 1,000 board feet increases cost $0.12 per 1,000, or $2.16 per acre.
Reduction of 1,500 board feet increases cost $0.18 per 1,000, or $3.24 per acre.
Reduction of 2,000 board feet increases cost $0.25 per 1,000, or $4.50 per acre.

Thus, while quality reduction brings the more valuable stands gradually down to the level of the poorer ones, quantity reduction is taking these poorer stands out of the merchantable class altogether. In one of these two ways, even the lightest fire that runs through the forest is having its part in destroying timber values for the landowner and for the logging operator.

EFFECT ON SILVICULTURAL PRACTICE

Not only do fires affect the possibility of exploiting the forests, but they also make the problem of securing natural reproduction much more difficult. Where no sale of mature timber is possible the only silvicultural measure available is fire protection. Many stands of excellent timber are so isolated in the vast brush fields of this region—virtually waste land from which timber has been driven by fire—that the expense of reaching and exploiting the scattered islands of valuable growth still found here and there is not justified. And even where the process of repeated fires has not produced the brush-field stage of retrogression, it has often so far reduced the density of the stand that there are no continuous bodies of merchantable timber large enough to justify modern logging operations, with their heavy investment in transportation. The resulting inability to encourage reproduction through cutting must remain until timber becomes much more valuable than it is now, or until, with the help of fire exclusion, the stands are enabled to build up sufficiently to warrant exploitation.

An illustration of this situation is to be found in the Shasta National Forest. Out of an area, in round numbers, of 803,000 acres of Government land, approximately 215,000 acres are brush fields, and an additional 143,000 are protection forest or naturally treeless or barren land, leaving an area of 445,000 acres classed as timberland. Of this, some 22,000 acres have already been cut over under silvicultural management and an aditional 30,000 acres can be exploited profitably under present economic conditions. The balance of this area, 393,000 acres, consists of open, understocked stands of patches of excellent merchantable timber surrounded by brush, or of forests so badly decayed that the mature timber is practically worthless.

The difficulty of silviculture and management on stands where, through the influence of fire, defective trees of inferior species are abundant, may become very serious. Decay entering through fire scars has in many localities rendered white fir and incense cedar in particular so defective that it is often extremely difficult, in national forest sales, to have them cut as closely as good silvicultural practice and sanitation, or the removal of infected trees, demand (*17*). On Government timber sales these problems have been measurably solved by making the valuable pines carry the losses due to the removal of the inferior species. On private lands, with unrestricted cutting, the general practice is to cull out the more valuable species and some of the more sound trees of inferior species, leaving as a nucleus for a new forest the most badly decayed and least valuable species and individuals.

Silvicultural practice is difficult enough under these circumstances, but in reproducing areas even these difficulties are multiplied. There, as elsewhere, the average yearly loss from fire must be known and discounted in calculating for the future. Serious fires, which may delay growth or destroy the growing stock, can entirely disrupt a working plan. In merchantable forests under the present scale of protection the losses from fire can be stated with a fair degree of certainty; but for brush fields and cut-over areas the extra hazards have not yet been sufficiently recognized, nor has it been realized that especially intensive protection is necessary there.

The problem of the brush fields is perhaps the most serious one to be met in fire protection in this region. The fires here are crown fires in effect, spreading rapidly and becoming difficult to control. They ordinarily result in the complete wiping out of all reproduction and frequently of all seed trees, thus reducing many areas from a timber-producing to a nontimber-producing type. The momentum acquired by fires in brush, too, tends to carry them with a rush into adjacent timber, gradually pushing back the forest and enlarging the brush field. Satisfactory protection of present timberlands can not be guaranteed while the threat of the brush fire exists; and as long as large fires continue to occur even very occasionally in brush fields and cut-over lands no effective system of silvicultural management of these lands is possible.

Forest management is thus seen to be practicable only where a high degree of protection is put into effect. This prerequisite any workable theory of protection must provide for, and on brush and cut-over areas nothing less than fire exclusion can fulfill this requirement.

THE THEORY OF FIRE PROTECTION AS CONTROLLED BY FIRE DAMAGE

Two principal theories of fire protection have been proposed (*23*). One of these, the minimum cost, or economic theory, postulates that the intensiveness of protection shall be such that the sum of protection, suppression, and damage costs shall be a minimum. The other has been termed the minimum damage theory and postulates that burned areas and hence damage shall be kept at an accepted, arbitrary minimum.

THE MINIMUM-COST THEORY

The minimum-cost theory can be regarded as a clear-cut, sound, and workable theory only if there is a relation between intensity of protection and the reduction of damage, and if the facts and value of damage can be readily and accurately determined in advance. The first of these conditions is thoroughly proved, but the second is practically impossible. The true extent of damage, even in the virgin forest, is not easily determined, for many years must elapse before all the facts are at hand. The immediately evident losses are thus usually erroneously accepted as the complete and final result of fire.

Table 23 shows the extent and value of the various types of measurable damage to virgin forest, using the averages derived in this study.

TABLE 24.—*Summary of fire damage to merchantable timber*

Type of loss	Average per acre (feet b. m.)	Value
Direct immediate physical loss:		
1. Heat killing	1,500	$3.00
2. Burning down	1,000	2.00
Secondary physical losses:		
1. Reduction of growth	500	1.00
2. Insects	1,000	2.00
3. Fire scars	250	.50
4. Fungi	(1)	(1)
Indirect financial losses:		
1. Reduction of quality		
2. Increase in logging costs	3,500	7.50
Losses to other resources:		
1. Water	(1)	(1)
2. Soil	(1)	(1)

[1] No definite figure.

So long as the fire damage in merchantable virgin forests is considered to be merely the direct immediate physical loss, there is a serious undervaluation of this factor in the minimum-cost theory formula. But even with such an inadequate appraisal of damage, the damage factor far overshadows the cost of protection.

A third consideration vitally affects the value of the mimimum-cost theory, and is even more difficult to weigh accurately. This is the task of determining and valuing the importance of forest in modern civilization. Forest economists (*9, 28*) have shown convincingly that the stage of civilization is intimately related to the condition and use of forests and indeed that the secondary and indirect benefits may outweigh their value as a source of useful products. Whether in the future forests will be more or less important than they are today is purely speculative, but certainly there can be no question that forests will continue to be one of the fundamental physical bases of civilization as we conceive it at present.

Therefore, in considering the rôle of fire in forest, we can not overlook the vital conclusion that the continued existence of forests is of paramount importance, for countries which were once forested and later denuded give striking proof of the dependency of civilization upon forests and of the impossibility of expressing in terms of money the value of such fundamental, primal requisites. A theory which proportions protection to a supposed money cost of damage can not in the larger sense be considered acceptable, even for our virgin stands.

Further, while damage in virgin forests is ordinarily confined to a reduction in the quantity and quality of the stand, without annihilation of the forest, fire damage in restocking brush fields and cut-over lands is of a different degree. Complete or nearly complete destruction is the rule rather than the exception with fires on such lands. A given degree of protection which merely keeps these lands at their present state of relative unproductivity is for all practical purposes a useless expenditure of money. The present degree of protection results in an average fire rotation of 160 years for timberlands, even including the open and understocked stands, and an average of less than 30 years for brush fields. It may, therefore, fairly be said that the objects of protection are being measurably accomplished in one case and are not in the other.

The minimum-cost theory is particularly difficult to use in considering brush fields and cut-over lands. It may well be impossible to justify statistically the necessary expenditures for complete exclusion of fires, the fundamental requirement once an area of brush land is dedicated to the production of timber. But no halfway measures can apply. This study has shown clearly that the primary need of this class of land is complete protection. Any theory which fails to recognize this must ultimately fail in its application and can at best result in merely maintaining the status quo. The brush fields, as now, will continually be just coming into a state of productiveness, after a period of decades devoted to the establishment of reproduction, only to be again swept by fire.

Thus the principal difficulties in applying the minimum-cost theory of protection to restocking brush fields are:

1. The factor of damage in the equation can not be readily determined because it depends on an assumed interest rate, on assumed stumpage values, and on a knowledge of yields which we do not possess.

2. The expenditure for protection during the first timber rotation is partly a capital investment and can not be charged entirely to the initial crop, for adequate protection not only assures the maturity and harvest of the advanced growth already on the ground, but perpetuates the forest without the expense of artificial regeneration.

THE MINIMUM DAMAGE THEORY.

The most simple and direct statement of our objectives as applied to forest lands is contained in what is termed the minimum-damage theory.

To the extent that present expenditures make it easier and more certain to establish future forest crops after the first is harvested; to the extent that systematic fire exclusion produces a type of cover which makes fire protection itself more easy; to the extent that site quality improves as a result of fire protection—to this extent it is evident that a great part of the money that must be spent in growing the first timber crop can not be properly charged against that crop. It is a capital investment in the land itself which will benefit successive timber crops.

Even the most ardent advocate of forest production will recognize that on very poor sites and where logging is physically impossible the deliberate production of timber for a wood crop can not be justified, but the danger of confusing current and capital expenditure is that, through mathematical computation and by charging all expenditures to the initial crop, it is easily possible to make timber production even on favorable sites appear financially unwarrantable.

Systematic fire protection in the virgin forest has as its object not merely preventing losses, but building up the forest and the quality of the land itself, both of which are, in part, capital investments.

In the brush fields, so far as our present experience goes, something more than the intensive use of man power is required to guarantee successful protection. A very comprehensive system of protective measures will be needed, such as will include the construction of firebreaks, trails for rapid communication, and similar improvements serving to break up large units into smaller ones and make for easier fire control. It is clear that such expenditures are investments rather than carrying charges against the initial crop. This distinction between carrying charges and capital investment in the land is one of fundamental importance when the financial aspects of reforestation are considered.

If the brush areas continue in their present condition, the cost and success of protecting adjacent timber stands will be vitally affected. A weakness of the minimum-cost theory is that it tends to consider each acre of land by itself, as something apart from the forest area or region as a whole, whereas the problem is as complex as the forest region itself. What is accomplished in the regeneration of the brush fields is of the greatest importance not only to the brush fields but to adjacent virgin forests. It follows, therefore, that the cost of protecting the brush fields is properly chargeable not only against the particular area but against near-by lands.

In restocking brush fields the overwhelmingly important element in the cost of producing timber is fire protection, a great part of which is capital investment; but the impossibility of stating precisely which part of such expenditure is a capital investment makes any but the most simple and direct fire-protection theory impracticable in actual application.

To determine the justifiable protection expenditures for chaparral areas is even more difficult than for restocking brush fields. The damage resulting from fire in chaparral can not be readily discerned nor accurately valued, since it consists mostly of indirect damages such as injury to watersheds, erosion, etc. The minimum-cost theory of protection applied rigidly to these areas would lead to the same absurdities as in the restocking brush fields.

If the facts and figures given in this bulletin point to any one conclusion relative to a desirable theory of fire protection, it is that the degree of protection in the California pine region can not be mathematically restricted but must in all instances be sufficient—once it is determined that a given area is to be devoted to forest growing—to insure the continuity of the forest on such a high level of quality and quantity as to justify the total effort of forest management. The minimum-damage theory provides for this. It recognizes fire not merely as an enemy of the timber crop now standing, but as a ruthless foe to the very existence of the forest, and one whose destructive work is always cumulative and always aimed at finally reducing forest land to worthless desert or chaparral.

Applied with a reasonable degree of intelligence, the minimum-damage theory is a more economical method of attacking the fire problem than the minimum-cost theory. It provides a complete rather than superficial and immediate plan of action. It considers all forms of loss and total damage rather than merely the more obvious and less important losses. It takes into account the full possibilities of the land, as well as the immediate crop, and so protects the capital values. But perhaps the strongest evidence of the superior economy of this theory is that with every fire or fire-threatened area handled on the basis of insuring minimum damage, the risk of subsequent fires is lessened and future losses are reduced. The destructive processes of acceleration and attrition which this bulletin has endeavored to bring out in their true guise can be checkmated only by fire protection planned on such a basis.

SUMMARY

Throughout every section of the detailed examination of the rôle of fire in the forests of the California pine region there have appeared two principal phases which may fairly be regarded as major conclusions of the entire investigation.

1. Fire in the 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. This process of acceleration has characterized the action of fires through past centuries and is of outstanding importance in the fire problem to-day. 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.

2. Fires in the virgin forests of the California pine region rarely are catastrophes, for they do not wipe out at one stroke the entire stand over a large area. Indeed, they are generally distinguished by the fact that much of the damage is relatively inconspicuous and not immediately evident. But a study of the fires of the past and those of the present shows unmistakably that attrition is the inevitable concomittant of repeated fires. This wearing down of the forest is remarkably exhibited in all its varied stages in the California pihe region to-day, from the well-stocked areas of mature timber to the nontimber-producing chaparral. The fire-scarred virgin forest; the broken, patchy timber stand of no present merchantability; the brush fields with scattered, isolated trees, and small groups of trees; the continuous brush fields occupying potential timberland and restocking only slowly; and finally, pure brush or chaparral, the end product, are but the different chapters of the story of attrition.

The rapidity with which the processes of acceleration and attrition operate to reduce the virgin forest to a nontimber-producing chaparral area varies widely, depending on a large range of factors, the most important of which is site quality. Even the lightest spring surface fires, such as have been used in an attempt to reduce fire hazard, exhibit the same destructive tendency toward quality and quantity reduction as do the more devastating summer fires. In the virgin forest the initial steps of attrition and acceleration are slow; but in brush fields and cut-over lands of the present day we find these processes in their most destructive and consequential phases, since here even a single fire ordinarily accomplishes the annihilation of the new forest.

Through site deterioration effected by centuries of acceleration of fire damage and attrition from fire injury, the forest of to-day has assumed a definite character very different from what it is popularly supposed to be. The general public viewpoint that the national

forests of California are large unbroken reservoirs of timber is thus not altogether in accordance with the facts. Large areas of these national forests must be considered rather as a future source of timber, depending largely on care and cultivation, than as a source of material available immediately for exploitation.

Some beneficial uses of fire appear. Instances have been mentioned in which fire has beneficially thinned out young growth or assisted reproduction in other ways, purely by chance or accident. But much more evident from the data here presented has been the conclusion that in the main the damage from even the lightest fire has definitely contributed to destroying the value of timber and timberland. This cost, when truly estimated, has been shown to be greater than the cost of fire exclusion.

That maximum protection or fire exclusion inevitably increases hazard by the encouragement of undergrowth is, of course, true, but such added hazard in no way vitiates the reasons for protection. It is an additional danger, but one that can willingly be accepted.

Uses of fire which are contrary to the interests of the forest, such as the firing of the forests or reproducing areas for grazing purposes, are incompatible with timber growing. With rising timber values, grazing will doubtless take its place as subsidiary to silviculture. In the pine region trees are a far more profitable crop than forage. Nor is it by any means proved that fire is the friend of the grazier that he has been wont to consider it, whatever the nature of the land on which it is employed.

The old misconceptions regarding the rôle of fire in the California pine region can profitably be cast out and destroyed alike by the timber owner, the possessor of potential forest land, the lumberman, and the forester. It is to the interest of all who have to do with these forest areas to recognize that the true rôle of fire is that of destroyer and that any policy of protection must first insure the highest practicable degree of protection, amounting to fire exclusion in brush and cut-over tracts. It is to their interest further to grasp the economic truth back of such a policy, namely, that protection is not merely a temporary measure to get a maximum first crop of timber, but that it is far more in the nature of a permanent investment in building up a highly productive permanent forest.

Much of the progress of forest management and of fire protection itself thus depends on a thorough knowledge of fire damage. The more intensively fire damage is studied, the more evident it becomes that a complete appreciation of its importance is fundamental to a sound and workable philosophy of fire protection. Conversely, failure to appreciate in full the rôle of fire in our forests may easily lead to an inadequate scale of protection which, in its broadest aspect, serves merely to maintain the present unsatisfactory condition of our forest property, a condition in itself the outcome of centuries of repeated fires.

The present values of second-growth timber and the trend of prices upward, as well as the obvious future needs of the country, now compel consideration of adequate protection, as a precautionary measure for the private owner, and as a public necessity.

LITERATURE CITED

1. BERRY, SWIFT. 1921. Value of young growth on cut-over land. *In* Jour. Forestry, v. 19, p. 907–916.
2. BOYCE, J. S. 1920. Dry rot in incense cedar. U. S. Dept. Agr. Bul. 871. 58 p.
3. ——— 1921. Fire scars and decay. *In* Timberman, v. 22, p. 37.
4. BRUCE, DONALD. 1923. Light burning: Report of the California Forestry Committee. *In* Jour. Forestry, v. 21, p. 129–133.
5. CALIFORNIA STATE BOARD OF FORESTRY. 1886. Annual report.
6. ——— 1923. California forestry committee. *In* Ninth Annual Report, p. 35–39.
7. COOPER, W. S. 1922. The broad-sclerophyll vegetation of California. Carnegie Inst. Wash. Pub. 319. p. 124.
8. DUNNING, DUNCAN. 1923. Some results of cutting in the Sierra forests of California. U. S. Dept. Agr. Bul. 1176. 25 p.
9. FERNOW, B. E. 1902. Economics of forestry. 520 p.
10. HOFMANN, J. V. 1917. Natural reproduction from seed stored in the forest floor. *In* Jour. Agr. Res., v. 11, p. 1–26.
11. HOPKINS, A. D. 1909. Insect depredations in North American forests and practical methods of prevention and control. U. S. Dept. Agr. Ent. Bul. 58, Part V. 101 p.

    ——— 1909. Practical information on scolytid beetles of North American forests, genus dendroctonus. U. S. Dept. Agr. Ent. Bul. 83, Part I. 169 p.
12. HOUGH, FRANKLIN B. 1877–1882. Report upon forestry. U. S. Dept. Agr. 3 vols. 1877, 1878–79, 1882.
13. HUNTINGTON, ELLSWORTH. 1914. The climatic factor as illustrated in arid America. Carnegie Inst. Wash. Pub. 192. 341. p.
14. KITTS, JOSEPH A. 1919. Prevention of destructive forest fires. So. Pac. Co.
15. LACHMUND, H. G. 1921. Some phases in the formation of fire scars. *In* Jour. Forestry, v. 19, p. 638–640.
16. LEWIS, J. G. 1922. Proposed method of fire prevention. *In* Timberman, v. 23, p. 48L–48N.
17. MEINECKE, E. P. 1916. Forest pathology in forest regulation. U. S. Dept. Agr. Bul. 275. 63 p.
18. MILLER, JOAQUIN. 1887. Paper read before the American Forestry Congress. Report Am. For. Cong., p. 25–26.
19. MUNGER, T. T. 1914. Damage by light surface fires in western yellow pine forests. *In* Proc. Soc. Am. Foresters, v. 9, p. 235–238.
20. MUNNS, E. N. 1923. Erosion and flood problems in California. Calif. State Bd. Forestry, Report to Legislature on S. Con. Res. 27 (1921), p. 9–165.
21. OLMSTED, F. E. 1911. Light burning in California forests. U. S. Dept. Agr. Circ. (unnumbered). 4 p.
22. SHOW, S. B. 1915. Light burning at Castle Rock. Proc. Soc. Am. Foresters, v. 10, p. 426–433.
23. SHOW, S. B., and KOTOK, E. I. 1923. Forest fires in California, 1911–1920, U. S. Dept. Agr., Dept. Circ. 243. 80 p.
24. WALKER, T. B. 1909. *In* Report of National Conservation Commission, v. 2, p. 424–425.
25. WEAVER, ROSCOE B. 1921. The burning of dead and down trees as a practical protection measure. *In* Jour. Forestry, v. 19, p. 506–511.
26. WEBB, J. L. 1906. The western pine-destroying bark beetle. U. S. Dept. Agr. Bul. 58, Part II. 14 p.
27. WHITE, STEWART EDWARD. 1916. The tree-killing beetles of California and possible remedies. Am. Lumberman, no. 2169, p. 30–31.

    ——— 1917. The tree-killing beetles of California. *In* Am. Lumberman, no. 2181, p. 32–33.

    ——— 1917. Surface burning. *In* Am. Lumberman, no. 2182, p. 36–37.
28. ZON, RAPHAEL. 1920. Forests and human progress. Geog. Rev., v. 10, p. 139–166.

○

ADDITIONAL COPIES

OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
20 CENTS PER COPY

▽