Issued August 12, 1910.

U. S. DEPARTMENT OF AGRICULTURE,

FOREST SERVICE—BULLETIN 82.

HENRY S. GRAVES, Forester.

PROTECTION OF FORESTS FROM FIRE.

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FORESTER.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

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A Lookout Station, Cabinet National Forest.

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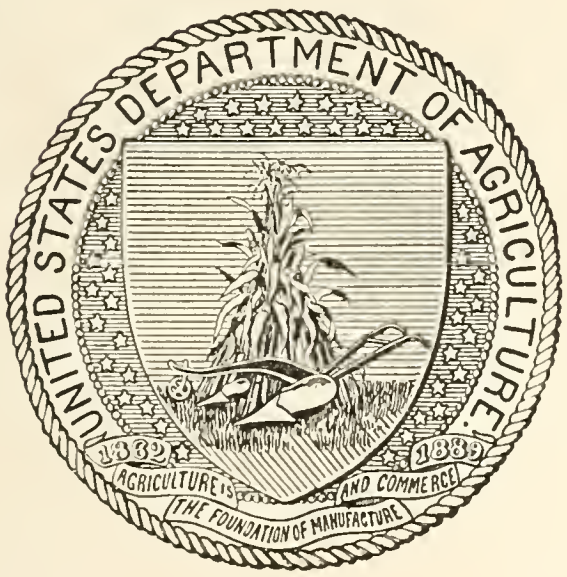

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Forest Service,
Washington, D. C., March 30, 1910.

Sir: I have the honor to transmit herewith a manuscript entitled "Protection of Forests from Fire," and to recommend its publication as Bulletin 82 of the Forest Service.

The 10 plates and 1 text figure which accompany the manuscript are necessary for its proper illustration.

Respectfully,

Henry S. Graves, *Forester.*

Hon. James Wilson,
Secretary of Agriculture.

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PROTECTION OF FORESTS FROM FIRE.

INTRODUCTION.

The first measure necessary for the successful practice of forestry is protection from forest fires. As long as there is any considerable risk from fire, forest owners have little incentive to make provision for natural reproduction, to plant trees, to make improvement cuttings, or to do other work looking to continued forest production.

In many localities great progress has lately been made in forest protection. Organized fire protection has been established in the National Forests and in most of the state forest reservations. A number of States have begun to develop systematic fire protection on private lands through the organization of state fire wardens. In some instances private owners have formed cooperative associations for fire protection and employ a regular force of rangers for patrol during the fire season. The most conspicuous and successful associations are those formed by certain lumber companies in Idaho and Washington. Throughout the country there are here and there instances of serious effort toward thorough fire protection by individual private owners. In spite of all that has been done, however, the fact remains that most of the forests of the country, particularly those privately owned, are inadequately protected from fire. It is probable that in fully 75 per cent of the private forests there is no attempt whatever at systematic protection.

CHARACTER OF FOREST FIRES.

It is customary to distinguish three classes of forest fires, as follows:

(1) *Surface fires*, which burn the surface layer of dry leaves and other litter, dry grass, brush, and small trees.

(2) *Ground fires*, which occur where the mineral soil is covered with a deep accumulation of vegetable mold, and which, on account of the peaty character of the material, burn much more slowly than surface fires.

(3) *Crown fires*, which burn through the crowns of the trees.

SURFACE FIRES.

Nearly all forest fires start as surface fires. The dry litter on the surface of the ground is ignited by a spark, perhaps from a locomotive or a camp fire. At first the fire burns in a small circle, gradually eating out in all directions. If there is a wind, the fire burns with greatest intensity on the leeward side, and quickly assumes an oval form. If the wind is very strong, the fire may die out entirely on the windward side, but it burns intensely on the other side, soon developing a distinct front or head, with side wings running diagonally with the wind. At first the front of the fire is very narrow, but it gradually widens and takes the form of a broad, irregular line. The front may reach indefinite proportions, from a few hundred feet to a number of miles in width. Irregularities of topography and differences in the amount of inflammable material cause the fire to burn more rapidly in some spots than in others, so that the entire front becomes scalloped and irregular.

Ordinarily a surface fire simply burns along the ground and does not get into the tops of the trees. Sometimes, however, the flames reach up into the crowns and scorch them, or even ignite them here and there; but such a fire still has the character of a surface fire, unless it actually burns through the crowns.

The manner of burning, the form of the fire area, the rapidity of burning, and the intensity of the fire depend upon the following conditions:

(1) The character and quantity of inflammable material.
(2) The topography.
(3) The character of the soil.
(4) The condition of the atmosphere.

INFLAMMABLE MATERIAL.

The severity of a surface fire depends largely on the quantity of dry material in the forest. If there is an accumulation of leaves representing the fall of a number of years the fire is much more severe than if the litter is the result of the fall of only a year or two. The quantity of accumulated litter is greatest with species having large leaves and large crowns. Maple and red oak, for example, make a heavier litter than ash or birch; white pine makes a heavier litter than pitch pine. The severity of a fire depends further on the character of the leaves. A layer of resinous softwood needles burns more rapidly and with a hotter fire than does a layer of hardwood leaves.

The amount of dry wood on the ground influences largely the severity of a fire. In some types of forest there are a great number of fallen dead trees, which litter the ground, and thus increase the fire danger. This is well illustrated in the lodgepole pine forests of the Rocky Mountains. In localities subject to windfall there is likely to be a

large amount of fallen timber, while fires, disease, and insects leave standing dead trees and snags, which are easily ignited. After lumbering in the old-fashioned way, the ground is covered with a mass of tops and rejected logs, which soon become dry and highly inflammable.

Again, the condition of the litter and débris governs largely the character and severity of the fire. The most severe fires occur where the material is thoroughly dried to the mineral soil. When the material is only partially dry the fire is slow and the litter is not completely burned.

Since the ground litter is, as a rule, unevenly distributed, a surface fire burns very irregularly. Still another cause of the irregularity of surface fires is the varying soil moisture.

TOPOGRAPHY.

A fire runs uphill with great rapidity, because the heated air currents draw the flames upward. If the litter is evenly distributed, the velocity with which a fire will run up a slope is in direct proportion to the steepness of the slope. After passing the crest, a fire travels slowly in its descent on the other side.

Mechanical obstructions, such as abrupt walls, narrow ridges, outcropping ledges, and so on, tend to check a fire and to prevent its gathering volume. On extensive level ground fires burn more uniformly, gather a greater volume, generally do more damage, and extend over a larger area than in rugged topography.

CHARACTER OF THE SOIL.

Any influence which tends to dryness increases the intensity of a fire. Thus on sand and limestone soils, which warm up and dry out readily, fires are likely to be very severe. Southern and western slopes are apt to be more severely burned than others, because they are the warm and dry exposures.

CONDITION OF THE ATMOSPHERE.

The character of a fire is influenced, further, by the condition of the atmosphere. Roughly, the greater the velocity of the wind, the more rapid is the progress of the fire. A fire burns more severely when the wind is constant than when it is gusty. It is the steady high wind which makes the most intense fire.

A fire burns most fiercely when the atmosphere is dry. Fires are, therefore, most severe during the hot part of the day and when fanned by a dry wind. A moist atmosphere retards a forest fire. The well-known fact that the night is the best time to fight a fire is

thus explained; for at night there is usually little or no wind, while the air is comparatively heavy and damp.

RAPIDITY OF SURFACE FIRES.

No reliable estimate of the rapidity of surface fires can be made, because it varies so greatly under different conditions. In the hardwood regions of the East a surface fire seldom travels more than 5 miles a day, but in the coniferous forests of the West instances are known where this rate of speed has been more than doubled.

GRASS FIRES.

In nearly all open forests there is a certain quantity of grass which, when dried, carries fire very rapidly. In many forests the presence of grass constitutes one of the important problems connected with surface fires. This is particularly true in the southern pine forests.

A grass fire is more influenced by the density of the grass than by its height. Where the grass is in separated patches, with no leaves or other inflammable material between, it is difficult for a fire to spread. Uniformly dense grass burns with the greatest intensity. High grass burns with greater intensity than low grass, but the fire does not usually run so rapidly. Grass a foot high, if dense, may produce such a hot fire as to start a crown fire. In short grass, with an ordinary wind, a fire will run from 3 to 4 miles an hour; with a high wind, twice as fast. The chief factors affecting the burning of grass are its dryness and the force of the wind. Other factors have their influence, however, just as they do in the burning of litter.

BRUSH FIRES.

Bushes and small trees frequently retain many dried leaves late into the fall, and in some cases even into the following spring. This is particularly true of some of the oaks. A fire will sometimes run through such brush and do an immense amount of damage. Such a fire is called a brush fire. It is carried along in part by the burning of the litter, but, wherever the opportunity offers, it runs up through the dried leaves remaining on the brush. In the eastern United States a brush fire is most likely to run during the late fall. Under ordinary circumstances it has rather the character of a surface fire than that of a crown fire.

Fires running through young stands of conifers consume the foliage and readily kill the trees. In a very young stand, in which the trees stand isolated and the crowns have not yet grown together, the fire has the nature of a surface fire, intensified by the burning crowns. If the crowns meet, and there is a more or less complete canopy, a true crown fire is developed.

A special class of brush fires are those in the chaparral of the Southwest. The brush is dense and there are many species with inflammable foliage. In many places a thick layer of litter and humus is formed on the ground, just as in a dense forest. Fires in this type of scrub forest are very fierce and destructive, and are analogous to fires in dense stands of young conifers.

GROUND FIRES.

This term is applied to the slow fires that burn in the deep accumulations of vegetable matter common in many of our damp northern forests. Here the fallen leaves, needles, and other offcastings of the trees decompose very slowly, and a deep layer of partially decayed organic matter accumulates, often to a depth of from 2 to 3 feet. This material absorbs moisture with avidity and retains it tenaciously. Consequently, in moist seasons it is not readily ignited. In some seasons, however, it becomes thoroughly dry and will burn. A fire in this peaty substance burns slowly, but with very intense heat, and is exceedingly difficult to extinguish. Ground fires in the Adirondacks have been known to burn all winter, creeping along under a deep layer of snow.

Ordinarily a ground fire will not cover more than a few acres in a day. Frequently, however, there is upon the surface a large amount of dry débris or small coniferous trees, so that there accompanies the ground fire a surface fire or a brush fire, or both, and occasionally a crown fire.

CROWN FIRES.

Crown fires are those which burn through the crowns of the trees. (See Plate II.) They almost invariably start from surface fires. Occasionally, however, they are started when lightning strikes and ignites a dry stub or resinous tree surrounded by a dense stand of conifers. If the crowns are of such a character that they will burn they may be easily ignited by the flames which rise from a surface fire. Sometimes a crown fire is started by the flames from a burning clump of young growth, and where the trees have exuded resin or there is loose inflammable bark, a crown fire may be started by the flame's running up the trunk.

Crown fires occur when the woods are very dry and when there is a high wind. Without a strong wind a crown fire is seldom started, and even if the crown of an individual tree is ignited, a fire does not usually spread and run through the crowns on a still day. Before a high wind, a crown fire spreads with great velocity, taking at once a V-shaped form with a distinct front or head. This head may be only from 50 to 100 feet wide, but in the case of the largest fires its width may be very great. In the case of the larger fires the front is

generally carried forward by a series of heads. The head of the fire burns very rapidly through the crowns, and there follows closely a surface fire burning with the same rapidity. There are well-developed wings, where the fire runs through the crowns on each side of the head. These, in turn, are accompanied by surface fires, while spreading out on the skirts are wider surface fires, eating out diagonally with the wind and covering a broader area than the crown fire.

The strong draft of heated air arising from the fire carries up with it an immense quantity of burning cinders and pieces of bark. The wind, in turn, carries this material far in advance of the main fire-head, and thus innumerable new surface fires are started. This gives rise to the popular idea of a spontaneous starting of fires in advance of a crown fire.

An ordinary crown fire does not run more than 2 or 3 miles an hour, although undoubtedly the great conflagrations of the north woods, such as the famous Hinckley fire in Minnesota in 1894, are swept along at a much greater rate, particularly if the starting of new fires by burning cinders is taken into consideration. Even in extreme cases, however, it is questionable whether crown fires burn at a rate of more than from 6 to 10 miles an hour.

The behavior of a crown fire depends on the character of the crowns. Crown fires are mainly confined to coniferous forests, for the leaves of hardwoods are not easily ignited.

They may, however, run through forests of mixed hardwoods and conifers, and in such cases the heat generated is so great that the hardwood leaves are scorched or killed. The velocity of the fire depends, further, on the density of the stand, the thickness of the crowns, and the force and steadiness of the wind. Other influences affect the severity of crown fires in much the same way as they affect that of surface fires.

DAMAGE BY FIRES.

The damage done by forest fires may be discussed under the following heads:

(1) Death of standing trees.
(2) Injury to trees that are not killed.
(3) Injury to the soil.
(4) Reduction of the rate of growth of the stand.
(5) Effect on reproduction.

DEATH OF TREES.

Crown fires kill outright most of the trees in their paths. In a severe crown fire the foliage of coniferous trees is completely consumed. Hardwood trees in mixture are generally so badly scorched that the buds, leaves, and living tissues in other finer parts of the tree are

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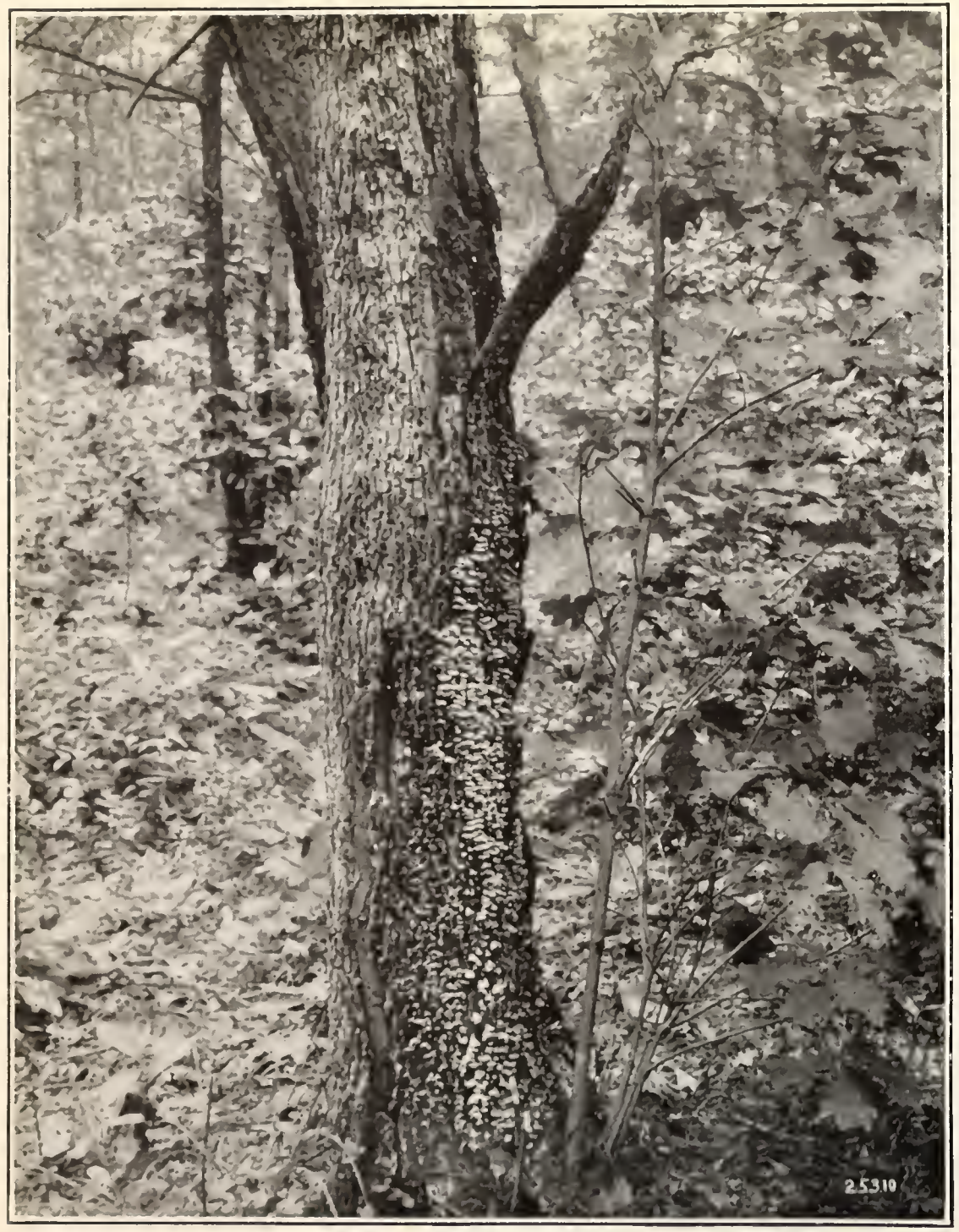


FIG. 1.—FUNGUS ATTACKING TREE THROUGH FIRE SCARS.

FIG. 2.—HOLLOW TREE, THE RESULT OF FIRES.

killed, if not consumed, by the heat. Sometimes, however, where the fire burns somewhat irregularly—as, for example, where there are a good many hardwoods in mixture or the fire is broken by irregularities in topography—single trees or groups of trees often escape injury.

Ground fires, also, usually kill all trees in their way, for although they burn very slowly, they generate a great volume of heat and kill the living tissues of the roots. Sometimes the injury is not apparent above ground, at all, but the trees die and after a time are blown over, because the roots have been killed and weakened.

Surface fires kill seedlings and young trees with tender bark, but in a great many cases do not kill outright the larger trees. Nevertheless, a very severe surface fire may kill everything in its path, and, not uncommonly, hardwood forests are entirely destroyed by fires which do not at any time assume the character and proportions of crown fires.

Some species have much greater power of resisting surface fire than have others. This is usually due to the character and thickness of the bark. Trees with delicate, thin bark are killed much more readily than those with thick, corky bark. Young trees are killed more readily than old ones, because the bark is thin and there has not been developed the layer of cork, which increases in amount with age. Accordingly, some trees which are very resistant to fire when mature are exceedingly sensitive when young. Good examples are the eastern and western white pines, the red pine, the western larch, and Douglas fir. The cork in the bark acts as a nonconductor and protects the living tissues from overheating.

Some species exude from the bark a great deal of resin, which catches fire and increases the intensity of the heat. A good example is lodgepole pine, which often exudes resin over a considerable portion of the trunk and increases the damage by fire. Other trees have soft, flaky bark, which catches fire readily. Like the resinous trees, these are killed at the point burned by the heat generated in this way. Shallow-rooted trees may be killed by surface fires when the heat of the burning humus is great enough to injure the insufficiently covered roots.

The living parts of a tree are more sensitive to intense heat at some periods of the year than at others. The most sensitive period is during the early part of the growing season, when active cell division is taking place and new cells are being formed, which are tender and naturally sensitive to abnormal conditions. This is very well shown by the damage of late spring fires. Thus, a surface fire in May or June may entirely kill hardwood trees which in the early fall would successfully resist a fire of equal severity.

Living tissue is killed when it is heated to 54° C. (129.2° F.).[a] Very often the forester wishes to determine after a fire the extent of the injury. If the inner bark is brown or black, in contrast to the normal green color, this is an indication that the cambium is dead.

INJURY TO TREES.

Many surface fires do not kill trees outright, but seriously injure them by killing a portion of the roots or trunks. It is very common to find, after a fire, that nearly all the trees in the forest have been killed on one side. (Pl. III, fig. 1.) This is usually the leeward side, because here the flames have an opportunity to burn in immediate contact with the tree long enough to injure it. If a fire is burning up a slope, even when there is no wind, the upper side of a tree is usually more damaged than the lower side, both because of the accumulation of leaves and other litter above the tree and because fires are carried upward by the currents of hot air, just as a fire on level ground is swept along by the wind.

In the case of a well-established tree, the killing of one side may not result in its death for a long period; and if the wound is not large it may heal over. Very commonly, however, the killing of one side of the tree induces the attack of some fungous disease, which ultimately results in the tree's death. (Pl. II, fig. 1.) Trees injured and weakened by fire are subject to the attack of insects. In many cases the death of trees after a burn is the result of insects' work and not of the killing of the tissues by the fire. Damage by fire often follows damage by insects. Thus, in certain conifers insects injure the trunks, causing a local accumulation of pitch. A surface fire later burns the tree at this point and kills one side. The defect called "cat-face" is often caused in this way. Insect attacks, moreover, by increasing the number of dead trees in the forest, increase the fire danger.

In the case of large trees, which are very resistant to fire, a first fire may kill the tissues on one side, and subsequent fires may then burn into the dead wood until the trunk is nearly hollow. This result is very commonly seen in large white pines, that have a large proportion of the butt gouged out by repeated fires and are still alive. Many of the large trees on the Pacific coast, like red fir, yellow pine, sugar pine, and bigtree, stand for many years after injury of this character.

The damage to a tree by killing a part of the trunk or a part of the roots depends on its resisting power and a variety of other circumstances. In some cases the tree is so weakened by the burning that it is afterwards broken off at the butt. This is very common in long-

[a] Der Waldbau, by Heinrich Mayr, p. 12

leaf pine forests, where old turpentine "boxes" burn out and weaken the tree. (Pl. III, fig. 2.)

The injury to the tree usually results in a reduced rate of growth. It is obvious that if a portion of the tree is killed the whole tree can not perform its functions so effectively as before. The killing of a part of the crown, stem, or root system necessarily reduces the amount of nourishment which the tree can take in and furnish the growing parts.

It is not only in shortening life and in reducing growth that fires injure trees; the quality of the product is also affected. Even where there is no infection by insects or fungous disease, a fire that has killed one side of a tree usually leaves its scar. In time the wound may entirely heal over, but there is nearly always a point of weakness which may ultimately cause a seam or wind shake and unfit the butt log for lumber. If rot sets in, it may spread throughout the trunk and make the tree worthless, even if it does not kill it.

INJURY TO THE SOIL.

A surface fire burns the dry leaves, and usually the humus which lies on the surface of the ground. If the trees are all killed by the fire, the crown cover, as well as the layer of litter and humus, is destroyed, and injury to the soil follows this exposure to the wind and sun. If the canopy is not seriously interrupted by the fire and only the surface litter and humus are burned, the extent of the soil injury from one burning is not serious. A very light surface fire that merely burns off the dry litter formed by one or two years' fall of leaves has little influence on the soil; and probably no single fire, even if it burned the entire humus and layer of litter, would so injure the soil as seriously to affect the growth of well-established trees. Normally in every forest a certain amount of humus is mixed with the mineral soil. This is of value, both physically and chemically. If a forest is burned over repeatedly, however, the humus in mixture gradually disappears, and since the leaves which fall are destroyed, and no new humus is formed, the soil is injured. While the soil loses its supply of nitrogen and the physical benefits of humus, the mineral ashes are not lost except as they are subsequently leached away. Nevertheless, repeated fires are very injurious to the forest.

Besides the direct injury to the soil through changes in its chemical content and physical quality, fires do further damage through opening the way to soil erosion. A leaf litter reinforces the forest canopy in protecting the soil against the impact of falling rain, and the network of roots which fills the ground holds the soil in place. The greater the humus content of the soil, the more absorptive the soil is. Fires leave the soil in condition to be easily borne away by running water, and increase the amount of water which runs over the surface

instead of sinking in. If the slopes are steep and the soil easily borne away, erosion is sure to follow fires. In mountain country, if the rainfall is heavy, thin soils may be so badly washed as to be no longer capable of supporting forest growth.

REDUCTION OF DENSITY.

Most fires kill a certain number of trees, or injure them so that they either die or deteriorate in value before the forest can be cut. This is particularly the case with immature forests. The result is a reduction in the number of trees which will come to maturity, and hence reduction of the total increment and the final yield.

If a stand is mature and a part of the trees are injured or killed, it is sometimes possible to prevent loss by cutting directly after the fire. Often, however, it is not practicable to make a cutting in a given part of a forest just when desired.

When some of the trees in an immature stand are killed or injured there is always a loss. If the stand is cut, there is a loss through cutting trees which are in full productive growth. If the stand is allowed to grow, the final yield is reduced nearly in proportion to the reduction in the number of trees killed in the dominant or leading class.

An owner is often confronted with the problem of dealing with an immature stand in which a part of the trees—say 30 to 60 per cent—are killed or injured by fire. If the remaining trees are sound and thrifty, the best plan is usually to cut out the dead and damaged individuals, utilizing such as are marketable, and permit the remainder to mature, provided enough can be realized to cover substantially the cost of the work.

EFFECT ON REPRODUCTION.

Reproduction in the forests of this country has been more influenced by fire than by any other one factor. The present composition, form, density, and yield of a great many stands are due to the influence of fires on reproduction.

Repeated fires prevent reproduction by destroying the seed and killing the seedlings. This is well illustrated in certain areas of the South, where longleaf pine is not reproducing itself—not because there is a lack of seed or because the conditions for germination are unfavorable, but because the annual fires kill the young trees.

Fires may influence reproduction through their effect on the soil and the soil cover. Frequently after fires the ground is occupied by heavy brush or by grass, which impedes or in some cases prevents the reproduction of valuable trees. Many of the grass parks in the western mountains are the result of fire. A grass vegetation has replaced the forest. The running wild of burned areas to

FIG. 1.—LODGEPOLE PINE DAMAGED BY FIRE.

FIG. 2.—A BURNING TURPENTINE BOX—LONGLEAF PINE.

a heavy growth of brush is a common occurrence after fires in many of our eastern forests, as, for example, in Pennsylvania.

Forest fires modify the composition of stands. The opening up of a forest may so change the conditions of germination that some species can not develop even when seed is abundantly supplied. This is in some cases due to the drying of the soil. A species which requires protection against drought in early youth might be excluded from openings made by fire. In the same way the reproduction of a species sensitive to frost in early youth is often confined to areas protected by old trees.

Where the fire makes a large clearing, the succeeding forest usually differs in composition from the burned stand, except where there are only one or two species native to the region. The first species to spring up on the burn are those whose seed is readily and abundantly distributed to a distance from the seed trees. Thus, in the north woods of the East, birch and aspen are among the first species, because their seed is very light and is blown by the winds to great distances. Bird cherry comes up in abundance, because its seed is spread widely by the birds, and probably much of it is already in the ground before the fire. The trees with heavier seed creep in gradually after a few years.

Fires may kill certain nonresistant species, and thus stop their supply of seed. The tendency of repeated fires is to reduce the number of species in a stand.

THE PREVENTION OF FIRES.

In some sections of the country forest fires have always been of such common occurrence that there is a popular notion that they can not be prevented. The risk from fires can never be entirely eliminated, for in the forest there is always inflammable material which is very easily ignited. They may, however, be largely prevented, and under efficient organization their damage may be kept down to a very small amount. The problem is like that in cities, where fires can never be entirely eliminated, but where the risk of loss to property may be reduced almost to insignificance.

For the successful protection of a forest from fire there are necessary:

(1) The elimination, so far as possible, of the causes of fires.

(2) A proper organization of the forest, including the disposal of slash, the opening of roads, the construction of trails, etc.

(3) An adequate supervision.

(4) Facilities for fighting fires, including an adequate force of men, proper implements, etc.

ELIMINATION OF THE CAUSES OF FIRES.

The causes of fires may be grouped under the following heads:

(*a*) Sparks from locomotives; (*b*) sparks from sawmills, donkey engines, etc.; (*c*) camp fires; (*d*) clearing land and burning brush; (*e*) burning to improve pasturage (*f*) careless smokers; (*g*) incendiarism; (*h*) lightning.

Back of any practical plan of fire protection there must be state fire laws and a competent organization to enforce them. In many States to-day there are laws, some of them fully adequate, requiring the use of spark arresters on engines, and punishing incendiarism, carelessness in clearing land and in leaving camp fires, etc. In most States, on the other hand, organizations to carry out the laws and an enlightened public sentiment to support them are lacking. Education of the people to the value of forests and the need for their protection is necessary to overcome the carelessness and ignorance that cause fires to originate from camp fires and clearing land. Vigorous application of the laws will accomplish this result, but the laws will not be vigorously enforced until there is a public opinion back of them.

For the most part, though probably not entirely, the starting of fires by sparks from locomotives may be prevented by the use of spark arresters. If the right of way is properly cleared and patrolled such occasional fires as start may readily be extinguished. Railroad fires are therefore unnecessary. Railroads should be held responsible for damage from fires which they cause.

In the same way there are excellent devices for arresting the throw of sparks from the stacks of donkey engines and sawmills. When fires start from these sources it is usually because such devices are not used at all or not properly used.

There will, of course, always be some accidental fires and an occasional incendiary fire, just as in a city. In certain districts, also, lightning will continue to be an unavoidable cause of fire. The management of the forest must, therefore, be so organized that such fires as do start may be extinguished as quickly as possible.

ORGANIZATION OF THE FOREST.

By organization of a forest for protection is meant the establishment of such conditions that the chances of a fire are reduced to a minimum, and that such fires as are started may be extinguished with the minimum of damage. Among measures variously used to accomplish this are:

(1) The disposal of slash from logging operations.

(2) The development of roads, trails, and fire lines.

(3) The establishment of lookout stations and telephone lines.

(4) The organization of a protective supervisory and fire-fighting force.

(5) The control of insects which kill trees and cause an accumulation of dead, inflammable timber.

No one measure is sufficient for adequate fire protection. The disposal of dry tops and brush reduces the danger from fire, but there always remains enough inflammable material in a forest to make possible a damaging fire. There must also be roads, trails, or fire lines giving ready access to the forest, so that fires may be located and reached. Nor are these together sufficient, for there must be a constant watching for fires in order that they may be discovered and attacked when they are small and easily controlled and before they have done much injury. All the measures of fire protection are used together, and supplement each other.

DISPOSAL OF SLASH.

The presence of dry tops and piles of brush in the forest constitutes the greatest menace from fires. The severity of a fire, and hence the damage done, is in direct proportion to the amount of dry débris on the ground. Still more serious is the fact that the presence of this material makes it exceedingly difficult to control and extinguish a fire. If there is no material on the ground other than the ordinary leaf litter, a surface fire may be easily extinguished. Old logs, dead and down trees, and snags lying about on the ground are also a great hindrance to fighting fires, for when once ignited they are apt to smolder for long periods, and so continue to threaten a further spread of the flames. In many of our forests the dead, standing snags constitute a dangerous feature. If these are surrounded by a dense stand of conifers, they often carry the flames up into the canopy and make a crown fire; if isolated, they may burn for days, and finally fall, throwing sparks in all directions. The forester aims to reduce the amount of this inflammable débris in a forest as rapidly as possible, since the "clean" stand is easy to protect in comparison with a stand that is littered with dry débris.

DISPOSAL OF BRUSH AND DÉBRIS.

A first practical step is to prevent a further accumulation of débris in a forest by disposing of the slash from new cuttings. The application in all forests of a uniform method for disposing of this material would, however, be unwise. It should be clearly understood that no fixed rule of procedure and no single method could possibly fit all the different forest conditions in a country so large as the United States. The method used in any given case must be chosen after a careful study, and must rest upon a complete knowledge of

the local conditions. Many methods have been tried in the disposal of brush, but those producing the best results are the following:

(1) Piling and burning as logging proceeds.
(2) Piling and burning in separate operations.
(3) Lopping the tops.
(4) Lopping the tops and scattering the brush.
(5) Broadcast burning.

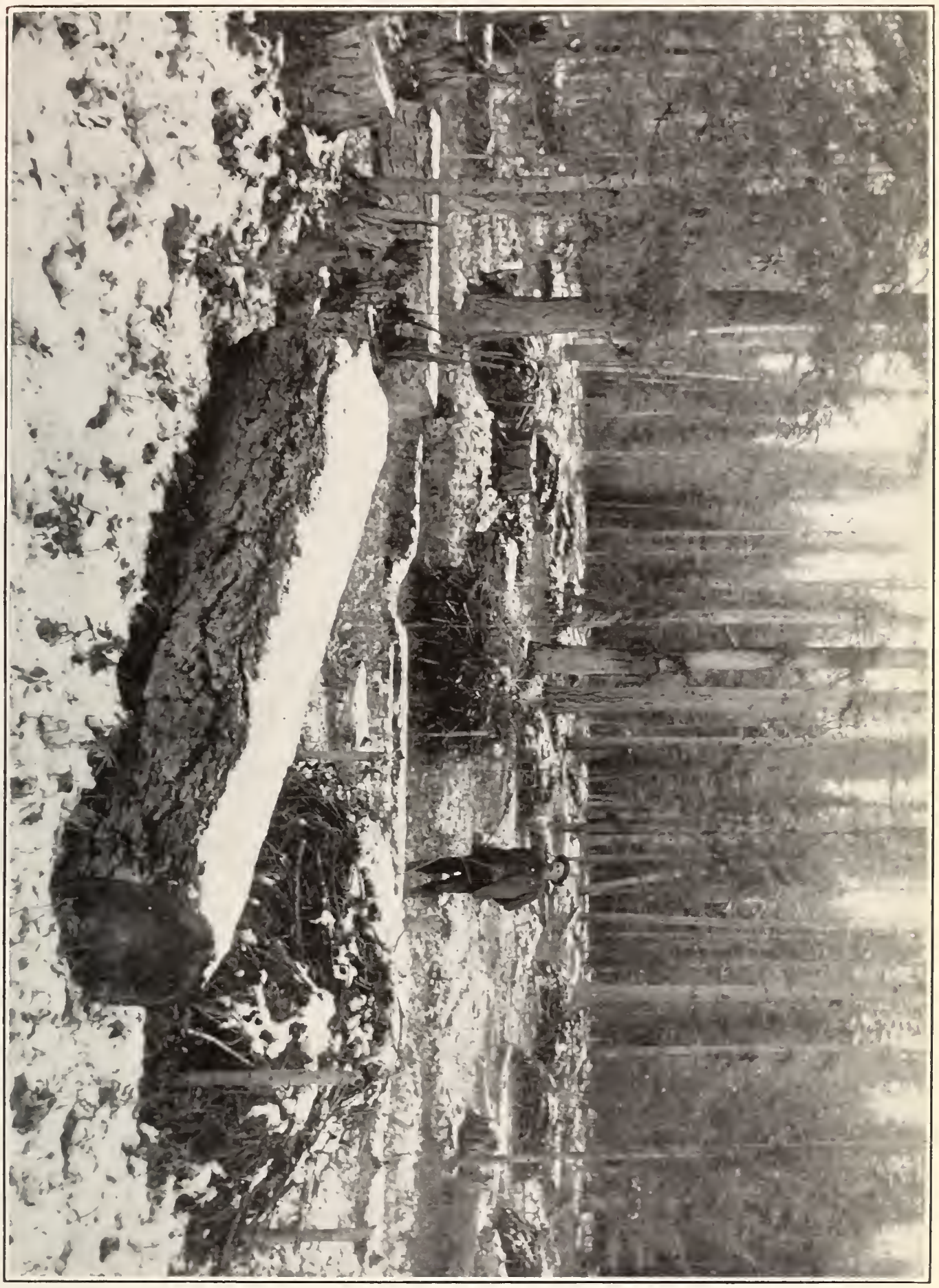
PILING AND BURNING BRUSH AS LOGGING PROCEEDS.

The most economical method of destroying brush and débris produced in lumbering is to burn it as the logging proceeds. This is possible when the ground is covered with snow or is so damp that fire will not spread. The work is done by the logging crew. As the trees are felled, convenient locations for burning the brush are selected, where no damage will be done to the trees and to young growth left standing, and where the fires will least interfere with skidding the logs. Small fires are started, and as the branches are cut off the trimmers throw them on the nearest fire. One reason why this method is cheaper than the others is because the branches need not be cut up so small, for the fire is already burning when they are thrown on. In coniferous forests the tops burn readily, even on the snow or in stormy weather. Sometimes when it is not practicable to start a fire near a given top, the trimming of the limbs is deferred until the skidders can haul it bodily near a fire. The branches are then lopped and the last cut made, enabling the skidders to go on with the top log, while the choppers throw the brush on the fire.

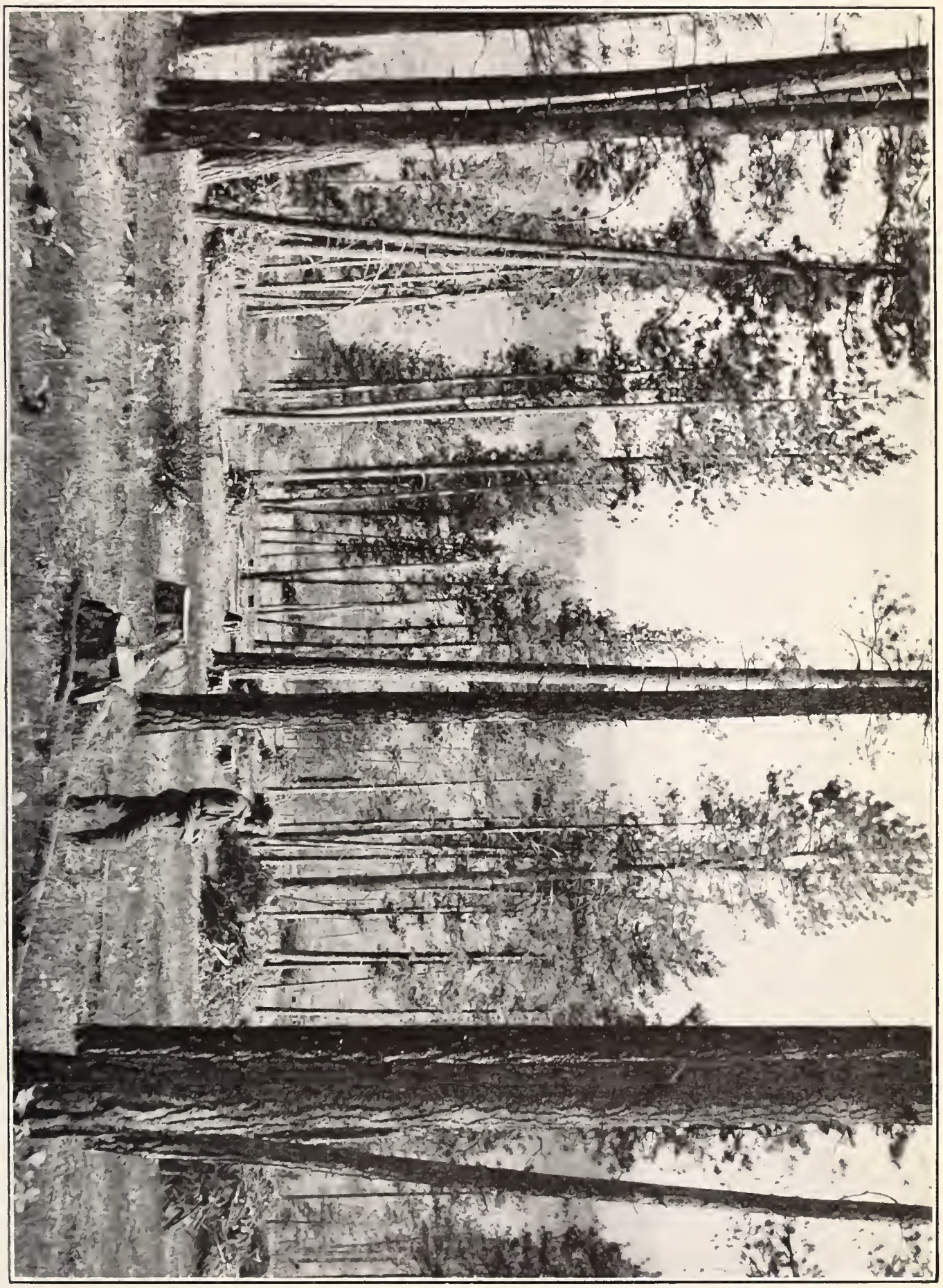
If the work is systematized, the brush is practically all disposed of as the logs are skidded, and the woods are cleaned up as the logging proceeds. There is a distinct advantage to the skidders through having open ground to work over. This method should be used only when there is no danger of a spread of fire. Its use on a large scale is confined to logging during the season of snow or rain.

The best method of calculating the cost of brush disposal is on the basis of the amount of timber cut, measured in board feet, log measure. A determination of cost per acre would be misleading, because of the great variation of yield in different forests.

The cost varies widely under different conditions. If trees have heavy crowns and large, heavy limbs, the cost is much greater than where the crowns are smaller. Thus, for example, the cost of destroying the brush produced in logging a stand of large hemlock would be greater per thousand feet of merchantable timber secured than in logging an equal amount in a small-crowned species like red pine. If the trees have a large volume, and the stand is heavy, the cost of disposing of their tops is less than it would be on an equal area for a



A FAVORABLE CONDITION FOR BURNING PILED BRUSH.



GOOD WORK IN PILING BRUSH.

sparse stand of trees that yielded only a small amount of merchantable timber per tree.

The cost and efficiency of labor must, of course, enter into the cost of piling or burning brush, as it does in any other logging operation. If the men know just how to perform the work to the best advantage, and are industrious and energetic, the cost of piling the brush is much less than otherwise. In many cases the high cost of brush disposal has been simply due to the fact that the men who were doing the work were inefficient, unwilling, or unskilled. Still another factor influencing cost is the ease of the work as influenced by the density and amount of small growth and the irregularities of the ground.

The Forest Service, working in forests in the Lake States composed of mixed red and white pine, has disposed of brush in the manner described at a cost of 12 cents per thousand board feet.

PILING AND BURNING BRUSH IN SEPARATE OPERATIONS.

Where the logging is done during the dry season, the brush is piled whenever convenient, but the burning of the piles is deferred until a favorable time, such as during damp weather or after the first snowfall.

The best time for piling brush is during the cutting and skidding of the timber. As the branches are lopped from the stem they are immediately cut up and thrown on a pile. The work is done by the regular trimming crew, and, ordinarily, the extra work requires the addition of only one man to the regular number. The advantages of organizing the brush-piling work in this way are:

(1) The brush is cleared at once for the skidding of the logs.

(2) The work is done more cheaply than if the brush is piled by a separate crew after the logging is completed; besides, the trimmers have to throw aside the brush in any case to clear the way for skidding. Piling after the logging means a second handling of the brush, and is an expensive operation on account of the inevitable difficulties of picking up the branches from tangled piles.

(3) The men work more efficiently and cheerfully when a part of a trimming crew than when they do nothing but pile brush.

(4) Supervision is more effective and less costly when the brush is piled with the logging than when it is a separate, later operation.

There are circumstances where it is impracticable to pile the brush until after the logs are removed.

Sometimes, when the logging is done in the winter, it is impracticable to burn brush at the time of logging, in the way described in the previous section, or, on account of the deep snow, to pile the brush for later burning. In this event the piling is done in the spring, as soon as the snow permits.

In locating the piles it is necessary to take into consideration the convenience and cheapness in handling the brush, the clearance of way for skidding the logs, and the safety to standing trees and young growth when the piles are burned. Ordinarily they are placed at least 15 feet away from any trees or groups of young trees that may be injured. In forests like spruce, which have a great amount of branches, and where the trees stand so close that the piles can not be placed at this safe distance, the brush is either piled and not burned, or is thoroughly lopped and left scattered evenly over the ground. When the brush is piled after the logging, the piles are located in the logging roads, skidding trails, and on spots where skidways were located.

The brush piles should be small and compact. (Pl. VI.) As a rule they should not be over 10 feet across or over 6 feet high. The very small branches are put in the bottom of the pile, with successively larger material laid on afterwards. The tops of the branches are placed toward the center of the pile. Trimmed sticks may be leaned against the pile to hold it in shape, keep it from blowing over, and render it more compact for burning. Windrows and large piles make control of burning difficult, and are likely to make such a large fire that the crowns of trees are scorched and injured. Where the stand is clear-cut, however, large piles and even windrows may sometimes be used.

When the piles are loosely thrown together complete burning is very difficult and often impossible. To secure "clean burning" (so called), it is necessary to rebuild open and loose piles. This is called "chunking up" the piles. It is very expensive, for it costs as much as the first piling.

Brush should not be thrown on a top, at least until all branches are trimmed off. Ordinarily, they should be piled away from the top piece of the stem.

In some instances in the National Forests the practice has been to stake the piles. Sticks are driven into the ground 6 or 8 feet apart and the limbs are ranked lengthwise between them. (Pl. IV.) The advantage of this method is that it insures thoroughness of work and a compact pile. It has been proved that it costs much less to burn a staked pile than the ordinary irregular pile, and the area of ground burned over is considerably less. This method has been found of especial value when the brush piling has followed the logging. The foreman of the piling crew selects the locations for the piles, drives the stakes, and supervises the work. Organized in this way, the work is done rapidly, and the expense is but little if any more than if the piles are irregular. Any extra expense of the staking is more than offset by saving in the cost of burning.

The cost of piling brush necessarily varies under different conditions. The first work undertaken in this country cost as high as $1 per thousand feet, log run, of timber cut. This high cost was largely due to lack of knowledge of methods and to the inexperience of labor. With better organization and with trained workmen the cost of piling brush in coniferous forests has been reduced to from 10 to 50 cents per thousand There is no reason why the piling alone in coniferous forests should cost more than 25 cents per thousand, except where the tops are unusually large and the physical difficulties unusual.

BURNING OF THE PILES.

An excellent time for burning brush is after the first snow of winter. (Pl. IV.) This is usually a light fall, and the snow does not penetrate the compact piles of brush sufficiently to prevent burning. There is no danger of the fire running on the ground, and the branches of the standing trees are so damp as to prevent injury by the rising flames. If the brush is burned before winter, it should be only during damp weather, when the ground is so wet that fire will not run easily.

When large areas of piled brush are to be burned the work should be organized with care. It should never be undertaken when there is a strong wind, and the best time is in calm weather. If there is any wind, the burning should begin with the piles on the lee side. Several piles may be fired at one time, but they should be some distance apart, with one or more unburnt piles between them. When the first fires have burned down to coals, the intermediate piles may be ignited. This alternating method of burning the piles prevents the injury to trees and young growth between the piles that might result from the collective volume of heat of adjacent fires. Just as the brush on level ground is burned against the wind, so, on a hillside, the piles near the top are burned first, and the work progresses down the slope.

Whenever large areas of piled brush are to be burned, a sufficient force of men, equipped with fire-fighting implements, should always be present to insure that the fire will not get beyond control. In some instances, when brush is piled in the winter during logging and left for later burning, the piles become very wet from the snow and rain and do not dry out till late spring or summer, a time when burning on a large scale is dangerous. If the brush of winter lumbering can not be burned as the logging proceeds, the piles must ordinarily remain unburned till the first snow of the following winter, or till especially wet weather comes in late summer or fall.

The devices used in different localities for starting fires in piled brush are many. Some loggers use a torch of burning wood, as resinous pine; others carry live coals from one pile to another; others use a long-handled torch; others, again, pour a little oil on the brush

and start it with a match. The most satisfactory seems to be an ordinary tubular torch with wicking and a ferrule into which a rake handle can be inserted. A good substitute, though a crude one, for the last is a piece of bagging or burlap wound around an iron rod or stick of wood and occasionally saturated with oil.

The cost of burning piled brush in the coniferous forests may vary from 1 to 30 cents per thousand, according to the manner in which the brush is piled, the condition of the brush, the size of the crew needed to prevent the running of fire, etc. Commonly, it ranges from 5 to 15 cents per thousand feet. Where the cost has been higher than this, it has been attributable either to poor work in piling or to inefficient management in the work of burning. The average cost of both piling and burning should range in coniferous forests between 10 and 50 cents, and as the lumbermen become more experienced in performing the work the cost will be correspondingly reduced.

In the logging operation shown in Plate IV, where the brush was burned just after a slight snowfall under particularly favorable conditions, the actual cost of burning was only a fraction of 1 cent per thousand feet. No watching of the piles to see that fire did not run was necessary; it was simply a case of walking from one pile to another and starting the fire.

In some coniferous forests careful records were kept of the area actually burned over. Where the stand per acre ran from 10,000 to 50,000 feet per acre, the aggregate area burned over by the brush fires was found to be approximately 7 per cent of the total area cut over in the logging operations. Where the brush is burned as the logging proceeds, the percentage of the area burned over is less.

DISPOSAL OF HARDWOOD BRUSH.

Most of the work of piling and burning brush has been in coniferous forests. Of late, however, there has been considerable discussion of burning the slash after logging in hardwood forests. So far as the author is informed, systematic brush burning after hardwood logging has not been conducted anywhere on a large scale or in a manner to justify a judgment as to its practicability. Hardwood tops are necessarily large, heavy, and awkward to handle. The cost would be much greater than in coniferous forests. It is probable that lopping and scattering will be used rather than piling and burning.

The author has conducted some experiments in the burning of hardwood brush in the second-growth forests of New England, where the wood was utilized to about 3 or 4 inches, so that the amount of brush to be disposed of was much less than would have remained from logging old timber in the ordinary manner. The results of these experiments showed the average cost of piling and burning to be between 10 and 25 cents per cord. In this class of material with good

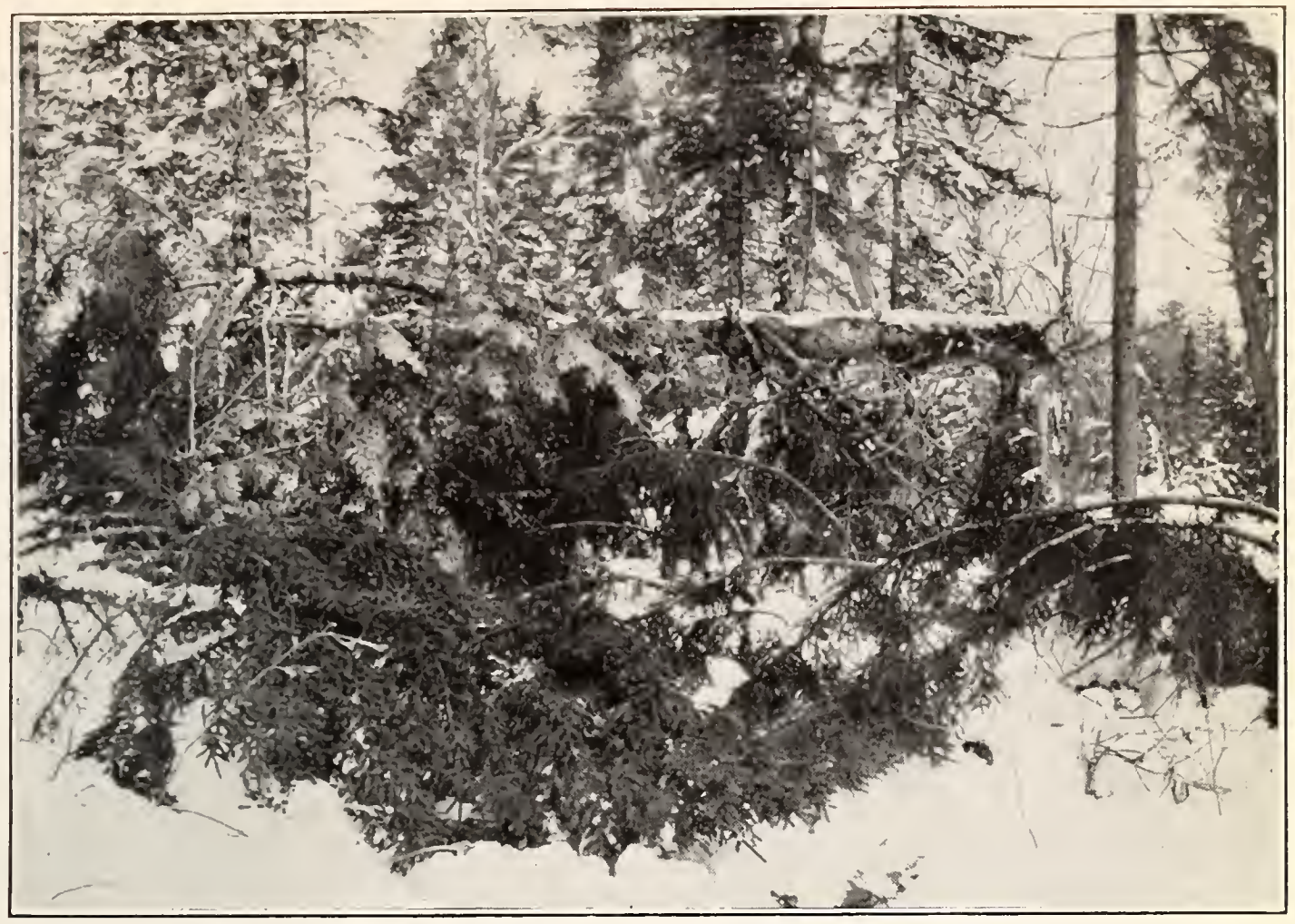


FIG. 1.—A SPRUCE TOP IMPROPERLY LOPPED.

FIG. 2.—THE SAME SPRUCE TOP PROPERLY LOPPED.

organization the cost would probably not exceed 10 to 15 cents per cord, though these figures furnish but scant basis upon which to make calculation of the cost of piling and burning the brush and débris from an ordinary hardwood logging operation, where the size and number of the limbs would be very much greater.

LOPPING OF TOPS.

In some forests the burning of the brush may be unnecessary or actually undesirable. A method of brush disposal applicable in many forests is to lop off the branches from the tops and leave the material on the ground. The purpose is to bring all the brush in close contact with the ground, so that it will absorb moisture more readily, dry out less in summer, and decay more rapidly than when propped high above the ground.

So far as the author is informed this method was first used on an extensive scale in the Adirondack Mountains in lumbering spruce and pine. At first the plan was to cut off only the upper branches of the top as it lay on the ground. This left the stem still propped above the ground. (Pl. VI, fig. 1.) The next step was to cut off the under branches and lower the whole mass to the ground. The heavy snows during the first winter after cutting flattened down all the branches. (Pl. VI, fig. 2.) In this condition the brush absorbs moisture so rapidly that after three years there is little risk of fire.

This method was first used in private shooting preserves, mainly to prevent the tops from obstructing the hunter's view. It also enables a freer movement over the ground and facilitates the fighting of fires.

A later development of the method is to cut up and scatter the branches about over the ground. This has been used in the cuttings on second-growth woodlands when the amount of material left after cutting the cordwood in the tops was small. It has also been extensively used in certain National Forests in the dry districts of the West, where the scattered branches serve as protection to the soil and aid reproduction.

The cost of lopping the tops of spruce in the Adirondacks was 12 cents per thousand feet of lumber cut.

Lopping is the most advisable method of brush disposal under the following conditions:

(1) Where there is very little danger of fires starting.

(2) Where the region is moist and the branches will absorb moisture quickly.

(3) When the forest is so dense that piling and burning is impractical.

(4) Where the custom of logging and of utilizing the crown is such that the greater part of the tree is utilized and but little crown is left,

while what is left will not be especially dangerous if thoroughly lopped and scattered.

(5) Where the scattering of the branches is necessary or desirable to protect the soil and small seedlings from drought or frost.

BROADCAST BURNING.

For a number of years it has been the custom of certain lumbermen to burn their slashings, in order to protect valuable standing timber on neighboring areas. There is usually no attempt to regulate the fire within the area burned, and all living trees and young growth upon it are destroyed along with the brush and débris. From the standpoint of forest production such fires are very destructive.

The principle of broadcast burning may, however, be used to advantage in making clear cuttings, provided the fire can be confined to small areas and fully controlled. Thus, in making clearings in patches and strips in certain of the National Forests, the slashings are burned on the ground without piling. This method is now under trial in some of the clear cuttings in the northwestern National Forests, where, in addition to the slash from the cuttings, there is a great accumulation of débris and the litter and humus is very heavy. In some instances this débris and litter is a hindrance to reproduction, as well as an invitation to fire, and its destruction is beneficial. The heavy loss of humus which must accompany so hot a fire may be more than counterbalanced for the forester by the improved conditions for reproduction of the species desired. The expense of piling all the slash and débris would under these conditions be very large, probably not less than from $1 to $2 per thousand feet of timber cut.

In order to control the fire in burning over the ground broadcast, ample fire lines should be constructed around the outside of the areas to be burned. These should usually be not less than 1 rod wide and should be entirely cleared of inflammable material. The material in the lines may often be thrown on the side of the cut-over area and burned with the other débris, but if this would make a dangerously large pile near the line it is better to burn it in piles on the cleared space.

The burning should be done with great caution. A time should be selected when the slash is dry enough to burn well, but not so dry that it will be impossible to confine the fire within the fire lines. The best time is usually when the slash in the open, cut-over area has just dried out sufficiently to burn, and while the contiguous forest is still too damp to burn freely. In the case of wide, cleared strips it may be advisable to construct a fire line through the middle, as well as along the edges. Very often the logging trails can be used for intermediate fire lines for the control of the burning, and in this way the expense of making special lines may be partly saved.

In the work of burning it is usually advisable to have a crew of at least 10 men, properly equipped with fire-fighting implements, in order to control the fire. So far as possible only small portions of the area should be under fire at one time, especially when there is any possible danger of the fire spreading to the adjoining woods.

There is no question that this method is much more dangerous than burning brush in piles, and for this reason the latter method should be used whenever possible. A great objection to broadcast burning is that any remaining trees, reproduction, or young growth, already started on the cut-over area, are almost inevitably destroyed.

ANNUAL OR PERIODIC BURNING OF LITTER.

In many places, notably in the pine districts of the South, it has been the custom to let surface fires run through the woods every year, usually in order to improve the range. This is defended on the theory that if the litter is allowed to accumulate for a number of years, a fire would be so severe as to kill all the timber, whereas an annual fire burns only the year's fall of leaves or needles, and does little damage to the standing trees. Where the trees are tapped for turpentine the litter is raked away from the boxed trees so that the fire will not reach them.

There is no question that in the unprotected yellow-pine forests this custom has resulted in saving a large amount of old timber, but it has also retarded the reproduction of the forest by killing off young growth and seedlings in their tender stage. Deliberate burning of the litter as a protective measure is justified only under special conditions and only on selected areas. The considerations bearing on the use of fire in this way are:

(1) It should never be used except where absolute fire prevention can not be assured and there is real danger resulting from heavy leaf litter.

(2) It should be used only in stands in which there is no reproduction that it is desired to conserve.

(3) It should be used only where the benefit in fire protection more than offsets the injury to the soil resulting from repeated burnings.

(4) It should be used only with very fire-resistant species.

(5) It should be used only when the trees are old and large enough to have developed the corky bark necessary for resistance to the heat of the fires.

(6) It should be used only when the fire can be controlled.

The burning is done best in early spring, when the loose litter is dry but the ground below is damp, the purpose being to burn only the upper litter.

In many places it is very difficult to control the burning without the use of fire lines. A tract divided by roads and paths into small

blocks presents a simple problem, for each block may be burned separately, and there is no danger of the development of a fire too large to control. On large tracts without roads, ground-cleared fire lines may be used to protect areas of young growth, or they may be developed at certain points to aid in the control of broadcast burning.

Annual burning for fire protection is never justified where it can not be systematically controlled. The practice in many parts of the South and West, of setting out fires to burn off the litter and brush, usually for the sake of a better range, can not be justified, for the fires are uncontrolled; and they destroy an immense amount of young growth and otherwise damage the forest. Merely setting fire to the woods without control is nothing less than forest destruction.

FIRE LINES.

Broadly speaking, a fire line is a cleared strip in the forest used as an aid in the protection from fire. It may be a road, a trail, a river or stream, a line cleared especially for a fire break, or a plowed furrow. The purpose of fire lines is to check or stop fires and to facilitate fighting them. A small surface fire may be stopped entirely by a road or even a path. Some surface fires are easily checked in their progress by narrow fire lines, others can be stopped only by very wide lines. Crown fires and surface fires of unusual severity will readily leap across even very wide fire lines. Fire lines, therefore, should not be built with the idea that they will *always* stop fires. They are intended to serve primarily as an aid, and often are an indispensable aid, in controlling fires and preventing their spread. Even when they do not actually stop or check a fire they serve as vantage points from which the fighting crew may work. Their establishment usually makes the woods accessible, so that a crew can get to a fire or near it quickly with appliances for fighting it. If back firing is necessary it can often be done best from the fire line.

Fire lines differ very greatly in construction and width, according to local conditions of fire danger and of special forest organization. They will be discussed under the following heads: (1) Roads; (2) trails; (3) special fire lines.

ROADS.

An ordinary dirt road ranks as one of the best of all fire lines. The wider the road the more effective it is. A forest well cut up with roads is, therefore, much more easily protected than one with few or no roads. In Europe every well-organized forest has a thoroughly planned network of roads. These are located primarily with reference to the problem of logging, but they serve also as a network of fire lines, and special lines are cleared to supplement them where necessary. Every part of the forest is readily accessible not only for

FIG. 1.—A MOUNTAIN TRAIL BUILT FOR FIRE PATROL.

FIG. 2.—A PLOWED FURROW THAT STOPPED A SURFACE FIRE.

FIG. 1.—A FULLY CLEARED FIRE LINE IN THE SAN GABRIEL MOUNTAINS.

FIG. 2.—LOCATION OF FIRE LINES IN THE ANGELES NATIONAL FOREST, CALIFORNIA.

patrolling for fire during the danger season, but for the quick transportation of fire-fighting appliances. In case a fire should start in this forest and be discovered within a reasonable time it would be easy to confine it to a small area.

We can not expect to have such a well-organized system of roads and fire lines in our forests for a long time, but much can be done in the way of utilizing the more or less temporary roads that are used in logging and afterwards abandoned. This is particularly true in the second-growth woodlots.

In most woodlots there are a great number of old wood roads, often badly overgrown with weeds, brush, or trees. If these are kept clear they are of great value in fire protection. They make the different parts of the woods accessible and offer points from which the fighting crews may work. The author has in mind a tract in Pennsylvania which was burned over in 1909 with great loss, but which might easily have been saved had the old roads been clear.

It is usually impracticable, on account of the expense entailed, to keep all the roads free of leaves, grass, etc., but they may be kept brushed out with very little cost. The author recently had some work of this sort done on a Pennsylvania tract, eight years after abandonment of the road, for less than $3 per mile. It may not always pay to repair bridges and restore badly washed roads, but in almost every second-growth woodlot most of the overgrown roads may be reestablished sufficiently for fire lines with very little cost.

TRAILS.

The first object of trails is to open up a forest and make it accessible for patrol and for fighting fires. In the National Forests this work of trail construction constitutes the first step in organizing for fire protection. In undeveloped mountain regions it is impossible without good trails to get to a fire in a reasonable time and with means for fighting it. The trails in the National Forests are permanently constructed and are designed for saddle and pack horse travel. (Pl. VII, fig. 1.) While their first purpose is to facilitate patrol and access to a fire, they may be used as starting points for back firing, and will often check or actually stop a small surface fire.

SPECIAL FIRE LINES.

When there are no roads or trails which will answer the purpose, it may be advisable to construct special fire lines. (Pl. IX, fig. 2.) Special fire lines are necessarily expensive, and are used where the property to be protected is very valuable. They are most used in woodlands in the better settled portions of the country, where land values are relatively high. In many cases it is advisable in a valuable

woodlot to construct here and there a special fire line at points where it is not worth while or practicable to build a road or trail. Thus, special lines are frequently run along the boundaries or at strategic points connecting roads. It is a sound principle, however, that special fire lines should never be built where a road or trail can be used for the same purpose.

In the less intensive forest conditions, such as occur in the lumber woods, special fire lines have so far been constructed only under exceptional conditions. In a large forest, the first work is to open up the area for communication by the construction of trails, and, where possible, of roads. Like all other work in forestry involving an investment, the use of fire lines must be based on sound business principles. They should be used only where necessary and where their expense is justified by the returns.

Special fire lines may be classed under the following heads: (*a*) Fully cleared lines; (*b*) tree-cleared lines; (*c*) ground-cleared lines.

FULLY CLEARED LINES.

The ideal fire line is a completely cleared strip, from which are removed not only the trees and brush but also all ground débris down to the mineral soil.

Fully cleared lines are advisable when the risk of fire is very great, and adequate protection can be secured only by having a clear break which will either stop or check possible fires. Such lines are necessarily expensive to construct and maintain. They are, therefore, used only when the property is valuable and the damage from a fire would be very great, as, for example, to protect nurseries, plantations, or valuable blocks of timber.

They are especially necessary wherever fire will run swiftly and it may not be possible to reach the fire promptly with fighting appliances. A conspicuous example of the necessity of such fire lines and of the service rendered by them is found in the chaparral zone of the mountains in southern California. (Pl. VIII, fig. 1.) The preservation of the chaparral cover is of great importance in protecting the local watersheds. The area is large, the mountains are rough and difficult to travel, and fire runs with great rapidity. Fire lines are very necessary in such localities to control any fires that may start, and they must be of a character to stop fires, or to check them to such an extent that they can be controlled. The Government is, therefore, building extensive trails for patrol to prevent fires, and supplementing them by wide, cleared fire lines to stop any fires that may start.

Cleared fire lines are also used in extensive pine forests on dry, sandy land. Fires start easily and run swiftly under such conditions, and fire lines are easy to construct and comparatively cheap to main-

tain. Thus, in the pine forests of northern Germany and southern France, wide cleared lines are used to supplement the road systems.

The danger from fire is always very great in the regions of the Tropics that have a pronounced dry season. In India, for example, fire protection constitutes one of the greatest problems of management. The forest becomes very dry in the hot season, and there is a great abundance of grass, which ignites readily and carries fire swiftly. Under these conditions cleared fire lines are absolutely necessary for efficient protection.

The width of fire lines varies greatly under different conditions. In general the following classes from the standpoint of width may be recognized: Normal, from 6 to 15 feet; wide, from 15 to 30 feet; very wide, from 30 to 60 feet. In Europe fire lines are usually about 10 to 15 feet wide, but in the pine plains they are often as wide as 50 feet.

In this country such fire lines as have been constructed are usually less than 1 rod in width. In the chaparral of California, however, broad lines from 40 to 60 feet wide have given the best results in stopping fires.

It is seldom necessary or practicable to make fire lines over 60 feet wide. Usually it is more economical to make a number of narrow lines rather than a few very broad ones.

In constructing a fully cleared fire line the timber and brush should all be removed or disposed of to the desired width. Where it is impossible to utilize the timber, the logs may be left along the side of the lines. The brush and other débris should be burned. Piling the brush along the edge of the line is a dangerous practice. As a rule, the best plan is to burn the brush in piles in the cleared area, and then burn the ground litter by a broadcast fire.

In the best permanent lines the stumps are all grubbed out and the soil is occasionally stirred by grubbing or harrowing. Sometimes only a part of the line is cleared to the soil. Thus, for example, the timber and brush may be cleared from a strip from 10 to 15 feet wide, and a narrow strip or trace about 4 feet wide ground-cleared. This cleared trace may be located in the middle of the line, or on one side. A good plan is to make two traces, one on each side of the fire line. The advantage of the last plan is that it affords a very good protection when burning the débris on the line.

The method of constructing a narrow, ground-cleared trace, covering only a part of the fire line, is very commonly used where there is a deep duff on the ground. It is then a question of protection against ground fires. Under such circumstances the trace is usually a trench. In the north woods the duff is frequently 2 feet deep. A narrow trench, from 1 to 3 feet wide to the mineral soil, suffices to stop or check a ground fire. The trees and brush are cleared for a

width of from 6 to 15 feet, to facilitate work in fighting fire and in constructing and maintaining the trench.

Fully cleared fire lines should be cleaned off every year or two. The leaves and other débris accumulating upon them should be removed by burning or otherwise, and in the case of grubbed lines the soil should be stirred over by raking or harrowing.

The work of burning over the fire line can best be done in early spring. The leaves and other débris will become dry on the open fire line sooner than in the adjoining forest or chaparral. The aim should be to do the burning at exactly the time when there will be the least danger of the fire spreading to the woods. It is, however, not always possible to organize the crew so as to have the work done at the most favorable period. In the case of an extensive tract the work may be begun exactly on time, but the whole woods may become dangerously dry before it can be finished. It is especially difficult to carry out this work of burning over the fire line in open pine woods on dry, sandy soil.

When the burning has to be deferred until the woods as well as the fire line are dry, great care should be exercised in the work. If the ground cover consists of leaves or needles, the procedure is as follows:

Narrow, cleared traces are made on each side of the fire line proper by raking or brushing aside the leaves, or needles, and débris. Sometimes, in flat, level areas it is possible to make the trace by plowing one or two furrows. Usually these traces need be no more than a foot wide. A fire is set along the side of the fire-line. One or more men follow this up, constantly brushing the burning or smoldering embers toward the center of the fire line, the idea being to keep the fires confined between the traces. Other men follow behind and watch the burning area to prevent a possible spread of fire. If there is a strong wind, no burning should be done. If there is a slight wind across the line, one trace may suffice on the lee side, and the burning should proceed against the wind. Under ordinary circumstances a crew of from four to six men suffices for burning over fire lines, but if the weather is very dry a much larger crew may be required.

In very dry weather the burning is best done early in the morning or in the late afternoon and evening. The air is moister and there is usually less wind at those times.

In California several interesting experiments in keeping down the brush on the broad lines are being tried. One is to pasture on the line a flock of goats, which eat down the new weeds and sprouts, and trample the ground. Another is to establish on the line a dense growth of succulent herbaceous plants, which would tend to keep out ordinary weeds and obviate annual or periodic grubbing.

FIG. 1.—FIRE LINE CLEARED NEAR RAILWAY.

FIG. 2.—A FIRE LINE IN THE ADIRONDACKS.

The cost of constructing fully cleared fire lines varies enormously, just as does the construction of a road or trail. The cost of clearing the line depends on the width, character, and quantity of timber and brush to be cut, the quantity of tops to be disposed of, and the character and quantity of ground débris, as well as on the labor, the difficulties of work, the efficiency of organization, etc. If the ground is grubbed, the cost is affected by the character of the work done, the difficulties of working the ground, and the topography. In general, the first construction of an 8-foot fully cleared line costs anywhere from $10 to $100 per mile. An average for a second-growth woodlot would be from $30 to $50. If there is a good market for cordwood and other material, the timber might return 50 or 60 per cent of the whole cost. The wide fire lines in southern California cost from $100 to $200 per mile. They are now cleared every two years at a cost of from $50 to $75 a mile, and the cost of maintenance will be progressively smaller from year to year.

TREE-CLEARED LINES.

By a tree-cleared line is meant one from which the trees and brush are removed, but from which no effort is made to clear the leaves or other small litter. The object of such lines is not to stop a fire, but to furnish a vantage ground for patrol and for fighting fires. The brushing out of all wood roads, already mentioned on page 29, makes the best kind of tree-cleared lines.

Very frequently special tree-cleared lines are made where there are no roads or trails, as, for example, along the boundary of a tract, about a recent clearing around a body of young timber, etc. In Europe such lines are often made between two compartments where there is no road or other permanent boundary.

The width of tree-cleared lines is usually from 6 to 15 feet. The European tree-cleared lines between compartments are usually about 6 or 8 feet. Often a line from 10 to 15 feet is cut, especially where a road may later be located. In a number of instances in this country very wide lines have been cut, 75 or 100 feet in width. Such great width is ordinarily unnecessary. Strips a rod wide are usually of fully as great value as the very wide lines, except in conifers, where there is danger of crown fires. The maintenance of these lines consists in brushing them out every year or two.

GROUND-CLEARED LINES.

By ground-cleared lines are meant strips on which the small brush and ground débris are destroyed, and the larger trees are left standing. Ground-cleared lines may be made in open woods, where there is little or no undergrowth to be injured or to interfere with the work of

clearing the ground. The usual procedure is to burn a strip through the woods from 10 to 20 feet wide. This can be done only where the conditions are such that a surface fire may be controlled and restricted to the desired strip.

The open pine woods of the South present an ideal condition for the use of ground-cleared lines. In burning the lines practically the same methods as those described on page 32 for burning over regular fire lines should be used.

LOCATION OF FIRE LINES.

The existing roads usually constitute the base or framework of a system of fire lines. Ordinary roads, old wood roads, skidding trails, and other open strips are used first, and special lines are constructed only when necessary. Special lines should always be located at the strategic points.

In any given forest the boundaries should first be protected. There must be protection from fires that may start on a neighboring tract. Often roads running along or near the boundary will give adequate protection. If not, and there is danger of fire entering from the outside, a fire line is desirable, even if it is only a tree-cleared strip.

Fire lines are often constructed around recent cuttings, where there is young growth established or on areas where there is still considerable slash.

One of the places where fire lines are most needed is along railroads. It is the custom of certain railroads to keep their rights of way clear, usually by annual burning. In some States this is required by law. In spite of this precaution, innumerable fires are set on the right of way, and very commonly by sparks thrown into the woods beyond.

Many special fire lines have been tried. In general, these are based on the principle that the right of way should be cleared, then a strip of woods left standing, and then a second cleared fire line constructed back of this strip of timber. The theory is that the trees on the timbered strip will catch the sparks thrown beyond the right of way. Any fire set by these sparks on the timbered strip will be stopped by the second fire line.

This principle has been used in a number of instances in this country. One good example is found in a hardwood forest in southern New York. A railroad runs through the tract, along a stream valley. The stream acts as a fire line on the low side of the railroad, but the opposite side is exposed to frequent fires resulting from the sparks escaping from the locomotives. A stretch of several miles is on a steep grade, and the locomotives, under forced draft, throw out great showers of burning cinders, and no spark arresters whatever are used. As a protection, a fire line varying in width from 8 to 15 feet has been constructed on a bench at a distance of from 50 to 150 feet from the

railroad. (Pl. IX, fig. 1.) The strip between the line and the railroad is left untouched. A patrolman rides over the strip about the time the trains going up grade pass by. Ordinarily the small fires are extinguished by beating. In case, however, a number of fires are started by a train, as often happens, one or two of them burn over the strip to the fire line before the patrolman can reach them. The strip is so narrow, however, that they gain little headway, and are absolutely stopped by the fire line.

In mountainous country, fire lines are located with reference to the topography. Where roads are used, or fire lines are made that are intended to be used later as roads, the location is governed largely by the principles of road construction. Special fire lines, however, constructed for protection alone, are built mainly on the crest of ridges. (Pl. VIII, fig. 2.) Thus, the wide lines in southern California, already mentioned, are on the various ridges. A fire runs up a slope very rapidly and works over a ridge slowly. If there is a wide, cleared fire line on the ridge the fire may be stopped entirely by it alone. In the southern Appalachians and other mountains, the old mountain trails on the ridges may be developed into admirable fire lines.

The question of when and where to construct special fire lines must depend on local conditions, the danger from fire, the value of the forest, the organization of patrol and force available for fighting fire, the object of the owner in protecting the forest, and many other factors. As with other operations of management, the expense must be justified by the results which their construction is intended to accomplish.

ARTIFICIAL FIRE OBSTRUCTIONS.

It is well known that a small, creeping surface fire is stopped or checked by a stone wall or other similar obstruction. This principle may be used in fire protection, and other types of fire lines may often be dispensed with where there are such obstructions. A well-known railroad has been experimenting with a specially constructed fire wall.

SUPERVISION AND PATROL.

A careful supervision or patrol during the dry season is one of the most important measures in organized forest protection. Its purposes are: (1) To prevent fires from starting; (2) to detect fires as soon as possible after they start; (3) to fight fires.

The mere fact that a tract is carefully watched makes it safer, because campers, hunters, and others crossing it are less careless on that account. By an efficient supervision most of the unnecessary fires can be prevented, such as those arising from carelessness in clearing

land, leaving camp fires, and smoking; from improperly equipped sawmills, locomotives, donkey engines, etc.

One of the fundamental principles in fire protection is to detect and attack fires in their incipiency. In an unwatched forest a fire may burn for a long time and gain great headway before being discovered. In a forest under proper protection there is some one man or corps of men responsible for detecting fires and for attacking them before they have time to do much damage or to develop beyond control.

AIDS TO SUPERVISION AND PATROL.

Under the head of aids to supervision and patrol are included: (1) The posting of fire warnings; (2) lookout stations; (3) telephone systems; (4) signal systems.

POSTING OF FIRE NOTICES.

One of the first steps in organizing protection in a forest is to post it with fire warnings. These notices emphatically warn against carelessness in the use of fire, and often give instructions how to construct camp fires and how to extinguish them when breaking camp. They usually contain also the prescribed penalties for infringement of the fire laws. Notices are posted at frequent intervals along roads and trails, at camping grounds, near permanent camps and settlements, and in many cases along the boundaries of tracts. On private tracts the fire warning is combined with the trespass notice.

In the National Forests fire-warning notices are printed in English, Italian, French, and Spanish. Notices printed in Italian are posted where Italians are employed in railroad construction or section work. Spanish notices are used in New Mexico, southern Arizona, or other localities where there are many Spanish-speaking people. Near the northern boundary French notices are sometimes used. Beyond question many forest fires have been prevented by these warnings.

In the case of a forest owned by a nonresident it is a good plan to have on the notice the name of the responsible local agent, as well as the owner's name. This lends emphasis to the fact that there is a local man who is looking after the property.

LOOKOUT STATIONS.

Lookout stations include watch towers, mountain lookouts, and other elevated stations used for overlooking tracts and watching for fires. On small tracts they consist usually of some simple structure which enables the person responsible for the property to overlook the forest to see if there are any fires, and, in case he sees smoke, to locate the fire. Sometimes an arrangement on the roof of the house or barn serves as a watch tower, or a lookout may be built in a tall tree, or it may be necessary to build a rough tower to see over the tree tops.

In a rugged country it is usually possible to find some convenient peak from which a large area can be looked over. (See Pl. I, frontispiece.)

In the organization of large tracts in mountain regions special lookout stations are sometimes provided. These are located at high points from which a large area of the forest can be seen. A man is kept constantly at each station during the dry season. The various stations should be in communication by telephone or telegraph, or by some system of signals. Each is provided with range-finders or other equipment, by means of which any fires that may occur can be precisely located. They are also in communication with the forest ranger or superintendent at headquarters, so that a force of men may be called at once to the fire and put it out. In extensive mountain regions these lookout stations constitute an important part of organized fire supervision. They have been successfully operated in the National Forests.

TELEPHONE SYSTEM.

One of the great difficulties in extensive forest districts is to secure the necessary help in fighting fires. The telephone is the greatest aid in fire patrol. It enables the man who discovers a fire to call for help and to give directions as to the number of men and the equipment needed. By the use of the telephone on the National Forests millions of dollars have doubtless already been saved. The Forest Service has since 1906 built 4,850 miles of telephone line, and it is extending the lines as rapidly as Congress furnishes the funds for the work.

SIGNAL SYSTEMS.

When there is no telephone system and a regular lookout station is not feasible, a special system is used for signaling for help in fighting a fire. Some prominent peak is selected, from which, in case of fire, the location and size of the fire and the required help are signaled by a prearranged code. There are various systems of signals in use. The fire signal is one of the oldest methods. At a time when the signals are not needed small piles of wood, brush, or other inflammable material are gathered and placed in position at about equal distances, usually about 50 to 100 feet apart, ready for firing on short notice. The number of fires burning at the same time conveys the information required. Thus, one fire might mean that a forest fire is burning in a certain locality on one side of the mountain; two, in another locality; three, in another; and so on.

Another system that is sometimes employed is the smoke signal. This was once very commonly used by the Indians in communicating with each other from one distant peak to another. A small fire is built, and after it gets under good headway, damp moss or

earth is used to deaden it and develop a heavy smoke. A blanket or other covering is thrown over the top of it to smother the smoke down for a few moments. The blanket is then raised, and a dense puff of smoke is released. The blanket is again thrown over the fire to check the smoke for a moment, then it is again removed, and another puff of smoke ascends. This system also requires a prearranged code. The smoke signal may be used in the same manner as the fire signal, by causing two or three separated columns of smoke from dampened fires to be steadily rising at the same time. This system of signaling may be used to good advantage on a still day for communicating long distances. The separated fire signal on top of prominent peaks can be used in the night as well as in the day.

The heliograph is an instrument which may be used for flashing signals from the lookout stations. The Forest Service has recently conducted successful experiments with this instrument.

Another system sometimes used when the wind is blowing and the sun is shining is a windmill signal. A small windmill is set up on some conspicuous elevation. This is provided with a small belt and pulley connecting with a revolving ball or wheel in which small mirrors are set at different angles. In case a fire starts and the wind is blowing, the watchman simply connects up his windmill with the ball in which the mirrors are set, and goes on to the fire, leaving his automatic signal to flash to the settlement the news of the fire and the fact that assistance is wanted.

In some cases it might be possible to use flags and the code of the Army Signal Corps. Near settlements the fire bell, gong, or whistle is commonly used to bring together the men for fighting fires.

The organization of an efficient patrol varies under the following conditions: (1) Size of tract; (2) character of the forest; (3) condition of the forest with reference to the amount of inflammable material; (4) difficulties of communication; (5) difficulties of securing help in fighting fires; (6) the topography with reference to the amount of territory which can be overlooked; (7) special sources of fire, such as the presence of a railroad; (8) local sentiment.

SUPERVISION OF SMALL TRACTS.

The supervision of a wood lot attached to a farm is exceedingly simple. If a farmer himself uses proper care in starting fires, in clearing out his roads, in disposing of brush, and in keeping a careful watch for fires, his wood lot is comparatively safe. Many woodlot fires are caused by the owner's own carelessness in clearing land, destroying brush, burning meadows, etc. The fact that the owner is careful in the matter of fires becomes known very quickly in the neighborhood, and that fact in itself is a great protection. It is not

necessary for a farmer to patrol his woodlot at regular intervals, as would be necessary in the case of a large tract.

Many fires start on the property of nonresident owners, who themselves are unable to supervise it on the ground. Nonresidents may secure protection by an arrangement with some farmer living near the forest. The usual course is to pay a small retaining fee for general supervision, with the understanding that the farmer goes over the tract every few days, thus giving the impression of constant patrol. In case fire starts, the agent has the responsibility of repairing to the fire and putting it out and employing such help as is necessary. There is no reason why this plan should not provide adequate protection for tracts of from 100 to 500 acres at an annual cost of from 3 to 5 cents an acre.

One of the most essential measures in the protection of small tracts is to secure the cooperation of the owners of all the neighboring tracts in watching for fires and in mutual assistance in extinguishing fires, no matter on whose land they start.

SUPERVISION OF LARGE TRACTS.

In the protection of large tracts from fire a special organization for patrol is necessary. This organization can best be combined with that required for the management of the tract. In every forest that is being developed there is necessary a certain force to supervise any work such as logging, the construction of roads, the protection of game, the prevention of trespass, etc. This organization is best illustrated in the National Forests. There is a permanent corps of trained rangers who live on the Forest, each in charge of a specified area. These men have executive charge of all the work in the woods. During the dry season this force may be supplemented by temporary forest guards for special fire patrol. Each guard is assigned to a specified part of the Forest, which he is required to patrol regularly; he prevents the start of fires as far as possible and watches for any fires which may start within his range. It has already been explained that one of the purposes of the construction of trails through the Forests is to enable constant patrol and access to fires which may be started. The guards ride or walk over these trails under a systematic plan. There is usually a regular beat over which the guard travels at regular intervals. In some tracts it is possible to go over the beat once a day; in others it requires a much longer period. When not on patrol the guards are engaged in the general work on the Forest.

In the plan of patrol the guards keep in close touch with each other and with the ranger in charge of the whole work, in order that they may communicate in case of fire by signal from lookout stations, by

telephone, or any other method of communication that may be established in the Forest.

Most of the National Forests of the West are in rugged mountain regions, with comparatively few roads and trails. The guards usually travel on horseback over certain roads or trails, keeping track of the people who enter the Forest, and giving them special warning regarding carelessness with fire. In this way each person entering the Forest is impressed with the fact that his movements are watched, and the result is that he is more careful with camp fires, smoking, etc.

On large tracts patrol is concentrated at critical points. The guards spend the most time where there is the greatest travel, frequently inspecting camp grounds, sawmills, and other points where fires are most likely to start.

In some instances the actual patrol over trails is more or less dispensed with, and men are kept continuously at lookout stations, from which a large area can be overlooked. In case of fire, signals are sent to other lookout stations and to headquarters, with the necessary instructions regarding the location of the fire, the number of men needed to fight it, etc.

It is impossible to give a specific rule regarding the number of men required to protect tracts of different sizes. There is no question that the National Forests are very much undermanned. In some cases a single man has the responsibility of protecting more than 100,000 acres. This area is much too large even under the most favorable conditions, and it is only through the most efficient work that the damage by fires has been kept down to 1.86 per cent of the forest area. Even with proper facilities for communication, the fire protection force on the National Forests should be quadrupled. Very good results would be obtained if there were, during the dry season, one guard for each 20,000 or 25,000 acres. This will follow naturally as the increased receipts from the Forests justify a more intensive management.

In flat regions more men are required for patrol than in a rugged country, where large areas may be overlooked from prominent elevations. It has been the general view that in flat regions like the Lake States and the plateau portions of Maine and the Adirondacks there should be at least one guard for each 10,000 acres.

The required force of guards is governed by the risk of fire and the value of the property to be protected. In the case of a forest of very great value there is necessarily a correspondingly greater justification for expenditure in fire protection, just as one takes out fire insurance in proportion to the value of his property. As the value of our forests increases, there will be a correspondingly greater amount of money spent on protection. This principle is illustrated in Europe, where the forests are very valuable and where frequently

there is one forest guard for each 1,000 acres. (Prussia, one for 1,700 acres; Baden, one for 750 acres.)

PATROL ALONG RAILROADS.

Railroads in many cases are the most prolific source of fires. In some sections over 50 per cent of the fires are from the sparks from locomotives. While most of these fires could be prevented if the railroads used proper appliances on the locomotives for arresting the sparks, nevertheless, in many cases, it is probably impossible to prevent sparks which will start fires in very dry weather. It is, therefore, necessary to supplement the use of spark arresters by patrolling the right of way.

The most effective method of patrol is to follow every train with a speeder equipped with mattocks, shovels, pails, and other necessary equipment for fighting fires. A fire started by a spark from a locomotive may be put out before it has an opportunity to gain any considerable headway or to do much damage.

It is not always practicable to follow every train over a long distance, and it may happen that there is danger from the sparks only at steep grades. In that event the patrol is concentrated at the dangerous points.

The plan of following every train by patrolmen may be practical where the distance traversed by the road is not great, but it would not be feasible for a great mileage. Thus, for example, the problem of patrol is being considered by certain large railroads with the view of applying it over the entire system, wherever there is danger from fires. The purpose is to save the annual expense of fire damages. Thus, one system in the Northeast, covering not over 2,000 miles, is said to have an annual expense of over $50,000 for forest-fire claims. It is probable that the most practical method of supervision of the right of way would be through the organization of the section men, with a special patrol at certain grades where the danger from fires is particularly great. There is no reason why the section men, if provided with proper speeders and other equipment, should not be trained to repair at once to fires which may start along the right of way and put them out, with a comparatively small loss of time.

In Minnesota the law requires that railroad companies must put on patrolmen to patrol their tracks. The forest commissioner may compel the companies to put on as many as one man to each mile of track.

METHODS OF FIGHTING FIRES.

The principles of fighting forest fires are essentially the same as those recognized in fighting fires in cities. The following are of first importance: (1) Quick arrival at the fire; (2) an adequate force;

(3) proper equipment; (4) a thorough organization of the fighting crew, and (5) skill in attacking and fighting fires.

QUICK ACCESS TO FIRES.

Quick access to fires is accomplished through the work of supervision and patrol in discovering fires before they have gained much headway, and by a well-developed system of communication through the forest by roads and trails.

AN ADEQUATE FORCE OF FIGHTERS.

A small fire may be put out by one man, but in extensive forests several hours may pass before the fire can be reached. It is important to secure an adequate force of men and to get them to the fire quickly. In a well-organized system of patrol the guard who discovers a fire communicates quickly to other guards and to headquarters by telephone, signal, or other means, and indicates the number of men he needs. It is essential that there be definite arrangements for securing a force of men in case of fire. This may be accomplished by cooperation with lumber or sawmill operators who employ forces of men, and through cooperation with local residents, or, in case of small tracts, through the cooperation of neighboring owners, each of whom agrees to assist his neighbor in case of fires. In some States there is a system of fire wardens. In case of fire, the fire warden may call upon residents to assist in extinguishing it. They are required by law to repair to the fire in case of call, and there is a small statutory compensation for services. In case of extensive forests cooperative arrangements should be made with every resident within the forest and with every user of the forest to assist in fighting fires. In most cases where lumbering is going on the men who are employed in the logging operations, at sawmills, in road construction, etc., will furnish a large force on occasion. Through an efficient system of cooperation it is possible to secure quickly a large force of fighters, and through this same system all the residents soon take an active interest in preventing fires from starting.

The cooperative fire protective associations in the Northwest, following the example of the Forest Service, have organized systems of patrol and are doing highly important work in suppressing forest fires in the white-pine regions of Idaho and Montana and the fir forests of Washington. These associations now include practically all of the large timber owners in the Northwest, and many small owners as well. The expense of maintaining a patrol during the dry season, of fighting fires, and of building trails and telephone lines to assist in fire fighting is apportioned among the members of the association on an acreage basis.

PROPER EQUIPMENT FOR FIGHTING FIRES.

Just as in a city the efficiency of a fire service depends in large part on the equipment, so also in forest work it is essential that fire fighters be furnished with the proper tools and other equipment. The implements needed for fighting fires differ under different conditions. Wherever dirt can be used the men should be provided with long-handled shovels. If water is available, buckets should be provided, and, where possible, bucket pumps. Under most conditions it is desirable to have mattocks and iron rakes, and there should always be axes to aid in clearing brush or cutting through down timber and old tops.

These implements should be kept in a convenient place for use in fighting fires. Proper organization for fire protection includes an adequate equipment for the fire-fighting force. No matter how numerous or skilled the crew, the men are helpless without proper implements. In the protection of woodlots in settled regions every farmer who repairs to a fire usually takes his own shovel, rake, ax, or other implement. In the more remote forests under organized protection, the implements are usually provided by the ranger. A very good plan is to have caches at convenient points on the trails or at the lookout stations, containing fire-fighting tools. In some cases in the mountain regions tools are kept in a special pack outfit ready to be thrown upon horses and taken at once to the fire. Such special outfits usually include shovels, collapsible pails, axes, mattocks, ropes, and in some cases fire extinguishers, and a small quantity of provisions to enable fire fighters to camp out over night if necessary. Where there are good roads, as in the woodlot regions, special fire wagons have been used to advantage. (Pl. X, fig. 1.) These consist of an ordinary wagon of the Concord type, furnished with a complete equipment of tools, bucket pumps, fire extinguishers, water tanks or barrels, etc. The author has used on his own tract in Pennsylvania a crude fire wagon consisting of a two-seated buckboard provided with a special galvanized-iron water tank with a capacity of about $1\frac{1}{2}$ barrels. The wagon is also equipped with two fire extinguishers, two bucket pumps, one-half dozen buckets, shovels, rakes, axes, and such other tools as are needed in fighting fires.

ORGANIZATION OF THE FIGHTING CREW.

It is important that there be in charge of the fighting crew someone in authority to thoroughly organize the work. A small crew well organized can do much more effective work than a loosely organized large crew. One of the advantages of the fire-warden system adopted in a number of States is that the warden has authority not only to impress men to fight fire but to direct their work.

The efficiency of the fire-fighting crew depends very largely on their skill and experience, and particularly on the skill and experience of the man directing the work. It is not only a question of knowledge of how to assign each man where his work will be most effective, but there must be judgment exercised in determining the general method of attack. The character of the fire, the character of the forest, the condition of the atmosphere, the strength and direction of the wind, the rapidity with which the fire is running, and many other points have to be taken into consideration.

METHODS OF FIGHTING SURFACE FIRES.

Small surface fires may often be beaten out. This is possible when the fire is burning chiefly in a dry leaf litter or short grass. Where there are tops or piles of dry brush, or the fire is burning through thick brush or undergrowth, beating is very difficult.

There are various devices for beating. A blanket, coat, or riding slicker is often used. A gunny sack is one of the best implements for beating, particularly if it can be wet from time to time. A handful of green brush serves also very well for a beating device. In beating out a fire, one strikes the fire with a sideways sweep, driving the flames and burning material back upon the burned ground. A direct stroke scatters the fire. (Pl. X, fig. 2.)

The best way to extinguish running surface fires is to throw sand upon the flames. This method is, of course, practicable only when the soil is fairly clear of rocks and loose enough for ready digging. In the plains of the Atlantic Coast, for example, the sand is so loose that it can be dug up and thrown on a fire almost anywhere. The fighting crews are equipped with long-handled shovels, and the sand is thrown along the line of fire. When the fire is running in the open woods, in pine needles, a single shovelful of sand, properly thrown, will extinguish over 10 feet of fire.

Loose loam is also very good, but not so effective as sand. Heavy soil which clods is difficult to manipulate. Frequently sand or loose loam can be dug up in spots, but it is too stony to secure it all along the line of fire. The fighters must then supplement the use of sand or earth with beating or other methods.

Where, on account of the accumulated débris, the flames are intermittently too severe for beating, water is used if available. Water usually has to be brought from some distance; it must therefore be used very economically. The best way is to deaden the flames by a little water, and then beat them out with a gunny sack or other device. Experience has shown that water may be most effectively applied by a hand spray pump. This pump throws a stream 20 or 30 feet and makes it possible to apply the water exactly where it is most needed. The pump can be purchased at prices varying from

FIG. 1.—A FIRE WAGON.

FIG. 2.—METHOD OF BEATING OUT A FIRE WITH AID OF WATER.

$3 to $4.50. They are extensively used by farmers in the Northeast. (Fig. 1.) Collapsible pails are excellent for carrying water, because of their lightness and compactness. Ordinary metal water pails are commonly used by farmers, and are much cheaper than collapsible pails.

When water must be brought over mountain trails special water sacks are used, which can be slung on a pack saddle. Water kegs adapted to pack horses have been tried in Pennsylvania. Where there are passable roads water is hauled in barrels or in specially constructed tanks.

Patent fire extinguishers have also been used in fighting fires. These throw a stream of water from 15 to 20 feet. The stream is chemically charged, so that it is very effective in putting out flames which would be little affected by ordinary water. In practice a crew is provided with several extinguishers, a supply of water, and extra chemical charges. As soon as an extinguisher is emptied it is reloaded, so that there may be a continuous play along the line of fire. In case of an ordinary fire running through grass or leaf litter, one extinguisher will putout 200 feet of flame.

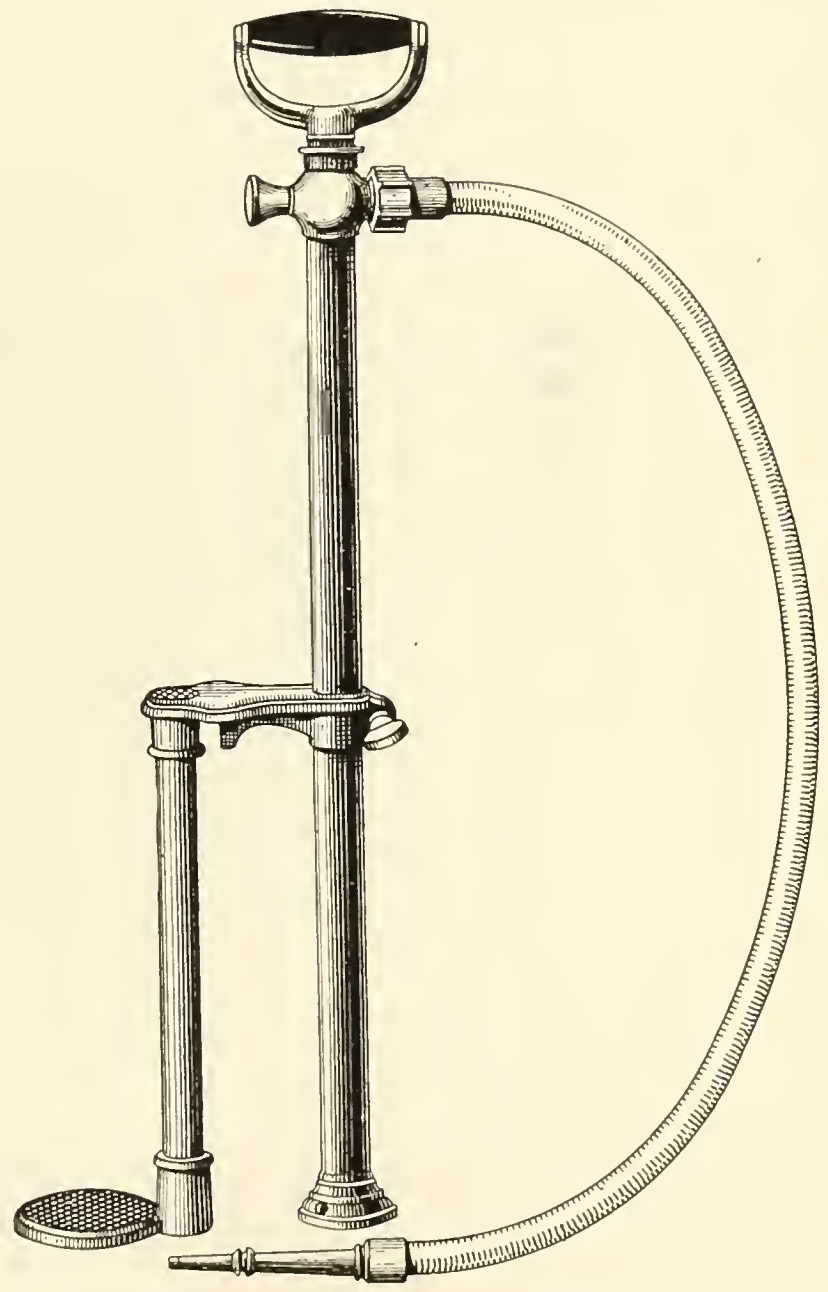


FIG. 1.—Bucket pump used in fire fighting.

A very good method in fighting running surface fires, where there is not much slash, is to make a narrow trace in front of the fire by raking to one side the leaves and other litter. As soon as the fire reaches the trace it is checked and readily beaten out. Sometimes, on level land and in open woods, a furrow is plowed as an emergency fire line. (Pl. VII, fig. 2.) This same principle is used to check fires burning through young growth and brush where it is difficult to get at the flames. A narrow lane is cut through the brush ahead of the fire. This gives a space where the crew can work without hindrance. As soon as the fire approaches, it is attacked by all the crew with the various fighting devices with which they may be provided.

Sometimes the front of the fire is so fierce that it is impossible to meet it directly. One method under such circumstances is to direct the course of the fire. The attack is made on the sides near the front, separating the forward portion of the fire from the main wings. A part of the crew attacks the forward part and others run down and extinguish the wings. The front of the fire, attacked from the sides, is forced gradually and constantly into a narrower path. Usually the front can be directed toward some cleared space, road, pond, stream, swamp, or fire line, when it will be checked enough to admit of a direct front attack. Sometimes by this plan the front may be rapidly narrowed by working from the sides, until it is at last entirely extinguished. The plan of giving direction to the course of the fire has often been successfully carried out when the fighting crew is too small for a direct attack.

METHODS OF FIGHTING GROUND FIRES.

Ground fires, burning in the deep layer of organic matter, are exceedingly difficult to extinguish. If the layer of vegetable matter is not very deep, it is sometimes possible to put out the flames by water or sand. If the layer is deep, trenching is the only practical method of stopping the progress of the fire. In using this method of fighting ground fires, one judges the rapidity with which the fire is burning and then, at a proper distance away, digs a trench through the vegetable layer down to the mineral soil, using axes, mattocks, and shovels, as the particular case may require. Such a trench, which has a width at the bottom of 1 foot, will enable the fighters to stop an ordinary ground fire, especially if the work can be supplemented by the use of water or sand at the trench.

METHODS OF FIGHTING CROWN FIRES.

Crown fires are always accompanied by surface fires. Crown fires stop when there are no longer inflammable crowns through which the fire will run, or when there is no longer any material on the ground to carry the surface fire. An ordinary crown fire will jump a wide fire line, and many fires have been known to cross wide rivers, almost without check. In the mountains, a crown fire running up a slope is almost impossible to check.

BACK FIRING.

On level ground it is possible to stop crown fires by back firing, when the conditions are such as to make back firing possible at all. Thus in the pine forests of the Atlantic coast crown fires are frequently checked by back firing. The back fire burns off the surface material, and thus in itself acts as a check to the crown fire, and, if the

area burned by the back fire is large enough, will stop it in this way. At other times, when the back fire has been successfully started and is well under way, eating back against the wind, it is caught by the hot volume of air generated by the heat of the crown fire. The flames are then turned quickly toward the crown fire, and the meeting of the two lines of flame stops the advance of the fire.

When fires gain such headway that it is impossible to stop them by direct attack, no matter how numerous and efficient the crew or complete the equipment for fighting, back firing becomes the only means of stopping the fire. It should, however, be used only when it is absolutely necessary. One of the commonest mistakes in fighting fires is to overestimate the rapidity of the fire and the difficulty of putting it out. A forest fire is always a frightening spectacle, particularly if it is sweeping in the direction of one's own property. Men often become excited and start back fires when it is entirely unnecessary. Back firing necessarily involves deliberately burning over property. When this belongs to another person and one's own forest seems in danger, there is a great temptation to sacrifice it.

A second principle in back firing is to burn over as small an area as possible. The counter fires are therefore set only as far ahead of the fire as is necessary to make them effective. Very often, however, there is only one point from which a back fire can safely be started, so that the fighters have no choice.

If it is found that a back fire is necessary, a favorable point is selected directly in front of the fire, from which to set the new fire. This must be a point where it is safe to start a back fire, such as a road, fire line, stream, or swamp. The leaves are ignited at points 5 feet to a rod apart for a distance not greater than the estimated width of the head of the fire. These small fires gradually meet and form a continuous line, eating back against the wind. A part of the crew is stationed across the road or other break from which the back fire is started and put out at once the small fires which may result from the sparks blown over from the back fire.

The meeting of the two fires stops at once the head of the main fire. It is usually possible then to attack the wings with the ordinary methods of fighting. It is necessary to attack the wings at once, particularly if there is a strong wind, for otherwise each wing of the old fire would soon form an independent fire with a well-developed head. It is necessary, also, that a number of men be stationed where the original fire and the back fire meet in order to extinguish smoldering fires in tops, logs, and other débris.

PATROL AFTER A FIRE IS EXTINGUISHED.

A fire is never out until the last spark is extinguished. Often a log or snag will smolder unnoticed after the flames have apparently been conquered, only to break out afresh with a rising wind. After the fire-fighting crew has left the ground it is always well to assign at least one man to patrol the edges of the burned area until it is certain that the fire is entirely out. This may not be for several days.