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Artificial Pruning in Coniferous Plantations

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ARTIFICIAL PRUNING IN CONIFEROUS PLANTATIONS

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A Note to Readers
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INTRODUCTION

THE Eli Whitney Forest comprises 20,000 acres of land located in the territory surrounding New Haven, Connecticut. The forest is owned by the New Haven Water Company and managed under the supervision of the Yale University School of Forestry.*

As part of the forestry operations in the Eli Whitney Forest approximately 2,500 acres of coniferous plantations have been established since 1900. One of the important problems in the management of these plantations is to produce trees from which, eventually, forest products of the highest value can be obtained. Early in the development of the plantations it became apparent that the lower branches on the planted trees died so slowly and remained attached to the trunks for so many years even after death that it would be practically impossible to produce lumber of high quality. Unless the branches are removed artificially by pruning, the chief product will be timber of the lower grades. This may be of little consequence for some species and for certain products, such as fuelwood, where value of the wood does not increase appreciably with freedom from knots. For other species, where lumber products will be produced, pruning becomes an essential operation in management. This is true of northern white pine (*Pinus strobus*†), the conifer deemed the best for planting in southern Connecticut.

The purpose of this bulletin is to set forth the pruning policy and practices employed in the Eli Whitney Forest in managing coniferous plantations. Publications on pruning, heretofore, have dealt primarily with the pruning of trees in natural stands rather than in those artificially established, which because of their origin require different treatment.

The pruning practices here outlined should be applicable on the thou-

* For further description of this forest the reader is referred to Bulletin 27 of the Yale University School of Forestry series, entitled *The Eli Whitney Forest: A Demonstration of Forestry Practice.*

† Scientific names of tree species appearing in this bulletin are taken from Sudworth (1927), with the exception of Norway spruce, which is taken from Sargent (1922).

sands of acres of coniferous plantations which have been established in southern New England and portions of New York, New Jersey, and Pennsylvania having similar forest conditions. In this general region land prices are relatively high, but the population is dense and markets accessible. Plantations for the production of timber, in order to prove profitable, should be made only on good soils and of the more valuable species and should be intensively tended. Artificial pruning is one of the silvicultural operations needed in the care of such plantations.

Before discussing pruning practices it is advisable to consider in further detail the need for pruning in rlantations.

THE NEED FOR PRUNING

PRUNING in commercial forestry operations is justified only as a means of increasing the value of the timber produced. This will be accomplished if clear lumber of the species in question is worth more than knotty lumber. Generally speaking, clear lumber has a higher value because of its greater strength and better appearance. It seems reasonable to expect this situation to coptinue regardless of fashions, such as the use of knotty interior trim, which are believed to be ephemeral, and in spite of the increasing use of the lower grades of lumber brought about by the growing scarcity of the higher grades.

It is perhaps not widely realized that in the case of most conifers clear lumber cannot be grown economically without pruning. Under virgin forest conditions clear lumber was found only in old trees, and there only in an outer zone of wood. There was always a core of knotty wood in the center, for, contrary to common belief, old-growth trees did not prune themselves any better when they were young than do second-growth trees now growing in similar mixtures.

A certain amount of clear lumber could be produced by allowing the stands to reach an age of 200 or more years before cutting. This is out of the question in commercial forestry, since the added value of the clear lumber produced would be insufficient to pay for the cost of growing the timber for so long a period. A relatively short rotation of from 50 to 100 years ordinarily will be used. Clear lumber, if produced at all on such a rotation, must be grown in some way other than that employed by Nature in the virgin forest.

One method often advocated is the establishment and maintenance of a dense stand containing several thousand trees per acre. This aids somewhat in natural pruning, but it is not likely to produce clear lumber on a short rotation. With white pine, especially, stand density has but little bearing upon natural pruning. It is true that the branches in densely stocked stands die at an early age and when of small size, and that knot size is inversely proportional to stand density (Tarbox and Reed, 1924). However, the branches persist upon the trees for so long that practically no natural pruning is attained for many years.*

Dense stocking has the disadvantage of reducing diameter growth (also in some cases height growth) and lengthens the time necessary to secure trees of a given size. These serious disadvantages more than offset, even in a naturally reproduced stand, the slight advantage in natural pruning which arises from dense stocking.†

Pine grown in mixture with hardwoods or hemlock (*Tsuga canadensis*) is thought to attain somewhat better natural pruning than does pure pine. The reasons for this have not been thoroughly investigated, but it seems probable that hemlock exercises a shading effect which inhibits the growth of lower side branches, causing them to die early, and increases the humidity within the stand, facilitating the decay of the dead branches. Hardwoods exercise a whipping action against the pine branches, both during the summer and winter, and in the latter season, because of their lack of

* An extreme example of density of stocking in white pine is found in some abandoned nursery seed beds near Keene, New Hampshire, where the trees originating from seed sown 25 years ago have been allowed to grow naturally without human interference. In one of these seed beds, measuring 4 by 36 feet, with similar beds on either side separated by 18-inch paths, are 108 living trees. The density of this stand is approximately 23,000 trees per acre. The average size of dominants is about 16.5 feet in height and 2.3 inches in diameter, breast high. The average height to the first living branch is approximately 8 feet, but dead limbs persist to within 18 inches of the ground. This stand at the age of 25 years has pruned itself naturally to an average height of only 18 inches. It illustrates the persistence of dead limbs upon white pine, even in abnormally overstocked stands. For further information about these interesting seed beds see Deen (1934).

† It may be argued that complete natural pruning is not necessary, since lumber need not be absolutely clear, i.e., free of all knots, to command a good price, because a few small sound knots are admitted in several of the better grades of lumber. Natural pruning in a densely stocked stand might keep knot size so small as to come within the specifications for the higher lumber grades. In the case of white pine, with its numerous branches at each whorl, it is probable that there would be too many small knots in a given piece of lumber to allow its acceptance for the higher grades, even though the knot size came within the specifications.

foliage, freer access to the interior of the stand is given to wind, snow, ice, and frost. In a mixed stand the action of these elements tends to break off the dead pine branches, which in a pure stand are more sheltered and consequently persist longer. But in spite of this assistance from its associates, white pine in mixture with either hemlock or hardwoods does not attain satisfactory natural pruning, since the production of clear lumber does not begin until about the fiftieth year.

Conditions are less favorable for natural pruning in plantations than in natural stands. If natural pruning cannot be relied upon to produce appreciable quantities of clear lumber on the relatively short rotations used in growing forest crops in naturally reproduced stands where frequently several thousand trees per acre are established, how much less likely is it that satisfactory natural pruning can be expected in plantations where from 700 to 1,200 trees per acre are the number customarily planted? The cost of establishing artificial stands of the same density as those obtained by natural regeneration would be very high and in most cases would be more than the expense of artificially pruning the planted trees.

In the case of white pine in New England, for example, increasing the number of trees planted from 1,200 (6 by 6-foot spacing) to 2,700 (4 by 4-foot spacing) involves an additional cost of approximately $15 per acre, for which sum artificial pruning could be accomplished. Furthermore, the density obtained from the 4 by 4-foot spacing would be inadequate to improve appreciably the natural pruning. The necessity of artificial pruning in white pine plantations cannot be avoided by increasing the density of stocking except at prohibitive cost.

A study of the situation leads to the conclusion that artificial pruning will be an essential operation in growing profitable crops of white pine and probably of other conifers. Unless a plantation of white pine is skilfully managed, and particularly unless it is systematically pruned, thinned, and protected against injurious agencies, it is doubtful whether the original expense of establishing the plantation can be justified on the basis of the timber crop which will be grown.

Norway pine (*Pinus resinosa*), locally known as red pine, at the present time is rarely found in New England in merchantable sizes, though thousands of acres of plantations have been established. Just what will be the most profitable use for red pine from 40 to 60 years hence is difficult to predict. Red pine is quite similar to white pine in the character of its wood, and there are indications that plantation-grown red pine may be nearer like white pine than is the old timber today. While in the past red pine lumber was usually thrown in with white pine, in the Lake States, where red pine is cut in its largest volume, the better grades of red pine are now sold on their own merits. There appears to be no reason why, if clear lumber may in the future be expected to command a premium over knotty lumber in the case of white pine, this same principle should not apply also to red pine. Pruning of red pine is advised on these grounds.

This general conclusion should hold true also for Norway spruce *(Picea abies)* and white spruce *(Picea glauca)* planted in Connecticut. If the spruces are to be put into pulpwood, pruning would of course be a waste of money. No market for pulpwood exists at present in this region, and, because of the predominance of oak in the forest, pulp mills are not likely to be developed. The spruce now being planted should find its best market as lumber of good quality and merits pruning to develop such a product.

CHARACTER OF THE CONIFEROUS PLANTATIONS

IN securing lands for water-supply purposes the New Haven Water Company purchased forested and open areas needed for the proper development and protection of their watersheds. Several thousand acres of non-forested land formerly devoted to agriculture were thus acquired. Since forested lands furnish better watershed protection than those not forested, the latter are being planted with trees. The natural growth in the New Haven region is composed chiefly of deciduous trees, although various conifers such as white pine and hemlock are native in the territory. Conifers were chosen for the planting for several reasons. They gave variety to the landscape in contrast to the prevailing deciduous forest and in some respects made a superior protective cover and promised better ultimate returns in timber. White pine and red pine are the two species which have been planted most frequently, the former being considered the more desirable of the two in the Eli Whitney Forest.

Most of the plantations already established are pure stands of white or red pine, although some mixtures, by alternate rows, of the two species have been made. This particular type of mixture has proved less desirable than the pure stands, because in most cases, instead of the two species growing evenly in height as had been anticipated, the red pine has donlinated the white pine. On the whole the pure stands of the two species have proved more successful. Creation of mixed stands containing two or more species in agroupwise arrangement, which has some advantages over pure stands, has been attempted within recent years.

The plantations in which pruning data have been collected are the pure stands of white and red pines, mixed stands of these two species, and a few stands of Norway spruce.

A spacing of 6 by 6 feet, which results in setting about 1,200 trees per acre, has been used in most cases, although in recent yearS an 8 by 8-foot spacing for red pine has been employed. At maturity stands of white and red pines are expected to contain from 100 to 150 trees per acre or approximately only one tenth of the number originally planted. The relatively close early spacing is necessary to allow for losses during the critical first years after planting and to assure the early establishment of a complete forest cover.

The life of a plantation may be divided into at least two phases. The first includes the period before the stand closes, while each tree is growing as an individual unit unaffected by the neighboring planted trees. During the first few years of this period the death of some trees is certain to occur because of competition from surrounding vegetation, such as grass and shrubs, and the influence of the site factors and of insect pests and plant diseases. In normally developed plantations by the time the individual trees have grown together to form a closed stand the number of trees originally planted has been reduced to about 900 white pine or 1,000 red pine per acre. A plantation requires from 10 to 15 years to pass through this first period.

The second phase is initiated with the closing of the stand and is characterized by a competitive struggle between the individual trees, which by this time have reached the size where their branches begin to interlace. The sod, which at the time of planting covered the ground, now is replaced by a carpet of pine needles, and the lower branches of the trees are shaded and sooIi die. Some trees excel others in height growth, owing to greater natural vigor or to advantages in soil and exposure or to freedom from attack by plant diseases and insects. An opportunity for wider enlargement of the crown comes with increased height growth, resulting in still more rapid growth, so that trees which start with only a slight advantage over their neighbors may come to occupy dominating positions in the stand. These larger trees eventually crowd, suppress, and kill the less fortunate individuals which surround them, continually reducing in this natural process the number of stems per acre. It might be assumed that competition severe enough to cause the death of many trees would result in excellent natural pruning of the survivors, but this is not the case in the coniferous plantations.

Although the lower branches are killed farther and farther up the trunk as they are shaded through closure of the stand, there is no natural pruning for many years. (See Plates I and 2.) The dead limbs lose their needles and some of their small branchlets, but the limbs themselves persist upon the trees. Pines more than 30 years of age in the oldest plantations in the Eli Whitney Forest do not show any appreciable amount of self-pruning. Natural stands of white pine, originally more densely stocked than the plantations and now from 40 to 80 years of age, which have been observed in parts of Connecticut and in central New England still retain dead branch stubs nearly to the ground and contain little if any clear lumber.

Unquestionably, unless artificially pruned, white pille planted pure or in mixture with other pine will retain the dead limb stubs for the 60 to 80-year rotation contemplated in growing crops of white and red pine timber. The limbs on red pine may drop off a few years earlier than those on white pine, but yet not soon enough to permit production of clear lumber on a 60 to 80-year rotation.

PRUNING POLICY

ARTIFICIAL pruning has been adopted as an essential silvicultural operation in managing pine plantations in the Eli Whitney Forest, because otherwise the trees will not be pruned of branches by natural means early enough to produce clear lumber before the end of the rotation. The policy is to prune in all plantations of white pine, red pine, and spruce that show promise of producing timber. This includes practically all plantations of these species, with the exception of occasional areas on the poorest sites where the cost of pruning is considered unjustifiable.

Pruning is confined to from 150 to 200 trees per acre distributed as uniformly over the area as is consistent with the selection of the best individuals, which presumably will be kept until the end of the rotation. Pruning all trees in the stand would be a waste of effort, because the final crop will consist of less than 200 trees per acre, the other trees in the original plantation having either been removed in thinnings or died as a result of competition with larger individuals.

The purpose of pruning is to produce as much clear lumber as possible within reasonable limits of expense. Pruning becomes more and more expensive the higher it is extended up the tree, but it can be carried to 17 feet at a reasonable cost. For this reason, and because pine logs usually are cut in 16-foot or shorter lengths and a large proportion of the merchantable contents of a 60 to 80-year-old tree is contained in the first 16-foot log, the policy is to prune just high enough to obtain a clear 16-foot butt log from each selected tree. Allowing for stump height and trimming length, the height to which pruning must be carried under this policy is 17 feet, all whorls of branches up to and including this height above the ground being cut.

In pruning, the option is offered either of waiting until the limbs die and then pruning only the dead limbs or pruning many of the limbs while they are still alive. Coniferous plantations are best handled under the latter plan, which calls for removing the limbs in most cases before they die. Removing only dead limbs sometimes has been considered the safest method of pruning, since no living tissue is cut; but as a matter of fact dangerous plant diseases (heart rots), liable to attack the conifers, enter the tree through the dead branches rather than through wounded living tissue. Even the pruning of dead limbs has been opposed in some quarters by the argument that it leads to the creation of loose knots.* This viewpoint is absurd, since the loose knots can be developed only within the knotty central core where no pruning was done.

Injury from live-limb pruning, either may be caused by fungi, afforded access to the tree through the branch scars, or may be expressed as retarded growth due to the reduction of the live crown. If the branches which are cut are small, as will be the case in coniferous plantations pruned at the proper time, damage from fungi is unlikely and is of no practical significance with the species covered by this study. Small live branch stubs contain vigorous healthy tissue and no heartwood and heal over so rapidly as to afford little opportunity for the entrance of disease.

Damage to the pruned trees could conceivably be caused by insects, pos-

* As long as the branch lives, its wood grows in union with the surrounding portions of the main stem, and the knots formed are termed intergrown knots. When wood grown in this manner is cut into lumber, the knots will be an integral part of the lumber. On the other hand, when a branch dies, the stem continues to add new wood around the dead branch, but no longer do the stem and branch grow solidly together. Hence, when such portions of the tree are sawn into lumber and dried, the knots may become loose and in thin lumber may fall out, leaving open cavities in the boards. Artificial pruning has nothing to do with the formation of these loose knots.

sibly attracted by the odor of fresh pitch and entering through the pruning scars. As a matter of fact such injury to the species covered in this study has never been reported and in the opinion of forest entomologists is unlikely to occur.

Diminution of the growth rate occurs only when too large a portion of the live crown is removed by the pruning. Hawley (1935) found a decrease in height growth of approximately one third when the live crowns of white pine in an eight-year-old plantation were reduced by more than 50 per cent in pruning. Evidently too large a proportion of the live crown was removed for the conditions existing in that particular stand. The proportion of the live crown which it is safe to remove may be expected to vary with trees of different species and ages and in stands of different densities.

A safe rule to follow and the one which has been adopted in the pruning policy of the Eli Whitney Forest is to remove only those live branches which do not receive direct sunlight. Shaded leaves, contribute little to the growth of the tree and, consequently, can be removed without harm. In a closed stand this permits the removal of all live branches up to but not including the highest branches which interlace with the crowns of adjoining trees. So long as pruning is not carried above this point, the growth of the tree will not be reduced by the operation. Sometimes in partially stocked plantations closure between adjoining trees is delayed abnormally. In such cases pruning of live limbs may be started while the trees are still isolated and can safely include the cutting of the lower live branches forming from one fifth to one fourth of the length of the live crown. Pruning more than this proportion of the live crown in a plantation not yet closed is likely to cause not only a reduction in growth but also sun scalding of the exposed stems.

When live limbs are cut, the pruning of the tree can be completed several years sooner than when time must be spent in allowing the limbs to die before removal. Hence, the size of the central knotty core will be kept smaller. In plantations this point is of especial importance, since it takes from 10 to 15 years for a plantation to close, during which time the branches will have become quite large and should be pruned at the earliest possible moment. Pruning of live limbs is clearly demanded in coniferous plantations.

The total pruned length of 17 feet might be obtained by pruning to that height in one operation or in several operations spaced from 3 to 5 years apart. If done in one operation, it would be necessary to wait until the live limbs were in contact with adjoining trees above the 17-foot level. At that time in the case of white pine the diameter of the tree would be approximately 4 inches at 17 feet above the ground and 7 inches at stump height. Under such circumstances the central knotty core ultimately produced will be approximately 8 inches in diameter.

The objective in pruning is to produce a log with the smallest possible knotty core, which requires starting the pruning operation early. The central knotty core can be kept at approximately 6 inches in diameter by conducting the pruning in three operations, the first going up to 7 feet (see Plate 3), the second to 12 feet, and 'the third to 17 feet (see Plates 4 and 5). Each operation is undertaken as soon as the branches of adjoining trees are in contact above the height to be pruned. Thus, if the pruning is done in several operations, a larger volume of clear wood can be produced in a stem of a given size. In white and red pine plantation.s this results in pruning each time to an average top diameter of 4 inches. For practical purposes the knotty core includes not only the zone of actual knots in the log, but any defects which may occur as a result of pruning in the zone immediately outside of the branch stubs, such as bark pockets and streaks, pitch pockets, and discoloration of wood. Their effect is to lengthen the time required after pruning before the branch stub is calloused over and the formation of clear wood started, and to increase by from 1 to 2 inches the diameter of the knotty center, which has been taken into consideration in estimating its diameter.

To recapitulate, the policy for the coniferous plantations is to prune from 150 to 200 trees per acre to a height of 17 feet in several operations, removing both live and dead limbs, but never going higher in anyone operation than the highest interlacing branches of adjoining crowns.

DETAILED PRACTICE

SELECTION OF TREES

ONE of the first problems encountered when forest pruning is undertaken concerns the selection of the trees to be pruned, since for reasons already indicated only a relatively few trees per acre will be treated.

Even spacing of the pruned trees over the area is the first, although not necessarily most important, consideration. To obtain maximum use of the land and the maximum growth of the pruned trees, they should be distributed uniformly over the area rather than in large or small groups. The spacing of 200 trees uniformly distributed over an acre would be about 15 by IS feet, and of IS0 trees, 17 by 17 feet. Most plantations are made with a spacing of 6 by 6 or 8 by 8 feet, so that a theoretically perfect distribution of pruned trees could not be attained even if spacing were the primary consideration in the selection of trees. As a matter of fact even spacing is less important than the condition of the individual trees. A desirable average spacing to approach, when the maximum number of pruned trees is wanted, would be IS by 15 feet. The spacing actually used will vary from 12 to 18 feet, with occasional cases of pruned trees as close together as 6 feet or as far apart as 24 feet.

The pruned trees in plantations with 8 by 8-foot spacing might be selected 16 feet apart or at the rate of 170 trees per acre, and in plantations with 6 by 6-foot spacing, 18 feet apart or at the rate of 130 trees per acre. Even the lowest figure, 130 trees per acre, will provide enough trees to occupy the acre completely before the timber is ready for cutting and thus provide for a fully stocked stand of pruned trees. Some of the trees first selected and pruned early in the life of the stand are likely to be injured during the course of time and may not live until the final harvest. To provide for such a contingency it is considered advisable to prune from 150 to 200 trees per acre, with the expectation that at least 125 of this number will form the final crop. In the simplest cases met in practice in young plantations of regular form, where practically all trees are vigorous and thrifty, the pruned trees can be selected uniformly distributed either 16 or 18 feet apart, depending on the original spacing, and some additional trees can be pruned to allow for the losses likely to occur during the succeeding 40 to 60-year period.

Important factors governing selection of the trees for pruning are species and character of the individual tree as to position in the crown canopy, its form, and freedom from injury. In mixed plantations containing species differing in value, most of the trees pruned of course will be of the more valuable kinds. When the species are so similar in value that it is desired to include equal proportions of each in the final crop, special attention often is required to insure that equal numbers of each species are pruned. This may be overlooked in cases when one species is a more conspicuous element in the stand than the other, as, for example, in an alternate row planting of white and red pine, where the latter species is the more abundant in the dominant and codominant crown classes due to its faster early height growth.

In pure plantations the trees selected for pruning should be those which exhibit the most promise for the final crop, namely, the more vigorous trees with the best form and greatest freedom from diseases and injuries. Usually trees showing the fastest growth are selected, other points being equal. Growth rate for this purpose is determined by the crown class which the tree occupies at the time of pruning. The trees which have grown the fastest up to the present are in the upper crown classes (dominant and codominant), and, because of their more advantageous position in the stand, they will continue to grow faster than those in the lower crown classes (intermediate and overtopped). Dominant trees stand up above their neighbors so that their crowns receive full sunlight from above and on the sides, while codominant trees receive full sunlight upon the tops of the crowns and a little on the sides. The crowns of intermediate trees penetrate into the general level of the crown canopy and may receive some direct sunlight on the top but none on the sides. Overtopped trees are below the general level of the crown canopy and receive no direct sunlight.

The trees selected for pruning are in the dominant and codominant crown classes except in rare instances. The expense of pruning an intermediate or overtopped tree is not justified unless such treatment is promptly given these trees as will place and keep them in a free position where they will be stimulated to increased growth. Fast growth after pruning is an essential requirement for pruned trees, since the zone of clear wood around the central knotty core must be wide enough to produce boards of merchantable width.

Form of bole is of primary importance in the choice of trees for pruning. Crooked trees, unless the crook is slight and will evidently be outgrown in a few years, should never be pruned (see Plate 6). Trees with a straight stem for at least the first 17 feet should be selected.

A common injury to white pine which affects the selection of trees for pruning is caused by the white pine weevil (*Pissodes strobi* Peck). This insect kills the terminal shoot or leader of white pine and of certain other species of conifers so that a lateral branch turns upward and assumes the position of leader, causing a crook in the log. If possible, white pine trees which have not been weeviled in the first 17 feet of stem should be selected. Where there are not at least 150 unweeviled trees per acre suitable for pruning,* trees with small crooks may be included (see Plate 7). Small

* In plantations in the Eli Whitney Forest 200 unweeviled trees per acre can usually be found (Maughan, 1930).

crooks in stems from 4 to 6 inches in diameter should be outgrown and a straight log produced long before the tree is harvested.

White pine may be weeviled from the time it iS3 to 4 feet high, and the fact that a tree has escaped this injury up to the time of the first pruning is no indication that it will not suffer later on. However, any weeviling which occurs above 17 feet is of little consequence as regards the pruning policy. The trees selected for pruning, being the best trees in the stand, have attained heights of 17 feet or more by the time the first pruning is made. Hence in the original selection of trees for pruning, individuals weeviled in the first 17 feet can be avoided. In white pine plantations with height growth below normal the first pruning should be delayed until the dominant and codominant trees are more than 17 feet high.

The white pine weevil attacks exposed trees rather than those which are sheltered. Intermediate trees seldom suffer from weeviling, and codominants less than dominants. Therefore, in badly weeviled plantations the intermediate and smaller codominant trees rather than the larger codominant and dominant trees are sometimes selected for pruning.

The selection at the time of the first pruning ordinarily is final, although it may sometimes be necessary to select additional trees at the time when later prunings are being made, to replace individuals whose value has been lost through injury since the first pruning.

With a little training average workmen can be taught to recognize suitable crop trees. Until they become proficient in selection their work should be closely supervised, or the trees to be pruned should be marked in some way in advance of pruning as, for example, by breaking a branch on each selected tree on the side at which the pruner will approach. Skilled pruners can operate in crews of two or more men, each man covering two or three rows of trees in the plantation and pruning those which are suitable, having regard for the spacing with reference to the trees pruned by the man on either side.

After the first pruning there is no longer a problem of selection, since in subsequent operations the trees already pruned are quickly found and are pruned higher.

The time required to select the trees for the initial pruning should not exceed half a minute per tree and in most cases will be considerably less. In a uniform, pure plantation, where spacing is frequently the deciding factor in selection, the time between trees should be only the few seconds required to walk from one pruned tree to the next one to be pruned. In a mixed plantation with irregular crown development more judgment is required in the selection of trees, and the time spent may be increased. Experience in this sort of work reduces the selection time.

SEASON FOR PRUNING

Pruning is a job which can be fitted into odd periods in the work schedule of woodland owners. It is a useful off-season project for retaining the full-time services of the best employees, who, if not provided with steady work, might drift into other jobs. Pruning is not as hard work as many other forms of manual labor. It requires only a little practice and no great. skill, except in the initial selection of the trees, where good judgment and knowledge of the growth characteristics of the trees are needed. Men who are accustomed to working in the woods or on the farm have proved to be good pruners.

Most landowners will find it convenient to prune during the winter, when other work is slack. In the Eli Whitney Forest the work usually commences in December and ends in March. There is no reason, however, why pine cannot be pruned at any time of year, particularly if only dead limbs are removed. In pruning live limbs there is likely to be a greater flow of pitch if cut during the growing season than if cut during the dormant period. If an excessive amount of pitch hardens on the stub, a large pitch pocket may be produced,delaying the formation of clear wood. White pine branch stubs exude more pitch than those of red pine or Norway spruce.

In horticultural and ornamental pruning opinion varies as to the best season. For specific physiological results in horticulture,-pruning should be done at certain seasons; for example, winter pruning is used to check fruit formation on young trees and summer pruning to encourage fruit formation and check wood growth. Healing is accomplished most rapidly if pruning is done at the beginning of the growing season. The effect of pruning in the dormant season varies according to the climate, in some cases causing decay, checking, or dying back of the tissue around the wound with consequent delay in healing. In general the consensus of opinion concerning ornamental pruning is that the best season is just before vegetative activity begins in the spring..

For the pruning of coniferous plantations in the Northeast- the dormant season is favored, but chiefly for convenience in the work schedule rather than because of any injurious effects of pruning at other seasons.

PRUNING TOOLS

A variety of tools have been tried for pruning the limbs from forest trees, including axes, machetes, billhooks, knives, chisels, shears, and many types of saws. Small knives or billhooks, or any tools which cut by direct pressure, are too slow for forest pruning. Tools, such as axes and machetes, which cut by means of a blow are the fastest pruning tools, but it is practically impossible to do a good job with them. U suaUy a branch stub is left on the tree, or the branch is cut too close, wounding the bole, and even when a close cut is made the branch stub may crack under the force of the blow, leaving a protruding splinter. Dead branches may be knocked off with a club, but this practice leaves a ragged stub sticking out which increases the diameter of the knotty core and may result in a loose knot later on.

Pruning shears and clippers obtain their cutting power through the leverage in the handles. They are used for forest pruning in some places, but have been found unsatisfactory in the Eli Whitney Forest. Shears powerful enough to cut pine branches an inch in diameter need to have fairly long handles, even when equipped with a po\ver-shifting device. These handles make the shears hard to manipulate quickly and accurately among the dense branches of young trees. Even with the greatest care it is not possible to cut as close to the bole with shears as with a saw, and the cut surface usually is not so smooth as that obtained with a saw. Shears are too clumsy and heavy for high pruning from a ladder (see page 20).

Pole clippers operated by a wire running down the pole can only be used for small branches, because of the relatively small amount of leverage obtained and the comparatively narrow spread of the jaws. Aside from saws, other tools which can be used for high pruning are a knife on the end of a pole and a chisel which cuts from below with an upward thrust or a blow from a mallet. The former is unsatisfactory for cutting even moderately large branches, and the latter has the same disadvantages as an axe, combinedwith clumsiness of manipulation on the end of a long pole. Neither has been used extensively for forest pruning in America as far as known.

The pruning saw has the advantages of speed of operation, precision of work, and smoothness of cut. It is possible with the saw to make the cut exactly where it is wanted, without wasting time in adjusting the tool to the proper position. The surface of the cut stub is covered with fine scratches and loose wood fibers, but no splinters are left protruding, as is the case with some other tools.

Pruning saws fall into two classes, the hand saws for low pruning or for high pruning from a ladder, and the pole saws for high pruning from the ground. Properly speaking, hand saws are the type used for ordinary carpentry work, although all saws operated by hand with a reciprocating motion maybe broadly classed as hand saws (Disston, 1915). A curved saw with pistol grip handle, which will be referred to in this bulletin as a hand saw, is known to the saw trade as a pruning saw and is the type advised for forest pruning. The style of handle on the true hand saws is preferred by some workmen to the pistol grip type employed on the pruning saws; but the latter is favored in the Eli Whithey Forest because it fits the gloved hand better and is easier to manipulate in the awkward positions in which the pruner often has to work. A straight saw with an open, compass saw handle is sometimes used for pruning, but neither the handle nor the blade of this saw has been found as satisfactory as those on the curved pruning saw.

The hand saws described are all single-edged saws. Double-edged saws are convenient for making an undercut to prevent tearing of the bark when the branch falls, but they are likely to cause excessive scratching and wounding of the bark of the tree unless used with great care. Even with a single-edged saw care must be exercised to avoid this sort of damage, for the bark of young trees is tender.

Most tension saws, such as butcher's saws and coping saws, with narrow, thin blades, are not satisfactory for pruning pine. The teeth are too small for fast cutting and the frames too large for working among the close-set branches in the whorls.

Hand saws for forest pruning may be designed to cut on either the thrust or draw strokes or on both strokes. The curved hand saw used in the Eli Whitney Forest cuts both ways. Such a saw is likely to be preferred by the average person for low pruning or for high pruning on a ladder. The number of points (one more than the number of teeth) to the inch varies on different models from as many as 12 in saws with fine teeth to as few as 3½ in saws with coarse teeth. Coarse teeth cut large branches faster than do fine teeth, since they cut deeper at each stroke, but are less satisfactory than fine teeth for cutting small branches, because large teeth tend to catch on the branch and break it instead of cutting through it. For pruning branches of the sizes ordinarily found in white and red pine plantations a saw with medium-sized teeth (6 to 8 points to the inch) is the most satisfactory, since it combines reasonably rapid cutting of large branches with suitability for cutting small branches.

Pole saws can be obtained in several different models, similar to the different models of hand saws, except that they have long poles for handles. The blade is set at an angle with the axis of the pole, varying from about 10 to 55 degrees. (On some models the angle of the blade can be shifted into three positions.) Consequently pole saws cut neither horizontally on the upper surface of the branch nor vertically on the side of the branch, but on the upper side at an angle between the horizontal and the vertical.

Pole saws commonly are made to cut on the draw stroke, which is preferable, because it makes use of gravity and because a vigorous push upward is likely to cause the pole to bend unless it is made of exceptionally stiff, heavy wood. Direct pressure cannot be utilized with a saw on the end of a long pole. Therefore the pressure must be obtained by using a heavy blade, or by equipping the saw with long sharp-pointed teeth designed for cutting without much pressure.

O. M. Pratt, who has had much experience in pruning natural stands of pine at Holderness, New Hampshire, uses a straight-edged, heavy-bladed pole saw, 24 inches long, tapering from 4 inches at the rear end to 2 inches at the tip, 3½ points to the inch" with the blade set at an angle of 30 degrees with the pole and cutting on the draw stroke (Cline and Fletcher, 1928).

In the Eli Whitney Forest a curved, light-bladed pole saw has been used. This saw is 14 inches long, tapering from 2 inches to ½ inch, with 8 points to the inch. An iron socket is mounted on the end of a pole, and the saw blade is fastened to the end of this socket by a bolt and wing nut. A stud on the socket fits into any one of three holes in the base of the blade, making it possible to set the blade at three angles, 10, 25, or 55 degrees, with the axis of the pole. For most work the central position, 25 degrees, is best. O. M. Pratt's saw is worked with less effort, due to the weight of the blade and the coarseness of the teeth, but the type used in the Eli Whitney Forest is easier to manipulate among the branches because it is lighter. Between these two types the choice is a matter of personal preference. Tension saws and double-edged saws mounted on poles have the same disadvantages that these types have when used as hand saws.

The handles of pole saws can be made in any length desired. When trees are to be pruned as high as 17 feet, it is necessary to have a pole about 12 feet long. It is also desirable to have one about 8 feet long for pruning the branches from 7 to 12 feet above the ground when this is done as a separate operation, because the longer pole is difficult to operate on branches at this height and more awkward to carry between the trees. Extension poles in sections can be obtained for pruning to any height desired, but for work in plantations where the trees are of even height the work can be conducted efficiently with two standard lengths of pole. The poles may be made of any light" strong wood, and should preferably be round rather than square, so as to slide through the hands easily.

The ladder is an important piece of equipment in forest pruning operations, being used when high pruning is done with hand saws. Like the poles already mentioned, ladders should be provided in two lengths, 8 and 12 feet respectively for the middle and higher branches. When made of light, strong wood, even the longer ladder is not fatiguing to carry from tree to tree. The ladder should taper from about 2 feet at the bottom to not over 1 foot at the top. The wide base gives a firm hold on the ground, while the narrow top decreases the likelihood of the ladder turning when a man standing on thetop rung shifts his weight from one foot to the other. A strip of cloth should be wound around the top rung to prevent its bruising the bark where it rests against the tree. In the Eli Whitney Forest the ladder and hand saw are preferred to the pole saw as pruning tools.

The conduct of the pruning operation, involving use of the hand saw, pole saw, and ladder will be discussed in the next section.

CONDUCT OF THE PRUNING OPERATION

It has already been stated (page 10) that for the production of the largest percentage of clear wood in the log the pruning should be divided into several operations spaced from 3 to 5 years apart, so as to prune each part of the bole while it is still small in diameter. In theory the ideal arrangement would be to prune a whorl of branches each year, keeping just below the point of contact between adjoining trees. Such frequent return for the smallamount of work done results in high costs for the pruning and is out of the question in commercial practice, but it is practicable to divide the pruning into three operations.

Pruning may be separated into two phases: low pruning, defined as the pruning of the first 6 to 8 feet of the bole which can be easily reached by a man with a hand saw standing on the ground; and high pruning, or the pruning of the bole above the 6 to 8-foot point.

The first or low pruning operation should be delayed until the trees can be pruned up to an average height of 7 feet. Low pruning is most efficiently accomplished by a man standing on the ground and working with a hand saw. Seven feet is the logical stopping point for the first pruning, because a man cannot reach higher without using a ladder or exchanging his hand saw for a pole saw.

Above this height there remains 10 feet of bole to be pruned later by the high pruning method. The objective of keeping the central knotty core small will not be so well fulfilled if pruning is delayed until the whole upper portion of the bole can be pruned in one operation. Consequently high pruning should be done in several operations, preferably two, the first removing branches from 7 to 12 feet and the last from 12 to 17 feet above the ground. High pruning in two operations is efficiently executed with the aid of two different lengths of ladder or pole saw, each suited for the particular phase of pruning for which it is used.

Pruning practice in the Eli Whitney Forest follows this schedule of three operations, the technique of which is described in the following pages.

LOW PRUNING

In pruning from the ground to 7 feet it is convenient to remove first a few branches at shoulder height, to permit free movement of the arm and saw in cutting the remaining branches, and then proceed either up or down the bole. There is sometimes an advantage in working down first, in that it clears away the lower branches, enabling the pruner to stand wherever he wishes while cutting the upper branches.

Each cut is made flush with the shoulder or swelling where the limb joins the bole. It is dangerous to cut deeply into the shoulder, both because of the large amount of wood surface exposed and because of the danger of girdling the tree. This is especially true of white pine, in which the branch shoulders often form a complete ring or swelling encircling the bole. In red pine the shoulders are much smaller.

Ordinarily the branch can be cut all the way through from above, but with occasional large or heavy branches it is advisable to make a small cut on the lower side, to prevent tearing of the bark when the branch falls. When pruning is begun at the top and progresses downward, the weight of previously pruned branches lying on the branch being cut may cause it to break or tear off before it is cut through, unless carefully handled.

As discussed under PRUNING POLICY, pruning of live limbs is carried up only to the highest whorl of branches which interlace with those of neighboring trees, this whorl being left on the tree. If the first pruning operation is timed correctly, the lower 7-foot section of bole on most of the trees will be below this *zone* of contact and hence ready for pruning.

HIGH PRUNING

High pruning includes operations which require the employment of extension tools, such as a saw mounted on a pole, or a ladder upon which the operator climbs and uses a hand saw. High pruning, as previously stated, is best separated into two operations, the first of which carries the pruning fronl 7 to 12 feet above the ground and the second from 12 to 17 feet. The time at which each of these two operations should be made is determined by the speed with which the highest point of contact between the crowns of adjoining trees moves upward, which in turn depends upon the rate of growth of the trees. Ordinarily in plantations of white or red pine the first high pruning should follow 3 to 4 years after the low prul1ing, and the final operation approximately 3 years later. Both the ladder method and the pole saw method are used in the Eli Whitney Forest, although the former is preferred and is more extensively employed.

Ladder Method. In the ladder method each workman carries with him a light, wooden ladder, of the type described under PRUNING TOOLS, and a curved pruning saw with pistol grip, usually with a loop of string tied to the handle for hanging the saw upon the ladder or the wrist when not in use. For the first high pruning operation the best length of ladder is 8 feet, while for the final operation a 12-foot ladder is needed. The ladder is placed against the tree with the base about 2 feet from the bole and the top rung of the ladder resting against the bole, which is protected from bruising by the strip of cloth previously mentioned (see Plate 8).

Pruning is started with the lowest whorl of branches and progresses upward until the desired height is reached. If the operator is a short man, a few lower branches may be left until last, to grasp or climb upon while sawing the highest branches.

The sawing technique is the same as in low pruning, care being required to avoid cutting too deeply into the shoulder, leaving protruding stubs, or scarring the bark of the tree with the saw. In addition, caution must be exercised to avoid the stripping of bark down the bole when the branch falls. This is more likely to occur in high pruning than in low pruning, because the branches average longer and heavier than the lower branches and tend to break away more rapidly when nearly severed. Furthermore, the pruner cannot always hold the branch up with one hand while sawing as he can in low pruning, since one hand is often needed to grasp the bole of the tree for support and leverage. Stripping of the bark usually can be avoided by pausing an instant when the branch begins to droop, allowing it to come to rest in a hanging position, and then sawing rapidly through the remaining portion.

Pole Saw Method. In the pole saw methoa each workman is equipped with a pruning saw mounted on an 8-foot handle for the first high pruning operation and a 12-foqt handle for the final operation (see Plate 9). The man starts work standing at some distance from the base of the tree, for the pole has to be held on a slant to cut the lower branches. This is one disadvantage of the pole saw method as contrasted with the ladder method, for it often requires the man to stand with his back up against or among the branches of a neighboring unpruned tree, an awkward position in which to work. As he prunes higher, he moves nearer to the tree and holds the pole more nearly upright.

The usual procedure is to cut all of the branches which can be reached from one side of the tree, both those on the right and on the left of the bole as the man stands facing it, and then to move approximately one quarter of the way around the tree to remove the branches which can be reached from that side. It is necessary to work from at least three sides of the tree before all the branches can be cut flush with the shoulders. This brings up another disadvantage of the pole saw as contrasted with the ladder method, namely, the tendency with the pole saw to reach too many branches from one position, with the result that many branches are not sawed flush against the shoulder but are left with a short protruding stub, thereby increasing at that point the diameter of the knotty core.

Ordinarily it is best to start with the lowest branch on one side and work up. Sometimes, when the lower limbs do not interfere, it is possible to start on the second or third whorl and work down, allowing the saw to fall with the branch into position for cutting the next lower limb, thus saving time. The amount of time needed to place the saw in position for sawing is another deficiency of the pole saw as contrasted with the ladder method. In the former method some manoeuvring both of the saw blade and of the workman's location is required to place the saw, set as it is on the end of a long pole, in position for making the cut correctly. With a light-bladed saw there is a tendency for it to jump out of the groove formed by the first cutting stroke, so that time often is wasted in starting the cut. In the ladder method the workman has as much control over the saw as he does in low pruning and he can work with much greater precision.

The constant craning upward of the neck in pole saw pruning is objectionable to some workmen, although no more so than clinging to the side of the tree and working above the ground is to others.

The cutting procedure in pole saw pruning is somewhat different from that in hand saw pruning. The cut usually is made only on the draw stroke, so that more strokes are required to cut through a given thickness of branch. The pruner cannot so well see what he is doing and consequently must exercise more care in making the cut in the proper place and at the right angle, and in avoiding binding of the saw against other branches or cutting through two branches at once. There is more likelihood of the bark being stripped down the trunk in pole saw than in hand saw pruning, because there is no possibility of supporting the branch with one hand, but this usually can be overcome by exercising the same precaution as in hand saw pruning.

Pole Saw Compared to Ladder Method as to Quality of Work. To test the quality of work done by the pole saw as compared with the ladder method, 25 red pine trees pruned by each method were examined. These trees were picked at random in stands recently pruned by workmen who did not know that their work was to be checked. On each tree all the branch stubs cut in the high pruning were counted and each stub was classified as a good cut or a poor cut. A good cut was defined as a smooth cut made flush with the shoulder, while a poor cut was defined as one made either too far from or too close to the bole, or at the wrong angle, or with a ragged lower edge.

TABLE I. COMPARISON BETWEEN LADDER AND POLE SAW METHODS AS TO QUALITY OF WORK

	Ladder		*Pole saw*	
	Number	*Per cent*	*Number*	*Per cent*
Number of trees (red pine) included	25		25	
Number of stubs counted	903	100	386	100
Number of good cuts	863	96	226	59
Number of poor cuts	40	4	160	41
Classification of poor cuts:	20	100	160	100
Cut too far from trunk	7	35	54	34
Stub cut at wrong angle	7	35	55	34
Ragged lower edge	3	15	46	29
Cut too close to trunk	3	15	5	3

Results of the test, given in Table 1, indicate the superiority of the ladder method in the quality of the work. In the ladder method 96 per cent of the branches pruned as contrasted to 59 in the pole saw method were found to have properly cut stubs.

Table 1 shows also a classification of the poor cuts into four groups based upon the character of the defect. The poor cuts in sawing by either method are approximately one third in the nature of long stubs cut too far from the trunk and one third in stubs cut at the wrong angle and hence too long on one side. The remaining poor cuts are attributable to ragged lower edges on the stubs or to cuts made too close to the trunk. The hand saw is evidently much more efficient than the pole saw in preventing ragged lower edges.

The branches which were cut further from the bole than necessary were classified as "cut too far from trunk," while those in which one side of the stub protruded more than necessary were listed as "cut at wrong angle." The two classes were kept separate to indicate the cause of the mistake. In the former case it was due to careless placing of the saw; in the latter to sawing from a wrong position, making it impossible to work the saw at the proper angle.

"Ragged lower edge" included all cases where the branch was broken or torn off before being cut through. In some cases a strip of bark was peeled from the bole below the stub; in other cases the lower surface of the cut was splintery and ragged. The detrimental effects of such bark-peeling as is likely to occur in careful pruning are negligible, but protruding splinters widen the zone of low-grade wood by just the length of the splinters.

"Cut too close to trunk" covers chiefly the mistake of cutting too deeply into the shoulder, thereby unnecessarily increasing the pruning time. This is of minor importance as compared with the other types of poor cuts.

PRUNING TO 17 FEET IN LESS THAN THREE OPERATIONS

The best procedure for reasons already indicated is to start the pruning early and divide the work into three operations. Where a correct pruning policy is not adopted until the plantations have passed the time for the first pruning, these neglected plantations should be pruned to 17 feet in one or two operations, either going to 17 feet or as high as contact exists between adjoining crowns. If neglected plantations are taken in hand and pruned not later than the twenty-fifth to thirtieth years, it will still be possible to obtain some clear lumber on a 60 to 80-year rotation.

From the standpoint of cost alone it would be somewhat cheaper both in plantations and natural stands to wait until all the lower limbs up to a height of 17 feet had died and then prune these limbs in one operation, for dead limbs are sawed more easily than live limbs. Waiting until the limbs die causes a large increase in size of the central knotty core, however, and consequently a decrease in the proportion of clear wood which can be secured. This sacrifice of clear wood makes postponement of pruning until the limbs are dead an undesirable policy.

COST OF PRUNING

TESTS were conducted in pure white pine, red pine, and Norway spruce plantations to obtain data for estimating pruning costs for different species and methods of operation classified as follows:

(1) The cost of pruning white and red pine in each of the three operations, low pruning (0 to 7 feet) and high pruning (7 to 12 feet and 12 to 17 feet).

(2) The cost of high pruning (7 to 12 and 12 to 17 feet) by the ladder method and by the pole saw method for white and red pine.

(3) The cost of pruning (0 to 17 feet) in one operation for white pine, red pine, and Norway spruce.

The results of the first two investigations are summarized in Table 2 and the third in Table 4. Before discussing these tables an explanation of the manner in which the data were obtained isneeded.

The trees were selected for pruning according to the policy already advised, that is, on the basis of spacing and promise as final crop trees. The pruning in all the tests was done by students of the Yale School of Forestry employed on an hourly wage basis. It was possible by using students instead of common laborers to obtain better control of the factors entering into the tests. The figures given in Tables 2 and 4 are considered conservative and might easily be improved upon in practice by using regular labo;r continuously on the job.

Data were collected on an individual tree basis and were analyzed separately for each species, in each of the three operations, and by each method of pruning. In each set of data thus obtained the speed of pruning each tree was computed, and trees where speed deviated from the mean by more than twice the standard deviation were omitted in computing the averages which appear in the tables.

Time recorded for the pruning of individual trees included all the time chargeable to the pruning of the particular tree in question, such as setting up, ascending, and descending the ladder, or adjusting the pole saw, but did not include ineffective time—such as time spent in moving from one tree to the next, selecting trees to be pruned, or cleaning the saw. Special records were kept of ineffective time in certain of the tests, and additional figures were obtained from the work of regular employees from which an average rate of 0.6 minute per tree for low pruning and 0.25 minute per tree for each operation of high pruning was obtained. These rates are ample to cover all ineffective time necessary to the conduct of the pruning operation. In preparing Tables 2 and 4 ineffective time has been included. It forms from 8 to 13 per cent of the total time per tree.

TABLE 2. SPEED OF PRUNING WHITE AND RED PINE IN THREE OPERATIONS

(Using either the ladder or pole saw method for high pruning.)

		White Pine			*Red Pine*		
Method	*Height pruned feet*	*Basis: number of trees*	*Linear feet pruned per hour*	*Hours per tree*	*Basis: number of trees*	*Linear feet pruned per hour*	*Hours per tree*
			Low pruning				
	0 to 7	39	95.2	0.074	39	114.3	0.061
			High pruning				
Ladder	7 to 12	49	95.0	0.053	49	122.9	0.041
Ladder	12 to 17	45	52.6	0.095	47	78.7	0.064
Total	0 to 17		76.6	0.222		102.4	0.166
Pole saw	7 to 12 }	48	65.5	0.153	49	121.3	0.041
Pole saw	12 to 17 }				48	80.9	0.062
Total	0 to 17		74.9	0.227		103.7	0.164

Table 2 shows for white and red pine the costs expressed in linear feet pruned per hour for low pruning and for the two operations included under high pruning by the ladder method and by the pole saw method. The hours per tree spent in each operation, and in pruning the total distance from o to 17 feet in three operations, using each method of high pruning, are also included in the table.

No significant difference in speed of pruning between the two methods of high pruning, ladder or pole saw, is revealed by the data in Table 2. In quality of work, however, the ladder method is superior and is favored for this reason.

Field experience with both methods leads to the belief that further investigation may show the ladder method to be significantly faster than the pole saw method, when work of equal quality is secured, because of the fact that the hand saw can be made to cut faster than the pole saw. Greater pressure can be exerted with the hand saw, since the strokes can be made faster without causing the saw to jump out of the cut, and since the former t60l cuts both ways while the latter cuts only on the draw stroke. The time required to set up and climb the ladder is offset by the time required to manoeuvre the pole saw into position for each cut and keep it there until the cut is well started.

The advantage of the ladder method will be more pronounced with white pine than with red pine for two reasons. In the first place, white pine has more branches per whorl than red pine, making it more difficult to get the saw into position for cutting, and the pole saw is more difficult to manoeuvre in a small space than is the hand saw. In the second place, white pine tends to have heavier branches than red pine in the upper part of the length to be pruned, and, since the pole saw cuts slower than the hand saw, relatively more time is lost in pruning the higher branches of white pine than of red pine with the former tool.

High pruning from 12 to 17 feet is the most expensive of the three operations, since it includes the heights more difficult to reach from the ground.

Since the data in Tables 2 and 4 are expressed as number of linear feet of bole pruned per man-hour and also as hours per tree, they can be converted into dollar values by applying the hourly wage, rate locally prevailing. Table 3 has been constructed to sho,v the dollar cost of pruning on the basis of applying a labor wage rate of So cents per hour to the data in Table 2.

The costs obtained in the present study and summarized in Tables 2 and 3 are within the limits of cost found by Cline and Fletcher (1928) for white pine in a somewhat similar study_ Based upon cost figures obtained from various sources and upon the pruning of a badly weeviled plantation and of a densely stocked stand of natural origin, they estimated the rate of pruning white pine to vary from 50 to 200 linear feet of bole per man-hour.

TABLE 3. COST PER TREE TO PRUNE WHITE PINE AND RED PINE TO A HEIGHT OF 17 FEET

(Using either the ladder or pole saw method.)

Method	*White pine*	*Red pine*
Ladder	$0.111	$0.083
Pole saw	0.113	0.082

Speeds of 100 to 200 linear feet of bole per man-hour for white pine can be attained only in pruning a relatively short total length, such as 12 to 16 feet (thus omitting all or part of the most expensive high pruning), and only when pruning well-formed trees in a natural stand in one operation with most of the limbs dead at the time of removal. The early pruning of plantations will always prove more expensive than relatively late pruning in stands of natural origin.

RELATIVE COSTS OF PRUNING WHITE PINE, RED PINE, AND NORWAY SPRUCE

The data presented in Table 2 indicate that red pine can be pruned in approximately 75 per cent of the time required for white pine. Some of the reasons for the faster pruning of red pine as compared with white pine are as follows: Red pine wood is commonly less pitchy than white pine and consequently can be cut faster with the saw. Red pine limbs are likely to average somewhat smaller in diameter than white pine limbs, because of the higher average density of the red pine stands. Red pine commonly has fewer branches per whorl than white pine, and lacks the secondary whorl of small branches just below a main whorl, which is characteristic in white pine. Red pine limbs have fewer side branches than do white pine limbs, so that it is easier for the pruner to work with the former species, particularly in low pruning. It occasionally happens that the pruner cuts through the shoulder of a white pine limb, and the larger diameter at that point considerably increases the time required to cut through the branch. This does not happen in pruning red pine, because there are practically no shoulders.

While most of the plantations studied were of white or red pine, a few Norway spruce plantations were included and 30 trees of this species were pruned to 17 feet in one operation. For the sake of comparison a number of white and red pine trees were pruned in the same way. Table 4 showing the results of this study compares the speed of pruning for white pine, red pine, and Norway spruce.

TABLE 4. RELATIVE COSTS OF PRUNING WHITE PINE, RED PINE, AND NORWAY SPRUCE TO 17 FEET IN ONE OPERATION

(Expressed in feet pruned per man-hour and in hours per tree, using hand saw and ladder.)

Species	*Basis: number of trees*	*Feet pruned per man-hour*	*Hours per tree to prune to 17 feet*
White pine	28	75.7	0.225
Red pine	44	116.4	0.146
Norway spruce	30	91.7	0.185

Taking white pine as a standard, the figures in Table 4 show that red pine can be pruned in approximately 65 per cent of the time required for white pine (thereby checking reasonably well with the tests made on other trees summarized in Table 2), and that Norway spruce can be pruned in approximately 80 per cent of the time required for white pine.

Norway spruce requires more time than red pine for pruning because it has many more branches. As compared with white pine, Norway spruce has approximately the same number of branches, but they are of smaller average size making for faster pruning. This factor is partially compensated for by the more scattered distribution of the spruce branches, many of which occur in the intervals between the branch whorls and require individual attention in their removal. The branches of white pine are concentrated in a congested zone at the branch whorls, which tends to facilitate their removal.

PER ACRE COSTS OF PRUNING

The individual tree has been used as the basis for the preceding calculations of cost. This is the most practical method of arriving at the cost of pruning and forms the best basis upon which to compare costs with returns.

It is often convenient, however, to know the cost per acre of a forest operation, and for this reason Table 5 has been included, converting the individual tree costs of Table 3 to an acre basis for the ladder method only, since this method is considered the more satisfactory. Obviously the cost per acre is closely related to the number of trees pruned per acre. Costs are given for the pruning of 150 and 200 trees per acre, since the number selected for pruning in a plantation is likely to fall within this range.

TABLE 5. COST PER ACRE OF PRUNING 150 OR 200 WHITE OR RED PINE TREES TO 17 FEET IN THREE OPERATIONS

(Using the ladder method for high pruning.)

Number of trees pruned per acre	*Cost per acre*	
	White pine	*Red pine*
150	$16.65	$12.45
200	22.20	16.60

Some of the costs given here may appear to contradict the statement made earlier (page 4) that artificial pruning could be accomplished for the added expenditure per acre ($15) necessary to secure dense stocking by close planting. However, the two statements are in harmony, for on a 60-year rotation the planting cost is carried at interest for 60 years, while the pruning cost is carried only for an average period of 45 years. The sum of $15 compounded annually at 4 per cent for 60 years amounts to $157.80, while $22.20, the highest cost in Table 5, compounded annually at the same rate for 45 years amounts only to $129.67.

PHYSICAL RESULTS OF PRUNING

PRUNING in the Eli Whitney Forest has not yet progressed to the stage where final conclusions regarding its financial results can be drawn, for the earliest experiments in pruning in this forest were initiated only 12 years ago. However, it is possible at this time to make some statements regarding the physical results of pruning. The most important questions which arise are:

(1) How long after pruning will it be before clear wood is produced over the pruned stub?

(2) What, if any, are the injurious effects of pruning?

In the spring of 1934 a thinning was made in a white pine plantation in which selected trees had received a first pruning in 1922. Ordinarily, pruned trees are not removed in thinning a pine plantation, but in this case a few were felled to afford opportunity for studying the rate and manner of occlusion of pruning wounds, and to provide the basis for answering the above questions. Three of the pruned trees after being felled were dissected and the process of healing investigated. A few of the pruned branch stubs showing the character of the knots and the extent of the healing are illustrated in Plate 10.

The indications from the data available are that stubs less than one-half inch in diameter, cut close to the trunk of the tree, heal over within 10 years, while larger stubs usually require more than 10 years. It is important at this point to define what is meant by "healing over." A cone-shaped involution of the growth rings characteristically accompanies the occlusion of pruning wounds in white pine. This is formed by the annual, partial encroachment of the new wood upon the exposed surface of the stub. The first annual growth ring to cover a portion of the stub will leave a central circle of old wood still exposed. The second ring covers another portion of the exposed stub, leaving a smaller central circle of old wood exposed. As this process continues, the old wood eventually is completely covered, but the new annual rings still turn in toward the center of the old stub. A pruning wound is not healed over until the old stub is entirely covered by new wood. The wound is then healed, regardless of the continued involution of subsequent growth rings, which may persist for many years, although becoming less pronounced each year. The involution of the growth rings does not in itself constitute a defect. The only effect is a local distortion of the grain, which is practically invisible in tangential view (as it would appear on the surface of a board cut by sawing around the log).

The length and diameter of the protruding stub obviously influence the time required for healing, by increasing the area of exposed old wood which must be covered.

The injurious effects sometimes ascribed to pruning are retardation of the growth of the tree and the encouragement of defects in the wood. Retardation of growth undoubtedly will follow removal of too large a portion of the live crown, but pruning applied correctly as recommended in this bulletin never removes such a large portion of the live crown as to reduce growth. Retardation of growth need never be feared as a consequence of pruning forest crops,provided the work is skilfully done.

Defects which it is sometimes alleged might be attributed to pruning can be classified as bark pockets and streaks, pitch pockets, discoloration of wood around the pruned stub, and decay. Bark pockets sometimes are formed by the new wood growing in across the stub from all sides and creating temporarily a hollow within which pieces of bark are caught and finally covered over instead of being pushed outward. The completion of the healing process sometimes is retarded by the presence of a narrow streak of bark which was folded in and caught as the rings grew together, and which runs radially from the branch stub to the surface of the bole. This streak, as far as it goes, will form a defect similar to the pith in a knot. Elongation of such streaks stops with the first annual ring which grows completely across the stub.

With species like white pine which exude pitch freely, pruning of live limbs causes a flow of pitch which accumulates over and around the stub and is'finally in part or entirely overgrown by the new wood and thus sealed in, forming a pitch pocket. Cline and Fletcher (1928) found thatbark and pitch pockets are more likely to occur when live limbs larger than one inch in diameter are pruned than in the pruning of smaller live limbs. Of courSe when dead limbs are pruned, there is no pitch. In pruning red pine by the system recommended in this bulletin it will seldom be necessary to cut limbs more than one inch in diameter, and in most white pine plantations it will be found that the best trees, those which are naturally selected for pruning, seldom have branches over one inch in diameter in the first 17 feet of height.

Discoloration of two types was found around the point of occlusion in the pruning wounds studied. One type, a red-brown tinge penetrating from less than 0.1 to a maximum of 0.5 inch into the new wood formed over the stub was quite common. It is not caused by any type of fungus but probably is due to a filtration of soluble substances from the stub to the new wood or to a possible oxidation of substances already present as a result of the drying out of the stub. After the wound has closed this discoloration is not likely to spread.

The second type, found in only 10 of the 77 wounds studied, was a gray-green tinge, penetrating not more than 0.3 inch into the new wood and caused by a sap-staining fungus which entered the exposed stub before healing took place. The occurrence of sap stain around wounds of any sort in healthy trees always is extremely local. The spread of such a stain,. being conditioned by the amount of air and moisture to which it has access, is prevented after the wound has closed. The staining fungus may remain alive for several years and continue to spread after the log is cut into boards, but then only under unsanitary conditions in the lumber yard or when use is made of improper seasoning methods such as would give rise to the entrance of stains in boards not previously infected.

Probably the most serious effect of discoloration of either type is slightly to increase the zone of low-grade wood in the center of the log. No evidence of decay was found in any of the discolored wood tissue examined.

Decay is unlikely to occur as a result of correct forest pruning of the species and in the region covered by this report, since the types of decay commonly attacking these species enter the tree only through exposed dead wood. The cutting of dead limbs, by removing the dead wood in which the fungi become established, should tend to safeguard the trees against rather than to encourage the entrance of decay. The cutting of small live limbs be harmless,because such limbs contain little or no heartwood and the pitch exudation forms a good seal against the entrance of spores. Making large wounds and leaving protruding stubs and splinters possibly may encourage heart rots, but these practices have no place in correct pruning.

A point of great importance is that all the defects which have been discussed occur in or immediately adjacent to the central knotty core of the tree and their effect is to enlarge somewhat the size of this core. At first thought this might be construed, as an unfavorable effect of pruning, but when it is remembered that unless the trees are pruned the central knotty core will occupy the entire log, this alleged injurious effect becomes in reaHty only the small price to be paid in return for the benefits which follow pruning.

CONTROLLING THE GROWTH OF THE PRUNED TREES BY THINNING

A relatively large investment per acre has been made in pruning 150 to 200 trees from 40 to 60 years before they will be ready for harvest. If the investment is to be successful financially, the growth in volume and in quality of lumber must be rapid in the pruned portion of the trees. The purpose of the pruning, as previously stated, is to obtain a butt log 16 feet long which, although having a central core of knotty wood, will consist principally of clear wood. If this purpose is to be accomplished within as short a rotation as 60 years, the diameter growth must progress at a fast rate. Frequent thinnings of the crown-thinning type, which free the crowns of the pruned individuals from crowding by adjoining trees, are essential for the maintenance of a sufficiently fast rate of growth.

In a white pine plantation originally set out on a 6 by 6-foot spacing the first thinning usually is needed by the twentieth year after planting, and only rarely should be delayed as late as the twenty-fifth year. In most cases the material removed in the first thinning will not have a sale value equal to the expense of making the thinning. Subsequent thinnings should more than pay their way, including the outlay for the first thinning. The thinnings should be repeated at 3 to 5-year intervals during the period when the stand is 20 to 40 years of age and at 5 to 8-year intervals when the stand is 40 to 60 years old.

At each thinning the trees which are seriously crowding pruned trees are removed. Usually the larger of the unpruned trees are removed. Complete freedom from crowding cannot be secured for the pruned trees all at one time, but is best accomplished in two to three thinnings.*

Pruning and thinning in pine plantations have not been carried on as yet throughout a whole rotation. Hence the size of the butt logs which can be produced for the final crop can only be approximated. It is estimated that from the twentieth to the sixtieth year by means of frequent thinnings the diameter growth at the top of the 16-foot butt log can be maintained at 0.3 inch or more per year or a total growth of 12 inches for the period. Since at the twentieth year the diameter at the top of the log averages 4 inches, the diameter at that point should be at least 16 inches in the sixtieth year.

FINANCIAL ASPECTS OF PRUNING

TABLE 3 gave the total cash outlay per tree for pruning white and red pine to 17 feet by either the ladder or pole saw method. In order to make a comparison with the probable returns from pruning, the initial cost

* As an example, one white pine plantation was first thinned in its fifteenth year, removing 18 of the largest unpruned trees per acre. A second thinning was made 5 years later removing 32 trees per acre. These two thinnings, although each as heavy as was silviculturally desirable, have not freed all the pruned trees from serious crowding. At least one more thinning will be needed to set the pruned trees fairly free of their neighbors.

of the operation must be carried forward at interest to the end of the rotation. Table 6 shows what this cost will amount to based upon the figures of Tables 2 and 3 and using the ladder method for high pruning. It is assumed that the three pruning operations occur in the twelfth, fifteenth, and eighteenth years after planting and that the pruned trees will be harvested at the age of 60 years. Wages are set at 50 cents per hour and interest at 4 per cent compounded annually.

TABLE 6. COST OF PRUNING ONE 17-FOOT LOG OF WHITE OR RED PINE IN THREE OPERATIONS

(Using the ladder method for high pruning.)
Compounded to the end of a 60-year rotation at 4 per cent, with labor at 50 cents per hour.

		White Pine		*Red Pine*	
Operation	*Interest compounded for years*	*Initial cost*	*Cost compounded*	*Initial cost*	*Cost compounded*
0 to 7 feet	48	$.0370	$.2420	$.0305	$.1995
7 to 12 feet	45	.0265	.1548	.0205	.1197
12 to 17 feet	42	.0475	.2478	.0320	.1669
Whole log		$.1110	$.6446	$.0830	$.4861

Under the conditions stated, the cost of pruning one tree to 17 feet is, at the end of a 60-year rotation, 64 cents for white pine and 49 cents for red pine.

Assuming that a 16-foot log is cut from the 17-foot pruned length, and that the diameter inside bark at the small end is 16 inches when the tree is felled at 60 years of age (see page 33), the volume of the log by the International log rule, ¼-inch kerf, will be 180 feet, board measure. The pruning cost will be for white pine 64 cents for 180 board feet or $3.56 per thousand feet, board measure, and for red pine 49 cents for 180 board feet or $2.72 per thousand feet, board measure.

With a given cost of pruning, the profit depends upon the amount of clear lumber sawed from a log and the prices of clear and knotty lumber. Logs with an appreciable width of clear wood in the outer zone are sawed around, rather than through and through, so as to get the maximum number of board feet of clear lumber. Sawed in this manner a log 16 inches in diameter at the small end, with a 6-inch central knotty core, will saw out at least 75 per cent clear boards and not more than 25 per cent knotty.*

On this basis and using the prices of $50 per thousand feet, board measure, for clear white pine lumber and $25 for knotty lumber as suggested by Cline and Fletcher (1928),† the value of white pine butt logs, if unpruned, would be at the rate of $25 per thousand feet, board measure, and, if pruned, at the rate of $43.75. This shows a difference in favor of the pruned logs of $18.75 per thousand feet, board measure. Subtracting the pruning cost of $3.56 per thousand, the profit from pruning white pine butt logs is found to be $15.19 per thousand feet, board measure. Pruning red pine and spruce cannot be expected to show as large a profit as is indicated for white pine, but the operation should prove profitable for all these species.

The best indication of the expectable profit from pruning would come from actual experience derived from all phases of the operation, extending from the removal of the limbs to the sale of the pruned lumber. Such experience is practically nonexistent. One excellent example can be found, which is cited by Cline and Fletcher (1928) in the case of O. M. Pratt‡ of Holderness, New Hampshire, who for many years has been pruning white pine and logging, manufacturing, and selling the lumber himself, and who has experienced a difference of as much as $40 per thousand feet, board measure, between the prices of lumber from pruned and unpruned white pine logs.

One could arrive at almost any figure of profit, or even loss, by using different combinations of values for the factors involved in pruning, which may be listed as follows: Age of stand when pruned, growth rate of trees after pruning, length of rotation, speed of pruning, wage rate, interest rate, and value of clear and knotty lumber. Since experience as to results is so limited, all that Can be attempted in the way of estimating the financial results of pruning is to set forth reasonable and conservative conditions under

* This estimate is based upon the diagramming of the small end of the log to show the number and width of clear and knotty 1-inch boards when properly sawed with a saw cutting a ¼-inch kerf. To be conservative, short clear boards which might be sawed from the butt end of the log were not included.

† These prices are considered conservative over a long period of time such as a crop rotation, ignoring temporary fluctuations.

‡ For further Information on Pratt's work the reader is referred to the study cited above (Cline and Fletcher, 1928) and to an article by Butler (1925).

which pruning can be done at a profit. It is the problem of each individual plantation owner to analyze the factors as they apply to his particular situation and determine for himself whether or not he should practice pruning. The present publication is intended to furnish the basis and incentive for such analysis.

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PLATES

PLATE 1

A WHITE PINE PLANTATION WHICH NEEDS PRUNING

CHARACTERISTIC appearance of the unpruned portion of a well-stocked, thrifty, 18-year-old white pine plantation. The original planting was 1,200 trees per acre, spaced 6 by 6 feet, which has been reduced by the normal losses of establishment to approximately 800 trees per acre. The lower branches are dead up to a height of 8 feet on the two trees in the foreground and up to 12 feet on trees in the denser part of the stand. Timber of high quality cannot be produced on a 60 to 80-year rotation in these plantations without artificial pruning. Pruning to 17 feet should already have been completed in this plantation.

PLATE 2

A RED PINE PLANTATION WHICH SHOULD HAVE BEEN PRUNED SEVERAL YEARS AGO

A TYPICAL unpruned plantation of red pine established 15 years ago. At present over 900 out of the 1,200 trees per acre originally planted are still living. Red pine is so much more hardy than white pine in survival after planting that the stands are much denser, like the one in the picture as compared to the white pine plantation shown in Plate 1. Even this density of stocking has not caused the dead limbs to fall off. Clear lumber in satisfactory amounts can be secured only by artificial pruning.

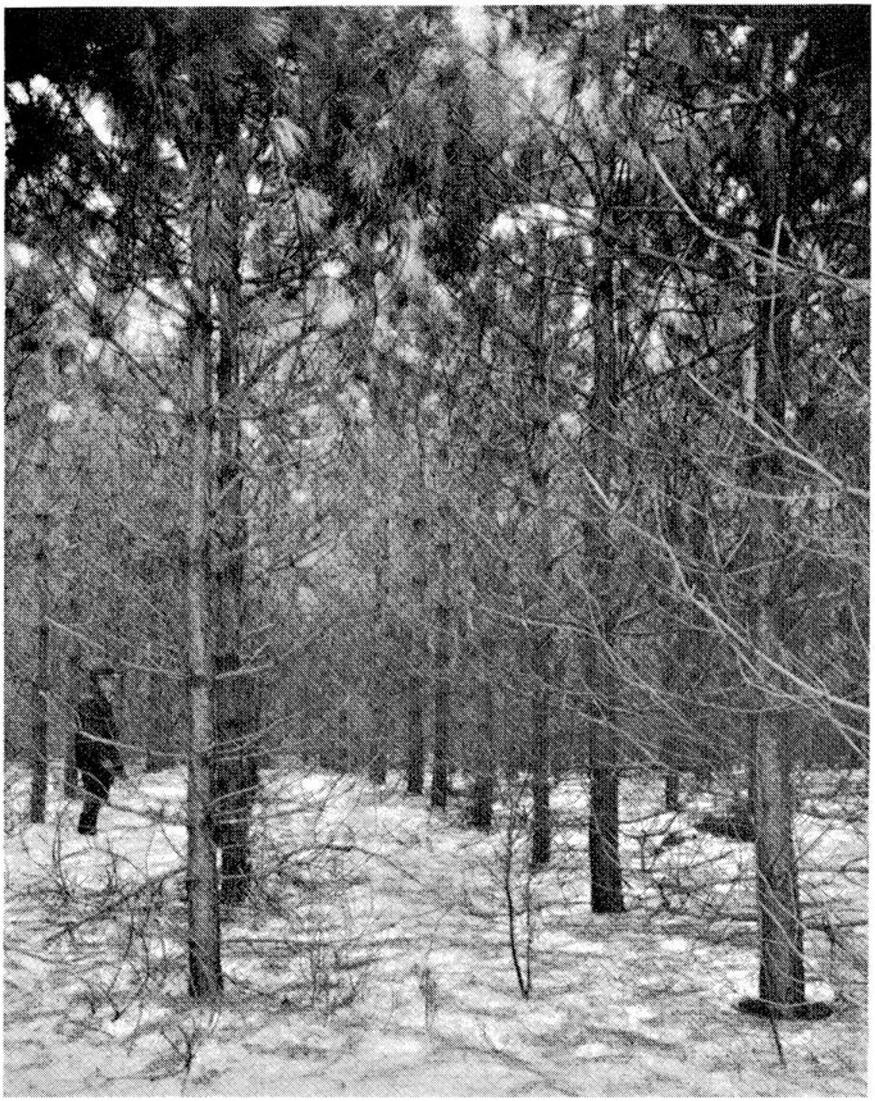


PLATE 3

LOW PRUNING OF RED PINE

A 10-YEAR-OLD plantation of red pine which has just had its first pruning. Selected trees spaced about 17 feet apart have been pruned to the height of the highest interlacing branches, which in this stand is about the height to which a man standing on the ground can conveniently reach with a hand saw (approximately 7 feet).

PLATE 4

WHITE PINE COMPLETELY PRUNED

PRUNING has been completed to a height of over 17 feet on the tree in the center. In this case the pruning was done in two operations (0 to 7 feet and 7 to 17 feet). The whitish stubs indicate the whorls removed in the second operation, which did not extend above the highest interlacing of the crowns. The diameter of this tree is 6 inches at breast height and 4 inches at the 17-foot point. This is an 18-year-old plantation of white pine in which selected trees have been pruned. The high pruning was done by the ladder method.

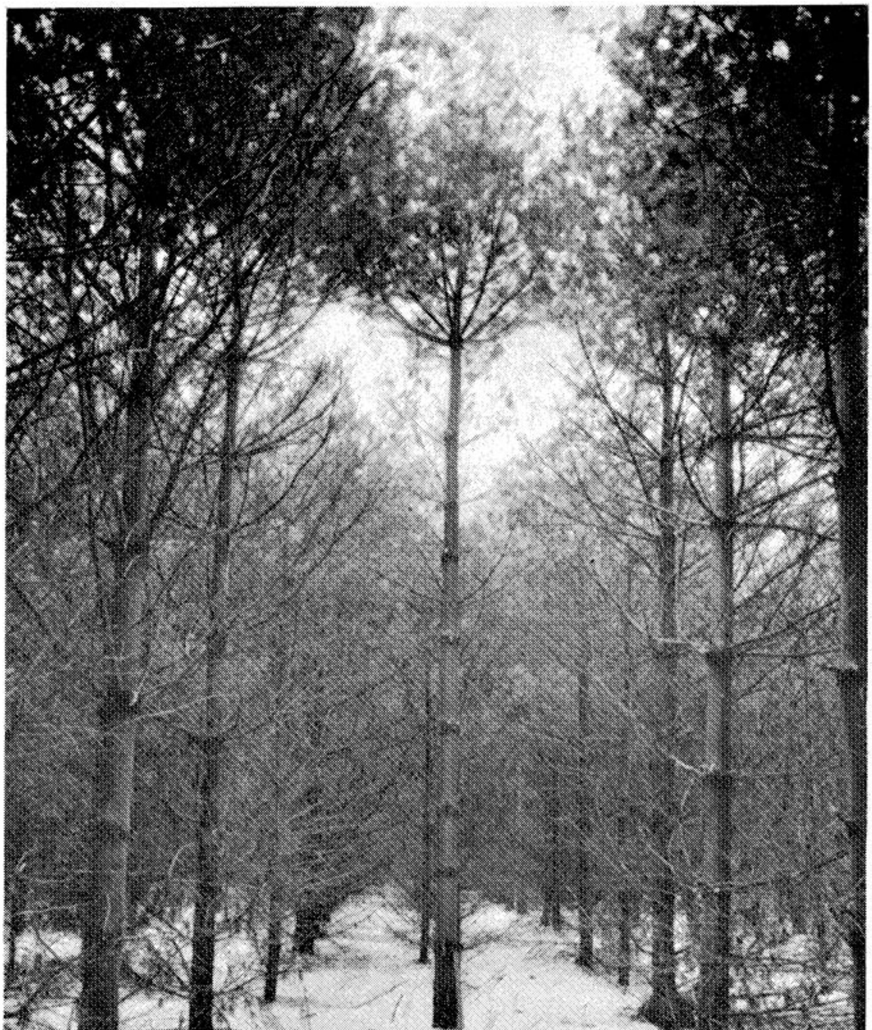


PLATE 5

RED PINE PRUNED TO 17 FEET

The red pine in the center foreground has just received its third pruning, completing the operation to a height of 17 feet. The tree on the right has not been pruned quite so high, because of its exposed position on the edge of the stand (a southern exposure). In this case two trees quite close together have been pruned because of extra growing space resulting from the opening in the foreground.

PLATE 6

THIS TREE WAS NOT WORTH PRUNING

THE white pine with the calipers has two bad crooks in the bole resulting from two attacks of the white pine weevil within a period of three years. The lower branches have been cut off to show the crooked bole. The crooks are so serious as to ruin the first 8 feet of the bole for high-quality lumber. Trees of this type should not be selected for pruning but should be removed in the early thinnings.

PLATE 7

THIS TREE WAS WORTH PRUNING

A WHITE pine only slightly injured by weeviling. In this case the weeviled top was cut out and a lateral branch straightened and developed so well that only a slight crook now remains. As the tree is only 18 years old, it is expected that this crook will be entirely overgrown in the next 40 to 60 years before the age of cutting is reached. The tree has a diameter of 8 inches at breast height.

PLATE 8

PRUNING BY THE LADDER METHOD

THE man is using a curved pruning saw with a 14-inch, single-edge blade cutting on both thrust and draw strokes. The ladder is 8 feet long. This is the type of ladder used in pruning the heights from 7 to 12 feet. For higher pruning (12 to 17 feet) a 12-foot ladder is used.

PLATE 9

PRUNING BY THE POLE SAW METHOD

THE saw in this illustration is a 14-inch curved pruning saw with a single-edge blade cutting on the draw stroke only. The handle is 8 feet long. For pruning above 12 feet a 12-foot handle is used.

PLATE 10

SECTIONS FROM PRUNED WHITE PINE TREES

All the branch stubs shown were alive at the time of pruning.

The lower of the two small sectors on the left illustrates conditions at the time of pruning. The branch stub is 0.9 inch in diameter, but the diameter of the cut surface is 1.1 inches, because the cut was a little too close and passed through a portion of the shoulder.

The other small sector contains a branch stub pruned 4 years ago. The diameter of the cut is 1.5 inches, of which 1.45 inches is now covered with new wood. Occlusion has been rapid and satisfactory.

The two complete cross sections, the larger cut at 9 feet and the smaller at 2 feet above the ground, are from different trees pruned 10 years ago. Both trees were planted 21 years ago. The larger tree grew in diameter inside bark after pruning from 5.4 inches to 9.0 inches. The average thickness of clear wood formed outside the knots is 1 inch. The three stubs shown healed over completely in 4, 6, and 7 years, respectively. The average diameter of these knots is 0.43 inch.

The smaller section illustrates the following characteristics:

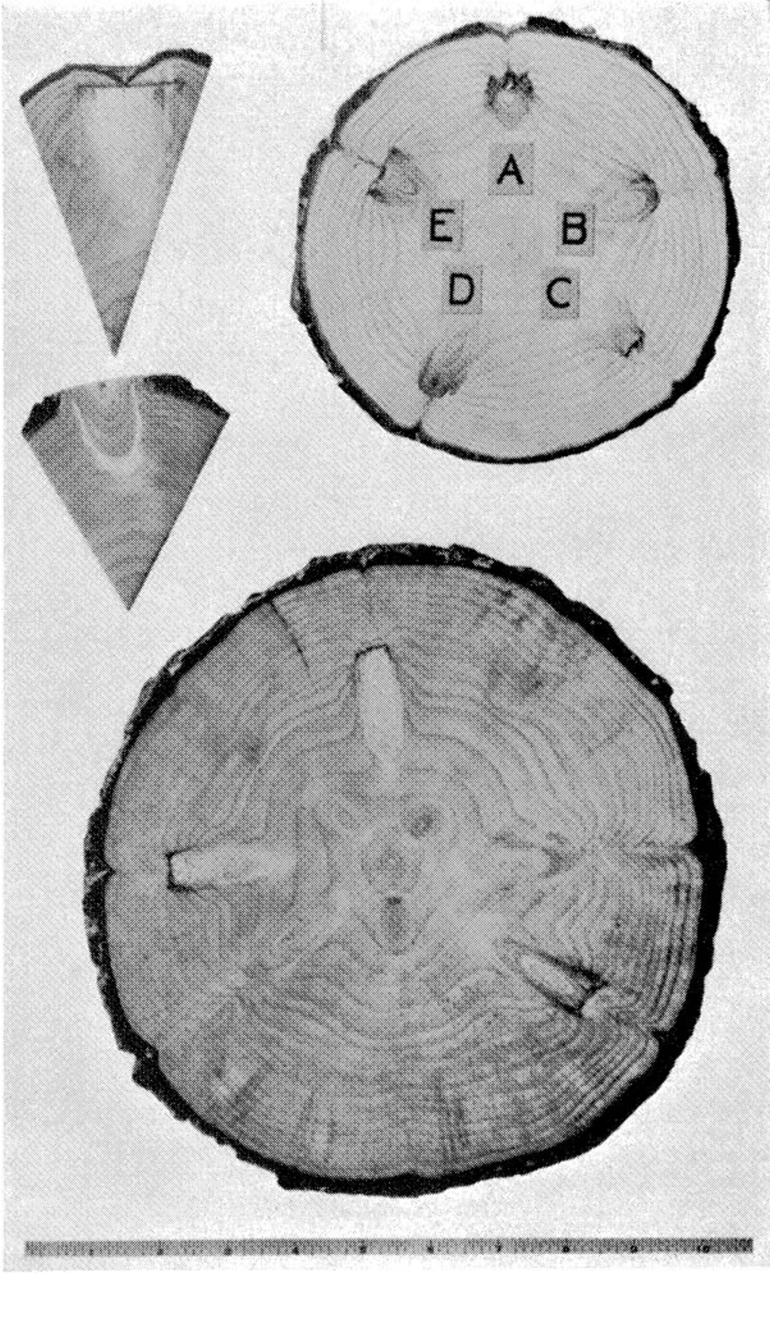
A. A small pitch pocket with discoloration around the point of occlusion.

B. A perfectly healed cut with the typical involution of the growth rings almost eliminated in the last year of growth.

C. A pitch pocket smaller than that shown in A.

D. Sharp infolding of the annual rings, with a radial streak of bark included. The bark streak has been covered by clear wood in the last year of growth.

E. A radial streak of bark extending from the end of the stub to the surface of the stem. This wound cannot be considered healed. This type of defect is not common.


A
E
B
D
C

ARTIFICIAL PRUNING IN CONIFEROUS PLANTATIONS

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