KNOTS IN SECOND-GROWTH DOUGLAS-FIR

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KNOTS IN SECOND-GROWTH DOUGLAS-FIR

By

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The total area of second-growth Douglas-fir in the states of Oregon and Washington is estimated at approximately 5 million acres. In these states, 2-1/4 million acres, largely from this area, have been designated as "tree farms." A study of the quality of second-growth Douglas-fir on various lands that differ in site quality has been undertaken by the Forest Products Laboratory, Madison, Wis., in cooperation with the Pacific Northwest Forest Experiment Station, Portland, Oreg., in order to gain information that will be applicable to such tree farms.

The harvesting of second-growth Douglas-fir already under way in many places indicates a yield of very little clear wood, in the production of which old-growth Douglas-fir has been given preferential value for the manufacture of veneer, finish lumber, sash, doors, flooring, silo and tank staves, and aircraft.

As a part of this study of second-growth Douglas-fir, approximately 1,000 knots have been analyzed from stands of site-quality classes[1] II and IV located in the vicinity of Oakridge, Lane County, Oreg.

Purpose

It was the purpose of this study to determine the facts concerning the development of branches and resulting knots with respect to their number and size, the number of years the branches remain alive, and how long they persist after death in different heights in the tree under varying conditions of site and density of stocking. The main objective is to obtain information that can be applied to second-growth Douglas-fir to improve the quality and to increase the value of forest products.

Fortunately, it is not necessary to make repeated observations of a stand over a period of 100 years or so in order to determine how the limbs and knots develop in trunks of merchantable size. Their history is recorded year by year within the trees and can be studied at any time the trees are cut.

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[1]Site-quality classes in the Douglas-fir region are designated as I, II, III, IV, and V according to average heights of 200, 170, 140, 110, and 80 feet, respectively, of dominant trees at 100 years of age.

Development of Knots

It is characteristic of Douglas-fir to produce a whorl of branches at the termination of each year's shoot. In addition, smaller branches grow at irregular intervals along the stem. As trees grow in height, branches thus added above the older ones, as they lengthen horizontally, shade the lower branches and those of nearby trees. Lack of sunlight causes leaves or needles to die first, and, finally, the shaded branches. Death of branches occurs early near the ground in densely stocked stands, somewhat later in understocked stands, and usually not at all in fully open-grown trees. Rapid height growth of trees on the better sites causes branches higher along their trunks to die earlier than branches at the same height in trees on poor sites that are making slower height growth.

Before its death, the branch is an integral part of the tree, with each succeeding growth ring of the trunk extending over the entire surface of the branch. After the death of the branch, the growth ring in the trunk surrounds the branch but has no physiological connection with it. Dead branches serve no useful purpose in the growth of trees, and natural agents of destruction, such as wind, snow, ice, fungi, and insects, begin their removal, the accomplishment of which sometimes proceeds at a snail's pace and may require many decades.

Knots in lumber may comprise both the living, intergrown branch portion and such parts of the dead branch as become surrounded by the growth rings of the trunk before the branch breaks from the tree.

Source of Material

Knots were studied in trees from two fully stocked stands of second-growth Douglas-fir -- one 100 years of age on site II and one 150 years of age on site IV. Some additional knots from a 70-year understocked stand, also on site II, were included. The 100-year stand averaged about 200 trees per acre, and the 150-year stand, 400 trees per acre.

Tree cross sections for studying knots were taken from 14 trees each in the 100- and 150-year stands and from five trees in the understocked stand. The trees selected for study on site II ranged from 15 to 36 inches d.b.h.; those on site IV, from 10 to 27 inches; and those in the understocked stand, from 23 to 34 inches. The tree cross sections supplying knots for study were cut at approximate heights of 2 to 4, 16 to 20, 36 to 40, 61 to 64, and 76 to 80 feet in each tree. No knots higher than 32 feet were investigated from the understocked stand. Additional knots were counted and measured from three butt logs cut into veneer from each of the two fully stocked sites, and from a number of bolts from the understocked stand. Consideration of the development and persistence of knots in the fully stocked 100-year and 150-year stands will be given major emphasis in this discussion, but, unless specifically mentioned, trees from the understocked stand will not be included in the discussions of trees from site II.

Number and Size of Knots

The number of knots per unit length of a Douglas-fir tree is determined to a great extent by the site quality of the area in which the tree has grown, which quality is reflected in the amount of annual height growth of the trees. The greater the annual height growth, the farther apart are the knot whorls and the fewer are the branches in a given length of trunk. In Douglas-fir, small branches forming pin knots also occur near to and scattered between the whorls of branches, as already stated. In this study, all knots less than 0.3 inches in diameter have been classed as pin knots. Although of small size, pin knots sometimes persist for a long time after the death of the small branches that formed them.

Comparison of the two fully stocked stands showed that there were about 1-1/2 times more knot whorls per unit of tree length on site quality IV than on site quality II. Knots per whorl averaged six for site II and five for site IV. In butt logs cut into veneer from these two sites, there was an average of 1.6 pin knots and 3.5 larger knots per lineal foot of log length on site II and 4.1 pin knots and 6 larger knots on site IV. In veneer bolts from the understocked stand on site II, there was an average of 1 pin knot and 3.5 larger knots per lineal foot. The pin knots are omitted from the further analysis of knots in this report.

Method of Analysis

The method of analysis consisted of sawing open short tree cross sections, or bolts, in such a way that complete longitudinal sections of knots were exposed. The bolts, 16 inches in length, were first cut from the trunks of the trees. They were then sawed radially into segments by a band saw, with the cuts being made to bisect vertically all knots visible on the outside of the bolt. Other cuts were made through the segments near the bolt center at right angles to the radius to expose knots that had been completely overgrown (fig. 1). These knots likewise were bisected longitudinally. The information recorded included:

1. The number of knots at each branch whorl.
2. The maximum diameter of each knot at the outer end of the live portion.
3. The distance from the pith at which the branch died.
4. Age (annual rings from the pith) at which the limbs forming the knots died.
5. The number of years the dead limbs or stubs persisted on the tree trunk.
6. The length of the dead portion of the limb within the trunk inside the bark.
7. The radial width and number of annual rings included in any clear wood present between the end of the overgrown knot and the bark.

Arrangement of Data

In order to present a clear picture of the variations among trees of different sizes in each site, the data on the live and the dead portions of knots were tabulated by groups for trees of different diameters, and hence of different rates of growth, since the trees in each group were of approximately the same age (table 1). The tabulation is accompanied by diagrams representing averages for three typical trees each of large, medium, and small diameters from the range of sizes for each site (fig. 2).

Live-knot Portion

The age of the live-knot portion of each branch was determined by counting the growth rings of the bolt from the pith to the point where they ceased continuity with the branch. At this point the maximum vertical diameter at right angles to the knot axis was measured. The horizontal distance from the pith to the end of the live portion was recorded. In some cases, the continuity of the branch with the stem ceased at different years on the upper and the lower side of the branch. In such cases, the averages of the two age counts and of measurements were recorded.

Branches remained alive for less time near the stump than higher in trees on both sites II and IV. Although lower branches died at about the the same ages (16 to 19 years on site II and 16 to 22 years on site IV), there was a marked difference in the average radial length and average diameter of the live portion of the lower branches among trees of different sizes on each site (table 1) due to differences in diameter growth of the trees. At the 2- to 4-foot height in the small trees of site II, the length of the live portion of knots averaged 2.8 inches, and the diameter of the same knots 0.37 inch. Correspondingly, in medium-sized trees of this site, averages of the length and diameter of knots were 3.7 inches and 0.41 inch, respectively, and for the large trees, 4.7 inches and 0.49 inch. At other heights in the three sizes of trees, the average trend in age, length, and diameter (fig. 3) of live knots was irregularly greater upward in the tree, with averages at the 60- to 64-foot level sometimes slightly exceeding those at the 76- to 80-foot level. The average ranges for live knots from below upward in age, radial length, and diameter for the three sizes of trees from site II were as follows:

1. Age of live portion: small trees, 16 to 28 years; medium trees, 19 to 32 years; large trees, 18 to 43 years.
2. Length of live portion: small trees, 2.8 to 3.7 inches; medium trees, 3.7 to 5.7 inches; large trees, 4.7 to 7.4 inches.
3. Diameter of the live portion: small trees, 0.37 to 0.85 inch; medium trees, 0.41 to 1.20 inches; large trees, 0.49 to 1.60 inches.

On site IV, age, length of live portion, and diameter of knots also increased on the average from the smaller to the larger trees and from below upward, with the ranges as follows:

1. Age of live portion: small trees, 16 to 37 years; medium trees, 18 to 51 years; large trees, 22 to 61 years.
2. Length of the live portion: small trees, 1.9 to 2.1 inches; medium trees, 2.0 to 3.7 inches; large trees, 3.6 to 4.5 inches.
3. Diameter of live portion: small trees, 0.42 to 0.60 inch; medium trees, 0.44 to 1.11 inches; large trees, 0.63 to 1.20 inches.

In a comparison of trees of approximately the same diameters from the two sites, live knots of trees of medium diameter of site II were lower in age but were fairly close in range of length and diameter to those of the large trees of site IV. Comparisons of trees of small diameter on site II to medium trees of about the same diameter on site IV also showed greater ages for knots at the higher levels in trees of site IV, but differences in the length of knots were small. (It should be noted that the total age of the trees does not influence the size of live knots from branches that have died, but knots from branches still living would increase in diameter with further growth.) At the higher levels, average knot diameters differed more, probably due to greater age when branches died on site IV (fig. 2).

In the understocked stand, the live knots grew to gigantic proportions in comparison to those of the fully stocked stands (fig. 4). Ages of the live knots averaged 21 years near the ground to 42 years near a 32-foot height. An average live-knot length of 11.6 inches and diameter of 3.2 inches were attained.

Dead-knot Portion

The extent to which the dead-knot portions of the branches have become incorporated within the trees is a measure of the importance of this phase of the study, since dead or encased knots depreciate lumber grades more than live or intergrown knots. Dead knots, unlike living knots, no longer have a structural connection with newly formed wood above, below, and on each side of them. They are, to be sure, structurally connected to the live portion toward the center of the tree, but when severed from that, as when a log is sawed into boards, the dead portion of the knot may be pushed out of the boards or drop out of its own weight. Besides the degrade they thus cause by creating knotholes in lumber, such loose knots are a hazard in the operation of woodworking machinery.

Even for these stands of 100 and 150 years of age, information on the total length of dead knots that might be included within the trunks of the trees is not complete, since in both stands many dead branches still extended through the bark and the length of time that they might have persisted is a matter of conjecture. The length of time that dead branches have persisted (figs. 5, 6, 7, and 8) is already so great, however, that they have had a predominant influence upon the quality of lumber in the tree up to the present, especially on site II. The indications are that this influence may last many years more, especially in the case of branches having large diameters.

Persistence of Dead Branches

Since among the trees of different diameters on site II branches died at about the same age regardless of size of the trees, the time of their persistence after death based upon the years represented in the cross sections of trees at any given height, likewise is equal. Thus, at a given height, the sum of the average age of the branches when alive plus the average number of years of persistence of the same branches when dead equals the average age of the cross section of the trees, except near the ground, where some of the dead branches were overgrown.

The length of the dead knot portion of the branch included within the trunk is then determined largely by the size of the tree, which in an even-aged stand, like those under consideration, is determined by age and rate of growth. In the small trees of site II, the average dead-knot length ranged from 6.6 inches at the base to 4.2 inches at the 76- to 80-foot height; in the medium trees, comparable lengths were 8.5 to 7.0 inches; and in the large trees, 12.2 to 8.8 inches. The shortening of this dead length of branches upward is, of course, due to the fact that cross sections are younger and smaller, while the live portions are correspondingly longer.

On site IV, despite the 50 years' additional age of the trees, lengths of dead branches incorporated within the trunks averaged a little shorter than on site II. This undoubtedly was due largely to the slower growth and, hence, smaller size of the trees. The dead length of branches in small trees on site IV ranged from 4.3 inches at the base to 3.2 inches at 60 to 64 feet. In the medium-sized trees, their length ranged irregularly upward from 5.5 inches at the base to a maximum of 6.4 inches at 36 to 40 feet, and then fell off to 4.3 inches at 76 to 80 feet. In the large trees of this site, the length of dead branches ranged from an average of 8 inches at the base to 5.5 inches at 76 to 80 feet.

Comparison of dead-branch lengths on these two sites, even with a difference of 50 years in age of trees, shows mainly that tree groups of the same approximate size fall fairly close together with respect to average dead length of the knots. The dead-knot length of medium-sized trees of site II is close to that of large trees of site IV, although noticeably longer. If the comparison had been made at the same age, namely, 100 years, a still shorter dead-knot length would have been obtained on site IV (see age zones indicated by broken lines in diagrams, fig.2). Similarly, the dead-knot lengths of small-sized trees of site II are close to those of the medium-sized trees of site IV with some differences in the same direction as in the above groups, both for present size and for size of the site IV trees 50 years ago. Because of exceedingly slow growth in diameter in most of the site IV trees during the last 50 years, the dead-knot length of branches still extending to the bark and incorporated within the trees during that time averaged only 1.25 inches radially for all heights in the trees. Thus, with the more rapid radial growth of trees on site II averaging 3 inches during the last 50 years, the dead-knot length incorporated in them has exceeded that of trees on site IV even in 50 years less time. This explains the differences in proportions of No. 1 and

No. 2 lumber grades from these sites reported in an earlier paper[2], where the percentage of No. 2 lumber from site II exceeded that from site IV.

The diameters of dead knots were practically the same as those of the live knots measured at the outer extremity of the live portion. There was some slight taper of the longer branch lengths included in the trees and sometimes a reduction in diameter of dead branches due to weathering.

Clear Wood

Among the 34 trees studied from the 100- and 150-year stands, there were only three from each stand that had no dead branches extending through the bark at the 2- to 4-foot level. These were among the smaller, more slowly growing trees in which the radius of knot-free wood averaged only 1.7 inches. At the 16- to 20-foot level, no trees on site II, and only three trees on site IV, possessed clear wood all around the circumference. At higher levels, some dead branches extended through the bark at all branch whorls in all trees.

Of the trees on site II included in table 1, 74 percent of the branches at the 2- to 4-foot level in the large trees were overgrown. At the same level, 80 percent of the branches in the medium trees and 82 percent in the small trees were overgrown. In the large trees, no branches were overgrown at the 16- to 20-foot level or higher. In the medium trees, 23 percent were overgrown; and in the small trees, 20 percent. In the medium trees at the 36- to 40-foot level, 5 percent of the branches were overgrown, but none at a higher level. No branches were overgrown in the small trees above the 20-foot level.

On site IV, 75 percent of the branches at the 2- to 4-foot level in the large and medium trees were overgrown, and 57 percent in the small trees. At the 16-foot level, percentages of overgrown branches were 43, 72, and 10 in the large, medium, and small trees, respectively. In the same order, the percentages of overgrown branches at the 36- to 40-foot level were 20, 30, and 6, respectively.

In these stands the amount of clear wood between the ends of dead knots and the bark is insignificant from a lumber standpoint, as little advantage can be taken of it in sawing lumber or cutting veneer. On site II, some trees during early stages of growth extended their height 2 to 3 feet in a single year. Such trees might yield short veneer bolts containing only pin knots between the knot whorls.

Some Silvicultural Aspects

The analysis of ages and sizes of the knots, especially those in the lower portion of the trees on site II and site IV, shows that in the

[2] Paul, Benson H., Lumber Grades vs. Site Quality of Second-growth Douglas-fir. Forest Products Laboratory Report No. R1688, May 14, 1947.

small trees of each site the average diameter of the knots is the least. This is an indication that close stocking resulted in slow growth and that branches died at relatively smaller sizes than in the larger trees (fig. 9). Presumably, the larger trees grew under conditions of somewhat less dense stocking, and while their branches became thicker and longer, they died at about the same age as those of the smaller trees. Thus, the diameter and length of knots apparently can be reduced by originating stands at high density in order to kill side branches while they are yet very small.

At the other extreme, the presence of dead branches in second-growth Douglas-fir can be avoided by growing young trees in understocked stands to be harvested before the lateral branches die. This practice will yield lumber containing excessively large intergrown knots, which for some uses may be preferable to lumber with smaller loose knots. The yield per acre from such understocked stands may be expected to be relatively low, yet the rotations might be considerably shorter than for fully stocked stands.

Persistent dead branches in second-growth stands of Douglas-fir, even when fully stocked, have prevented the production of high-grade lumber in unpruned stands up to 100-150 years of age. The addition of 50 years to the rotation evidently would have been of little help, since during the last 50 years in the stands investigated, radial growth had slowed to an average of only 1-1/4 to 3 inches (fig. 10). Thinning of the stands 50 years ago would have increased the diameter growth of the residual trees, but without benefit to lumber grades, since the result would have been the inclusion in the trunk of longer portions of the persistent dead branches.

Early pruning of normally stocked or understocked stands will yield high-grade lumber from the pruned portions of trees, and lumber from intergrown knots higher in the trees, if the thicker stands are thinned after pruning and the trees cut soon after the branches above the pruned length have died.

Summary

1. Approximately 1,000 knots from second-growth stands of Douglas-fir, site quality II and IV, were studied to determine the progress of natural pruning.
2. Knots in butt logs of second-growth Douglas-fir averaged 3.5 in number per lineal foot of log length on site II and 6 per lineal foot on site IV. In addition, there were 1.6 and 4.1 pin knots (knots less than 0.3 inch in diameter) per lineal foot, respectively, in the same logs from the two sites.
3. In stands 100 and 150 years of age, dead branches extended through the bark along the entire merchantable length of most of the trees studied.

4. Clear wood between the ends of dead branch stubs and the bark was insignificant in amount in any trees, and for most of the trees studied was found only at the outer ends of a fraction of the branches at any whorl.

5. In the trees on both sites, branches below the 20-foot level remained alive for 16 to 26 years, with their lifetime increasing progressively upward along the trunk. Branches remained alive somewhat longer at levels in the trees on site IV equal to those on site II.

6. The diameter of branches at the time of death averaged from about 1/2 inch near the ground on both sites to 1.6 and 1.2 inches, respectively, in the upper portions of trees on sites II and IV.

7. The length of the live portion of branches varied from 2.6 to 7.4 inches in trees on site II, and from 1.9 to 4.5 inches on site IV.

8. The length of the dead portion of most branches within the trunks corresponded closely to the radial distance from the end of the live-branch portion to the bark.

9. In the younger, understocked stand on site II, the live portions of knots were older, longer radially, and larger in diameter than those in the fully stocked stands.

10. Some silvicultural practices such as close stocking or thinning may decrease the diameter of knots or increase the proportion of lumber with intergrown knots.

11. Early pruning appears advisable if any clear lumber is desired in relatively short rotations.

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At the other extreme, the presence of dead branches in second-growth Douglas-fir can be avoided by growing young trees in understocked stands to be harvested before the lateral branches die. This practice will yield lumber containing excessively large intergrown knots, which for some uses may be preferable to lumber with smaller loose knots. The yield per acre from such understocked stands may be expected to be relatively low, yet the rotations might be considerably shorter than for fully stocked stands.

Persistent dead branches in second-growth stands of Douglas-fir, even when fully stocked, have prevented the production of high-grade lumber in unpruned stands up to 100-150 years of age. The addition of 50 years to the rotation evidently would have been of little help, since during the last 50 years in the stands investigated, radial growth had slowed to an average of only 1-1/4 to 3 inches (fig. 10). Thinning of the stands 50 years ago would have increased the diameter growth of the residual trees, but without benefit to lumber grades, since the result would have been the inclusion in the trunk of longer portions of the persistent dead branches.

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6. The diameter of branches at the time of death averaged from about 1/2 inch near the ground on both sites to 1.6 and 1.2 inches, respectively, in the upper portions of trees on sites II and IV.

7. The length of the live portion of branches varied from 2.6 to 7.4 inches in trees on site II, and from 1.9 to 4.5 inches on site IV.

8. The length of the dead portion of most branches within the trunks corresponded closely to the radial distance from the end of the live-branch portion to the bark.

9. In the younger, understocked stand on site II, the live portions of knots were older, longer radially, and larger in diameter than those in the fully stocked stands.

10. Some silvicultural practices such as close stocking or thinning may decrease the diameter of knots or increase the proportion of lumber with intergrown knots.

11. Early pruning appears advisable if any clear lumber is desired in relatively short rotations.

Table 1.--Number, age, and sizes of knots at various height intervals in large, medium, and small trees in stands of second-growth Douglas-fir from two sites

Site quality class	Age of stand	Relative size and No. of trees	Diameter breast high-range	Height in trees	Averages for knots in whorls at designated heights: Intergrown (live) portion: Knots in whorl	Intergrown (live) portion: Age	Intergrown (live) portion: Radial length	Intergrown (live) portion: Diameter	Encased (dead) portion: Age	Encased (dead) portion: Radial length	Total length inside bark	Percentage of knots overgrown	Clear wood-[1] radial width
	Years		Inches	Feet	No.	Years	Inches	Inches	Years	Inches	Inches		Inches
II	100	large (3)	29-36	2-4	9	18	4.7	0.49	62	7.5	12.2	74	1.3
				16-20	5	25	6.6	1.13	69	5.1	11.7	0	.0
				36-40	6	27	7.3	1.45	58	3.3	10.6	0	.0
				60-64	5	43	7.4	1.40	41	2.2	9.6	0	.0
				76-80	5	41	7.3	1.60	32	1.5	8.8	0	.0
		medium (3)	23-25	2-4	9	19	3.7	.41	51	4.8	8.5	80	1.7
				16-20	6	21	5.0	.81	70	4.0	9.0	23	.2
				36-40	5	24	5.0	.97	55	3.1	8.1	5	.2
				60-64	5	33	6.0	1.37	45	1.5	7.5	0	.0
				76-80	5	32	5.7	1.20	35	1.3	7.0	0	.0
		small (3)	14-19	2-4	5	16	2.8	.37	59	3.8	6.6	82	1.0
				16-20	5	17	2.6	.69	64	2.7	5.3	20	1.5
				36-40	5	21	3.7	.63	57	2.3	6.0	0	.0
				60-64	4	26	3.7	.85	39	1.5	5.2	0	.0
				76-80	8	28	3.2	.77	31	1.0	4.2	0	.0
IV	150	large (3)	23-27	2-4	6	22	3.6	.63	77	4.4	8.0	75	2.0
				16-20	5	26	4.2	.76	101	3.5	7.7	43	.3
				36-40	5	32	3.9	.80	85	3.3	7.2	20	.2
				60-64	5	43	4.4	1.14	57	2.0	6.4	0	.0
				76-80	7	61	4.5	1.20	31	1.0	5.5	0	.0
		medium (3)	16-19	2-4	6	18	2.0	.44	72	3.5	5.5	75	1.7
				16-20	5	21	2.3	.49	74	3.1	5.4	72	1.2
				36-40	4	33	3.2	.80	75	3.2	6.4	30	.3
				60-64	4	51	3.7	1.00	44	1.8	5.5	0	.0
				76-80	5	49	3.7	1.11	28	.6	4.3	0	.0
		small (3)	10-13	2-4	5	16	1.9	.42	102	2.4	4.3	57	.3
				16-20	4	23	2.0	.49	87	1.8	3.8	10	.2
				36-40	5	30	2.3	.60	73	1.2	3.5	6	.0
				60-64	4	37	2.1	.60	57	1.1	3.2	0	.0

[1] The data in this column is the average for clear wood if all knots had been overgrown at their average length. Actually clear wood did not extend around the entire circumference as shown in the preceeding column.

Z M 73586

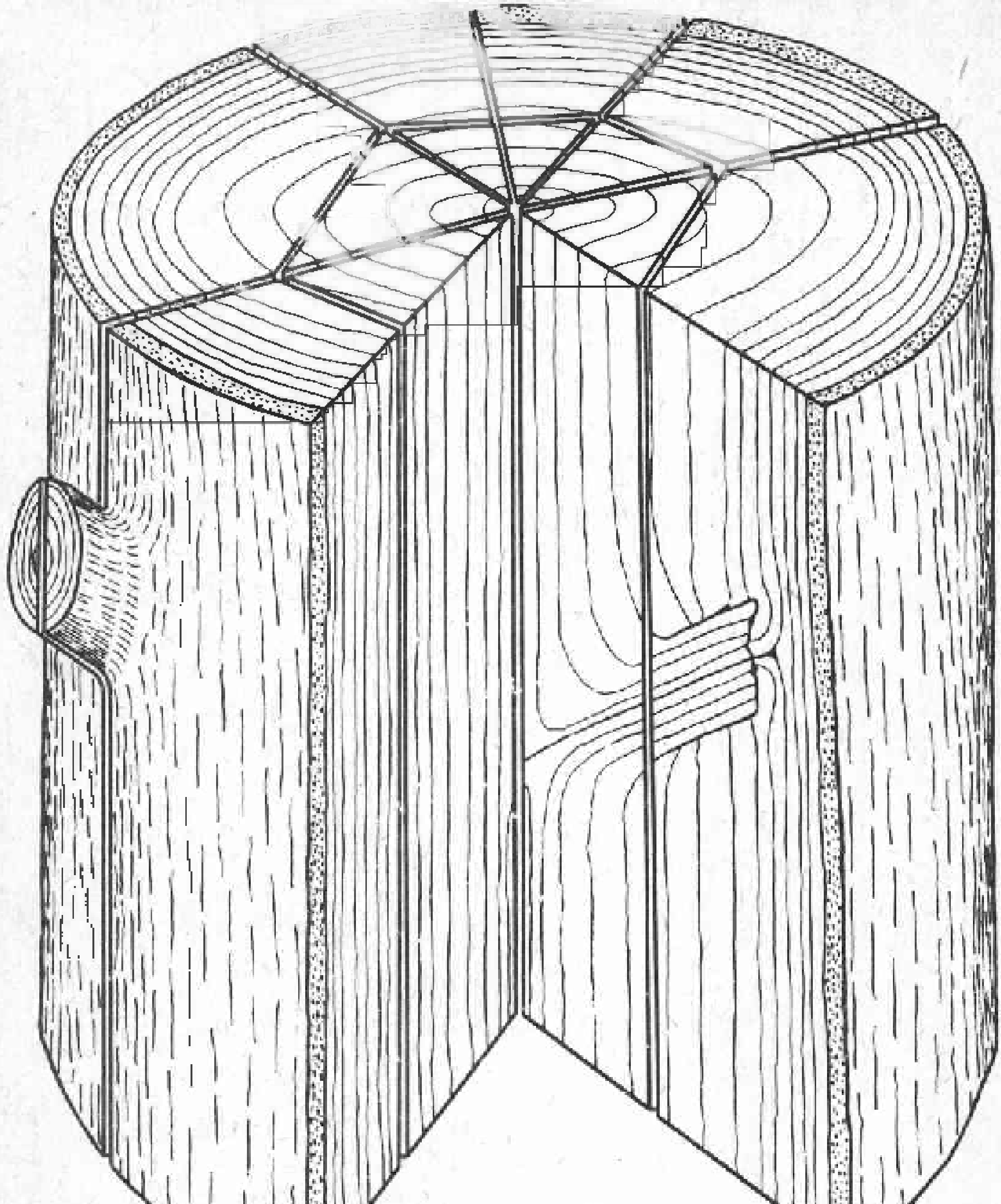

Figure 1.--Method of sawing bolt for knot study.

Z M 27293 F

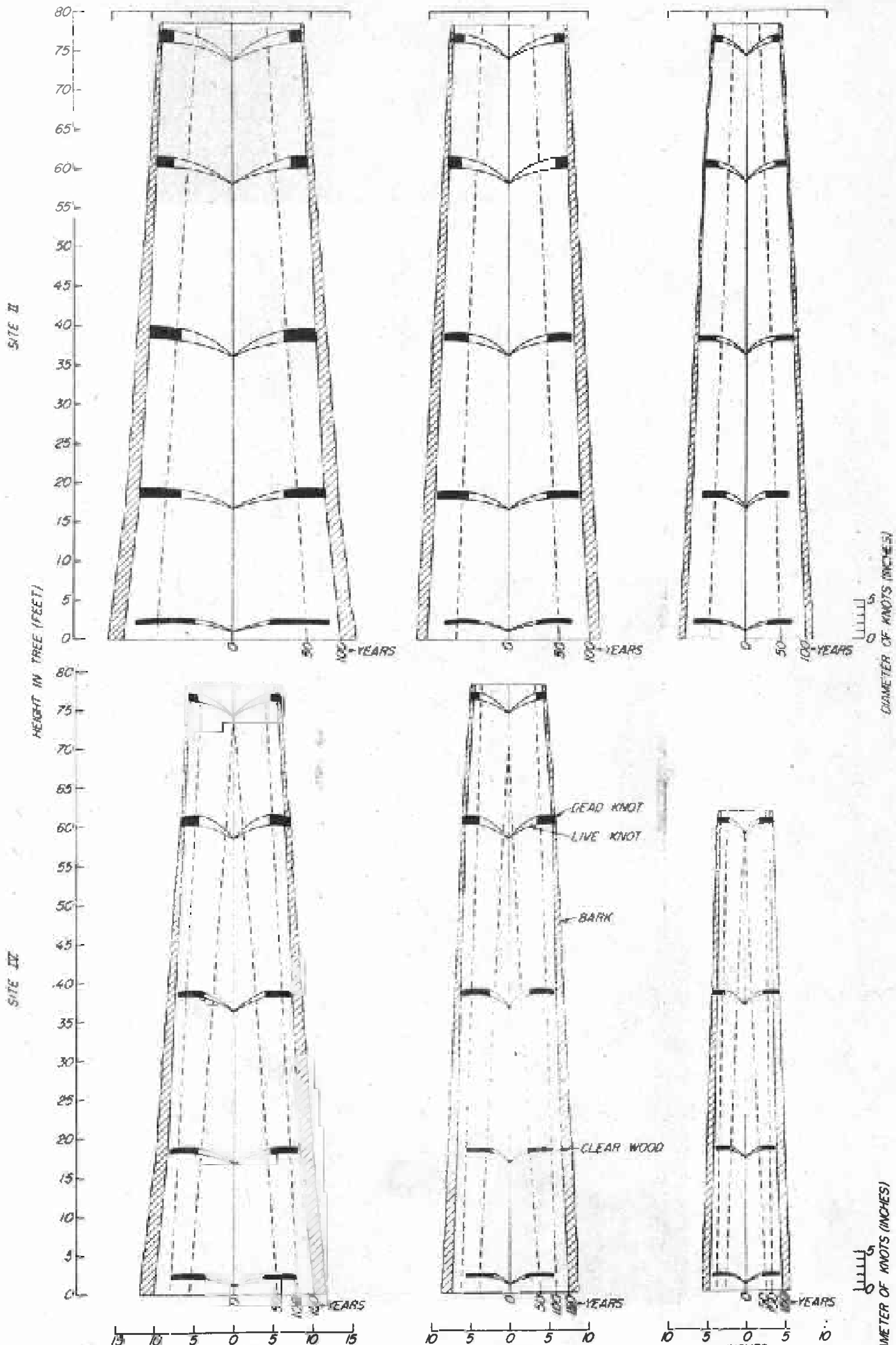

Figure 2.--Diagrams showing live and dead knots at representative heights in large, medium, and small Douglas-fir trees in each of two second-growth stands, one 100 years of age, site II, and the other 150 years, site IV.

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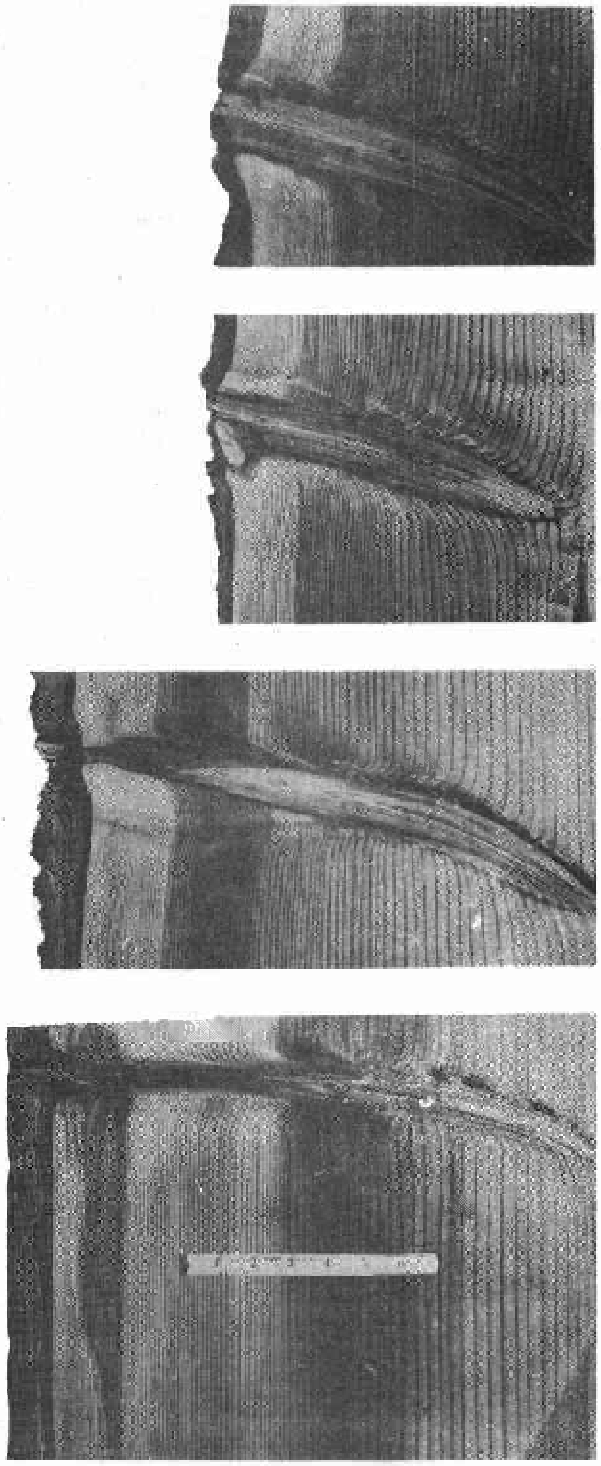

Figure 3.--Comparison of diameters of branch knots at heights of approximately 2, 18, 38, and 62 feet in second-growth Douglas-fir. Maximum diameters of knots shown are 0.8, 1.2, 1.5, and 1.7 inches, respectively, from bottom to top.

Z M 75689 F

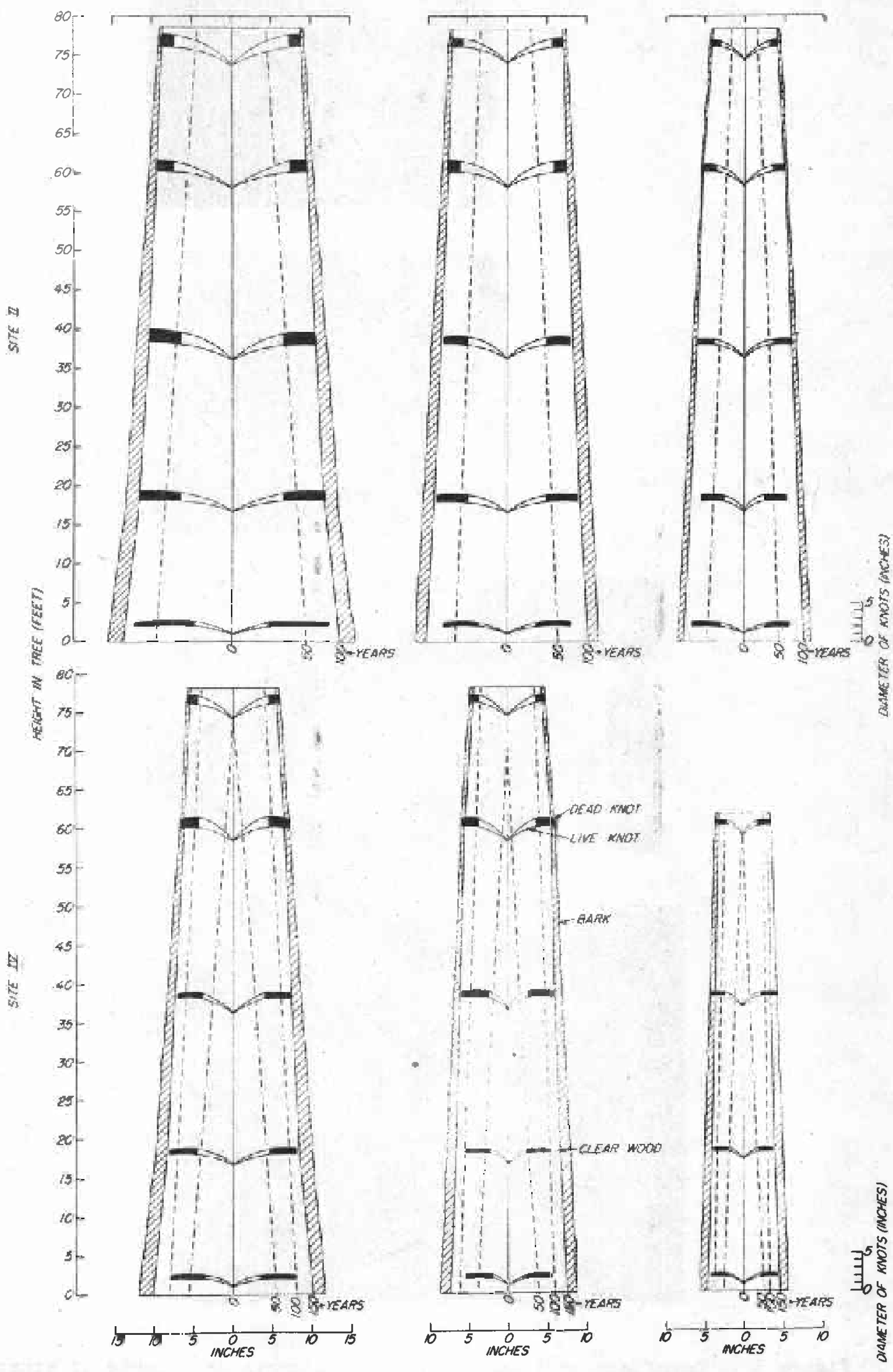

Figure 2.--Diagrams showing live and dead knots at representative heights in large, medium, and small Douglas-fir trees in each of two second-growth stands, one 100 years of age, site II, and the other 150 years, site IV.

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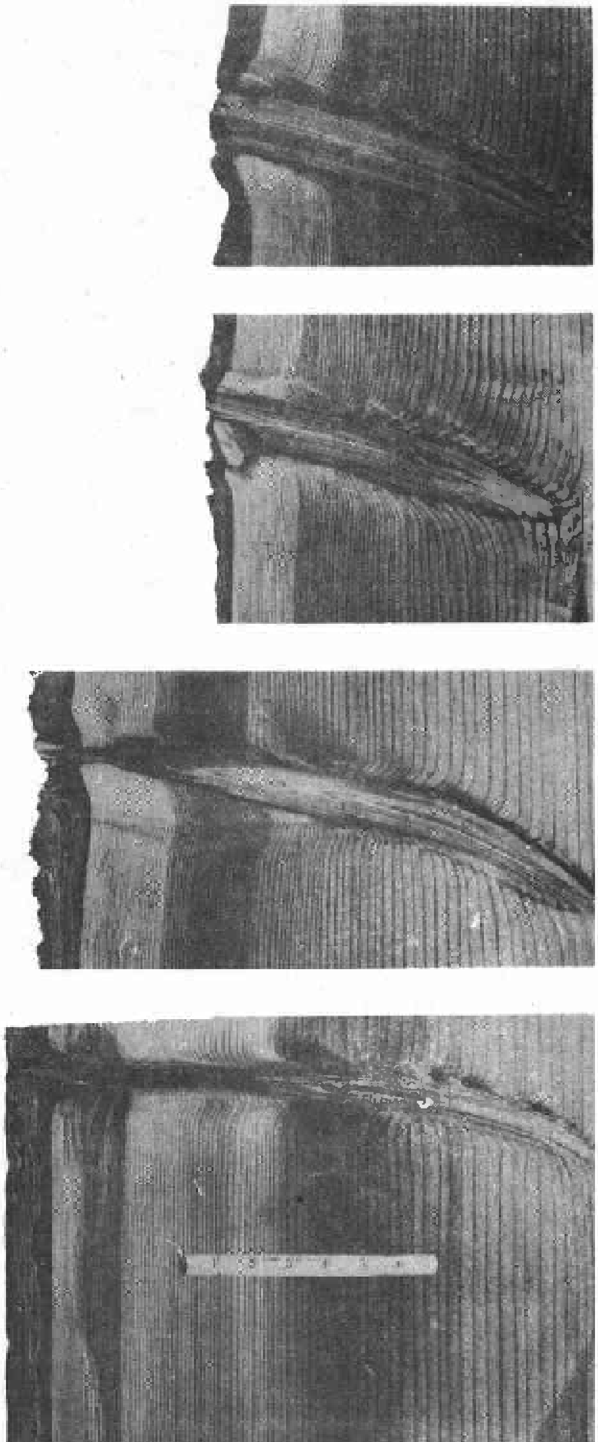

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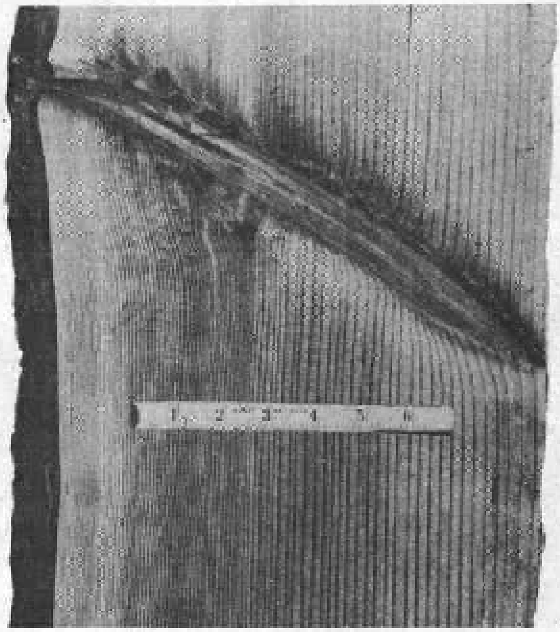
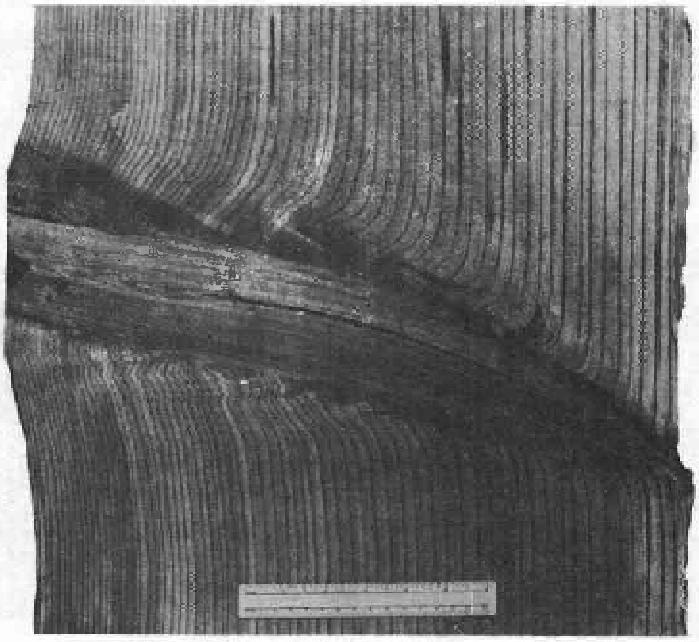


Figure 4.--Above - Branch died at 20 years in a fully stocked stand. Live-knot length, 4.7 inches. Dead-knot length, 5.8 inches. Diameter of knot, 0.9 inch. Height in tree, 20 feet. Below - Branch died at 40 years in an under-stocked stand. Live-knot length, 13.6 inches; dead-knot length, 2.9 inches. Diameter of knot, 2.8 inches. Height in tree, 20 feet.



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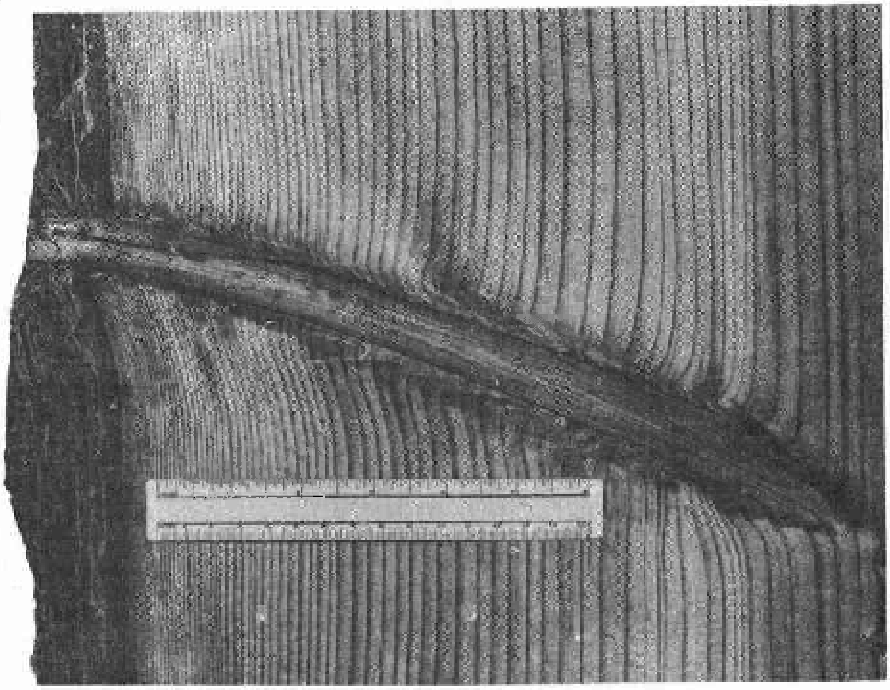

Figure 5.--Branch that died at the early age of 10 years, already has persisted 62 years and doubtless could have lasted many years more. Diameter, 1.1 inches. Length of live portion, 2.6 inches; length of dead portion, 8.2 inches.

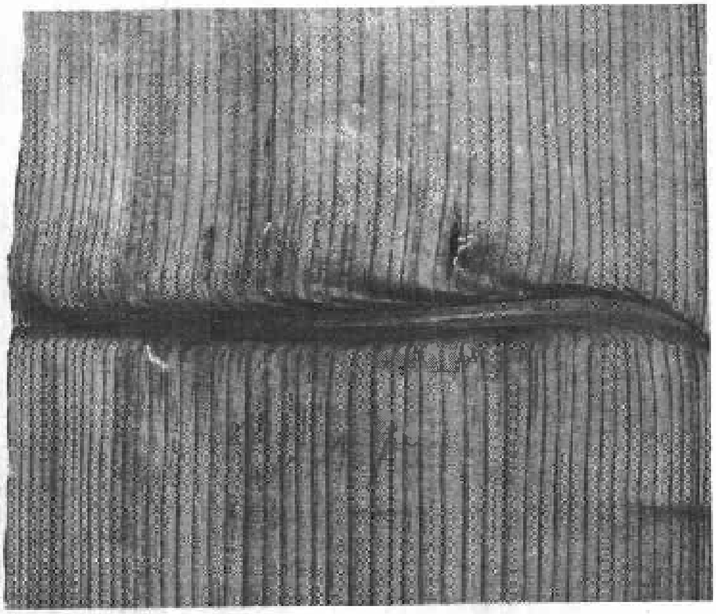

Figure 6.--Knot from a branch 0.4 inches in diameter that remained alive 11 years and persisted 40 years after dying.

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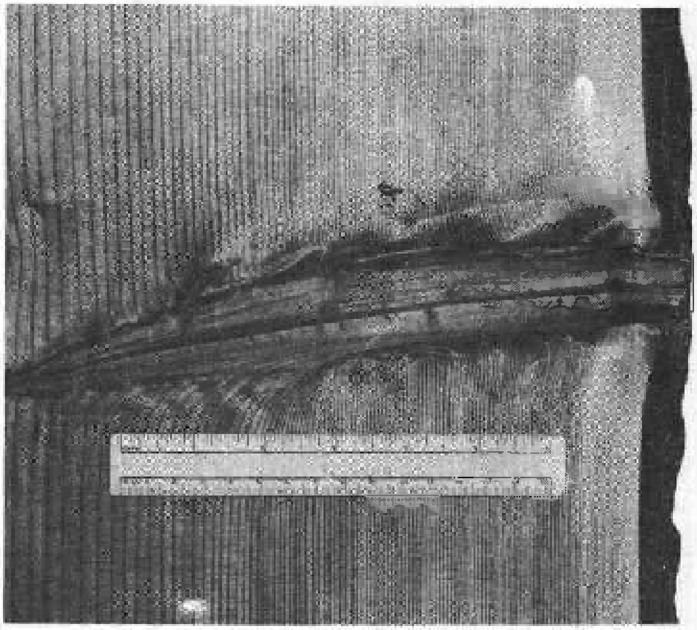

Figure 7.--Knot 1.2 inches in diameter from branch in 150-year, site IV stand, died at 25 years. Live length, 4.5 inches; dead length, 4.5 inches. Has persisted 115 years. Height in tree, 20 feet.

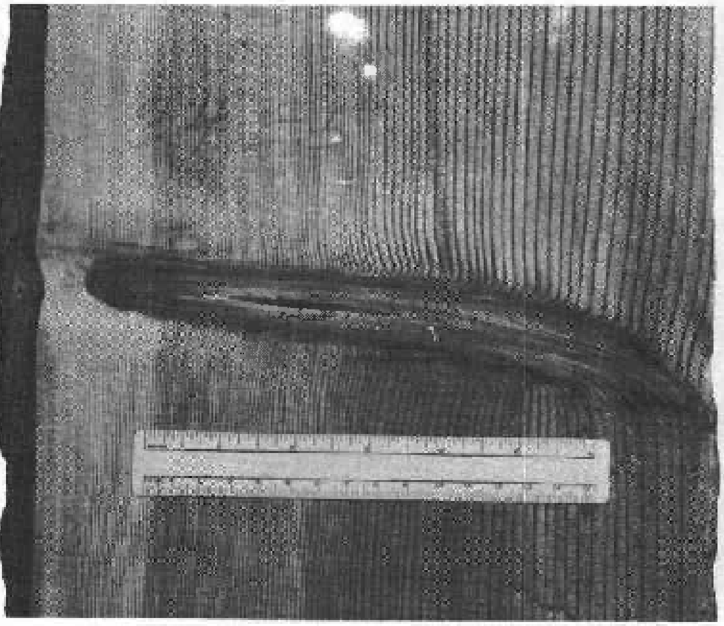

Figure 8.--Overgrown knot in 150-year stand died at 25 years, persisted 85 years, and has been overgrown 32 years. Height in tree, 20 feet. Live length, 3.9 inches; dead length, 4.4 inches; overgrown, 0.7 inches.

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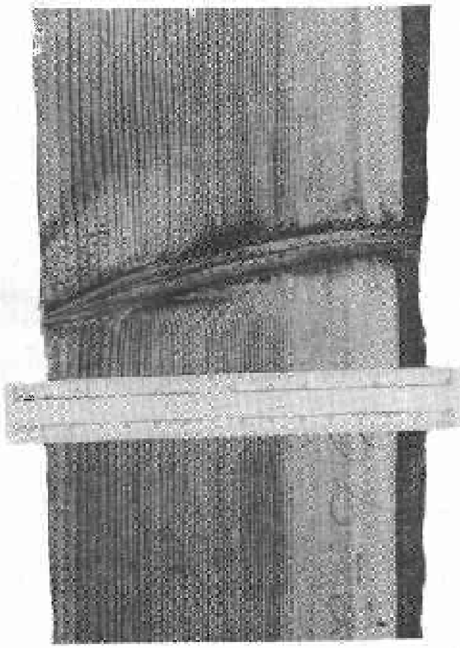

igure 9.--This knot, 1/2 inch in diameter, died at 19 years. It has persisted 118 years. The tree, of 13-inch diameter at breast height, in a 150-year stand, site IV, exhibits exceptionally slow growth as the result of overstocking.

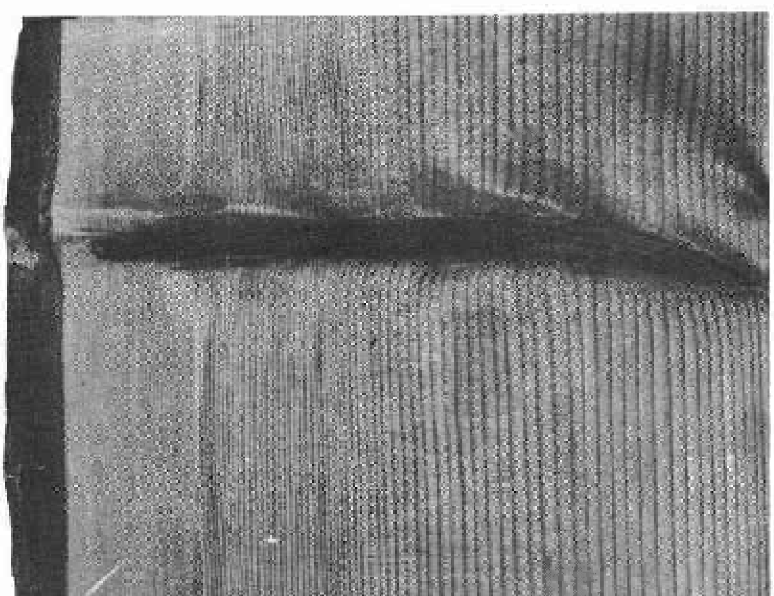

Figure 10.--Knot near the stump in 100-year stand, site II. Age of live portion, 15 years; dead portion, 72 years. Overgrown, 12 years. Live length, 2.8 inches; dead length, 6.2 inches; overgrown, 1/2 inch. Slow growth for last 50 years indicates close spacing of surrounding trees, and need of thinning.

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