BULLETIN OF THE
U.S. DEPARTMENT OF AGRICULTURE

No. 154

Contribution from the Forest Service, Henry S. Graves, Forester.
January 14, 1915.

THE LIFE HISTORY OF LODGEPOLE PINE IN THE ROCKY MOUNTAINS.

By D. T. Mason, *Assistant District Forester, District 1.*

GEOGRAPHIC DISTRIBUTION AND ALTITUDINAL RANGE.

Lodgepole pine (*Pinus contorta* Loudon) is one of the most widely distributed western conifers. Its botanical range, shown in figure 1, extends from the Yukon Territory southward through the Cascade, Sierra Nevada, and San Jacinto Mountains to northern Lower California, and through the main range of the Rocky Mountains to northern New Mexico. Its commercial range, however, is much more restricted. At present lodgepole is being lumbered extensively only in Montana, Wyoming, Colorado, and the Uinta Mountains in northeastern Utah. Large areas also occur in Idaho, Washington, Oregon, and California, but in these regions the tree is rendered less important commercially by the presence of other and more valuable timber trees.

The "lodgepole region"—that in which lodgepole is the preeminently important species—is mountainous, frequently interrupted by broad, open valleys, or plains, partly fertile and devoted to farming, and in part suitable only for grazing. The forests, as a rule, are confined to the mountains.

The altitudinal range of lodgepole pine in the Rocky Mountains decreases from south to north. In Colorado and southern Wyoming the tree is found at altitudes ranging from 7,000 feet to timber line, or 11,500 feet; in northern Wyoming at from 6,000 to 10,500 feet; and in southwestern and central Montana at from 4,500 to 9,000 feet. As a rule, however, it forms commercial stands only within an altitudinal belt from 2,000 to 2,500 feet in width. In Colorado the best stands are usually between 7,500 and 9,500 feet; in Wyoming between 7,000 and 9,000 feet; and in southwestern and central Montana between 6,000 and 8,500 feet. In the more humid northwestern portion of Montana, outside of the main lodgepole region, the species grows at an altitude as low as 1,800 feet, and occurs as a temporary type following fire with little regard to elevation.

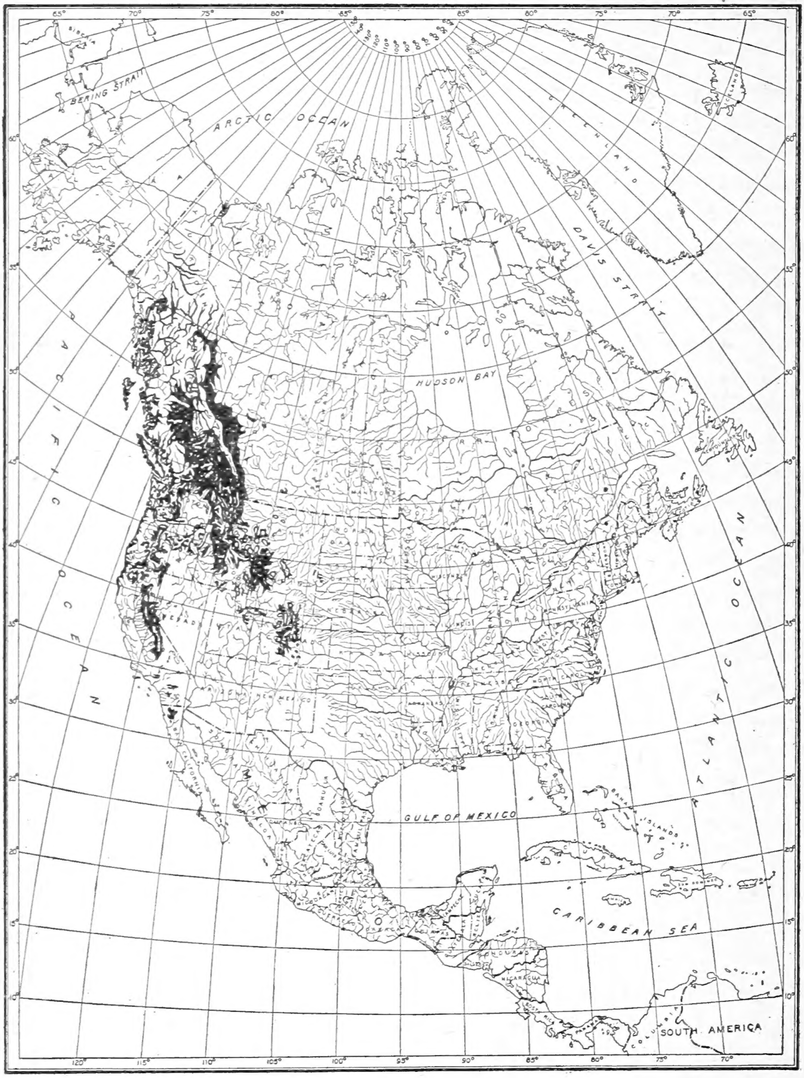

FIG. 1.—Botanical distribution of lodgepole pine.

SIZE, AGE, AND HABIT.

Lodgepole is one of the smallest of the commercially important pines. In well-developed stands approximately 140 years old, at which age the tree may be considered mature, most of the merchantable trees are from 8 to 14 inches in diameter breasthigh, and from 60 to 80 feet in height. However, trees up to 20 inches in diameter and 85 feet in height are common. The largest lodgepole of record in the Rocky Mountains is one on the Gunnison National Forest, Colo., which is 34 inches in diameter and 100 feet tall. On the Deerlodge National Forest in Montana is a tree 26 inches in diameter and 115 feet tall, containing six 16-foot logs and scaling approximately 1,000 board feet. Individuals over 30 inches in diameter have been found at other places in the lodgepole region. In California there are individuals much larger in diameter than any mentioned, but these are usually short and limby.

Lodgepole pine seldom attains a very great age because of fire and insect damage. Stands over 250 years old are uncommon, and stands over 300 years very rare. The oldest stand on record is one on the Beaverhead National Forest, Mont., which has attained an age of about 450 years.

As a forest tree lodgepole characteristically forms a straight, slim, gradually tapering trunk with a compact, conical crown. In very dense stands trees which have been crowded throughout life may have extremely narrow crowns with a spread of only 3 or 4 feet and occupying only from 10 to 20 per cent of the stem length. In such cases the crown is usually irregular, and often appears as a mere bush at the top of the tree. In stands of moderate density the crown is still characteristically narrow, though more regular, and occupies from one-half to one-third of the stem length. Even in open-grown stands the crown seldom spreads more than from 16 to 20 feet, but the branches often come down nearly to the ground and the taper is usually rapid.

CLIMATIC, SOIL, AND MOISTURE REQUIREMENTS.

The climate of the lodgepole region is comparatively dry. Table 1 gives the essential climatological facts, so far as they are available from United States Weather Bureau reports. It indicates roughly the precipitation requirements of the various forest types of the region, data being given for stations in open country below timber line, where there is too little moisture to permit natural tree growth, up through the various timber types to the area above timber line.

Lodgepole will probably grow only where the average annual precipitation is 18 inches or more. As a rule the best-developed stands occur where the precipitation exceeds 21 inches. It is not total precipitation alone, but the amount of available moisture in the soil, which determines the possibility of tree growth. This latter varies with the degree of slope, ground cover, and the permeability, kind, and depth of soil, and its degree of exposure to wind and sun. Air humidity also plays a part.

TABLE 1.—*Climate within the lodgepole region.*

[Compiled from United States Weather Bureau reports.]

Station.	Type of land or forest at station—timbered or open.	Approximate period on which averages are based.	Elevation.	Annual precipitation.			Annual temperature.		
				Mean.	Maximum.	Minimum.	Mean.	Maximum.	Minimum.
Colorado:		*Years.*	*Feet.*	*In.*	*In.*	*In.*	*Deg. F.*	*Deg. F.*	*Deg. F.*
Gunnison	Below timber line	21	7,670	9.48	13.45	6.86	37.0	96	−46
Moraine	Yellow pine	23	7,775	16.13	22.37	11.74	40.8	90	−32
Marble	Lodgepole	4	7,951	29.60	35.66	21.82	40.2	90	−29
Grand Lake	do	5	8,153	17.66	22.74	12.80	......	......	......
Georgetown	Yellow pine (cut over)	11	8,550	12.82	19.05	11.72	......	......	......
Longs Peak	Lodgepole	18	8,600	20.00	29.84	13.93	37.8	85	−31
Redcliffe	do	20	8,695	20.70	30.02	10.96	......	......	......
Columbine	Engelmann spruce	3	8,766	25.00	......	......	......	......	......
Frances	Lodgepole	8	9,300	25.89	33.72	21.65	40.6	86	−14
Breckinridge	do	24	9,536	23.90	46.41	14.22	33.7	90	−37
Spruce Lodge	Engelmann spruce	5	9,600	31.64	36.12	26.02	......	......	......
Leadville	Open	15	10,248	14.98	23.76	11.75	35.0	83	−27
Carona	Above timber line	6	11,660	45.87	58.32	35.90	26.2	67	−30
Wyoming:									
Centennial	Below timber line	10	8,074	18.59	27.68	5.14	38.8	40.2	−37.9
Woodrock[1]	Lodgepole	1	8,500	44.39	44.39	......	......	......	......
Dome Lake[2]	Alpine	2	8,821	34.78	......	......	30.7	......	......
Yellowstone National Park:									
Fort Yellowstone.	Juniper	9	6,200	16.93	20.35	13.31	38.3	40.2	−36.3
Tower Falls[3]	Douglas fir	3	6,250	16.27	19.29	13.63	35.6	39.3	−33.6
Riverside[3]	Lodgepole	4	6,500	19.58	23.85	14.38	35.3	36.8	−33.9
Sylvan Pass[3]	do	4	7,000	25.48	27.72	24.03	34.2	34.7	−33.7
Snake River[3]	do	4	7,000	27.79	33.77	21.32	34.6	36.2	−33.2
Fairview[3]	Douglas fir	6	7,000	16.11	18.83	11.51	34.9	37.0	−32.9
Fountain[3]	Lodgepole	3	7,220	17.90	19.07	15.88	33.2	35.8	−31.5
Geyser Basin[3]	do	4	7,395	21.23	22.69	19.33	34.4	36.2	−31.6
Norris[3]	do	3	7,500	19.23	22.62	17.13	33.4	35.8	−30.4
Lake Yellowstone.[3]	do	5	7,733	25.04	42.15	17.39	31.2	33.7	−29.4
Grand Canyon[3]	do	2	7,900	25.72	27.81	23.62	31.9	33.1	−30.7
Montana:									
Helena	Below timber line	33	4,110	13.42	19.94	6.71	43.3	103	−42
Livingston	do	14	4,488	14.36	19.96	10.68	45.8	106	−34
Bozeman	do	33	4,700	18.72	32.63	14.18	43.2	112	−53
Anaconda	Juniper	11	5,300	14.99	18.89	9.03	42.1	96	−33
Butte	Below timber line	18	5,716	13.80	20.55	6.95	42.1	94	−29
Pipestone Pass	Douglas fir	3	5,800	18.87	19.66	17.61	......	......	......
Bowen	Below timber line	6	6,060	13.75	18.56	10.10	32.7	90	−55
Fish Creek	Lodgepole	3	7,800	23.31	24.70	20.69	35.1	80	−22

[1] Probably reaches freezing every month; no temperature record.
[2] Likely to get freezing temperature any month.
[3] Freezing temperatures every month in year.

TABLE 1.—*Climate within the lodgepole region*—Continued.

Station.	Type of land or forest at station—timbered or open.	Approximate period on which averages are based.	Mean annual snowfall.	Killing frost.			
				Spring.		Fall.	
				Average latest.	Latest known.	Average earliest.	Earliest known.
		Years.	*Inches.*				
Colorado:							
Gunnison	Below timber line	21	46.5	July 10	([1])	Aug. 20	([1])
Moraine	Yellow pine	23	96.1	June 17	([1])	Aug. 18	([1])
Marble	Lodgepole	4	157.4	June 16	July 5	Aug. 26	Aug. 3
Grand Lake	....do	5	173.2	([2])	([2])	([2])	([2])
Georgetown	Yellow pine (cut over)	11	94.0	([2])	([2])	([2])	([2])
Longs Peak	Lodgepole	18	119.5	July 10	([1])	Aug. 28	([1])
Redcliffe	....do	20	205.4	([2])	([2])	([2])	([2])
Columbine	Engelmann spruce	3	211.5	([2])	([2])	([2])	([2])
Frances	Lodgepole	8	183.5	May 29	June 14	Sept. 10	Aug. 25
Breckinridge	....do	24	193.9	July 21	([1])	Aug. 9	([1])
Spruce Lodge	Engelmann spruce	5	270.7	([2])	([2])	([2])	([2])
Leadville	Open	15	134.9	June 15	June 21	Aug. 31	Aug. 3
Carona	Above timber line	6	346.5	July 18	([1])	Aug. 19	([1])
Wyoming:							
Centennial	Below timber line	10	134.8	June 23	July 9	Sept. 8	Aug. 25
Woodrock[3]	Lodgepole	1	321.1	([3])	([3])	([3])	([3])
Dome Lake[4]	Alpine	2	223.2				
Yellowstone National Park:							
Fort Yellowstone.	Juniper	9	96.7	May 14	June 3	Sept. 19	Aug. 25
Tower Falls[5]	Douglas fir	3	86.9				
Riverside[5]	Lodgepole	4	102.0				
Sylvan Pass[5]	....do	4	140.9				
Snake River[5]	....do	4	218.8				
Fairview[5]	Douglas fir	6	73.0				
Fountain[5]	Lodgepole	3	126.0				
Geyser Basin[5]	....do	4	156.8				
Norris[5]	....do	3	153.2				
Lake Yellowstone.[5]	....do	5	181.3				
Grand Canyon[5]	....do	2	158.5				
Montana:							
Helena	Below timber line	33	54.7	May 7	June 9	Sept. 28	Sept. 5
Livingston	....do	14	40.4	May 20	June 20	Sept. 17	Do.
Bozeman	....do	33	71.1	May 28	..do....	Sept. 7	Aug. 9
Anaconda	Juniper	11	40.6	June 17	July 8	Sept. 6	Aug. 14
Butte	Below timber line	18	55.2	June 5	June 26	Sept. 15	Sept. 5
Pipestone Pass	Douglas fir	3	101.3				
Bowen	Below timber line	6	70.1				
Fish Creek	Lodgepole	3	182.5				

[1] Midsummer.
[2] No data.
[3] Probably reaches freezing every month; no temperature record.
[4] Likely to get freezing temperature any month.
[5] Freezing temperatures every month in year.

In southwestern Montana lodgepole occurs at elevations as low as 4,500 feet on northern exposures, where there is the greatest atmospheric humidity and the least evaporation from the soil. South slopes at this elevation, if timbered at all, usually support only such species as juniper (*Juniperus scopulorum*) or Douglas fir (*Pseudotsuga taxifolia*), which require less soil moisture than lodgepole and are better constituted to resist transpiration. Lodgepole is found on southern exposures at about 6,000 feet, provided the gradient is less than 10 per cent. A steep south slope is generally too dry for the species.

At the upper limit of its range lodgepole gives way to other and more tolerant trees. Increase in soil and atmospheric moisture encourages such species as Engelmann spruce (*Picea engelmanni*) and

Alpine fir (*Abies lasicarpa*), while the relatively short growing season at high elevations does not furnish the total amount of heat which lodgepole needs for its growth. The range of the species is thus limited on one hand by lack of moisture and on the other by lack of heat.

Lodgepole occasionally endures for short periods extremes of temperature varying from approximately 100° F. to −55° F. The growing season of the region is short, since killing frosts are likely to occur until about the middle of June and the first autumn frost comes early in September. In the lodgepole zone frost and snow may occur at any time during the growing season.

May and June are the months of heaviest precipitation, but in the lodgepole zone much of this is in the form of snow, which usually covers the ground until late April or the middle of June, depending upon the elevation and aspect.

Too much soil moisture is unfavorable to lodgepole, and good drainage is essential. The tree will not stand a water content of more than 35 per cent in a loam soil and only about half as much in gravel or sand. The best water content is between 12 and 15 per cent, though in gravel it may even fall below 5 per cent without effect upon the tree beyond a decrease in its rate of growth.[1] In respect to their moisture requirements the different conifers of the region may be grouped as follows, those demanding the least moisture being placed first: Juniper, limber pine (*Pinus flexilis*), yellow pine (*Pinus ponderosa*), Douglas fir, lodgepole, white bark pine (*Pinus albicaulis*), Alpine fir, and Engelmann spruce.

Lodgepole is not exacting in its soil requirements, though it does best on deep, fresh, well-drained agricultural land. It is able to make good growth, however, on shallower, poorer soils, provided a reasonable amount of moisture is available. The typical soil of the lodgepole region is gravelly, with a considerable admixture of loam in valley bottoms and open benches, but with little or none on ridges and steep slopes. Unless lightened by a mixture of sand, gravel, or loam, clays are usually not well enough drained, while limestone soils are apt to be too dry to enable the tree to make a normal growth. In the Big Horn Mountains in Wyoming, for example, lodgepole is rarely found on the limestone soils, though granitic soils immediately adjoining show extensive areas of the lodgepole type.

LIGHT REQUIREMENTS.

In relation to light, lodgepole pine exhibits three striking characteristics—intolerance of any considerable degree of overhead shade; ability to survive for long periods in a badly crowded or suppressed condition in pure, even-aged stands; and ability to recover and make

[1] Forest Service Bulletin 79, The Life History of Lodgepole Burn Forests.

increased growth after being released from suppression. For its best development lodgepole requires considerable light from above. With full sunlight as standard, no vigorous seedlings were found in Colorado in light values of from 0.08 to 0.05. Since the light values in mature forests range from 0.12 to 0.05, with an average of 0.08 or 0.07, it is obvious that satisfactory reproduction can not be expected in such stands.[1] Seedlings often start under the partial shade of moderately open stands, particularly in restricted groups in small openings, but their growth and development is slower than in the open. Full sunlight will result in the best development at all ages, provided sufficient soil moisture is available. In the order of their tolerance the species of the lodgepole region may be grouped as follows: Alpine fir, Englemann spruce, Douglas fir, white bark pine, lodgepole pine, yellow pine, limber pine, juniper.

Although not as tolerant as most of its associates, lodgepole is truly remarkable for its ability to live for long periods in a badly-suppressed condition in the shade of larger trees of the same species. It is this characteristic which makes dense reproduction undesirable. The extremely dense stands which follow fire will remain dense indefinitely to the practically complete stagnation of growth. Some stands over 50 years old have more than 50,000 live trees per acre from 8 to 10 feet high. On Buffalo Creek on the Deerlodge National Forest, Mont., in a 70-year-old stand on a north slope, a count on 1 square rod in a fairly typical situation showed a density at a rate of 101,000 live trees per acre, together with 79,000 dead ones. (Pl. I, fig. 2.) The "trees," which could be pulled up like so many weeds, had an average diameter of about three-tenths inch at 1 inch above ground and a height of about 4 feet. The largest tree was 8 feet high and 1.5 inches in diameter. The wonderful persistence of the individual is shown by the loss of only 45 per cent in numbers after 70 years of crowding. This behavior of lodgepole, which is evident in Colorado and Wyoming, as well as in Montana, contrasts strongly with that of yellow pine, an area of which near Missoula, Mont., showed only 1,300 live trees per acre after 30 years in a stand which had originally numbered 3,500 trees per acre. Of the surviving trees, moreover, 310 completely dominated the rest.

In overdense stands of lodgepole the side branches are killed by shading for the better part of the distance up the bole. In moderately dense stands, however, natural pruning of the side branches is not extensive enough to result in the production of clean stems. It has been estimated that reproduction at the rate of about 8,000 seedlings per acre is necessary to secure a high degree of natural pruning. In a stand of 1,500 to 2,000 seedlings per acre, well distributed, the lower side branches will remain small and die at an early age. Many

[1] Forest Service Bulletin 79, History of Lodgepole Burn Forests, and Forest Service Bulletin 92, Light in Relation to Tree Growth.

of these dead branches will, of course, persist for years, but they will not be large enough to detract from the value of the timber for the purposes to which it is best suited. Even this moderate density would be undesirable, however, if the stand could not be thinned fairly early in its life—when from 40 to 60 years old. Trees which have come up in openings in stands grow more slowly than trees which start in full sunlight, but, on the other hand, develop small side branches on the lower stem and in the end produce better timber.

In a typical dense stand of merchantable lodgepoles there is usually a large number of suppressed trees from 2 to 6 inches in diameter. These are not younger than the larger trees in the stand, as might be supposed, but are generally of about the same age.

There is a general belief that lodgepole will not recover from suppression when openings are made in the stand. Recent investigations, however, prove that recovery does take place and often to a remarkable degree. The photograph of the cross section of lodgepole pine (Pl. II) shows the effect of a very heavy thinning in which the stand was well opened. This particular cross section was selected for photographing because the rings formed previous to the release are large enough to show, which is not the case in many badly suppressed trees.

Another tree studied was released from suppression 16 years ago, when 94 years old. Since then its diameter has increased from 1.44 inches to 5.06 inches and its height from 15 feet to 25 feet. The rate of growth has increased from 1 inch in diameter in 67 years to an inch in 4 years and from 1 foot in height in 7 years to 1 foot in 1.6 years. After its neighbors were removed the rate of diameter growth increased immediately, but for the first 8 years it grew in height only at the rate of 1 foot in 4 years. During the last 8 years, however, it has been growing in height uniformly at the rate of a foot a year. The rate of volume growth has increased 4,680 per cent.

Another tree which, at the age of 50 years, had a stump diameter of nine-tenths of an inch and a height of 5 feet, was opened to the light by a cutting made 43 years ago. After 43 years of sunlight the tree had grown to a diameter of 6.6 inches and a height of 27 feet. The volume of wood produced in the period of accelerated growth was about 25,600 per cent more than that produced during the period of suppression.

Even small seedlings which have been badly suppressed will respond vigorously when the stand is well opened. A seedling about 30 years old, three-tenths of an inch in diameter at the ground, and 2½ feet high, grew to a diameter of seven-tenths of an inch and a height of 6 feet in 5 years after its release.

Whether or not a tree will recover from suppression depends upon the condition of its crown at the time of release, the amount of light

FIG. 1.—DENSE LODGEPOLE REPRODUCTION.

This stand is the result of fire. It runs about 3,500 green trees per acre and is about 50 years old. Many of the larger trees are suitable for lagging. The stand should be thinned as soon as possible so that the better trees left may grow rapidly to stull size.

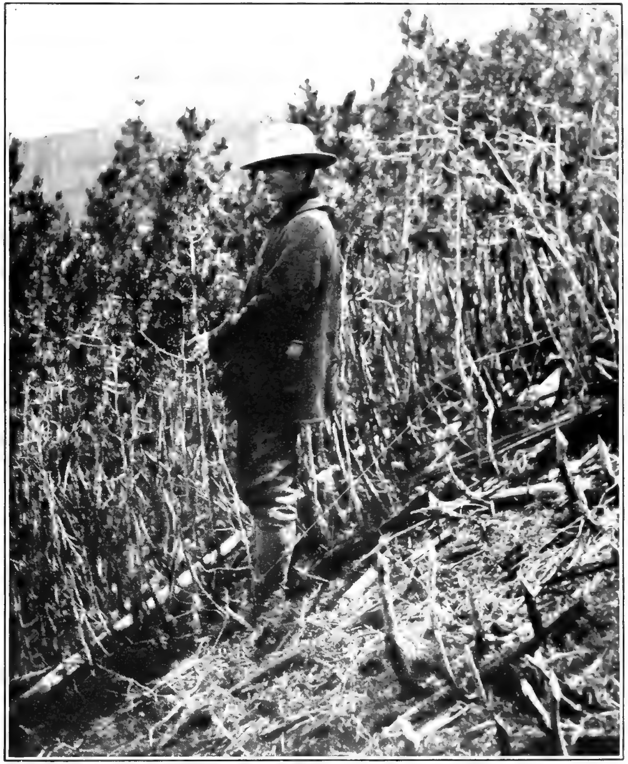

FIG. 2.—DENSE LODGEPOLE REPRODUCTION.

This 70-year-old stand, situated on a north slope, has approximately 101,000 green "trees" per acre, with resulting stagnation in the growth. The better trees bear cones. Note the débris from the previous stand only partially decayed after being dead 70 years.

EFFECT OF THINNING LODGEPOLE.

After its release this tree increased in diameter from 3.5 to 6.3 inches in 12 years. In the last 12 years the tree has been growing at the rate of an inch in diameter in 4 years, while in the previous 12 years it had been growing at the rate of an inch in 25 years. The tree has been growing 772 per cent faster in volume in the last 12 years than in the preceding 12 years. Note the thin bark.

admitted to the stand, and probably to some degree upon the tree's height. Tall trees with very poor crowns are often killed outright when exposed to full sunlight. The more thrifty and vigorous the crown and the shorter the tree, the surer the recovery. Trees which stand full light immediately show the greatest increase in growth. Observations made so far do not tend to show that the quality of the site has any effect upon recovery from suppression.

REPRODUCTION.

CONE AND SEED PRODUCTION.[1]

Lodgepole pine usually produces a fair crop of seed each year. Particularly abundant seed production may occur at two or three year intervals, but it is not yet possible to say whether there is any uniform periodicity in such years, as is often the case with yellow pine and Engelmann spruce. Open-grown trees produce seed at an earlier age and in larger quantities throughout life than do trees in dense stands. Seedlings in the open have been known to mature cones at the very early age of 5 years, while crowded trees in the forest may reach an age of 50 years without doing so. In somewhat open stands moderate seed production usually begins when the trees are from 15 to 20 years old. Careful tests show that seed from trees less than 10 years old have as high a germination per cent as seed from mature trees.

Typical lodgepole cones vary in diameter from 1 to 2.5 inches. The cones are generally larger on open-grown than on close-grown trees, and tend to increase in size with the age of the tree up to its maturity. They are nearly always flattened on the side oppressed to the parent branch. The extreme basal scales of the cone and from 3 to 6 scales at the tip do not bear any seeds, but the remainder of the scales, between base and tip, nearly always do. Seed-collecting operations on nine National Forests in Colorado and Wyoming show an average of about 26 seeds per cone. The number of cones per tree, and consequently the total seed production, varies greatly. Clements has estimated the average annual production of seed per tree in certain cases at from 21,000 to 50,000. Hence the total seed production of a stand may be enormous. Lodgepole is unquestionably a more prolific and regular seed producer than any of the species commonly associated with it.

SEED DISSEMINATION.

Lodgepole cones ripen in late August or September of their second year. It is a notable characteristic of the species, however, that the cones often fail to open and discharge the seed as soon as mature.

[1] Detailed results of an investigation on this subject made by F. E. Clements in Colorado are given in Forest Service Bulletin 79.

Sealed cones as old as 75 and 80 years have been found attached to the parent tree. Sometimes the lower part, or even the entire cone, is embedded in the wood. Closed cones are more common on old than on young trees, and on trees growing in dense stands than on those in the open. MacDonald found on the Targhee Forest that on trees less than 55 years old five-sixths of the cones opened at maturity, while on trees over 55 years old only one-fourth of the cones opened. Seeds retain their vitality for many years in sealed cones, and in one case had a germination per cent as high as 8 after being locked up for about 75 years.

Clements states that cones open normally as a result of the drying out of the cone scales rather than from the action of heat alone. The majority of cones capable of opening normally probably do so within a short time after maturity, and scatter their seeds while still attached to the tree. Some cones, however, after remaining upon the tree closed or only partly open for a number of years finally fall to the ground with more or less seed still in them.

There appear to be two distinct periods of general opening, the first in the years immediately following maturity and the second from 10 to 13 years later. The opening during the second period is probably due to the fact that the pedicel of the cone breaks about this time and the cone no longer receives moisture from the tree. The size of the cone appears to have no effect upon the time when it opens.

Tower[1] states that the amount of lime in the soil has a strong influence upon the time when the cones open; that on soils rich in silica and deficient in lime the majority of cones open at maturity, while on soils rich in lime they remain closed and persist on the trees for many years. Observations by other investigators in Colorado and Montana, however, indicate that this tendency is not sufficiently marked to constitute a rule. Individual trees in the same stand show the most extreme differences in cone opening; one tree may have all of its cones open, while beside it another tree of the same age may have all of its cones closed; and in most cases both open and closed cones are found on the same tree. Probably the differences in behavior in this respect observed by Tower indicate merely the general tendency of cones to open less promptly on dry soils. This tendency is also indicated by the fact that fewer cones remain closed on the moister soils and in the moister climates of northwestern Montana, northern Idaho, and the Sierras in California.

The opening of the cone frees the small, winged seeds, which are distributed mainly by the wind. Other agents of seed distribution are gravity, surface drainage and streams, and such animals as squirrels and mice. The distance to which wind distribution is effec-

[1] A Study of the Reproductive Characteristics of Lodgepole Pine, by G. E. Tower, in Vol. IV, No. 1, of the Proceedings of the Society of American Foresters.

tive is very apt to be overestimated. One reason for this is that natural reproduction has often been credited to wind-sown seed, when in reality the seed was already present on the area in sealed cones. Hodson,[1] as the result of a study on a large number of cut-over areas in Montana and Wyoming, concludes that "the largest amount of seed falls within a hundred feet of the seed tree, and the radius of effective reproduction is much less than is commonly supposed." Clements states that the distance to which seed is carried by the wind "was never found to exceed 164 feet." Undoubtedly the distances seeds are carried varies considerably with the topography and the situation of the seed trees. Trees on a ridge exposed to high winds will distribute seed the maximum distance. Until more definite information is available, it is safe to assume that wind distribution should not be relied upon for distances of more than 150 to 250 feet, according to the character of the situation.

REQUIREMENTS FOR NATURAL REPRODUCTION.

Owing to its intolerance of overhead shade, lodgepole pine will not reproduce satisfactorily without considerable direct light. Although the seed will germinate with a vary small amount of light, the young seedling soon dies without it. In mature stands a heavy thinning which reduces the crown density to about one-half is usually necessary to permit a fair amount of reproduction to start and thrive. Where the stand is opened by the removal of groups of trees on areas of 3 or 4 square rods or more, reproduction will usually start and grow well in the openings. Reproduction starting in this manner is more apt to be uneven aged and better divided into height classes, and consequently in less danger of stagnation, than in the dense, even aged stands of uniform height which so often follow fire. Vigorous young growth has been observed under stands in which a heavy and uniform thinning had been made, causing the forest to resemble one undergoing regeneration by the shelterwood method. In stands of only moderate density, however, seedlings are apt to be spindling and slow of growth.

The most favorable seed bed for germination of lodgepole pine seed is a mineral soil with plenty of available heat and moisture. Needles and undecayed humus are apt to dry out rapidly in the spring, before the rootlets of most of the seedlings can reach the mineral soil. That mineral soil is not always necessary for germination, however, is shown by the fact that on old cuttings in Montana where there has been no fire, seedlings apparently start indiscriminately on patches of mineral soil and in small clumps of pine grass

[1] Silvical Notes on Lodgepole Pine, by E. R. Hodson, in Vol. III, No. 1, of the Proceedings of the Society of American Foresters.

(*Calemagrostis rubescens*), the latter usually not more than 8 or 10 inches high. Furthermore, in full sunlight even mineral soil may dry out so rapidly that many of the seedlings will be killed by drought. For this reason young stands are usually more dense on mineral soil lightly shaded by recently fire-killed trees than in the open. On the other hand, they are likely to be more open on sandy soil than on soils better able to retain moisture. The densest seedling stands are apt to occur on north slopes where there is a relatively small amount of direct sunlight and a large amount of moisture.

Competition with other native vegetation, such as blueberry (*Vaccinium*) and kinnikinnic (*Arctostaphylos*), for light and soil moisture often greatly reduces the amount of lodgepole reproduction; and the seedlings which do start have a much slower growth than where there is no competition. Aspen also is a hindrance to lodgepole, through its more rapid growth when young, wherever the two start on the same area. A light, overhead aspen cover, on the other hand, may be beneficial by protecting the soil.

Rodents reduce the seed supply to a certain extent, but there is probably always enough seed left for satisfactory reproduction if other conditions are favorable.

OPTIMUM DENSITY.

The right density for a stand of lodgepole is that at which the lower branches become suppressed and die while still small, but without overcrowding of the trees and consequent decrease in rate of growth. Hodson concluded that an original density of 8,000 seedlings per acre is required to produce clean stems at maturity. Later investigations show, however, that while this number of seedlings would secure good natural pruning, it would be at a great sacrifice in diameter growth. In the reconnaissance work on the Deerlodge Forest a "normal" seedling stand is considered one of about 1,000 trees per acre, fairly well spaced and of fairly even height growth. By "normal" is meant that degree and character of stocking which will produce the maximum yield of merchantable timber of the desired sizes at the end of the rotation. Stands containing too few, or too many, unevenly distributed trees, are abnormal to the extent to which they will fail to produce this maximum yield. Normality is thus seen to differ materially from "density," which refers to the extent to which the crown space is fully utilized. Stands with a density of 1.0 are nearly always too crowded for the most satisfactory development.

The number of trees constituting a normal stand naturally decreases with the age of the stand. While 1,000 trees per acre, evenly spaced, is a satisfactory stocking when reproduction first starts, this

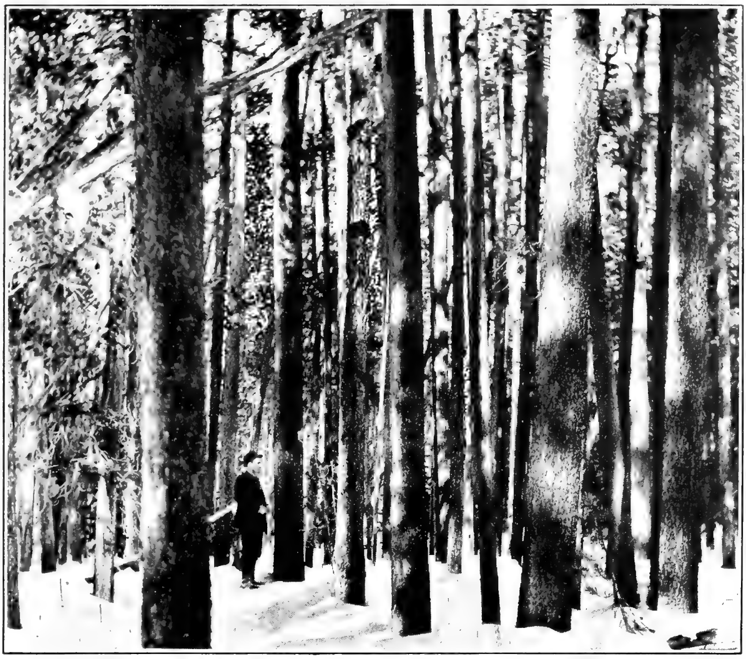

FIG. 1.—LODGEPOLE TIMBER.

Heavy stand of overmature stull timber about 200 years old, Deerlodge National Forest.

FIG. 2.—WELL-DEVELOPED YOUNG LODGEPOLE.

This stand is 60 years of age and now has about 250 trees per acre. The thinning was made 18 years ago, which removed about 250 trees per acre, although at that time the density was about normal. The stand now has 3,200 board feet per acre.

FIG. 1.—LODGEPOLE REPRODUCTION.

In the center of the picture is a 20-year-old stand of lodgepole on an old cutting. No fire has been over the area. The white streaks mark the location of the original windrows of brush only partly decayed.

FIG. 2.—LODGEPOLE REPRODUCTION.

Well-distributed seedlings coming up without fire on a cutting made 10 years ago. The stand is about 500 per acre, a density nearly ideal.

should be reduced to about 500 at the end of 30 years, to about 300 at the end of 90 years, and to about 250 by the one hundred and fortieth year, when the stand may be considered mature. Unfortunately, owing to the low mortality rate of lodgepole pine, a stand of 1,000 evenly distributed seedlings 10 years old will not, by natural means, be reduced to 500 at 30 years, 300 at 90 years, and 250 at 140 years. Ordinarily this could be brought about only by thinning. If, however, the stand is sufficiently open to arrive at maturity with 250 stems per acre without thinning, decidedly limby trees will be the result. On the other hand, a stand of 1,000 well-spaced seedlings 10 years old, at which age a stand may be considered as established, probably will have about half that number of trees at maturity. In such a case those of fairly good form and diameter may be cut and the others left to grow for an additional period. Seedling stands of from 300 to 500 plants per acre are preferable to those of 8,000 or more, even when thinning is possible, since for many years the latter will not produce material which can be taken out with profit in the course of thinning. Thinnings, moreover, will probably be impracticable, except in a few localities, and for this reason from 300 to 500 seedlings may generally be considered preferable to 2,000 or more. A good volume of limby timber is better than a large number of poles; besides, the spaces in an open stand will gradually fill in with individuals of a more satisfactory form. Where thinnings are practicable a density of about 2,000 plants at the start is best. Plate III, figure 2, shows a well-developed 60-year-old stand of lodgepole of something less than normal density.

It should be borne in mind that the figures for density given in the preceding paragraph are more or less arbitrary, and in determining the normality of a stand as much attention should be given to the spacing and height growth as to the number of stems. A relatively large number of trees per acre is not undesirable, provided there is enough variation in the height of individual trees to prevent stagnation of growth.

The production of clean stems is of comparatively little importance, since lodgepole is used mainly for mine timbers and railway ties, and in the future is not likely to have additional uses other than for telephone poles, pulp, and common lumber. Of far greater importance than clean stems are rapid growth and the production of large-sized timber. Lodgepole is slow-growing, and there is always an abundance of trees of small size. Ordinarily there is far greater danger of overstocking than of understocking. Observations on 40,585 acres of young growth on the Deerlodge National Forest show 78.7 per cent of the entire area to be overstocked, 20.5 per cent understocked, and only 0.8 per cent normally stocked.

EFFECT OF FIRE.

Fire has been one of the most important agencies in the reproduction of lodgepole pine. Its effect is fourfold: (1) By softening the resin and drying out the cone scales it opens the sealed cones and makes available the accumulated seed production of many years; (2) by reducing the density of the ground cover it admits plenty of light; (3) by exposing the mineral soil and removing the ground cover it prepares a favorable seedbed; (4) by killing and driving away for a time the rodents and birds it saves the seed from being eaten. Thus aided by fire, lodgepole has been able to replace to a considerable extent all the species within its range, since these usually produce seed in abundance only once in several years and discharge it immediately. Most of the extensive lodgepole stands now in existence have come in as a result of fire. On the other hand, areas formerly covered with lodgepole have been made barren by "double burns," where stands of young growth which followed the first fire have been destroyed by a second one before they were old enough to produce seed. Areas of this kind on which all of the trees have been killed will not reforest naturally for many years, since the only way reproduction can take place is by seeding from the sides.

Fire in a mature stand is usually followed by too dense a reproduction to permit the most satisfactory development of the young trees. Sample plots on the Gallatin National Forest, Mont., show reproduction after the fires of 1910 with a maximum density of about 300,000 one-year-old sedlings per acre. On the Deerlodge National Forest stands following fire have been found which, at the age of 8 years, had a maximum density of about 175,000 live seedlings per acre, averaging about 2 feet high. Ten small sample plots on the Arapaho National Forest, Colo., in a 22-year-old stand, showed an average of nearly 44,000 trees per acre. These figures, of course, represent maximum densities on small areas, but as extreme illustrations they show that severe overstocking is more than likely to follow fire.

The effect of fire on cut-over areas may be very different. Where all the trees have been felled and the brush piled in windrows—a practice in many private operations—a fire in the slash may be followed by reproduction of moderate density. Such a fire usually destroys all the seeds in the windrows, the locations of which are marked by the absence of reproduction, while a moderately dense stand starts in the intervening spaces from cones which did not get into the windrows and thus escaped destruction.

On unburned, cut-over areas reproduction is apt to be much less dense, and therefore more satisfactory than in the case of burned-over uncut stands. Throughout the Rocky Mountains are thousands of acres of old cuttings, untouched by fire, upon which the reproduction is decidedly satisfactory. This is especially true of the Deerlodge Forest, near Butte, Mont., where it is unusual to find an old cutting on which reproduction is not taking place. Observations on 32 separate tracts in the 20 and 30 year age classes on this Forest show a far more satisfactory reproduction on unburned cut-over areas than where stands have been killed by fire. On many clean-cut areas which have been left practically without seed trees reproduction has taken place solely from cones which remained on the ground after logging. Nearly all mature trees bear a considerable number of persistent, closed cones, some of which fall on the ground when the tree is cut, while others remain attached to the branches. These gradually open and drop their seed, resulting in fairly uniform reproduction if the brush is scattered. If it is piled in windrows, which decay very slowly, the spaces so occupied will not reproduce. (Plate IV, fig. 1.) Where the stand is not cut clean, or where clean-cut only over small areas, seed comes from above or from the side, as well as from the cones left on the ground and in the tops of felled trees. Sample plots in an unburned stand on the Arapaho National Forest, measured six years after the removal of about one-half of the original trees for ties, showed an average of 6,000 seedlings per acre, of which 3,500 had started since the cutting. Even with the same number of seedlings per acre reproduction is apt to be more satisfactory on an unburned than on a burned area, since the young growth comes in more gradually, giving trees of different heights and so materially lessening the danger of stagnation.

The greater part of the reproduction which comes in after either fire or cutting usually starts within a comparatively short time. The following figures, which represent averages obtained from 181 small sample plots, both burned and unburned, in Montana and Wyoming, show the proportion of reproduction which came in during each 5-year period for the first 30 years after the stand was opened up:

	Per cent.
First five years	69.5
Second five years	21.0
Third five years	5.4
Fourth five years	.9
Fifth five years	2.5
Sixth five years	.7
	100.0

It will be seen that nearly 70 per cent of the reproduction started in the first 5 years and over 90 per cent in the first 10 years. Unfortunately, it is not possible to separate the figures for burned and unburned plots. Similar observations on a 9-year-old burn on the Arapaho National Forest showed over 49 per cent of the reproduction to have started in the first four years and nearly 75 per cent in the first six years after the fire. In most places the character of the seedbed is so changed in the 10 years following a cutting or fire by the formation of a thick sod of grass that comparatively few seedlings are able to gain a foothold after that time.

GROWTH.

The rate of growth of lodgepole varies greatly with the quality of the site and the density of the stand. Other conditions being the same, the most rapid growth takes place on the best sites, but overstocking often reduces the rate of growth in such situations to a point at which it is considerably less than in more normally stocked stands on poorer sites. The effect upon growth of the density of the stand is discussed under "Factors influencing yield."

On account of the wide variation in lodgepole's rate of growth, it is impossible to give figures which will be universally applicable. Table 2 shows what may be expected under certain conditions. The data were obtained from 468 average trees cut by the arbitrary group method in the course of a yield study on the Deerlodge Forest, conducted in fully stocked stands on sites better than the average for that Forest. Since the stands were approximately fully stocked, and in some cases overstocked, the diameter growth shown is somewhat less than that which may be expected in the case of trees growing in stands of moderate density. On the other hand, since the sites were better than the average, the height growth shown is somewhat above the average.

TABLE 2.—*Average growth of lodgepole pine in fully stocked stands on the Deerlodge National Forest, Montana, on slightly better than average sites, based on 468 average trees, of which 158 were dominant.*

Age in years.	Diameter breast high.		Height.		Volume.			
	Average trees.	Dominant trees.	Average trees.	Dominant trees.	Average trees.	Dominant trees.	Average trees.	Dominant trees.
	Inches.	*Inches.*	*Feet.*	*Feet.*	*Board feet.*[1]	*Board feet.*[1]	*Cubic feet.*[2]	*Cubic feet.*[2]
10	0.4	0.5	3	4				
20	1.2	1.9	10	12				
30	2.1	3.2	19	20			0.5	1.0
40	3.0	4.4	27	32			.9	2.5
50	3.8	5.6	33	38			1.5	3.9
60	4.5	6.6	38	44		5	2.1	5.5
70	5.2	7.4	42	49		20	3.0	7.4
80	5.8	8.2	47	54		35	4.1	9.5
90	6.4	8.9	51	58	5	45	6.2	12.2
100	6.9	9.5	54	62	20	60	8.6	15.3
110	7.4	10.1	58	66	30	75	10.0	18.5
120	7.9	10.7	61	70	40	90	11.4	23.0
130	8.3	11.2	65	73	50	105	13.5	26.0
140	8.7	11.8	68	76	60	120	15.5	30.0
150	9.2	12.3	71	79	70	135	18.0	34.5
160	9.6	12.8	74	81.5	80	150	20.0	39.0
170	10.0	13.3	77	84	90	170	22.0	44.0
180	10.4	13.8	80	86.5	100	190	24.2	49.0
190	10.8	14.3	83	89	110	215	26.5	54.0
200	11.2	14.7	85	91.5	125	240	30.0	60.0

[1] The board foot volume is based on a minimum log of 6-inch top diameter and 16-foot length, scaled by the Scribner Decimal C rule.

[2] The cubic foot volume includes only the usable portion of the trunk from above the stump, usually from 6 to 10 inches high, to a diameter of 3 inches in the top.

This table shows how comparatively slow is the growth of lodgepole pine. One of the most striking points brought out, however, is the relatively rapid growth of the dominant trees, particularly in volume, amounting to approximately twice that of the average tree. This indicates clearly the need for sufficient growing space if the maximum development of individual trees is to be secured.

Measurements which would permit of comparison between the rate of growth in Wyoming and Colorado with that in Montana are not available. Table 3, however, shows the diameter growth by decades on two widely separated Forests in Wyoming, the Medicine Bow and the Bighorn. In both cases the growth is typical of the average sites on which the bulk of the lodgepole forests of the region are found. Since in this case the measurements were collected by following the sawyers through the woods, the data secured represent the growth of trees of more than the average diameter, since only the larger timber was cut. Also, the stand on the Medicine Bow was probably denser than on the Bighorn, which accounts for the slower rate of growth upon the former. On similar sites, and with the same stand density, the rate of growth for the two Forests would probably be about the same.

TABLE 3.—*Average diameter growth of lodgepole pine on average sites on the Bighorn and Medicine Bow National Forests, Wyo.*[1]

Age in years.	Bighorn National Forest.[2]	Medicine Bow Forest.[3]	Age in years.	Bighorn National Forest.[2]	Medicine Bow Forest.[3]
	Diameter breast high.	Diameter breast high.		Diameter breast high.	Diameter breast high.
	Inches.	*Inches.*		*Inches.*	*Inches.*
20	1.5	0.3	120	10.7	7.7
30	3.0	1.6	130	11.1	8.2
40	4.4	2.8	140	11.6	8.6
50	5.7	3.7	150	12.1	9.1
60	6.7	4.4	160	12.5	9.6
70	7.6	5.0	170	12.8	10.0
80	8.4	5.6	180	13.2	10.4
90	9.1	6.2	190	13.5	10.8
100	9.7	6.7	200	13.8	11.1
110	10.3	7.2			

[1] From Forest Service Circular 126, "Forest Tables: Lodgepole Pine."
[2] Based on decade measurements on 49 stumps of various heights, 72 to 340 years old.
[3] Based on decade measurements on 430 1-foot stumps, 159 to 300 years old.

The growth in height of young seedlings in Montana and Colorado is shown in Table 4. Figures for Montana are based on measurements of 86 trees on the Deerlodge National Forest made to determine the average age required to reach various stump heights; figures for Colorado are the results of measurements of reproduction on a burned area on the Arapaho National Forest. In the white-pine region of Northern Idaho lodgepole makes a more rapid height growth in the seedling stage than does any other species, with the possible exception of larch. Lodgepole seedlings from 5 to 7 years old with leaders 36 inches long have been noted. In one case a young tree, about 8 years old, had made a height growth of 7½ feet in the last 3 years. Another young tree of about the same age had a 45-inch leader.

TABLE 4.—*Average height growth of lodgepole pine seedlings on the Deerlodge National Forest, Mont., and the Arapaho National Forest, Colo.*

Age in years.	Height.		Age in years.	Height.	
	Deerlodge National Forest.	Arapaho National Forest.		Deerlodge National Forest.	Arapaho National Forest.
	Feet.	*Feet.*		*Feet.*	*Feet.*
1		0.1	5	0.8	1.4
2		.2	6	1.0	1.9
3	0.4	.4	10		4.5
4	.6	.9	15		7.9

The growth figures so far given all apply to unthinned stands. If it were possible to make thinnings when needed that would favor the best trees, the growth of the latter would undoubtedly equal, or even considerably exceed, that shown for the dominant trees shown in Table 2. Such intensive management, however, could be undertaken only in a few favored localities where the market is unusually good. Lodgepole pine stands have been thinned in the past only in the course of ordinary lumbering, which has usually left the smaller, poorly developed trees, many of which could take no advantage of the operation. That even trees of this character often respond to such haphazard thinning with a remarkable increase in rate of growth has already been stated. Out of 91 average trees measured on the Deerlodge Forest, representing those which remained when the surrounding stand was cut, 54 trees, or 59 per cent of the total number, showed a marked increase in growth, while the remainder, or 41 per cent, showed no increase. Differences in rate of growth before and after cutting are shown in Table 5.

TABLE 5.—*Effect of thinning; average diameter growth of lodgepole pine trees left after cutting, Deerlodge National Forest, Mont.*

PART I. [Based on 91 trees, irrespective of whether they showed increased growth or not.]

Diameter breast high.	Trees.	Periodic annual diameter growth for 20 years.		Time required to grow 1 inch in diameter.	
		Before thinning.	After thinning.	Before thinning.	After thinning.
Inches.	*Number.*	*Inch.*	*Inch.*	*Years.*	*Years.*
3	8	0.028	0.034	36	29
4	10	.031	.042	32	24
5	15	.037	.039	27	25
6	17	.051	.041	20	24
7	17	.047	.057	21	18
8	15	.059	.064	17	15
9	6	.050	.046	20	21
10	3	.058	.054	17	18

TABLE 5.—*Effect of thinning; average diameter growth of lodgepole pine trees left after cutting, etc.*—Continued.

PART II. [Based on the 54 trees which showed an increased growth.

Diameter breast high.	Trees.	Periodic annual diameter growth for 20 years.		Time required to grow 1 inch in diameter.		Rate of increase in volume growth after thinning.
		Before thinning.	After thinning.	Before thinning.	After thinning.	
Inches.	*Number.*	*Inch.*	*Inch.*	*Years.*	*Years.*	*Per cent.*
3	5	0.029	0.045	34	22	140
4	6	.030	.050	33	20	169
5	7	.023	.049	43	20	127
6	8	.029	.039	34	25	59
7	13	.038	.061	26	16	112
8	9	.047	.072	21	14	98
9	4	.027	.042	37	24	70
10	2	.022	.047	45	21	125

CAUSES OF INJURY.

FIRE.

Fire has been the most important agent in the destruction of lodgepole pine forests, as well as in their establishment. Though in some places it has enabled lodgepole to take possession of the ground, in others repeated fires have practically eliminated forest growth. Lodgepole pine is less susceptible to fire than Engelmann spruce and Alpine fir, but more susceptible than the other pines with which it grows or Douglas fir. Its susceptibility is due chiefly to its thin bark, which at stump height is only from two-tenths to four-tenths of an inch thick. Fire is most destructive in dense young stands of "jack pine," as the young trees are often called. Crown fires are infrequent, but may occur with high winds or when a large amount of débris litters the ground. When a lodgepole stand is killed by fire a period of from 15 to 30 years elapses before the dead trees fall to the ground. Fire-killed timber does not completely decay until from 60 to 120 years after the fire. Such débris, of course, greatly increases the fire danger in a new stand.

In comparatively open stands which have reached maturity without being burned over there is usually not much débris on the ground and consequently less danger of crown fires. Even here, however, there is in most cases a ground cover of grasses, weeds, needles, and similar litter to invite surface fires, which destroy reproduction, occasionally kill mature trees, and seriously injure the butts and lessen the vitality of many others. These ground fires, too, by destroying the organic content of the soil, reduce both its water-holding power and its productive capacity, which necessarily results in decreased growth of the surviving trees.

INSECTS.

Although lodgepole pine in the Rocky Mountains has not suffered severely from insect attack in recent years, bark beetles have undoubtedly killed more mature timber than has any other agency except fire. In Montana the mountain pine beetle (*Dendroctonus monticolae* Hopk.) has done some damage in the vicinity of Swan Lake on the Flathead National Forest, and in 1911 an aggressive attack by this beetle in the Big Hole Basin on the Deerlodge and Beaver Head Forests developed serious proportions.[1] In that year approximately 15,000 trees were killed on an area of about 1,500 acres. On some portions of the area practically all the trees over 5 inches in diameter were either killed or badly infested, while on the remainder of the area the attack was confined to the larger and less vigorous trees. The attack appeared to radiate from several centers where the damage was particularly severe. It appears likely that this infestation resulted largely from injury to the trees by adverse weather conditions during the winter of 1908–9, the insects taking advantage of the trees' weakened condition. The unusually dry summer of 1910 was also thought to have favored the attack. Fortunately many of the insects were destroyed during the winter of 1911–12, apparently by winter killing, to which the thin bark of lodgepole renders them liable.

In regions other than the one considered in this bulletin, damage by the mountain pine beetle has been very severe. On the Wallowa and Whitman National Forests in eastern Oregon it has recently killed 100,000,000 board feet of lodgepole. Here the infested area, which in 1906 covered only about a section, had by 1912 grown to approximately 320,000 acres, and the beetle was then extending its attack to yellow pine.

The presence of the mountain pine bark beetle is first made evident by pitch tubes, boring dust, and woodpecker work. Most of the adult beetles emerge during August, and by early fall are well established in their new hosts. The trees thus attacked usually remain green until the following spring, when their tops first turn a yellowish and then a reddish color. By the time the red-top condition is reached practically all the beetles have left the tree. The species apparently prefers to attack injured and felled trees; the more vigorous, and particularly the younger trees, are often able to drown the beetles in exudations of pitch. Thrifty trees, however, are sometimes killed.

In Wyoming and Colorado the most common insect enemy of lodgepole pine is the lodgepole pine beetle (*Dendroctonus murrayanae*

[1] For a complete description of this and other bark beetles of the genus Dendroctonus, together with methods of control, see Bureau of Entomology Bulletin 83, Part I, by Dr. A. D. Hopkins.

Hopk.). A few trees apparently killed by its attack have been found on the Medicine Bow and Bighorn National Forests in Wyoming, and on the Arapaho Forest in Colorado. The attack was confined mainly to the bases of the trees and to unhealthy individuals. The Oregon tomicus was also found, but it is probable that the dendroctonus made the first attack. A weevil similar to the eastern white pine weevil (*Pissodes strobi*) has also been found on the Arapaho National Forest. This insect destroys the terminal shoot, resulting in crooked and forked trees.

FUNGI AND MISTLETOE.

Lodgepole has, on the whole, suffered comparatively little damage from fungi. This is due chiefly to the dry climate of its range and to the fires which have renewed the stands from time to time, thus preventing any extensive development of the fungous diseases. Often badly fire-scarred trees may remain sound as long as 40 or 50 years, except for a small amount of blue stain along the edges of the scar. One of the two most common diseases of lodgepole is that caused by the ring scale fungus (*Trametes pini*), often called by woodsmen "white rot" or "red rot." Another common disease is caused by the fungus *Polyporus schweinitzii*. The ring scale fungus attacks chiefly the older trees, which it may enter at almost any point where a dead limb or wound affords an opening. From the point of infection it sometimes extends throughout the trunk. The wood at first turns a dark reddish brown, the trees at this stage being known to lumbermen as "red rot" or "red heart" timber. Later the color of the wood becomes lighter and small white spots and strands appear, increasing in size and number until the entire heartwood is filled with small holes lined with the thin, white cellulose of the wood which has not been used as food by the fungus. The wood never rots entirely away, but eventually becomes a mass of soft, spongy tissue.

The fungus *Polyporus schweinitzii* usually causes a heart rot at the butt. Since it is confined to the first or second logs it is less destructive than the ring scale fungus. When the roots are infected the tree may fall; in other cases it may break off close to the ground before the rot has had time to spread far into the trunk. The affected wood turns a light yellow and gradually dries out so that numerous fissures appear.

In overmature lodgepole stands from 7 to 10 per cent, or on limited areas even 15 to 20 per cent, of the timber may be affected by one or both of these fungi to an extent rendering it unmerchantable. It is seldom, however, that an entire tree is made worthless by rot, and one or more sound logs or ties can usually be obtained. The blue stain, which may appear almost immediately in the sapwood of fire-killed or insect-killed trees, does not render them unfit for use.

In some localities a rust (*Peridermium montanum*) attacks the leaves of lodgepole, causing them to fall prematurely. Another rust (*Peridermium harknessii*) attacks lodgepole in western Montana, causing galls to form on the trunk and branches, which stunts and sometimes kills the tree.

One of the false mistletoes (*Razoumfskya americana*) is often found on lodgepole, but does little serious damage except in certain localities, where it may greatly affect the growth of the tree. It usually attacks young stands, and in dense ones most of the trees may be infested. Mistletoe causes an abnormal growth at the point of attack, which on side branches forms a compact, bushy mass of twigs commonly called "witch's broom." In small trees infested stems or branches are sometimes swollen to twice their natural diameter.

SMELTER FUMES.

The Washoe smelter at Anaconda, just outside of the boundary of the Deerlodge National Forest, is the largest copper smelter in the world, handling approximately 10,000 tons of ore daily and producing 25 per cent of the copper output of the United States. Chemists have estimated that at least 2,500 tons of sulphur dioxide and at least 25 tons of arsenic trioxide are daily thrown into the atmosphere from the top of the stack. The arsenic does not damage the timber, but when deposited on the forage is injurious and sometimes fatal to grazing animals. Sulphur dioxide is injurious to vegetation in general. Experiments have shown that as little as one part of sulphur dioxide with a million parts of air will kill pine seedlings when the trees are exposed for any length of time. Even at a distance of many miles from Anaconda the air in the smoke stream may contain as many as 80 parts of sulphur dioxide to a million parts of air. At a distance of 10 miles from the smelter the sulphur is often so strong as to cause persons to cough.

Sulphur dioxide injures trees by destroying the chlorophyll in the leaves, which first turn yellow and later red-brown. The damage usually extends over several years, especially if the trees are at some distance from the smelter. At first only the weaker leaves are killed, but later the younger ones succumb to repeated baths in the smoke stream. Three stages in the defoliation of trees by smelter fumes have been recognized. The first is when the older leaves die and fall prematurely, the tree still retaining a considerable amount of foliage and the appearance of health. In the second stage the foliage becomes decidedly thin, and in the last or acute one only the needles of the current year are left green on the tree. (Plate V, fig. 1.) These latter are usually badly damaged or killed during the winter, and the tree may fail to put forth fresh leaves in the spring. In some cases, however, the acute stage lasts for several years. The annual rings of trees injured or killed by smelter smoke usually show a graduated decrease in size for the last six or eight years.

With respect to their susceptibility to injury from smelter fumes, the species in the lodgepole region may be grouped as follows, the most easily killed coming first:

Alpine fir.
Douglas fir.
Lodgepole pine.
Engelmann spruce.
Juniper.
Limber pine.

As between Douglas fir and lodgepole pine, the two most important species in the smoke zone, the former is considerably more susceptible than the latter. Nearly all the lodgepole trees will remain green when practically all the Douglas firs in the same locality have been killed. Susceptibility varies among different individuals of the same species. A few green and flourishing Douglas fir trees will often be found after practically all the other firs in the vicinity have been killed.

The injury is not the same in amount at all places equally distant from the smelter, since the smoke is carried by the prevailing wind along channels formed by the topography. Damage decreases both with distance from the smelter and distance from the main channels. In places the smoke seems to eddy in a peculiar manner, killing trees in isolated groups. The greatest damage, of course, is close to the smelter, but at places 9 miles distant most of the lodgepole is now dead and the remainder seriously injured. Slight damage at a distance of 30 miles has been observed.

WINDFALL, SUN SCALD, ETC.

Lodgepole pine is generally regarded as being decidedly susceptible to windfall. While to a certain extent this is true, there is a tendency to exaggerate the danger. The extent of the development of the tree's root system, as in the case of any other species, varies with the soil conditions and the density of the stand. On deep, fresh soil trees in moderately open stands develop good root systems, while on very shallow or very moist soils the root system is correspndingly shallow and the tree less wind firm. With the same soil conditions, the development of the root system varies inversely with the density of the stand, so that the denser the stand the less windfirm are the individual trees. Experience shows that heavy thinnings in dense stands are very likely to result in serious windfall unless the situation is well protected. For this reason the leaving of seed trees, either alone or in small groups, seldom works satisfactorily. On the more exposed situations, with shallow or wet soil, even unthinned stands may be blown down. As a rule, however, solid stands, even when overdense, are windfirm, provided they are of sufficient extent—not narrower than the height of the trees. Light or even heavy thinnings can usually be made without danger of windfall by conforming the operation to the height, age, and density of the stand, the character of the soil, and the exposure.

Haphazard thinnings made on the Deerlodge Forest from 13 to 25 years ago in the course of ordinary lumbering operations show a remarkably small amount of windfall. On only 2 of the 18 blocks examined was any windfall evident, and in each of these cases the stand had been very heavily thinned by the removal of 82 per cent of the original number of trees and 66 per cent of the cubic volume. On the remainder of the areas the stand was not so heavily thinned, though the cutting was heavier than would be considered advisable in present-day Forest Service timber sales. In one of the early Forest Service sales on the Deerlodge Forest, on an area partly exposed and partly protected from the wind, where the soil was deep, fresh, and firm, a selection cutting removed about 40 per cent of the total number of trees and 59 per cent of the cubic volume. In the five years following the cutting only 3 trees out of the approximately 5,000 left blew down. All of these were on the exposed portion of the sale area, and in each case a defective root system, due to fire injury, was the main cause of the fall. These and other observations indicate the importance of removing trees with defective root systems.

Another climatic factor which may cause damage to individual seed trees is sun scald. In many cases seed trees which have withstood the wind for a number of years have died apparently as a result of too great exposure to sun. Owing to the thin bark of lodgepole the cambium on the insolated side of the tree is killed first. Many of the trees crack open on the sunward side before they die. The drying out of the ground when it is exposed to the sun probably helps to kill such trees. If trees are left so that their trunks do not receive full sun during most of the day, the likelihood of damage from sun scald is very small.

Frost cracks sometimes appear in lodgepole pine, and when they take a spiral form lessen the value of the tree for saw timber. Strong winds sometimes open these cracks in a way to form large seams or checks which afford ready entrance for insects and fungi. The damage appears to be more prevalent in overmature than in younger stands, and is more often encountered in Wyoming and Colorado than in Montana. Frost may also cause injury by heaving 1 or 2 year old seedlings out of the ground.

Snow, accumulating on the tops of lodgepole trees 4 inches or less in diameter, especially when in dense stands, often bends the

FIG. 1.—LODGEPOLE SEEDLINGS INJURED BY SMELTER SMOKE. IN "ACUTE" STAGE.

Note the scant foliage, only that of the current year. Decreasing rate of height growth in last few years shown by shorter distance between whorls of branches. Taken 9 miles in an air line from the smelter.

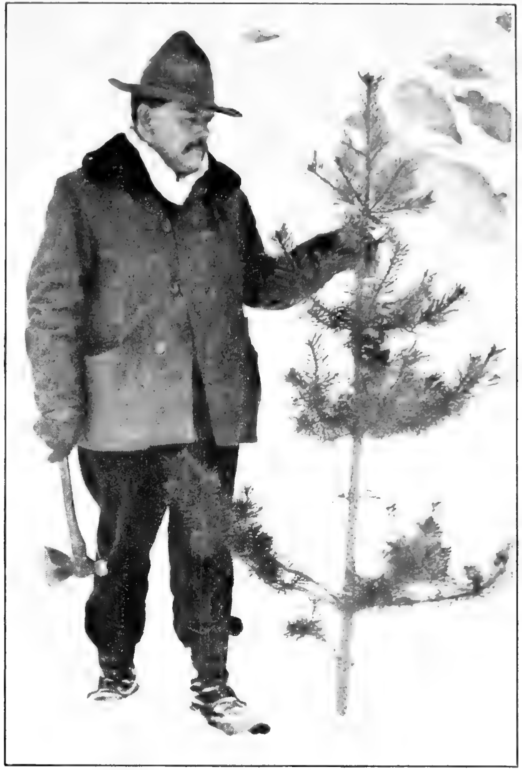

FIG. 2.—LODGEPOLE SEEDLING DAMAGED BY "RED BELT," BUT SINCE RECOVERED.

The damage occurred three growing seasons before the picture was made. Note luxuriant foliage on last three years' growth as compared with smelter-injured trees. Also that all of the leaves more than three years old have dropped from the stem.

poles to the ground or breaks them off at a height of from 10 to 20 feet. Snow-break may be beneficial in overdense stands which are in need of thinning, but may also do considerable damage in thinned stands where the individual trees can no longer rely on their neighbors for support.

The so-called "red belt" injury is manifested by the sudden reddening and subsequent death of practically all the needles on the exposed portions of the trees in a well-defined altitudinal belt. Some are killed outright, though usually the buds remain uninjured and the trees later recover, in some cases after complete defoliation. The most extensive damage of this nature on record occurred in January, 1909, when large areas were affected in the Black Hills and throughout the Rocky Mountains from Montana to Colorado. The belt was generally from 200 to 400 feet in width between elevations of 6,500 and 7,000 feet in the lodgepole region, and at lower elevations in the northwestern portion of Montana. Trees on all aspects were affected, but the greatest damage was done on southerly slopes and in situations exposed to the wind. The injury resulted from unusual weather conditions during the winter. In 1909 it was caused by a chinook of several days, when the ground was frozen and covered with snow. The air was quite warm and the sun very hot, especially when reflected from the surface of the snow, causing the leaves of the trees to transpire all of their available moisture. Since the roots were frozen and additional moisture could not be obtained from the ground, the leaves withered, and in some cases the buds also dried out excessively. The most satisfactory explanation of the occurrence of the injury in an altitudinal belt is that early in the winter, before the ground froze, snow fell at the higher elevations above the zone of injury. Later the ground in the belt froze solid, but not the ground in the zone below it nor that in the zone above it. Later still the entire area was covered by a heavy fall of snow. In this way the belt was the only part of the region in which the ground was solidly frozen and no soil moisture was available to replace the water transpired by the leaves.

Hedgcock grouped the species of the lodgepole region in respect to their susceptibility to this injury as follows, naming the most susceptible first:

Yellow pine.
Douglas fir.
Lodgepole pine.
Limber pine.
Engelmann spruce.
Alpine fir.
Juniper.

Douglas fir unquestionably suffered more than did lodgepole on areas where the greatest damage occurred. Many Douglas fir trees were killed outright, while even those lodgepoles which had their leaves killed retained their buds and put out new leaves the following spring. Lodgepole saplings affected in 1909 now present a peculiar banded appearance, that part of the stem which was above the snow at the time of the injury being bare of leaves, while that part below it, which was covered by snow, and that part above it, which has grown since, are green.

The red belt injury has sometimes been confused with damage from smelter fumes, but its nature is entirely different. (Pl. V, fig. 2.) Trees killed by the former die quickly as compared with those killed by the fumes. Weather-damaged trees which have recovered show a quick resumption of normal growth rate and a general healthy appearance, a marked contrast to the trees suffering from the smoke fumes.

ANIMALS.

Porcupines damage lodgepole to some extent by gnawing the bark in order to get at the tender cambium. They confine their efforts chiefly to young or middle-aged trees, though trees as large as 18 inches in diameter have been found completely girdled. Usually the bark is gnawed near the base of the tree, but occasionally animals work in the tops, as high as 50 or 60 feet from the ground, causing the trees to become stag-headed. Small branches are sometimes girdled near their junction with the main stem. Sometimes the attack may result in a beneficial thinning in an overdense stand, but porcupines have done considerable damage to trees on the Routt National Forest, Colo., where more than half of the trees on areas from one to several acres have been girdled, and in several localities on the Bonneville National Forest, Wyo., where 25 per cent of the trees have been injured.

Rabbits often bite through the main stem of young seedlings, particularly the slender ones in overdense stands. Squirrels may cause a slight decrease in the rate of growth by biting off a number of the cone-bearing twigs. They also eat considerable quantities of seed, the result of which may be harmful in places where reproduction is not up to the required density. Sheep grazing unrestricted may damage seedlings and very young growth by trampling.

ASSOCIATED SPECIES.

Over most of its range lodgepole pine occurs in almost pure stands. Other species, however, often grow in mixture with it, particularly at the upper and lower altitudinal limits of the lodgepole zone. At the lower limit its chief associate is Douglas fir, which tends to take possession of areas too dry for lodgepole. Fir reproduction often occurs under the latter, and many areas now covered with lodgepole would doubtless long since have given way to the more tolerant fir had it not been for recurrent fires. On south slopes and on dry, rocky knolls and ridge tops the fir may extend almost to the upper limits of the lodgepole belt. At the upper limit of the zone the chief associates of lodgepole are Engelmann spruce and Alpine fir, which come in on the moister sites. Spruce sometimes follows stream courses far down into the lodgepole type, where it takes possession of the moist bottomlands. Both the fir and spruce are much more tolerant than lodgepole, and reproduce under dense shade. At the higher elevations Alpine fir is apt to be more abundant in reproduction than spruce, but the latter is a longer-lived tree and of much greater importance in mature stands. Both species when growing with lodgepole assist to a large extent in pruning the latter of its side branches.

In Colorado and Wyoming limber pine and aspen also grow with lodgepole, though to a rather limited extent. In Montana white-bark pine is usually mixed with lodgepole toward the latter's upper limit.

PERMANENCY OF LODGEPOLE TYPE.

Many of the present stands of lodgepole undoubtedly occupy areas previously covered with other species which have been driven out by repeated fires. If fire were kept entirely out of the forests, therefore, the lodgepole would in many situations be replaced by the original species—at the lower altitudes by Douglas fir, at the upper ones by Engelmann spruce and Alpine fir. All of these species are more tolerant than lodgepole, and for this reason are able to crowd it out on sites adapted to all of them. It is likely, however, that there is a middle belt considerably narrower than the present lodgepole zone where conditions of soil and climate are more favorable to it than to competing species, and where it would probably be able to form a permanent type.

In connection with the ability of lodgepole to maintain itself in competition with other species, it is interesting to know that Knowlton, in his studies of the paleobotany of Yellowstone Park, found in Tertiary deposits a serotinous cone of a tree species which he named *Pinus premurrayana*,[1] because he considered it the immediate ancestor of the lodgepole of to-day. A fossil cone, perfectly preserved, is slightly longer and narrower than typical lodgepole cones of the present. In Yellowstone Park Knowlton also found the fossil remains of species of *Sequoia*, *Juglans*, *Hicoria*, *Fagus*, *Castanea*, *Ficus*, *Magnolia*, etc. Of all the species now present in the park lodgepole is the sole survivor from the Tertiary age.

[1] The form of lodgepole pine occurring in the Rocky Mountains, now known as *Pinus contorta*, has also been known as *Pinus contorta*, var. *murrayana*, and as *Pinus murrayana*.

GROUND COVER.

Lodgepole stands, particularly in Montana and northern Wyoming, have a ground cover of grasses and weeds, many of which are valuable as forage. These include pine grass (*Calamagrostis rubescens*) in very large amounts, timber oats grass (*Danthonia intermedia*), lupine (*Lupinus serviceus*), fireweed (*Chamaenarion augustifolium*), Indian paintbrush (*Castilleja chromosa*), etc. Other plants worthless for forage include huckleberry (*Vaccinium scoparium*), which is especially abundant on the poorer sites, arnica (*Arnica cordifolia*), and elk grass (*Xerophyllum tenax*). In moist places alder (*Alnus tenuifolia*) and willow frequently occur as underbrush. The forage plants are less abundant in Colorado and southern Wyoming and the huckleberry more prevalent. Ordinarily fallen leaves disintegrate so rapidly that there is no accumulation of duff from this source. In mature stands there is very little litter as a rule, and one can ride through them almost anywhere.

AGE CLASSES.

A striking characteristic of lodgepole-pine forests is their even age. This, of course, is due to the fact that most of the present stands have originated as a result of fire, followed almost immediately by reproduction. As a rule, the burned areas thoroughly stock in a few years, though sometimes the reproduction is very open, the blanks filling in slowly with young growth and so producing an uneven-aged stand. Young stands often contain a few older trees, most of them limby and fire-scarred at the base, which have managed to escape destruction.

Clear cutting is usually followed by even-aged stands, though the reproduction is apt to be slightly slower in establishing itself, particularly if fire is kept out. Some areas cut over 20 years ago now have their blanks filled from seed produced by the rather scattered reproduction which followed the cutting.

All the trees in even-aged lodgepole forests are not necessarily of the same size. Unless the stand is so dense as to cause stagnation some seedlings, especially on the more favorable sites, get a better start and develop more rapidly than others. A small, suppressed tree often may be as old as another more vigorous one at its side two or three times as large in diameter.

Fires have been so frequent in the region that they have brought about a wide range of age classes in the lodgepole zone as a whole. In Montana most of the stands are comparatively young. Figures collected there show that approximately two-thirds of the timbered area is now covered with nonmerchantable, immature growth, while the merchantable timber on the remaining third is partly immature, partly mature, and partly overmature. In Wyoming and Colorado there is a much larger proportion of mature, and especially overmature, lodgepole stands, a difference which leads to the conclusion that in the past fire has been less prevalent in Colorado and Wyoming than in Montana.

YIELD.

FACTORS INFLUENCING YIELD.

The yield per acre of any stand varies with its age, density, and the quality of the site on which it grows. Ordinarily the better sites and older stands produce the heaviest yields, provided deterioration has not set in. With lodgepole, however, the yield, particularly in board feet, is determined more by the density of the stand than by either its age or the quality of the site. It is not unusual to find young, properly stocked stands of lodgepole with larger yields than older, overstocked stands on better sites. The effect of density on yield is illustrated in Table 6, which gives the results of measurements of 10 sample plots, all of approximately the same age.

Table 6.—*Effect of density on yield per acre of lodgepole pine, Deerlodge National Forest, Mont.*

Sample plot.	Age.	Trees per acre.		Yield.			Ratio of board feet, 6 inches top diameter, to cubic feet.	Height of average tree (dbh. 8 in.).	Diameter of average tree.	
		Entire stand.	Main stand.[1]	Total.	Scale timber, top diameter, inside bark, to— 6 inches.	Scale timber, top diameter, inside bark, to— 8 inches.			All trees.	Main stand.[1]
	Years.	*No.*	*No.*	*Cu. ft.*	*Bd. ft.*	*Bd. ft.*		*Feet.*	*Inches.*	*Inches.*
1	110	501	293	4,187	10,542	3,217	2.52	59	7.2	8.4
2	109	701	325	5,441	8,682	1,580	1.60	67	6.5	8.1
3	109	764	338	6,286	19,440	4,387	3.09	71	6.6	8.4
4	108	810	338	7,331	20,400	2,456	2.78	72	6.6	8.6
5	107	960	250	5,614	15,260	1,190	2.72	69	5.7	7.9
6	107	987	303	6,178	12,070	1,610	1.95	69	5.9	7.8
7	107	1,249	149	5,080	2,980		.59	67	5.0	7.5
8	104	1,495	124	4,840	2,480		.51	57	4.7	7.3
9	101	1,564	124	4,668	2,480		.53	58	4.6	7.5
10	105	1,805	73	4,405	1,460		.33	57	4.2	7.4

[1] Includes all trees 7 inches and over in diameter, breast high.

The table shows that an increase in the number of trees per acre beyond a certain point results in a marked decrease in the number of trees which will make scale timber, in the average diameter and height, and in the yield, especially in board feet. Much denser stands existed than any of those shown in the table, with correspondingly smaller yields. One plot 160 years old, for example, contained approximately 3,500 live trees per acre, not more than 4 inches in diameter. Such a stand produces only lagging poles. Other stands of the same age are still denser, producing nothing of value.

AVERAGE AND MAXIMUM STANDS.

Reconnaissance estimates covering 65,000 acres on the Deerlodge National Forest, which may be considered as fairly representative of the lodgepole region in Montana, show that the average stand of merchantable timber for all ages, densities, and sites is approximately 5,564 board feet per acre.[1] In Wyoming and Colorado the average stand of merchantable timber is estimated to run from 5,000 to 8,000 board feet per acre. Average stands on timber sale areas are apt to run much higher than this, because they usually consist of the better timber, and also because the reconnaissance figures apply to a considerable amount of cut-over land and to areas covered with young growth that is barely merchantable. Average stands actually found on timber-sale areas on the different National Forests are shown in Table 7.

TABLE 7.—*Average stand per acre of lodgepole pine and associated species on timber-sale areas in Colorado, Wyoming, and Montana.*

National Forest.	Yield per acre.		
	Lodgepole.	Other species.	Total.
	Bd. ft.	*Bd. ft.*	*Bd. ft.*
Arapaho, Colo	19,410	....	19,410
Cochetopa, Colo	6,880	900	7,780
Gunnison, Colo	2,500	925	3,425
Medicine Bow, Wyo	14,225	....	14,225
Hayden, Wyo	8,884	....	8,884
Bighorn, Wyo	8,300	....	8,300
Bridger, Wyo	2,771	2,571	5,342
Deerlodge, Mont	14,318	....	14,318

While the stands on the Arapaho, Medicine Bow, and Deerlodge National Forests are considerably better than the average, they are not as heavy as the stands sometimes found on limited areas in virgin forests. Five of the heaviest stands yet measured contained the following amounts of lodgepole, together with small quantities of Engelmann spruce, Alpine fir, and Douglas fir:

National Forest:	Board feet per acre.
Arapaho, Colo	27,791
Routt, Colo	24,400
White River, Colo	36,335
Medicine Bow, Wyo	34,512
Deerlodge, Mont	35,935

In addition to the 35,935 feet of green lodgepole pine, the stand on the Deerlodge Forest, which was 200 years old, also contained 4,610 feet of Englemann spruce and Alpine fir, and 8,090 feet of dead lodgepole, a total for live and dead timber of 48,635 board feet per acre.

[1] All stands were considered merchantable which contained 2,000 board feet per acre or more, based on a minimum log 16 feet long and 6 inches in diameter at the smaller end. Many 7-inch lodgepole trees will yield such a log.

DENSELY STOCKED STANDS.

Table 8 shows the yield of stands which are densely stocked, but not so crowded as to cause stagnation of growth. The figures were obtained on the Deerlodge National Forest on the best quality of site. Most of the sample areas measured were 1 acre each.

TABLE 8.—*Average yield per acre of densely stocked stands of lodgepole pine at different ages on the best sites (Quality I), Deerlodge National Forest, Mont.*

Age in years.	Basal area, square feet.	Trees per acre.		Average diameter, main stand.	Average height, main stand.	Yield.		Annual growth.			
		Entire stand.[1]	Main stand.[2]					Mean.	Periodic.	Mean.	Periodic.
	No.	*No.*	*No.*	*Inches.*	*Feet.*	*Cu. ft.*	*Bd. ft.*[3]	*Cu. ft.*	*Cu. ft.*	*Bd. ft.*	*Bd. ft.*
40	106	1,550	50	7.0	36	1,400	....	35	....	....	....
50	128	1,250	175	7.5	46	2,250	....	45	85	....	....
60	144	1,000	225	7.7	56	3,100	4,800	52	85	80	....
70	156	825	255	8.1	60	3,800	6,200	54.3	70	89	140
80	166	725	280	8.5	64	4,350	7,500	54.4	55	94	130
90	174	650	300	8.8	66	4,900	9,000	54.5	55	100	150
100	180	600	320	9.0	68	5,400	10,800	54	50	108	180
110	184	535	330	9.4	70	5,800	12,600	53	40	115	180
120	188	500	345	9.6	72	6,200	14,800	52	40	123	220
130	192	460	350	10.0	74	6,550	17,200	50	35	132	240
140	194	430	355	10.3	75	6,850	19,800	49	30	141	260
150	196	415	360	10.5	76	7,150	22,200	48	30	148	240
160	198	400	370	10.6	77	7,400	25,000	46	25	156	280

[1] Includes all trees 3 inches and over in diameter, breast high.
[2] Includes all trees 7 inches and over in diameter, breast high.
[3] To a 6-inch top diameter limit.

NORMAL STANDS.

Normal stands are those which at maturity give the maximum yield possible to obtain under a given method on a given quality site. In the case of lodgepole pine properly or normally stocked stands are rare. Reconnaissance data, covering many thousands of acres of young growth in Montana, show that nearly 80 per cent of the area is overstocked, and that on the average the young growth is from one-half to six-tenths normally stocked. Because of its slow mortality lodgepole must start in comparatively open stands in order to yield the maximum amount of merchantable material at maturity. Such stands, however, are not dense enough to insure rapid, natural pruning. As already pointed out, the number of trees per acre adopted as the criterion of normality is 1,000 at 10 years, 500 at 30 years, 300 at 90 years, and 250 at 140 years. With these figures as a guide, and taking into account the total yield of the stand, Table 9 has been constructed from the figures obtained from those plots in Table 8 on which the stocking appeared to be most nearly normal. The amount of data is not sufficient to make the table anything more than indicative of what may be expected from normal stands of different ages on the best and on average sites. The original figures were secured on quality I sites, and the yields for quality II sites have been derived by multiplying the yields for quality I sites by 60 per cent, which seemed a fair reducing factor. In the case of board-foot yields strictly accurate results are not obtained when the same reducing factor is used for all ages and stands. The method is, however, sufficiently accurate to result in figures which indicate in a general way what results may be expected.

TABLE 9.—*Average yield per acre of normal stands of lodgepole pine at different ages, Deerlodge National Forest, Mont.*

BEST SITES—QUALITY I.

Age in years.	Yield.			Annual growth.					
	Cubic feet.	Board feet scaling in top to—		Cubic feet.		Board feet scaling in top to—			
						6 inches.		8 inches.	
		6 inches.	8 inches.	Mean.	Periodic.	Mean.	Periodic.	Mean.	Periodic.
10	150	...	...	15	15.0	...	...	...	...
20	450	...	...	22	30.0	...	...	...	...
30	950	900	...	32	50.0	30	90	...	...
40	1,900	3,200	...	47	95.0	80	230	...	...
50	3,050	5,600	...	61	115.0	112	240	...	...
60	4,000	8,100	...	67	95.0	135	250	...	...
70	4,900	10,700	...	70	90.0	153	260	...	...
80	5,600	13,400	...	70	70.0	167	270	...	...
90	6,300	15,800	...	70	70.0	176	240	...	...
100	6,800	18,200	2,500	68	50.0	182	240	25	250
110	7,200	20,500	5,000	65	40.0	186	230	45	250
120	7,450	22,700	7,600	62	25.0	189	220	63	260
130	7,600	24,600	10,700	58	15.0	190	190	82	310
140	7,750	26,400	14,000	55	15.0	189	180	100	330
150	7,850	28,200	17,300	52	10.0	188	180	115	330
160	7,900	29,800	20,400	49	5.0	186	160	127	310
170	7,925	31,200	23,300	47	2.5	184	140	137	290
180	7,950	32,600	25,800	44	2.5	181	140	143	250
190	7,975	33,600	28,000	42	2.5	177	100	147	220
200	8,000	34,600	30,000	40	2.5	173	100	150	200
210	8,025	35,600	31,500	39	2.5	170	100	150	150
220	8,050	36,600	32,800	37	2.5	166	100	149	130

AVERAGE SITES—QUALITY II.

Age in years.	Yield.		Annual growth.				Ratio of board feet to cubic feet.
			Mean.	Periodic.	Mean.	Periodic.	
	Cu. ft.	*Bd. ft.*[1]	*Cu. ft.*	*Cu. ft.*	*Bd. ft.*	*Bd. ft.*	
10	90	...	9	9	...	...	...
20	270	...	13	18	...	...	...
30	570	540	19	30	18	54	0.95
40	1,140	1,920	28	57	48	138	1.68
50	1,830	3,360	37	69	67	144	1.84
60	2,400	4,860	40	57	81	150	2.02
70	2,940	6,420	42	54	92	156	2.18
80	3,360	8,040	42	42	100	162	2.39
90	3,780	9,480	42	42	105	144	2.51
100	4,080	10,920	41	30	109	144	2.68
110	4,320	12,300	39	24	112	138	2.85
120	4,470	13,620	37	15	113	132	3.05
130	4,560	14,760	35	9	114	114	3.24
140	4,650	15,840	33	9	113	108	3.41
150	4,710	16,920	31	6	113	108	3.60
160	4,740	17,880	30	3	112	96	3.77

[1] Board feet scaled to 6 inches in the top.

It should be noted that these normal yields represent the best that have been found in unmanaged virgin forests, not the best which it is theoretically possible to obtain under proper methods of forest management. Table 2, for example, shows that a dominant tree at the age of 140 years is able to reach a diameter of about 12 inches and a height of about 75 feet, with a volume of 120 board feet. To determine in an approximate way how many trees could be produced per acre with the right kind of thinnings at proper intervals, the average space in the stand occupied by a tree of this size was measured in a number of instances and found to average approximately 166 square feet. At this rate there should be 262 such trees per acre, with a yield of 31,400 board feet, which is 19 per cent greater than that given in the table of normal yield for 140-year-old stands on the best sites. While it is probable that such a yield could seldom be obtained even under intensive management, the illustration serves to show the possibility of securing better results with improved spacing.

EFFECT OF THINNING.

The marked effect which thinnings often have in increasing the rate of growth of individual trees is also notable in the case of stands. This effect is seen in a number of cut-over areas on the Deerlodge Forest which were culled from 13 to 25 years ago. In every case the loggers removed only such timber as suited their purpose, in some cases taking the larger material for ties, in others, removing the smaller trees for fence posts. Some of the trees left had thrifty crowns, and for this reason could be expected to benefit from the increased light; while others were very badly suppressed, with small crowns, and could hardly be expected to accelerate their growth to any extent. In collecting the data summarized in Table 10, average trees were selected for measurement irrespective of the probability of their showing an increase in the rate of growth. The various periods which had elapsed since the different cuttings were made averaged 20 years, and for purposes of comparison the figures were all worked up on the assumption that the cutting was done just 20 years before the date of the investigation.

TABLE 10.—*Effect of thinning on yield per acre of lodgepole pine in individual sample plots on the Deerlodge National Forest, Mont.*

Age at time of thinning in years.	Period since thinning in years.	Stand 20 years ago.								Periodic annual growth (for 20 years) of trees left.		Increase or decrease in rate of growth after thinning.
		Trees.			Volume.			Average diameter.				
		Total.	Cut.	Left.	Total.	Cut.	Left.	Cut.	Left.	Before thinning.	After thinning.	
		Number.	*Number.*	*Number.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Inches.*	*Inches.*	*Cu. ft.*	*Cu. ft.*	*Per cent.*
PLOTS SHOWING NO INCREASE IN RATE OF GROWTH.												
48......	18	550	290	260	1,955	521	1,434	4.3	6.1	45.5	15.6	−66
49......	18	430	320	110	2,336	1,486	850	5.9	6.7	27.0	19.8	−27
106......	14	1,600	1,200	400	6,136	3,396	2,740	4.5	6.2	34.0	27.7	−19
108......	20	690	290	400	3,339	1,594	1,755	6.0	6.1	17.2	4.7	−73
123......	20	1,730	1,120	610	2,267	1,028	1,239	3.2	4.3	12.1	8.1	−33
PLOTS SHOWING INCREASE IN RATE OF GROWTH.												
44......	20	570	280	290	951	399	552	4.2	4.1	16.1	22.6	40
44......	15	650	420	230	1,305	697	608	4.2	4.4	21.6	30.4	40
45......	15	910	500	410	1,434	563	871	3.5	4.2	31.8	36.3	14
95......	14	930	730	200	3,146	2,316	830	4.9	5.3	6.2	17.5	182
95......	20	1,050	500	550	2,049	985	1,064	4.3	3.7	15.0	33.1	121
95......	25	940	610	330	2,412	1,058	1,354	4.1	5.2	13.7	24.7	80
100......	25	980	770	210	2,454	1,430	1,024	4.1	5.6	8.2	21.3	160
119......	20	580	470	110	2,216	1,335	881	5.5	6.5	10.1	15.1	50
125......	20	1,030	680	350	2,921	1,600	1,321	4.4	4.9	14.3	19.1	34
127......	20	520	270	250	3,443	1,388	2,055	5.7	6.7	15.9	21.4	35
141......	13	840	490	350	5,178	2,887	2,291	6.0	5.9	15.9	28.8	81
151......	24	440	176	264	4,459	2,286	2,173	8.9	6.9	9.5	29.2	207
154......	24	585	485	100	3,769	2,609	1,160	6.1	8.1	5.5	10.5	91

Of the 18 plots measured, 13, or 72 per cent, showed an increase in the rate of growth after the thinning. In other words, the small number of trees left after thinning produced more cubic feet of wood per acre than would have been produced by the entire stand had it been left unthinned and continued to grow at the same rate as before the thinning. This result is particularly remarkable when it is remembered that all of the plots had reached an age when the periodic rate of growth would ordinarily be decreasing. Table 9 shows that in normally stocked stands the periodic rate of growth in cubic feet increases rapidly up to 50 years, after which it decreases slowly. For this reason the falling off in the growth of the 106 and 123 year old plots is no greater than would be the case in unthinned stands of the same age, and very likely it is even less. The apparently abnormal rate of decrease in the rate of growth of the 48 and 49 year old plots is probably due to the fact that they were nearly normal at the time of cutting, as indicated by their volume, with the result that the rather heavy thining had an injurious effect upon the trees left. The 108-year-old plot is the only one for which the marked decrease in rate of growth can not be satisfactorily explained.

If areas logged without thought for the future show such results, it is reasonable to suppose that thinnings made with the object of improving the stand will result even more satisfactorily, for the trees left will be thrifty-crowned specimens of moderate size, which are best able to take advantage of the increased light. Next to the exclusion of fire, the most important respect in which systematic management will improve the growth and yield of lodgepole forests is in bringing the stands to a density more nearly normal.

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

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1914