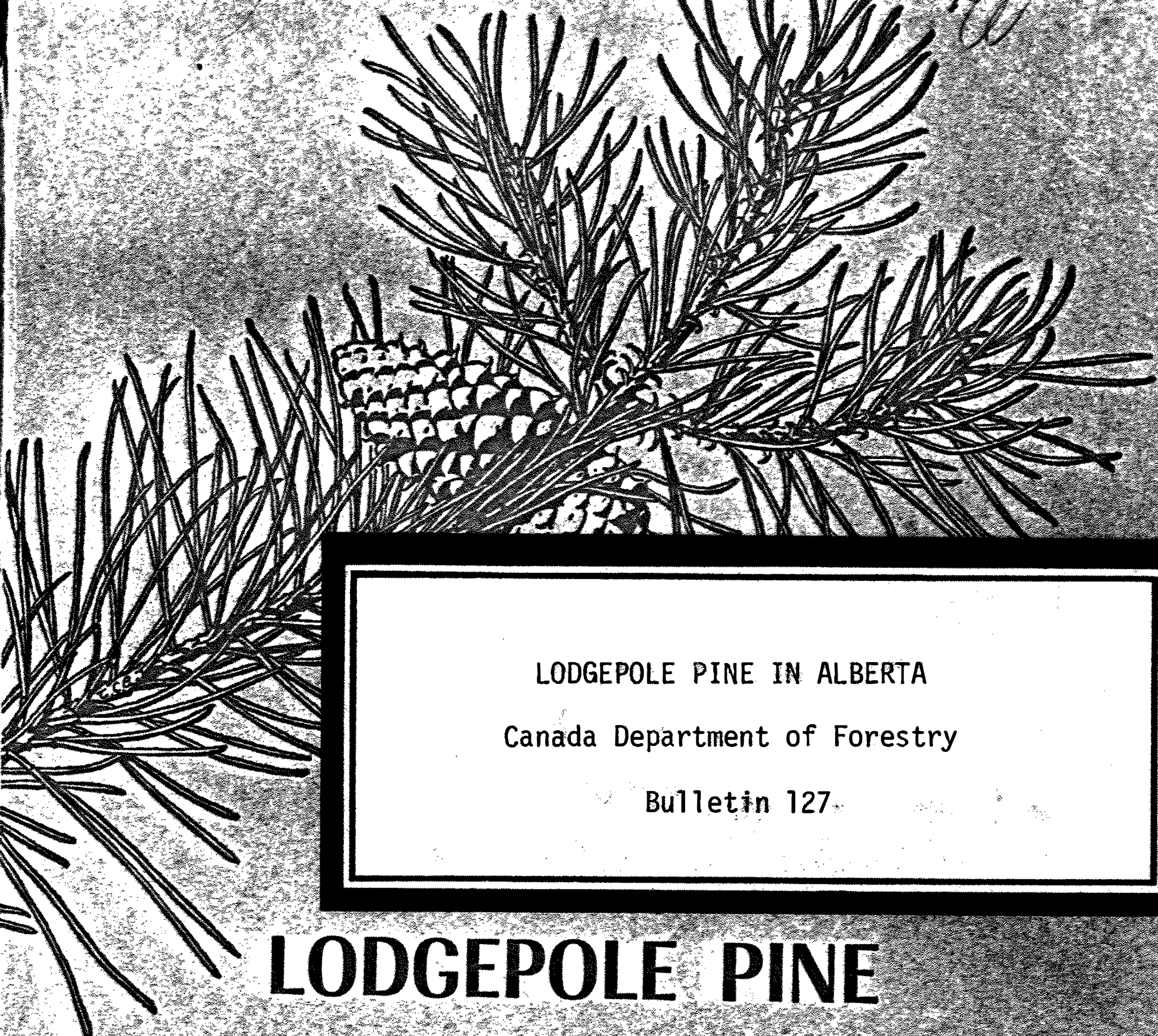

LODGEPOLE PINE IN ALBERTA

Canada Department of Forestry

Bulletin 127

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by L. A. Smithers

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PREFACE

Lodgepole pine (*Pinus contorta*) is potentially the most important pine species in the foothill and mountain regions of Alberta and British Columbia. The wide ecological amplitude of this two-needle pine permits it to occupy all but the most adverse mountain conditions, and while its form may sometimes be distorted, it provides important watershed protection for alpine areas denuded by fire. On the most productive sites this pine produces excellent trees of up to 30 inches d.b.h. and 130 feet in height.

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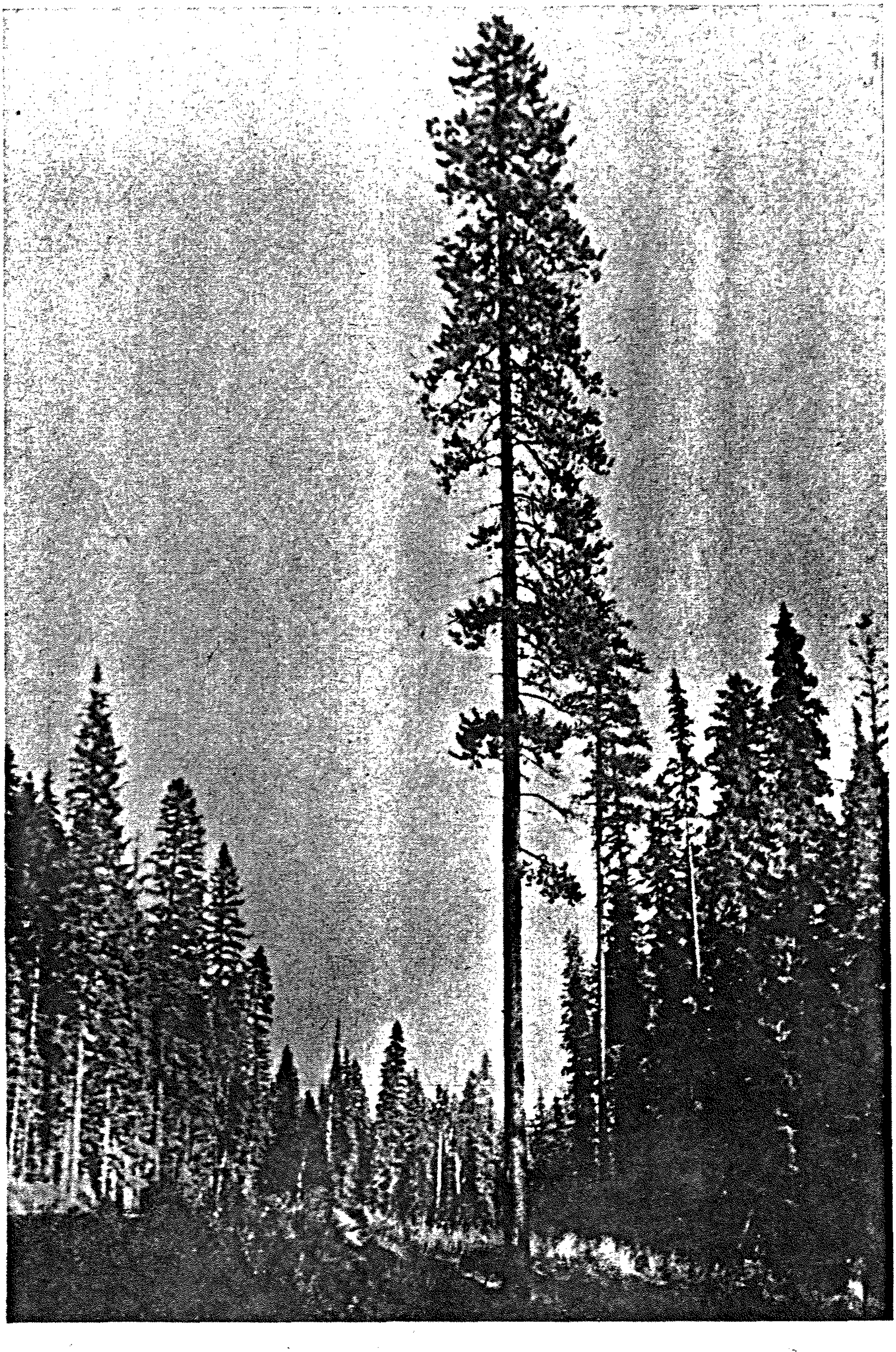

LODGEPOLE PINE IN ALBERTA

INTRODUCTION

The management of any commercial tree species is based on the accumulation of a multitude of facts and ideas obtained by careful observation and controlled experimentation. The welding together of these individual items into a sound plan incorporating the significant economic and biological factors produces a framework within which it is possible to carry out the rational management of the forest. A great variety of information and ideas have been assembled during the past 50 years on lodgepole pine (*Pinus contorta*). A detailed bibliography of this material has been prepared by Tackle and Crossley (1953). However, with regard to the management of this species in Alberta, very little has been done by way of assembling the available information into a pattern upon which the sound husbandry of the forest may be carried out.

The purpose of this report, therefore, is to assemble these isolated facts concerning the behaviour of lodgepole pine in Alberta and to develop a tentative system for managing the species.

Insofar as possible the report is confined to data on lodgepole pine gathered by the various forest research organizations in the province of Alberta. Where ideas are corroborated by research elsewhere, such work is noted. Where information is lacking in Alberta but is available from other areas, detailed conclusions of these studies are presented and their applicability to Alberta conditions is discussed.

In view of these considerations the report has been divided into six sections. The first five present summaries of observational studies and experimental research dealing with various phases of behaviour of lodgepole pine. The sixth section contains recommendations for the silviculture and management of lodgepole pine in Alberta.

To indicate the scope of this report, a brief description of the various organizations engaged in the study of lodgepole pine in Alberta is necessary. These include the federal Department of Forestry, formerly the Forestry Branch, Department of Northern Affairs and National Resources; the former Division of Forest Biology of the Canada Department of Agriculture, now part of the federal Department of Forestry; the Eastern Rockies Forest Conservation Board and the Department of Lands and Forests, Province of Alberta; and the Department of Botany, University of Alberta.

The Department of Forestry has been engaged in the study of lodgepole pine for about 40 years. During the early period, this department devoted itself to management and utilization, engaged in province-wide rate-of-growth studies, and prepared volume tables. Emphasis was also placed on silvicultural studies, particularly the thinning of dense pine stands. More recently, consideration has been given to the preparation of yield tables, regeneration surveys, studies of silvical and ecological characteristics, and the development of improved silvicultural practices, in particular harvest cutting methods.

The former Forest Biology Division of the Canada Department of Agriculture concerned itself with the investigation of various damage agencies,

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particularly fungi and insects, and the application of this information to the management of pine, and continues this work as part of the Department of Forestry. Both the Alberta Department of Lands and Forests and the Eastern Rockies Forest Conservation Board have carried out large-scale inventories of the forests of Alberta and have provided valuable information on the distribution of lodgepole pine in the province. The Department of Botany of the University of Alberta has confined its investigations to the study of ecology and plant associations of the lodgepole pine forest.

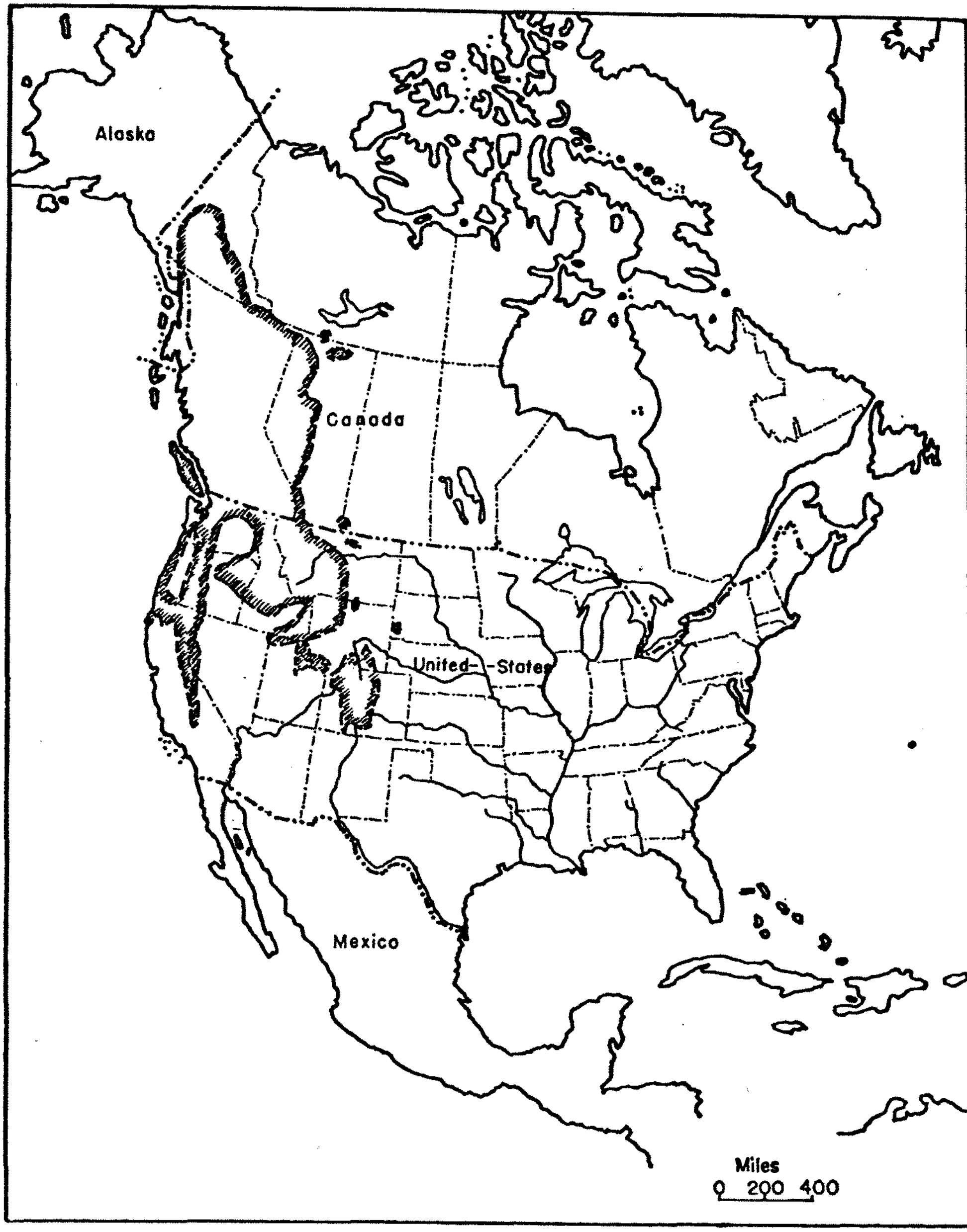

Figure 1. The botanical range of lodgepole pine in North America.

1. SILVICAL CHARACTERISTICS

1.1 Species Description

1.11 NOMENCLATURE

Lodgepole pine, like many other common tree species, has a complicated nomenclatural history. Little (1953) has contributed the following information.

The accepted scientific name is *Pinus contorta* Dougl. and the approved common name, lodgepole pine. *Contorta* was derived from the contorted, twisted crown of the typical shore or scrub pine, the coastal form of which was the first to be described. Other scientific names or synonyms are listed below in chronological precedence together with abbreviated citations:

Pinus contorta Dougl. ex Loud.	Arb. Frut. Brit. 4:2292. 1838.
Pinus murrayana	Grev. & Balf. in A. Murr., Bot. Exped. Ore. (Rpt. No. 8) 2, No. 740. 1853.
Pinus contorta var. *latifolia*	Engelm. in S. Wats. in King, Rpt. U.S. Geol. Expl. 40th Par. 5:331. 1871.
Pinus contorta var. *murrayana*	(Grev. & Balf.) Engelm. in S. Wats., Bot. Calif. 2:126. 1879.
Hybrid—*Pinus* x *murray banksiana*.	Righter & Stockwell (*P. banksiana* x *contorta*)

Little adds the following comments: "Some authors distinguish two varieties of which *Pinus contorta* var. *contorta*, shore pine, is a low scrubby tree of the Pacific coast from southeastern Alaska to northern California. *Pinus contorta* var. *latifolia* Engelm., lodgepole pine, is the taller, inland tree form of the mountains from Yukon southeast to Colorado. However, the differences are largely in habit rather than in botanical characters."

This report deals with the inland form, lodgepole pine, which is treated as a distinct variety for silvicultural purposes.

1.12 MORPHOLOGY

The morphological features of lodgepole pine make it readily distinguishable from most of its associates in Alberta. Only in the case of jack pine is there any degree of similarity. The leaves of lodgepole pine are needle-like, occurring usually in bundles of two; however, occasionally individual trees may be found bearing needles in bundles of three. Customarily, the needles are 2 inches in length but vary from 1 to 3 inches long and from 1/16 to 1/8 inch in width. The needles are somewhat twisted, stiff and yellow-green in colour. In general, the needles are somewhat longer than those of jack pine and foliage density appears heavier; however, because of variations among individual trees, foliage cannot be employed as a distinguishing feature.

Flowers of both sexes are borne on the same tree and become apparent during the month of May. Male flowers are reddish brown in colour, roughly cylindrical in shape, and are 0.3 to 0.4 inches in length and 0.2 inches in diameter. These flowers are borne in clusters at the base of the new shoot. Individual lodgepole pine (Crossley 1956a) have been recognized as consistently bearing heavy crops of male flowers. This characteristic imparts a distinctive whorled appearance to the foliage of lateral branches. The fruit appears as a greenish purple conelet borne at the base as well as some distance up the new shoot. Cones at both these locations may be fertilized during the same year and require two years to mature. Seed borne in these cones are winged and are among the smallest of the pine seeds.

The twigs of lodgepole pine are stout, with leaders up to ½ inch in diameter not uncommon. Colour varies from orange brown to dark brown. Buds are ovoid, about ¼ inch in length and are resinous. Normal bud formation produces a terminal bud and 4 or 5 laterals, constituting a primary whorl of branches. During the season's growth, a secondary whorl of 3, 4 or 5 laterals may develop at roughly two-thirds of the distance between successive internodes. Secondary whorls occur usually on rapidly growing trees or during that part of the tree's life cycle which is associated with rapid growth.

The bark of the main stem varies considerably in colour. New growth is orange brown and gradually changes toward a dark greyish brown as the bark matures. Individual mature trees, however, may show streaks of light reddish brown bark. In general the bark colouration of lodgepole pine in Alberta is considerably darker than in the southern portion of the species range and in this characteristic the Alberta trees more closely resemble jack pine. Lodgepole pine is noted as a thin-barked species, its loosely scaled bark rarely exceeding ½ inch in thickness. The wood is relatively light, soft and straight-grained although spiral grain may occur in local areas. Colour of the wood varies from light yellow to white and the demarkation of annual rings is distinct but not heavy.

1.13 SPECIES VARIATION

The lodgepole pine forest in the Low Foothills Division of Alberta north and west of Edmonton is of particular interest to ecologists because within this area is an overlap of the natural ranges of two similar species, jack pine (*Pinus banksiana* Lamb.) and lodgepole pine, (*Pinus contorta* var. *latifolia* Engelm.). The ranges of these two species in Alberta (Moss 1949) are shown in Figure 2. In accordance with criteria of natural hybridization (Allan 1937), Moss (1949) has reported the occurrence of what appear to be a number of hybrids of lodgepole and jack pines within the overlapping portion of their ranges. A number of phytogeographical explanations have been offered as a basis for the variation and location of this series of hybrid forms. The most tenable of these is that during interglacial times these two pines occurred as distinct species with overlapping ranges and formed hybrids as they now do. Under certain circumstances some of the forms were segregated by geographical barriers and survived in refugia, later migrating into the region. Such a theory might provide an explanation for morphological jack pine hybrid types found in Manitoba.

Various morphological features have been studied by Moss in an attempt to define hybrid forms. Some features, such as branch habit, crown shape, bark, foliage, and staminate cones, while adequate for separating the true forms of the two species, cannot be relied upon to distinguish the hybrid series. Others, such as leaf anatomy and position of seed cones, are not even adequate for this purpose. However, the shape and appearance of the seed-bearing cones does provide a basis for distinguishing the hybrid series as well as specimens of the true species form. Moss describes the mature cones of lodgepole pine as spreading or reflexed, ovoid or conical in shape, the scales conspicuously umbonate, each scale armed with a minute recurved prickle. Jack pine cones are erect (directed

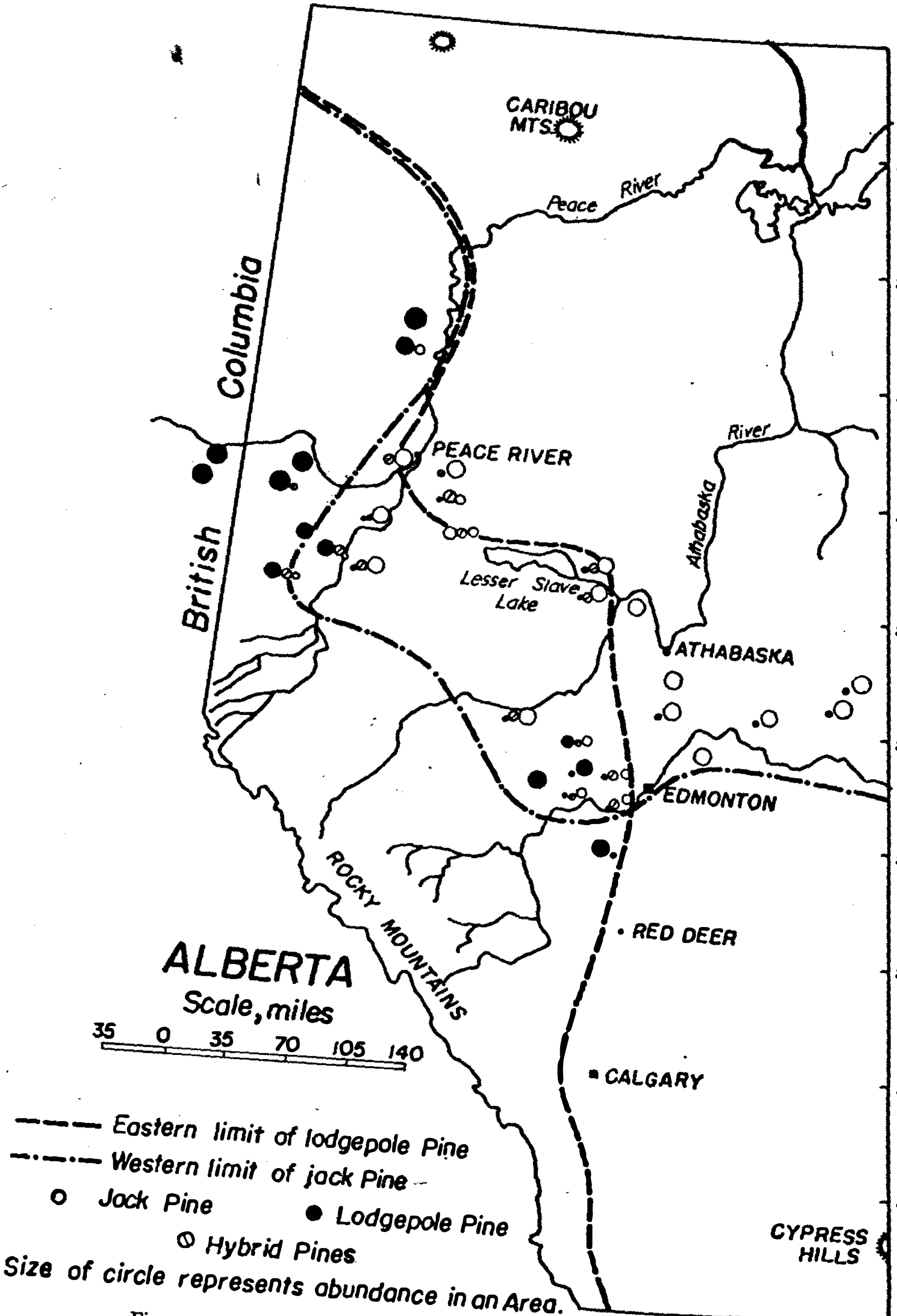

Figure 2. The botanical ranges of lodgepole pine and jack pine in Alberta.

toward the apex of the shoot), strongly incurved or slightly spreading, the scales variously thickened (outer and lower, large, mammiform) and unarmed. Moss also describes the cone characteristics of a series of hybrid forms which includes eight typical cone types showing intermediate characteristics, some of these being more closely related to jack pine and some to lodgepole pine. Trees showing intermediate characteristics are most abundant in the central parts of the overlapping range, particularly in stands where both lodgepole and jack pine occur. Such trees are rare or absent near the range limits of each species and in stands of only one species. Figure 2 shows the occurrence of hybrid forms recorded by Moss (1949).

A different approach to the identification of natural hybrids of lodgepole and jack pines has been made by Mirov (1956) who tested chemical and physical properties of turpentines collected from pure strains of each species, as well as from natural hybrids and artificial crosses between jack and lodgepole pines. Mirov's findings substantiate earlier conclusions based on morphological features, that natural hybrids between these two species do occur in Alberta. On the basis of these findings, it appears reasonable to expect some ecological differences between pines of this hybrid zone and those of the subalpine forests.

For further details on geographic variations in lodgepole pine, the reader is referred to Critchfield (1957).

1.14 RANGE AND OCCURRENCE

Lodgepole pine occurs in pure stands as well as in mixtures with a number of other species. However, for the purpose of this monograph the lodgepole pine type in Alberta is defined as including pure stands and also those mixtures in which it makes up 70 per cent of the volume.

The main species occurring in mixture with lodgepole pine include Engelmann spruce (*Picea engelmannii* Parry); white spruce (*Picea glauca* (Moench) Voss), and black spruce (*Picea mariana* (Mill) BSP.); alpine fir (*Abies lasiocarpa* (Hook) Nutt); balsam fir (*Abies balsamea* (L.) Mill); trembling aspen (*Populus tremuloides* Michx.); poplar (*Populus balsamifera* L.); and to some extent Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco).

The lodgepole pine type in Alberta occurs over a wide range of growing conditions and occupies a large area of the province. Reference to range maps for the species show that lodgepole pine in Alberta occurs in the western portion of the province, in a band of varying width, from the international boundary to approximately the 59th parallel of latitude. This band includes the eastern slope of the Rocky Mountains as well as the foothills region of Alberta. In the south of the province, the species range is limited by the prairie grassland formation while further north it is bounded by the aspen grove condition of the plains. At the northeast extremity of its range it merges with the western extension of the jack pine range and a transition area is formed containing hybrid forms of these two pines.

In Alberta, lodgepole pine has been broadly termed the dominant subclimax species in the subalpine and montane forests, and the Foothills Section of the boreal forest (Halliday 1937, Rowe 1959). A more detailed investigation has led to the recognition of four phytogeographic divisions within the lodgepole pine community of the province (Horton 1956). Their boundaries are shown in Figure 3, together with several known outlying areas of lodgepole pine. Each of these

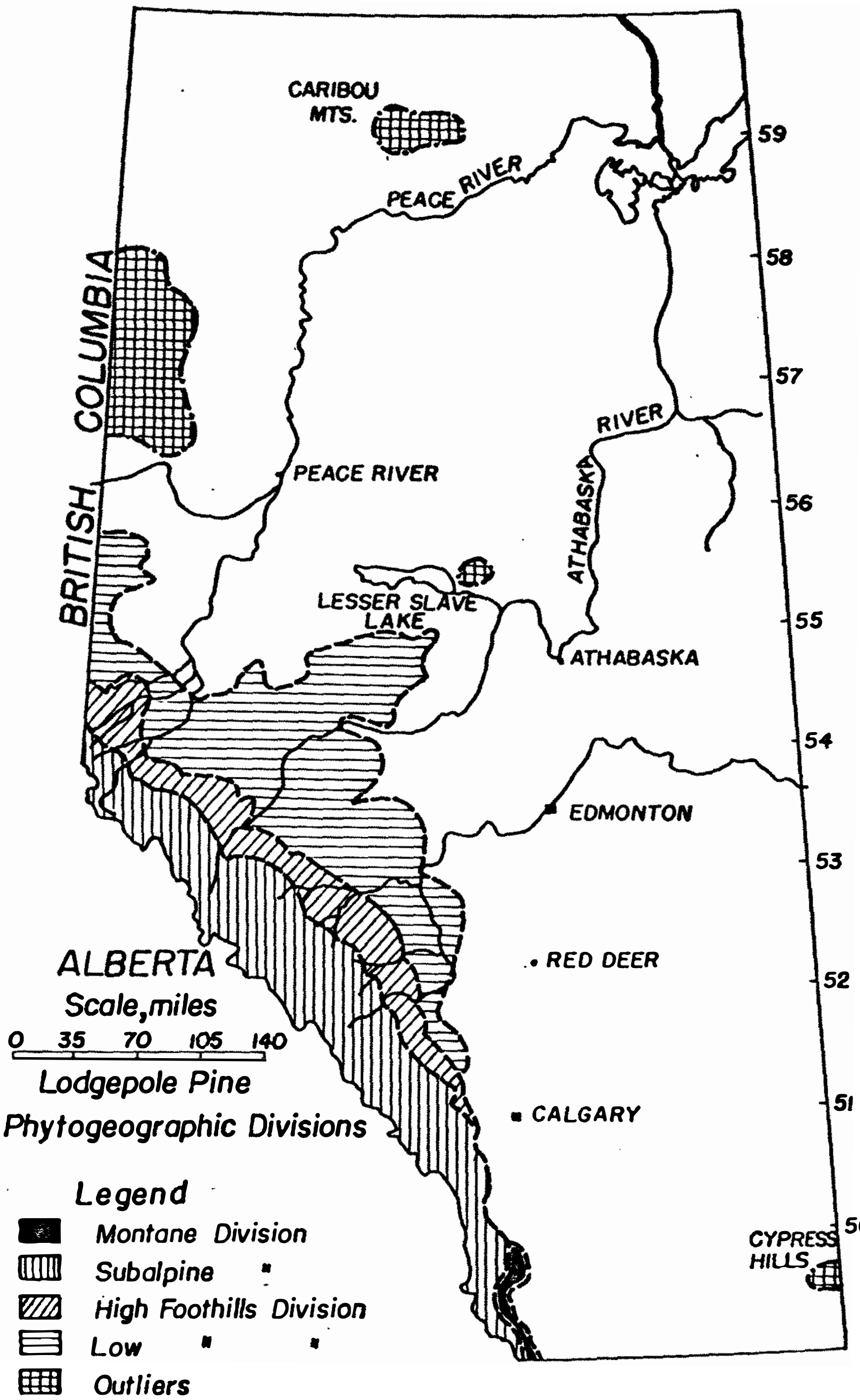

Figure 3. The phytogeographic divisions of lodgepole pine in Alberta.

isolated outliers occurs on ranges of high hills. Raup (1934) and Halliday and Brown (1943) suggest that the species survived the Keewatin glaciation in refugia at these locations. However, other ecologists maintain that post-glacial migration, combined with subsequent competition from better adapted species, have served to isolate these eastern outliers of lodgepole pine. Regardless of which theory is correct, it is implied that much broader distribution of lodgepole pine existed at some previous date. A description of the distinguishing physiographic and vegetative features of the four divisions follows:

Montane Division—This forest is localized in small sections of southwestern Alberta where it occupies an altitudinal zone between subalpine and prairie conditions. It is a northern extension of a type described by Larsen (1930) for the east slope of the Rockies in Montana. Douglas-fir is the characteristic species associated with lodgepole pine. Engelmann spruce, alpine fir and limber pine form an admixture at higher elevations and stunted aspen and white spruce occur with lodgepole pine along the prairie fringe.

Subalpine Division—This includes all of the Alberta portion of the Rocky Mountains, lying between the 4,500-foot elevation and timberline which is approximately at 6,500 feet. The characteristic tree is Engelmann spruce but subclimax stands of lodgepole pine predominate. White spruce replaces Engelmann in the lower valleys and these two spruces hybridize freely where their ranges overlap. Alpine fir is a frequent component, especially in older stands and higher altitudes. Black spruce, Douglas-fir and aspen are minor associated species of restricted distribution.

High Foothills Division—The long, narrow strip of country typified by high, wooded hills and deep valleys, usually between the 4,000- and 6,000-foot elevations, comprises this division. It closely resembles the subalpine forest. Lodgepole pine is preponderant and white and black spruce are the major associates. Alpine fir and aspen are localized and relatively unimportant.

Low Foothills Division—As its name implies, this forest occupies the low hills and plateaux between the plains and the foothills proper. Toward the south the zone occurs between the altitudes of 3,000 and 4,000 feet but further north it extends to lower elevations. It is an ecotone between the boreal and subalpine forests, containing some elements of each but favouring the former. The outstanding distinguishing feature is the prevalence of mixedwood types. Aspen, and to a much lesser extent balsam poplar, compete effectively with lodgepole pine as post-fire pioneers in this division only. White and black spruce and balsam fir are frequent but seldom abundant associates, and alpine fir is comparatively rare.

Clarke and Cowan (1945) have aptly expressed the general status of lodgepole pine as a temporary fire type running through all forest divisions and not diagnostic of any.

For descriptive purposes, where a less detailed subdivision of the lodgepole pine forest is required, the combined Subalpine, Montane and High Foothills Divisions will be referred to as the subalpine forest, while the Low Foothills Division will be termed the boreal forest.

Plate 1. Typical cone-bearing habit of lodgepole pine.

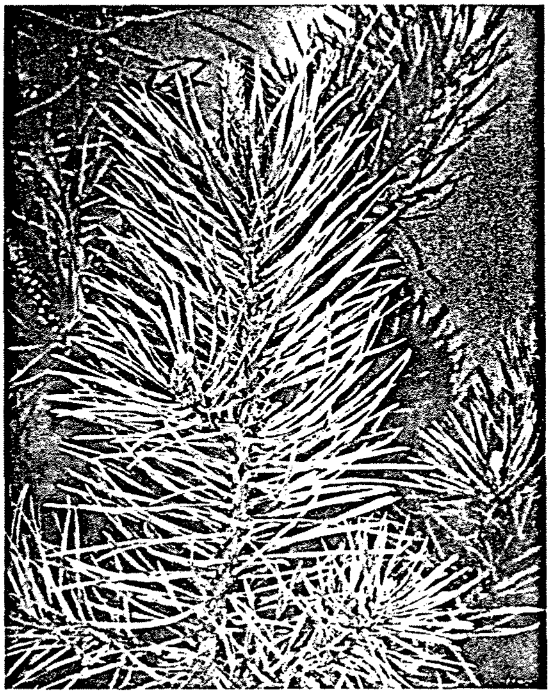

Plate 2. Dense foliage habit of lodgepole pine.

Photos for Plates 1 to 7 by P. Debnam, For. Ent. and Path. Lab., Calgary, Alta.

It was also found that direct sunlight or reflected radiation from some nearby mass was necessary to raise temperatures to the rupture point. Frequently the upper faces of suspended cones in direct sunlight ruptured while the under sides remained sealed. The surface temperature of a cone rises very rapidly upon exposure to direct sunlight and only a short period of such exposure is required to rupture the resin bond. It was demonstrated that the height of the cone above ground level was a significant factor in cone opening. Cone temperatures increased significantly as cone distance from ground level was decreased below 6.5 inches; whereas above this level there were no definite changes in cone temperature. Also at heights of more than approximately 7 inches from the ground or some other reflecting surface the cone temperatures were insufficient to rupture the resin bond. The effect of various ground surfaces as reflection media was studied. Although some difference was found in a comparison between charred conditions resulting from fire, bare mineral soil and undisturbed duff, these variations were not of sufficient magnitude to be limiting.

In the same study Crossley investigated the variable pattern of the opening of slash-borne cones under various degrees of crown canopy. Although the differences were not great, it was found that consistently higher temperatures were reached at both 3.5 feet and ground level under clear-cut conditions as compared with readings for various degrees of overstorey. As would therefore be expected, there was a higher percentage of cones rupturing their resin bond when overhead shade was at a minimum. In addition to rupturing the resin bond, the flexing of cone scales, termed cone opening, and the subsequent release of seed is of great importance. Here again the lightest degrees of overstorey produced the highest percentage of cone opening. Crossley attributed the higher percentage of cone opening, on the light overstorey conditions, to the increased ventilation, which brought about more rapid drying of the cone scales.

In the study it was also found that cone age had no effect on the ability of the cone to open. The greatest percentage of slash-borne cones opened during the first year under optimum temperature conditions. Additional cones opened during the second year owing to sagging of the slash and removal of shade by foliage deterioration. During the third year there were very few additional openings, since there was no appreciable change in the temperature or ventilation conditions. It has also been suggested in this study that local climate, particularly aspect, plays an important role in determining the maximum radiation temperatures. As would be expected, southerly aspects consistently produce higher temperatures than do northerly exposures.

It was observed that individual trees showed distinct habits of bearing their cones closed, or open. That is to say, on some trees the resin bond remained intact and the closed cones remained on the trees for an indefinite period, whereas on others the cones opened naturally within a short time after they had matured. This observation resulted in a further study by Crossley (1956a), to investigate the cone-bearing habits with particular emphasis on the circumstances surrounding the bearing of serotinous and non-serotinous cones. Both stands and individual open grown trees of various ages under a variety of conditions were studied. The study included two-year-old cones, as well as cones up to 20 years of age. On a series of individual open grown trees every cone on each tree was inspected, its age determined and its state, either closed or open, was recorded.

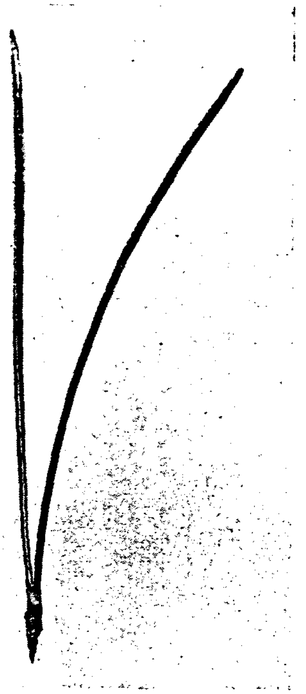

Plate 3. Needles of lodgepole pine.

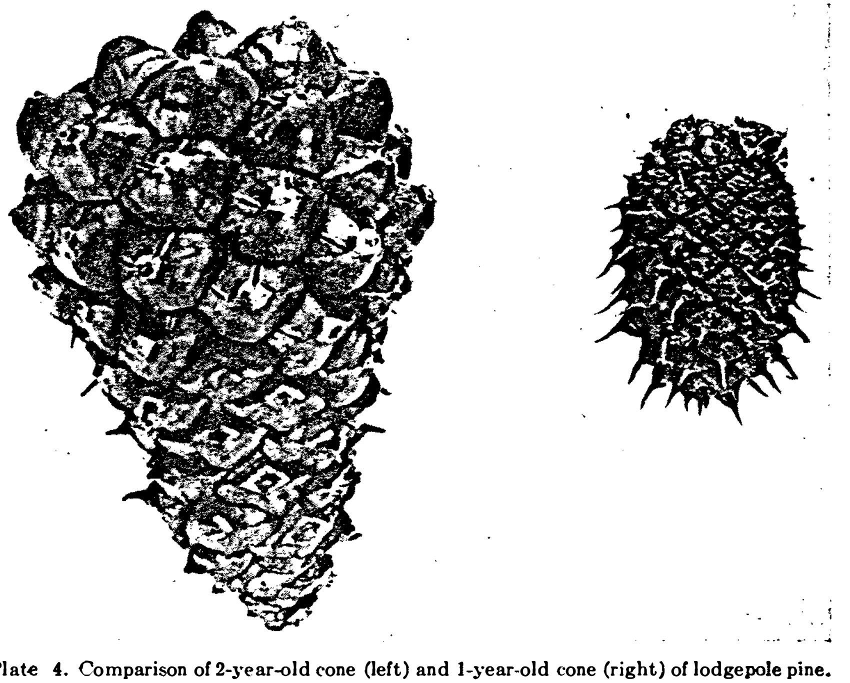

Plate 4. Comparison of 2-year-old cone (left) and 1-year-old cone (right) of lodgepole pine.

As a result of this study it was established that individual trees may be classified as bearing their cones serotinously, non-serotinously, or they may have intermediate tendencies, bearing some cones open and some closed. This habit, once set, remains in effect for at least 20 years. Notwithstanding this finding, it was noted that the majority of the trees in young stands were open-cone while the majority in mature and overmature stands were closed-cone. This reversal could not be related to differences in site or soil conditions, and therefore Crossley concluded that there was a general reversal of cone-bearing habit during the life of the stand. This conclusion is substantiated by Mason (1915) who states that on the Targhee Forest on trees less than 55 years of age, five-sixths of the cones opened at maturity while on trees over 55 years, only one-fourth of the cones opened. Crossley (1956a) observed that cone-bearing became general in lodgepole pine at a very early age. In a 17-year-old stand 50 per cent of the trees were classed as cone-bearing and a total of 6,500 cones were borne by 7,300 trees on an individual acre. Since by far the largest proportion of these cones opened upon maturing, the residual seed supply in closed cones would be insufficient to restock the area in case of fire. Crossley also found that cone-bearing of young trees decreased at higher elevations in the subalpine forest; whereas 58 per cent of the young trees bore cones at an altitude of 4,800 feet, only 20 per cent were cone-bearing at elevations of 5,700 feet.

In investigating immature stands (55 years) and overmature stands (125 to 250 years), it was found that not only was the number of cones borne per tree much higher than in young 17-year-old stands, but also the majority of the cones were serotinous and consequently in case of fire a larger seed supply would become available. In such stands there was no well defined relationship between size of cone crop and crown class of the individual tree. In the immature stands and, to a greater extent, in overmature stands, a number of the trees, usually intermediate or co-dominant stems, were open-cone trees; however, since the number of these is not large, Crossley suggests that harvest cutting procedures dependent on residual stands for seed supply should be designed carefully to reserve these open-cone trees for annual seed production.

Detailed examination of 20 years of cone crops on individual trees showed that while there is a variation in volumes of yearly crops there was no case during the 20-year period when a nil crop was recorded.

1.23 SEEDING HABITS

Because of the characteristics mentioned in the preceding section, it is necessary to consider the seeding habits of lodgepole pine under a variety of conditions, including stand age and nature of seedfall, whether fire-induced or natural from non-serotinous cones.

In young stands the majority of the seed is disseminated annually. Crossley (1956a) estimates a total cone crop of 6,600 cones per acre, of which roughly 17 per cent are serotinous. At an average of 40 seeds per cone, as suggested by Bates (1930), this would indicate that roughly 45,000 seeds would be retained in serotinous cones and would be available only in case of fire. Crossley suggests that this seed supply might in some cases be inadequate to regenerate the stand in case of fire.

Plate 5. Flushed vegetative buds of lodgepole pine and the position of 1-year-old cones.

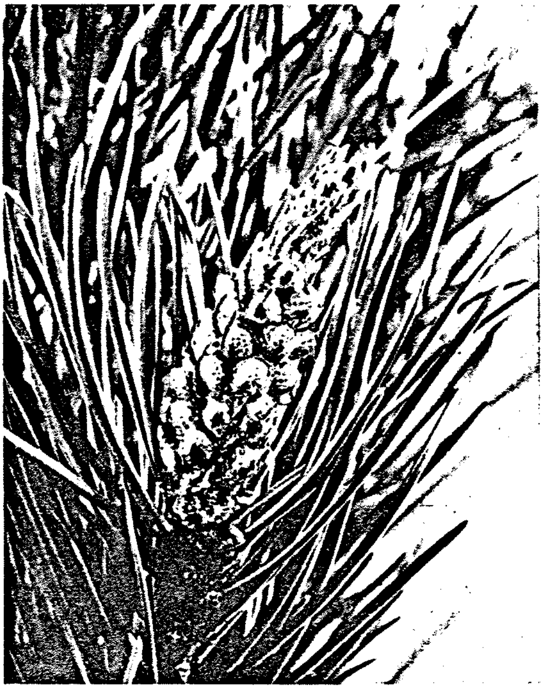

Plate 6. Position of male cluster on a lateral branch.

Plate 7. Partially opened lodgepole pine cone on a young pine.

Seed supply in immature stands presents an entirely different picture. Crossley (1955c) carried out a study on annual seed supply of naturally released seed using seed traps and estimated the annual seedfall per acre at roughly 30,000, 10,000 and 24,000 for the years 1952, 1953 and 1954 in a subalpine stand at Kananaskis, Alberta. However, since in this area 92 per cent of the trees fall into either the closed cone or intermediate classes, it may be estimated that the total seed supply carried in both serotinous and non-serotinous cones would lie between 100,000 and 300,000 seeds per acre. This figure may be compared with those shown by Bates (1930) for the Medicine Bow area in Wyoming. In this area, based on accurate cone counts from felled trees, the average annual total crop including new and old cones over a 10-year period was 253,699 seeds per acre with a range from roughly 26,000 to 536,000 in bad and good years. It is likely that additional records at Kananaskis will show an increase in yearly variability of seed crop. Crossley concludes that the seed crop borne in closed cones and released in case of fire would be adequate or even super abundant, while the annual crop available from non-serotinous cones might well be insufficient to adequately restock a cut-over area.

In addition to investigating the amounts of lodgepole pine seed released annually, Crossley used seed traps to investigate the distance to which this seed was carried by prevailing winds. The resulting catch of seed showed that there were no significant differences in the seed catch between various distances, from 1 to 5 chains, to the lee of the stand. For the period 1952-54 the annual seedfall to the lee of the stand varied from 550 to 2,450 viable seeds per acre. However, the amount of seed caught directly under the stand was many times as great as the catches at various distances from the stand. It was also found that while small amounts of seed were released continuously through the year, the maximum seedfall occurred over a 4 to 5 week period which climaxed around the first of October. In general, Crossley concluded that the annual seedfall from non-serotinous cones in mature stands would be inadequate to insure restocking of an area. The results of the seed trap catches have been checked by scarifying the area previously occupied by the seed traps and by tallying the weekly survival of lodgepole pine seedlings. The results of this study confirm Crossley's predictions in that a milacre stocking of 50 per cent was obtained at the edge of the seed source while stocking at 1 to 5 chains from seed source averaged only 8 per cent.

Planting in Alberta has largely consisted of erosion control and windbreak establishment; therefore, little attention has been given to planting of lodgepole pine or the associated problems of seed collection and extraction. However, in the northwestern United States considerable work has been done in the field. Bates (1930) found that the viable seed was borne in the upper half of the cone and that there was no object in attempting to spread the basal scales. While the average number of seeds per cone was considered to be 40, individual cones produced as few as one or two seeds. The normal number of cleaned seeds per pound was 100,000 and customary extraction methods yielded between one third and one half pound of seed per bushel of cones. It was found that the viability of seed from newly matured cones is generally greater and more regular in germination period than that of seed from old cones. Cone collection and cone storage methods for lodgepole pine vary little from that for other pine species. Squirrel caches are regarded as a simple and effective means of accumulating quantities of cones. The picking of cones from standing trees except for special experimental purposes is not regarded as economical, while the gathering of cones from logging operations is largely a matter of timing, although the serotinous nature of the cones makes the timing factor less important than in other species. Cone storage prior to seed extraction is important only insofar as it is necessary to provide a relatively dry location with adequate ventilation. Bates suggests that the highest quality of seed is produced when a maximum amount of air drying is accomplished during storage prior to kiln drying of the cones.

Seed extraction from lodgepole pine cones is a major problem since the serotinous character of the cones necessitates the application of considerable heat. Bates' work indicates that necessary extraction facilities include the provision of a steady supply of hot air with adequate circulation through cone trays each containing only a single layer of cones. The cone tray elevation in the kiln should be rotated to provide even heating of all trays and they should be shaken frequently to extract the seed. From a viewpoint of economy, the extraction room should be adequately insulated against heat loss. Bates, however, notes that heat alone does not cause the opening of cones, and that air dryness is of maximum importance. Heat serves mainly to dry the air and the process is wholly ineffective in warm moist air.

The storage method recommended for lodgepole pine seed is sealed storage at temperatures ranging from 32° to 50° F. It is worthy of note, however, that lodgepole pine seed can remain enclosed in the cones on living trees up to 30 years without serious loss of viability.

1.24 GERMINATION AND SEEDBED PREFERENCES

Two aspects of the germination ability of lodgepole pine are of particular interest. The first is the germinative capacity of artificially extracted seed under known conditions. Information on this subject is presented by Bates (1930). In a series of 413 uniform tests each with a duration of 62 days under minimum temperature of 57° and a maximum of 83° F., at moisture contents between 6 and 10 per cent, 41 days were required to bring about 80 per cent of capacity germination. Bates also predicts that no more than 75 per cent of capacity germination can be expected under ideal nursery conditions. Seed dormancy does not present a serious problem in this species; however, minor occurrence of what is probably embryo dormancy has been reported (Anon. 1948).

Unfortunately, there is very little specific information on the behaviour of lodgepole pine under field conditions. This species has been noted for its ability to regenerate following fire, which, in addition to releasing an abundance of seed, also creates a favourable seedbed by destroying litter accumulations, and reduces competition for both light and moisture to a low level. The fact that tallies of 500,000 established 5-year-old seedlings per acre have been recorded in the Cypress Hills area of Alberta provides some indication of how successful germination can be following some fires. Notwithstanding the spectacular results in germination produced on some burned-over lands, there are also burned areas where pine reproduction, even with a seed supply available, has been a failure. No doubt special circumstances related to soil conditions or character of the fire brought about such failures. Detailed investigation of fire in relation to lodgepole pine germination would produce valuable silvicultural information.

Studies of seedling establishment and stocking in subalpine lodgepole pine stands following fire were carried out by Horton (1953 and 1955). It was observed that while most of the seedlings came in within three years following the fire, a substantial percentage became established during the subsequent three-year period and some even later. Horton showed that stocking was poor on the steep slopes with southerly and south-westerly exposures and was densest on the northerly slopes. In general shallow, stony and dry soils showed low stocking while deep moist well-drained soils tended to over-stocking. Similar trends of stocking were noted by Stahelin (1943) on burned areas in Colorado. Mason (1915) showed that 70 per cent of the lodgepole pine reproduction of sample areas came in within the first 5 years after the fire, 21 per cent more came in during the subsequent 5 years and the balance seeded in during the next 20 years.

The basic factors affecting lodgepole pine germination and establishment include moisture, temperature, and light. Bates (1924) states that germination of lodgepole pine seed is best under wide diurnal temperature fluctuations amounting to 30° F. He points out that this species requires a high degree of insulation, the seedlings seldom being injured by direct heating. It is generally considered that temperature conditions in Alberta during the growing season are not limiting to the establishment of pine. Moisture conditions, however, may frequently be a critical factor for both germination and survival. In general, it has been observed that pine seedlings germinate and become established on mineral soil whereas on deep litter accumulations, germination may take place, but survival is poor because of the rapid drying of litter in drought periods and the failure of the root system to become firmly established in a permanent moisture supply. Horton (1953) and Mason (1915) both noted the tendency toward heavier stocking of lodgepole pine in burned areas on the cool moist ecoclimate of north and northeastern exposure. On the other hand, excessive moisture also appears to deter abundant germination and survival. It has been frequently observed that high water table areas, occurring under muskeg conditions in northern Alberta after fire, produce sparsely stocked stands of lodgepole pine. Lack of aeration and limited rooting area appear to be the causes for the low survival of pine on such areas.

While the light requirements for germination are low, the species is definitely intolerant and excessive shading may retard or prevent the subsequent growth of the seedling. The presence of overhead shade may help to reduce evaporation and thus increase moisture, but lodgepole pine must in general be regarded as a species adapted to reproducing on open dry conditions with an absence of vegetative competition. Bates (1924) states that its slow rooting habit is adapted to conditions where vegetational competition is negligible and where surface moisture must be well utilized.

Observations by Crossley (1952) suggest that germination and establishment of lodgepole pine seedlings are more readily obtained in cut-over stands in the northwestern region of the United States than in Alberta and he attributes this difference to the heavier accumulations of litter and more complete vegetative cover, particularly grasses, present in Alberta. It therefore appears that intensive study is required on the problems of germination and seedbed conditions for lodgepole pine in Alberta. Scott[1] established a replicated split plot experiment to investigate the effects of vegetation removal, trenching, duff removal, and burning, on the germination and survival of lodgepole pine. Reporting on this study, Ackerman (1957) concluded that none of the treatments produced significantly different results, although those treatments which increased available moisture caused somewhat better germination and survival. Since survival was good on all of the treatments, Ackerman suggests that the untreated area had adequate available moisture and consequently seedbed treatment did not significantly improve the results.

1.25 FORM OF BOLE AND CROWN

Lodgepole pine is notable for its variability in form of bole and crown, associated with differences in number of stems per acre and site quality. Age also plays an important role in the appearance of this tree. Relatively open-grown young trees have a fully foliaged, conical crown, and exhibit thrifty leaders up to two feet in length. The boles of such trees taper noticeably in an almost conical form. On the other hand, in extremely dense stands of up to half a million stems per acre, the young trees show a mere tuft of chlorotic foliage and leaders are extremely short, usually only a few inches in length. The stem itself is whiplike and hardly thicker at ground level than at the top. Surprisingly enough this general appearance is also exhibited in low-density stands where growing conditions for pine are submarginal, such as in muskegs and other high-water-table conditions.

In more mature stands, density again imparts a distinct appearance to lodgepole pine. In the highest density classes (10,000 stems per acre at 90 years) the individual trees are rarely over 20 feet in height and 3 inches in diameter. The crown consists of sparsely tufted foliage and the stem shows very little taper over its length. In medium densities (1,000 to 3,000 stems per acre) the crown is typically long and narrow and the tips of the branches are distinctly

[1]D. R. M. Scott, formerly forest research officer, Forestry Branch, Dept. of Northern Affairs and National Resources, Calgary, Alberta.

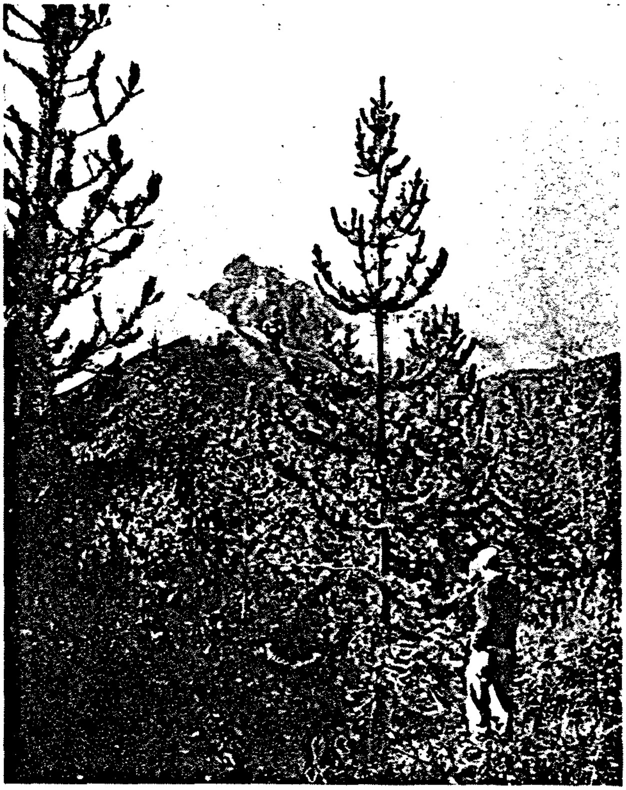

Plate 8. Typical form of a thrifty 14-year-old lodgepole pine sapling.

upswept. Such branches are usually fine, rarely over 3/4 of an inch in diameter. Form class in such stands usually is high, averaging 70 to 75 per cent. In low-density stands (100 to 600 mature trees per acre) the crown form is distinctly triangular with a greater width in relation to its length than in medium-density stands. The individual trees of the low-density stands have of course a much greater crown area than is present in medium or high-density trees. The bole form in low-density stands shows considerably more taper and form class customarily runs between 65 and 70 per cent. Branches in low-density stands are relatively large in diameter, 1 or 2 inches, and show little, if any, tendency to be upswept at the ends. As would be expected, variation in crown form occurs within a stand depending on the degree of dominance of the individual tree. While intermediates and co-dominants of high-density stands have the typical tufted crown, the dominants in such stands have the longer narrow crown more typical of medium-density stands.

Observation has indicated that there are some differences between the crown forms of lodgepole pine in the Subalpine and Boreal Regions of Alberta. While crowns in the Subalpine are typically long and narrow and consist of fine upswept branches, those of the Boreal are shorter, broader and composed of heavier, less upswept branches. It is difficult to say whether these crown differences are merely a reflection of lower density conditions which prevail in the boreal forest or whether they are also a result of genetic differences. It does appear likely, however, that the natural hybrids of lodgepole and jack pine may exhibit difference in crown form.

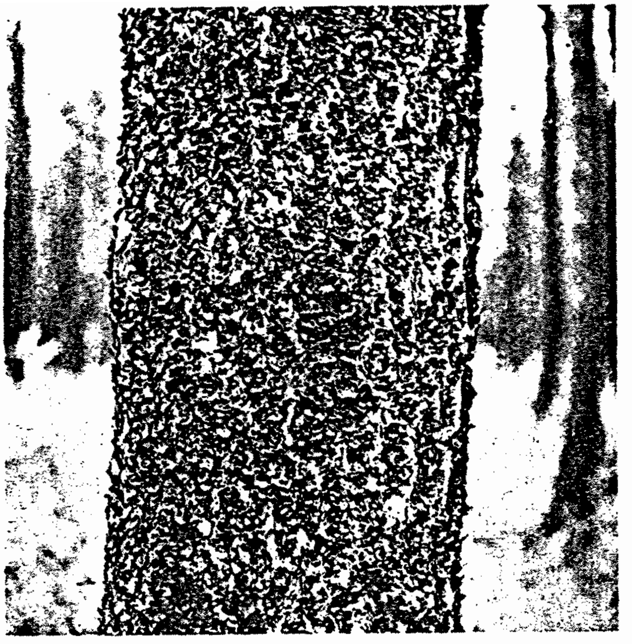

Plate 9. Bark habit of mature lodgepole pine in Alberta.

Plate 10. Crown form of an open-grown 85-year-old lodgepole pine in the Subalpine region.

While such crown differences are mainly of passing interest, they do affect thinning practice to some extent. In the Subalpine Region, in order to maintain the long, thrifty dominant crowns associated with vigourous growth, competing crowns must be separated quite widely. In the Boreal, however, the shorter, broader crowns may almost touch each other and still provide adequate space for rapid diameter growth.

The most widely used classification of lodgepole pine vigour based on crown form is that developed by Taylor (1937). This classification was based on data from Colorado and Wyoming and was designed for use in selectively cut pine stands. While it is doubtful if selective cutting will play an important role in pine silviculture in Alberta, it is possible that such a classification may be useful in research and inventory work. Based on the crown diagrams shown by Taylor, it appears that he was dealing with lodgepole pine similar to that occurring in the Subalpine Region in Alberta, i.e., long narrow finely branched crowns. However, it is doubtful if such a classification would apply in the Boreal Region of Alberta where crowns are typically broader, shorter and more heavily branched.

Maximum size of individual trees is a matter of only limited interest, since such trees are usually relics in a rapidly deteriorating over-mature stand. Horton (1956) found some of the largest pine in Alberta in a stand bordering the high and low foothills (4,100-foot elevation) on moist well-drained soil. The stand was 300 years old and lightly stocked. One of the largest trees in the stand was 29 inches d.b.h. and 117 feet in height. In the mountains and high foothills Horton describes lodgepole pine as reaching diameters of 15 inches and heights of 75 feet. Tackle (1953) describes one of the best stands in the Intermountain Region of the United States which reached a height of 80 to 90 feet and diameters of 20 to 26 inches on good sites. Volume table data gathered in British Columbia show measurements of lodgepole pine up to 30 inches d.b.h. and heights of up to 130 feet.

In Alberta, because of widespread fires, lodgepole pine stands rarely reach very great ages. Horton (1956) recorded a maximum breast height age of 375 years in a high mountain valley. Tackle (1953) states that lodgepole pine grows in pure and mixed stands up to 350 years old in the Intermountain Region of the United States.

1.26 ROOT SYSTEMS

While lodgepole pine was previously regarded as a deep-rooted species with a well-developed tap root system suited to survival on dry soils, studies by Horton (1957) show that this species has a more variable rooting characteristic than had hitherto been suspected. A series of open crown trees of various ages on different soil conditions were selected, and both their vertical and lateral root systems were excavated and studied. The primary problem studied was the relationship of root form to age but, as a secondary approach, an attempt was made to recognize simple differences in rooting habit associated with variations in the soil conditions. With regard to the primary problem Horton found that although root form varied widely from tree to tree, the tap root form is characteristic in seedlings and saplings on most soils. Maximum lateral extension of the roots occurs before the trees reach the polewood stage, and the development of a complex system of sinkers from near the bases of the laterals results in a heart-shaped rooting tendency at the polewood stage. This heart-shaped

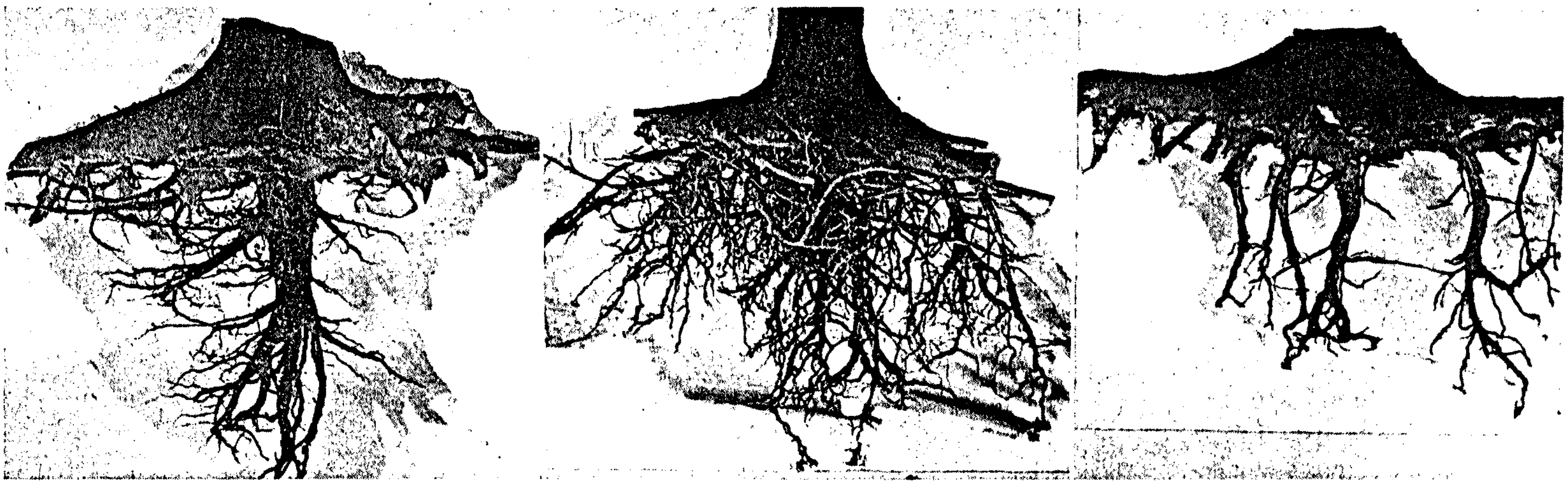

Plate 11. Three variations of root form in an 85-year-old pine stand.

form persists until maturity. The maximum rooting depth found in any specimen was 12 feet. Horton also reported the presence of root grafts in lodgepole pine stands.

In studying root form in relation to soils it was found that vertical rooting is restricted by either a desiccating layer of coarse soil, an impermeable layer, or a high water table; under such conditions the roots become bent, convoluted, clubbed or dead. Rooting is more concentrated in the finer textured soil where both moisture and fertility are superior, and this is reflected in superior stem height growth. It is concluded that under normal soil conditions lodgepole pine should be classed as a windfirm species but abnormal soil layers which discourage vertical root penetration subject it to windthrow.

There is little doubt that a relationship exists between stand productivity and rooting habits of lodgepole pine and many of the problems of yield in relation to soil conditions may be explained through the study of root characteristics. This work is, however, time-consuming and the full investigation of these conditions must rest with the future.

1.27 SEASONAL GROWTH

Certain aspects of seasonal growth of lodgepole pine have been already dealt with under the heading of phenology. However, additional information has been gathered in Alberta which is of some interest. Horton (1958), studying weekly height growth in the Kananaskis watershed, found that there was no appreciable difference in weekly growth trends on various aspects at a single location; however, on the southern aspect the commencement of growth was earlier. In the same study Horton suggests a relationship between weekly height growth and mean weekly temperature. However, it was further noted that a rapid decline in growth followed a mid-season decrease in temperature to below 30°F.

Studies of seasonal diameter growth of lodgepole pine were undertaken at Kananaskis in the Subalpine Division and at Strachan in the Low Foothills Division. Daily growth was measured using a dial gauge dendrometer. The study of average trends of 30 trees for 2 years at each of the two locations indicated that inception and cessation of growth took place at roughly the same date at both locations in spite of a difference in elevation of 1,000 feet. Differences in the length of growing period for individual trees were observed in this study. While trees of poor vigour had completed their diameter growth by the first of July, trees of good vigour continued their diameter growth, having completed only 75 per cent of their growth by July 1.

2. ECOLOGY

Forest ecology in the lodgepole pine region of Alberta has not, to date, been generally accepted as the basis for forest management; however, as the emphasis changes from exploitation to growing of forest crops, the need for ecological information will become more evident. Forest management on an ecological basis demands a knowledge of cover type distribution, yield capacity and successional trends. These factors depend on the interplay of habitat conditions, internal stand processes, silvical characteristics and stand history.

Research designed to describe environmental complex of the lodgepole pine area has been limited to date to broad reconnaissance studies such as those of Horton (1956), Moss (1953), and Halliday (1937). Research workers in other fields such as silviculture and mensuration have contributed some detailed information on certain of the factors involved, but such knowledge is incomplete and has never been tied together to form a clear picture of the lodgepole pine complex. The present requirements in this field of research are a detailed knowledge of the habitat features of the region and more specific information on the silvical characteristics of pine, particularly in the seedling stage.

The previous section of this report dealt with existing knowledge of the silvical characteristics of lodgepole pine; therefore this section is confined to a description of habitat conditions and stand history. On the basis of this limited information, current stand distribution, successional trends and stand productivity are discussed.

2.1 Physiography of the Lodgepole Pine Forest

The four phytogeographic divisions described by Horton (1956) within the lodgepole pine area of Alberta together occupy approximately 50,000 square miles or about 20 per cent of the province's total area of 255,285 square miles. The Low and High Foothills Divisions represent respectively 54 and 13 per cent of the lodgepole pine area. The remainder is made up of the Subalpine and Montane Divisions, the latter occupying less than two per cent of the lodgepole pine area.

2.11 GEOLOGY AND RELIEF

Allan (1943) states that with the exception of a very small portion of the Rocky Mountains, the underlying bedrock in Alberta is of sedimentary origin, both marine and non-marine. Exposed rocks in the lodgepole pine area range from the oldest, hard, Precambrian to the youngest, soft, Tertiary strata. Exposed formations become younger, thinner and softer on going from west to east. Topography varies from the very precipitous Rockies in the west to the gently rolling, low foothills to the east.

All the Alberta formations are found exposed in the Subalpine Division. Exposed rocks vary from marine to fresh water in origin. This division is characterized by rocks much older and harder than those found in the other divisions. While sandstones, quartzites and shales occur frequently, the major rocks are either limestone or dolomite. According to Laycock (1955), extensive folding and faulting strongly influenced the topography. Glaciated, U-shaped valleys are surrounded by precipitous peaks often rising above 10,000 feet. The mountain valleys are the result of differential erosion of less resistant rock formations along lines of structural weakness. The hard dolomites and limestones form the peaks, sandstone the ridges, and shales are found in the valley floors.

In that no interglacial beds were formed (Anon. 1947), it is recognized that the Subalpine Region of Alberta was subjected to only one glaciation by the Cordilleran ice sheet. Glaciation was confined to the valleys and lower slopes. The resultant debris was deposited in the valley bottoms by melt water. Deposits were usually silts and sands. Finer materials were usually composed of rock flour rather than clay.

While still of marine and fresh water origin, the exposed rocks in the High Foothills Division are younger and softer than those in the Subalpine. These rocks, belonging to the Wapiti and Saunder Groups of the Upper Cretaceous, are mainly sandstones, shales, conglomerates, and coal. The topography is rough but the precipitous slopes and high, serrated peaks of the Subalpine Divisions are absent. Folding and faulting are still very evident. The area is characterized by high ridges and narrow valleys which tend to parallel the Rocky Mountains.

Glaciation followed much the same course as in the Subalpine with the exception that almost the whole area was glaciated. Deposits which were much deeper and covered nearly the entire area were still light-textured in the main but appreciable amounts of clay were left.

Exposed rocks in the Low Foothills Division belong to the Upper Cretaceous and are of fresh water origin. They are young and quite soft in that they are composed principally of sandstones. Argillaceous sandstones, sandy shales, and coal, are also found frequently. The Paskapoo formation contributes the main surface rocks as it occupies the large trough-like depression known as the Alberta syncline which makes up a large portion of the Low Foothills Division. The Edmonton formation lies beneath the Paskapoo but is exposed in the rest of the area outside the syncline. The Edmonton differs from the Paskapoo formation in that it is older, and has no limestone, while the latter has many rocks of a siliceous limestone origin. The topography is rolling rather than hilly, and is characterized by the numerous rivers flowing to the east or northeast. These rivers have cut very deeply into the softer shales and argillaceous sandstones and have exposed very old strata. The ridges are usually found on the harder sandstones.

Glacial history is much more difficult to determine in this division of the lodgepole pine area of Alberta than in the other divisions. Three stages and two interglacial periods of the Keewatin ice sheet have been identified by Collins and Swan (1955). While the Cordilleran ice sheet played a part in the glaciation of this area, it must be pointed out that with the exception of the river valley floor gravels which are of subalpine origin, the vast majority of the deposits are the result of the last Keewatin ice sheet or Wisconsin glacial stage. These deposits, while still fairly light-textured, differ from those of the Subalpine and High Foothills Divisions, in that they may contain large amounts of clay and are usually several hundred feet in depth. The major deposit is in the form of an unconsolidated till mantle which covers the greater portion of the Low Foothills Division.

Figure 4 provides a broad picture of the changes in topography, climate and soil development found on an east-west transect of the range of lodgepole pine at approximately 53 degrees north latitude. Variations in the transect at other latitudes would include the progressive narrowing of the Low and High Foothills Divisions in the south of the province, and the disappearance of the Subalpine Region toward the north of Alberta.

2.12 CLIMATE

In general the climate of the lodgepole pine area in Alberta is characterized by short, moderately warm summers and long, relatively cold winters. While precipitation is low it is on the whole effective owing to the fact that more than 50 per cent of the year's precipitation falls during the short growing season.

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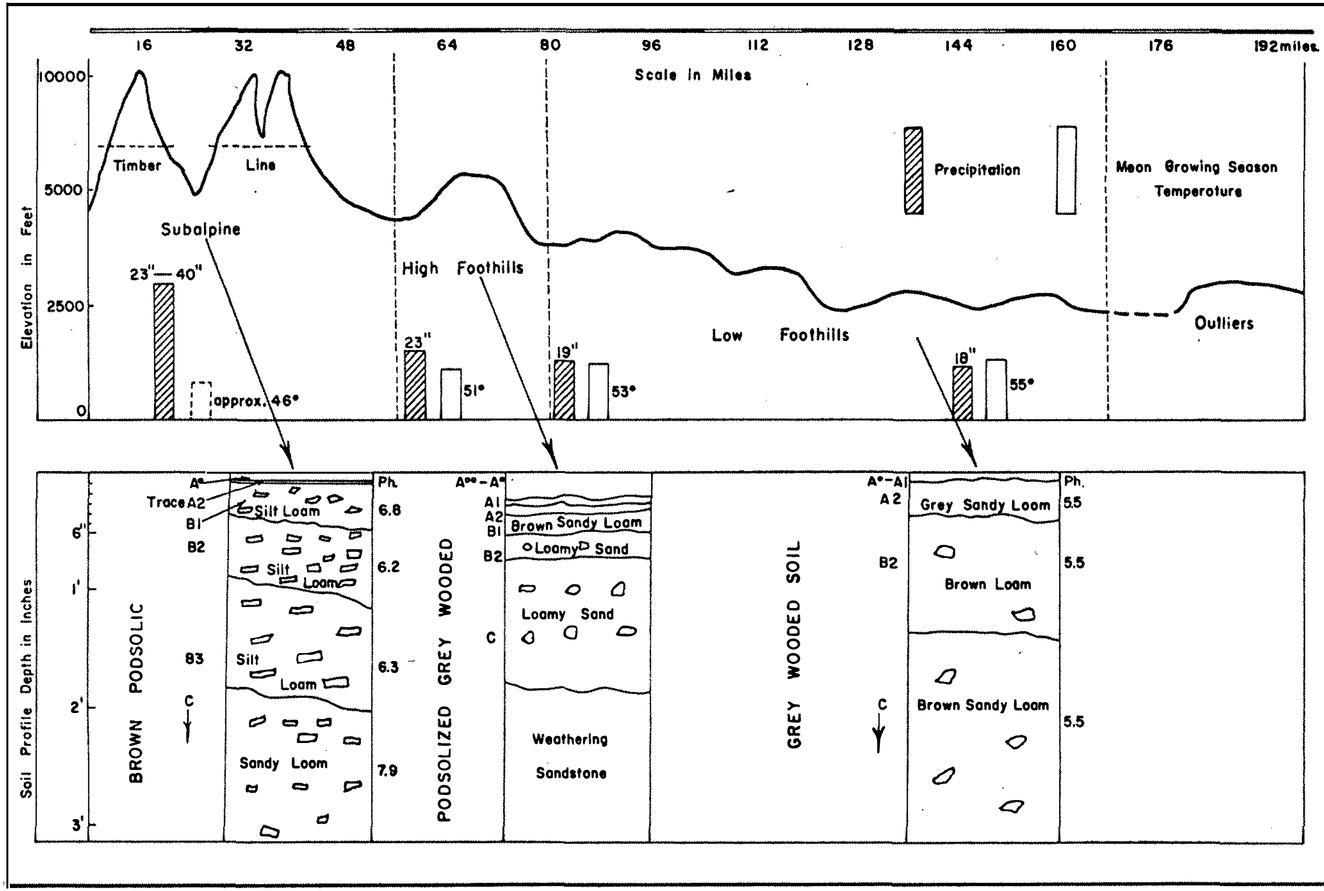

Figure 4. A profile of topography in the lodgepole pine region of Alberta, showing rainfall, mean growing season temperature, and soil profile development in the main phytogeographic regions.

Table 2 was compiled from "Climate Summaries" published by the Meteorological Division, Department of Transport, Canada. As no climatic data are available for either the Montane or High Foothills Divisions, any discussion of climate in the lodgepole pine area of Alberta must of necessity be restricted to the Subalpine and Low Foothills Divisions. Observation of the table indicates that, in general, precipitation increases with altitude but decreases with latitude. Temperatures become lower with an increased altitude.

In any discussion of climate in relation to soil development and the tree growth thereon it should be pointed out that local climate may be of much greater importance than regional climate. While the effect of local climate should be considered throughout the lodgepole pine area, its importance is greatly magnified in the Subalpine Division because of the pronounced relief. The weather stations of the Subalpine as indicated in Table 2 are not representative of the true climate. These stations are all in river valleys and lie at altitudes far below the average for the region. At altitudes over 7,000 feet, snowfalls of more than 30 feet are not uncommon.

2.13 LANDFORM AND SOILS

Throughout the lodgepole pine region of Alberta glaciation has been the dominant process of erosion and deposition. The landforms and soils occurring in the region are therefore typically of glacial or glacio-fluvial origin. A brief attempt is made to point out major differences in soil and landform between the main phytogeographic divisions rather than to describe in detail the individual landforms and soils of each division.

To date relatively few investigations of forest soils have been carried out in Alberta. Exceptions are the work of Crossley (1951) and Laycock (1955), concentrated in the Subalpine Region, and reconnaissance surveys of the Alberta Research Council in the Boreal Region. Currently, the Alberta Department of Lands and Forests is conducting management inventories on a basis of landform and forest site descriptions. However, the results of this information are not as yet available.

The broad differences in landform material in the various lodgepole pine divisions of Alberta may be summed up as follows. The depth of depositional material increases progressively from the Subalpine to the Low Foothills Division, while stoniness decreases. The texture of typical dumped till materials in the Subalpine Division is heavier than that of the Foothills Division. However, the occurrence of large areas of heavy-textured lacustrine and shoved lacustrine materials in the Low Foothills Division would indicate a somewhat heavier texture on the average in the latter area. The presence of these heavy textures in poorly drained depressions has resulted in a greater abundance of organic soils in the low foothills. The frequency of occurrence of wind-deposited materials appears higher in the Foothills Divisions than in the Subalpine. While the majority of the parent materials in all divisions are calcareous, this tendency is more pronounced in the Subalpine Region. Soil profile development varies from the typical grey wooded soil of the low foothills, through a podsolized grey wooded in the high foothills, to a brown or grey podsolic soil in the Subalpine Division. Soil profiles are in general better developed in the low foothills. It would appear that quality of the forest soils in the lodgepole pine region of Alberta mitigates the effects on tree growth of a rainfall deficiency which is characteristic of most of the area.

TABLE 2. CLIMATIC SUMMARY FOR SUBALPINE AND LOW FOOTHILLS DIVISIONS

—	Subalpine					Low Foothills				
	Lake Louise	Banff	Nordegg	Jasper	Subalpine Mean	Rocky Mtn. House	Edson	Beaver-lodge	Hudson Hope[1]	Low Foothills Mean
Years of Observation	21	49	24	22	—	22	22	31	23	—
Altitude (feet)	5,000	4,538	4,471	3,472	—	3,260	2,885	2,500	1,606	—
Latitude (degrees)	52	51	52	53	—	52	53	55	56	—
Total Precipitation (inches)										
Growing Season[2]	7.4	9.0	12.1	5.9	8.6	10.4	10.8	7.8	7.6	9.1
Annual	23.8	19.2	21.0	13.1	19.3	19.1	18.6	17.2	15.8	17.7
Snowfall (inches)										
Growing Season	4.8	6.3	7.2	1.9	5.0	2.7	1.8	3.0	0.6	20.1
Annual	139.7	78.1	78.2	40.3	84.1	55.7	57.3	70.1	58.9	60.5
Daily Mean Temperature °F										
Growing Season	49	53	50	54	51	53	55	56	55	55
Annual	31	36	34	37	34	34	36	35	34	35
Daily Maximum Temperature °F										
Growing Season	65	66	63	68	65	68	70	67	70	69
Annual	45	47	45	48	46	48	49	46	47	47
Daily Minimum Temperature °F										
Growing Season	33	39	37	41	37	38	40	43	40	40
Annual	17	24	22	26	22	20	22	25	21	22

[1]Station located in British Columbia but still in lodgepole pine region of foothills of Rocky Mountains.
[2]Months of May to August inclusive.

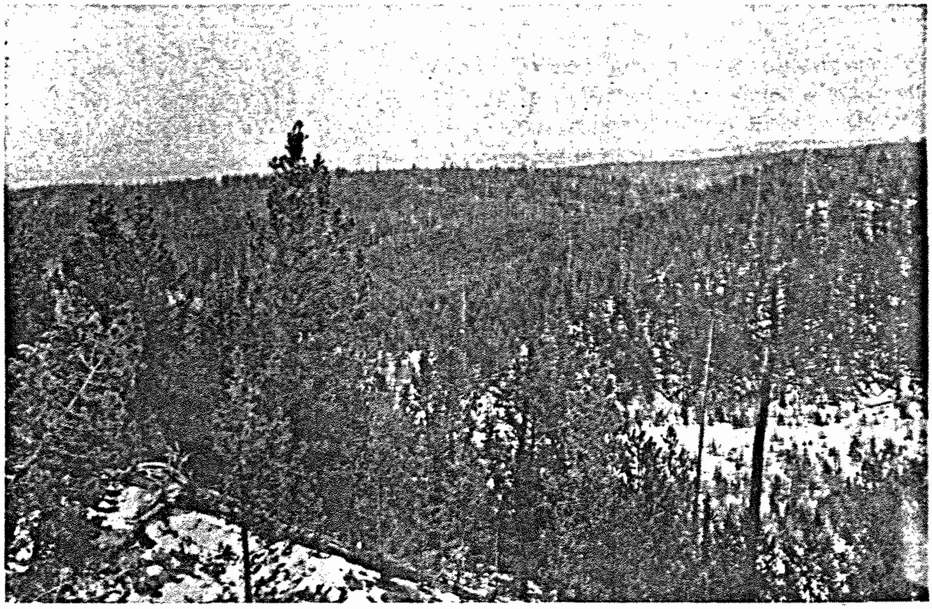

Plate 12. Topography associated with lodgepole pine in the high foothills section of Alberta.

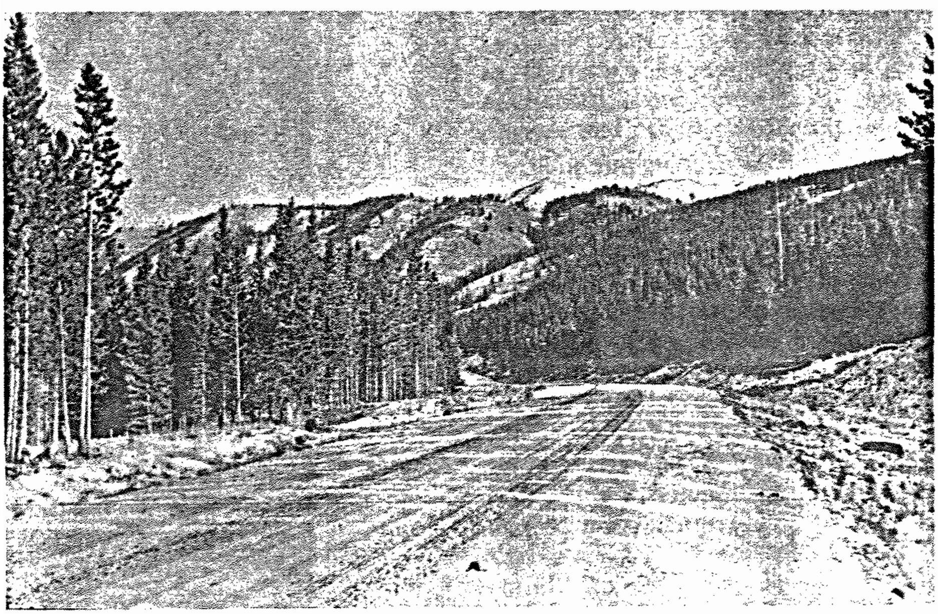

Plate 13. Topography associated with lodgepole pine in the subalpine region of Alberta.

2.2 Stand History Effects[2]

While both silvical characteristics and site requirements play a significant role in determining species distribution, nevertheless stand history in the form of various natural and human disturbances has been the major influence on the occurrence of lodgepole pine stands in Alberta.

In Alberta one historic event stands out as all-important in forest development—fire! Other events have been of secondary, or at any rate, of localized importance in Alberta's pine stands. Logging has been influential only in the Low Foothills Division where considerable partial cutting for pine ties and poles has been carried out in the more accessible mixedwood stands. The main effect of logging has been simply a depletion of the pine content, since the poplar was left untouched in practically every case. Neither windfall, destructive forest insects, nor pathogens have inflicted serious or extensive damage to lodgepole pine stands in Alberta within traceable history. Virtually all of the existing pine stands in Alberta are of fire origin.

The intensity of fire varies considerably, a fact which greatly influences the forest composition. In the denser pine stands it is usual for a fire to "crown", travelling rapidly and scorching all vegetation in its path. Broad comparison (Horton 1956) of successive pine stands affected by such intensive burning suggests that pine stocking tends to increase after each fire, providing the interval between fires is neither very short nor very long. The burning of immature and overmature pine stands will result in great variations in the regeneration stocking; instability of seed production usually exists in young stands owing to wide density variations, and in old stands because of a variable rate of succession to climax species.

Light ground fires occur infrequently in the three higher pine divisions but are very common in the low foothills, where the less combustible poplar is usually an abundant component of the forest cover. The effect of the ground fires is haphazard, some areas in a stand being untouched, some scarred in varying degrees and others completely denuded.

The importance of fire in the genesis of lodgepole pine stands is apparent from the consideration of the species' silvical traits. The serotinous cones allow seed to survive fire. They are, in fact, so adapted that only high temperatures will free the seed. Thus a great seed flight directly follows a fire. However, there is also considerable evidence that an appreciable amount of seed remains in semi-open cones to be disseminated periodically for several years afterward according to fluctuating weather conditions. Regenerated pine stands therefore usually have an age range of several years, though for practical purposes they may be called even-aged. The abundance of stored seed which is freed and the ideal germinating conditions for pine in recent burns account for the high density levels which so often exist.

There is a condition in which the age range of pine regeneration is liable to extend over many years, namely, when a light ground fire occurs, leaving a variable cover of residual trees. The result is generally termed a "two-aged stand". In actuality, the pine understorey is not even-aged but develops yearly or irregularly until the canopy is complete. In large openings this may involve up to 40 years. "Three-aged stands" resulting from two light fires since the original establishment also occur. Again, each "age" is represented by a variable

[2]The sections on stand history and succession of lodgepole pine were prepared by K. W. Horton, Research Officer, Forest Research Branch, formerly at Calgary, Alberta.

Plate 14. Two-aged stand of lodgepole pine resulting from a light ground fire.

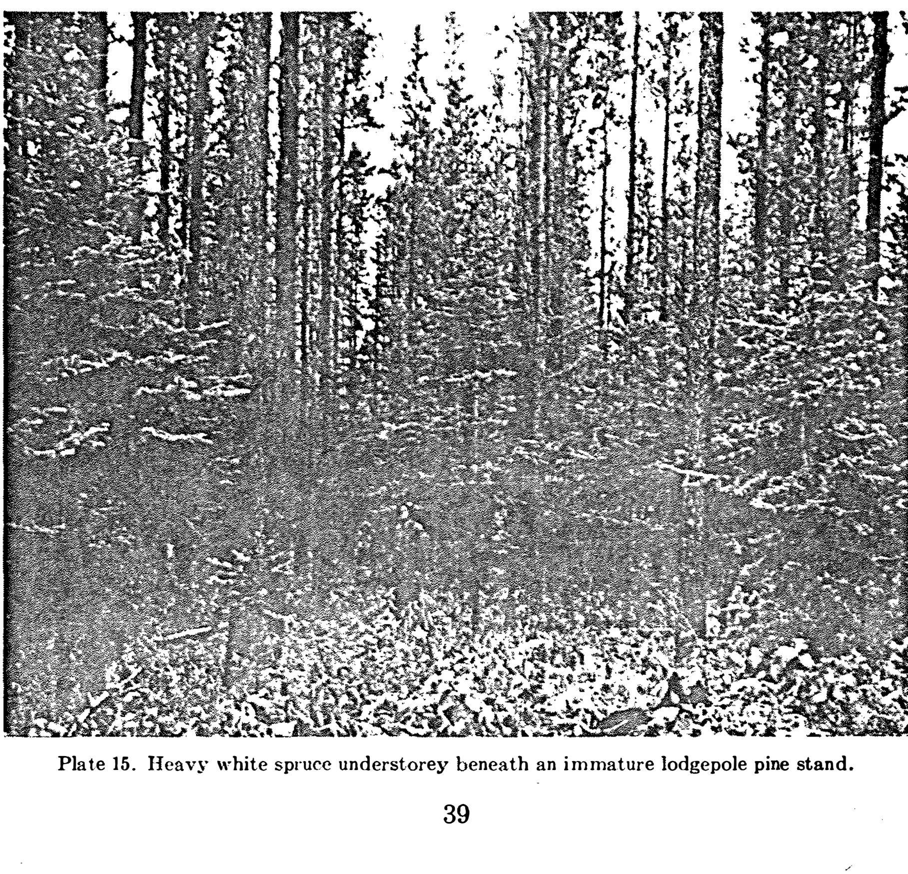

Plate 15. Heavy white spruce understorey beneath an immature lodgepole pine stand.

range of years. The abundance and vigour of the understorey in these cases relates directly to the density of the residuals. The denser the residuals, the poorer the regeneration in both stocking and size.

Occasionally a pine understorey may be found which did not originate from fire but through natural reproduction. Such stands are never extensive, apparently requiring two conditions, an abundance of light and a dearth of vegetative competition. Thus they are confined to open-stocked conditions on dry sites. This natural understorey differs from the fire-regenerated understorey in age distribution, generally occurring in two and three age concentrations. The explanation for this may be that the proper natural conditions for germination are likely to occur only once in many years. It was previously noted that a certain amount of seed is available annually from trees with non-serotinous cones, which explains the source of the natural reproduction. Competition from the parent trees usually results in suppression of the understorey and hence a high mortality rate.

Fire has influenced the development of lodgepole pine stands in another and more indirect way, through its effect on the distribution of associated species. Aspen, through its ability for prolific root suckering, is even better adapted than pine to regenerate in burns and, once established in an area, will multiply rapidly after each fire, except in the case of very intense fires which destroy the roots. The spruces and firs, not possessing the hard serotinous type of cone like pine, must rely on wind dispersal of seed from residual trees in order to spread into burned areas. Refugia for seed trees are common in the rough terrain of the mountains and high foothills, but are often scarce in the low foothills. Douglas-fir, when older, is capable of withstanding light ground fires by virtue of its exceptionally thick bark. As a result, residual Douglas-fir surrounded by irregular-aged fir reproduction may locally be found emerging above even-aged, younger pine.

2.3 Cover Type Habitat Conditions

While fire history has been the main factor influencing lodgepole pine distribution in Alberta, there is nevertheless evidence of site preferences which cause variations in cover type. Table 3 shows a broad scheme of cover type distribution in relation to landform material and moisture conditions in the Subalpine Division. This scheme indicates only the most prevalent condition and considerable variation in cover type and density can be expected within each physiographic condition.

In the Subalpine Division the most important landform-materials on an area basis are dumped tills. Moisture conditions on this heavy-textured stony till vary from arid to wet, depending upon slope, external drainage, aspect and exposure, and local climate. The three driest conditions are equally represented, while the moist and wet conditions are confined to local hangmoors.

The second most prevalent material of this region is a stony washed till of somewhat coarser texture. This material is commonly found on moderate slopes to flats. It is not uncommon to find washed till overlain by a cap of ponded silt and fine sand. The depth of this cap results in variations in the moisture regime. An uncapped washed till is classed as "arid", while a cap up to 18 inches in depth is regarded as "dry". Thicker caps result in a "fresh" condition.

Roughly stratified glacio-fluvial materials occur sporadically through the area. Exposed slopes on this material are termed "arid", while protected slopes are "dry".

Alluvial soils vary from coarse stony gravel deposits to loamy fine sands. Texture is the main factor distinguishing the arid, dry and fresh conditions; however, the presence of a water table frequently modifies the moisture regime.

Ponded materials usually consisting of stratified silt and fine sand also occur frequently in the Subalpine Region. Such materials are usually located in gently sloping or flat areas. Moisture regime on this material varies from "dry" to "moist", depending upon drainage and water table occurrence.

Talus soils occur at higher elevations in the subalpine forest. These are usually "arid" as a result of slope and stoniness.

Organic soils occur in the area in the form of beaver meadows, which may be classed as "moist" or "wet", depending on depth to water table.

TABLE 3. COVER TYPE HABITAT CHART, SUBALPINE DIVISION

Landform Material	Arid	Dry	Fresh	Moist	Wet
Dumped till	Pure pine, low density; scattered spruce understorey.	Pure pine or pine with scattered spruce[1]; moderate to heavy stocking; spruce-fir understorey usually present.		spruce pine mixture.	spruce with occasional pine.
Washed till					
Ponded					
Alluvial					
Roughly stratified					
Talus					
Organic				Spruce with scattered pine.	

[1]Spruce refers to either Engelmann or white spruce or hybrid forms, depending upon elevation.

Table 3 indicates the typical species habitat conditions of lodgepole pine in the subalpine forest. The pattern is one of even-aged lodgepole pine with varying intensities of spruce-fir understorey. This understorey is lightest on the arid and dry conditions and becomes progressively heavier as moisture increases. The density of the understorey and soil moisture influence rate of development toward a spruce-fir-pine forest.

In the Montane forest of southern Alberta, which is a warm-dry variant of subalpine conditions, it is not uncommon to find even-aged lodgepole pine containing overmature relics of a previous stand of Douglas-fir, particularly on the arid and dry conditions. Under some conditions reproduction of Douglas-fir occurs following the fire disturbance and results in an uneven-aged stand of lodgepole pine - Douglas-fir. This tendency appears to be more pronounced on the dry to fresh conditions.

Site conditions in the High Foothills are transitional between those of the Subalpine and Low Foothills Divisions. The influence of slope and drainage is similar to that of the Subalpine; however, the effects of aspect and local climate are less pronounced. The landform materials in this division include most of those present in the other two divisions. Talus soils are, however, absent and aeolian materials typical of the low foothills begin to assume importance in the high foothills. The net effect of the various factors would suggest a closer resemblance to subalpine conditions than to those of the low foothills.

TABLE 4. COVER TYPE HABITAT CHART, HIGH FOOTHILLS DIVISION

Landform Material	Arid	Dry	Fresh	Moist	Wet
Dumped till		Pure pine predominating, variable density; scattered white & black spruce & alpine fir understorey.		Dense pine with b. spruce understorey.	Black spruce with occasional pine.
Ponded					
Alluvial	Pure pine, usually low density; occasional spruce understory.				
Washed till		Pine–white spruce mixtures with scattered white & black spruce and alpine fir understorey.			
Roughly stratified					
Aeolian					
Organic				White spruce or black spruce with occasional pine.	

Cover type distribution in the High Foothills Division appears to be similar to that of the Subalpine with the exception that white spruce takes the place of Engelmann spruce and black spruce is frequently present, particularly in the northern portion of the division. Table 4 indicates a broad pattern of cover type distribution in relation to soil and moisture conditions in the High Foothills Division.

While aspect and exposure play a minor role in determining site conditions in the Low Foothills Division, the major emphasis is upon internal and external drainage. Table 5 shows the general conditions of cover type habitat distribution in the Low Foothills Division. Dumped tills in the Low Foothills Section are relatively stone-free, and the texture of the material varies from sandy loam to loam. Moisture regime on this material varies from "dry" to "wet" depending on slope position and degree of slope.

Lacustrine materials are prevalent on flat to gently sloping topography. These heavy-textured, clay loam to clay materials result in sites which vary from "dry" to "wet" depending on slope position. These materials frequently support lateral movement of moisture on gentle slopes and create "moist" to "wet" conditions owing to minor undulations in the topography.

Aeolian materials in the form of sand dunes occur frequently in the area. Moisture conditions may be either "arid" or "dry", depending upon slope and exposure.

Roughly stratified glacio-fluvial materials occur sporadically throughout the area. These are relatively stony and somewhat coarse in texture, sandy to sandy loam. Moisture regime on these materials varies from "arid" to "dry" owing to slope position and stoniness.

Alluvial materials varying from gravelly sands to sandy loams occur throughout the area in the form of terraces, flood plain deposits and old stream beds. Moisture conditions vary from "arid" to "moist" depending on stoniness, position of water table and slope position.

Ponded materials occur locally throughout the low foothills in minor depressions in the till plain. These deposits vary from fine sand to loam and are frequently stratified fine sand and silt. Moisture conditions are generally "fresh"; however, conditions may become "moist" in depressions.

Organic materials varying in depth from 3 to 10 feet are encountered in depressions in old lake beds. The edges of such depressions are classed as "moist", while the centers of these muskeg areas are termed "wet".

TABLE 5. COVER TYPE HABITAT CHART, LOW FOOTHILLS DIVISION

<table>
<tr><th>Landform Material</th><th>Arid</th><th>Dry</th><th>Fresh</th><th>Moist</th><th>Wet</th></tr>
<tr><td>Dumped till</td><td rowspan="2"></td><td rowspan="4" colspan="2">Pure pine or pine-aspen; scattered white spruce with spruce-fir understorey.</td><td rowspan="2">Pine, high density; heavy black spruce understorey.</td><td rowspan="2">Black spruce, scattered pine.</td></tr>
<tr><td>Lacustrine</td></tr>
<tr><td>Ponded</td><td rowspan="4">Pure pine or pine-aspen, low density; occasional spruce understorey.</td><td rowspan="2">Pine-aspen white spruce with white spruce-balsam fir understorey.</td><td rowspan="2"></td></tr>
<tr><td>Alluvial</td></tr>
<tr><td>Roughly stratified</td><td rowspan="2">Pure pine or pine-aspen.</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Aeolian</td></tr>
<tr><td>Organic</td><td></td><td></td><td></td><td colspan="2">Black spruce, occasional pine.</td></tr>
</table>

In the Low Foothills Division trembling aspen and, to a lesser extent, balsam poplar, become of major importance in the pine cover types. Table 5 indicates that pine-aspen mixtures are the most prevalent cover type and may occur on practically any site except the wettest conditions. A second cover type of major importance in the Low Foothills Division is the pine - black spruce mixture on moist tills and lacustrine materials. Such stands occur on very gentle slopes or poorly drained flats. Density of both pine and black spruce on such sites is usually excessive.

Stand development in the various cover types involves the interplay of silvical characteristics of the component species within the limitations imposed by site conditions. These factors are discussed under the heading of succession.

2.4 Succession

Several references to forest succession in connection with lodgepole pine may be found in the literature. Bloomberg (1950) and Cormack (1953) have recognized a general trend on the east slope of the Rockies from lodgepole pine, established after fire, to a spruce-fir climax. In the northern part of the low foothills, succession is less clearly evident but a trend from pine and aspen to white spruce is indicated (Moss 1953). Raup (1934) found a suggestion of succession from lodgepole pine to black spruce in the Caribou Mountains, an outlier of pine in the far north of the province.

Horton (1956) made a broad investigation of stand development, emphasizing the specific reactions which cause succession, and found that the situation in the Low Foothills Division differs from that of the three higher divisions. In the low foothills, where pine-aspen mixtures prevail, few stands have in the past escaped fire for more than 100 years and stands over 150 years old are rare indeed. This means that succession is a question of academic, not practical interest here. Following the destruction by fire of a mixedwood stand, pine and aspen regeneration compete as pioneers. The aspen suckers usually become established one or more years before the pine seedlings and are capable of much more rapid height growth. Thus aspen has an initial advantage over pine but this does not hold for long. Pine overtakes the aspen within 50 years and the two species compete equally to the point where aspen decadence becomes effective, about 120 years. At this time aspen mortality may be replaced to some extent by new sucker growth. Meanwhile, if the stand contains black or white spruce, many of the latter especially will have attained a position of dominance. Figure 5 shows the typical relative height growth trends of dominant lodgepole pine, aspen and white spruce competing together in an average mixedwood stand.

This trend applies on the majority of sites in the low foothills, those ranging between fairly moist and dry. Aspen is usually absent on the moister sites and is less vigorous than pine on very dry conditions. Any disturbance such as light ground fires or partial cutting greatly encourages fresh aspen suckering, whereas pine reproduction is sporadic or absent in such cases. The combined effects of fire and axe have thus led to an increase in aspen at the expense of pine in this division as a whole.

In the Subalpine, Montane and High Foothills Divisions, lodgepole pine has expanded to general dominance through the frequent recurrence of fire but the rougher topography has often provided local refugia where enough stands have attained advanced ages to give evidence of the course of succession. These also are seed sources for the dispersal of spruce and fir into adjoining young pine stands. As a result, there are few pine stands which lack some degree of a spruce, and to a lesser extent, an alpine fir understorey. Often it is merely an occasional seedling or sapling but rarely is it completely absent.

Most of the spruce will become established over an age range of some 10 to 40 years following the fire. The abundance and age variation of the understorey will decrease as the distance from the seed source increases. As the stand develops, the self thinning of the overstorey of pine will encourage scattered spruce seedlings to become established. Most of these will be confined to rotten wood seedbeds owing to the development of a dense feathermoss mat which discourages germination elsewhere. The spruce occurs as a suppressed understorey in young pine stands because it is initially slower in growth and often younger than the pine. However, as the pine approaches maturity its growth rate rapidly declines, whereas that of spruce remains steady. Thus there comes a point when the dominant spruce reach the pine canopy. This is a milestone in succession. It takes on the average about 125 years but ranges from 70 to 160 years. After this point, spruce waxes and pine wanes in a successional sense. As natural mortality

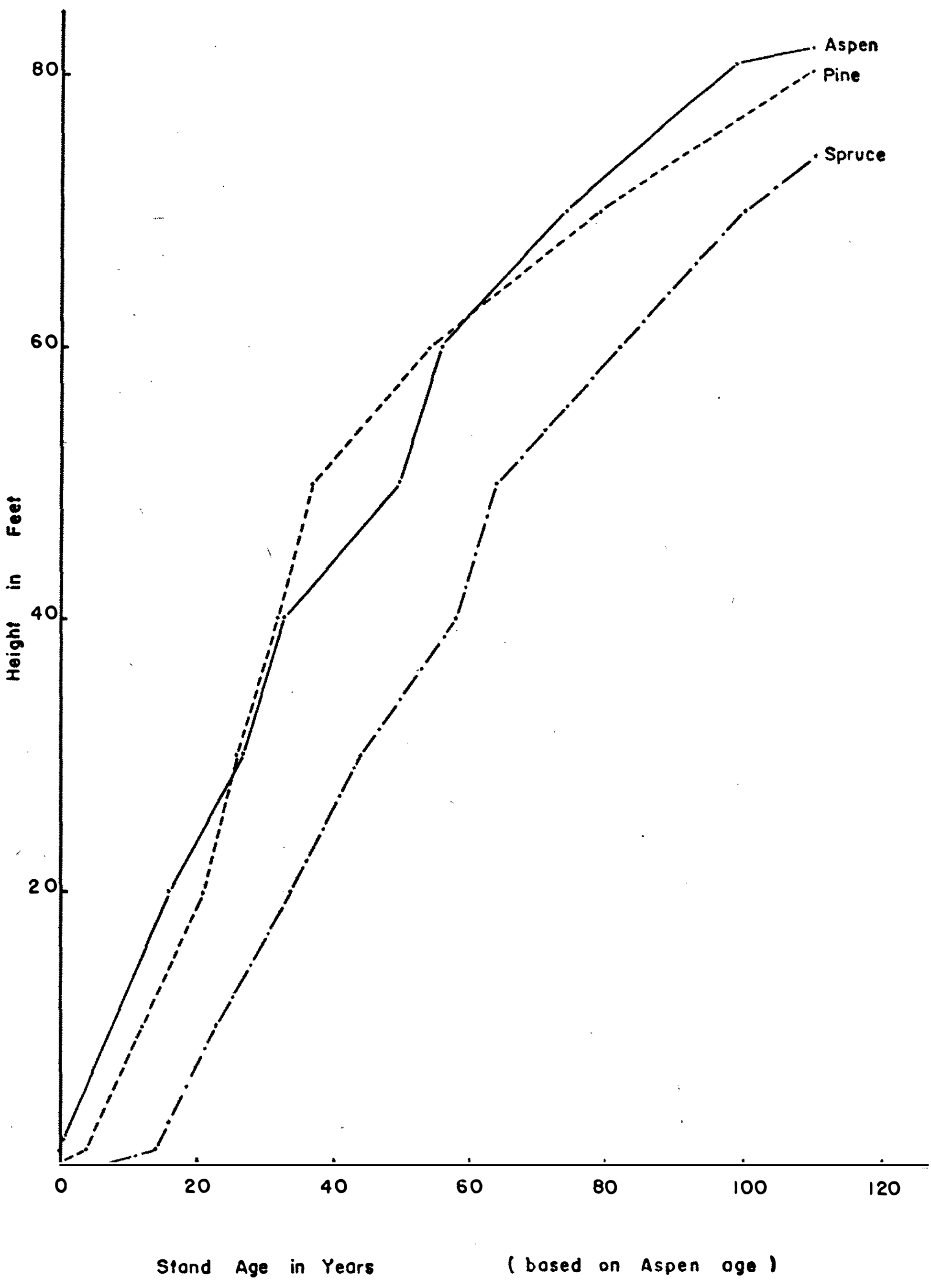

Figure 5. Sample height growth of competing dominant aspen, pine and white spruce.

gradually diminishes the pine canopy, an increasing number of spruce and fir trees are released to speed up the successional process. This could be called the near-climax stage in succession, consisting of a few remnant decadent pine, a dominant spruce overstorey of approximately the same age as the pine, and a spruce-fir understorey of uneven age, height and abundance.

The spruce referred to above could be either Engelmann or white, or hybrid. The successional development of both species in relation to lodgepole pine appears to be similar. This applies as well to Douglas-fir in the Montane Division. Black spruce, which is abundant in the foothills, has a much slower growth rate and hence is usually suppressed beneath pine and, later, white spruce throughout its lifespan. Once established in a stand, however, black spruce will perpetuate itself idefinitely by means of layers. Layering is also an important attribute of alpine fir; this, combined with its great tolerance and ability to reproduce by seed on a wide variety of natural seedbeds, makes fir the most abundant component of older stands. Despite this fecundity, alpine fir's relatively slow growth rate and high susceptibility to game browsing, insect attack and disease, generally prevent it attaining the position of dominance that white or Engelmann spruce holds in the overmature forest association.

Since competition from tolerant species is a major factor in the decline of lodgepole pine, the more abundant and vigorous the spruce and fir, the faster will be the rate of succession. Pine, therefore, will persist longer in stands where the original spruce seed sources were scarce. Moreover, such adverse conditions for spruce development as extremely high initial pine densities, and dry exposed sites, will retard succession. Examinations of old stands in the Subalpine and High Foothills Divisions indicate that succession from pine is usually complete by 300 years. It varies from about 225 to 375 years, the widest variation occurring in the Subalpine where conditions are more diverse. History has disclosed that long before the climax stand can become fully developed the chances are that fire will strike. Pine regeneration then evolves from seed sources in adjoining younger stands or from individual trees which have persisted locally within the spruce-fir community, and the cycle begins anew.

To summarize the foregoing discussion on the interplay of stand origin and site with the resulting successional trends, a series of representative pictographs are presented for the Low Foothills (Figure 6) and Subalpine Divisions (Figure 7). The latter can apply equally well to the Montane Division with the inclusion of Douglas-fir, and to the High Foothills, with the substitution of white spruce for Engelmann and the addition of black spruce.

2.5 Floristics

Table XXVI of the Appendix lists and evaluates the importance of the lesser flora of the lodgepole pine community by divisions (Horton 1956). These lists are similar to those compiled by Cormack (1953) for the southern part of the Subalpine Division, and by Raup (1934) and Moss (1953) for lodgepole pine associations in the Peace River region. A comparison between the divisions reveals a strong similarity in broad floristic structure and composition. Thus a general lodgepole pine association might be derived, considering the most important genera in each strata, as follows: *Pinus-Picea-Vaccinium-Elymus-Linnaea*-Feather Moss-*Peltigera*. Certain species are more characteristic of, and in some cases even exclusive to, certain divisions.

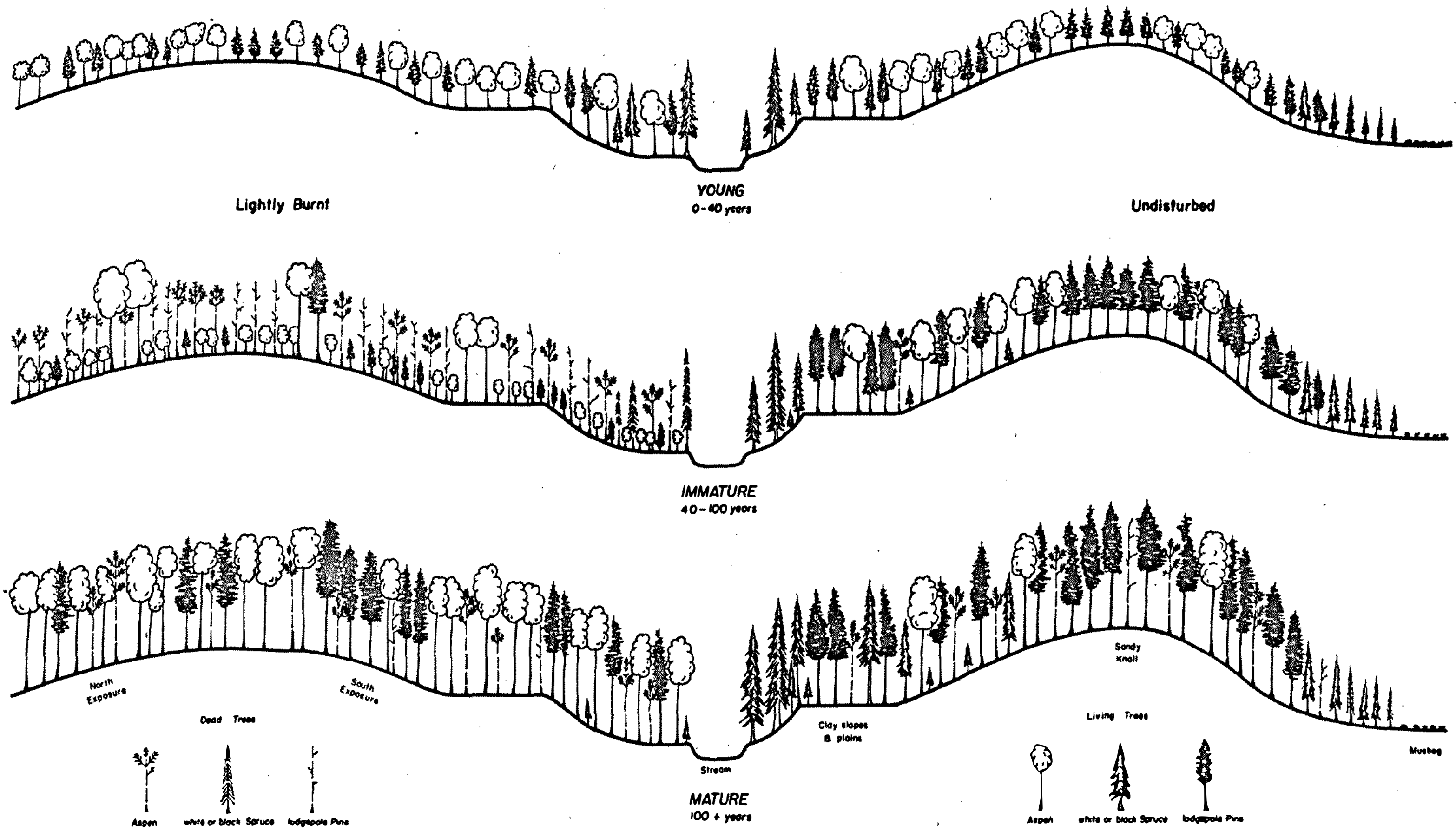

Figure 6. Stand development in the Boreal Forest of Alberta.

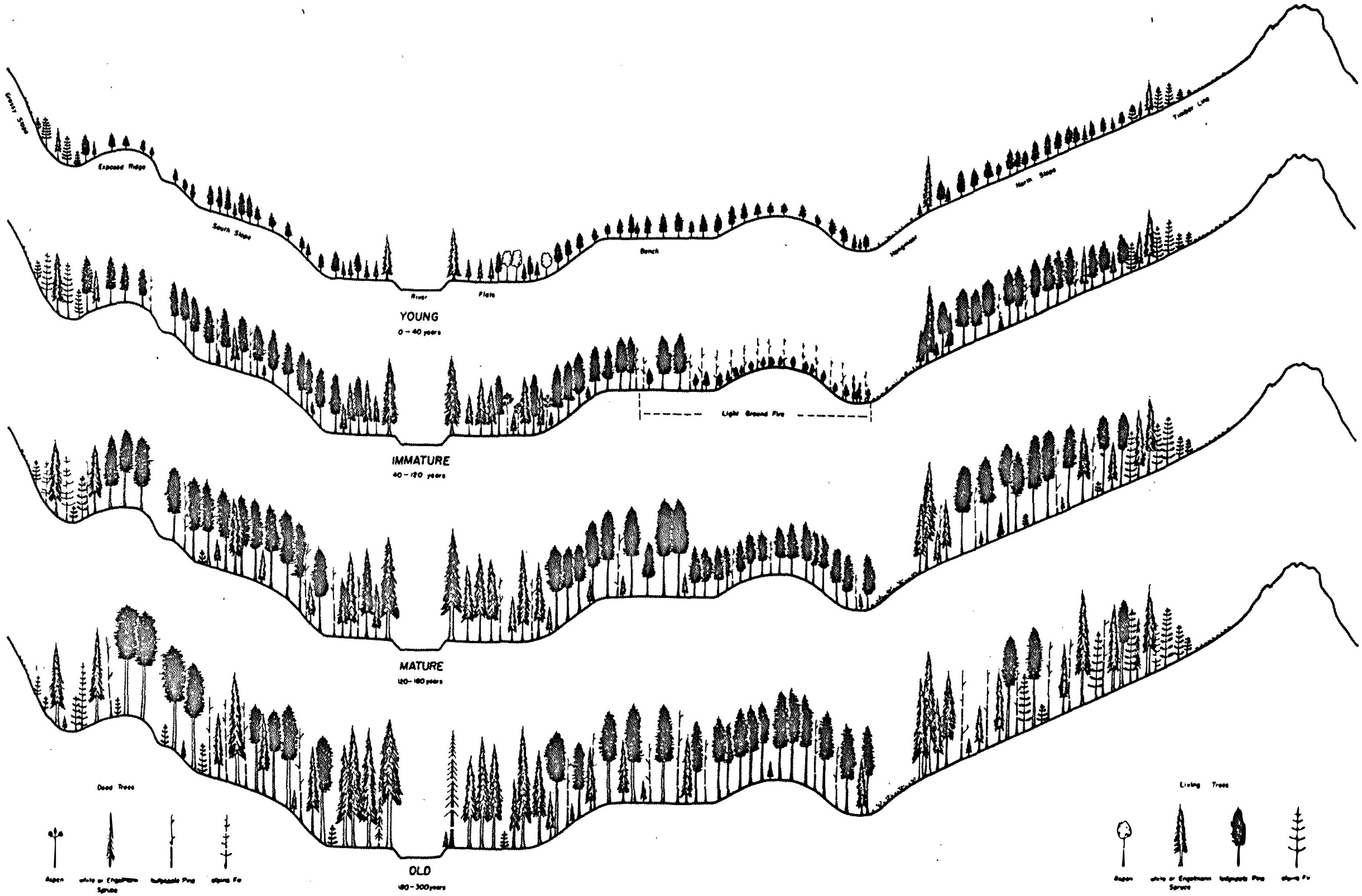

Figure 7. Stand development in the Subalpine Forest of Alberta.

Within each division the composition of the ground vegetation varies widely with site, density of the pine overstorey and stand age. Preliminary study suggests that the variations caused by stand density are as important or more so than those caused by site differences. Cormack (1953) describes the radical changes wrought on the lesser flora by long-term succession of the overstorey. The combinations of species resulting from these variables are so numerous as to defy further classification into associations on a practical level. Rather, the concept of a vegetational continuum would seem to apply. This envisages a continually varying series of species occurring on an environmental gradient mainly controlled by the reactions of the vegetation. In the lodgepole pine community the most significant reaction is succession which is primarily dependent on fire.

2.6 Site Classification Methods

A great variety of methods have been employed in attempting to classify site quality of lodgepole pine stands, but none of those tested to date can be regarded as completely successful. In order to be completely acceptable, a site classification method must show strong correlations with productivity and at the same time must distinguish sites from the standpoint of successional trends and reproductive capacities. In addition to being sufficiently simple to apply in the field, the system must lend itself to mapping both on the ground and from aerial photographs. Finally, a successful method of classification must provide for easy breakdown into sensitive classes for use in research work and also for grouping into broad classes suitable for large-scale management operations. In the case of lodgepole pine, none of the methods tested to date satisfactorily fill all of these requirements.

During the early years of exploitation in Alberta's forests, it was assumed that the simple relationship of dominant height at an index age might be successfully employed to define yield sites for lodgepole pine. Detailed study of the problem by Holman and Parker (1932) and Parker (1942) showed that variations in number of stems per acre exerted so much influence on the customary site index, dominant height, that its use for site classification purposes was limited. In the same study, Holman and Parker studied the effects of stocking on a site classification system based on vegetational associations. They concluded that vegetational associations in lodgepole pine stands were suited only to a very broad site classification and that stocking influenced the vegetation pattern as much as or more than did site quality. Parker (1942) attempted to develop an adjusted dominant height index through multiple correlation techniques using number of trees per acre as a correction factor. However, this approach met with only limited success and the index was not suitable for sensitive evaluations required for research purposes.

Systems of site classification have been recently developed based on physiographic, biological and cultural features (Hills 1952; Brown, Bedell and McLean 1954). The physiographic features serve as the frame of reference but this does not imply that they are all-important. The basic physiographic features emphasized are parent material, soil moisture and local climate.

Using physiographic site as the basis for classification, Smithers (1955) studied productivity of 90-year-old lodgepole pine stands in the subalpine forest. It was found that both dominant height and total volume were strongly influenced by variations in number of stems per acre on a single site. Basal area per acre showed the greatest stability and closest correlation with site quality. In dense mature lodgepole pine stands, dominant height could not be used as a valid measure of site quality nor as a measure of potential productivity. When dominant height was adjusted for variation in number of stems per acre, the results were still unsatisfactory. However, since both volume and dominant height are affected to a similar degree by the combined influences of stocking and site quality, the correlation between dominant height and current volume yield of lodgepole pine stands is moderately high. Consequently for simple yield table construction designed to determine future yields of stands which will not be subject to change in stocking owing to thinning and where the present stocking in terms of number of stems per acre can be established, dominant height may be regarded as a useful index of the combined effects of stocking and site.

From the standpoint of developing a measure of true site quality including potential productivity, regeneration capacity and successional trend, the "total site" concept appears to be the only method which indicates any possibility of success. This technique has been applied on only a limited basis in the pine stands of Alberta and considerably more research work is required before the method can be used for management in this area.

While detailed studies designed to subdivide lodgepole pine stands in Alberta into a series of site classes which represent productive capacity have not been carried out, it is possible on the basis of general observation to allocate representative physiographic conditions into broad preliminary productivity classes. This allocation has been based on the hypothesis that optimum moisture is the over-riding factor which determines lodgepole pine growth in Alberta. Limited investigations (Smithers 1955) tend to confirm this hypothesis. A similar trend in the relationship between productivity and moisture has been noted by Illingsworth (1958). The productivity range of lodgepole pine stands has been subdivided into four broad classes, "good", "medium", "poor" and "unmerchantable", which are designated as productivity class I, II, III and IV, respectively. For reasons mentioned previously, in particular the effect of stocking, it was necessary to select that growth function which exhibited the least influence from variable stocking; therefore, basal area in square feet per acre at stand ages between 75 and 100 years was selected. Basal area ranges have been assigned arbitrarily to the four productivity classes as follows: Class I — 160 square feet and up, Class II — 120–160 square feet, Class III — 80–120 square feet, Class IV — less than 80 square feet. Based on general observation and limited sampling of fully stocked lodgepole pine stands in the Subalpine and Foothills Divisions, the more important physiographic conditions have been assigned to productivity classes as shown in Table 6.

The classes I to III represent yield of lodgepole pine in pure fully stocked stands, i.e. 75 per cent by volume; however, class IV is either a swamp condition supporting black spruce with scattered lodgepole pine or a lithosol with occasional pine.

While yields in terms of basal area per acre are similar on related physiographic conditions in the Subalpine and Foothills Divisions, stocking is usually heavier in the subalpine forest; therefore merchantable volume yields will be lower in the Subalpine Division.

It must be re-emphasized that the tables showing relationships between stand composition, yield and physiographic conditions are based upon limited sampling and will be subject to revision when further data become available.

TABLE 6. SITE PRODUCTIVITY CHART, LODGEPOLE PINE IN ALL FOREST DIVISIONS OF ALBERTA

Landform Material	Arid	Dry	Fresh	Moist	Wet
Lacustrine					
Dumped till	III			II–III	IV
Ponded					
Alluvial			I		
Washed till	III	II			
Roughly stratified					
Aeolian					
Talus	III to IV				
Organic				III	IV

3. GROWTH AND YIELD

The study of growth and yield covers two main fields; the investigation of individual tree growth, and the determination of per acre yields. In the case of lodgepole pine, which grows in even-aged stands and produces a large number of small-sized trees, yield per acre is of primary interest. However, a knowledge of individual tree growth is essential to the development of thinning practice and also proves useful as a mensurational tool for determining yield per acre.

3.1 Individual Tree Growth

While various expressions of individual tree growth may be of importance to the forester, greatest interest is usually centred about the three variables, diameter, height and volume. These growth expressions are in turn dependent upon a variety of factors, those most generally accepted as important being age, density, and site quality. While certain growth expressions are primarily dependent upon a single independent variable (e.g. diameter growth is mainly influenced by density), none of the relationships are simple correlations and the effects of many independent variables can influence diameter, height, and volume growth. One of the most important phases of individual tree growth in pine is the study of the relative importance of site, age and density.

3.11 DIAMETER GROWTH

Because of its response to changes in density, diameter growth has been widely employed in thinning studies to measure the degree of release following treatment. Studies of this type are currently under way in lodgepole pine stands in Alberta and have been reported by Smithers (1957). The use of index diameter growth (Dwight 1931) as a means of measuring change in density in yield table construction is also being investigated but no reports have been prepared to date on this aspect of lodgepole pine growth. While lodgepole pine is generally regarded as a slow-growing tree in terms of diameter increment, such slow growth is mainly the result of excessive number of stems. A comparison of the diameter growth of the 100 largest trees per acre (Smithers 1957) shows that free-growing lodgepole pine in Alberta grow at the same rate as comparable red pine in Eastern Canada.

The effect of density at various ages on the average diameter of the 100 largest lodgepole pine per acre is illustrated in Figure 8. This graph is based on growth charts constructed from stem analysis data of 15 trees per plot from 25 sample plots of lodgepole pine stands in Alberta. These stands were on a uniform physiographic site consisting of a dry stony gravel, which resulted in a generally low level of diameter growth. Stand densities were based on number of stems per acre at 100 years of age and cover a range from 250 to 5,000 stems. Average diameter at various ages for the 100 largest trees was determined from growth charts (Smithers 1948) constructed for individual stem analysis plots. Figure 8 illustrates the wide range in maximum diameter which may be expected in stands of varying density on a single site condition.

While the effects of density upon diameter growth of lodgepole pine are well documented, there is little data which indicates the effect of site quality upon diameter growth. In one investigation at Kananaskis Forest Experiment Station the writer found that the average diameter of the 50 largest trees per acre in a stand of 1,000 stems per acre on a rich well-drained loam was 8.5 inches at 90 years. In comparison, the average diameter of the 50 largest trees in a stand of the same density on a dry gravelly soil was only 7.5 inches at 90 years. The difference of one inch would indicate the capacity of the better soil to produce larger trees and more rapid diameter growth under similar density conditions. Smithers (1957) presents data which indicate more rapid diameter growth of the 200 largest trees per acre on good sites than upon poor sites in stands of comparable density which varied in age from 5 to 75 years.

While the effects of site quality upon diameter growth are less significant than those of density, there is, however, a need for additional study in both of these fields. Further research should attempt to define clearly the rates of diameter growth under various conditions of density, age and site quality.

3.12 HEIGHT GROWTH

Height growth of individual trees has always been of great interest to foresters from a silvicultural as well as a mensurational standpoint. The silviculturist has usually aimed for the production of tall fast-growing trees providing maximum clear length and has sought to utilize strains capable of rapid height growth. The mensurationist's interest in height growth has stemmed primarily from the relationship between site quality and height of dominant trees at an index age.

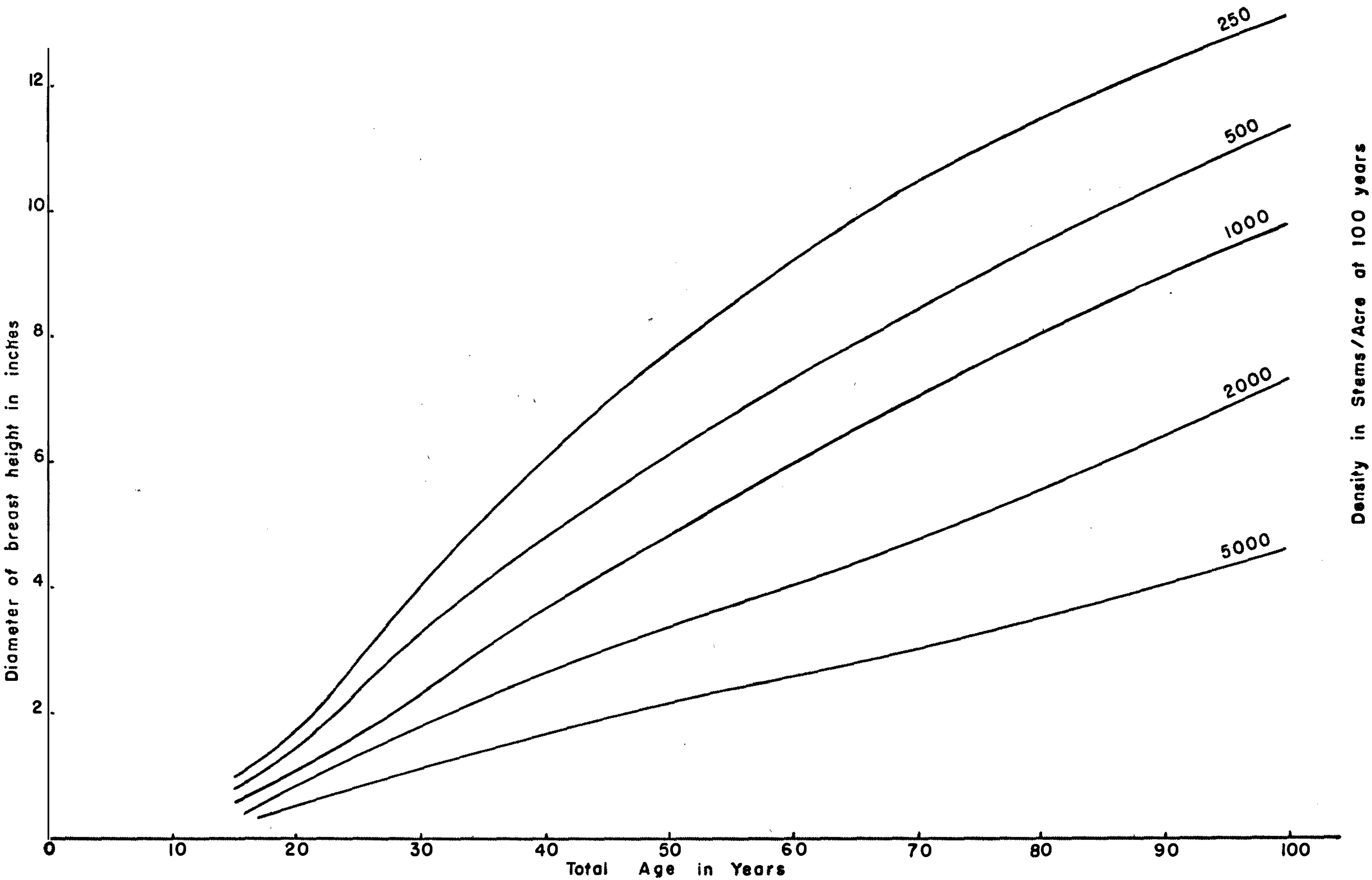

Figure 8. Average diameter of the 100 largest trees in lodgepole pine stands of varying density. (Based on 350 stem analysis trees from 25 sample plots.)

In the case of lodgepole pine, the validity of the site index relationship was questioned by Bates (1918). Subsequently, Parker (1942) attempted an adjustment to site index variations in stem density in order to provide a more accurate index. Smithers (1955), in studying productivity of subalpine lodgepole pine stands, found that site index did not conform with physiographic site conditions and that variations in stem density produced a substantial influence on the site index. In this investigation it was shown that per acre volume was also influenced by the effect of density on the average height of the stand. Subsequent studies by the writer in lower density pine stands in Alberta indicate that the influence of density on dominant height extends to stands containing as few as 200 trees per acre at 100 years of age. Figure 9 illustrates the serious effect of density, as expressed by number of stems per acre at 90 years of age, on the dominant heights for a single physiographic site. This site consisted of a flat gravel bench which was excessively dry and contained a high percentage of stones. A total of 25 single examination sample plots distributed through the range of density conditions were employed to sample this site. It is also of interest to note that on this site, basal area per acre remained relatively constant, ranging between 90 and 115 square feet per acre, and average height of the stand followed a parallel trend to the dominant height data; consequently, volume per acre, particularly merchantable volume, increased as density decreased.

The changes in dominant height associated with age are illustrated in Figure 10 which contains three dominant height/age curves for lodgepole pine. The Alberta curve was based on stem analysis of dominant trees checked by roughly 150 sample plot values. The Oregon curve was derived similarly but at a lower sampling intensity. The British Columbia curve originated for single examination plot averages of the height of both codominant and dominant trees. All curves were adjusted to the same index value of 60 feet at 80 years, which represented roughly the mean site index value of the data. Up to an age of 100 years, the Alberta and B.C. curves show a similar trend; however, beyond 100 years the Alberta curve is appreciably higher. It is probable that the two curves are not significantly different and that reduced sampling in the advanced age classes has caused the apparent discrepancy. In spite of the effects of density, site quality exerts a measurable influence upon the height growth of dominant trees. Smithers (1955) found that after the effects of density had been eliminated, the dominant heights of 90-year-old lodgepole pine stands varied from 50 to 65 feet in response to variations in site quality. Further studies in the Boreal Region have shown that in 90-year-old lodgepole pine stands, site quality alone produced a range in dominant height index from 70 to 85 feet. The total range of dominant height values at 90 years was 55 to 85 feet. Roughly 50 per cent of this range was associated with the effects of density while the balance was attributed to site quality.

It might be inferred from these investigations that, in the case of lodgepole pine, dominant height does not constitute a valid site index upon which to develop yield tables. However, since volume per acre, particularly merchantable volume, is affected by density in a similar fashion to the dominant height values, site index can be employed as a productivity rating for yield table purposes. The site index will, however, be a combined measure of site quality and density. Consequently, lodgepole pine yield tables constructed on such a basis will not describe the potential productivity of a site nor can they be employed to predict yield of stands in which density may be radically changed by thinning.

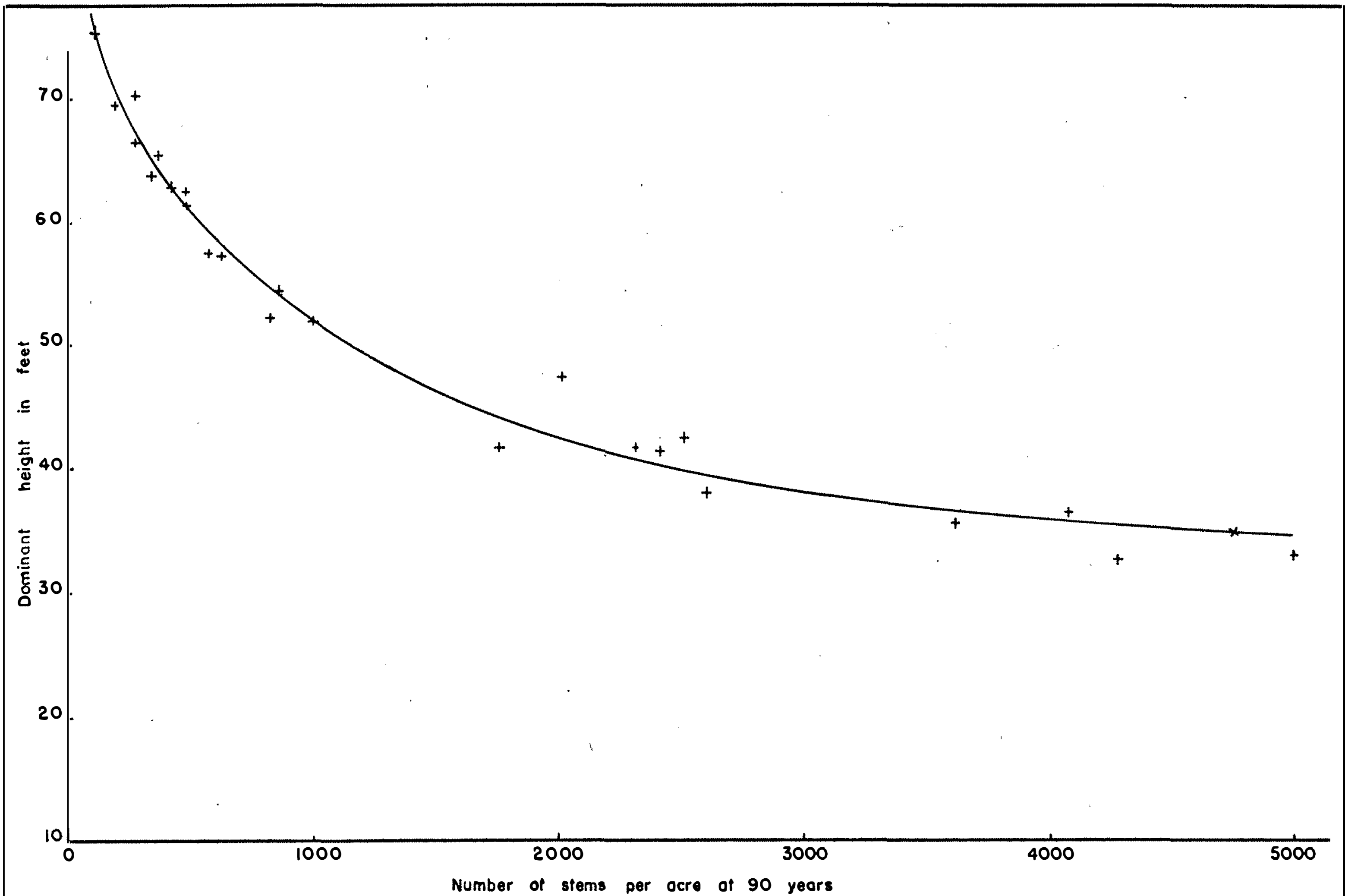

Figure 9. The effect of stocking on dominant height of 90-year-old lodgepole pine on a dry site. (Basis—25 sample plots.)

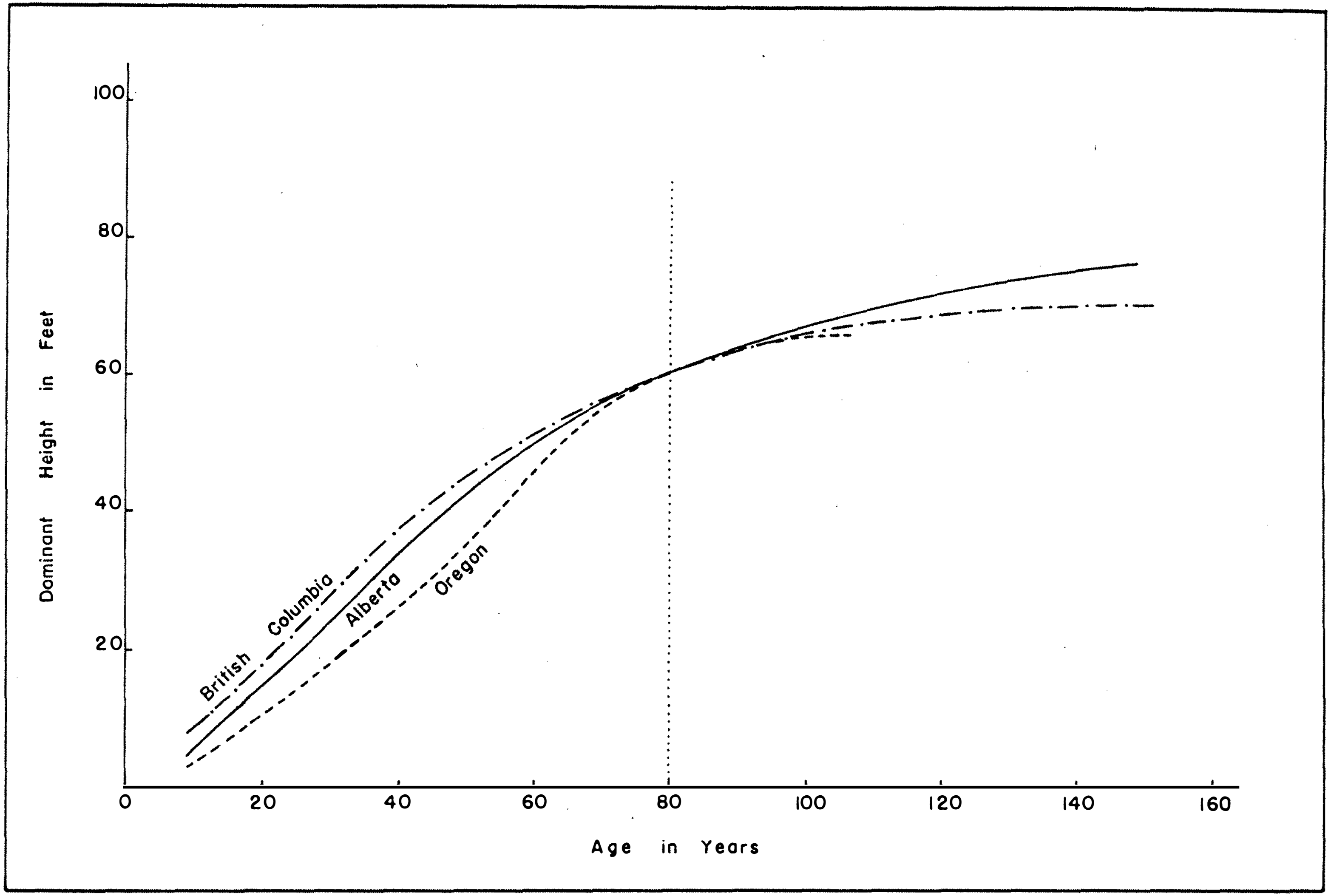

Figure 10. Three dominant height/age curves based on yield table studies for various regions within the range of lodgepole pine.

Plate 16. Young mixedwood stand in the low foothills with aspen initially overtopping lodgepole pine.

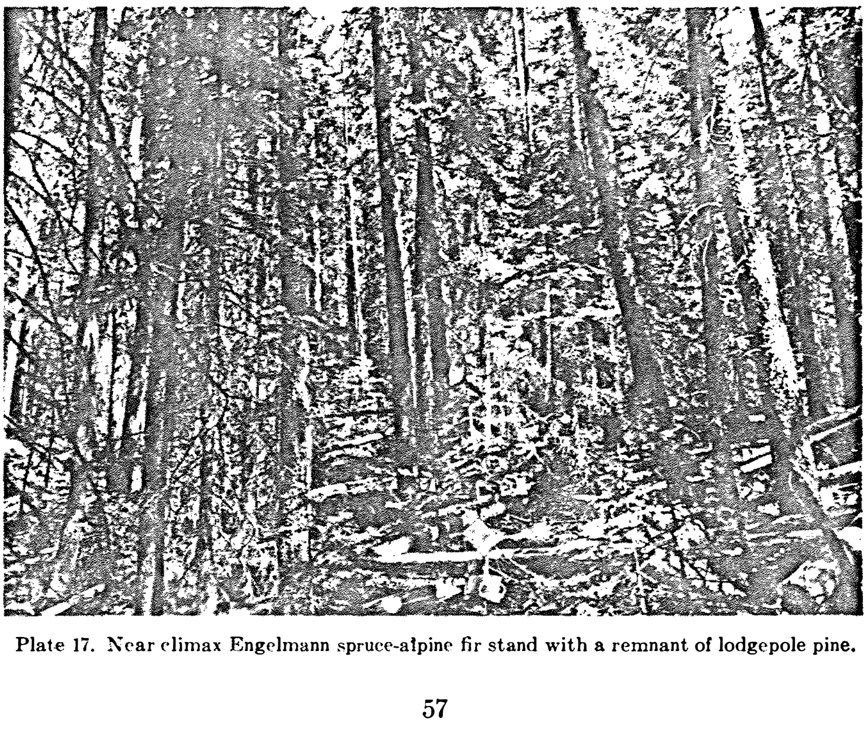

Plate 17. Near climax Engelmann spruce-alpine fir stand with a remnant of lodgepole pine.

3.13 CROWN SIZE

General descriptions of the typical crown form of lodgepole pine have been given under the heading of silvical characteristics. To date no extensive studies of the relationship of crown size to individual tree growth have been carried out. A limited sample of 160 crown measurements has been made by stem analysis in 90-year-old stands in the subalpine and boreal regions. Figure 11, which shows the relationship of crown surface area to diameter breast height, has been prepared from these data.

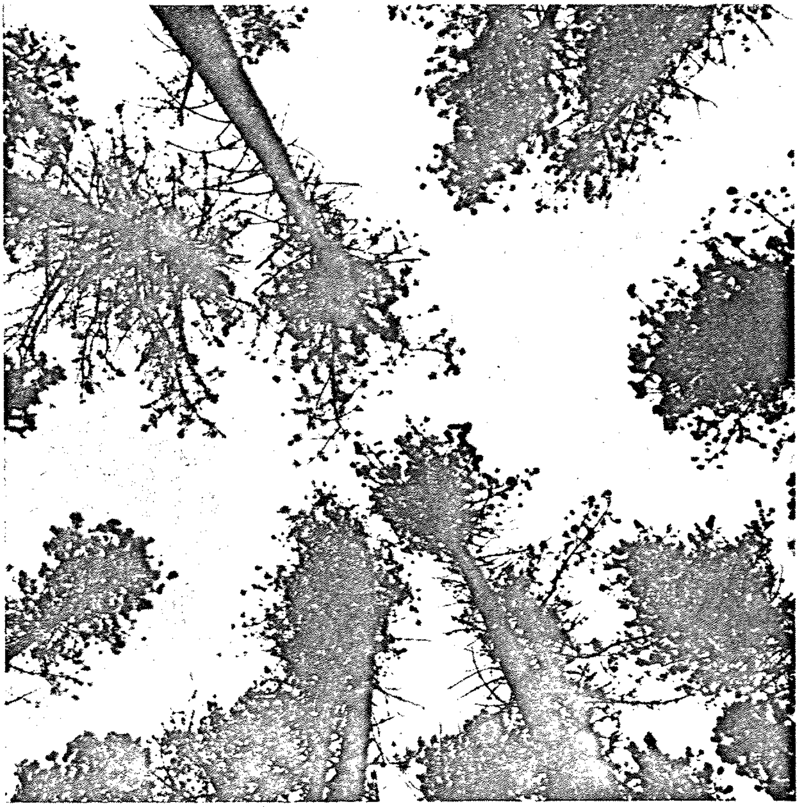

Plate 18. Typical degree of crown closure in fully stocked 85-year-old lodgepole pine stands.

3.14 INDIVIDUAL TREE VOLUME AND FORM[3]

Growing under stand conditions, lodgepole pine exhibits a minimum of butt swell, a high form-class, and an extremely straight bole. These characteristics have favoured the use of the species up to the present time for such products as railway ties, poles, piling, posts, and building logs. With the foreseeable enlargement of the use of lodgepole pine for pulp, the aforementioned form characteristics, especially the high form-class, are important in regard to merchantable cellulose content of individual trees.

[3]Sections dealing with volume and form of lodgepole pine were prepared by A. W. Blyth, Research Officer, Forest Research Branch, formerly at Calgary, Alberta.

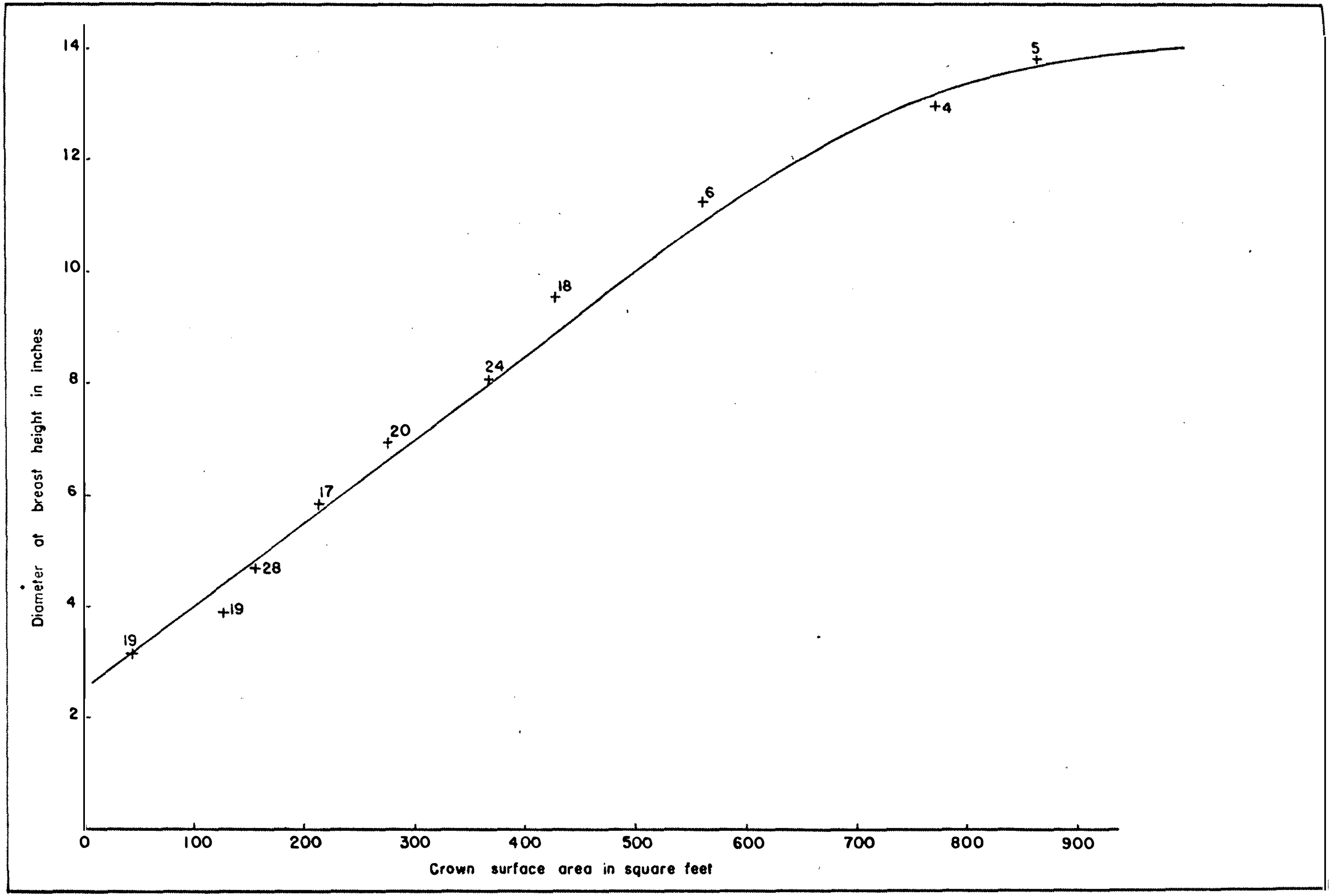

Figure 11. A generalized relationship between diameter and crown size of lodgepole pine based on measurements of 160 trees in Alberta.

Plate 19. Burned-over thicket stand of lodgepole pine.

The average form-class of lodgepole pine is considerably higher than that of most of the coniferous species with which it is commonly associated. Figure 12 shows pine form-class correlated with diameter in comparison to the same relationship for white spruce in two forest regions of Alberta where pine occurs. Throughout its diameter range, pine averages about eight form-class units higher than white spruce in the boreal region. Interpreted in terms of merchantable volume, this means that the average pine tree contains from 10 to 25 per cent more cellulose than the average spruce tree of the same d.b.h. and height. The same is true, but to a lesser extent, when pine is compared to subalpine spruce. It should be noted that while most of the volume difference is attributable to form-class, some of the higher pine volume is also due to the very thin bark characteristic of this species.

Recently the British Columbia Forest Service prepared new standard tables for most of the coniferous species found in the province. A study of these tables shows that lodgepole pine has a higher cubic volume for each diameter and height class than any other species with the possible exception of western

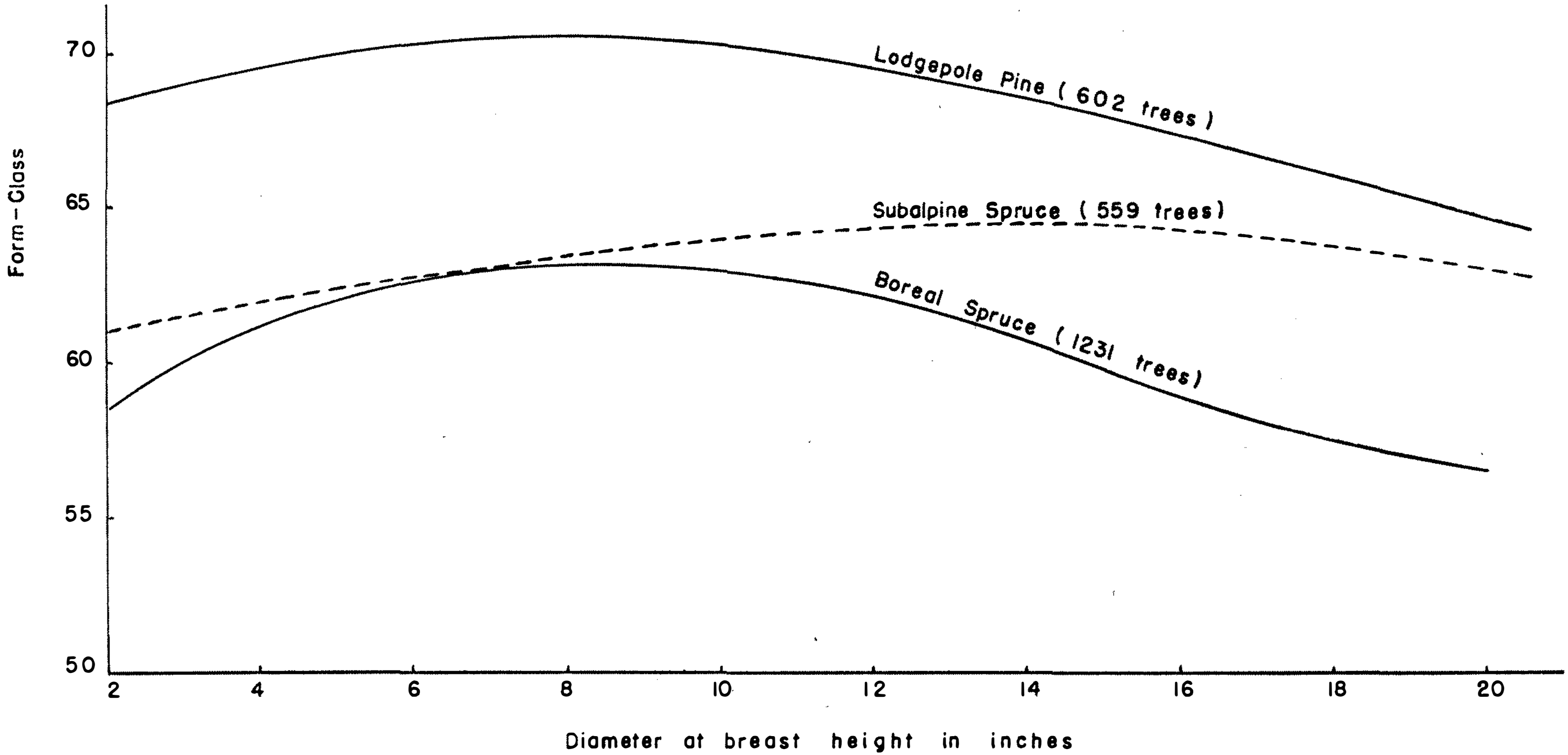

Figure 12. Pine form-class correlated with diameter in comparison to the same relationship for white spruce in two forest regions of Alberta where pine occurs.

hemlock. The high volume is again attributable to the high form-class and to the thin bark. It is of interest to note the influence of form-class on per acre yields as well as on individual tree volumes. It is quite possible to find pure stands of white spruce and lodgepole pine with almost identical stand structure in regard to basal area, average diameter, and height, but the pine stand under such conditions will exhibit a merchantable volume 15 to 20 per cent higher than that of the spruce.

3.15 VOLUME TABLES FOR LODGEPOLE PINE IN CANADA

Currently there are three sets of standard volume tables in use for lodgepole pine in Canada. In order that the reader may decide which is the most applicable for a particular area or purpose, each is described below.

A. Form-Class Volume Tables

These were prepared by the Dominion Forest Service in 1930 from taper measurements taken on 243 trees in British Columbia and Alberta. Average taper curves were constructed for form-classes 60, 65 and 70 and theoretical volumes were calculated from these curves for each diameter and height-class. Tables were prepared for total cubic feet, merchantable cubic feet, lineal feet of mine props, and board feet according to the British Columbia, Scribner, and ¼″ International Log Rules.

B. Standard Volume Tables for Lodgepole Pine in Alberta

These tables were prepared by the Federal Forestry Branch (Blyth 1955), and are based on the measurement of 676 trees in the province of Alberta. Total and merchantable cubic foot tables were prepared by the method of harmonized curves, and board foot tables for the Scribner and ¼″ International Log Rules by the volume-diameter ratio method. In 1956 the Province of Alberta adopted the 5/16″ International Log Rule and a further table was prepared to this specification.

C. British Columbia Cubic Foot Volume Table for Interior and Coast Lodgepole Pine, All Ages

This table was prepared by the British Columbia Forest Service in 1955 from measurements taken on 1,870 trees throughout the province. The table gives volumes in total cubic feet; however, converting factors for merchantable volumes are also given for three degrees of utilization. The table was prepared from a least squares solution of the basic data expressed in logarithmic form.

The Alberta and British Columbia volume tables as detailed in B and C above are presented in the appendix to this publication. (*See* List of Tables, page 134.)

In any discussion of the use of pine volume tables for the preparation of stand estimates, it is of interest to note that a shortcut method of merchantable volume determination can be employed. This method will work with several species but is especially suited to pine owing to the uniformity in distribution of diameters and heights. The following is an example of the application of the method.

A standard cruise of a pine stand yielded the following information:

Trees per acre	4″ +	= 563
B.a. per acre	4″ +	= 120 sq. ft.
Average d.b.h.		= 6.3″
Merch. volume per acre	4″ +	= 2,780 cu. ft.

To determine the volume per acre as above it was necessary to prepare a stand height/diameter curve, then a stand local volume table, and finally to accumulate the volumes by individual diameter classes. Using the short-cut method, the average diameter is calculated in the field and the height of this average tree is found by measuring 3 or 4 trees of the same diameter. Reference is then made to a standard volume table and the volume of the average tree is determined. This volume is then multiplied by the number of trees per acre to determine the stand volume. The following are the results obtained by the short-cut method.

Trees per acre	4″ +	= 563
B.a. per acre	4″ +	= 120 sq. ft.
Average d.b.h.		= 6.3″
Ht. of average tree		= 53′
Vol. of average tree		= 4.9 cu. ft.
Merch. volume per acre	4″ +	= 563 (4.9) = 2,759 cu. ft.

Comparing the volumes obtained by the standard and short-cut methods, one finds that the difference amounts to only $\frac{(2{,}780 - 2{,}759) \times (100)}{2{,}780} = 0.8\%$.

In general, it has been found that in lodgepole pine this short-cut method of merchantable volume estimation will yield results within $\pm 4\%$ of those obtained from standard procedures.

All of the evidence indicates that the behaviour of individual tree growth and yield per acre, owing to wide variations in density, are far from typical when compared with those of other native species. It will therefore be necessary to continue the investigation of individual tree growth and to describe with greater clarity the effects of density upon the growth of trees and stands.

3.2 Yield Per Acre

Lodgepole pine is a species which lends itself to even-aged management. Foresters are vitally concerned, therefore, with its growth and yield in terms of per acre production. Such production figures include number of stems, basal area, and volume per acre, as affected by age, density and site quality. Information on the per acre yields of lodgepole pine stands in Alberta has come from a variety of sources which include rate of growth surveys and large-scale inventories as well as detailed studies of productivity relationships. Within its Canadian range several yield tables for lodgepole pine are available. One of these, prepared by the British Columbia Department of Lands and Forests, is a normal yield table based on a site index which is an average of dominant and co-dominant heights. A number of empirical tables have also been prepared to fit local conditions in various regions of British Columbia. These have been published in a report on the Continuous Forest Inventory of British Columbia (initial phase 1957). The Alberta yield table study has been designed to incorporate a change in density factor based on remeasurement of permanent sample plots and will subsequently make use of a physiographic site classification. Since sufficient remeasurement data were not available to complete the final analysis at this date, a temporary table was constructed on a site index basis. In this table the site index is the average of the predominant (Craib 1933) or tallest trees on the plot. A merchantable cubic foot yield table for Alberta has not been prepared to date. It is apparent that because of differences in the site indices which were employed, there can be no direct comparisons of yield data from the two tables. A check of individual Alberta plot data against the British Columbia yield table using an adjusted site index, indicates similarity in the yield values above 80 years. Below this age, inadequacies in the sample of Alberta data have caused some discrepancy. It is therefore recommended that the British Columbia table be employed in Alberta lodgepole pine stands in the boreal region. Copies of the British Columbia table and the temporary Alberta table are included in the Appendix.

Only a very limited amount of yield data is available for the subalpine forest. On comparable site conditions basal area yields in the subalpine forest appear to be the same as those of the boreal forest. However, because of the higher average number of stems per acre in subalpine stands, the merchantable cubic foot volumes are appreciably lower than those of the boreal. So important is the effect of stocking in the subalpine forest, that a preliminary yield table of merchantable volume might well be constructed using number of stems, or preferably average diameter and age, as the independent variable.

3.21 NUMBER OF TREES

The most outstanding characteristic of lodgepole pine stands is the extreme variation in number of stems per acre which may be encountered at any age. Several attempts have been made in Alberta to investigate the relationship of stocking to site quality. Horton (1953) found that while initial stocking was generally low on dry sites, particularly south and southwest exposures on steep slopes, wide variations in stocking may occur on any site. Such variations appear to be connected with differences in fire intensity and seedbed condition, previous stand density and age, and available seed supply. On dry sites where litter accumulations are low, light fires may result in an excellent seedbed and heavy stocking, while hotter fires may impoverish the soil and decrease the water-holding capacity so that stocking is low. On moist or wet sites light fires are unable to reduce litter accumulations, thereby providing a poor seedbed and low stocking, while hotter fires may result in excellent seedbeds and heavy stocking. Young stands which carry many non-serotinous cones may lack a sufficient seed supply, while more mature stands bearing numerous serotinous cones usually provide an abundance of seed. Dense stands which are disturbed by fire may lack a sufficient seed supply, while the fully crowned trees of low-density stands provide an excellent seed source. The variations in stocking which may result from combinations of the aforementioned conditions seem to obliterate completely any natural tendencies toward a correlation between site quality and number of stems per acre.

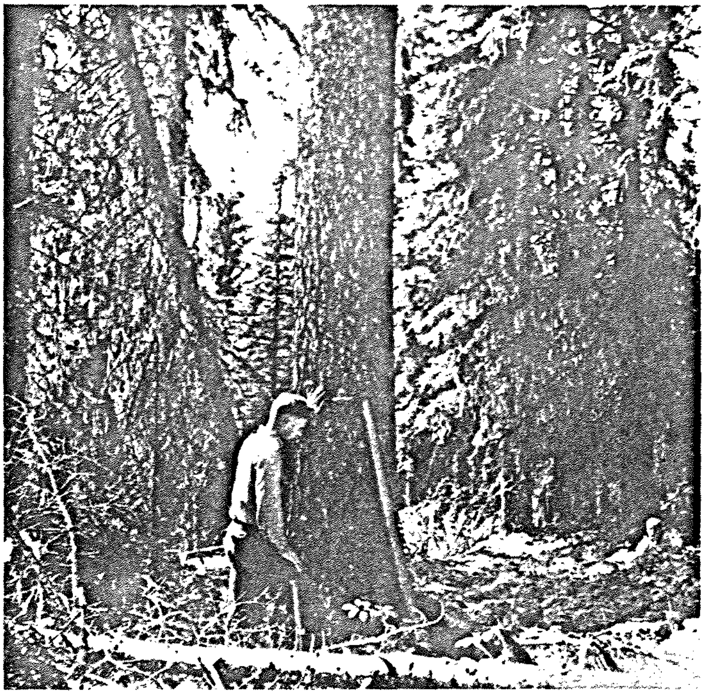

Plate 20. A large lodgepole pine 27 inches d.b.h., 107 feet tall, at 275 years of age.

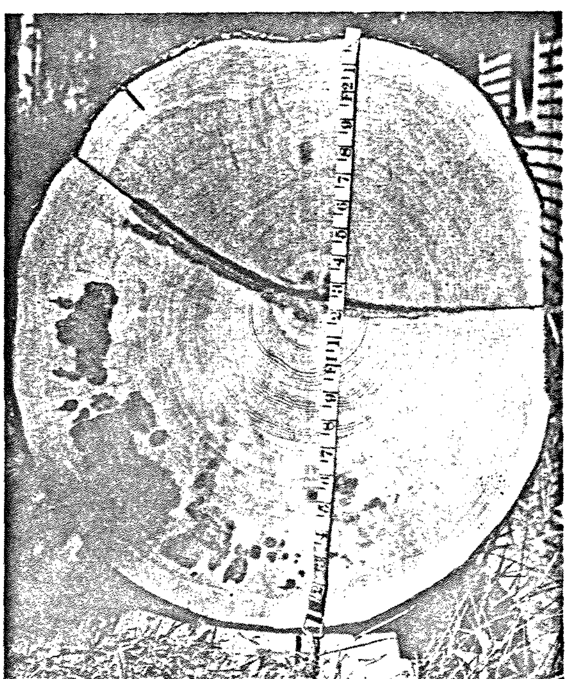

Plate 21. Butt section of a large lodgepole pine.

Plate 22. A dense stand of 14-year-old lodgepole pine with more than one-quarter of a million stems per acre.

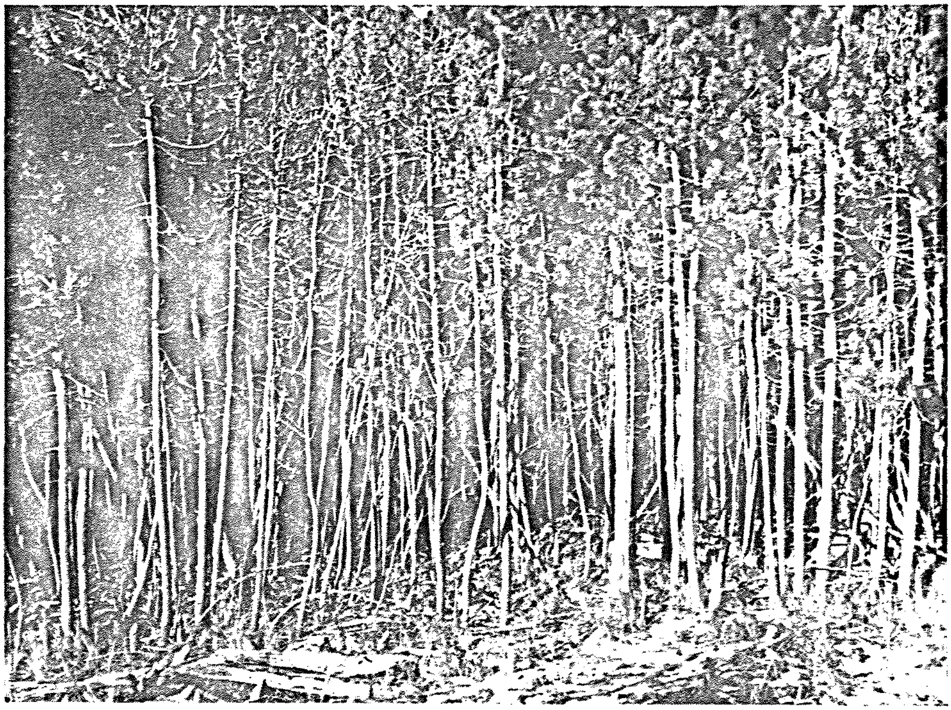

Plate 23. A dense 90-year-old stand of lodgepole pine with 5,000 stems per acre.

Table 7 shows the ranges in diameter distribution which were sampled in 90-year-old stands. All 25 samples were from similar physiographic site conditions and contained roughly the same basal area per acre. While stands ranging in stocking from 250 to 500 stems per acre show excellent possibilities of yielding poles, ties, lumber and pulp, it is equally apparent that stands of more than 2,000 stems per acre at 90 years are never likely to provide a reasonable merchantable yield.

TABLE 7. DIAMETER DISTRIBUTION IN 90-YEAR-OLD LODGEPOLE PINE

Diam.	Number of Stems Per Acre				
	3,010	2,020	975	515	255
1	85	95	30	—	—
2	325	225	70	—	—
3	1,800	550	125	15	—
4	550	670	290	25	—
5	240	330	190	55	5
6	10	110	130	85	10
7	—	40	100	60	30
8	—	—	20	90	25
9	—	—	8	85	55
10	—	—	7	55	40
11	—	—	5	30	35
12	—	—	—	15	30
13	—	—	—	—	5
14	—	—	—	—	5
15	—	—	—	—	5
16	—	—	—	—	5
17	—	—	—	—	5

The subalpine and foothills habitats of lodgepole pine show an appreciable difference in stocking. While a great range in stocking can be found in both areas, the average number of stems per acre is noticeably lower in the foothills and crown differentiation is better. The reason for such differences are obscure. It has been suggested that soil differences may greatly affect stocking. The subalpine stands occur mainly on soils derived from limestones, while many of the foothills stands occur on limey sandstones. Species composition, in particular the abundance of poplar in the foothills pine stands, accounts for lower stocking in some cases. Genetic differences may to some extent account for the more rapid crown differentiation and subsequent lower stocking in the boreal region. This situation requires further study.

Reduction in number of stems per acre as stand development progresses appears to be governed largely by the initial stocking. Very heavy mortality may occur in dense stands even at advanced ages. Permanent sample plot data show a mortality of 4,500 stems per acre during an 11-year period in a dense 75-year-old stand. Smithers (1957) suggests that the percentage decrease in number of lodgepole pine per acre is similar to that of other intolerant pine species. While the normal yield table concept of increased competition, more rapid crown differentiation, and faster natural thinning on areas of high site quality is applicable to a limited extent in lodgepole pine stands, nevertheless the effects of initial high stocking are modified only slightly by subsequent mortality. Dense stands tend to remain dense regardless of the site quality.

Plate 24. A low-density stand of 90-year-old lodgepole pine with 800 stems per acre.

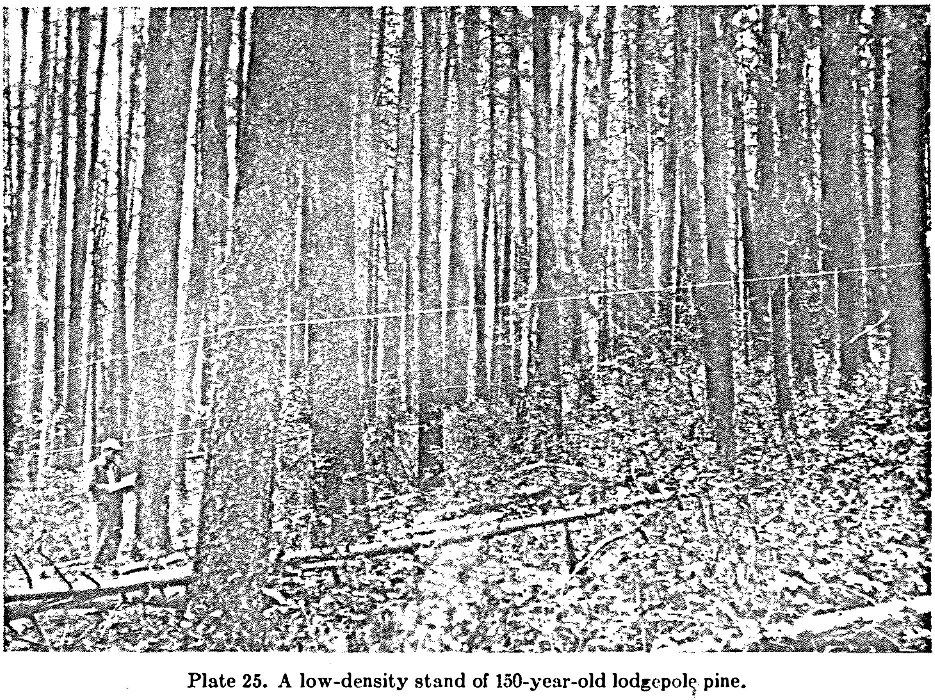

Plate 25. A low-density stand of 150-year-old lodgepole pine.

3.22 BASAL AREA

Basal area per acre of lodgepole pine and the factors which influence it, namely age, site and density, have been the subjects of several studies in Alberta. The basal area curves of fully stocked stands (Smithers 1957) based on permanent sample plot data, rise rapidly at ages up to 60 years; the curve then reaches a maximum level and, while minor fluctuations occur periodically, the basal area remains fairly constant until the stand begins to break up owing to over-maturity. This curve shape is consistent with those of comparable species, including red pine (Smithers 1954), ponderosa pine (Meyer 1938), and loblolly pine (Chapman and Demerrit 1932). The curve is, however, representative of the trend only in fully stocked stands. In understocked stands the basal area will continue to rise until such time as the carrying capacity of the site has been reached.

In contrast to permanent sample plot data, yield table basal area curves from British Columbia (Figure 13) indicate a slower increase in basal area at younger ages and a continuation of the increase to more advanced ages. These curves are, however, based on a site index which is subject to the effects of density and consequently they would not show the same form as those based on a physiographic measure of site quality. It is of interest to note that, for comparable site index values, the basal areas of mature stands in the Alberta and British Columbia yield tables are quite similar. However, in the younger age classes the Alberta yield table curves show lower values. It is believed that these differences can be attributed to inadequate sampling of some site conditions. Additional sampling will be undertaken to strengthen the data and revise the basal area age curves.

In the relationship of basal area to site quality, normal yield tables based on a site index customarily show a relatively narrow range of basal area. However, variation within a site class is relatively high. This trend is true of both the British Columbia and Alberta yield tables for lodgepole pine. In contrast an investigation by Smithers (1956) shows a strong correlation between physiographic site quality and basal area and indicates a much wider range in basal area due to variation in physiographic site. The relative ranges of the two sets of information are shown in Figure 13. This apparent contradiction is explained by the difference in method of site classification. Since dominant height is affected by both site quality and density, the basal area for a given site index will be an average of combinations of good and poor sites and high and low densities. Variability of basal area in relation to site index will therefore be increased and the overall spread of the basal area curves will be decreased. This wide divergence of basal area age curves, apparently due to differences in the method of site classification, poses a problem for the reader in attempting to select suitable growth information. It would appear that for purposes of forest regulation on large areas, yield data derived from tables based on site index are acceptable. However, for the more accurate assessments of growth demanded by intensive high-yield silviculture, it will be necessary to carry out more detailed investigations employing an ecological concept of stand development rather than a mathematical one.

It has been frequently assumed that basal area per acre is very sensitive to stocking. Smithers (1956) provides an illustration of the effect of stocking on basal area in 90-year-old lodgepole pine stands on a good site. The stands showed remarkably little variation in basal area through a range from 800 to

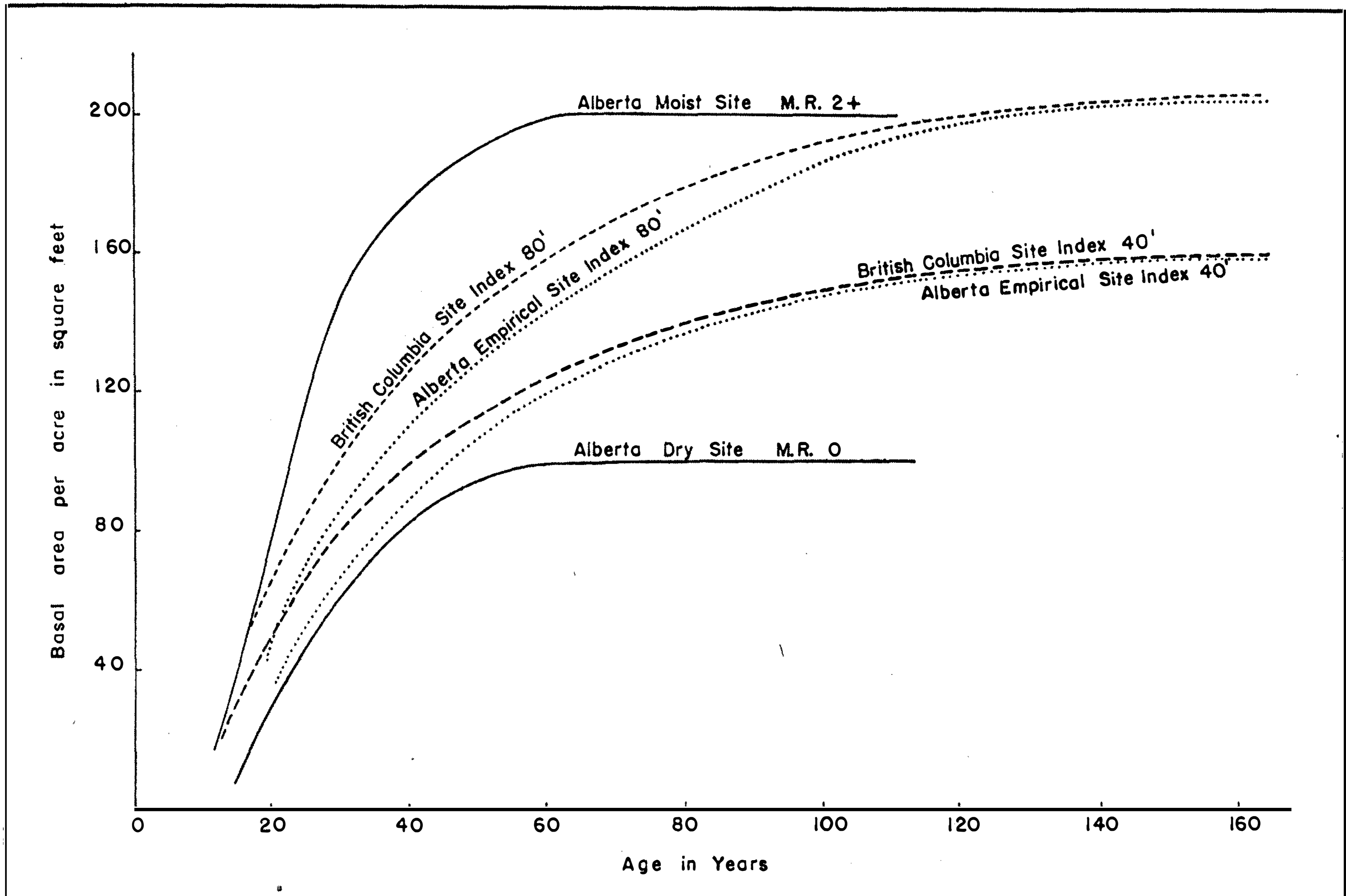

Figure 13. A comparison of basal area curves for lodgepole pine, indicating the variation in basal area resulting from differences in the method of site classification.

3,000 stems per acre. Data gathered subsequently in Alberta in a 90-year-old stand on a dry, poor site showed a range of only plus or minus 10 square feet even though the stocking varied from 230 to 5,000 stems per acre. In stands of less than 230 stems per acre a definite decline in basal area was found.

In general, basal area per acre appears to be a relatively predictable variable which is well correlated with age and physiographic site quality, and in badly understocked stands it is a useful expression of density.

3.23 VOLUME PER ACRE

Regardless of the value of any intermediate steps, volume per acre is the ultimate objective of any yield prediction. In Alberta, volume in terms of merchantable cubic feet is of greatest importance, while total cubic foot volume is of rather academic interest in view of the current merchantability conditions. Board foot volume is of only minor concern since lodgepole pine is not primarily a sawtimber species.

Studies of total cubic foot volume per acre in the subalpine forest of Alberta (Smithers 1956) show that the volume in lodgepole pine stands varies appreciably owing to the effect of number of stems per acre. In spite of consistent physiographic site conditions, increases in number of stems per acre reduce total volume per acre in densely stocked stands. While the study did not include merchantable cubic foot volumes, it is apparent that the effects of change in number of stems per acre on merchantable volume would be even more drastic since the number of trees above a given merchantable limit in fully stocked stands is inversely related to the total number of trees at any particular age.

The general situation regarding growth and yield studies in lodgepole pine stands presents a somewhat confused picture. Depending on the form of site classification employed, either physiographic or dominant height index, the form of the basic yield relationships may vary considerably. While it is not within the scope of this monograph to resolve these basic differences, it can be justifiably recommended that further study should be devoted to the problem. Currently, a large number of permanent sample plots in the lodgepole pine type in Alberta are being remeasured and these plots will be classified as to both site index and physiographic site quality. An analysis of these data should do much to clarify the growth and yield situation.

3.24 CONSTRUCTION AND APPLICATION OF YIELD TABLES

Two courses of action in the construction of yield tables are available. If physiographic site classes are employed, it will be necessary to include an additional independent variable, number of trees per acre. Such a yield table should provide maximum accuracy but will require additional data. One drawback of such a method will be the difficulty of determining number of trees per acre from air photos. In view of improvements in air photo technique, however, this may not be a serious problem. Alternatively, one may ignore the theoretical objections to the use of site index and continue to use normal yield tables. In these tables it may be assumed that both the site index and the merchantable volume in cubic feet are both affected in much the same way by variations in number of stems per acre. Although the index values will represent combinations of site quality and density, the yield predictions will be fairly satisfactory. Such yield tables will of course give little indication of potential yield under optimum stocking conditions.

It has already been recommended that the British Columbia yield table may be applied to Alberta lodgepole pine stands with certain limitations. In applying most normal yield tables, recommendations allowing for an increase in basal area owing to a gradual progress toward normal stocking are made. In the case of lodgepole pine stands in Alberta, it is believed that the majority are fully stocked and require no adjustment. Basal areas below those of the normal yield tables will be encountered. But no allowance for increase in stocking should be made, and volume values proportional to the current basal area should be employed in predicting growth.

While yield tables show the natural yield trends of the type, it is frequently of interest to record maximum yields encountered in the field. In lodgepole pine stands the highest total cubic foot volume recorded on a sample plot in Alberta was 8,400 cubic feet. This stand had a dominant height index of 81, a basal area of 202 square feet, 252 stems per acre, and an average diameter of 12.11 inches at an age of 150 years. A 115-year-old stand of height index 81 had a volume of 8,160 cubic feet. The average diameter of the latter plot was 10.2 inches and the number of stems was 380.

It is of interest to note that lodgepole pine yield tables show somewhat higher volumes per acre than do tables for comparable species such as red pine. In this regard it is well to remember that the high average form class of lodgepole pine stands may result in higher yields for a given age and site index.

3.3 Growth After Partial Cutting

It is essential that a clear distinction be made between partial cutting as practised in Alberta and intermediate cutting or thinning which is discussed under the heading of silvicultural practices. The basic difference which must be observed is that thinning aims at stand improvement combined with the salvage of mortality, while partial cutting is a harvesting method aimed at increased production and regeneration of the stand. In Alberta partial cutting has been widely practised in the lodgepole pine stands of the foothills area where the primary products consist of ties and poles. Since there was no market for small-sized trees, it was economically advantageous to remove only that portion of the stand which exceeded a diameter limit of roughly 12 inches. Since there was little motive for stand improvement, defective trees even of the larger sizes were not cut.

Partial cutting of this type can be justified only on one of two grounds. Either such a treatment must be essential to the satisfactory regeneration of the stand, or the residual stand must show a response to release, and gross volume increment after cutting must continue at full capacity of the site. Although stands of most species are capable of maximum increment with residual stocking of roughly 50 per cent, this is true only when the residual trees include a high proportion of fully crowned trees capable of rapid response. In the case of lodgepole pine in Alberta, the trees that would respond most vigorously following release are the very trees which are removed by partial cutting while the intermediate and suppressed stems are left.

Blyth (1957) has carried out a detailed investigation of partial cutting in pine in Alberta. All of the stands studied were of low density and were between 50 and 110 years of age at date of logging. The period of growth after logging ranged from 11 to 30 years. Blyth concluded from his study that diameter growth of residual stems was not stimulated. Volume increment, despite limited windfall and mortality, was appreciably less than that of fully stocked stands. At the same time, lodgepole pine regeneration was unsatisfactory.

In the United States, observations of partial cuts by Lebarron (1952) have brought about similar conclusions. However, he suggests that partial cuts may be satisfactory in some stands because of special considerations such as age structure. It appears, however, that the present methods of partial cutting of lodgepole pine in Alberta will neither increase yield nor regenerate the stand satisfactorily.

3.4 Stagnation

The term "stagnated stand" has been applied more frequently to lodgepole pine than to any other commercial tree species—and with justification—for it is doubtful if any other species can demonstrate such high levels of stocking. Descriptions of individual stands supporting half a million 5-year-old stems per acre (Smithers 1957) or 100,000 live stems in a 70-year-old stand (Mason 1915) convey very little to a forester who has never encountered such conditions in the field. Even if we imagine a two-foot-tall sapling on every piece of ground three and one-half inches square, it is difficult to grasp the staggering density of such a stand.

Stagnation to many foresters, however, implies much more than a mere excess of trees. The term "locked stands" conjures up an image of a forest in which increment even on a per acre basis has almost ceased.

Studies in Alberta based on permanent sample plot data and stem analysis have produced some interesting facts on stagnation. It can be readily shown that both diameter and height growth of individual trees are drastically reduced by over-stocking, and in some of the more dense stands, annual rings may be only two or three cells in width. In spite of this reduction in growth, it has been demonstrated (Mason 1915, Smithers 1957) that release in both diameter and height growth can be obtained following thinning even in older stands. An interesting comparison is provided by two adjacent stands in the subalpine region of Alberta. Stand No. 1, of fire origin, contained 9,000 stems per acre at an age of 75 years, and had an average diameter of 1.8 inches with a dominant height of 33 feet. Stand No. 2 was 60 years of age and had originated from a second fire which burned over part of the area. It had 860 stems per acre, an average diameter of 6.0 inches and a dominant height of 58 feet. Basal area and volume for the two stands were as follows:

Stand 1: 161 square feet/acre, 1,757 total cubic feet/acre

Stand 2: 167 square feet/acre, 4,440 total cubic feet/acre

Both plots were located on a flat bench, within 200 feet of each other. Soil pits showed no differences in soil profile or texture which would indicate a uniform site. These two stands illustrate with great clarity the basic effects of stagnation in lodgepole pine. In stand No. 1 both height and diameter growth have been drastically reduced; hence total volume, influenced by the height factor, is low. Nevertheless, basal areas of the two plots are almost identical, and remeasurement data show that there has been no increase in net basal area during the past decade.

To complete the comparison a third stand, comparable to stand No. 1, was thinned 15 years ago by removing 80 per cent of the basal area and 90 per cent of the stems. Diameter growth on the residual trees has approximately doubled, yet gross increment in volume and basal area has been almost identical to that of stand No. 1. Mortality in stand No. 1 equalled 100 per cent of the basal area increment and 30 per cent of the volume increment while on stand No. 3 it was 2 per cent of the basal area increment and 1 per cent of the volume increment. Mortality in number of stems during an 11-year period on stand No. 1 plot was 50 per cent.

From these data it is possible to outline in general terms the main effects of stagnation. Diameter and height growth of individual trees may be reduced to an almost non-existent level, yet release by thinning from below can bring about a substantial response in both of these factors. In contrast, basal area carrying capacity is dictated by the site conditions and is relatively unaffected by the stagnation. Gross increment in basal area is also unaffected. Volume, because of its dependence on average height, is greatly reduced by stagnation. Percentage mortality in number of stems per acre in comparison with yield table figures is normal. A comparison of cubic foot volume mortality data from permanent sample plots in dense lodgepole pine with figures for ponderosa pine, and red and eastern white pine, (Smithers 1957), shows that mortality in cubic foot volume is normal. In fact, the whole study of stagnated lodgepole pine stands does not indicate any exceptional behaviour but merely the natural development of extremely dense stands. However, regardless of whether stagnation is a normal development or not, such a growing condition is definitely not desirable. In order to provide a solution one of two courses must be followed. Either the stands must be thinned at an early age, which is economically unfeasible; or control must be exercised in the harvest cutting stage to ensure that extremely dense stands do not occur. It has been suggested by Crossley (1955a) that intensity of scarification may be one medium through which density may be controlled. Certainly the elimination of fire from both uncut and cut-over stands will do much to prevent excessive densities.

3.5 Rotation Age

The average rotation age suitable for the management of a species is unfortunately not a simple mathematical concept. Rather it is a compromise between many factors, biological, economic and mensurational, which must be weighed to determine the correct balance between the various considerations. Rotation age is therefore an average value lying between an upper limit based on the physical rotation and a lower limit involving maximum rate of wood production per acre. Fortunately these limits are reasonably well defined. The physical rotation for lodgepole pine stands is roughly 150 years, and while individual trees may remain sound for much longer, mortality among the largest trees causes the stand to decline rapidly beyond this age. The lower limit of rotation age coincides with the point at which mean annual increment in total cubic foot volume culminates and, according to available yield tables, occurs at roughly 70 years. Rotation age therefore lies between these limits and shifts up or down on economic considerations.

Figures 14 and 15 show the mean annual and current annual increment curves for total cubic foot and merchantable cubic foot volumes for trees 6 inches plus. These curves have been determined from the British Columbia yield table data, and are applicable to lodgepole pine in the Low Foothills Division of Alberta. If a four-inch merchantable limit is accepted as a standard for pulpwood utilization, it may be inferred from Figures 14 and 15 that a pulpwood rotation age of 90 years, including a regeneration period of 10 years, is

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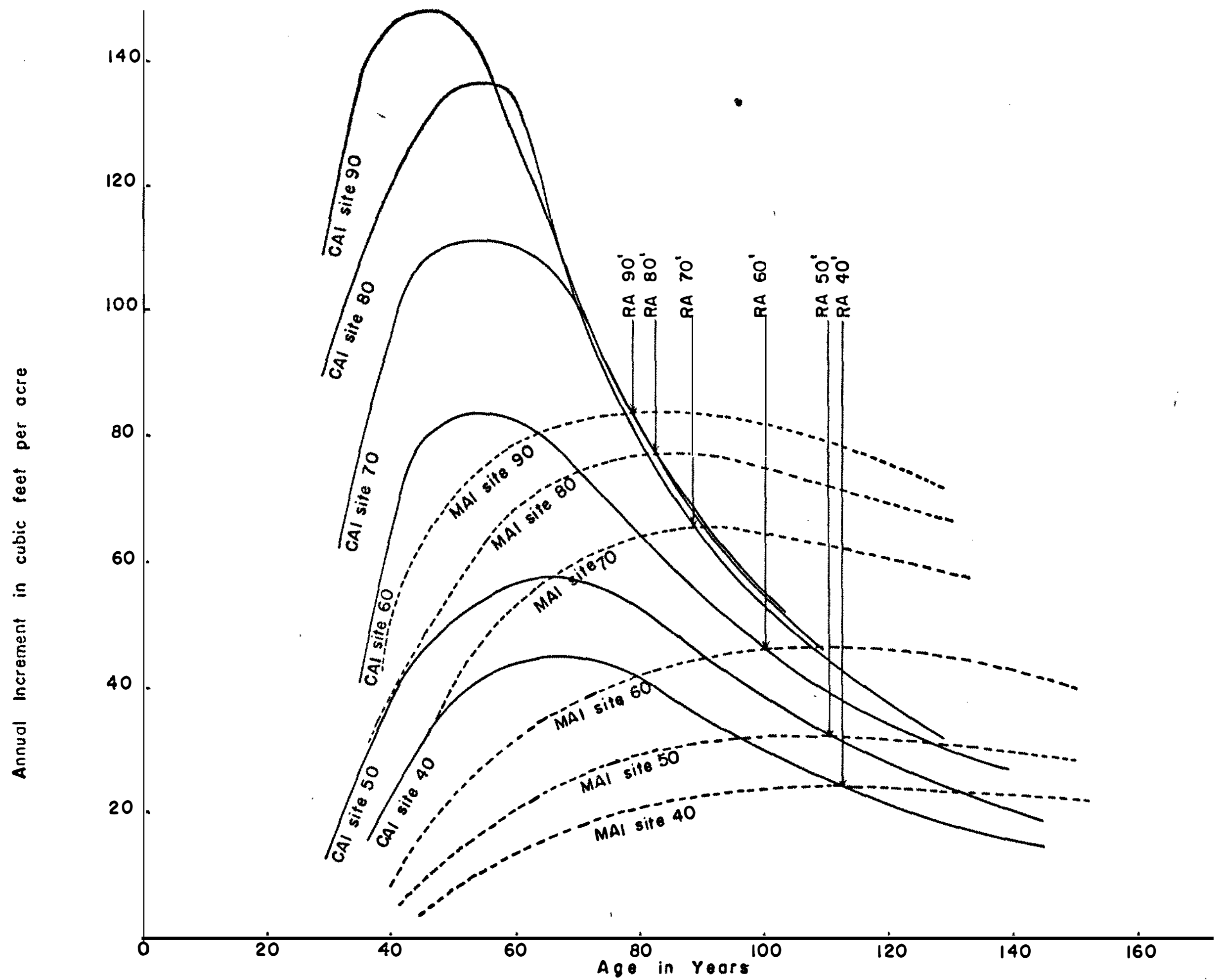

Figure 14. The variation of the rotation of maximum wood production with site index for the British Columbia yield table for merchantable cubic foot volume 6″+

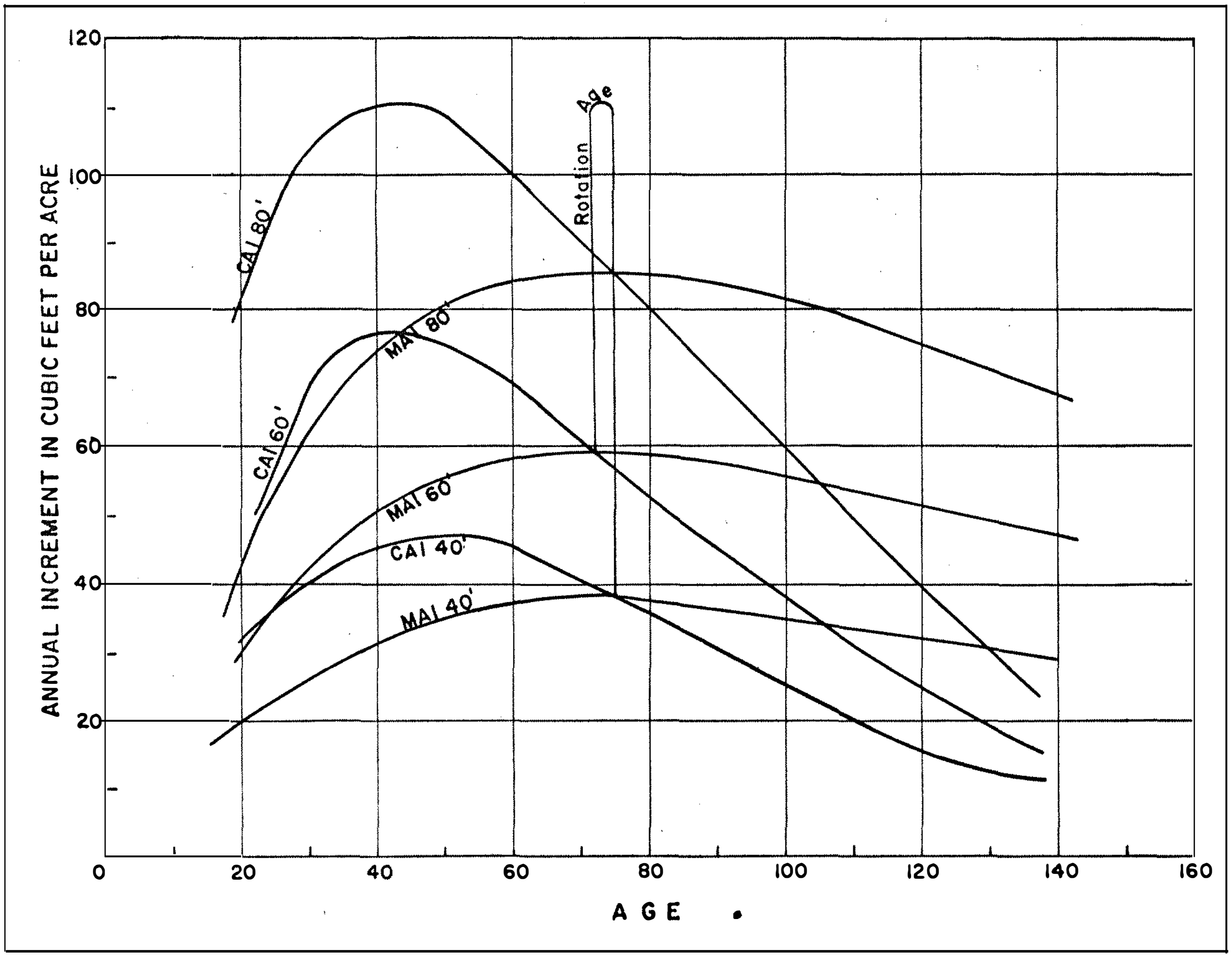

Figure 15. The variation of the rotation of maximum wood production with site index for the British Columbia yield table for total cubic foot volume 0.5"+.

acceptable. Cutting ages for individual stands would vary from 70 to 100 years, reflecting the effects of site quality and density upon stand maturity.

If a minimum diameter limit of 8 inches is specified for larger products such as poles, ties and lumber, then rotation age would increase to roughly 130 years, with a range of cutting ages of from 100 to 140 years depending on stand density and site quality.

Rotation age in the subalpine region will be somewhat greater than those of the boreal because of higher stocking. This increase in rotation age will, however, not be great since the products of this area will be mainly pulp, posts and poles. It is estimated that a rotation age of 120 years will be suitable for the majority of subalpine stands.

4. DAMAGE AGENTS

4.1 Insects Injurious to Lodgepole Pine in the Canadian Rocky Mountain Region[4]

Insect damage to lodgepole pine has been more extensive than to most other species of conifer in this region. The insects are discussed under six groups according to the type of feeding and the part of the tree attacked. These groups are the bark beetles, the foliage feeders, twig and terminal insects, sucking insects, root feeders, and wood borers. Lodgepole pine cone insects are not of economic importance. In each group, the more important species are mentioned, followed by a more detailed discussion of each, the outbreaks recorded, and control methods. As the title indicates, the information contained herein applies to the Canadian Rocky Mountain region unless otherwise stated.

4.11 The Bark Beetles

The mountain pine beetle, *Dendroctonus monticolae* Hopk., is by far the most destructive species. Outbreaks sometimes cover many thousands of acres, and unless control measures are taken in time, 80 to 90 per cent of the merchantable stand is killed. Two other species of *Dendroctonus* (*valens* Lec. and *murrayanae* Hopk.) attack the bases of trees weakened from other causes. They have not been primary tree killers. Outbreaks of the pine engraver, *Ips pini* Say, occasionally occur in the vicinity of logging operations but usually these are of short duration and cover small areas. *Ips perroti* Sw. has similar habits to *I. pini* but is of lesser economic importance. Many other bark beetle species play secondary roles, attacking suppressed and weakened trees, windfalls, fresh slash, and stumps. At times, some of them may be beneficial by killing the suppressed and weakened trees, resulting in a natural thinning of the stand.

The mountain pine beetle is a stout, black, cylindrical bark beetle about 3/16 of an inch in length, having a broad head without a frontal groove and with the prothorax slightly narrowed toward the head.

Adults emerge from infested material in mid-summer, the time varying considerably with weather conditions. They attack green standing trees during outbreaks, or windfalls and freshly cut logs during endemic periods. The female bores through the bark and excavates a fairly straight egg gallery up the tree between the inner bark and the sapwood. It is sometimes two feet or more in length. A mixture of resin and boring dust is pushed out of the entrance hole and

[4]This section was prepared and submitted in 1958 by G. R. Hopping of the Forest Entomology and Pathology Laboratory at Calgary, Alberta.

Plate 26. Mountain pine beetle gallery showing adults, larvae or pupae.

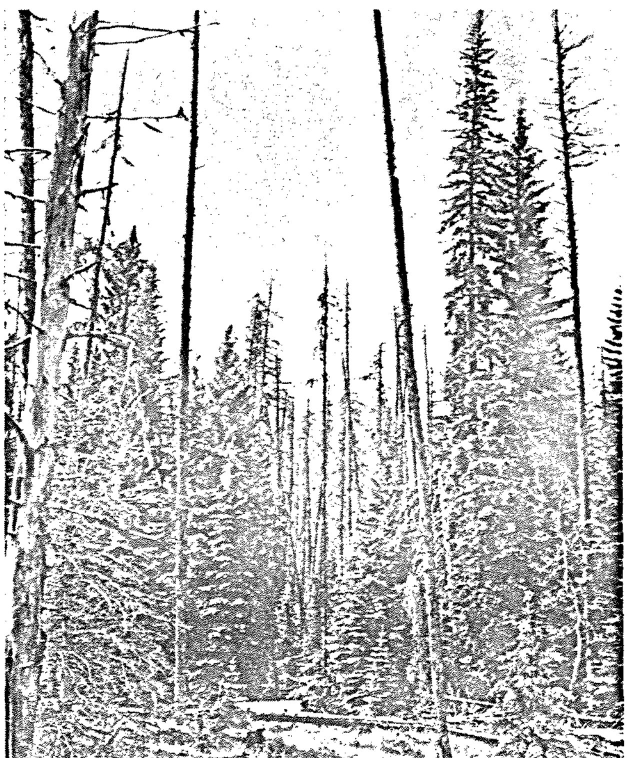

Plate 27. Mountain pine beetle damage in Kootenay Park.

Photos for Plates 26 to 32 by P. Debnam, For. Ent. and Path. Lab., Calgary, Alta.

accumulates on the outside of the bark to form a reddish brown pitch tube. On heavily attacked trees these pitch tubes are so numerous that they can be seen from a distance of 100 feet or more. In late attacks when the resin is not flowing to any extent, pitch tubes may not be formed and the only evidence of attack is the boring dust in bark crevices and around the base of the tree. The male usually enters the gallery shortly after it is started and he assists in the expulsion of the resin and boring dust. The eggs are laid in niches along each side of the main gallery. The larvae feed laterally from the main gallery between the inner bark and sapwood. By late fall they have become full-grown or some may have transformed to pupae within cells excavated at the ends of the larval mines. In the following spring larvae transform to pupae and pupae to adults, ready to emerge and attack fresh material in mid-summer.

After completing the first galleries many females emerge toward the latter part of summer or early fall and excavate second galleries, thus establishing two broods in one season. The larvae of the second brood overwinter in a fairly young stage reaching the adult form in late summer or early fall of the next year when they emerge and attack fresh material. Thus adults of two groups take part in the late attack, one composed of adults excavating first galleries and the other of those making second galleries.

The mountain pine beetle causes severe losses of white, sugar, ponderosa, and lodgepole pines in western North America. Losses have been particularly severe in mature to overmature lodgepole pine. Between 1920 and 1940, there were three outbreaks in lodgepole pine stands in British Columbia, each covering more than 100 square miles. No accurate damage appraisals were feasible but an educated guess would be at least one billion board feet destroyed.

An outbreak in Kootenay National Park started about 1930 and continued to 1942 (Hopping and Mathers 1945). In the main core of the infestation, sample plot data indicated that 400 million board feet were destroyed on 50,000 acres. The extreme outer margins of the outbreak enclosed a much greater area. No control was attempted. An outbreak in the Bow Valley and tributaries near Banff started in 1940. Fortunately, control measures were commenced in 1941 and continued to 1943. These were successful, probably aided by increased moisture conditions. The number of trees treated was 30,000 on an area of 15,000 acres. No other serious outbreaks have occurred in Alberta during the life of present stands.

The causes of outbreaks of the mountain pine beetle are imperfectly known but certain factors appear to exert a marked influence on infestations. It is known, for instance, that all of the large outbreaks between 1920 and 1945 occurred during, or immediately following, a long drought period. This could have contributed to the increase of the bark beetle in two ways. The growth rate of lodgepole pine was appreciably reduced in all age classes during the dry period and presumably tree vigour also declined. This may have prevented the trees from producing the amount of pitch necessary to drown the attacking beetles. Also the long dry seasons provided favourable conditions for egg laying and brood development over a longer period during the second or late summer and early fall attacks.

Outbreaks of the mountain pine beetle seldom develop in lodgepole pine stands under 80 to 90 years of age. This may be the reason why no serious infestations have occurred on the eastern slope of the Canadian Rocky Mountains where most of the pine stands are in this age class or younger.

It has often been stated that pure stands are particularly susceptible to insect outbreaks (Doane, Van Dyke *et al.* 1936, Prebble 1951, Graham 1952, Keen 1952). This is substantiated by the fact that mountain pine beetle outbreaks seldom originate in mixed stands. Windthrown trees and logging and road slash often cause a sufficient build-up of bark beetle populations to cause outbreaks in the surrounding timber.

Hopping and Beall (1948) have shown that few trees of diameters 6 inches and under are attacked, and that there is a rise of 4 to 5 per cent infestation with each one-inch diameter increase. This probably varies considerably with the level of the beetle population and the number of available trees. On nine plots aggregating 8.5 acres in the severe Kootenay outbreak there were 763 trees of 8 inches d.b.h. and under. Of these, 60 per cent was attacked, mainly in the 8-inch class, but 20 per cent of the attacked trees recovered, with a total survival (unattacked and recovered trees) of 51 per cent at the end of the outbreak. There were 714 trees of 10 inches d.b.h. and over, of which 90 per cent were attacked. Of the attacked trees, 91 per cent were killed with a total survival of only 12 per cent at the end of the outbreak, mainly in the 10 and 12-inch classes. These data suggest a preference on the part of the beetle for trees of the larger diameter classes. The higher recovery of the smaller trees was due to light attack, indicating that they were less attractive to the beetle than the larger trees.

Many types of direct control have been tried on bark beetle outbreaks in lodgepole pine. These have been described by Keen (1952). Two of the methods seem to be more successful than others. They are (1) cutting, decking and burning infested trees, and (2) treating infested trees, either standing or felled, with penetrating oil sprays. A third method, the salvage control operation, can be used effectively to stop small outbreaks in the vicinity of logging operations. In national parks, when salvage is not feasible, the decking and burning method is recommended because it maintains the aesthetic values as well as eliminating fire hazard from felled trees or standing snags. In commercial timber, treating with chemicals would probably be cheaper.

There are three main steps in a major control operation. The first is an examination of the infested area to determine whether the outbreak is increasing or decreasing. It can be done by a qualified man traversing the area and finding the ratio of green infested trees to red-topped trees attacked the previous year. The best time is in late fall after the fresh attacks on green trees have been completed.

If results show a rising infestation and control is decided upon, the second step is to make a 1 to 2 per cent cruise recording all green infested trees on the strips. It is advisable to record trees of the previous years attack (red tops) as well, because this will give the rate of increase more accurately than in the preliminary examination. The most important function of this cruise, however, is to provide data for the estimation of control costs.

The third step is the actual spotting, marking, and treating of the infested trees. On large outbreaks this may require 150 men or more. Cruising parties of three to four men each must first make a 100 per cent cruise of the infested area, marking and plotting every infested tree or group of trees. This enables the treating crews to locate them with ease (Hopping 1946).

The cost of control varies considerably with economic conditions, size of trees and intensity of infestation. In lodgepole pine, it has been done at a cost of from 50 cents to $1.00 per treated tree, using the decking and burning method (Keen 1952).

Several management practices can be suggested to reduce the stand susceptibility to mountain pine beetle outbreaks.

1. The older stands containing the larger diameters should be given cutting priority on extensive timber licenses no matter what the cutting system may be.

2. The age of stands should be kept to 80 years or under, or as low as possible commensurate with the wood product requirements and economics of the operation. For instance, on pulpwood leases this should be entirely feasible as soon as the older stands are converted to young growth. After that there should be little trouble from the mountain pine beetle.

3. Where a selection cut is silviculturally desirable and where there is an understorey of spruce it would probably reduce the bark beetle hazard to convert the stand to mixed pine and spruce. This is recommended particularly in national parks where the bulk of the mature and overmature pine stands are now situated. Although this may take considerable time, it offers the only permanent solution to reduce bark beetle outbreaks in the future and at the same time maintain aesthetic values. In the meanwhile bark beetle outbreaks must be controlled by direct methods whenever they occur in extensively used recreational areas.

The pine engraver *Ips pini* is a small black bark beetle, about $\frac{1}{8}$ of an inch long, with four teeth on the margin at each side of the elytral declivity. The second suture of the antennal club is angled at the middle.

Adults emerge during the first warm days in May and attack fresh material, usually slash or windfalls. After boring through the bark a small chamber is excavated between the inner bark and sapwood. From this, three to five galleries are excavated, sometimes arranged in a radial pattern, sometimes with a few galleries extending up and a few down the tree. The species is polygamous and three to five females and a male may be found in the same gallery system. The eggs are laid along these radiating galleries and the larvae feed out laterally from them excavating cells in which they pupate. The pupal stage lasts only a week or ten days and the adult stage is reached during August and September. Many of the new adults emerge and overwinter in the duff. The parent adults often emerge and excavate second galleries producing a second brood in the same season. This brood overwinters in the galleries as larvae, pupae, and some as young adults (Reid 1953).

This beetle occurs in all pines and in some spruces from eastern Canada and the United States to Alberta and British Columbia. It does not cause widespread outbreaks. A few small outbreaks have occurred in Alberta in the vicinity of logging or road slash, but these lasted one or two years and covered only a few acres.

I. perroti is similar in appearance to *pini*, a little smaller, and the sutures of the antennal club are straight or nearly so. The life history is about the same but adults emerge a little later in the spring. There is one important difference in the gallery pattern caused by a difference in larval behaviour. The larvae of *perroti* do not feed out laterally from the main gallery but excavate cells right beside it. The entire larval development takes place in these cells (Reid 1955).

Little is known of its distribution since it was found in only two places in eastern Canada before it was discovered in central Alberta in 1952. No outbreaks have been found in Alberta but potentially it could cause flash outbreaks similar to those of *pini*.

4.12 THE FOLIAGE FEEDERS

The lodgepole needle miner, *Recurvaria starki*, Free., is the most important defoliator. A large outbreak occurred in the Rocky Mountain National Parks from at least 1942 until 1950. Although no appreciable tree mortality resulted, the growth rate of trees was drastically reduced. A closely related species, *Recurvaria milleri* Busck, has caused heavy mortality to lodgepole pine in Yosemite National Park, California. One other needle feeder, the grey pine looper, *Caripeta angustiorata* Wlk., occasionally causes noticeable damage over small areas but has never been known to kill trees in Alberta forests.

The lodgepole needle miner adult is a small, narrow, grey moth about $\frac{5}{16}$ inch long, with a wing expanse of half an inch. The front of the head is white to silvery grey, the thorax usually grey. The fore-wings are extremely variable from pale to dark grey. The hind wings are creamy white. The legs are white, annulated with black.

The life cycle covers approximately 24 months, of which 21 are spent in the larval stage. Adults normally appear in the even-numbered years, i.e. 1952, 1954. Moth emergence begins in the first week of July and is generally completed by the first week in August. Copulation begins soon after emergence and eggs are found to the latter part of August. They are usually laid within the previous needle mine, but sometimes on the outside at the base of the needle or on the sheath. They hatch in about 15 days in good weather. From this time until the early summer of the next even year, only larvae are present in the needles. Pupation begins early in June of the even-numbered year and is completed by June 30th. Pupation takes place in the mine and the moth emerges through an exit hole prepared by the last instar larvae (Stark 1954).

Tree-ring studies have shown that the current outbreak is the only one of such severity that has occurred during the life of the present pine stands. It was first noticed in June 1942 on an area of 50 square miles between Mt. Eisenhower and Vermilion Pass in Banff National Park. Subsequently, the outbreak spread into Yoho and Kootenay National Parks. A small, short-lived outbreak developed in Jasper which was separated from the southern one by a considerable distance owing to intervening high country where there was no lodgepole pine. At one time the southern outbreak covered 450 square miles. (The heaviest infestation is believed to have occurred between 1940 and 1944.) Since 1950 outbreak conditions have declined until at the present time none exist.

Weather seems to be the most important factor in the development and decline of needle miner outbreaks. Unusually low temperatures in two separate winters caused a very high mortality of larvae at the lower levels in the Bow Valley. This suggests that a succession of mild winters could permit a great increase in the miner population. An examination of the weather records for Banff, Anthracite and Lake Louise shows that there was, in fact, a succession of relatively mild winters prior to the present outbreak.

There is small promise of direct control of the needle miner by the application of sprays. The larvae are protected within the mined needles throughout nearly all of their development. Although all ages and sizes of trees are susceptible to attack, there is a possibility of minimizing the damage through silvicultural practices. There is some evidence that pine mixed with spruce does not have such high populations of larvae per tree as contiguous stands of pure pine of comparable size. However, definite conclusions must have more supporting evidence. Thus far evidence indicates that natural control of the needle miner by insect parasites, predators, and disease has not been very effective.

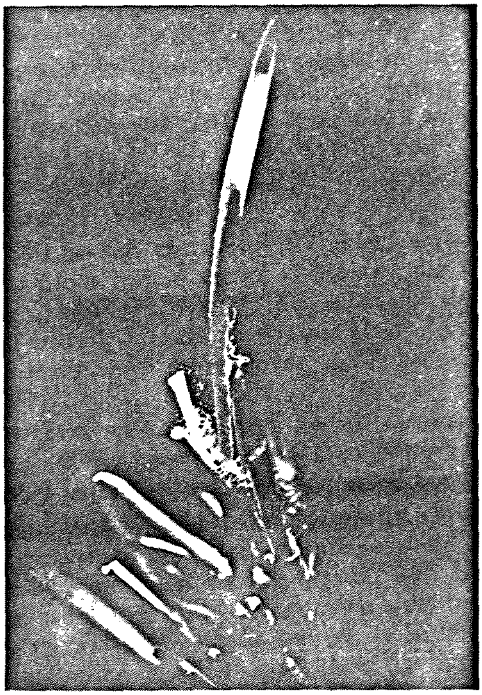

Plate 28. Needles of lodgepole pine mined by *Recurvaria.*

Plate 29. Terminal shoot of lodgepole pine killed by *Pissodes terminalis.*

The grey pine looper adults fly and lay eggs in July. These hatch in a short time and the larvae become full grown and pupate in one season. The winter is spent in the pupal stage, probably in the duff. No widespread outbreaks have occurred but in 1949 defoliation was noticeable on small areas in the Miette and Athabasca Valleys near Jasper.

4.13 TWIG AND TERMINAL INSECTS

Only a few insects cause serious injury to the twigs and terminals of lodgepole pine. Perhaps the most important of these are the pitch nodule moths, *Petrova* spp. They are much more prevalent in plantations than in natural forests. The lodgepole terminal weevil, *Pissodes terminalis* Hopp., kills the tops of young pines. The damage is sometimes severe over small areas, causing malformed trees.

There are at least three species of pitch nodule moths, *Petrova albicapitana* (Busck), *P. luculentana* (Heinr.), and *P. metallica* (Busck). The moths have a wing expanse of about $\frac{3}{4}$ inch and are speckled with brown or grey markings.

The eggs are laid in June at the base of the needle sheaths. The larvae bore into the new and old growth of pine twigs, branches, and stems. Their work is characterized by a nodule or round lump of pitch and frass formed over the feeding site. Branches are often killed by girdling and breakage is sometimes caused in the main stem. The life cycle is two years in length (Turnock 1953). No extensive damage is known in Alberta but there are numerous small patches of lodgepole pine where the nodules are quite plentiful.

The lodgepole terminal weevil is an oval-shaped beetle about $\frac{1}{4}$ inch in length, light to dark brown in colour with grey bands or mottling. There is a prominent curved beak on the front of the head. In late spring or early summer the adults feed on the tender bark of the terminal shoots and the females lay eggs in small punctures made with their beaks. The larvae, which are white legless grubs, mine up and down through the pitch and parts of the wood. When fully grown, they pupate in cells excavated in the pitch. There is probably only one generation per year. One area was found in 1949 where young pine was rather heavily infested. This was a strip about $\frac{3}{4}$ mile long by $\frac{1}{5}$ mile wide near Mercoal, Alberta.

4.14 SUCKING INSECTS

Two insects in this group are of economic importance, the pine needle scale, *Phenacaspis pinifoliae* (Fitch), and the black lodgepole aphid, *Cinara* sp. They occasionally cause noticeable damage over small areas but seldom kill trees in Alberta forests. The former sometimes kills trees in plantations and shelterbelts.

The pine needle scale female is wingless and is stationary on the needle for most of its life with stylets imbedded in the needle tissue. The insect is covered by an elongate scale formed by a waxy secretion. The males are winged. Winter is passed in the egg stage beneath the mother scales. The number of eggs per female varies from a few to 90. Hatching may take place any time between May 26 and June 26 depending on weather conditions. The newly hatched young are minute, reddish pink, oval insects. They crawl from beneath the scale and disperse over the needles. When they find suitable feeding sites they become stationary with mouth-parts thrust into the needle tissues. In contrast to the stationary females, the males eventually develop wings and fly about to fertilize the females.

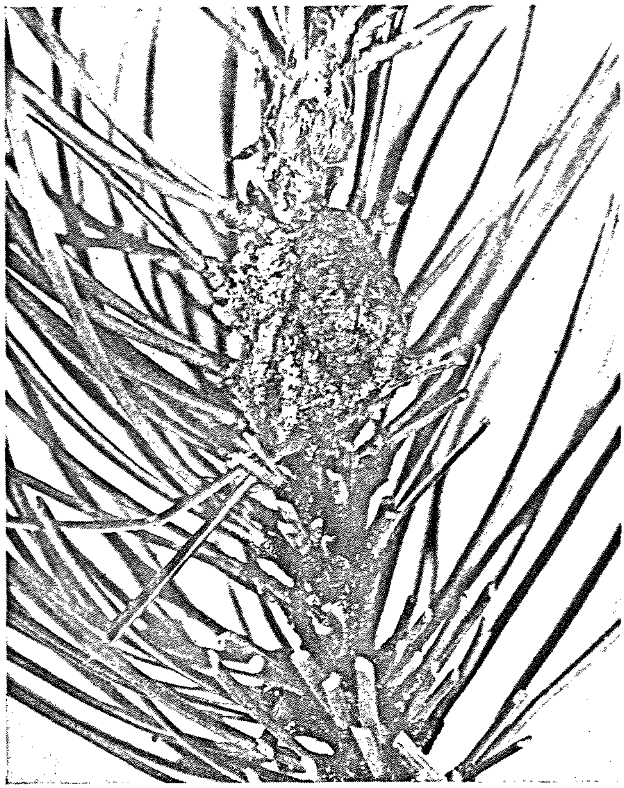

Plate 30. Pitch nodule formed by nodule moth.

Egg laying begins about mid-August and, unless cold weather sets in, may continue until late October (Peterson 1950).

During the past seven years only one heavy infestation has been found in the pine stands of this region. The area was first noted in 1955 near Hillcrest in the Crowsnest Pass district. It was 3 miles long by ½ mile wide. Such outbreaks seldom occur in forests and are generally in stands on the poorer sites.

The black lodgepole aphid is a fairly large dark brown to black plant louse about ⅛ inch long. Little is known of the life history of this particular species but other members of the genus *Cinara* spend their entire life on one host. The winter is passed in the egg stage. The first few generations in the spring are apterous, viviparous females. Winged females occur later and finally winged or wingless males and oviparious females. They occur in dense colonies on the small limbs and twigs, feeding by inserting the stylets into the plant tissue. Near Nordegg, in 1952, young lodgepole pine on several hundred acres was severely damaged, with some top killing.

4.15 ROOT FEEDERS

There is only one important root feeder, the large pine weevil, *Hylobius warreni*, Wood. The adult is a robust oval beetle about ½ inch long with a prominent stout beak. The body is black with the wing covers flecked with grey. The larva is a legless white grub.

Details of the life history have not been fully determined, but they are currently under investigation. The life cycle extends over more than one year. Adults, larvae, and pupae can be found during the summer, but the bulk of the population appears to overwinter in various larval stages. Some adults probably hibernate in the duff.

This insect occurs in the timbered sections of the Prairie Provinces, British Columbia, and the Northwest Territories, as well as in Eastern Canada. It is not common in the subalpine regions, but high populations have been found in several places in the boreal forest of the Alberta foothills. These are at Strachan near Rocky Mountain House, near Lesser Slave Lake, north of Peace River, near Robb, and in Water Valley north of Morley. A high population of active larvae was found at Strachan where more than 95 per cent of an 85-year-old stand had sustained varying degrees of root damage. The more severe infestations were found on heavily timbered sites where there was a fairly deep layer of moss or duff. Root damage was seldom found in more open stands on dry or sandy sites.

The larval feeding results in a girdling or engraving action on the lateral roots and tap roots and on the trunk to the upper level of the duff. The feeding is confined to the bark and cambium layer. Large masses of pitch, soil, and duff accumulate adjacent to the feeding site. Larvae feed along roots for distances up to several feet, even into the mineral soil. Examination of stumps with known cutting dates indicates that the Strachan infestation has been in progress for at least 10 years. Damage occurs in all age classes from 16 years to maturity but it is most severe in the more vigorous trees in the dominant, co-dominant, and intermediate classes (Reid 1952).

4.16 WOOD BORERS

There are four important groups of wood borers. The round-headed borers (*Cerambycidae*) and the flat-headed borers (*Buprestidae*) are beetles in the adult stage, as are the ambrosia beetles (*Scolytidae*). The horntails or wood wasps (*Siricidae*) form another important group.

The round-headed borer, *Monochamus oregonesis* Lec., is an elongate black beetle an inch or more in length with antennae about twice the body length. The larvae are white and grub-like, 1 to 1¾ inches long. They bore large holes in scorched, injured, or recently felled lodgepole pine, Douglas-fir, or true firs. Logs left too long in the woods or in decks may be riddled by these borers. Other round-headed borers of lesser importance are *Asemum atrum* Esch., *Arhopalus productus* (Lec.), and *Spondylis upiformis* Mann.

The flat-headed borers are usually not so destructive to the wood as the round-headed borers. The adults are flat, boat-shaped beetles, black or brilliant metallic green, or with coppery tints. There are no species of economic importance infesting lodgepole pine in Alberta.

The ambrosia beetles cause only minor damage to lodgepole pine. The main species belong to the genera *Trupodendron* and *Gnathotrichus*. Adults of the former are small, very shining, dark-coloured beetles often with yellowish longitudinal strips on the wing covers. They project branching galleries through the wood of dying trees and logs and the larvae develop in cradles excavated off the main tunnels. The galleries become blackened by the fungus upon which the insects live. *Gnathotrichus* is rare in Alberta.

The horntails or wood wasps infest dead and dying trees and are particularly attracted to recently fire-killed timber. Adult females are cylindrical wasps with thick waists, dark metallic blue or black, and some with yellow bands or markings on the body. There are two pairs of membraneous wings and a horn-like ovipositor extending back from the tip of the abdomen. This is inserted deeply into the wood where the egg is deposited. The larvae make perfectly circular holes through the wood, packing the boring dust in the galleries behind them.

Although attacks on sawlogs by borers may be minimized by the application of certain sprays, the best means of preventing loss is to utilize the logs before the damage can become serious. Logs and trees scorched by fire should be salvaged before the following spring. Logs cut in the winter should be hauled to the mill and utilized before June. Logs cut in the summer before August 1 should be utilized within two months of cutting. If they are cut after August 1 they can be sawn any time before the following June (Simpson 1951).

4.2 Forest Diseases of Lodgepole Pine in Alberta[5]

Lodgepole pine is subject to diseases from the seed to the time of harvest. These diseases are non-infectious or infectious, or they may be the result of inter-relationships of both these categories.

Non-infectious diseases include damage caused by unfavourable soil conditions, water deficiency or water excess, climatological disturbances, and by fire, animals and logging. Infectious diseases are those caused by pathogenic agencies such as fungi and parasitic flowering plants.

The most important diseases affecting lodgepole pine in Alberta are discussed in this presentation. For additional information the reader is referred to the references that deal with the pathology of lodgepole pine and to the books by Boyce (1948), Baxter (1952), Cartwright and Findlay (1946), and Hubert (1931).

4.21 Red Belt

Red belt is a foliage disease of climatological origin which develops in late winter and early spring. Warm winds, called "Chinooks", move along well-defined belts following contours of the south and west slopes, causing rapid warming and drying. Apparently the disease is caused by the alternate chilling and warming by the cold valley air and the "Chinook" (Henson 1952).

The fluctuation of warm and cold air, combined with factors of low relative humidity and high solar radiation, predispose the trees to excessive transpiration when frost in the ground prevents the uptake of compensating moisture. The needles become desiccated and progressively turn from green to red, to reddish-brown, to brown. Most of the affected needles are cast by late summer.

The disease derives its name from the red-brown foliage occurring on trees in generally well-defined altitudinal belts of 200 or more feet. In the Bow River Valley, red belt occurs between 5,800 to 6,200 feet (Henson 1952).

Aesthetically, red belt is frequently a significant factor in the National Parks particularly where affected forest cover surrounds townsites and recreational areas. Trees may appear unsightly and those severely injured may become deformed and develop dead tops. Mortality is rare. Of the "red-belted" trees

[5]This section was prepared and submitted in 1958 by Dr. V. J. Nordin, Associate Director, Forest Entomology and Pathology Branch (forest pathology), Ottawa.

examined over a three-year period at the Kananaskis Forest Experiment Station (Blyth 1953), only one tree died; 95 per cent of the crown had been affected. This disease, however, may increase mortality in stands affected by *Atropellis piniphila* (Weir) Lohman & Cash. In the third year following "red belting" at Robb, relatively heavy tree mortality resulted in stands with a high incidence of *Atropellis* canker. This mortality did not occur in adjacent cankered stands unaffected by red belt (Bourchier 1953).

Blyth (1953) found that three years following injury, the loss in tree growth is considerable and is closely proportional to the amount of crown damaged. There was little evidence of growth recovery up to three years following the initial damage and many trees sustained permanent injury through dead and deformed tops.

Under certain conditions salvage operations are advisable in severely affected stands.

4.22 RED STAIN

Red stain is an incipient or early firm stage of decay that has been found associated with a number of fungi (Denyer 1953; Nordin 1953, 1954, 1955, 1956, 1957, and 1958). The fungi associated with red stain, in alphabetical order, are *Fomes pini* (Thore ex Fr.) Karst. (*see* Plate 31, no. 2), *Polyporus anceps* Pk., *Polyporus tomentosus* Fr.,[6] *Stereum pini* (Schleich. ex Fr.) Fr. (no. 1), and *Stereum sanguinolentum* Alb. & Schw. ex. Fr. (no. 3). Previously, red stain was attributed predominantly to *Fomes pini* (C.S.A. 1956).

In a study of 133 lodgepole pines (even-aged, 85 years old) distributed in three localities (Nordegg, Strachan, and Water Valley) in Alberta (Nordin, Heming and Blyth 1955), at least 80 per cent of the trees had one or more infections of red stain and 237 of a total of 265 infections were red stain. Of the red stain infections identified with four principal fungi, the incidence of infection was, *Stereum pini*, 86 per cent; *Fomes pini*, 7 per cent; *Polyporus anceps*, 4 per cent; and *Stereum sanguinolentum*, 3 per cent. A similar incidence of red stain resulted from a study of 157 trees in the region of Marlborough (Nordin and Carmichael 1957).

The predominance of *Stereum pini* is significant because the development of standards for poles and ties exhibiting red stains (C.S.A. 1956) are based on experimental results with *Fomes pini* (Atwell 1948). At present, very little is known about *S. pini* in living trees and its effect on the strength (Eades and Roff 1959) and durability of various forest products in service such as poles, ties, lumber, and pulp. The firm reddish-brown stage of *S. pini* in the heartwood of lodgepole pine has been described (Denyer 1952; Nordin, Heming, and Blyth 1955), and laboratory inoculations of wood blocks with *S. pini* have produced red stain with the subsequent re-isolation of the organism from the discolored blocks (Nordin, Heming, and Blyth 1955). The advanced stage of decay has not been observed or described in nature, but Nobles (1956) has reported that wood blocks inoculated with *S. pini* were discolored a reddish-brown and, within a one-year period, a decay resulted which was described as a "yellow fine stringy rot".

The major fungi associated with red stain enter the tree mostly through branch stubs but entrance points in crotches and in scars caused by fire (Nordin 1958) and falling trees sometimes occur.

[6] *Polyporus tomentosus* is synonymous with *Polyporus circinatus* Fr. var. *dualis* Pk.

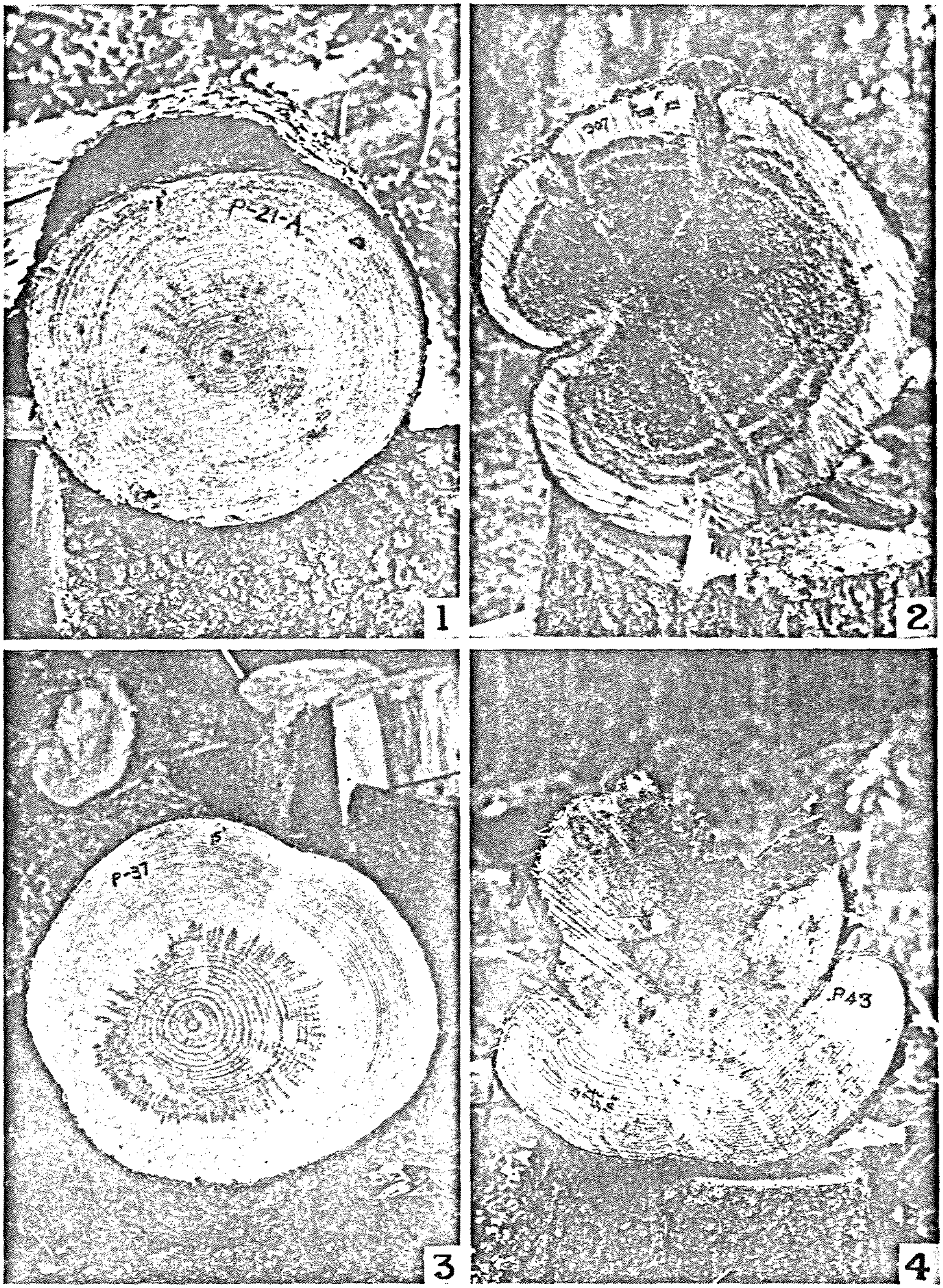

Plate 31.

1. Red stain caused by *Stereum pini*. Characteristic rays extend from the central core of light reddish-brown stain.
2. Cross-sectional view of advanced decay caused by *F. pini* with attached fruiting body.
3. Cross-sectional view of the reddish-brown ray stain caused by *Stereum sanguinolentum*.
4. Brown cubical decay caused by *Coniophora puteana* originating through a basal fire scar.

4.23 MISCELLANEOUS DECAYS AND STAINS

The occurrence of decay in lodgepole pine reported in the United States and elsewhere has been reviewed in a recent report (Nordin, Heming, and Blyth 1955).

During a study of decay of spruce in the vicinity of the Kananaskis Forest Experiment Station (Denyer and Riley 1953), 13 overmature lodgepole pines were dissected and the following fungi associated with decay: *Fomes pini*, *Flammula connissans* Fr., *Polyporus circinatus* Fr. var. *dualis* Pk. (*P. tomentosus*), *Stereum pini*, and *Stereum sanguinolentum*.

Armillaria mellea (Vahl ex Fr.) Quèl., the cause of the mushroom root-rot, has been detected causing mortality in dense regeneration in the Robb area (Bourchier 1953). Regeneration from two to five feet high exhibit typical symptoms and signs of the disease including chlorosis of the foliage, mycelial fans under the bark, resinosis, and rhizomorphs associated with decayed roots.

In addition to the fungi already discussed that were associated with red stain, studies at Nordegg, Strachan, Water Valley (Nordin, Heming, and Blyth 1955), and Marlborough (Nordin and Carmichael 1957), have disclosed the occurrence of other fungi.

Brown cubical decay and white pitted decay were associated respectively with *Coniophora puteana* (Schüm. ex Fr.) Karst. (Plate 31, no. 4) and *Polyporus abietinus* Dicks. ex Fr. *Polyporus abietinus* primarily causes a sap rot of logging slash, windfalls, and cull logs. However, this fungus may occur in living trees attacking wood exposed by wounds such as basal fire scars (Nordin 1958).

Blue stain enters mainly through branch stubs and scars caused by fire and falling trees. *Oidiodendron fuscum* Robak has been isolated from blue stain in living trees, and its ability to cause blue stain has been corroborated by laboratory tests. Species of *Cephalosporium* and *Cytospora* have also been associated with blue stain (Nordin, Heming, and Blyth 1955).

4.24 DWARF MISTLETOE

Dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) is one of the most destructive diseases of lodgepole pine of all sizes in the Alberta region.

The disease is distributed sporadically throughout the range of lodgepole pine in the Banff, Jasper, and Waterton Lakes National Parks and on the east slopes of the Rocky Mountains from the area of Edson south to the United States-Canadian border. The occurrence of dwarf mistletoe on lodgepole pine north of Edson and Jasper has not been determined. The parasite is also present in the Cypress Hills of southeastern Alberta (Bourchier 1953). Centers of heavy infection are frequent; in Jasper townsite, for example, it is difficult to find a tree that is not infected to some degree.

The presence of the yellow-green male and female plants of the parasite on the branches and stems of the host (Plate 32, no. 1) constitutes the main signs of the disease. Visible host reactions or symptoms may include chlorosis of the foliage, fusiform swellings of the branches and stems, elongation of infected branches, resinosis, witches' brooms (no. 2), and spike tops.

In very dense stands where infection may be heavy, the presence of numerous shoots of the parasite may be the only obvious evidence of infection. Witches' brooms, however, are pronounced on open-grown trees or on residuals of thinned stands. Opening of stands through selective logging appears to accelerate the growth of the parasite on the remaining infected trees, resulting in an increase in the incidence and size of brooms.

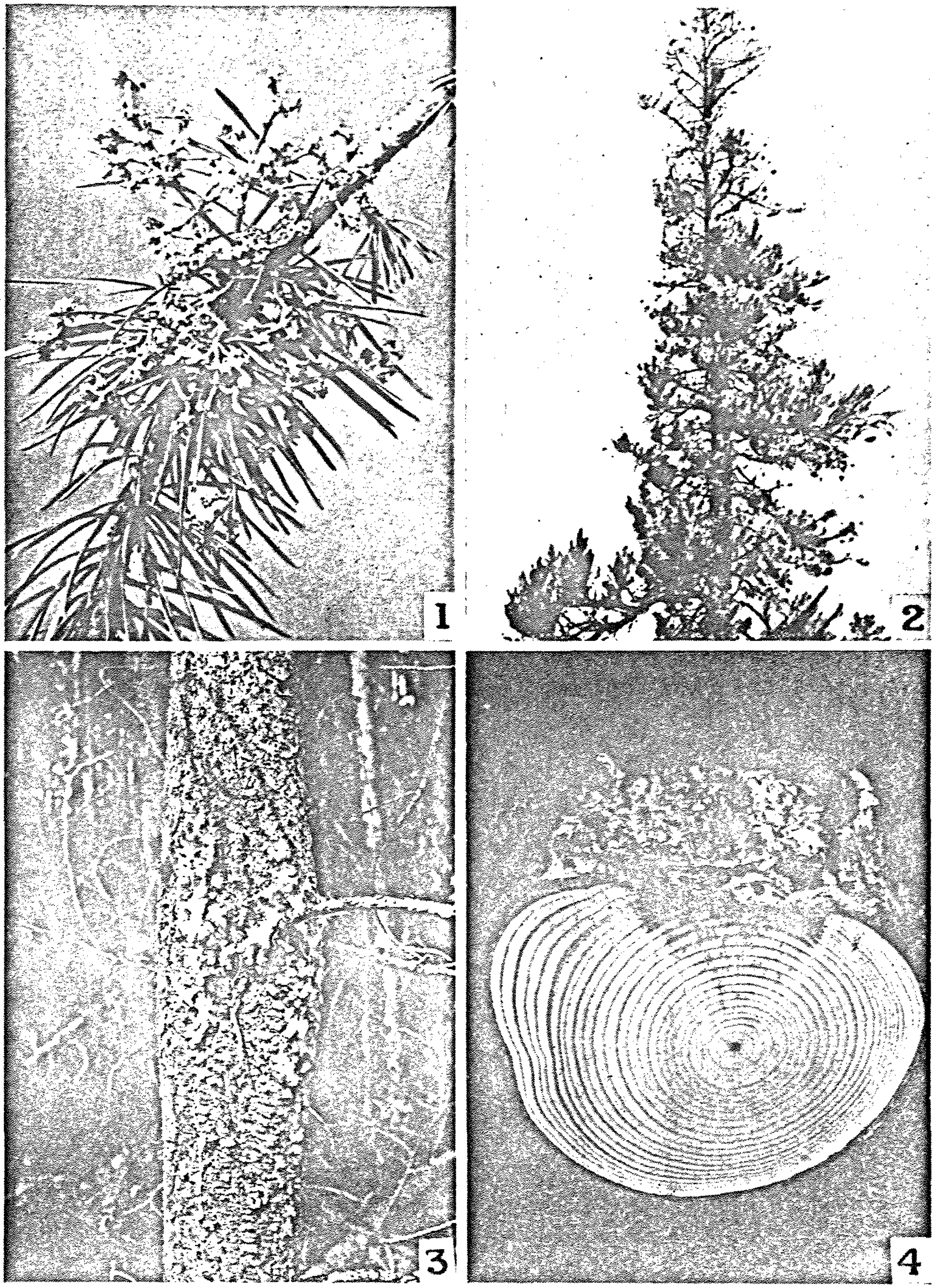

Plate 32.

1. Male plants of the dwarf mistletoe parasite, *Arceuthobium americanum* (photo by Dr. J. Kuijt).
2. A lodgepole pine severely affected by *A. americanum*. Note the numerous witches' brooms (photo by Dr. J. Kuijt).
3. Canker of the main stem caused by *Atropellis piniphila*. Note the apparent origin of the canker at a branch whorl.
4. A cross sectional view of a canker caused by *A. piniphila* showing the characteristic blue-black stain underlying the canker.

Dwarf mistletoe is damaging to lodgepole pine of all ages. In commercial stands this damage takes the form of loss in vigor and growth, mortality, marked decrease in the strength and grade of timber, and severely infected stands may serve as breeding centres for bark beetles and other insects. In the Rocky Mountain National Parks and similar areas of high recreational value, dead, dying and deformed trees consitute a significant aesthetic loss.

There are serious gaps in our knowledge of the life history of *Arceuthobium americanum.* The following account, however, is based on observations in Alberta and from the literature (Boyce 1948, Dowding 1929, Gill 1935, Kuijt 1955).

The yellow-green to green, male and female shoots occur singly or in clusters and range from about 35 to 150 millimeters or more in length. The shoots flower in spring and early summer and a bright yellow pollen is produced. The pollen is disseminated mainly by insects to the female flowers where fertilization takes place a few days following pollination. The olive green "seed" matures in late autumn of the following year when it is forcibly ejected up to distances of 30 feet or more. The "seed" has a mucilaginous material which enables it to adhere to the host. Germination may be immediate but is usually delayed until the following spring. The parasite may successfully penetrate the bark of stems up to 58 years old (Hawksworth 1954). The radicle grows along the bark surface until it reaches an obstruction. At the obstruction a "foot" or "holdfast" is formed which sends down the primary haustorium. This initiates the endophytic system consisting of two types of structure, cortical strands and "sinkers". The endophytic system develops in the living host and, following an unknown period, depending possibly upon factors such as bark thickness and exposure to light, the male and female aerial shoots are again produced to complete the life cycle.

There have been three principal considerations for the control of dwarf mistletoes: natural biological control, the application of selective herbicides, and the utilization of various procedures in forest management.

Various insects, birds, mammals, and fungi effect some local control of the parasite but none of these show promise of general application. Natural control in some instances, however, appears to have occurred as the result of ecological conditions favouring high populations of two fungus hyperparasites, *Septogloeum gillii* Ellis and *Wallrothiella arceuthobii* (Pk.) Sacc. For example, in 1953 at the Kananaskis Forest Experiment Station, the incidence of *S. gillii* was so frequent that it was difficult to locate healthy mistletoe plants for the testing of selective herbicides (Bourchier 1954). Previously, *Wallrothiella arceuthobii* has been considered of little consequence in natural control because of its apparent restriction to wet habitats (Gill 1935). Recently, however, various observers (Kuijt 1955, Thomas 1954) have noted the occurrence of this fungus in very dry localities in Western Canada and the role of this fungus in natural control, therefore, may have been under-rated.

In the Rocky Mountain Parks in Alberta, the serious incidence of dwarf mistletoe on lodgepole pine presents a problem because the eradication of infected trees is frequently impractical. This situation has resulted in an attempt to discover a selective herbicide which might prove toxic to the parasite without short-term (killing) or long-term (genetic injury) adverse effects on the host. Of six chemical compounds tested in Alberta (Bourchier 1954), M-C-P sodium salt and "Endothal"[7] initially gave encouraging results killing up to 90 to 100 per cent of the aerial shoots with only light to moderate damage to the foliage. The endophytic system, however, was not killed and re-sprouting occurred. Similar results have been obtained in the United States.[8]

Although initial studies have not provided a satisfactory chemical spray or injectant, this approach, because of its potential value in dwarf mistletoe control in recreational areas, deserves further investigation. Fundamental studies on the physiology of the parasite and host may reveal clues essential to a successful systematic evaluation of chemical compounds.

Under certain conditions, an interim solution may be the development of an inexpensive herbicide which would kill 100 per cent of the aerial shoots for one year. Periodic or annual applications of this chemical would give effective control.

Very little work in dwarf mistletoe control through forest management has been attempted in Alberta. In 1937, Parker (1942b) established two trial eradications as follows:

(i) "A three-acre tract of infected pine was clear-cut. For three consecutive years all mistletoe observed at the edges of the tract was removed by pruning or felling."

(ii) "A twelve-acre block was isolated from supposedly uninfected timber by clear-cutting around it a strip 25 feet in width. For three consecutive years all mistletoe observed at the edges of the clear-cut strip across from the 12-acre block was removed in the same manner as in tract 1."

Re-examination in 1941 revealed "much mistletoe was present at the edges of each clear-cutting operation" and the eradications, therefore, were unsuccessful. It was concluded that "examination from the ground was inadequate" and that it was impractical to eradicate or control dwarf mistletoe through pruning of observed infected branches.

An examination of unpublished project notes[9] has revealed the results of extensions of the foregoing work for the period of 1941 to 1952. On a ¼-acre plot, careful annual examinations were made and infected branches were pruned and trees with stem infections were felled. Despite this treatment a high number of infected trees were observed annually which provides further evidence on the difficulty of pruning as a method for eradicating dwarf mistletoe on lodgepole pine. However, in areas of high aesthetic value in the Rocky Mountain National Parks and townsites, pruning may improve the general appearance and condition of infected individuals or infected stands.

Except for the eradication of infected trees, there have been no extensive programmes to control dwarf mistletoe in specific areas. In the Jasper townsite, sanitation cuttings in 1955 and 1956[10] removed the most severely infected trees exhibiting dead branches and tops.

The lack of success in the control of dwarf mistletoe through forest management points to the need for fundamental knowledge on the rate of development and the characteristics of growth of the endophytic system of the parasite.

[7]"Endothal" was first tested by Dr. J. L. Mielke, U.S. Forest Service, L gan, Utah, who recommended the compound to the Calgary Laboratory for evaluation in this region.
[8]Pers nal communication from Dr. J. L. Mielke.
[9]Provided by the Forest Research Branch, Department of Forestry, Calgary, Alberta.
[10]Personal communication from S. Kun, Forest Engineer, Department of Northern Affairs and National Resources, National Parks Branch, Jasper National Park, Jasper, Alberta.

4.25 ATROPELLIS CANKER

The most important canker disease of lodgepole pine in Alberta is caused by *Atropellis piniphila* (Weir) Lohman and Cash. Atropellis canker occurs generally throughout the range of the host and is serious in a number of localities. Detailed surveys have revealed a disease incidence of not less than 70 per cent over an area of 125 square miles in the Robb-Coalspur region of west-central Alberta, and over an area of six square miles in the Blakiston Brook Valley of the Waterton Lakes National Park (Bourchier 1956). A high incidence of canker has also been observed elsewhere in the vicinity of the Clearwater Ranger Station, the Kananaskis Forest Experiment Station, Sundance Canyon, and the Castlemount Ranger Station.

The disease is characterized by perennial branch and trunk cankers that tend to become depressed and elongated. Individual cankers can exceed 10 feet in length. Resin flow is frequently copious and may accumulate in lumps. Minute, short-stalked, dark-brown to black apothecia (fruiting bodies) from two to five millimeters in diameter, are eventually produced on the cankered bark (Plate 32, no. 3). Another host symptom, depending upon the location, number, and size of cankers, may be the chlorotic appearance of the foliage of individual branches or parts of the crown.

In the underlying wood of the canker there is a blue-black zone (no. 4) from which cultures similar to single ascospores cultures of *A. piniphila* have been obtained. Surrounding this zone there may be an incipient reddish-brown zone about two to three millimeters in width which is virtually free of a pathogenic agency (Hopkins 1957). Weir (1921) has attributed the blue-black discoloration of the wood to the dark-brown mycelium of *A. piniphila* which penetrates the tissue of the medullary rays.

It is presumed that mature ascospores are wind-borne to the host where, under suitable conditions of temperature and moisture, they germinate and initiate new infections generally at branch whorls. Recent investigations by Hopkins (1957) indicate that most infections occur at nodes. He found 78 per cent of 80 trunk cankers originated at nodes and 22 per cent at internodes. Sixty-three per cent of 165 branch cankers were traced to nodes. The exact mode and most likely period of infection and the age of the cankers before ascospores are produced are unknown. Research currently in progress at the Forest Entomology and Pathology Laboratory at Calgary has been designed to clarify these and other etiological questions.

The chief damage to the tree is the malformation of the stem and retardation in growth; the extent of the latter has not yet been determined. The occurrence of multiple stem and branch cankers often renders trees unmerchantable. The part of the bole occupied by a canker is reduced in value because of the associated stain and stem malformation.

Difficulties may result in attempting to cut through cankers in milling for lumber and in debarking for woodpulp. Further, the blue-black discoloration associated with the cankers will degrade lumber and may increase bleaching costs in the processing of pulp. Rodents will sometimes chew the resin-impregnated cankers. In British Columbia, Molnar (1954) has reported the apparent susceptibility of cankered trees to secondary attack by bark beetles and Armillaria root rot. Losses may also result from wind-breakage at sections in the stem weakened by canker.

Although no critical evaluation of mortality has been made, dead trees occur which appear to have been killed by the disease. In recent examinations of sample plots near Robb, Bourchier (1957) has recorded a limited mortality of five out of 60 cankered trees over a period of two years. In the same area, however, heavy tree mortality occurred in cankered stands two years following "red-belting". In cankered stands affected by red-belt, therefore, appropriate consideration should be given when assessing damage.

Boyce (1948) states that the removal of incipient cankers early in the life of a stand could result in trees reasonably free of canker. This suggestion has merit but unfortunately it is impractical in Alberta under present standards of management and utilization. Control may be feasible in pulpwood operations where the application of clear cutting procedures may check the distribution of the canker and, in some instances, largely eliminate the disease. A more detailed discussion of cutting methods for disease control in lodgepole pine is recorded in a previous paper (Nordin 1954).

4.26 NEEDLE CAST

Needle cast is the most serious foliage disease affecting lodgepole pine in Alberta. Fungi causing this type of disease include *Elytroderma deformans* (Weir) Darker, *Hypodermella concolor* (Dearn.) Darker, *Hypodermella medusa* Dearn., *Hypodermella montana* Darker, and *Hypodermella montivaga* (Petrak.) Dearn. Of these, *H. montivaga* is the only fungus that has been reported in epidemic proportions (Stark and Bourchier 1956). Epidemic infections occurred in 1954 and 1955 in various locations in the Banff and Jasper National Parks (Stark and Bourchier 1956).

Very little is known of the life history of *Hypodermella montivaga* but it possibly has a one-year cycle as Darker (1932) has described for a similar fungus, *H. concolor*. The youngest needles are infected by *H. concolor* in July but no discoloration or other symptoms develop until the following spring when the needles begin to turn brown. The fruiting bodies (hysterothecia) mature and cast spores by July. The ascospores of *H. montivaga* probably are wind-disseminated in mid-August from adhering needles (Stark and Bourchier 1956).

Mortality caused by needle cast fungi is rare; the principal damage to stands is the loss in annual increment (as yet unassessed) resulting from epidemics.

4.3 Forest Fire Hazard in Lodgepole Pine[11]

Although conducive to the regeneration of lodgepole pine, fire is also its worst enemy. Practically all lodgepole pine forests in Alberta may be traced to fire origins. Horton (1956) found few lodgepole pine stands more than 100 years old in the most accessible Low Foothills Division. Considering such a demonstrated degree of susceptibility to fire, intensive protection measures are required if this species is to be successfully grown to merchantable sizes.

The following discussion is based on studies originally made for the development of forest fire danger and hazard tables for Alberta (Beall 1946, Anon. 1959). The term "fire hazard" refers to the probability of fires starting and spreading in specific fuel types and to the probable degree of difficulty to be encountered in controlling such fires. The numerical scale of the fire hazard tables developed by the Department of Forestry and used throughout Canada is divided into five classes: Nil (0); Low (1–4); Moderate (5–8); High (9–12);

[11] This section was prepared by J. S. Mactavish, Forestry Officer, Forest Research Branch, Department of Forestry, Ottawa.

Extreme (13–16). In some instances the term "test fire hazard" is substituted for "fire hazard" in these remarks. Test fire indexes relate to the ease with which fires start and spread in the surface fuels of specific fuel types, and includes some consideration of difficulty of control. These indexes are determined from the observations of small-scale experimental fires.

Under given weather conditions the development of fire hazard in a specific timber type depends upon the kinds, amounts, and arrangements of fuels present, their state of decay, and their abilities to shed water and dry quickly following precipitation. The needles of lodgepole pine form a loose well-aerated litter layer on the forest floor. Even the F layer tends to remain uncompacted. Because of this arrangement pine duff tends to hold relatively less moisture from a given amount of rain than do the duffs of most other species. It drys quickly to moisture levels of 25 to 30 per cent, at which it becomes readily inflammable.

In contrast to pine, the duffs of spruce and fir lie in compact layers, and tend to retain a greater proportion of precipitation, other factors being equal, than does lodgepole pine duff. In the most hazardous part of the day the moisture levels of these surface fuels are usually higher in spruce and fir than in lodgepole pine stands.

Because of the widespread distribution of mixed pine and aspen stands, aspen litter often represents a significant fuel in the lodgepole pine region. The moisture content of aspen litter usually remains higher than that of lodgepole pine, but the relationship varies considerably from season to season. Studies made in the Subalpine Division indicate that aspen stands maintain their highest relative litter moisture contents in the fall. (As described below, however, fuel moisture is only one of the variables affecting the combustion of forest fuels.) Aspen leaves have a relatively high moisture content when freshly-fallen and have a characteristic ability to catch rain in small pools and store it for some time. The lack of canopy in the fall permits rapid cooling of surface fuels at night and the consequent formation of dew. The short length of day and the more oblique angle of the sun's rays tend to inhibit subsequent drying.

Although a leaf canopy is also poorly developed during the spring period, the effect of night weather is usually gone by the following afternoon. Average mininum relative humidities tend to be lower in spring and, consequently, the aspen duff usually reaches lower moisture levels then than during fall. It is usually driest relative to lodgepole pine during the spring period.

During the summer months the compacted and decayed condition of aspen litter is conducive to adsorption and retention of moisture. At the same time, the fully developed vegetation reduces the drying influences of insolation and wind. Mid-afternoon moisture content levels of aspen duff usually range between those of spring and fall when related to lodgepole pine moisture levels.

The degree of compaction of surface fuels affects forest fire hazard in two ways. As described above, it influences the adsorption of moisture and subsequent drying of the fuels and, consequently, the development of fire hazard. Compaction of fuels also affects fire intensity through its influence on amounts of oxygen available for combustion. Loose well-aerated litter with a high ratio of surface area to fuel volume, typical of lodgepole pine stands, is much more readily ignited with small heat sources, such as matches and small campfires, than is the well-compacted litter of spruce stands.

The previously unpublished results of experimental fire observations made in the duff of a hybrid lodgepole pine stand indicate that autumn leaf fall may result in an increase of 1.5 to 2 fire hazard index units compared to the duff of the same stand and at the same moisture content levels during the summer months. A major portion of this hazard increase is thought to result from the abundance of oxygen available to support combustion in the loosely lying leaves. It is not thought to be a result of a higher concentration of volatile oils in the freshly fallen litter (Beall 1934).

Besides the characteristics of the leaf litters of individual species, the kinds and amounts of plant cover such as mosses, herbs, and shrubs are important considerations in relating fire hazard ratings among stands. Generalizations are difficult to make since there are wide variations found among stands of even one species. However, the lesser flora of pine stands, often including species of vaccinium and cladonia and shallow growths of feather mosses, are usually more inflammable than the frequently deep and poorly drained mosses of spruce stands or the herbaceous cover of aspen stands.

Figure 16 depicts the relationship of test fire hazard among neighbouring nearly-mature stands of trembling aspen, white spruce, and hybrid lodgepole pine near the edge of the Low Foothills Division. On the average, the trembling aspen stand maintained a hazard nearly as high as the pine in spring and fall throughout the range of weather and fuel moisture conditions encountered during a four-year period. When examining these curves it must be borne in mind that only the hazard of surface fires has been considered. Inclusion of the crown fire hazard that develops on occasion in pine and spruce stands would change the relationships among the species considerably. Unfortunately, insufficient data are available to permit inclusion of this factor.

Under given weather conditions the hazard in the pine varied relatively little from season to season. The hazard in the moss and litter of the spruce stand proved to be very low throughout the fire season, except on a few days when winds were high. The low relative hazard of the aspen stand during the summer resulted from the presence of a leaf and herb canopy together with decay and compaction of the surface litter.

Fahnestock (1960) has reported on controlled experiments comparing the inflammabilities of logging slash in northern Idaho. When equal weights of slash of local coniferous species were burned, he found that species had little influence on the rate of spread in fresh slash, but did have an important bearing on one-year-old slash inflammability. Thus the quantity of logging slash is the prime factor affecting relative rate of spread during the year of cutting. Because of differences in the rates of needle fall and slash decomposition, species affects inflammability thereafter.

Under typical conditions to be found in the field, Fahnestock (1960) suggests that fresh lodgepole pine slash is in the most inflammable class together with that of western white pine, western red cedar, Douglas-fir, western hemlock, and grand fir. The second most inflammable class included one-year-old lodgepole pine, fresh ponderosa pine and Engelmann spruce, one-year-old western white pine and western red cedar.

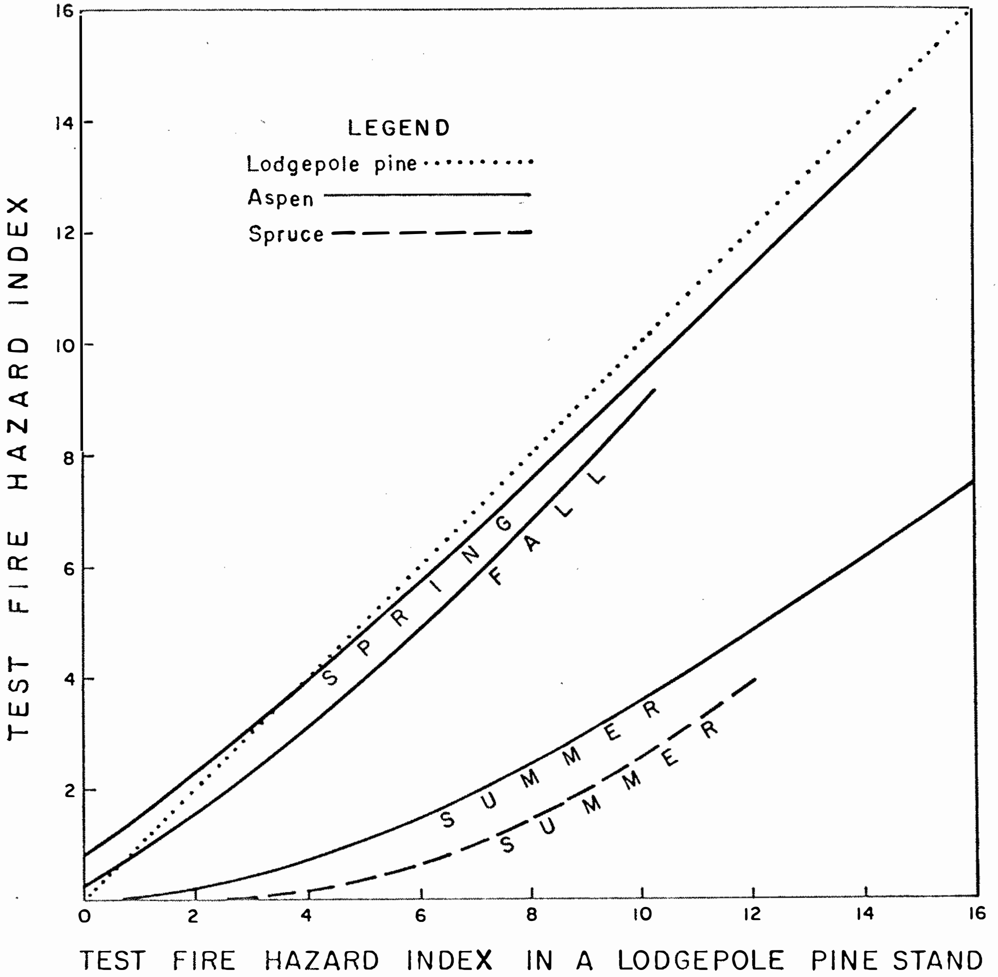

Figure 16. Test fire hazard in an aspen and a spruce stand in relation to that in a hybrid lodgepole pine stand in the Low Foothills Division.

One year after logging, the needles of Douglas-fir, western hemlock, grand fir, western larch, and Engelmann spruce have been shed, rendering the lash of these species much less inflammable. The decrease in inflammability in one year was found to be most spectular in western larch, grand fir, and Douglas-fir. Apparently the greatest decrease in inflammability of lodgepole pine slash does not occur until the third year after logging. Although Fahnestocks' work was confined to Idaho, he suggested methods whereby the relative inflammability of species may be determined for other areas.

To sum up, the degree of fire hazard in lodgepole pine stands usually changes little from season to season for the same weather conditions. The surface fuels usually drain and dry rapidly and the fire hazard may reach the "Moderate" class in as little as two days following rains of more than 0.50 inch. The shallow organic layer, typical of lodgepole pine stands, dries sufficiently in just a few days following rain to sustain a high level of persistent smouldering. Crown fires, especially in young stands, tend to develop readily with moderate winds. Fire hazard in lodgepole pine usually exceeds that in similar stands of other species growing in the same vicinity.

5. SILVICULTURE AND MANAGEMENT

5.1 Regeneration Silviculture

The recognized harvest cutting methods, i.e. clear cutting, seed tree, shelterwood, and selection cuts and their modifications, have been the subject of limited research in Alberta, but by far the greatest amount of commercial cutting has been done under a pure exploitation system involving economic clear cuts to minimum merchantability standards and selective high-grading. Since the primary purpose of harvest cutting is to secure adequate regeneration, this aspect will receive the greatest stress in the discussion of silvicultural practices.

5.11 regeneration surveys

Candy (1951) conducted regeneration surveys in Alberta and reported on conditions following logging, logging and fire, and fire. Table 8 has been prepared from data collected on these surveys.

The areas sampled for reproduction following disturbance (Table 8) in the subalpine region originally supported almost pure lodgepole pine stands, but in the boreal region most of the original stands of lodgepole pine contained an appreciable admixture of spruce and aspen. Following logging, reproduction is generally poor with failures usual in the boreal region and understocking common in the subalpine areas. After logging and fire, reproduction is adequate in both regions but the clumped distribution often results in an excessive number

TABLE 8. REPRODUCTION IN LODGEPOLE PINE FOREST FOLLOWING DISTURBANCE

Class of Disturbance	Forest Region	Number of Quadrats	Milacre Stocking (per cent)		Seedlings per Acre (number)	
			Lodgepole Pine	All Species	Lodgepole Pine	All Species
Logging.............	Subalpine	5,300	22	54	950	3,000
	Boreal (B.19)	4,140	6	32	100	660
Logging and Fire.....	Subalpine	1,800	60	82	7,400	9,000
	Boreal	1,480	68	88	10,500	14,400
Fire..................	Subalpine	400	81	85	8,600	9,000
	Boreal	—	—	—	—	—

of stems per acre in some areas. Following fire alone, results are similar to logging and fire but stocking and number of stems tend to be more variable. Species composition in the reproduction stands which follow disturbance reflects the composition of the original stands, with those in the boreal forest normally containing a higher proportion of aspen and spruce than those in the subalpine region.

The problem areas from a management standpoint are principally the inadequately stocked cut-over areas in the boreal region and the extremes of stocking which may occur in the subalpine region following fire.

Blyth (1954) studied regeneration in boreal areas logged for pine poles and ties during the past 20 years. The logging method in this case consisted of a selective high-grading. Blyth concluded from this study that partial cutting of pine stands did not produce satisfactory pine reproduction in the foothills area and that continued application of such a form of cutting would result in the retrogression of the present pine stands into a brush-aspen type. Bloomberg (1952) substantiates this finding and states that "pine regeneration was negligible after logging" in partially cut stands.

5.12 HARVEST CUTTING METHODS

Harvest cutting experiments following the recognized silvicultural cutting systems have been tested to a limited degree in Alberta by Crossley (1952, 1955a and 1955d) and Ackerman (1955). Crossley (1952) described a strip cutting experiment in a 73-year-old residual stand of lodgepole pine which had suffered a light ground fire in 1936. In 1942 the stand was clear cut in two-chain strips leaving a one-chain strip uncut. A generation survey in 1951 showed an average stocking to lodgepole pine of 60 per cent on the cut strips and 16 per cent on the uncut. Stocking to all species on the cutover was 80 per cent, the difference being made up of advance-growth spruce and poplar regeneration. Pine ages varied from 2 to 13 years but the bulk of the new crop seeded in 2, 3 and 4 years after cutting. Crossley suggests that the droughty soil conditions of the area which limited litter accumulations and vegetation density were to some extent responsible for the success of the treatment.

A second study at Strachan, Alberta, employing prescarification and strip clear cutting was designed to show the effect of seedbed preparation on pine regeneration and to indicate the importance of marginal and slash-borne seed sources. Crossley (1956a), reporting on this study, states that some form of prescarification was the only treatment producing satisfactory lodgepole pine regeneration. However, the experiment did not definitely establish the differences between slash-borne and residual-stand seed sources. Two years after the strip cutting, average stocking on the scarified areas was 90 per cent, with an estimated frequency of 7,000 seedlings per acre. Crossley suggests that the intensity of scarification may be varied to regenerate the stand to the desired number of stems per acre, thus avoiding the necessity for intermediate cuttings. He also points out that protective measures against fire, disease and insects may be accomplished by windrowing and burning the slash in conjunction with the scarification treatment. A further experiment (Crossley 1955d) was established in the same area to investigate the results of various harvest cutting methods without the benefit of special seedbed preparation. The cutting methods tested included clear cut, seedtree, uniform shelterwood, group selection, diameter limit, and various forms of partial cutting including thinning, sanitation, and conversion cuts. The regeneration resulting from these harvest cuts was re-measured in 1956 and is shown in Table 9.

TABLE 9. REGENERATION 5 YEARS AFTER HARVEST CUTTING IN AN 85-YEAR-OLD LODGEPOLE PINE STAND

Treatment	Stocking Per Cent[1]			
	Species			
	Pl	Sw	Po	Bw
Seed Tree	9.2	.4	1.2	0
Clear cut	19.4	0	3.5	12.5
Group selection	0	0	0	0
Conversion cut	5.2	.4	8.4	0

[1]Based on milacre quadrats.
Note:—Pl = lodgepole pine; Sw = white spruce; Po = trembling aspen; Bw = white birch.

Table 9 indicates that without scarification none of the harvest cutting methods resulted in satisfactory regeneration. The apparent superiority of the clear-cut area has resulted from the degree of seedbed preparation brought about by more intensive logging and the accompanying disturbance of the seedbed. It is worthy of note, however, that remarkably little windthrow and no sunscald have occurred five years after the cutting. Such windthrow as did occur could be definitely traced to special soil conditions which inhibited vertical rooting, particularly shallow soils, coarse droughty conditions, or impermeable horizons.

A further experiment (Ackerman 1955) was established in the B.19 section of Alberta near Carrot Creek, to test the effects of strip clear cutting in mature lodgepole pine, combined with various methods of slash disposal and seedbed treatment.

Three combinations of seedbed and slash disposal were tested in a replicated experiment. These include:

(a) Seedbed undisturbed—slash removed and piled

(b) Seedbed undisturbed—slash lopped and scattered

(c) Seedbed scarified—slash windrowed

A tally of regeneration one year after treatment showed the following results:

TABLE 10. REGENERATION ONE YEAR AFTER TREATMENT

Treatment	Per Cent Stocking			Number of Seedlings Per Acre		
	Pl	Sw	Pl + Sw	Pl	Sw	Pl + Sw
Seedbed undisturbed Slash removed	7.5	0.5	8.0	135	5	140
Seedbed undisturbed Slash lopped	9.5	1.5	11.0	310	20	330
Seedbed scarified Slash removed	29.0	10.0	35.0	805	140	945

A further breakdown (Table 11) of the regeneration resulting on individual plots in the scarified area indicates the importance of seedbed preparation.

TABLE 11. REGENERATION ONE YEAR AFTER TREATMENT
(Scarified Seedbed, Slash Removed)

Per Cent Mineral Soil Exposed	Per Cent Stocking Milacre Quadrats			Number of Seedlings Per Acre		
	Pl	Sw	Pl + Sw	Pl	Sw	Pl + Sw
95	52	24	64	1260	340	1600
60	34	14	44	920	200	1120
40	18	0	18	560	0	560
30	12	2	14	480	20	500

The author concludes that scarification has produced a significantly more receptive seedbed and that the degree of scarification, as expressed by percentage of mineral soil exposed, has had a direct effect on the establishment of reproduction. However, the general levels of stocking cannot be interpreted as indicative of what may be expected under optimum silvicultural treatment since the windrowing of slash prevented to some extent the dissemination of slash-borne seed. In order to obtain some indication of the seeding potential of the marginal stand, seed traps were set out for a nine-month period in 1954–55. This period, however, did not include the time of maximum seed dispersal, the months of August and September. It is of interest to note that while 9,000 spruce seed were trapped per acre, not a single pine seed appeared in the traps. As a further indication of the inefficiency of marginal seed supply, a study was made of the relative stocking at various distances from the marginal seed source. Since there was only a slight reduction in stocking at maximum distances from the marginal stand it was concluded that this seed source played only a small role in restocking the area to pine. This study further substantiates the importance of a slash-borne seed supply.

Harvest cutting methods for lodgepole pine have been the subject of many investigations in the northwestern portion of the United States. Crossley, following a visit to various national forests in the North West, reports that natural regeneration of lodgepole pine in the United States was more readily obtained than in Alberta, without the necessity for intensive seedbed preparation. He attributed this to the lighter accumulations of litter and less vigorous competition from herb and shrub strata occurring in the lodgepole pine forests of the United States. He suggests that lodgepole pine in the United States is more prevalent on the drier sites which are more readily reproduced, whereas in Canada this pine covers a greater range of growing conditions and reproduction is more difficult to obtain.

Tackle (1953) has summarized the investigations on harvest cutting of lodgepole pine in the Northwestern United States. In coming to the conclusion that some form of clear cutting is best suited to the management of this species, he cites the work of Lebarron (1952) and Lexen (1949).

In contrast, Baker (1934) described current silvicultural practice on the national forests and, although admitting that even-aged management on a 150-year rotation probably produces maximum yields, he advances a number of points in the favour of a selection system with cutting cycles of 20 years. With regard, however, to harvesting of overmature stands, Baker suggests that they must be clear cut to prevent excessive decay and deterioration of the forest.

Most of the evidence seems to indicate that some form of clear cutting will be the most satisfactory system of harvesting lodgepole pine in Alberta. Not only does clear cutting lend itself to scarification which appears to be a prerequisite for regeneration of this species, but it also fulfils the requirements of the species for abundant light. The many variations of such a system, including strip clear cutting and patch cuts, provide reasonable security from wind damage and for watershed control. Last but not least, the system lends itself to the natural stand development of the species which is typically even-aged. It must be remembered that lodgepole pine is essentially a pioneer species following fire, and in order to perpetuate this stage in the successional development, it will be necessary to resort to drastic disturbance of the forest.

5.13 SLASH DISPOSAL AND SCARIFICATION

Slash disposal also constitutes an important phase of any harvest cutting system, particularly in extensive clear cuts where slash volumes will be heavy. Two aspects of this problem must be considered—slash disposal in relation to seed supply, and slash disposal in relation to fire hazard. With regard to seed supply, Crossley (1955c and 1956b) indicates that the amount of seed from open-coned residual trees may well be insufficient to restock cut-over areas. It has also been demonstrated (Crossley 1956b) that natural cone opening is greater in slash which is within seven inches of the ground. It might therefore be inferred that slash should be lopped and scattered to secure maximum cone opening and that slash must not be piled and burned until such time as the cones have been opened and the seed disseminated.

Although data are not available to substantiate the following conclusion, it appears from observation that slash volumes in clear-cut lodgepole pine stands are lower than those of many other species. In intensively managed forests lopped and scattered slash does not appear to represent a serious fire hazard.

Experimental data on regeneration following various forms of slash disposal are available from the United States. Boe (1951) indicates that on clear-cut areas slash handled in three methods, concentrated, piled and burned, and natural concentrations burned, produced a stocking below 50 per cent; whereas three other methods, no slash treatment, scarification with dozer piling, lopping and scattering, gave a stocking of 75 per cent or better with approximately 9,000 seedlings per acre, one year after cutting.

In general, it appears that slash disposal must be a compromise between the requirements of seed supply and fire hazard. From the standpoint of seed dissemination, lopping and scattering of slash appears to be required, but fire hazard conditions may necessitate piling and burning of the slash. The conflict between these two factors can, however, be partially resolved by consideration of a third essential factor of harvest cutting, namely scarification.

Studies to date indicate that some form of scarification is essential to the successful regeneration of the richer lodgepole pine sites in Alberta. The most successful method of carrying out this seedbed preparation appears to be through the use of a caterpillar tractor equipped with a special toothed scarifying blade. Although detailed studies have not been conducted on the relative efficiency of various types of equipment, it is apparent that the conventional bulldozer blade accumulates excessive piles of slash and dirt. In comparison, a blade with heavy scarifier teeth lacks this objectionable quality.

From the standpoint of regeneration, pre-scarification and post-scarification appear to be equally successful. However, the physical difficulties of pre-scarifying in dense pulpwood stands seem to render this method unapplicable. The method of scarification bears a direct relation to slash disposal. Provided that it is first lopped, the process of scarifying with a coarsely toothed blade will distribute the slash. Coarse slash components such as lopped tops, felled snags, etc., can be piled by the blade, while the finer cone-bearing slash will pass between the teeth and will be distributed so that the seed can be released in a uniform pattern. The accumulations of coarse slash can then be burned to satisfy the requirements of fire protection.

5.2 Intermediate Cuttings

Various forms of thinning and intermediate cutting in lodgepole pine stands have been the subject of considerable research in Alberta. More than 13 experiments, many of which have been remeasured for 18 years, have been established. These studies cover both manual and chemical thinning treatments, and include stands of various ages. In addition, a wide range in intensity of treatment has been tested. The results to date in this field of research have been summarized by Crossley (1955), Quaite (1947), and Smithers (1957).

With one exception these experiments have shown a definite response in diameter growth. Maximum stimulation has been shown by young stands, and the best individual tree growth has been on the most thrifty trees. The degree of growth release has been roughly proportional to the intensity of thinning. In the one experiment (Crossley 1955) which failed to show response, the treatment consisted of thinning by means of burning or chemical spraying in a 19-year-old stand which was badly stagnated. Whether failure to respond was due to the treatment or to the excessive stagnation, or whether recovery is merely delayed, is not yet definite. It is hoped that further remeasurement will clarify this situation.

In studying diameter growth of thinned lodgepole pine stands, Smithers (1957) makes a comparison of growth rate with thinned red and Eastern white pine, and ponderosa pine. In comparable stands thinned to the same intensity, the growth stimulation of lodgepole pine is equal to that of these other species.

The information on stimulation of height growth in response to thinning is less conclusive. However, the data from young treated stands, and also from studies of height growth in relation to stocking (Smithers 1955), indicate that improved height growth can be expected in thinned lodgepole pine stands.

Experiments in Alberta have covered a wide range in intensity of thinning. Treatments removing approximately 50 per cent of the basal area from full-density stands appear to be most desirable from the standpoint of achieving maximum growth per tree without sacrificing per acre increment. Treatments removing up to 80 per cent of the basal area have been employed with success in extremely overstocked stands but these appear to be too heavy for general application in stands of moderate stocking.

The method of thinning also shows a definite effect on the response of lodgepole pine. High thinnings removing dominant trees are unsuccessful. Both uniform low thinnings and crop tree thinnings seem to provide about the same degree of stimulation; however, from an economic standpoint the crop tree thinning provides a maximum return, since a higher proportion of merchantable trees is removed. Following crop tree thinnings removing 50 per cent of the basal area and leaving a minimum of 300 thrifty future crop stems, it appears that a period of roughly 25 years is required to replace the growing stock and return the stand to a full-density condition.

Appreciating the excessive cost of manual thinning in very young stagnated stands, Crossley (1955) studied the effects of applying chemical sprays to lodgepole pine with a view to using such a method for thinning. A variety of sprays was tested in various concentrations and dosages on replicated milacre plots. It was found that an application of 2 gallons of 2, 4-D in an oil-water emulsion consisting of 25 gallons of diesel fuel and 75 gallons of water per acre was the most effective and efficient spray. Three years after treatment, mortality of pine was 96 per cent and although the balance of the seedlings had been slightly damaged they had recovered and appeared to be in healthy condition. Obviously the limiting factor in the broad application of such a technique for thinning treatments lies in the large amount of spray (102 gallons) required per acre. It is doubtful if any form of application from the ground would prove successful, and the practicability of aircraft spraying of such large volumes of material is also somewhat dubious. Definite statements on the feasibility of aerial spraying must await further research to determine whether the per-acre amounts of spray can be reduced.

Regardless of the method or intensity, economic factors impose limitations on the applicability of thinning treatments in Alberta. Lodgepole pine has never constituted a major source of lumber in this province, nor is it expected to do so in the immediate future. The larger pine have been used to a limited degree for ties, poles and piling; however, the local market for these products has never been extensive and the demand can be met for some time by the natural low-density stands of the foothills area. Should the requirements for this type of product increase greatly in the future, it may be necessary to consider the thinning of overstocked stands. A limited application of thinning might be necessary to stimulate pole and tie production in the vicinity of established processing plants. In order to produce pole and tie sized timber from overstocked pine stands in a minimum rotation, it is recommended that the initial thinning be carried out in stands of 5 to 20 years of age to achieve a maximum stimulation. The first thinning should reduce the stand to roughly 1,500 stems per acre with a uniform spacing. No merchantable material will be produced by this treatment. A second thinning at 40 to 60 years removing 50 per cent of the growing stock may be required. This treatment will produce roughly 15 cords of merchantable pulpwood per acre. All growing stock will be replaced by the time the stand has reached 100 years of age. Since the rotation age required to produce poles in a dense untreated stand is roughly 175 years, the rotation will have been reduced by 75 years.

The second form of thinning which may prove feasible in special locations is one designed to increase per-acre production through the salvage of mortality, with no particular regard for the stimulation of individual tree growth. Such a treatment would be applicable only in high-yield sites close to pulp mills or in locations where pulpwood is the primary product. Under such circumstances, treatment should be delayed until the thinnings will contain a high proportion of merchantable pulpwood. This means that the first thinning will not occur until the stand has reached an age of 50 years or more. At this time 50 per cent of the growing stock in heavily stocked stands may be removed by a combined crop tree release and thinning from below in which the thinnings will consist of a high proportion of co-dominant and intermediate stems plus some suppressed trees and dominants which are competing with crop trees. The yield should amount to between 10 and 15 cords per acre. The period required to replace the growing stock should be roughly 25 years; therefore successive thinnings of a similar intensity could take place at ages of 75 and 100 years with a final harvest cut at age 125 years. For pulpwood purposes, however, the stand should at no time be reduced below 300 stems per acre.

Even in pulpwood areas such thinnings are justified only when increased mill demands rise above the productive capacity of the unmanaged forest or, alternatively, to increase production temporarily when a scarcity of mature and overmature stands exists. In this manner production may be sustained without clear cutting immature stands and degrading the forest. With the exception of some local areas there appears to be a sufficient supply of pine pulpwood in Alberta and therefore there should be little necessity for thinning at the present time. The demand for large quantities of small treated lodgepole pine fence posts in Alberta has resulted in limited trials of a practical thinning treatment. The detailed specifications for such thinnings in stands of various densities have been described by Smithers (1958). In essence, these treatments are designed to remove roughly half of the basal area of stands between 45 and 80 years of age, leaving the 250 largest well-spaced trees per acre, plus all stems which will not produce a merchantable fence post of 6-foot length to a minimum top diameter of 3 inches. The treatment is designed to stimulate production of pole and tie sized material in a rotation of 100 to 120 years plus the salvaging of mortality.

Although the thinning of lodgepole pine stands in the United States has been extensive, Tackle (1953) reports that much of the information has not been analyzed or reported. In his general summary of the situation, Tackle supports the findings in Alberta with regard to the capacity of lodgepole pine to respond to treatment and the necessity for relatively heavy thinnings. Tackle also stresses the danger of windfall after heavy thinnings in pole stands and suggests the necessity for modification of treatment to reduce wind risk. However, in none of the thinning studies carried out in Alberta has there been any serious wind damage and it is doubtful if any special precautions are required if low thinnings of suggested intensities are employed.

5.3 Fire as a Silvicultural Tool

Because of the usual fire origin of lodgepole pine stands, it is only natural that considerable thought should be given to the use of fire as a silvicultural tool.

The success of fire in regenerating pine depends to a great extent on the quantities of seed which are released from the serotinous cones, and it appears that a relatively hot fire, such as may occur when a fire crowns in an uncut stand, may be required to produce a sudden release of seed. A second main effect of fire is the destruction of litter and raw humus accumulations and the elimination of plant and shrub competition. In addition to these obvious effects of fire, there are less noticeable chemical and physical changes in the soils underlying burned areas. Austin and Baisinger (1955) noted in particular a serious reduction in the organic content in the surface layers of soil and observed that recovery is slow. They suggest that, while deep soils rich in organic content may withstand a moderate fire, shallow, gravelly or droughty soils on southern exposures cannot. The general tone of this paper is one of extreme caution. While it is admitted that fire may be a necessary tool of silviculture, it must be handled with care, and further investigation is most necessary.

Since the primary effects of fire are the release of seed, the baring of mineral soil and reduction of competition from vegetation, and since these effects can be accomplished without the use of fire, its value as a silvicultural tool must rest on the relative costs of these treatments.

No cost data for broadcast burning are available in Alberta; however, considering the high standard of protection required, and the difficulty of providing it in the rugged terrain of the subalpine region, it appears scarification would be a less costly method of seedbed preparation. From the standpoint of seed dissemination it has already been shown that proper treatment of slash can effect the release of seed without fire. In general, it does not appear that there is any special economic inducement to employ fire in this phase of pine silviculture. However, this does not mean that research investigations should ignore the possible use of fire for special circumstances where other methods may prove unsuccessful or too costly. At the same time, there is much to be learned from detailed study of regeneration following wildfire.

5.4 Seeding and Planting

Artificial seeding and planting are frequently regarded as "last ditch" methods of silviculture which should be used only when other treatments have failed. However, such a concept is not justifiable; in many cases artificial regeneration may be the most satisfactory and economical of the silvicultural methods. To date very little attention has been given to such methods for lodgepole pine in Alberta. A small number of plantations were established on experimental areas during the period 1920 to 1940, but these were all small-scale trials and provenance tests, in many cases unsuitable for growth measurement on a plot basis. This work has contributed very little to our knowledge of artificial reforestation with lodgepole pine.

An experiment to study the effect of seed-spotting lodgepole pine on mountain lithosols (Ackerman 1959) has provided limited information on direct seeding. The results of this study indicate that lodgepole pine is to be preferred over white spruce or Douglas-fir for restocking mountain lithosols in the Alberta portion of the Rocky Mountains. The best conditions for restocking such an area to pine were found on the cool moist northeast exposures while the poorest chance of success was on the warm dry southwest slopes. The heavy losses of seed to rodents and birds on unprotected areas indicates that some form of seed protection is necessary for adequate restocking. Some evidence was found to

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indicate that broadcast sowing of seed in the fall was to be preferred to spot seeding at other seasons of the year. The effect of various seedbed preparation methods was also tested in this study. The best results were obtained by cultivating the seedbed as opposed to removing vegetation or removing the stones. The results of this study indicated the relative value of various treatments but do not show the levels of stocking which might be expected in a practical application of these methods.

Published information from the United States on the subject of lodgepole pine planting is little more complete than that from Alberta. While seed extraction processes have been dealt with in some detail, information on the subject of nursery practice and planting is not extensive. Korstian and Baker (1925) have described the nursery and planting procedures for lodgepole pine in the Intermountain Region during the period 1913 to 1920. These techniques do not differ substantially from those for other native pines and such procedures have been suitably described by a variety of writers. It was noted that lodgepole pine was one of the few species which could be reared without shading of the seedbeds. The age and size of lodgepole pine planting stock were found to be important factors. Studies of root-top ratio and general size and vigour indicated that 2-1 stock produced the highest proportion of transplants suitable for plantation establishment. Survival and growth data for these lodgepole pine plantations showed considerable variation. Four years after establishment, survival ranged from 94 per cent to 1 per cent, with first-year survival apparently being the outstanding factor in establishing the plantation. The majority of these plantations showed survival of 40 per cent or better at the end of 4 years. Of the surviving trees, roughly 75 per cent could be classed as vigorous but considerable variability was also noticed in this factor. It was noted that site exerted considerable influence on both survival and growth of planted lodgepole pine. The behaviour of this species in planted stands indicated that it might be the best choice for reforesting unstocked burned areas. The reasons given for the selection of this species include its lower mortality and more vigorous establishment, its frost hardiness and its rapid growth.

It is perhaps not surprising that a great deal of interest has been shown in the planting of lodgepole pine in Europe. Reports on plantations of this species are available from Great Britain, Finland, Sweden, Denmark, France, Belgium and Ireland. Results from Finland reported by Tigerstedt (1922 and 1926), Tigerstedt (1927), and Hiley (1928) suggest that growth of lodgepole pine plantations compares favourably with that of Corsican pine in Britain. From Sweden, Lagerberg (1930) reported that 30-year lodgepole plantings corresponded in height growth to Quality Class I Scots pine in Britain. He suggests that lodgepole pine is more suited to rich moist sites. Sylven (1947) also reported on the excellent growth of lodgepole pine in Sweden.

From Denmark, Larsen (1943) reports that both shore pine and lodgepole pine have been planted on exposed sites, and while neither strain is completely satisfactory, lodgepole pine is more suitable. Christensen (1946) also describes the use of lodgepole plantings on sandy soils.

Pourtet and Duchaufour (1946), summarizing planting results in France, state that the lodgepole strain is of interest while the coastal variety is poor of form and slow in growth. Lodgepole pine gives good results in difficult soils and under severe climatic conditions.

Results of planting in Belgium reported by Bard (1937) conclude that lodgepole pine is superior to shore pine and may be of use in planting sand dunes in Flanders. Literature dealing with the planting of lodgepole pine and shore pine in Ireland is extensive. Wittich (1942) notes that the growth of *P. contorta* is satisfactory in youth. Redmond (1956) reports that lodgepole pine suffers less defoliation than Scots pine, but is more sensitive to wind. On the most exposed sites many branches are killed and the formation of a closed canopy is impossible. Where conditions are less severe, growth is slightly more rapid than for vigorous Scots pine. Shore pine showed more rapid height growth and formed as canopy under the worst conditions. Its form has proved to be excellent on poor shallow soils, but on better soil there is a strong tendency to coarseness. Bigson (1951) confirms this report on shore pine and considered it of considerable value on a wide range of poor soils. Lodgepole pine in his opinion, however, had little advantage over Scots pine on exposed sites. O'Kelly (1952) describes shore pine as an excellent volume producer on poor soils. These findings seem to reflect the differences in climatic regions in Europe. In those areas with an oceanic climate shore pine is favoured except on the dry soils, whereas lodgepole pine is superior when the climate is more continental.

The results of seed-spotting on burned areas have been studied by Roe and Boe (1952). The seeding site consisted of a broadcast-burned clear-cut area at an elevation of 6,400 feet. Seeds were planted on 908 prepared seed spots per acre. Ten seeds with a 30 per cent viability factor were planted on each spot. Rodent control measures were undertaken and a number of sample spots were fenced to prevent rodent damage. Nursery transplants of 1-1 stock were employed as a control on survival and growth. At the end of two years the proportion of seed spots supporting one or more seedlings was roughly 70 per cent. In comparison, 98 per cent of the nursery stock survived.

Cost of planting or spot seeding is the limiting factor in the use of these silvicultural methods at the present time. Average figures for planting costs are roughly $45 per acre, of which between $10 and $15 represents the cost of raising planting stock. Seed-spotting cost is reduced somewhat because the cost of seed amounts to only roughly $2.50 per acre. It is extremely doubtful if any drastic reductions in the cost of planting can be developed and the widespread use of such a technique can become feasible only through increased prices for forest products, associated with a limited wood supply. On the other hand, costs of seed-spotting could conceivably be reduced if less seedbed preparation were required. It would appear that considerable research in this field is justified. At the same time, planting investigations should be undertaken, particularly from the aspect of determining growth and development in plantations and planting requirements for specific site conditions.

5.5 Management of the Lodgepole Pine Forest of Alberta

5.51 Estimate of area and volume

The sound administration and management of a forest resource is dependent to a large measure on inventory information describing the available areas and volumes of the resource and its distribution by merchantability classes. In the case of lodgepole pine in Alberta the mountainous topography which comprises much of the natural habitat has slowed down the gathering of this inventory data.

The first concerted attempt to obtain a sound overall picture of the forest resources of Alberta, including the available quantities of lodgepole pine, was undertaken by the federal government during the period 1929–30. This inventory was carried out in conjunction with the transfer of jurisdiction over the natural resources from the federal government to the provincial authorities.

The physical and technical difficulties of carrying out this inventory were almost insurmountable. Road systems were meagre and accessibility to much of the area was almost impossible. While air photos for part of the area were available, the techniques of employing them had not been fully developed. In spite of these difficulties a large amount of valuable information was gathered and for the first time some idea of the forest resources of parts of the province was available. The next major step toward obtaining an evaluation of the forest resources of Alberta and in particular the status of lodgepole pine commenced in the late 1940's. Two organizations were involved in this inventory. The Eastern Rockies Forest Conservation Board, a joint provincial-federal body, was assigned the task of assessing the forests of the Rocky Mountain Forest Conservation Area while the Department of Lands and Forests, Province of Alberta, undertook the inventory of the remainder of the forested area of the province excluding the National Parks and other areas under federal jurisdiction.

While many superficial differences existed in the inventory procedures used by these two organizations, the basic method was similar on both areas. Air photos designed especially for forest inventory purposes were obtained and suitable base maps were prepared where necessary. Forest sub-types based on cover type, density, and height were established and the areas of these sub-types were determined from the photographs. Selective ground sampling covering a full range of existing conditions was undertaken to provide volume per acre figures upon which the forest inventory could be computed. In Figure 17 the boundary of the range of lodgepole pine, upon which the inventory of this species was calculated, is outlined on the map of Alberta. The areas covered by the two inventory organizations together with the boundaries of national parks and federal forest reserves are also delineated. Volume and area figures for these three lodgepole pine areas have been combined in Table 12. Because of the lack of suitable inventory information it has been necessary in the case of federal park areas to use rough estimates based on the opinions of foresters familiar with the area. While it is impossible to draw well-substantiated conclusions from the table, certain interesting comparisons can be made.

It appears that, within the range of lodgepole pine covered by the provincial inventory, there is a slightly higher total volume of pine than spruce; however, the pine volume 11 inches plus is less than that of the spruce. The pure lodgepole pine type, i.e. 75 per cent plus by volume, represents roughly 12 per cent of the area and 13 per cent of the volume of all species. The pure pine stands contain nearly half of the pine volume below 11 inches but they support only one sixth of the pine volume 11 inches plus. These broad inventory figures therefore substantiate the observations of foresters who have maintained that the bulk of the large pine has been produced in mixedwood stands.

The Rocky Mountain Forest Conservation Area also contributes substantially to the total volume of lodgepole pine in Alberta. This area is composed of four forests known as the Bow, Clearwater, Crowsnest and Brazeau, which are administered by the Eastern Rockies Forest Conservation Board. The

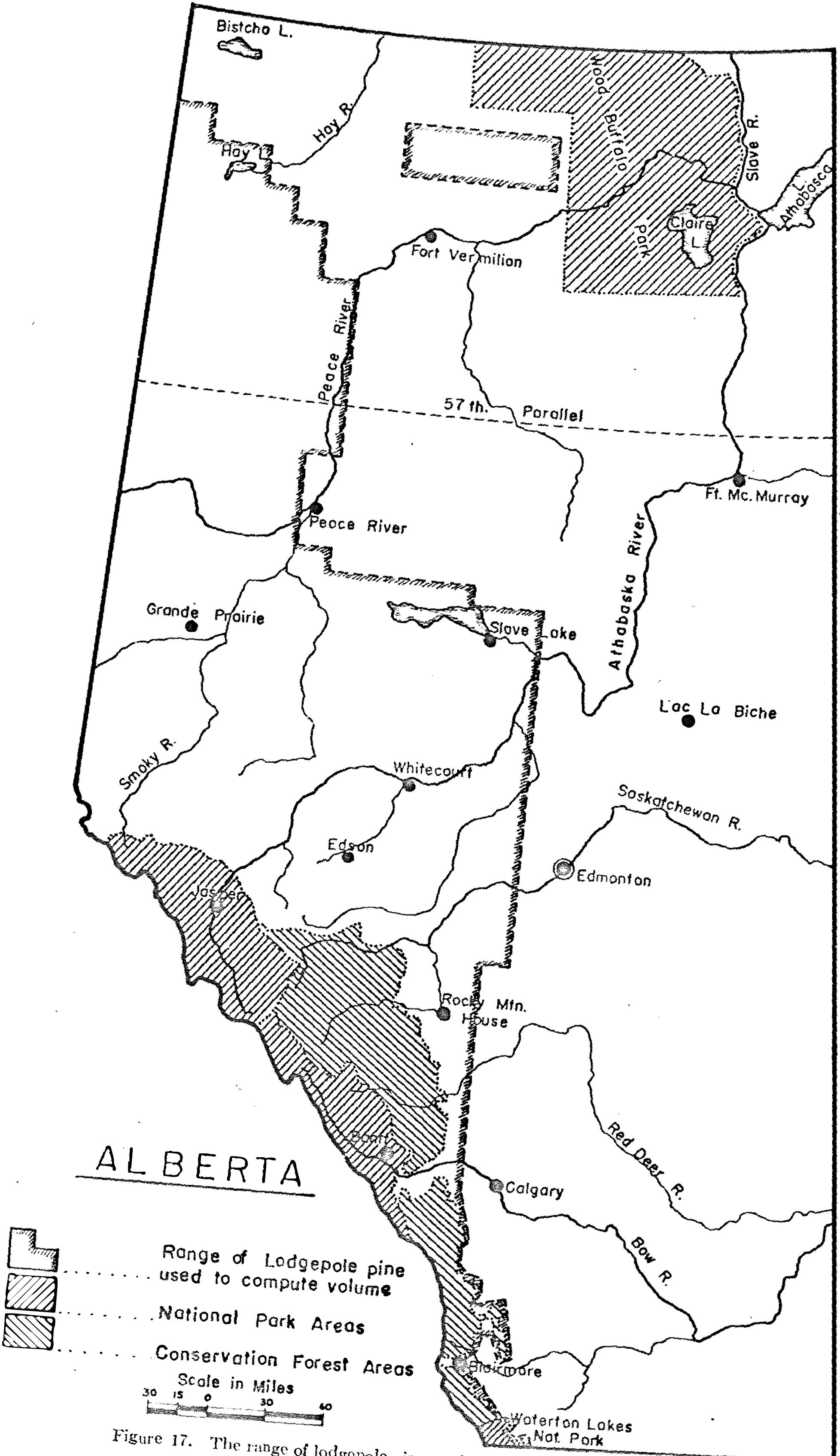

Figure 17. The range of lodgepole pine used to compute volume in Alberta.

TABLE 12. AREA AND VOLUME OF MERCHANTABLE[1] LODGEPOLE PINE IN ALBERTA

	Sub-type	Area in Acres	Volume by Species in Millions of Cubic Feet									
			Lodgepole Pine		White Spruce		Black Spruce	Balsam Fir	Alpine Fir	Douglas Fir	Other Swds.	Aspen
			4-10″	11″ +	4-11″	12″ +						
Provincial Forest Districts......	All Sub-types	16,235,366	6,891	1,897	4,355	2,655	817	822	—	—	—	11,085
	Pure Pine[2]	1,933,457	3,019	392	161	11	20	108	—	—	—	108
Rocky Mountain Forest Reserves	All Sub-types	938,580	1,110	298[3]	286	489	—	—	85	31	7	100
	Pure Pine[2]	600,000	1,000	100[3]	—	—	—	—	—	—	—	—
Federal Lands, Parks, etc........	All Sub-types	958,400[4]	1,700[4]	400[4]	—	—	—	—	—	—	—	—
	Pure Pine[2]	700,000[4]	1,500[4]	100[4]	—	—	—	—	—	—	—	—
Total Areas.....................	All Sub-types	18,132,346	9,701	2,595	—	—	—	—	—	—	—	—
	Pure Pine[2]	3,233,457	5,519	592	—	—	—	—	—	—	—	—
Total Pine 4″ +................			12,296									

[1]Merchantable stands 4″ d.b.h., 30′ in height.
[2]Stands containing 75 per cent plus of lodgepole pine by volume.
[3]Volume 10″ plus.
[4]Rough estimate only.

inventory data for this area in Table 12 have been taken from an unpublished report of the Board. In preparing the inventory it was necessary to establish an arbitrary standard of accessibility. Since these forests are of a mountainous nature the standard has been based on elevation, with all forests lying below the 6,000-foot mark being classed as accessible.

It is apparent from Table 12 that nearly 60 per cent of the volume of trees 4 inches d.b.h. and larger in the Rocky Mountain Reserves consists of lodgepole pine. In terms of volume of trees 10 inches d.b.h. and larger, pine represents only 35 per cent of the volume for all species.

Table 12 suggests that the average volume per acre of all species and types is roughly 30 per cent higher in the Rocky Mountain area than in the remainder of the lodgepole pine region. This does not mean that the mountain sites are more productive but merely indicates the more advanced age of the subalpine stands and their tendency to be more heavily stocked.

Lodgepole pine also occurs in areas under federal supervision. These include the National Parks, Banff, Jasper and Waterton, and the Kananaskis Forest Experiment Station. A rough estimate, based on the per acre volume figures for the Rocky Mountain Forest Conservation Area, has been prepared. The figures for this estimate are shown in Table 12.

Although some disagreement may arise with an estimate that shows a greater volume of pine in the National Parks than in the Forest Conservation Area, it is believed that this relationship is valid. The parks area is only slightly less than that of the conservation area and because of the exclusion of recent fire and logging and the concentration of the forest in the lodgepole pine types there is a higher volume of merchantable pine in the parks area. On the basis of the figures in Table 12, it is estimated that the province of Alberta currently contains about twelve and one-quarter billion cubic feet of lodgepole pine 4 inches and over in diameter. Of this volume roughly 30 per cent or four billion feet consists of trees 10 inches or more in diameter.

In addition to areas now supporting pine stands of 30 feet or more in height, it is estimated that there are an additional two million acres of young pine stands in Alberta.

For purposes of comparison it is of interest to note that the province of British Columbia contains an estimated 72 billion cubic feet of lodgepole pine according to the 1957 report of the Minister of Lands and Forests. However, because of the somewhat lower number of stems per acre as compared with Alberta, it is believed that a slightly higher proportion of the volume would be contained in trees 10 inches and up in the British Columbia area.

5.52 HISTORY OF UTILIZATION

The history of the use of lodgepole pine is as colourful as that of the settlement and development of Alberta itself. Even before the establishment of farming in this province, lodgepole pine was cut and used by both Indians and white trappers to satisfy their basic needs for shelter and warmth. The slim straight poles of the species were admirably suited to the support of the hide teepees of the Blood, Sarcee and Stoney Indians, while larger trees formed excellent building logs for winter cabins. With the advent of ranching and farming about the year 1850 in Alberta, lodgepole pine assumed new uses in the form of corral rails and fence posts as well as small-dimension timbers.

During the late 1800's coal mining and the transcontinental railroad became important forces in the economy of Alberta, and lodgepole pine was first used commercially for ties, mine timbers and lagging. To what extent the species was used is difficult to determine; however, indications are that the utilization was limited. Early reports show that logging was carried on in the Crowsnest Pass area from 1898, and during the first ten-year period 36 million board feet of lumber, 50,000 ties, and one and one-quarter million feet of mine timber were logged in the area. Part at least of this material was lodgepole pine. Elsewhere in Alberta the further construction of railroads also created a demand for lodgepole pine ties and Edson became a centre of the tie hacking operations.

While the basic demand for lodgepole pine fuelwood, railway ties, posts, and small timbers continued on a local basis, electrification of Alberta produced a demand for small poles to which the qualities of the species were admirably suited. However, competition from imported species and buyer resistance to an untried commodity permitted only a limited usage for this species.

Since 1880 lodgepole pine has been logged and utilized locally for a variety of purposes, but it cannot be regarded as having been of truly great commerical importance. Current industrial development, however, has provided a new opportunity for increased utilization of pine. The recently established pulpwood industry located at Hinton, Alberta, and the promise of further development in this field at other locations, suggest that the real future of pine in Alberta lies in the manufacture of pulp and paper. If this is the case, the utilization of this species will face a new, rapidly expanding future.

5.53 IMPORTANCE OF FOREST PRODUCTS

While lodgepole pine cannot be regarded as a widely used species from a national standpoint, it has been of some importance on the local scene. The typical uses for this species as listed in "Canadian Woods"[12] include lumber, piling, ties, poles, construction timber, and sulphate pulp. In the ranching country of Alberta the additional uses of corral rails, fence posts and fuelwood have been of local importance.

Information on annual utilization, made available by the Alberta Department of Lands and Forests, and presented in Table 13, shows that within the range of lodgepole pine approximately 20 per cent of the cut consists of pine.

TABLE 13. WOOD PRODUCTION IN THE LODGEPOLE PINE REGION, 1954-55

Product	Production in thousands of f.b.m.			
	Pine	Spruce	Poplar	Others
Lumber	62,700	296,048	905	1,485
Pulpwood	—	1,034	—	—
Poles	1,247	—	—	4
Ties	26,494	—	—	—
Round Timber	3,994	128	—	192
Plywood	—	—	2,572	—
Other Uses	80	243	—	—
All Uses	94,515	270,453	3,477	1,681
Total All Species	—	—	370,124	

[12] "Canadian Woods, Their Properties and Uses". 1951. Forestry Branch. Dept. of Resources and Development. 367 pp. Available from Queen's Printer, Ottawa.

Plate 33. Salvage operation in fire-killed lodgepole pine.

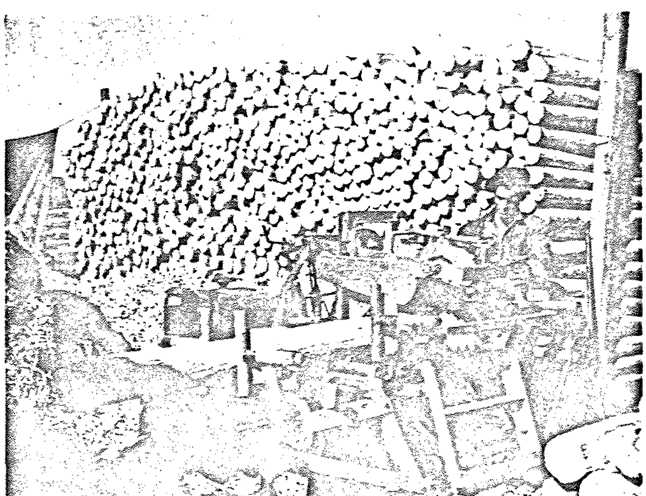

Plate 34. Peeler utilizing pine thinnings for fence posts.

As an indication of the stability in utilization of pine in the province, Table 14 shows the percentage utilization by species for the years 1950 to 1954.

TABLE 14. PERCENTAGE OF TOTAL WOOD PRODUCTION BY SPECIES, ALBERTA, 1950-54

Year	Lodgepole Pine	Spruce	Poplar Species	Others
	(per cent)			
1950-51	19.2	79.7	1.0	0.1
1951-52	19.0	79.5	1.4	0.1
1952-53	21.5	76.7	1.7	0.1
1953-54	20.2	78.3	1.4	0.1

Actual production figures for lodgepole pine in Alberta show a high degree of consistency with the uses listed for this species. In Table 15, percentage use by years for the period 1950–55 is shown.

TABLE 15. PERCENTAGE UTILIZATION OF LODGEPOLE PINE IN ALBERTA, 1950-55

Use	1950-51	1951-52	1952-53	1953-54	1954-55
Lumber	73.4	70.0	66.9	73.6	82.1
Ties	24.9	26.0	28.5	22.0	14.5
Poles	.8	1.1	3.6	3.2	1.4
Round Timber	.5	2.4	.7	.7	1.8
Fuelwood	.4	.5	.3	.5	.2
Total	100.0	100.0	100.0	100.0	100.0

Several points of interest are illustrated by Table 15. Two commodities, lumber and ties, constitute 95 per cent or more of the utilization of pine. Lumber itself represents 70 per cent of the pine volume. Much of this lumber is produced from mixed pine-spruce stands which are logged primarily for their spruce content. Thus lodgepole pine may currently be regarded as a species of only minor economic importance in Alberta.

The most noticeable difference between utilization in Alberta and prescribed use for pine, is the lack of pulpwood production in the province. However, the establishment of a pulp industry during 1955 has provided a start on pulpwood production, and there is little doubt that expansion in this field will continue. It is anticipated that a major proportion of the pulpwood consumption of such mills will consist of lodgepole pine.

A comparison of information from the preceding section of the report dealing with available supplies of lodgepole pine shows a growing stock 10 inches plus d.b.h. of roughly four billion cubic feet or 16 billion f.b.m. Classing this volume as mature and over-mature timber which must sustain cutting for 25 years, the possibility of increasing annual pine consumption to 600 million f.b.m. can be visualized. Assuming that the present-day improved standards of fire protection are maintained and probably increased and that it will ultimately be recognized that selective harvesting of mature and overmature stands in park areas is essential to avoid insect epidemics, it is possible that lodgepole

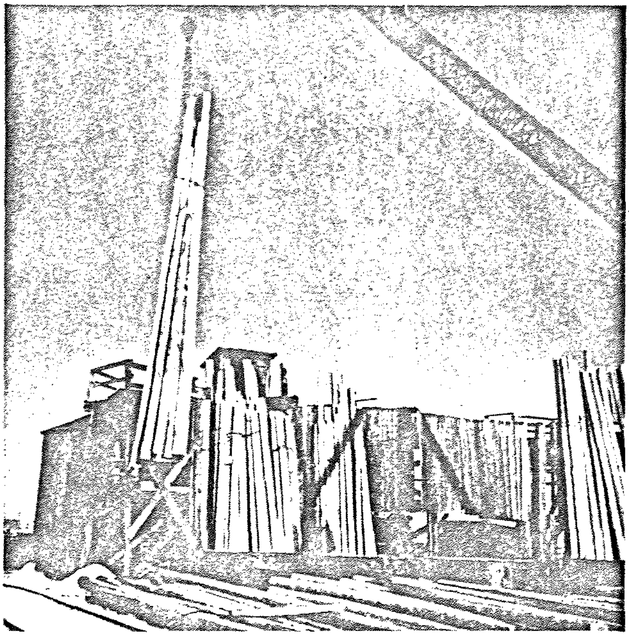

Plate 35. Butt treatment of lodgepole pine power poles.

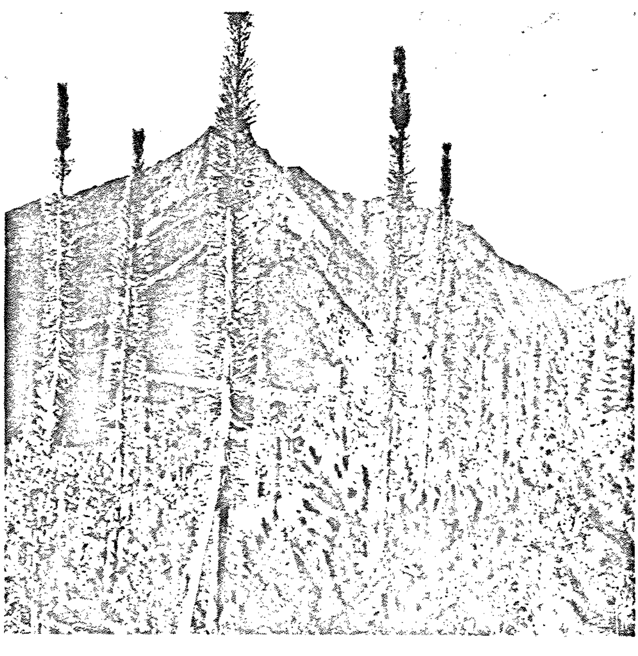

Plate 36. Debudded 14-year-old lodgepole pine saplings.

pine utilization in Alberta could be increased by at least five times over the present rate of consumption, with adequate allowances for fire and insect depletion. Such an increase would of course have to be gradual since much of the growing stock is located in areas not currently serviced by roads or other improvements.

5.54 MULTIPLE-USE MANAGEMENT

The lodgepole pine forest of the subalpine region of Alberta presents a unique problem in management, for it is doubtful if any other forest combines so many potential uses. In addition to its wood supply, this forest plays a significant role in watershed management, grazing, wildlife conservation, and recreation. While to date only a limited amount of factual information has been obtained on the various uses of the area, the problem is recognized and, through the medium of the Eastern Rockies Conservation Board, steps are being taken to gather this vital information. In spite of the lack of detailed information the general concepts of this problem may be stated. As in all such multiple-use areas, the basis of management is a compromise between the various uses without excluding any of them.

A large proportion of the Canadian prairies depends upon water supplies originating on the eastern slopes of the Canadian Rockies. The watershed protection of this area is of prime importance and the role of forests in this conservation cannot be over-exaggerated. Because of its wide adaptability to extreme site conditions, its ability to reoccupy burned-over areas, and its widespread occurrence in the subalpine region, lodgepole pine is of prime importance in watershed protection. Special consideration will have to be given to management and silviculture practices with a view to maintaining a reasonably complete cover on the area. Large areas of a single age class must be avoided, and extremely dense reproduction stands which prevent snowfall from reaching the ground cannot be tolerated.

The lodgepole pine forest, particularly in the subalpine region, is also an important recreation area which provides both winter and summer sport facilities. However, it is probable that within the foreseeable future recreation areas additional to those in the National Parks may be required. In such areas where commercial wood production is secondary to recreation values, special techniques of silviculture and management must be employed and the aesthetic values of the lodgepole pine forest enhanced by judicious cutting methods.

Many areas of the subalpine lodgepole pine forest border on grassland conditions and therefore the problem of grazing must receive consideration. Because of the extensive range of lodgepole pine, there is great diversity of growing conditions, especially where fire has played an important role in plant succession. In the Canadian Rockies and foothills the stands range from a few scattered trees in grassland or among poplars, through pure pine stands on poor to moderately good timber sites, to mixed pine-spruce on the better sites. Forage available to grazing animals varies from abundant in the scattered open lands, through sparse on rocky, poor sites to none in dense, stagnated stands. The quality of the forage varies in about the same order.

About half the subalpine lodgepole pine stands constitute usable range of fair to poor quality. The other half contains so little palatable forage that it supplies feed for only transient animals. This type of range will not support any appreciable population of livestock or big game animals by itself.

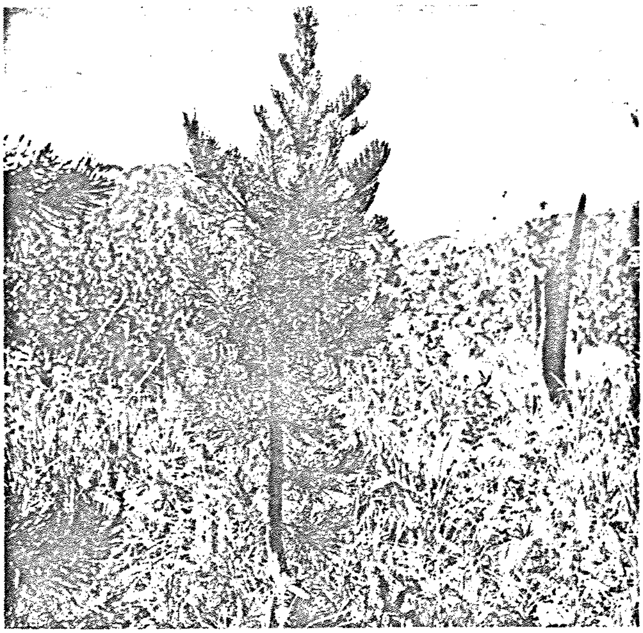

Plate 37. Stump cultured lodgepole pine Christmas tree, three years after cutting the original tree.

Plate 38. Scarified clear-cut patch in the subalpine forest.

Grazing has certain impacts upon the use and conservation of the timber, the recreational values and the watershed. Whether these impacts are good or bad depends upon the efficiency of management. Overgrazing destroys plant cover, tramples and damages seedlings, compacts the soil and spoils camping or recreation areas. However, if the grazing is properly managed and co-ordinated into a multiple-use management program, it will not cause serious damage.

6. RECOMMENDED SILVICULTURE AND MANAGEMENT

As mentioned in the introductory sections of the monograph, the purpose of this publication is to integrate the current information into a program of silviculture and management suited to both existing economic conditions and the silvical limitations of the species.

It has been suggested that silvicultural practice may be logically divided into two major fields, that of "regeneration silviculture" concerned with obtaining satisfactory regeneration of harvested stands, and that of "high-yield silviculture" devoted to securing the maximum wood yield from the individual acre. Of these two classes, regeneration silviculture is of major interest since it is not only economically feasible at the present time but is also essential to any form of proposed management and sustained production of pine stands. On the other hand, high-yield silviculture is practicable at this time only on the most productive and accessible areas and only when a high demand exists for the wood products.

While integrated utilization of both large and small trees is the ultimate goal of silviculture and management, it must be recognized that there is great diversity in the size distribution of natural lodgepole pine forests and therefore different silvicultural practices may be required for stands producing different products. Gross physiographic differences between the subalpine and boreal forests of lodgepole pine also provide a logical basis for subdivision of the silviculture and management of this species. While an even more sensitive breakdown of lodgepole pine stands based on site conditions and age structure would be possible, it is doubtful whether existing silvical information warrants recommendation of such intensive silvicultural practices.

6.1 Silviculture and Management of the Subalpine Forest

While the subalpine lodgepole pine forest has been described in detail elsewhere in the monograph, there are a number of outstanding characteristics which bear directly on the silvicultural practice for the area. Topography of this area is extremely rugged since it consists of mountain slopes and valleys and the highest foothills adjacent to the Rocky Mountain Range. Such factors will limit both the logging methods and the silvicultural practices of the area. Economics of this region which is sparsely settled will also influence the management of the area. Lodgepole pine sites of the subalpine area are typically dry although some moist areas do occur. Soils are frequently shallow and may be excessively stony. Local climate conditions vary greatly as a result of the deeply cut topography, and dry desiccating winds may constitute a serious factor in silvicultural treatment. Litter under pine stands in this region is frequently shallow, especially on the drier sites, and mineral soil is usually closer to the surface than on the more moist conditions of the boreal forest. The lodgepole pine stands of the subalpine region are usually even-aged as a result of extensive fires, and number of stems per acre is generally too high to permit optimum development of individual trees. Each of these factors places its own special limitations on the silvicultural methods which are applicable to the region.

6.11 REGENERATION SILVICULTURE IN PINE STANDS

Within the subalpine forest, management methods must be adapted to the tendencies of such areas to produce dense stands. The wood products therefore will consist largely of pulpwood, posts, mine timbers and rails. In such stands regeneration silviculture is of primary importance. Three distinct phases of such silviculture must be considered. These are harvesting method, slash disposal, and seedbed preparation. As a compromise between topographic and silvical characteristics it appears that some form of clear cutting in either patches or strips is to be desired. In valley bottoms and lower slopes of broad valleys, patch clear cuts up to 40 acres in size are suggested. However, on the main slopes which require a greater degree of watershed control, strip cutting should be employed. Local climatic factors including aspect and presence of desiccating winds will govern variations in strip width and direction. Protected locations with superior moisture supplies may permit a wider clear-cut strip up to 10 chains while drought areas will necessitate a narrower strip of possibly five chains width. In general, measures designed to conserve moisture on the drier locations will be required. Such factors as strip orientation and progression of cutting may be employed to improve moisture conditions and reduce windfall.

Slash disposal, in pine stands which are utilized for pulp or other products requiring small trees, should not constitute a serious problem since the slash will consist to a large degree of branches and small tops. The method of slash disposal will, however, have to be geared to the seedbed preparation which is required on individual site conditions.

On dry sites, where litter accumulations are thin and mineral soil is already available as a seedbed, scarification should not be required. A form of slash disposal designed to distribute seed over the area will, however, be necessary. Lopping and scattering of the slash under such circumstances will have the three-fold effect of reducing fire hazard, assisting in the opening of slash-borne cones, and distributing the seed. Where a heavier litter accumulation has been generated under increased moisture conditions, scarification will be required to provide a mineral soil seedbed. Basic equipment required for scarification consists of a caterpillar tractor and a scarifying blade with a series of large scarifying teeth. These teeth should be designed so that at proper scarifying depth a space is available between the ground and the solid portion of the blade, through which light slash and raked-up litter can pass. Such a design will provide maximum mobility, and will prevent the accumulation of large piles of slash and litter.

Correct timing of scarification in relation to the cutting operations will be an important factor. Pre-scarification in the heavily stocked stands would be unfeasible because of close spacing of individual trees. Since high summer temperatures are necessary to break the resin bond of lodgepole pine cones, and since scarification will play a major role in distributing the slash over the area and shaking the seed from the opened cones, this treatment should be delayed until sufficient time has elapsed following cutting for the cones to break off the

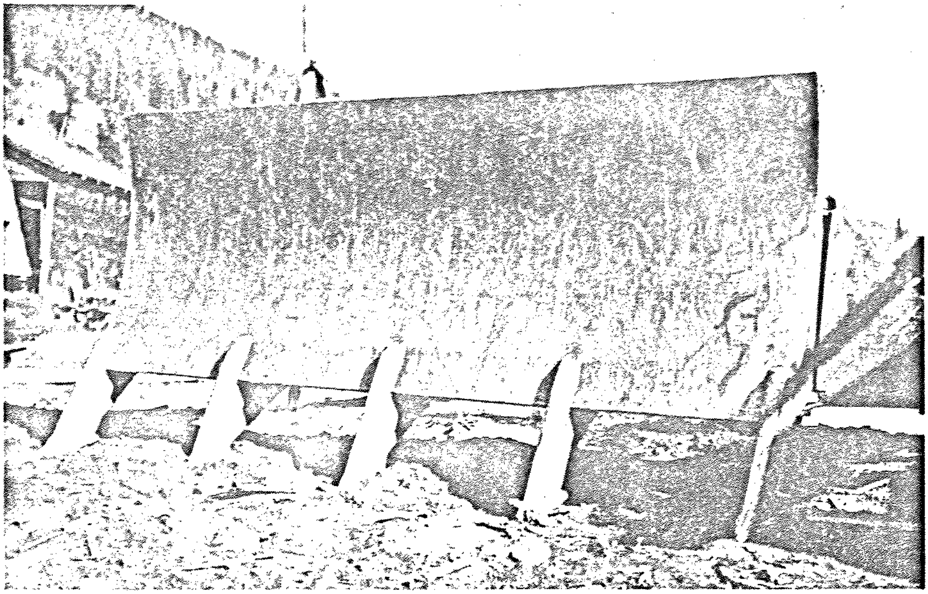

Plate 39. Homemade scarification blade used on a TD 18 tractor.

slash readily. The intensity of scarification should be such that roughly 20 per cent of the cut-over area consists of bare mineral soil. This situation should result from a single pass over the entire area with scarifying equipment.

Under such a procedure slash disposal will not be a serious problem. Intensive utilization of the small trees will result in a high percentage of the crown being lopped. The design of scarification equipment will provide for distribution of the light slash and accumulation of the tops. This heavier slash should be windrowed at intervals and subsequently burned. Although fail spots will no doubt result under the burned windrows, these will occupy a relatively small proportion of the logged areas. The most recent developments in scarification equipment indicate that the use of very heavy equipment can remove the necessity for piling and burning of slash. Tractors of the D9 class with large toothed blades can provide a mineral soil surface without accumulating large concentrations of slash. The alternate raising and lowering of the blade releases the slash accumulations and the "cat walks" over the slash piles, breaking up the tops and grinding them into the soil. On areas treated in this manner, the fire hazard appears to be very low. Where equipment of this class is available, it is to be preferred to the lighter tractors for scarification.

It is almost inevitable that some of the areas of heavy litter accumulation will exist on slopes which are too severe to permit scarification with mechanical equipment. Under such circumstances it may be necessary to employ broadcast burning of slash to reduce litter accumulation and release the seed from serotinous cones. In employing such a procedure it is advocated that the width of the clear-cut strip be reduced to not more than 5 chains to increase the possibility of seed supply from marginal stands.

6.12 HIGH-YIELD SILVICULTURE IN PINE STANDS

High-yield silviculture has very little place in the management of subalpine stands for small-dimension products. In such mountain valleys a high proportion of the area consists of sites of low productivity, in which increases in yield, through salvaging of potential mortality, would not justify the cost of thinning. Furthermore, the production of large trees is of minor importance in an area devoted to pulpwood and other small-tree products. Nevertheless it is possible that at some time in the future there may be a need for increased pulpwood production. Under such circumstances it is estimated that yields could be increased by the removal of up to 50 per cent of the volume of heavily stocked stands at ages of 50 to 75 years. Because of the characteristics of lodgepole pine it is suggested that a "crop tree release" form of thinning, using thrifty dominant trees as the final crop stems, should be employed.

One of the most obvious silvicultural problems of the subalpine forest is the presence of numerous lodgepole stands of extremely high stocking which are unlikely to produce a merchantable product. It is recommended that until such time as economic conditions warrant, these stands should be regarded as unproductive forest land, of value mainly from a standpoint of watershed protection. If in the future these lands must be brought into production, the cheapest method of removing the present crop must be sought; and the stands must be restocked at a satisfactory density. It may in some cases be possible to employ portable chippers, while in others it may be necessary to resort to controlled burning. It is not believed, however, that any form of intermediate cutting can be justified in such stands.

An ecological problem which causes concern among foresters assigned to the management of subalpine lodgepole pine stands is the frequent presence of a seemingly younger understorey of spruce. Because of the higher economic importance of spruce, silviculturists fall into the trap of devising ways and means to perpetuate the spruce content of the stand and frequently attempt some form of conversion cutting. In pine stands on dry subalpine sites suited to the production of pulpwood or similar products, it is believed that the forest should be clear-cut with no attempt being made to convert the stand to a mixed spruce-pine condition.

6.13 SILVICULTURE IN PINE-SPRUCE STANDS

While the management of subalpine lodgepole pine stands should be primarily directed towards a small-tree product, there will be some areas capable of producing larger products such as poles, piling and lumber. Such areas will occur only on the better soils where favourable moisture conditions prevail. The present stands will in most cases contain considerable amounts of spruce either as an understorey in younger ages or as part of the main canopy in older stands. Silvicultural practice should endeavour to maintain the mixed character of these stands. The harvest cutting procedure designed for these stands must take into consideration both seed supply and moisture conditions. Since extensive clear-cut areas would not only increase the distance to marginal seed sources upon which spruce reproduction must depend but also cause excessive drying of the soil, it will be necessary to employ either strip or patch clear cutting in these stands. Since high-quality sites supporting mixed spruce-pine stands are confined to small patches, there appears to be a logical basis for the use of small patch clear cutting. Such patches should seldom exceed an area of 20 acres and successive annual cuts must be regulated so that a marginal seed source remains intact at least on the windward side until spruce reproduction has "caught". Because of differences in the silvical characteristics of spruce and pine, it is suggested that a dual rotation be employed in these stands. At approximately 100 years of age a harvest of spruce and pine pulpwood and pine poles should be made, removing roughly 60 per cent of the volume. Residual trees will consist of up to 150 best spruce crop trees selected from the dominant and codominant classes. These crop stems will be allowed to develop for an additional 50 years when a final harvesting of the stand should take place.

Seedbed preparation following the final harvest cutting should consist of scarification, during which process slash will be windrowed and subsequently burned. As a result of the nature of the marginal seed source, the regenerated stand will tend to increase in spruce content. If necessary, consideration should be given following treatment to the planting of a limited number of thrifty spruce seedlings. These trees should be nursery reared 2–2 stock of superior genetic qualities. They should be carefully spaced to take advantage of natural fail spots and should be well spaced since they are designed to become the final crop trees of the next rotation.

While the silviculture of these areas will be much more intensive than that of the bulk of the subalpine forest, nevertheless, the total costs will not be high because only a limited area comprising the very best sites will be so treated.

6.14 MANAGEMENT OF PINE IN THE SUBALPINE FOREST

The management practices advocated for the majority of the subalpine lodgepole forests can only be described as extensive. The population of the area is low and accessibility is very poor. While the wood productivity of the forested area is satisfactory, the products are mainly small trees. Furthermore, a high percentage of the area is classed as unproductive because of the mountainous conditions. Perhaps the most important aspect of management in this subalpine forest is fire protection. The combination of destruction of watershed protection and deterioration of the lodgepole pine forest into stagnated stands makes fire the foremost enemy of management in this area. The history of this mountain region, as demonstrated by its forest conditions, shows that large fires have ravaged most of the area in the past and have resulted in large areas of immature even-aged stands. The three primary age classes in subalpine lodgepole pine stands at this time are the 90-year, 60-year, and 30-year or lower age classes. While some mature pine of 120 years or older is present, it is apparent that at present there is a scarcity of older age classes. However, since it is doubtful if there will be a high demand for small wood products from the subalpine area within the next 25 years, it is believed that by the time extensive exploitation of the pine stands takes place a substantial amount of pine will have reached an acceptable pulpwood rotation age, of about 120 years, and age class distribution will be reasonably regular. It appears logical that in this subalpine forest natural topographic features should form the basis of management units. Main valleys will constitute the working circles while tributary valleys will be the compartments. In addition to balancing the allowable cut over the working circle, it will also be necessary to avoid overcutting of tributary valleys because of the recreational and watershed values of the subalpine forest. As mentioned previously, the basic cutting method for these subalpine stands should be clear cutting and consequently the management of the forest will entail the development of a regulated series of even-aged stands. While small areas of two or three-storeyed stands may be present in the unmanaged forest, no special treatments should be undertaken to create or perpetuate the multi-aged stands.

6.2 Silviculture and Management of Lodgepole Pine in the Boreal Region

Forest practice for lodgepole pine in the boreal region or Low Foothills Section of Alberta will vary greatly from that of the subalpine. Not only are the silvical and ecological characteristics different but also the general topography and economy of the region lend themselves to a different and more intensive form of management. Low-density stands producing larger individual trees are more common and consequently more emphasis can be placed on the production of large wood products such as ties, poles, piling and lumber. While pure stands of pine still occur frequently, there is a greater tendency for the boreal forest to produce mixed stands of pine and aspen, which lend themselves to a more intensive form of silviculture. While dry sites also occur in the boreal forest, heavier soils and more moist conditions are usually more common and vegetational competition is more severe.

The boreal region is capable of supporting a larger human population with a more diverse economy than is the subalpine area. To this end careful thought should be given to the proper balance between agriculture and forestry and the integration of the two industries. Water resources of the area in terms of rivers and streams suitable for wood transport and location of pulp mills are also superior to those of the subalpine area and road construction is less expensive than in the mountainous region.

6.21 REGENERATION SILVICULTURE

Much of the boreal region is currently occupied by stands which are around 100 years in age. In these stands the harvest cut and regeneration silviculture are of prime importance. Since the topography is generally rolling to flat and excessive grades are seldom a problem, there is considerable latitude in the harvest-cutting method. It is believed that alternate strip clear cuttings of five chains in width, oriented at right angles to the prevalent winds, will provide a safety factor in terms of marginal seed supply and will at the same time give maximum utilization of the stand. As experience with this form of cutting increases and regeneration becomes a certainty, it may be possible to increase the size of clear-cut areas by patch cutting areas of 100 acres. This suggestion is of course based on the assumption that the slash-borne seed source for lodgepole pine can be properly utilized.

In the course of clear cutting, all trees four inches and over should be utilized. Those suitable for high-grade poles, piling, lumber and, in the case of aspen, veneer logs, should be diverted to their special uses and the balance of the crop should be utilized for pulpwood. Such a procedure will require careful training of woods personnel and in particular the individual cutter who will make the decision on allocation of individual trees to specific uses. Slash disposal in these operations should consist of lopping the upper sides of unmerchantable tops. On the majority of sites, scarification will be required and a period of delay between the cutting and subsequent scarification is desirable. Definite recommendation on the length of the delay period cannot be made now, but experiments are under way to provide this information. It is expected that slash should remain for a full year before scarification. By that time a percentage of the cones will have opened and some seed will have been shed. During scarification, the cones will be broken from the slash and more widely scattered over a mineral soil seedbed, and all small standing trees will be pushed over.

On some sites, in particular those which are somewhat wet owing to impeded drainage, scarification will be impractical since it could be done efficiently only during dry periods. In such cases a mineral soil seedbed must be provided by either broadcast burning or by hand scarification of small seedspots. It is believed that in some circumstances broadcast burn will not only be more efficient but will also provide adequate control of fire hazard by destroying logging slash. In cases where broadcast burning is required the slash does not require lopping. Burning should be carried out during the first autumn following logging operations to insure that an adequate seed supply will still be available in the slash-borne cones and that vegetation and slash will be sufficiently dry to provide a satisfactory intensity of burn.

Five years after logging the success of the reproduction should be assessed by a stocking survey. Stocking figures of 50 per cent based on milacre quadrats can be considered satisfactory and the number of established seedlings should be between 2,000 and 3,000 per acre. If satisfactory reproduction has been obtained the uncut strips may then be removed and similar seedbed preparation employed on these. However, where reproduction has been unsuccessful it will be necessary to employ logging slash from the intervening strips to provide a seed source for the initial cutting strips. In such cases re-scarification should be employed on the strips cut five years ago and a portion of the slash from the current cuttings should be moved to the earlier cutting and lopped and scattered over the area. The current cutting strips should then be scarified, and lopped slash should be distributed over these. It is, however, doubtful if many of these fail areas will occur provided the initial treatment is carried out in a suitable fashion.

6.22 HIGH-YIELD SILVICULTURE

Stands which are currently 70 years or less in age may be suitable for intermediate cutting provided there is a demand for small sized products, particularly pulpwood. Such treatments may be applied to both pure pine and mixedwood stands, but should be confined to the better sites. Treatment should take place when the stand is capable of yielding merchantable pulpwood, which will be between 50 and 80 years, and may consist of the removal of not more than 50 per cent of the volume. The trees composing the cut should include intermediate-sized pine as well as all merchantable aspen except sound elite specimens which are capable of producing veneer. The final crop stems, not fewer than 300 per acre, which should be retained in the stand to a rotation age of 120 years, should consist of the highest quality and thriftiest pine, capable of producing poles, piling and lumber. Such a cut, in addition to increasing quality, should result in a 50 per cent increase in yield with only a 20 per cent increase in rotation length. Such thinnings may also serve to stabilize cutting in an area deficient in mature timber, thereby eliminating the necessity of harvesting immature stands. The feasibility of such intermediate cuttings will be greatly improved through the use of portable chippers.

While the bulk of the silvicultural practice in pine stands of the boreal forest will be based on the production of both small and large trees from the same stands, there will be some stands of such high density that only small-sized products, particularly pulpwood, will be produced. Such stands will usually be pure pine and will occur mainly on poor sites. In such cases intermediate cutting will not be possible. Harvest cutting should take place at roughly 90 years and the stand should be clear cut in 5-chain alternate strips. Scarification after logging should be carried out and heavy windrowed slash accumulations should be burned. Cutting in such stands should not be delayed in an effort to increase the immediate yield of merchantable wood, but every effort should be made to insure that the regenerated stand is of low density and capable of rapid production of merchantable wood.

The foregoing silvicultural recommendations are not intended to be the ultimate in silvicultural practices for pine stands. Even following the application of these treatments failures will occur and new methods will need to be developed to handle these problem sites. It is, however, important that some minimum standards of regeneration silviculture be placed in effect immediately, for it is only through the application of such treatments that improvements and modifications may be made in silvicultural practice and that special methods may be developed for areas in which the proposed treatments fail.

6.23 MANAGEMENT OF PINE IN THE BOREAL FOREST

The most important management problem which must be faced in the boreal forest is the intensive integration of forest production and agriculture. In this problem lodgepole pine plays a distinctive role, for it is the only native species which is capable of producing good yields of high-quality wood on the dry stony sites which are least suitable to agriculture. The most successful integration of these two industries would appear to be in the selection of farm villages on small units of highly productive soil at a central location within a forest working circle. Farming on small individual farms would constitute a secondary occupation to woods employment. Mixed farming which would supply a great variety of products should be encouraged. The forest area surrounding the village should be sufficiently large to support continuous operations on a sustained yield basis but should be small enough so that all parts of it are readily accessible from the forest village. Such a development should produce the highly skilled forest workers so essential to intensive management and utilization of the forest.

It is suggested that such forest communities should be initiated by large wood-using industries rather than being operated on a communal or individual farmer basis since the proper management of such an area will involve large capital expenditures in roads, improvements and equipment.

Lodgepole pine stands in these forest communities should be operated to produce the maximum volume of a variety of wood products. Thinnings will supply pulpwood, fence posts and other products while the final harvest will produce sawtimber poles, piling and pulpwood.

Under such a form of management rotation age for lodgepole pine stands will depend to some extent on the intensity of silviculture which is practised. Where frequent thinning is practised rotation age may be increased to roughly 125 years and a higher proportion of large trees will be produced. On areas where only a single cut is practised, rotation age should be about 85 to 100 years, and the proportion of large trees will be reduced. Management practices for the lodgepole pine stands of the boreal forest should be designed to perpetuate the even-aged character of the present stands which have in most cases resulted from fire. An effort, however, should be made to break up the larger even-aged areas into small even-aged stands. Variation in density and commercial value of the present stands will aid in this breaking-up process by varying the date of harvest.

It is anticipated that the increased utilization and value of lodgepole pine and its common associate aspen will result in these species becoming the backbone of the wood economy in much of the foothills section of Alberta.

6.3 Silviculture and Management of Denuded Lands

The practice of silviculture and management in pine stands should not be confined to areas currently supporting lodgepole pine, but should also include denuded areas which have previously supported merchantable pine stands. A program of restocking such areas which are not currently producing wood of a usable species should be undertaken immediately. Priority should be given to areas with the highest potential productivity and the program should envisage the restocking of all potentially productive forest land within a period of 30 years. While accurate figures on the amount of denuded land are not available, it is estimated that, initially, the annual restocking of 1,000 acres of land, which previously supported pine stands, would be a reasonable target.

The areas requiring treatment would consist of old clear-cut areas which have not been restocked and areas which have been subjected to repeated fires at short intervals. The extent and location of such areas must be determined by "on-the-ground" assessment.

The proposed treatment for such areas would be determined primarily by site quality and potential productivity. The methods to be followed would consist of scarification and broadcast seeding with pelleted lodgepole pine seed. The site conditions requiring treatment would include the "dry" and "fresh" conditions. The "arid" and "wet" conditions would not justify silvicultural treatment for lodgepole pine, while the "moist" conditions might better be regenerated to white spruce. Each of the site conditions suggested for treatment can be adequately scarified with a toothed blade mounted on a tractor. The objective of the scarification should be to create a mineral soil seedbed which is well distributed over the area and occupies 20 per cent of the surface. Artificial seeding should consist of the application of between one-half to one pound of seed per acre depending on the method of seeding. Hand application of seed would require lesser amounts since optimum seedbed conditions could be selected, whereas aerial or mechanical seeding would require larger amounts of seed.

While little is known of the rodent populations in denuded lands in Alberta, it may safely be assumed that pelleting of seed with a suitable rodenticide would be necessary.

While such a program would cost in the neighborhood of $25 per acre, the results would not be confined to the restocking of forest land, but would also contribute valuable knowledge toward management of the forest.

6.4 Forest Inventories

No program of management can be considered satisfactory without adequate provision for forest inventories. The current policy of forest inventory in Alberta which includes the main areas supporting lodgepole pine is quite adequate. The inventory procedure calls for adequate sampling of yields, age class distribution, condition of regeneration, and site potential at the provincial management level. This inventory will be maintained by re-survey and depletion records as necessitated by logging and other disturbances.

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APPENDIX

List of Tables

(Tables XIII to XXIV inclusive—courtesy B.C. Forest Service)

Table I

Lodgepole Pine

(*Pinus contorta* Dougl. var. *latifolia* Engelm.)

Cubic Feet

Diameter Breast Height	Total Height of Tree in Feet: 10	20	30	40	50	60	70	80	90	100	Double Bark Thickness at Breast Height	Number of Trees
	TOTAL VOLUME (Stump and top included)											
1	.03	.05	.08	.11							.08	5
2	.13	.23	.33	.44							.16	48
3	.25	.48	.72	.97	1.21						.23	83
4	.49	.89	1.28	1.68	2.08	2.47					.28	93
5		1.45	2.04	2.63	3.23	3.83					.32	74
6		2.13	2.98	3.84	4.70	5.55	6.41				.36	57
7		2.92	4.12	5.31	6.50	7.71	8.92				.39	34
8			5.43	7.02	8.63	10.3	11.9	13.5			.42	51
9			6.87	8.89	10.9	13.0	15.1	17.1			.44	42
10				10.9	13.4	15.9	18.5	21.0	23.6		.47	42
11				13.0	16.0	19.0	22.0	25.0	28.0		.50	44
12				15.2	18.7	22.2	25.6	29.1	32.6	36.1	.53	28
13					21.7	25.6	29.5	33.4	37.3	41.2	.56	35
14					25.0	29.3	33.6	37.9	42.2	46.5	.60	27
15					28.8	33.5	38.2	42.9	47.6	52.3	.63	8
16						38.4	43.5	48.6	53.6	58.7	.66	1
17						44.1	49.5	54.8	60.1	65.5	.69	1
18						50.6	56.2	61.7	67.3	72.8	.72	1
19							63.5	69.3	75.0	80.8	.75	2
20							71.5	77.4	83.3	89.3	.79	—

Aggregate difference = Table 0.185% high
Average deviation = ± 5.71%.
Basis of Table 676 trees.
Trees measured at 1/10 sections above d.b.h.
Volumes calculated by Smalian formula.
Heavy line indicates range of basic data.

Table prepared from harmonized curves, with refinements as suggested by T. W. Dwight, For. Chronicle, Vol. XIII, No. 2, June, 1937.
Data collected in Alberta.

Table II

Lodgepole Pine
(*Pinus contorta* Dougl. var. *latifolia* Engelm.)

Cubic Feet

Diameter Breast Height	Total Height of Tree in Feet: 20	30	40	50	60	70	80	90	100	Double Bark Thickness at Breast Height	Number of Trees
	MERCHANTABLE VOLUME (Stump height 1.0 feet: Top diameter 4 inches I.B.)										
5	0.9	1.2	1.4	1.7	2.0					.32	74
6	1.6	2.2	2.9	3.5	4.2	4.9				.36	57
7	2.3	3.4	4.5	5.6	6.7	7.8				.39	34
8		4.7	6.3	7.8	9.4	10.9	12.4			.42	51
9		6.1	8.1	10.1	12.1	14.1	16.1			.44	42
10			10.0	12.5	14.9	17.5	20.0	22.6		.47	42
11			12.0	15.0	17.9	20.9	23.9	26.9		.50	44
12			14.1	17.6	21.0	24.4	27.9	31.4	34.9	.53	28
13				20.3	24.2	28.1	32.0	35.9	39.8	.56	35
14				23.4	27.7	32.0	36.3	40.6	44.9	.60	27
15				27.0	31.7	36.4	41.1	45.8	50.5	.63	8
16					36.4	41.5	46.6	51.6	56.6	.66	1
17					41.8	47.2	52.5	57.8	63.2	.69	1
18					48.1	53.7	59.2	64.8	70.3	.72	1
19						60.8	66.5	72.2	78.0	.75	2
20						68.5	74.4	80.3	86.3	.79	—

Aggregate difference = Table 0.251% high.
Average deviation = ± 7.55%.
Basis of Table 447 trees.
Trees measured at $\frac{1}{10}$ sections above d.b.h.
Volumes calculated by Smalian formula.
Heavy line indicates range of basic data.

Table prepared from total cubic foot volume table by subtracting a variable non-merchantable volume.
Data collected in Alberta.

Table III

Lodgepole Pine
(*Pinus contorta* Dougl. var. *latifolia* Engelm.)

Diameter Breast Height	Total Height of Tree in Feet: 30	40	50	60	70	80	90	100	Scribner Log Rule: Double Bark Thickness at Breast Height	Number of Trees
	MERCHANTABLE VOLUME IN BOARD FEET (Stump height 1.0 feet; Top diameter 6 inches I.B.; Log Length 16.3 feet)									
7	10	11	14	19	26				.39	30
8	19	21	24	30	38	48			.42	51
9	29	32	36	42	51	63			.44	42
10		46	50	57	67	80	96		.47	42
11		61	66	74	85	99	117		.50	44
12		79	84	93	105	121	140	162	.53	28
13			104	113	127	144	164	188	.56	35
14			127	136	150	169	191	217	.60	27
15			151	161	176	196	220	248	.63	8
16				188	204	225	250	280	.66	1
17				217	234	256	283	315	.69	1
18				248	266	290	318	352	.72	1
19					300	325	355	390	.75	2
20					335	362	394	431	.79	—

Aggregate difference = Table 0.621% high.
Average deviation = ± 13.19%.
Basis of Table 312 trees.
Top log scaled to a minimum length of 8 feet.
Heavy line indicates range of basic data.

Table prepared by volume-diameter ratio method.
W. H. Meyer, Journal of Forestry, Vol. 42, No. 3, March, 1944.
Data collected in Alberta.

Table IV

Lodgepole Pine
(*Pinus contorta* Dougl. var. *latifolia* Engelm.)

Diameter Breast Height	Total Height of Tree in Feet: 30	40	50	60	70	80	90	100	International ¼" Log Rule: Double Bark Thickness at Breast Height	Number of Trees
	MERCHANTABLE VOLUME IN BOARD FEET (Stump height 1.0 feet; Top diameter 6 inches I.B.; Log Length 16.3 feet)									
7	8	11	15	22	31				.39	30
8	20	23	27	35	45	59			.42	51
9	35	38	42	50	62	77			.44	42
10		55	59	68	81	97	116		.47	42
11		75	79	89	102	120	141		.50	44
12		97	102	112	126	145	168	189	.53	28
13			127	137	152	173	197	220	.56	35
14			155	165	181	203	228	252	.60	27
15			185	196	213	235	262	287	.63	8
16				229	246	270	298	325	.66	1
17				264	282	307	336	364	.69	1
18				302	321	346	377	406	.72	1
19					362	388	420	450	.75	2
20					405	432	465	496	.79	—

Aggregate difference = Table 0.401% high.
Average deviation = ± 14.02%.
Basis of Table 312 trees.
Top log scaled to a minimum length of 8 feet.
Heavy line indicates range of basic data.

Table prepared by volume-diameter ratio method.
W. H. Meyer, Journal of Forestry, Vol. 42, No. 3, March, 1944.
Data collected in Alberta.

Table V

Lodgepole Pine
(*Pinus contorta* Dougl. var. *latifolia* Engelm.)

International
$\frac{1}{16}$" Log Rule

Diameter Breast Height	Total Height of Tree in Feet: 30	40	50	60	70	80	90	100	Double Bark Thickness	Number of Trees
	MERCHANTABLE VOLUME IN BOARD FEET (Stump height 1.0 feet; top diameter 6 inches I.B.; Log Length 16.3 feet)									
7	5	8	12	16	20				.39	30
8	17	20	24	30	38	46			.42	51
9	29	33	39	47	57	68			.44	42
10		47	55	65	76	90	104		.47	42
11		63	72	84	97	113	129		.50	44
12		79	90	104	120	138	158	178	.53	29
13			110	125	143	165	190	216	.56	35
14			130	146	167	194	226	259	.60	27
15				169	193	225	264	305	.63	9
16					221	259	304	353	.66	5
17					249	294	345	402	.69	1
18						330	387	452	.72	2
19						367	430	503	.75	3
20						405	474	555	.79	—

Aggregate difference = Table 0.15% low.
Average deviation ± 13.85%.
Basis of Table 320 trees.
Top log scaled to a minimum length of 8 feet.

Table prepared from harmonized curves.
Data collected in Alberta.

Table VI

Lodgepole Pine
(*Pinus contorta* Dougl. var. *latifolia* Engelm.)

International
$\frac{5}{16}$'' Log Rule

Diameter Breast Height	Total Height of Tree in Feet: 50	60	70	80	90	100	Double Bark Thickness	Number of Trees
	MERCHANTABLE VOLUME IN BOARD FEET (Stump height 1.0 feet; top diameter 9 inches I.B.; Log Length 16.3 feet)							
10	15	17	20	25	35		.47	28
11	39	44	50	58	72		.50	44
12	64	71	80	92	111	132	.53	29
13	90	99	110	128	152	181	.56	35
14	116	127	141	165	196	231	.60	27
15		156	172	202	240	282	.63	9
16			204	240	285	334	.66	5
17			237	279	329	387	.69	1
18				317	373	440	.72	2
19				356	418	493	.75	3
20				395	463	546	.79	—

Aggregate difference = Table 0.10% high.
Average deviation = ± 21.17%.
Basis of Table 183 trees.
Top log scaled to a minimum length of 8 feet.

Table prepared from harmonized curves.
Data collected in Alberta.

Table VII

Interim Cubic-foot Volume Table for Interior and Coast Lodgepole Pine—All Ages

B.C. Forest Service 1955

DBH	TOTAL HEIGHT—FEET: 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	Basis No. of Trees
	TOTAL VOLUME ENTIRE STEM—CUBIC FEET																
2	0.1	0.2	0.4	0.5	0.6												83
4	0.4	0.8	1.3	1.7	2.2	2.7	3.2	3.7	4.3								48
6	0.8	1.7	2.6	3.6	4.7	5.7	6.8	7.9	8.9	10.1	11.2						406
8		2.9	4.5	6.2	7.9	9.7	11.5	13.3	15.2	17.0	18.9	20.8	22.8				364
10		4.3	6.7	9.3	11.9	14.6	17.3	20.0	22.8	25.6	28.5	31.4	34.3	37.2			379
12			9.4	13.0	16.6	20.3	24.1	27.9	31.8	35.8	39.7	43.8	47.9	51.9	56.1		278
14			12.5	17.2	22.0	26.9	31.9	37.0	42.2	47.4	52.7	58.1	63.5	68.9	74.4	79.9	165
16			15.9	21.2	28.1	34.4	40.8	47.3	53.9	60.6	67.3	74.1	81.0	88.0	94.9	102	97
18					34.8	42.6	50.6	58.6	66.8	75.1	83.4	91.9	100	109	118	126	34
20							61.4	71.2	81.1	91.2	101	112	122	132	143	154	7
22							73.0	84.6	96.4	108	120	133	145	157	170	182	9
24							85.6	99.3	113	127	141	156	170	185	199	214	
26								115	131	148	164	180	197	214	231	248	
28								132	150	169	187	206	226	245	264	284	
30								149	170	192	213	234	256	278	300	322	
																	1,870

Basis of table—1,870 trees; 232 from Research Division, B.C.F.S., and 1,638 from Forest Surveys Division.
Regions sampled—Sayward, Similkameen, Okanagan, Yahk, Elk, Windermere, Slocan, Lower Arrow, Kettle, Shuswap, Tranquille, Rivers Inlet, Queenel, Upper Fraser, Lower Skoona, Babine, Morice, Stuart Lake, Parsnip.
Trees measured in $\frac{1}{10}$ sections above breast height by Forest Surveys Division, and in 8-foot or 16-foot logs by Research Division.
Log Volumes calculated by Smalian formula; top volume 0.4 times basal area times length of top; 1.0-foot stump cubed as a cylinder.
Table gives total volume of stem inside bark, including stump and top, without allowance for trim, breakage, or defect.
Table prepared by converting DBH outside bark, total height, and total volume to logarithms, and solving by least squares.
Formula derived: Log V = −2.63943 + 1.83071 Log D + 1.10880 Log N.
Approximate Standard Error of estimated total volume for single trees—± 12.0%; table values are 0.64% low.
Extent of basic data indicated by block.

Table VII (Continued)

Merchantable Volume Factors

DBH	Curved Av. Ht.	CLOSE UTILIZATION					INTERMEDIATE UTILIZATION					ROUGH UTILIZATION				
		Stump Ht. (ft)	Top Dib. (in)	Per cent			Stump Ht. (ft)	Top Dib. (in)	Per cent			Stump Ht. (ft)	Top Dib. (in)	Per cent		
				Short	Merch.	Tall			Short	Merch.	Tall			Short	Merch.	Tall
2	20	1 . 0	4 . 0	—		—	1 . 0	6 . 0	—		—	2 . 0	8 . 0	—		—
4	39			6		32			—		—			—		—
6	55			71		79			—		16			—		—
8	67			88		91			60		66			5		7
10	76			92		94			80		84			44		48
12	83			94		96			87		90			64		70
14	89			94		96			90		93			75		81
16	94			95		96			92		94			82		87
18	98			95		96			93		95	↓	↓	85		89
20	102			—	96	—			94		95	2 . 0	8 . 0	87		90
22	105			—	96	—	↓	↓	—	94	—	2 . 0	8 . 8	89		91
24	108			—	96	—	1 . 0	6 . 0	—	93	—	2 . 0	9 . 6	—	90	—
26	111			—	96	—	1 . 1	6 . 0	—	93	—	2 . 2	10 . 4	—	90	—
28	113	↓	↓	—	97	—	1 . 2	6 . 0	—	93	—	2 . 3	11 . 2	—	90	—
30	114	1 . 0	4 . 0	—	97	—	1 . 2	6 . 0	—	93	—	2 . 5	12 . 0	—	89	—

$\frac{\text{Factor I Total Volume}}{100}$ = Merchantable Volume to the Utilization Limits Shown.

Merchantable factors obtained from freehand curves of per cent merchantable, by each standard, plotted over DBH. Factors for trees shorter or taller than curved average height are given separately up to the DBH class where difference is less than one per cent. Beyond this point a combined factor is given, since the effect of height is negligible.

Table VIII

*Tentative Empirical Yield Table—Lodgepole Pine
Foothills Section
Site Index Class 40′

Total Age	Number of Stems Per Acre	Average Diameter	Dominant Height	Basal Area in Square Feet Per Acre	Stand Density Index	Total Volume in Cubic Feet Per Acre
	ALL TREES 0.5″ +					
20	9,730	0.9	5	36	204	75
30	7,665	1.3	10	72	284	445
40	5,735	1.7	18	90	327	860
50	4,215	2.1	25	101	346	1,285
60	3,280	2.5	32	114	361	1,745
70	2,695	2.9	37	127	372	2,240
80	2,310	3.3	40	138	390	2,765
90	2,095	3.6	43	150	404	3,145
100	1,930	3.9	45	158	425	3,390
110	1,785	4.1	46	162	427	3,565
120	1,650	4.3	48	163	427	3,690
130	1,520	4.5	49	164	424	3,795
140	1,400	4.7	50	163	419	3,875
150	1,290	4.8	50	163	399	3,945
160	1,195	5.0	51	162	393	4,000

*Alberta tables based on 150 sample plots.

Table IX

*Tentative Empirical Yield Table—Lodgepole Pine
Foothills Section
Site Index Class 50′

Total Age	Number of Stems Per Acre	Average Diameter	Dominant Height	Basal Area in Square Feet Per Acre	Stand Density Index	Total Volume in Cubic Feet Per Acre
	ALL TREES 0.5″ +					
20	6,940	1.0	8	40	173	210
30	5,325	1.6	16	77	277	645
40	3,840	2.2	26	96	342	1,125
50	2,745	2.7	34	107	340	1,620
60	2,155	3.2	41	121	347	2,150
70	1,825	3.7	46	134	369	2,715
80	1.585	4.1	50	146	379	3,310
90	1,435	4.4	53	158	386	3,760
100	1,310	4.8	56	166	405	4,080
110	1,200	5.1	58	171	408	4,320
120	1,095	5.4	60	172	408	4,505
130	1,000	5.7	61	174	406	4,675
140	915	5.9	63	174	392	4,810
150	840	6.2	64	174	390	4,915
160	775	6.4	64	173	378	4,995

*Alberta tables based on 150 sample plots.

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Table X

*Tentative Empirical Yield Table—Lodgepole Pine
Foothills Section
Site Index Class 60′

Total Age	Number of Stems Per Acre	Average Diameter	Dominant Height	Basal Area in Square Feet Per Acre	Stand Density Index	Total Volume in Cubic Feet Per Acre
	ALL TREES 0.5″ +					
20	4,925	1.3	12	44	182	355
30	3,640	2.0	23	82	273	865
40	2,475	2.8	34	101	324	1,425
50	1,685	3.5	42	113	312	1,995
60	1,350	4.1	50	127	323	2,600
70	1,190	4.6	55	141	344	3,245
80	1,070	5.1	60	153	364	3,910
90	960	5.6	64	166	379	4,445
100	865	6.1	67	175	391	4,840
110	780	6.5	70	180	390	5,160
120	705	6.9	72	182	388	5,425
130	635	7.3	74	183	383	5,650
140	575	7.7	76	183	378	5,845
150	520	8.1	77	184	371	5,995
160	475	8.4	78	184	359	6,105

*Alberta tables based on 150 sample plots.

Table XI

*Tentative Empirical Yield Table—Lodgepole Pine
Foothills Section
Site Index Class 70′

Total Age	Number of Stems Per Acre	Average Diameter	Dominant Height	Basal Area in Square Feet Per Acre	Stand Density Index	Total Volume in Cubic Feet Per Acre
	ALL TREES 0.5″ +					
20	3,610	1.6	15	48	188	510
30	2,540	2.5	29	87	279	1,105
40	1,580	3.5	41	106	292	1,750
50	1,000	4.4	51	119	269	2,400
60	895	5.1	58	134	304	3,085
70	805	5.8	65	148	336	3,810
80	725	6.4	70	161	354	4,565
90	650	7.0	75	174	367	5,175
100	570	7.7	78	183	374	5,650
110	505	8.3	81	189	374	6,050
120	445	8.9	84	191	369	6,395
130	395	9.5	87	193	363	6,700
140	350	10.1	88	193	356	6,950
150	305	10.7	90	195	339	7,145
160	275	11.4	91	195	339	7,290

*Alberta tables based on 150 sample plots.

Table XII

*Tentative Empirical Yield Table—Lodgepole Pine
Foothills Section
Site Index Class 80′

Total Age	Number of Stems Per Acre	Average Diameter	Dominant Height	Basal Area in Square Feet Per Acre	Stand Density Index	Total Volume in Cubic Feet Per Acre
	ALL TREES 0.5″ +					
20	2,990	1.8	18	52	188	675
30	2,025	2.9	36	92	279	1,350
40	1,195	4.2	49	112	298	2,075
50	800	5.2	59	125	281	2,815
60	670	6.1	67	141	303	3,580
70	605	6.8	74	155	325	4,390
80	550	7.5	80	168	346	5,235
90	485	8.2	85	182	353	5,925
100	435	9.0	90	192	367	6,490
110	375	9.8	93	198	363	6,975
120	325	10.6	96	200	356	7,395
130	280	11.5	99	203	350	7,780
140	245	12.4	101	204	346	8,090
150	210	13.4	103	206	336	8,330
160	180	14.5	105	207	327	8,510

*Alberta tables based on 150 sample plots.

Table XIII

Normal Yield Table—Lodgepole Pine
British Columbia
Site Index Class 40′

Total Age	Number of Trees Per Acre	Average Diameter	Average Height of Dominant and Co-dominant	Basal Area in Square Feet Per Acre	Total Volume in Cubic Feet Per Acre
	ALL TREES 0.5″ +				
20	over 4,000	1.4	12	50	400
30	" 2,000	2.7	18	78	800
40	" 1,440	3.5	25	98	1,275
50	" 1,140	4.2	30	112	1,750
60	" 1,000	4.8	34	125	2,200
70	" 895	5.2	37	134	2,600
80	" 800	5.7	40	141	2,900
90	" 735	6.1	42	147	3,200
100	" 685	6.4	44	151	3,500
110	" 640	6.6	45	154	3,700
120	" 620	6.8	46	157	3,850
130	" 590	7.0	46	159	3,950
140	" 565	7.2	47	160	4,100
150	" 545	7.3	47	161	4,200

Table XIV

Normal Yield Table—Lodgepole Pine
British Columbia
Site Index Class 50′

Total Age	Number of Trees Per Acre	Average Diameter	Average Height of Dominant and Co-dominant	Basal Area in Square Feet Per Acre	Total Volume in Cubic Feet Per Acre
	ALL TREES 0.5″ +				
10			7	25	
20	over 3,000	1.6	15	54	475
30	" 2,000	2.9	23	83	950
40	" 1,350	3.7	31	104	1,500
50	" 1,090	4.5	37	120	2,100
60	" 925	5.1	42	132	2,650
70	" 825	5.6	47	142	3,150
80	" 750	6.1	50	150	3,550
90	" 690	6.5	52	156	3,950
100	" 645	6.8	54	161	4,250
110	" 605	7.1	56	164	4,500
120	" 580	7.3	57	167	4,700
130	" 550	7.5	58	169	4,850
140	" 530	7.7	59	170	4,950
150	" 510	7.8	59	171	5,000

Table XV

Normal Yield Table—Lodgepole Pine
British Columbia
Site Index Class 60′

Total Age	Number of Trees Per Acre	Average Diameter	Average Height of Dominant and Co-dominant	Basal Area in Square Feet Per Acre	Total Volume in Cubic Feet Per Acre
	ALL TREES 0.5″ +				
10			8	27	
20	over 3,000	1.8	18	57	600
30	" 1,620	3.2	27	89	1,275
40	" 1,200	4.1	37	112	2,050
50	" 980	4.9	45	129	2,800
60	" 840	5.6	51	143	3,500
70	" 750	6.1	56	154	4,100
80	" 675	6.6	60	162	4,700
90	" 625	7.0	63	169	5,150
100	" 580	7.4	65	174	5,550
110	" 550	7.7	67	178	5,900
120	" 525	8.0	68	181	6,150
130	" 500	8.2	70	183	6,300
140	" 480	8.4	70	184	6,500
150	" 460	8.6	71	185	6,600

Table XVI

Normal Yield Table—Lodgepole Pine
British Columbia
Site Index Class 70′

Total Age	Number of Trees Per Acre	Average Diameter	Average Height of Dominant and Co-dominant	Basal Area in Square Feet Per Acre	Total Volume in Cubic Feet Per Acre
	ALL TREES 0.5″ +				
10			10	28	
20	over 2,000	2.1	21	62	800
30	" 1,370	3.6	32	96	1,650
40	" 1,000	4.7	43	120	2,625
50	" 820	5.6	53	139	3,600
60	" 695	6.4	60	153	4,500
70	" 620	7.0	65	165	5,350
80	" 555	7.6	70	173	6,050
90	" 510	8.0	74	180	6,650
100	" 477	8.5	77	186	7,175
110	" 450	8.8	79	190	7,600
120	" 430	9.1	80	193	7,950
130	" 410	9.3	81	195	8,175
140	" 395	9.5	82	196	8,350
150	" 380	9.8	83	197	8,500

Table XVII

Normal Yield Table—Lodgepole Pine
British Columbia
Site Index Class 80′

Total Age	Number of Trees Per Acre	Average Diameter	Average Height of Dominant and Co-dominant	Basal Area in Square Feet Per Acre	Total Volume in Cubic Feet Per Acre
	ALL TREES 0.5″ +				
20	over 2,000	2.4	24	64	875
30	" 1,000	4.2	37	99	1,850
40	" 780	5.4	49	125	2,950
50	" 670	6.4	60	144	4,050
60	" 545	7.3	68	159	5,050
70	" 485	8.1	75	171	5,950
80	" 440	8.7	80	180	6,750
90	" 400	9.2	84	187	7,450
100	" 376	9.7	87	193	8,050
110	" 355	10.1	89	197	8,500
120	" 338	10.4	91	200	8,900
130	" 322	10.7	93	202	9,200
140	" 312	11.0	94	204	9,400
150	" 300	11.2	95	205	9,500

Table XVIII

Normal Yield Table—Lodgepole Pine
British Columbia
Site Index Class 90′

Total Age	Number of Trees Per Acre	Average Diameter	Average Height of Dominant and Co-dominant	Basal Area in Square Feet Per Acre	Total Volume in Cubic Feet Per Acre
	ALL TREES 0.5″ +				
20	1,500	2.8	26	66	950
30	835	4.7	41	102	1,950
40	610	6.2	56	128	3,100
50	500	7.4	67	147	4,300
60	425	8.4	76	163	5,350
70	377	9.2	84	175	6,300
80	343	10.0	90	185	7,150
90	315	10.6	94	192	7,900
110	295	11.1	98	198	8,500
100	278	11.5	101	202	9,000
120	264	12.0	103	206	9,400
130	254	12.3	104	208	9,700
140	244	12.6	106	209	9,950
150	235	12.9	107	210	10,100

Table XIX

Normal Yield Table—Lodgepole Pine
British Columbia
Site Index Class 40′

Total Age	Number of Trees Per Acre	Average Diameter	Average Height of Dominant and Co-Dominant	Basal Area in Square Feet Per Acre	Merch. Volume Per Acre in Cubic Feet	Number of Ties Per Acre
	ALL TREES 6″ +					
20	—	—	—	—	—	—
30	0	—	—	—	—	—
40	28	6.0	25	5	76	—
50	114	6.4	30	25	400	—
60	180	6.9	34	47	835	—
70	235	7.1	37	64	1,250	—
80	288	7.3	40	85	1,710	—
90	330	7.5	42	100	2,100	—
100	350	7.7	44	110	2,400	—
110	352	7.8	45	118	2,700	—
120	366	7.9	46	124	2,900	—
130	366	8.0	46	130	3,120	90
140	367	8.2	47	134	3,320	110
150	367	8.3	47	137	3,440	120

Table XX

Normal Yield Table—Lodgepole Pine
British Columbia
Site Index Class 50′

Total Age	Number of Trees Per Acre	Average Diameter	Average Height of Dominant and Co-Dominant	Basal Area in Square Feet Per Acre	Merch. Volume Per Acre in Cubic Feet	Number of Ties Per Acre
	ALL TREES 6″ +					
20	—	—	—	—	—	—
30	—	—	—	—	—	—
40	54	6.1	23	10	200	—
50	152	6.6	31	36	630	—
60	220	7.0	37	59	1,220	—
70	280	7.3	42	81	1,790	—
80	330	7.5	47	102	2,350	—
90	366	7.8	50	117	2,840	40
100	380	8.0	52	127	3,230	70
110	385	8.2	54	136	3,600	100
120	388	8.3	56	142	3,850	130
130	385	8.5	57	147	4,120	155
140	382	8.6	58	151	4,250	180
150	372	8.7	59	154	4,350	190

Table XXI

Normal Yield Table—Lodgepole Pine
British Columbia
Site Index Class 60′

Total Age	Number of Trees Per Acre	Average Diameter	Average Height of Dominant and Co-Dominant	Basal Area in Square Feet Per Acre	Merch. Volume Per Acre in Cubic Feet	Number of Ties Per Acre
	ALL TREES 6″ +					
20	—	—	—	—	—	—
30	—	—	—	—	—	—
40	108	6.1	37	22	410	—
50	200	6.8	45	52	1,150	—
60	285	7.8	51	83	2,000	—
70	337	7.6	56	105	2,700	—
80	370	7.9	60	123	3,400	—
90	387	8.2	63	138	4,060	80
100	394	8.3	65	150	4,600	130
110	396	8.6	67	158	5,130	180
120	398	8.7	68	165	5,600	230
130	395	8.9	69	168	5,900	260
140	390	9.0	70	171	5,910	290
150	380	9.1	71	174	6,070	310

Table XXII

Normal Yield Table—Lodgepole Pine
British Columbia
Site Index Class 70′

Total Age	Number of Trees Per Acre	Average Diameter	Average Height of Dominant and Co-Dominant	Basal Area in Square Feet Per Acre	Merch. Volume Per Acre in Cubic Feet	Number of Ties Per Acre
	ALL TREES 6″ +					
20	—	—	—	7	—	—
30	40	6.0	29	22	148	—
40	160	6.6	40	42	945	—
50	278	7.2	49	79	2,050	—
60	354	7.7	55	112	3,150	20
70	384	8.0	60	135	4,220	90
80	394	8.4	65	152	5,200	160
90	394	8.7	69	164	5,920	230
100	390	9.0	73	175	6,520	290
110	382	9.3	76	180	7,000	340
120	374	9.5	78	185	7,400	390
130	365	9.7	79	187	7,650	440
140	355	9.9	81	190	7,850	480
150	350	10.0	82	191	8,030	520

Table XXIII

Normal Yield Table—Lodgepole Pine
British Columbia
Site Index Class 80′

Total Age	Number of Trees Per Acre	Average Diameter	Average Height of Dominant and Co-Dominant	Basal Area in Square Feet Per Acre	Merch. Volume Per Acre in Cubic Feet	Number of Ties Per Acre
	ALL TREES 6″ +					
20	—	—	—	—	—	—
30	100	6.2	37	23	425	—
40	226	7.0	49	66	1,560	—
50	340	7.7	60	105	2,830	—
60	365	8.2	68	135	4,200	130
70	374	8.8	75	157	5,300	230
80	370	9.2	80	171	6,200	330
90	360	9.6	84	179	6,920	430
100	346	9.9	87	187	7,550	520
110	334	10.2	89	191	8,060	590
120	324	10.5	91	196	8,450	640
130	312	10.7	93	200	8,750	670
140	306	11.0	94	202	9,000	700
150	297	11.2	95	203	9,100	720

Table XXIV

Normal Yield Table—Lodgepole Pine
British Columbia
Site Index Class 90′

Total Age	Number of Trees Per Acre	Average Diameter	Average Height of Dominant and Co-Dominant	Basal Area in Square Feet Per Acre	Merch. Volume Per Acre in Cubic Feet	Number of Ties Per Acre
	ALL TREES 6″ +					
20	—	—	—	—	—	—
30	142	6.6	41	35	700	30
40	286	7.5	56	89	2,080	150
50	340	8.2	67	126	3,570	270
60	344	9.0	76	151	4,860	390
70	332	9.6	84	168	5,860	510
80	313	10.3	90	181	6,800	620
90	306	10.7	94	190	7,580	680
100	290	11.1	98	196	8,150	720
110	275	11.6	101	202	8,680	750
120	264	12.0	103	206	9,100	770
130	254	12.3	104	208	9,500	790
140	244	12.6	106	209	9,650	800
150	235	12.8	107	210	9,800	810

Table XXV

Percentage Taper Table

Height in Tenths of Length of Stem above Breast Height	Form-class 60	Form-class 65	Form-class 70
D.B.H.	100.0	100.0	100.0
1st tenth	90.2	90.5	93.1
2nd tenth	83.9	84.1	87.6
3rd tenth	76.8	78.2	82.7
4th tenth	68.6	72.4	76.7
5th tenth	60.0	65.0	70.0
6th tenth	52.2	57.5	62.9
7th tenth	43.5	48.2	53.9
8th tenth	32.2	36.6	40.6
9th tenth	18.8	22.1	23.8
Top of tree	—	—	—

In this taper series the diameters inside bark at each tenth part of the stem above breast height are expressed as percentages of the diameter at breast height inside bark.

Table XXVI

Ground Vegetation

SPECIES ASSOCIATED WITH LODGEPOLE PINE IN ITS FOUR FOREST DIVISIONS IN ALBERTA

Shrubs	Montane	Subalpine	High Foothills	Low Foothills	Herbs	Montane	Subalpine	High Foothills	Low Foothills
Ledum groenlandicum		2	3	4	*Elymus innovatus*		4	5	4
Rosa acicularis	2	3	3	*5*	*E. glabrum*	*3*	1		
Shepherdia canadensis	2	3	2	2	*Calamagrostis* spp.	1	2	1	4
Vaccinium vitis-idaea		2	5	4	Other grasses	3	2	1	2
V. caespitosum		2	3	3	*Linnaea borealis*	4	5	5	5
V. myrtilloides				4	*Cornus canadensis*	3	4	4	5
V. membranaceum		2	2	1	*Arnica cordifolia*	4	3	4	2
V. oreophilum	*3*	1			*Epilobium angustifolium*	2	2	3	4
V. scoparium	2	*3*			*Mertensia paniculata*		1	3	3
Menziesia glabella	2	*3*			*Aster conspicuus*	2	2	2	3
Juniperis communis	2	3	2	1	*A. ciliolatus*	1	1	1	3
J. horizontalis		1	1	1	*Petasites palmatus*			3	4
Arctostaphylos uva-ursi	2	2	2	2	*Mitella nuda*		2	2	3
A. rubra		1			*Pyrola secunda*	3	3	2	1
Salix spp.	2	3	2	3	*P. asarifolia*	3	3	2	3
Alnus crispa	2	2	2	3	*Moneses uniflora*		1		
Empetrum nigrum		2	*3*		*Fragaria glauca*	2	2	2	3
Spiraea lucida	*5*	2	1	2	*Zygadenus elegans*	1	1	2	1
Symphoricarpos alba	3	1	1	1	*Lycopodium annotinum*	1	2	2	2
Lonicera involucrata	1	1	1	*3*	*L. complanatum*		1	1	2
L. glaucescens		1		1	*L. clavatum*				1
L. utahensis	2	1			*Smilacina amplexicaulis*	2	1	1	1
Ribes lacustre	2	1	1	2	*Stenanthium occidentale*	2	2	2	
R. triste				1	*Streptopus amplexifolius*		1	1	2
R. viscossisimum	*2*				*Achillea millefolium*		1	1	2
Rubus idaeus	1	1	1	2	*Senecio indecorus*		1		
R. parviflorus	*3*			1	*Aquilegia* spp.		1	1	
Cornus stolonifera		1	1	1	*Pedicularis bracteosa*		1	1	1
Rhododendron albiflorum		1	1		*P. labradorica*			1	1
Betula glandulosa		1	1	1	*Hedysarum sulphurescens*			1	
Phyllodoce spp.		*1*			*Galium boreale*		1	1	*3*
Viburnum edule		1	1	*3*	*Lathyrus ochroleucus*	1	1	2	3
Potentilla fruticosa	2	1	1	1	*Clematis columbiana*	1	1	1	
Amelanchier sp.	1			1	*Rubus pubescens*			1	3
Sambucus racemosa				1	*R. pedatus*			1	1
Sorbus scopulina			1	1	*Habenaria* spp.			1	1
Acer glabrum	*2*				*Maianthemum canadense*				*4*
Berberis repens	*3*				*Antennaria* spp.		1	1	2
Pachystima myrsinites	*2*				*Aralia nudicaulis*				*2*
Chiogenes hispidula				*1*	*Viola rugulosa*		1	1	2
					V. orbiculata	*3*			

Table XXVI (Continued)

Shrubs	Montane	Subalpine	High Foothills	Low Foothills
MOSSES AND LICHENS				
Feather mosses (3 spp.)	3	5	5	5
Thuidium abietinum			1	
Dicranum spp.	2	3	2	3
Polytrichum spp.	1	2	2	3
Mnium spp.	1	1	1	1
Cladonia spp.	2	3	3	2
Peltigera apthosa	3	5	5	4

Herbs	Montane	Subalpine	High Foothills	Low Foothills
Equisetum scirpoides		2	2	2
E. sylvaticum				3
E. pratense				1
Carex spp.		1	1	2
Dryopteris disjuncta				2
Thalictrum occidentale	4	1		
Clintonia uniflora	2	1		
Vicia americana	1	1		
Actaea rubra	1			1
Castilleja spp.	1	1	1	2
Geocaulon lividum				1
Xerophyllum tenax	2			
Tiarella unifoliata	1	1		
Goodyera spp.	2			1
Chimaphila umbellata	2			
Erythronium grandiflorum	2			
Osmorhiza occidentalis	1			
Disporum trachycarpum	1	1		1

Scale

Frequency Distribution

1. rare
2. occasionally present
3. often present
4. usually present
5. constantly present