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Lodgepole Pine: Regeneration and Management

LODGEPOLE PINE: REGENERATION AND MANAGEMENT

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INTRODUCTION

Anthony F. Gasbarro

Early in 1979, the School of Agriculture and Land Resources Management of the University of Alaska surveyed forest managers in a number of northern countries to identify topics of circumpolar interest in forest management. Responses most frequently centered on problems of forest regeneration. As a result we initiated what was to be a series of international workshops to address the problem of obtaining adequate and economical forest regeneration at high latitudes. Our initial efforts were financed by a generous grant from the United States Department of Agriculture, U. S. Forest Service.

The first international workshop was held in November 1979, in Fairbanks, Alaska. Representatives from Canada, Finland, Norway, Sweden, and Alaska discussed general problems related to forest regeneration in their respective countries. The second workshop, held in Umeå, Sweden, in August 1980, focused on Swedish attempts to deal with the problems of forest regeneration. A third workshop, held in Prince George, British Columbia, Canada, in August 1981, dealt with Canadian efforts to address the forest regeneration issue. The fourth workshop took place at Hinton, Alberta, Canada, in August 1982 and dealt with the management of lodgepole pine in the boreal forest. This report contains the papers given at the 1982 workshop.

The meeting at Hinton, Alberta was sponsored by the Canadian Forest Service. The principal organizers of the workshop were Alex Gardner, Forestry Officer of the Canadian Forest Service, and John Powell, Program Manager, Environmental Forestry, Canadian Forest Service. The objective of the workshop was to review techniques and discuss problems related to lodgepole pine management in western Canada with the hope of providing insight to those forest managers wishing to introduce and/or manage lodgepole pine in other northern-latitude countries (i.e. Alaska, USA, Sweden and Finland). Sincere appreciation is expressed to the authors of the papers in this publication.

The next workshop will be held in Fairbanks, Alaska, in August 1983. It will address the problem of site identification and classification at northen latitudes.

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NATURAL LODGEPOLE PINE IN WEST-CENTRAL ALBERTA
PART I: REGENERATION STOCKING

Imre E. Bella

INTRODUCTION

Natural lodgepole pine (*Pinus contortu* Dougl. var. *latifolia* Engelm.) is generally considered to be a seral species and exhibits a very broad ecological amplitude. It commonly regenerates abundantly and rapidly following wildfire or scarification. Lodgepole pine is capable of rapid juvenile growth on a wide variety of forest sites, but overabundant regeneration often results in reduced tree growth and merchantable yield. Therefore, the usefulness of regeneration surveys could be much enhanced if they were to provide factual information on actual seedling densities in overstocked regeneration. This would facilitate the planning of any thinning treatments required to increase merchantable timber production. Many studies have shown that thinning a young, overdense lodgepole pine stand is the most effective stand treatment option for yield improvement.

Fertilization, in addition to regeneration stocking control and juvenile spacing, provides another opportunity to improve,fiber production. Information is required on the kind, quantity, and timing of fertilizer application under a variety of stand conditions that produces the best returns on this investment.

STOCKING – DENSITY RELATIONSHIP

When stocking standards are defined in terms of stocking percentages, those percentages imply a certain minimum number of established, acceptable seedlings per hectare. Although this specified minimum number of seedlings is an important guideline, the actual number may be considerably higher and dependent on the spatial pattern of the seedlings over the area.

Past studies (Bella '1976; Bella and DeFranceschi 1978) have shown that over 90% of lodgepole pine natural regeneration has a clumpy pattern whether it originates after logging and site preparation or after wildfire. This aggregation, or clumping, of seedlings generally means a surplus of seedlings on some stocked quadrats over the number implied by the stocking percentage. The degree of clumping and thus the number of surplus seedlings' may vary considerably and depends on several factors including seed source, seed bed, and weather (moisture) conditions.

Although factual data on the number of these extra seedlings would assist intelligent, early planning of density-control treatments, only a limited amount of information is available. Bella (1976) published information on average expected number of seedlings in relation to stocking percentage. In a follow-up report, Bella and DeFranceschi (1978) presented trends of relative frequencies of stocked quadrats with at least 1, **2, 3,** etc. established seedlings in relation to stocking percentages for the major commercial forest types in western Alberta. Using the same data base, this paper takes the analysis one step further for lodgepole pine types and provides detailed information on seedling densities per ha. based on estimates from 4- and 8-m^2 quadrats, when those density estimates include only one, up to **2,** 3, 4, **....** 9, or all coniferous seedlings per quadrat.

THE SAMPLE

Data for this analysis were collected in the Foothills Section, mainly in the B.19a-Lower Foothills area (Rowe **1972**), fig. 1 (over), where the major coniferous species are lodgepole pine, white spruce (*Picea glauca* (Moench) **Voss),** black spruce ***(P.*** *mariana* (Mill.) B.S.P.), balsam fir ***(Abies balsamea*** (L.) Mill.), and alpine fir ***(A.*** *lasiocarpa* (Hook.) Nutt.). They cover a large geographic area encompassing a considerable variation in soil and site conditions. Soil moisture was probably the most important single variable affecting seedling establishment and growth.

Sampling was conducted in the springs of 1975 and 1977 in cutover blocks approximately ten growing seasons after logging. These blocks, therefore, represented a range of stocking and stand conditions in the region. Ground treatment (drag-type scarification) had generally followed logging within a year. On each cutover block sampled, three 0.04-ha^2 square plots were established to represent low, average, and high stocking levels in that stand.

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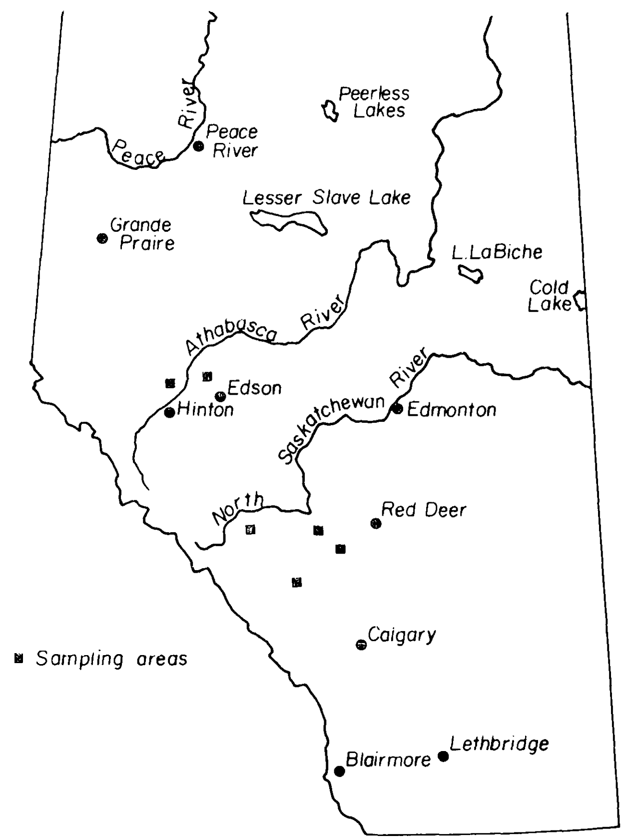

Figure 1.--General locarions ot sample plots.

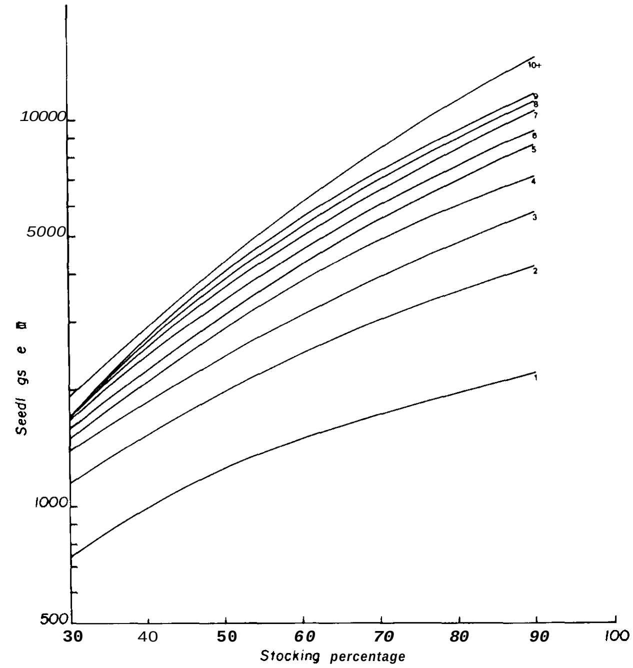

Figure 2.--Density-stocking relationships for pine after logging, based on 4-m^2 quadrats.

The sample plots were subdivided into a grid of 10 x 10 4-m^2 (1 milacre) quadrats. On each quadrat, all seedlings 2 and 3 years old or older as well as vigorous advance growth were tallied by species, and the health of each individual recorded.

Data collected by J. Soos (on file at the Northern Forest Research Centre) in 1966 in 8-year-old lodgepole pine near the Upper Saskatchewan Ranger Station (Rocky-Clearwater Forest) were also used. This was a complete tally (100% sample) of pine regeneration orily by a 4-m^2 quadrat of a 15.5-ha area where the original lodgepole pine stand had been destroyed by fire 8 years earlier. For this analysis, this sample was partitioned into contiguous 36- x 36-m plots (i.e., an 18 x 18 matrix of 4-m^2 quadrats). A total of 85 plots was used in the analysis. Plots that had roads or logging trails preventing regeneration were excluded from the analysis.

ANALYSIS

The number of seedlings per hectare in relation to stocking percentage was compiled from quadrat tallies on each plot considering only one, up to 2, 3, ...9 or all acceptable seedlings, viz, healthy 3-year-olds and older, and advanced growth per quadrat. Either pine or pine-spruce-fir were considered. Two quadrat sizes, 4-m^2 and 8-m^2, were used. The data were summarized by 5% stocking classes and freehand curves were drawn tu class means.

RESULTS AND DISCUSSION

Figures 2 through 6 show trends of seedling densities per hectare in relation to stocking percentage when 1, 2, ...9 or all seedlings are considered. Figures 2 and 5 are based on 4-m^2 quadrats and those in figures 3, 4, and 6 on 8-m^2 quadrats. The implication of quadrat size in regeneration surveys in Alberta has been discussed at some length by Bella (1976).

These relationships indicate a substantially greater number of trees per unit area than is implied by a given stocking percentage. For instance, considering up to two pine trees per 4-m^2 quadrat means a density nearly twice as high at stocking levels above 50% than would be expected from the stocking percentage. At lower stocking, there are fewer extra seedlings, both in absolute and relative terms.

Increasing the number of trees counted per ha to 3, 4, ...etc., after two trees means a fairly gradual increase in density per hectare; but there is a definite rise in the trend for "all" trees at higher stocking levels that indicates over-dense conditions. This suggests that, at higher stocking levels, a stocked quadrat often has two trees, although it may also have a clump of ten or more.

Essentially the same general relationship prevail when the trends are based on 8-m^2 quadrats (rather than 4-m^2), although, as expected, they show lower tree numbers at low and medium stocking levels; at over 80% stocking (figs. 2 and 3), the two sets of trends tend to converge.

No substantial differences in seedling densities were found between logged areas and those regenerating after wildfire (fig. 3 vs. fig. 4), although a midrange of stocking (60-80%) density levels were higher after logging than after fire. These higher densities may arise from the clumpiness of pine regeneration associated with postlogging site treatment.

Spruce and fir, in addition to pine, in the quadrat tally do not seem to have much effect on these relationships, although a few more extreme-density values have occurred at high stocking levels with the inclusion of these two other conifers.

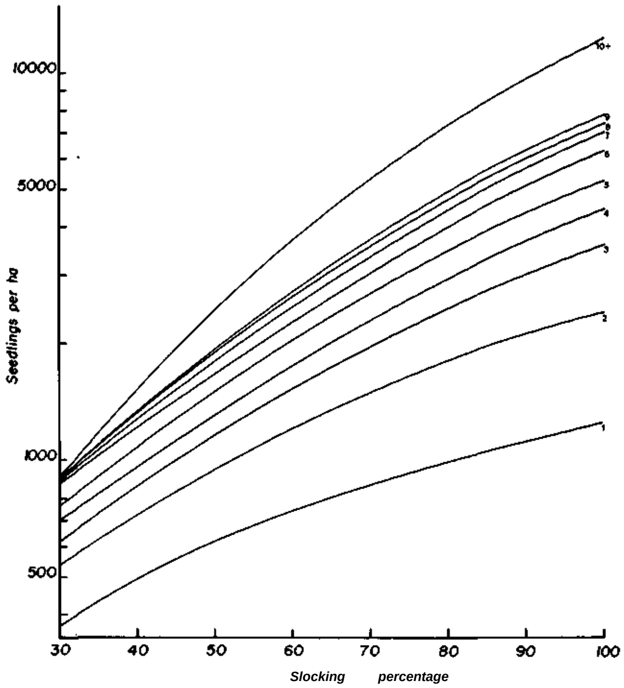

Figure 3.--Density-stocking relationships for pine after logging, based on 8-m^2 quadrats.

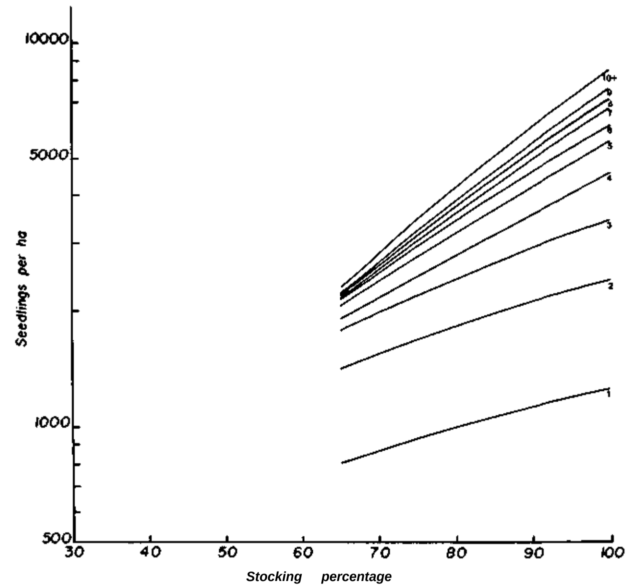

Figure 4.--Density-stocking relationships for pine after wildfire, based on 8 -m^2 quadrats.

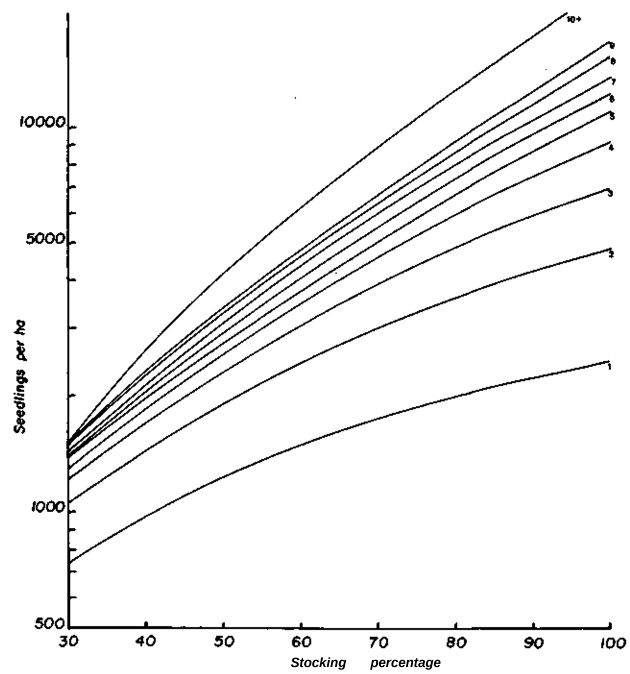

Figure 5.—Density-stocking relationships for pine-spruce-fir after logging, based on 4-m^2 quadrats.

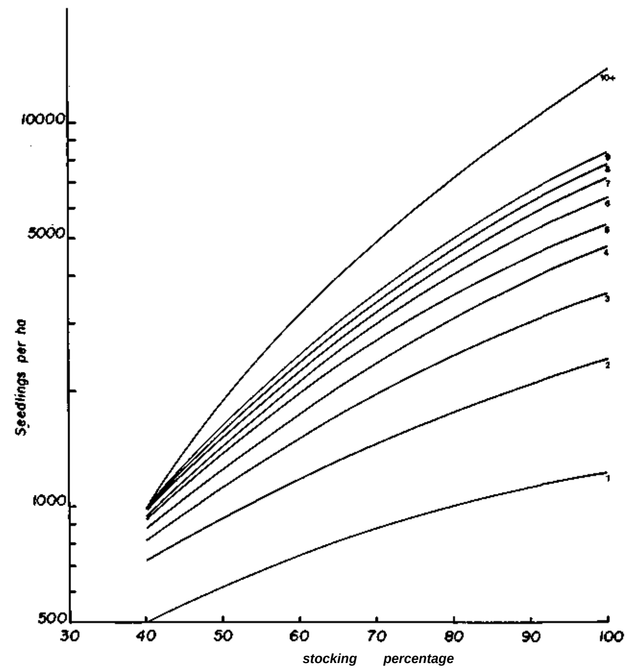

Figure 6.--Density-stocking relationships for pine-spruce-fir after logging, based on 8-m^2 quadrats.

CONCLUSIONS

Clumping and excessive crowding of lodgepole pine regeneration requires factual information on seedling densities in order to plan thinning treatments that will enhance merchantable wood production. Such requisite data may be obtained during regeneration surveys with relatively little extra work. Besides its direct use, such information would provide data for developing guide curves for the more important sites, cover types, and postlogging treatment combinations which later may be used to estimate seedling densities from stocking percentages.

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NATURAL LODGEPOLE PINE IN WEST-CENTRAL ALBERTA
PART II: JUVENILE SPACING

W. D. Johnstone

INTRODUCTION

The juvenile growth and, ultimately, the harvest of natural lodgepole pine stands can be seriously reduced when excessive stand density results in severe intertree competition (Johnstone 1976). Smithers (1961) warns that stands containing over 5000 stems per hectare at 90 years of age will probably not provide a reasonable merchantable yield. Although apparently unable to thin itself, lodgepole pine, particularly at young ages, will respond favorably to precommercial thinning or juvenile spacing (Alexander 1956, 1960, 1965; Barrett 1961; Cole 1975; Dahms 1967, 1971a, 1971b, 1971c, 1973; Daniel and Barnes 1958; Johnstone 1981a, 1981b, 1982; Smithers 1957, 1961). This report updates, to 18 years after treatment, a study (Johnstone 1981a) which examined the effects of various spacings on the development of dense, fire-origin stands of 7-year-old lodgepole pine.

METHODS

Site Selection and Study Establishment

The study was established in an area known locally as the Gregg Burn, which is located just south of Hinton, Alberta (53'25' N, 117'34' W). This area is classified as the Upper Foothills Section (classification: B. 19c) of the Boreal Forest Region (Rowe 1972). Three sites, judged to be of low, intermediate, and high productivity, were chosen within pure, even-aged stands of 7-year-old lodgepole pine which regenerated naturally following a 1956 wildfire. Detailed descriptions of these sites are reported by Johnstone (1981a).

The experimental design and methods of establishment are described in detail by Johnstone (1981a). Briefly, five spacing levels or levels of growing stock (LGS) were established on variable-area plots, containing 100 treatment trees per plot (table 1), during the fall of 1963 and the spring of 1964. A square (10 x 10) grid was established on each plot, and all trees except the healthiest and most vigorous tree within 46 cm (18 in.) of each grid intersection were removed. Grid distances and variable plot size are shown in table 1. Two blocks, each containing the five spacings, were established on each site. Therefore, the study is based on 3000 treatment trees from three sites, each containing two blocks of five plots each.

Measurement, Compilation, and Analysis

In the fall of 1964, after the first growing season following spacing, and in the fall of 1966, the total height was measured and recorded for all treatment trees. The diameter at breast height, total height, crown width, and crown length of each tree were measured in the falls of 1971, 1976, and 1981. Damage to treatment trees caused by insects, diseases, or animals was also recorded. All invading conifers were removed from the plots in 1971.

All measurements were performed in Canadian yard/pound units and these values were subsequently converted to the Systéme International d'Unités (SI) using Bowen's (1974) recommended conversion factors. Breast-height measurements were taken at 1.37 m (4.5 ft.). The total volume of each tree was calculated from the following equations[1]:

1. Trees ≤8.9 cm (≤3.5 in.) dbhob:
   $V = 0.0232 + 0.00253\, D^2 H$
2. Trees 9.1-21.6 cm (3.6-8.5 in.) dbhob:
   $V = -0.0949 + 0.00272\, D^2 H$

where V = volume in cubic feet (stump and top included, bark excluded)
D = diameter at breast height outside bark (dbhob) in inches
H = total height in feet

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[1] Kirby, C. L. Unpublished file report on tree-volume equations and volume basal-area ratios for white spruce and lodgepole pine in Alberta, 1973. Northern Forest Research Centre, Canadian Forestry Service. Edmonton, Alberta.

Table 1--Spacing, grid intervals, and variable plot size for the treatment plots.

Levels of growing stock (LGS)	Spacing		Grid interval		Plot size	
	Trees/ha	Trees/acre	m	ft	ha	acre
1	494	200	4.50	14.76	0.200	0.500
2	988	400	3.18	10.44	0.101	0.250
3	1977	800	2.25	7.38	0.051	0.125
4	3954	1600	1.59	5.22	0.025	0.063
5	7907	3200	1.12	3.69	0.013	0.031

Merchantable volumes, based upon a 10.16-cm (4.0-in.) diameter inside bark top and a 0.30-m (1.0-ft.) stump, were calculated for all trees $\geq$ 11.68 cm (24.6 in.) dbhob using Honer's (1967) merchantable conversion function for lodgepole pine.

In lieu of the presence of a similarly treated buffer zone, the analyses were based on the 64 inner sample trees in each plot (*i.e.*, the 36 perimetrical trees were eliminated from analysis). Average and per-hectare stand values of each plot were analyzed for each measurement period. Per-hectare values are net values (*i.e.*, exclude mortality) and were determined for each plot by multiplying the mean value of the sample trees (volume, basal area, or crown area) times the spacing level times the number of live sample trees as a decimal fraction of 64. In these calculations, the tree crowns were assumed to be circular in shape. The following randomized complete-block analysis of variance was used for all average and per-hectare value comparisons:

Source	Degrees of freedom
Sites (S)	2
Spacing (T)	4
Site x spacing (S x T)	8
Block within site (B wi S)	3
Spacing x block within site (T x B wi S)	12
Total	29

Treatment means were compared using Duncan's new multiple-range test. In addition, an analysis of covariance (Zar 1974) of 1981 data, was used to determine the effect of spacing on the parabolic relationship between height and diameter over the range of sites.

RESULTS AND DISCUSSION

Data from both blocks in each site were combined for ease of presentation in this report. This was done despite significant differences in crown width and crown closure between the blocks within each productivity site. For the first time in this experiment, significant differences between blocks within sites were also observed for periodic height growth and periodic diameter growth. These differences between blocks within sites may indicate that the catastrophic mortality, which will be discussed in a later section, is beginning to compromise individual treatment responses within the overall experiment. The effects of site and spacing on growth and yield are summarized in table 2 along with detailed comparisons of treatment means. No significant site x spacing interactions were observed 18 years after treatment, indicating that site productivity was not modifying the response to spacing. In all cases, both site and spacing have significantly affected these characteristics.

Table 2--Effects of site and spacing on lodgepole pine stand development, and a comparison of treatment effects.

Characteristics	Source of variation[1]	Statistical significance[2]	Level of growing stock[3]
Mean height (Age 25)	S	**	5 4 3 2 1
	T	*	
Mean periodic height growth (Age 20-25)	S	*	5 4 1 3 2
	T	*	
Mean dbhob (Age 25)	S	**	5 4 3 2 1
	T	**	
Mean periodic dbhob growth (Age 20-25)	S	*	5 4 3 2 1
	T	**	
Crown width (Age 25)	S	**	5 4 3 2 1
	T	**	
Crown closure (Age 25)	S	**	1 2 3 4 5
	T	**	
Percent live crown length (Age 25)	S	**	5 4 3 2 1
	T	**	
Basal area (Age 25)	S	**	1 2 3 4 5
	T	**	
Mean total volume/tree (Age 25)	S	**	5 4 3 2 1
	T	**	
Net total volume/ha (Age 25)	S	**	1 2 3 4 5
	T	**	
Net merchantable volume/ha (Age 25)	S	**	5 4 3 1 2
	T	*	

[1] S = site; T = treatment (spacing).
[2] * significant at p = 0.05 level; ** significant at p = 0.01 level.
[3] Treatments are arranged in ascending order of means. Treatments underscored by the same line are not significantly different at p = 0.05.

Height

Spacing had a significant effect on mean stand height of the 25-year-old lodgepole pine (table 2) particularly on the low and intermediate sites (fig. 1). Johnstone (1981a) previously speculated that this may reflect more-intense competition for moisture and nutrients on these lower sites. Note that, on the high site, the greatest mean height continues to occur at LGS 2, and the mean height of LGS 1 is now ranked second lowest of the five spacing levels. During the past five years, LGS 5 grew significantly slower than the remaining treatments (table 2), and, on the highest site, the slowest growth was observed at LGS 1 and LGS 5 (fig. 1).

Analyses of covariance detected no between-block differences in the height-diameter relationship, within each site, for each spacing. Consequently, data from both blocks within each site were combined for each treatment. Differences in the intercepts resulted in significant overall between-treatment differences on the high site even though there were no differences in the slopes of the relationships. Equations for LGS 1 and LGS 5 were not parallel on the intermediate site, giving significant overall differences between spacings when combined with differences in intercepts. On the low site, differences in intercepts, plus differences in the slopes of LGS 3, 4, and 5, resulted in significant differences between spacings in the height-diameter equations. For a given diameter, tree height was inversely related to degree of spacing (*i.e.,* the wider the spacing, the shorter the tree). Although these differences were consistent for all sites, the magnitude of the differences varied directly with site productivity (*i.e.,* differences between spacings on the high site were substantially larger than differences between corresponding spacings on the low site). There also appears to be a trend toward slightly taller trees, for a given diameter, on the high site than on the low site.

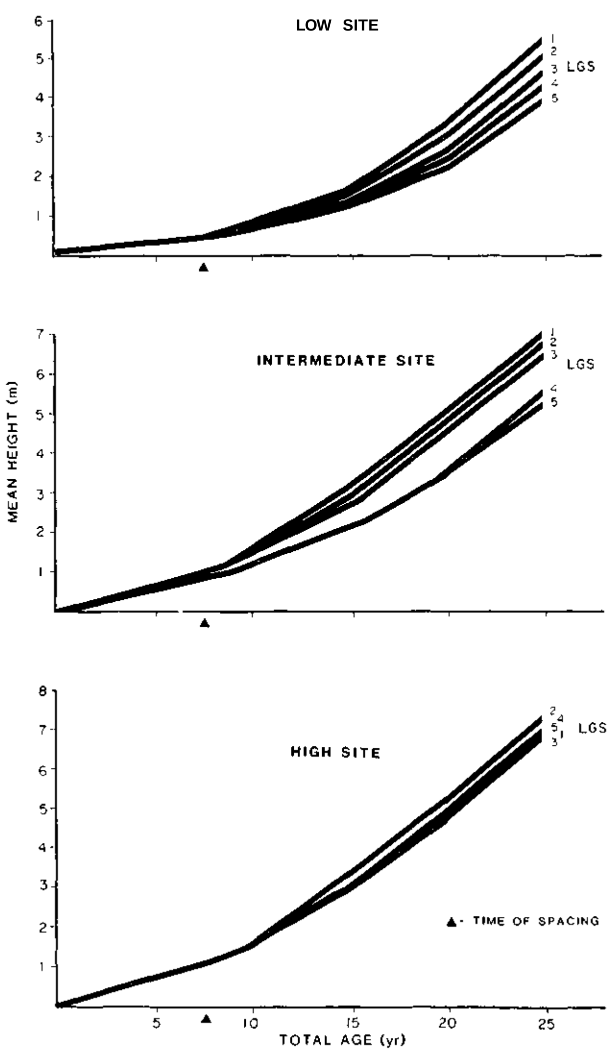

Figure 1.--Height development of spaced lodgepole pine.

Diameter

Spacing continues to have a significant and dramatic effect on diameter development on all sites (fig. 2) in that the mean diameter and diameter increment are directly related to

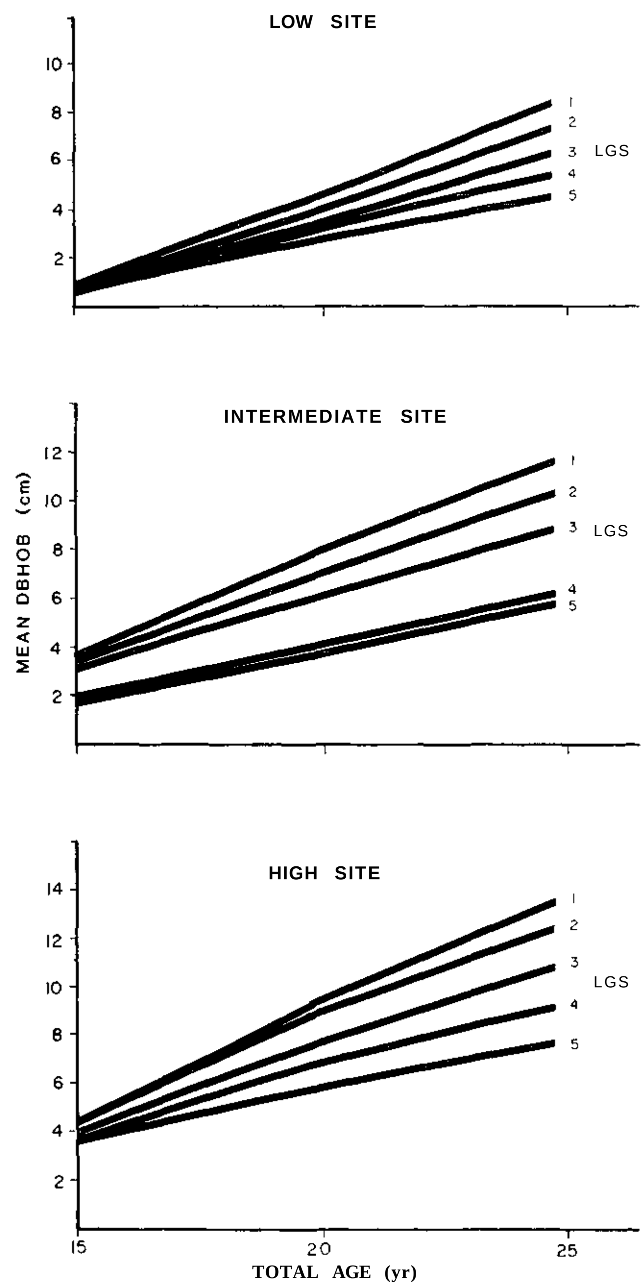

Figure 2.--Diameter development of lodgepole pine.

amount of growing space. The mean diameters at LGS 4 and LGS 5 were smaller than the remaining spacing levels, and mean diameter increment increased significantly with each increase in spacing (table 2). The previous analysis (Johnstone 1981a) showed a significant site x spacing interaction in periodic (from ages 15 to 20 years) diameter growth, which reflected a more rapid decline in growth with respect to spacing on the high site compared to the lower sites. No significant site x spacing interaction was observed from ages 20 to 25 indicating that there is no longer a differential diameter growth response to spacing on the various sites.

Crown Development

Site and spacing had significant effects on crown expansion and crown width (table 2 and fig. 3). Trees on the best site and at the widest spacings exhibited the widest crowns, and trees on the poorest site and at the closest spacing had the narrowest crowns. Consequently, the rate of crown closure is directly related to site productivity for a given level of growing stock (fig. 4). The crowns have fully closed (crown closure of 123%) and overlap by about 11% at LGS 5 on the high site. Both site and spacing also had a significant effect on the proportion of the bole supporting the live crown (table 2). The relative rate of crown lift is faster on the higher sites and at the closer spacings (fig. 5, over). Rate of crown lift is presumably directly related to rate of crown closure.

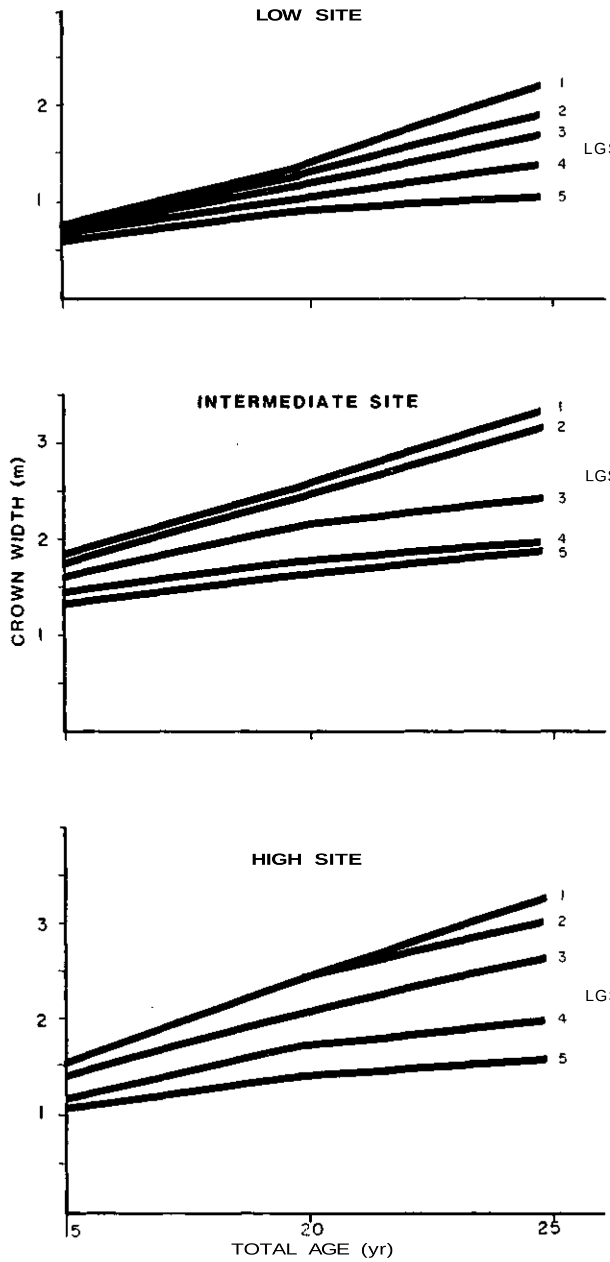

Figure 3.--Crown-width development of spaced lodgepole pine.

Basal Area and Volume

Wider spacing resulted in significantly lower basal areas and total stand volumes at 25 years of age (table 2) despite signifi-

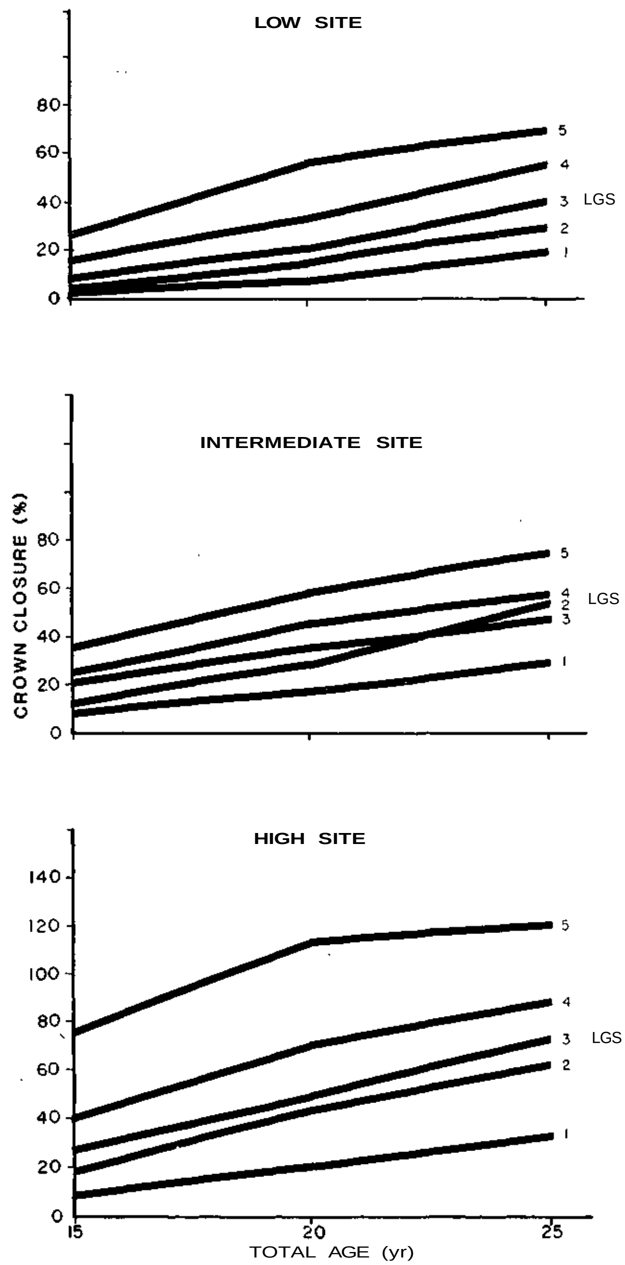

Figure 4.--Effect of spacing on crown closure of spaced lodgepole pine.

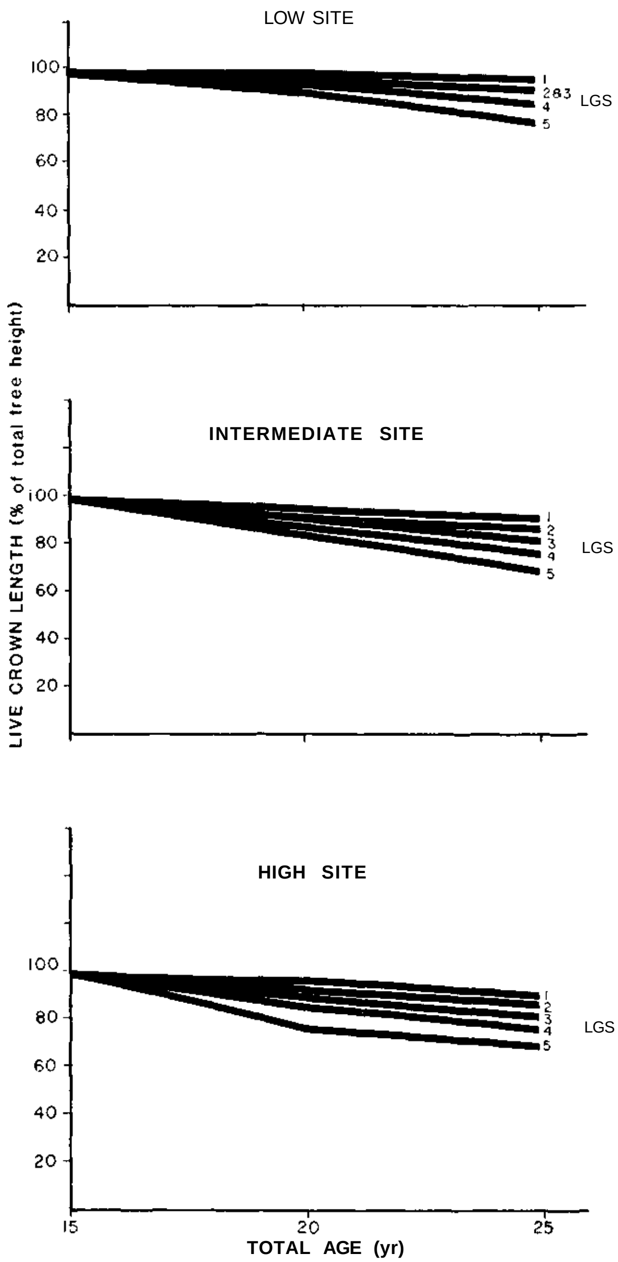

Figure 5.--Effect of spacing on the crown length of lodgepole pine.

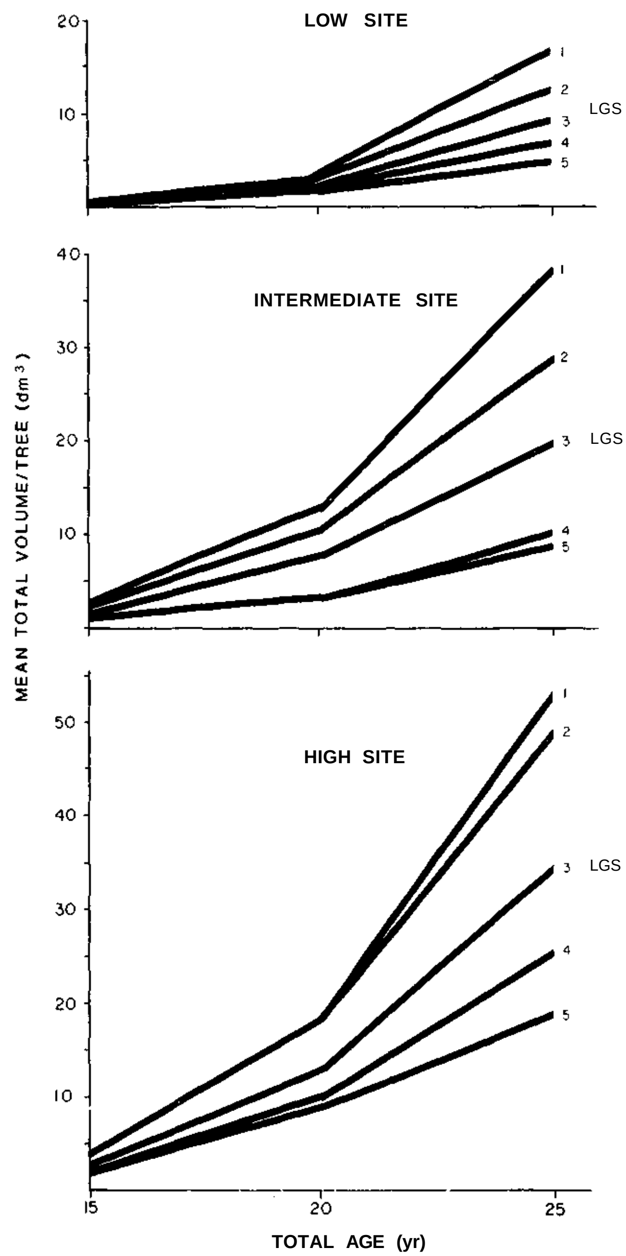

Figure 6.--Effect of spacing on total volume per tree of lodgepole pine.

cantly larger (fig. 6) and faster growing trees, because of the disproportionately greater number of stems at the closer spacing. Several important yield trends are developing (fig. 7), although it is still uncertain whether the wider spacings will ever achieve the same total volume production of the close spacings. Averaged over all sites, the difference in total volume per tree at LGS 1 compared to LGS 5 has increased during the past 10 years from 195% to 344%, while the difference in total volume per hectare has declined from 814% to 304%. It is probable that this gap in net total volume production will continue to decline when mortality resulting from intertree competition becomes more severe at the closer spacings.

The production of merchantable (pulpwood) volume was also significantly affected by both site and spacing (table 2). Except on the poorest site, where merchantable volume is essentially negligible, LGS 2 produced the highest pulpwood yield at 25 years of age (fig. 8). LGS 2 and LGS 3 have surpassed the merchantable volume per hectare of LGS 1 on the high site because substantially more (85% and 66%, respectively) trees achieved merchantable size. Furthermore, height growth at LGS 1 is slower. It is likely that LGS 2 and LGS 3 will continue *to* produce higher pulpwood yields than LGS 1, particularly on the high site, because more trees are currently approaching the merchantability-size threshold at LGS 2 and LGS 3 than at LGS 1.

Mortality

Mortality, which varied on an individual-plot basis from 0% to 66%, is of real concern in this study. The two main causes of mortality (Johnstone 1981a) are shoe-string root rot *(Armillaria mellea* (Vahl. ex Fr.) Kummer) and small-mammal girdling

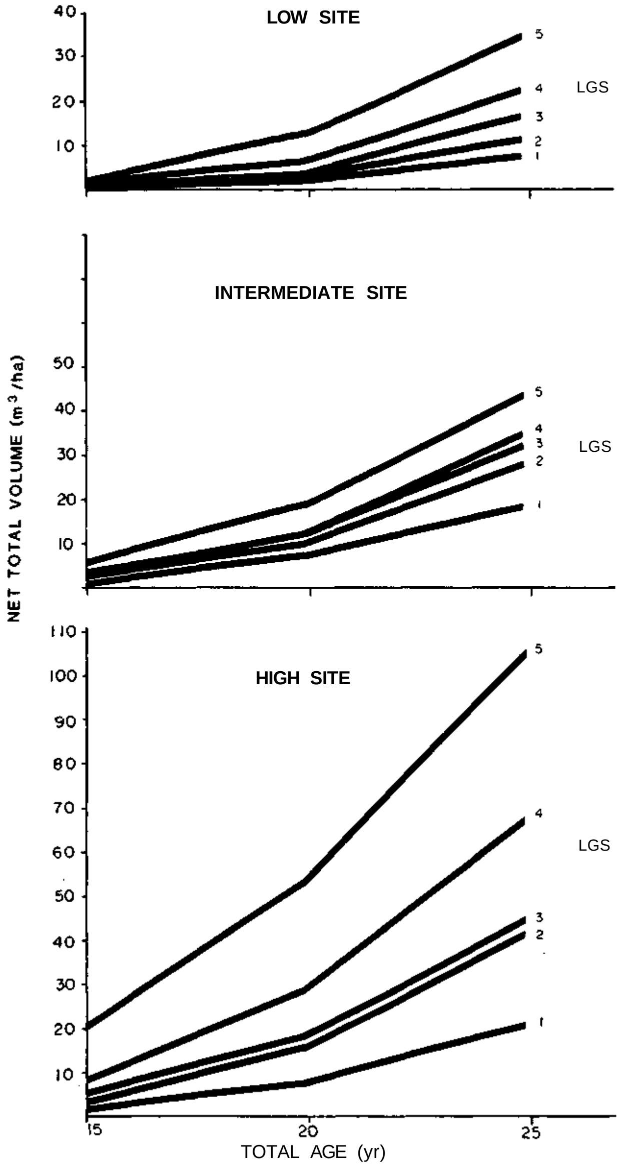

Figure 7.--Total volume-per-hectare development of spaced lodgepole pine.

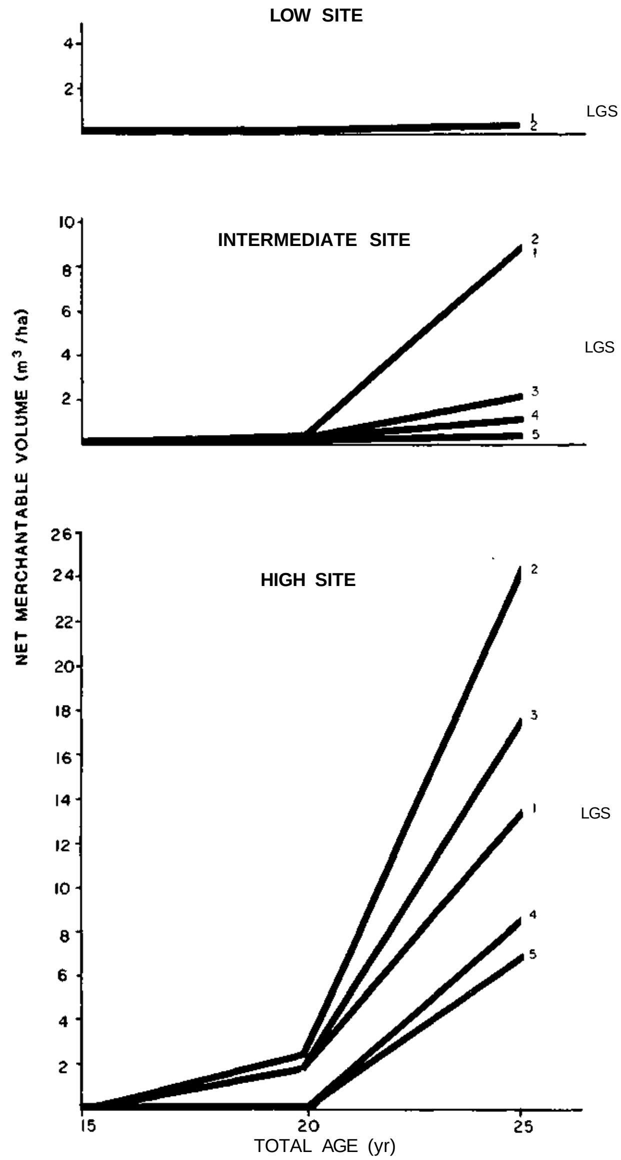

Figure 8.--Merchantable volume-per-hectare development of spaced lodgepole pine.

(i.e., snowshoe hares, *Lepus americanus,* and red squirrels, *Tamiasciurus hudsonicus,).* Damage and mortality are localized within the experiment, thus resulting in the significant differences among blocks within sites. An analysis of variance indicated that mortality was not related to spacing, but was significantly higher on the most productive site than on the low site. A large proportion of the sample trees have also been infected by western gall rust *(Endocronartium harknessi* (J. P. Moore) Y. Hiratsuka), which not only reduces tree growth and quality, but which also increases the risk of snow or wind breakage.

CONCLUSIONS

Natural lodgepole pine stands in west-central Alberta are frequently too dense to produce merchantable yields in keeping with the productive capacity of the sites on which they grow. Excessive stand density also increases the rate and amount of mortality, the length of rotation, and harvesting cost. Juvenile spacing can drastically alter stand growth and yield, and is a valuable silvicultural tool for remedying many of the problems associated with densely regenerated lodgepole pine. This study continues to provide the biological-response data required to identify optimum management regimes for lodgepole pine.

The dramatic effects of spacing on average stand diameter and diameter increment are consistent with earlier studies of the species. The mean diameter and recent diameter growth of LGS 1 increased by 89% and 131%, respectively, relative to LGS 5 when averaged over all sites. These differences have increased since last reported at age 20 (Johnstone 1981a). Diameter growth response to selective thinning, such as is studied here, will undoubtedly exceed the response to mechanical strip thinning (Bella and De Franceschi 1982), because those trees most likely to respond favorably can be retained for future crop trees.

The effects of spacing on average height and height growth were less dramatic and less conclusive than on diameter, except on the low and intermediate sites. The widest spacing on the best site may even have reduced height growth. Trees at the widest spacing on the high site may be expanding their crowns so rapidly that diameter increment accelerates at the expense of height growth. This hypothesis is supported by analyses of the height-diameter relationship. 'Trees grown at wider spacings were shorter than trees grown at closer spacings for a given diameter class. Consequently, bole taper will increase with increases in spacing, and both the total volume and the sawmill recovery by diameter class will be reduced. It is fortunate that this effect of spacing is less pronounced on poorer sites, because wider spacing appears to be more advantageous on low sites compared to high sites. These results support other studies (Alexander 1960;Johnstone 1981b, 1982) which indicate that lodgepole pine requires a limited degree of crowding to maximize height growth.

This study demonstrates the need for forest managers to clearly identify and define their future timber objectives, preferably on a site -specific basis. Despite significantly larger and faster-growing trees, both total volume and total volume growth were significantly lower at the widest spacing. At the same time, the largest merchantable yield did not occur at the widest spacing. At the same time, the largest merchantable yield did not occur at the widest spacing. Consequently, although wide spacing may shorten technical rotation lengths (*i.e.*, the time required to grow trees of a desired size), wide spacing may also reduce total stand productivity. Obviously, some method of optimizing individual tree growth with levels of growing stock is warranted to maximize the yield of desired products on an area basis. The practice of increasing the current allowable annual cut of mature timber in proportion to the anticipated improvement of future volume yields is often used as an incentive to encourage more intensive forest management. In order to ensure the continuity of future harvests, this method of apportionment should only be applied after the productive capacities of the sites to be managed have been duly considered. With respect to the stand-density management of natural lodgepole pine, the present study shows that the largest relative gains occur on poorer sites but that the actual absolute gains on these sites may be negligible.

Because of the high mortality losses caused by biotic agents in this study and by climatic factors in other studies (*i.e.*, Johnstone 1982), there is an urgent need for a comprehensive evaluation and study of the risks and uncertainties associated with the management of natural lodgepole pine stands. Quantitative risk factors developed from such a study should be incorporated into planning models and stand-management regimes. Continued renieasurement and analysis of the present study will continue to contribute to the understanding of the management of natural lodgepole pine stands in west-central Alberta and elsewhere.

ACKNOWLEDGMEN'I'S

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NATURAL LODGEPOLE PINE IN WEST-CENTRAL ALBERTA
PART III: FERTILIZATION

Richard Yang

INTRODUCTION

Along with regeneration stocking control and juvenile spacing, fertilization provides a further opportunity for foresters to increase site and stand productivities. Although the actual acreage of commercial forest land fertilized in Canada is small, many research studies have been established by federal and provincial agencies as well as by industry (Rennie 1974). Little information is currently available, however, on effects of fertilization on growth and yield of lodgepole pine in Alberta.

Forest fertilization involves an investment in forest stands and sites. Information on the kind, quantity, and time of application of fertilizers needed to produce the best return is required before a sound decision can be made. This section reports preliminary analysis on the effects of N, P, and S fertilizers on a preharvest, 70-year-old lodgepole pine stand. Fertilization of preharvest stands is of great interest to forest managers since there is a possibility that investment costs plus interest can be more than recouped in a short period by increased yields.

METHODS AND MATERIALS

Study Area

Four study areas were selected in 1970 on St. Regis (Alberta) Ltd. (formerly the Northwestern Pulp and Power Company) lands near Hinton, Alberta. The study areas were located with normal density stands of two stand ages (30 and 70 years old) on Coalspur (Orthic Gray Luvisol) and Mercoal (Bisequal Gray Luvisol) soil types. Results from the 70-year-old lodgepole pine stand on the Coalspur soil type are reported here.

The study area was divided into three blocks, each of which contained twenty-four plots as required by the experimental design. The plot centers were established systematically on a square grid at about 30-m (15-chain) intervals. When a plot center fell within an abnormally open portion of the stand, the plot was omitted or moved to an adjacent fully stocked portion of the stand. Circular plots (8.0-m radius) of 1/50 hectare (1/20 acre) were used. Each plot center was marked with an aluminum post bearing the plot number, and ten unsuppressed trees closest to the plot center were tagged 15 cm above breast height. The diameter at breast height outside bark (dbhob) of all living trees in each plot and sufficient heights to form a reliable height-diameter relationship were taken in the fall of 1971.

Experimental Design

The central-composite, rotatable, second-order design (Cochran and *Cox* 1957) was selected for the study because the primary objective of the study has been to develop a general, predictive relationship between tree and stand responses and the incremental addition of fertilizer. Fourteen treatment combinations plus six repeating central treatments are required for three factors with five levels of fertilizer (fig. 1). Table 1 illustrates the five coded fertilizer levels being tested and the actual rates of N, P, and S on a hectare basis.

Table 2 presents the treatment combinations included in this study. In addition to the twenty composite design treatments (treatments 1-20), four combinations (treatments 21-24) were also incorporated to facilitate the analysis of an additional 2^3 factorial (-1.68 and 0 levels). The twenty-four treatments were randomly assigned to plots within a block.

Nutrient sources and their composition are listed in table **3.** Nitrogen-free treatments were made using the required quantities of triple superphosphate, and elemental sulfur and phosphorus-free treatments were prepared by combining the required quantities of urea and sulfur. To minimize the contamination of the sulfur-free treatments by phosphorus ammonium phosphate was used whenever possible.

The fertilizer combination for each plot was precisely weighed out, bagged, and identified by plot number in the laboratory prior to the field application. All of the fertilizer treatments were broadcast using cyclone seeders prior to the 1972 growing season.

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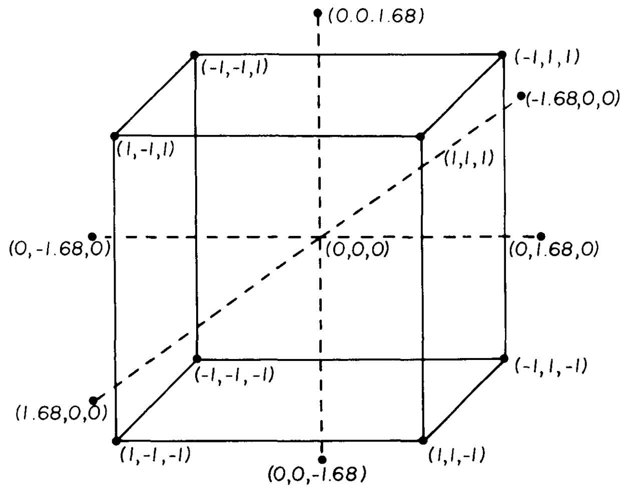

Figure 1.--Graphical representation of a 3-factor central composite rotatable design.

Table 1--Amount of N, P, and S elements applied

	Amount of elements (kg/ha)		
Code level	N	P	S
-1.68	376	188	113
1	300	150	91
0	188	94	56
- 1	76	38	23
-1.68	0	0	0

Table 2--Combinations of fertilizer treatments applied

Treatment	Code amount of element		
No.	N	P	S
1	-1	-1	-1
2	1	-1	-1
3	-1	1	-1
4	1	1	-1
5	-1	-1	1
6	1	-1	1
7	-1	1	1
8	1	1	1
9	-1.68	0	0
10	1.68	0	0
11	0	-1.68	0
12	0	1.68	0
13	0	0	-1.68
14	0	0	1.68
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0
21	0	-1.68	-1.68
22	-1.68	0	-1.68
23	-1.68	-1.68	0
24	-1.68	-1.68	-1.68

Data Compilation and Analysis

After ten growing seasons, the plots were remeasured in the summer of 1981 to determine the fertilization effects on individual tree and stand growth. All living trees in each plot were identified by species and dbhob was tallied. For accurate determination of individual tree-volume increment due to various fertilizer treatments, three dominant or codominant trees in each plot were felled for stem analysis. Disks were obtained at 0.3-m stump, breast height, 3.05-m, live crown, and other height positions where a major bole shape change was taking place.

Table 3--Nutrient sources and their chemical composition

Nutrient sources	Composition	Elemental composition
Urea (46-0-0)	46% N	46% N
Ammonium phosphate (11-55-0)	11% N 55% P_2O_5	11% N 24% P trace S
Tri. super-phosphate (0-45-0)	45% P_2O_5	19.7% P 0.9% S
Elemental sulfur	100% S	100% S

Periodic dbh increment was determined by the diameter at breast height of the ten tagged trees with two successive measurements. Tree dbh data were excluded from the analysis whenever a tagged tree was found dead or missing in the remeasurement. Individual tree-volume increments were ascertained from volumes of the three sectioned dominant or Codominant trees.

Stand-volume increments during the ten growing seasons were obtained by deriving an average diameter-height curve for trees of the study area and by using the volume equations for lodgepole pine which were described in Part II: Juvenile Spacing. Merchantable volumes, based on a 10.16-cm (4.0-in.) diameter inside bark (dib) top and a 0.30-m (1.0-ft.) stump, were calculated for all trees >11.68 cm (>4.6 in.) dbhob using Honer's (1967) merchantable conversion function for lodgepole pine. All measurements were performed in imperial units and subsequently converted into the SI system.

Efforts were made to analyze the compiled data by the central-composite, rotatable, second-order design by fitting the data to the second-degree polynomial function. The equation, however, accounted for only 30-40% of the variation in the response variables. In all cases, the lack of fit term which determines the adequacy of the equation was highly significant.

The data were subsequently analyzed by the two subfactorials incorporated in the design and randomized, complete-block arrangement of treatments. The analysis of covariance with individual tree dbh, volume, or basal area per hectare prior to fertilization as a covariate was employed.

RESULTS AND DISCUSSION

Adjusted treatment means of response variables showing 10-year periodic growth increments are summarized in table 4. The mean dbh and volume increments are respectively adjusted for average tree dbh or volume for each treatment prior to fertilization, whereas stand-response variables are adjusted for basal area per hectare of respective treatments. The analyses of covariance were justified and necessary to compare the fertilization effects of the same basis.

It was generally observed in the field that the effects of fertilizer on tree and stand growth are influenced not only by stand density but, to a certain, extent by topographical characteristics such as slope position and soil depth as well. Growth responses of the preharvest lodgepole pine are usually more pronounced for trees grown on low, concave surfaces than for those on high, concave ones. Nutrient movement and soil erosion probably explain to a large extent the variation in tree-growth responses.

Individual Tree dbh Increment

Although some fertilizer treatments produced a substantial increase in dbh growth in the 10-year period (fig. 2), the periodic increments in dbh of the ten tagged trees were not significantly different from that of the unfertilized control

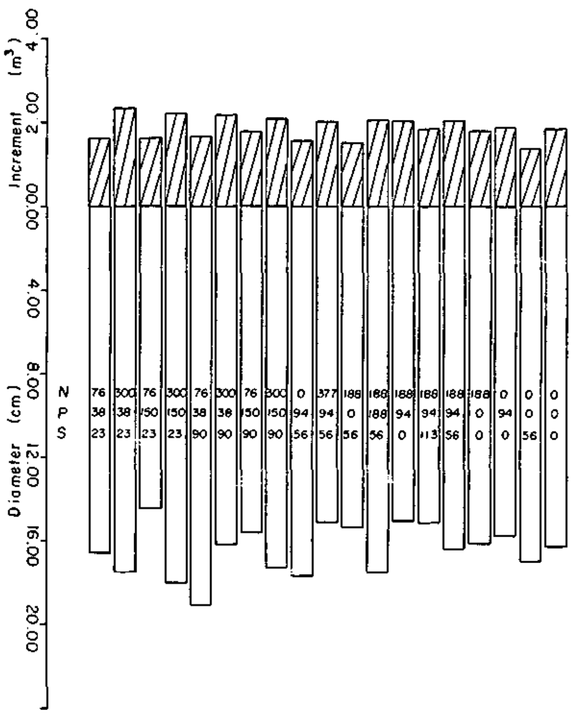

Figure 2.--Tree dbh increments in response to N, P, and S fertilization (kg/ha).

plots, due primarily to a large variation among trees within treatments. As a result of intertree competition in the preharvest, lodgepole pine stand, some of the ten tagged trees became unavoidably suppressed by the others after 10 years of dynamic development. While trees in dominating positions showed substantial increases in dbh growth in response to a fertilizer treatment, the suppressed trees produced little growth.

It is also noted that the periodic dbh increment is significantly poorer in some treatments (*e.g.*, treatments 5, 9, and 23) than that of the control. These plots were treated with medium to high rates of S (0 to 1 level) and mixed with a nil to low (-1.68 to -1) level of N. Luvisol is reportedly deficient in sulfur, nevertheless, the results seem to indicate that, in the absence of N, excessive sulfur could adversely affect the dbh growth in the preharvest lodgepole stand.

Figure 3 illustrates dbh increments in response to five incremental additions of N, P, and S. Apparently, N is required in large quantities for dbh growth because the dbh increment increased with an incremental addition of N in the range tested. The growth response showed quadratic trends to added P with a maximum growth at the 0 level of P (94 kg/ha). On the other

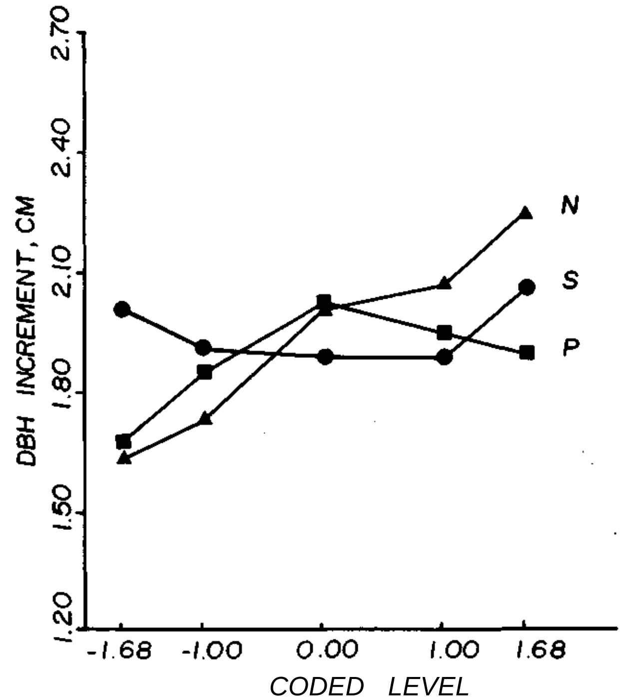

Figure 3.--Periodic dbh growth increment in response to 5 levels of N, P, and S fertilization.

hand, the dbh growth responded negatively to the addition of S to the 1 level; the reduction in dbh growth, however, is not significant.

Individual Tree-Volume Growth

Figure 4 shows the average tree-volume increments and tree volumes for treatments before the application of fertilizers. For dominant or codominant trees in the unfertilized control plots,

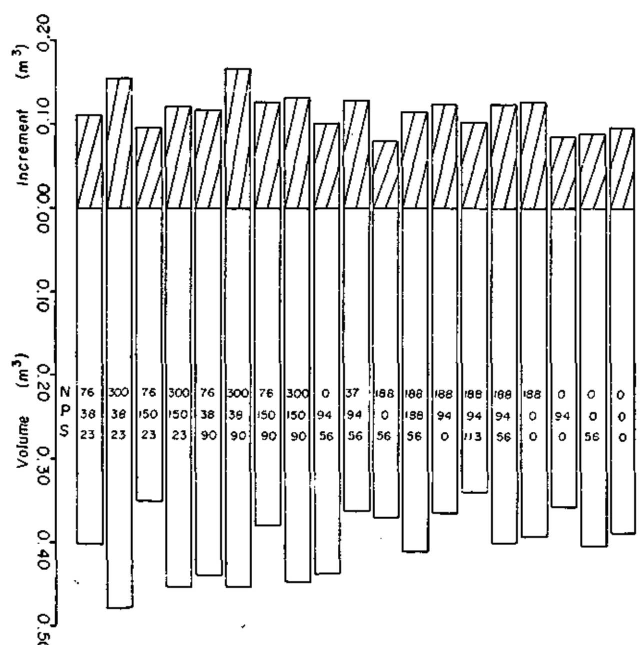

Figure 4.--Periodic tree volume growth in response to N, P, and S fertilization (kg/ha).

volume increment averaged 0.095 m^3 in the 10-year period. The volume increment was improved 28-68% by the fertilizer treatment.

Treatments which showed a considerable periodic volume increment over the control plot are, with one exception, those with an N dosage higher than the 0 level (188 kg/ha). It appears an appreciable increment in individual tree-volume growth requires a sufficient application of N. Table 1 and figure 4 suggest that an optimum gain in the periodic tree-volume growth in the preharvest lodgpole stand is obtained with N:P ratio in the range of 2-8:1 on the Luvisol.

In the absence of N supply, the tree-volume increments seem adversely affected by the addition of either P or S alone or combined. The reduction in the tree-volume growth is statistically not significant, but it indicates that P and S should not be applied to the preharvest stand without a simultaneous application of N.

The volume-increment curves in response to incremental additions of N, P, and S remain essentially similar to those of the dbh increments (fig. 5). While the responses were linear toward added N in the range tested, they were quadratic to added P and S with a maximum increment occurring at the -1 and 1 level for P and S, respectively.

Stand-Growth Increments

The effects of fertilization on stand basal area, total volume, and merchantable-volume increments per hectare are less pronounced compared to those on individual tree-volume growth because of natural variation introduced during the 10-year experiment period. Mortality and, to a lesser degree, in-growth are sources of variation; some pole-size trees were found dead of natural causes in the 10-year period. Because of the variation among plots within treatments, the power of the experiment to detect the fertilization effects on stand growth is markedly reduced.

Periodic stand basal area, total volume, and merchantable-volume increments in the control are 6.49 m^2, 66.01 m^3, and 69.92 m^3 per hectare, respectively. Three fertilizer treatments (treatments 2, 10, and 13) resulted in a significant enhancement in the periodic increments (table 4) over the control. The productivity of the preharvest stands can potentially be improved by 43-49%, 44-54%, and 45-47% for stand basal area, total volume, and merchantable volume increments, respectively, with an application of fertilizer.

The response curves for stand basal area (fig. 6), total volume (fig. 7), and merchantable-volume increments (fig. 8) per hectare are essentially identical: a linear response to added N and a quadratical response to P and S. These response curves are relatively consistent for all five response variables examined.

CONCLUSIONS

Based on the above results and discussion, it can be concluded that the site and stand productivities of preharvest lodgepole pine can be considerably improved by the application of fertilizer. In all tree- and stand-response variables investigated, the periodic increments responded linearly toward the incremental addition of N in the ranges tested and quadratically to the added P and S. An appreciable growth increment can occur only after a sufficient amount of N is applied. The results on the effects of P and S fertilization on the preharvest stand are less conclusive. Further studies of the effects of P and S and how they are interacting with N in lodgepole pine growth in preharvest stands are needed.

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Table 4--Adjusted treatment means of response variables showing 10-year growth increment

Treatment No.	Mean DBH increment[a/] (cm)	Mean volume increment[b/] (m^3)	Basal area increment (m^2/ha)	Total volume increment (m^3/ha)	Merchantable vol. increment (m^3/ha)
1	1.57	0.1101	5.30	57.74	59.20
2	2.15	0.1399**[c/]	9.70*	101.43*	101.61*
3	1.97	0.1058	7.76	79.20	81.74
4	1.93	0.1095	6.86	75.46	78.27
5	1.43*	0.1075	6.51	67.90	69.75
6	2.23	0.1608**	8.62	89.87	87.42
7	1.94	0.1343**	8.77	91.73	95.25
8	1.94	0.1227*	8.16	83.70	85.21
9	1.33*	0.0913	6.88	70.73	70.18
10	2.26	0.1394**	9.29*	99.73	102.51*
11	1.70	0.0831	6.36	63.41	65.27
12	1.88	0.1134	7.39	77.31	79.30
13	2.29	0.1338*	9.28*	94.84*	92.75
14	2.07	0.1174	6.67	71.24	76.57
15-20	2.05	0.1246**	7.81	82.01	83.81
21	1.84	0.1281**	6.46	70.06	70.29
22	2.01	0.0919	6.38	68.92	73.14
23	1.29*	0.0835	5.46	57.42	59.94
24	1.89	0.0955	6.49	66.01	69.92

[a/] Based on ten tagged trees per plot;
[b/] Based on three felled dominant or codominant trees;
[c/] **Treatment means significantly different from the control at the 1% level; * at the 5% level.

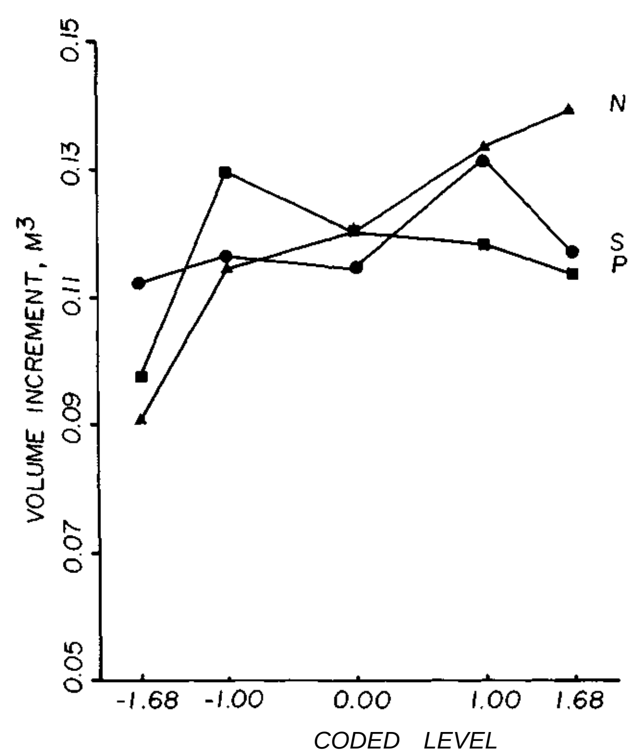

Figure 5.--Periodic tree volume growth increments in response to 5 levels of N, P, and S fertilization.

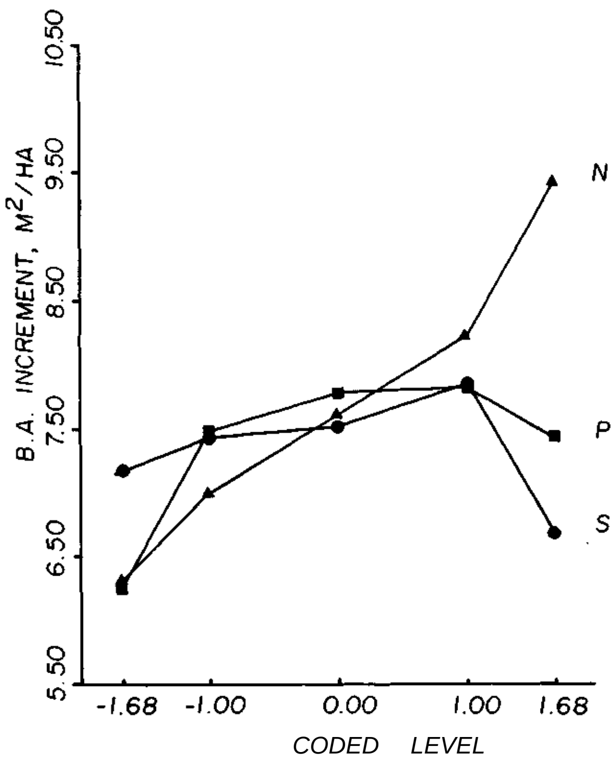

Figure 6.--Periodic basal area growth in response to 5 levels of N, P, and S fertilization.

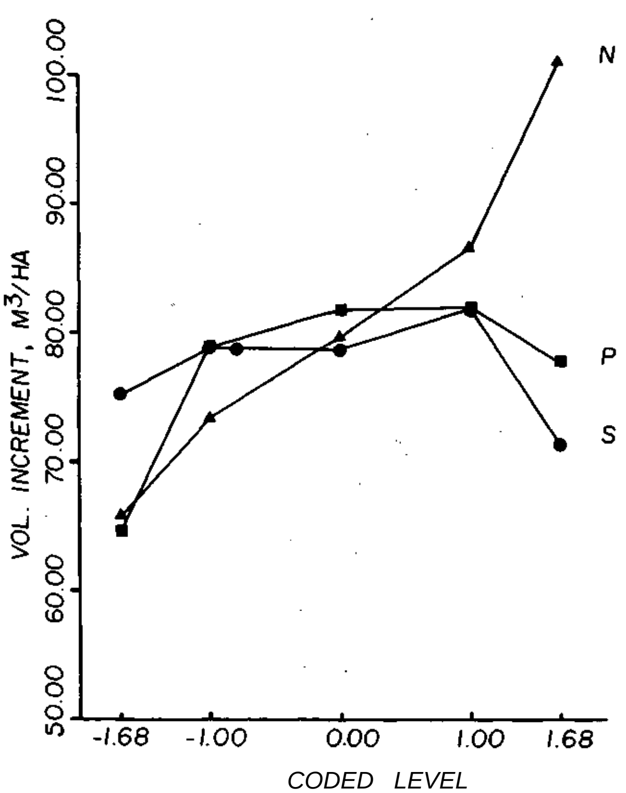

Figure 7.--Periodic total volume growth in response to 5 levels of N, P, and S fertilization.

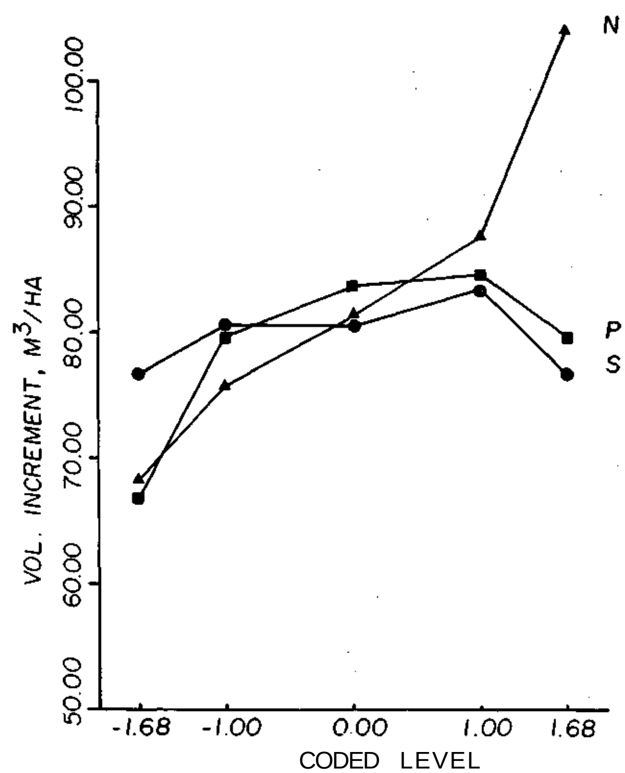

Figure 8.--Periodic merchantable volume growth in response to 5 levels of N, P, and S fertilization.

DEVELOPMENT OF GENETICALLY IMPROVED STRAINS OF
LODGEPOLE PINE SEED FOR REFORESTATION IN ALBERTA

Narinder K. Dhir

INTRODUCTION

Lodgepole pine is the second most important reforestation species in Alberta. It occupies about 15 percent of the forested area in the province and accounts for approximately 35 percent of the merchantable timber inventory (McDougall 1975). Currently, approximately 6 million lodgepole pine seedlings are produced each year for forest plantings in Alberta, and this figure is expected to rise to about 10 million by 1985.

The Alberta Forest Service initiated work on genetic improvement of lodgepole pine in 1976 as part of a comprehensive forest-genetics and tree-improvement research and development program. The objective is to develop genetically superior strains of this species through selection and breeding, and to produce improved seed for production of nursery planting stock for reforestation in selected regions. The traits to be improved were specified as follows:

a. adaptability and hardiness
b. height and diameter growth
c. stem form and taper
d. crown and branching characteristics
e. wood quality
f. resistance to western gall rust.

PROGRAM STRUCTURE

The most important commercial forests of lodgepole pine are found in west central Alberta. It was decided that work on genetic improvement of this species would be confined to this region, which accounts for nearly 90 percent of all lodgepole pine reforestation plantings in Alberta. For technical planning and organizing program work, the region was subdivided into four breeding regions (fig. 1), taking into consideration pertinent physiographic data, administrative boundaries of forest districts, and lease areas of various forest industries. Each breeding region is covered by a separate genetic-improvement project and serves as a target area within which promising source materials are selected and tested to develop genetically superior

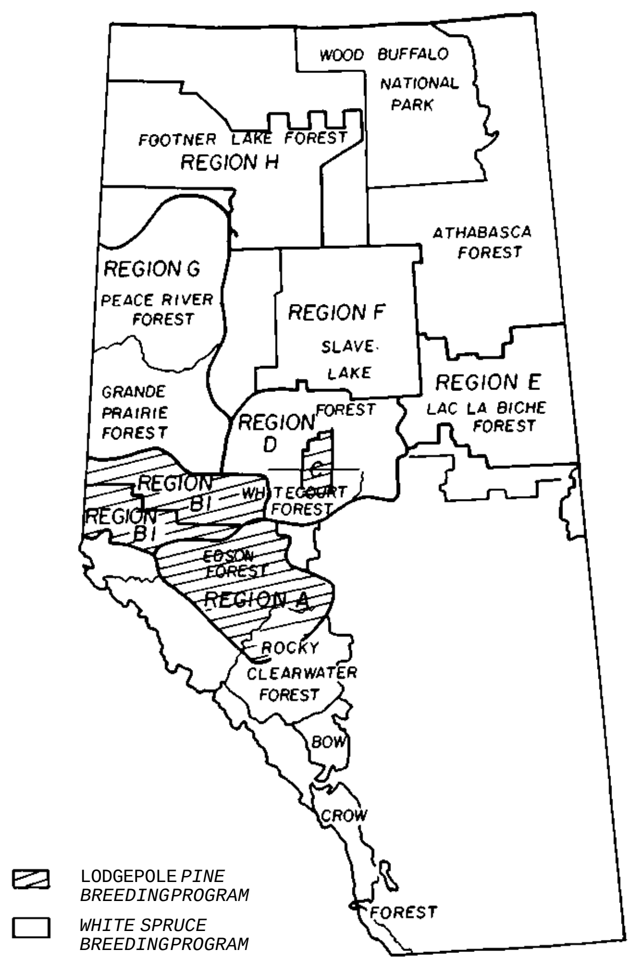

Figure 1.--Forests and tree breeding regions of Alberta.

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strain(s) of seed which is presumed to be prescribed for reforestation only within that region.

The Alberta Forest Service is the primary agency responsible for genetic-improvement projects and related research and development in the province. The work is done jointly with forest industries on a cost- and work-shared basis. The industries participating in lodgepole pine improvement projects are:

Blue Ridge Lumber (1981) Ltd.
British Columbia Forest Products Ltd.
Canadian Forest Products Ltd.
Procter and Gamble Cellulose Ltd.
St. Regis (Alberta Ltd.

The work is already in progress on genetic-improvement projects for breeding regions Bl, B2, and C. Work on the breeding region A project is scheduled to start in 1985.

BREEDING SCHEME

The work of a genetic-improvement project is carried out following a breeding scheme which defines strategy for realizing genetic gain through selection and breeding; the work is advanced through succeeding generations. The breeding scheme chosen for lodgepole pine improvement projects for regions Bl, B2, and C is diagramatically illustrated in figure 2. It defines the general course of the program for the first three cycles of genetic improvement. Briefly, it is described as follows:

1. Building selection population by propagating (through seed and/or scions) desirable individual trees (mass selection) located in natural stands (base population). Selection population is defined as the population on which selection is to be practiced.
2. The first cycle of improvement follows a breeding procedure referred to as *half-sib family selection.* It consists of building a selection population which consists of a collection of individual single-tree (open pollinated) seedlots. These seedlots are tested in field trials to identify a set of best seedlots. The best seedlots are retained in already established seed orchard plantations by roguing other materials. The group of trees produced by each single-tree seedlot is called a half-sib family in which individual trees are related by having a common female parent. A part of the observed variability in field performance of half-sib families is attributed to genetic causes. Therefore, superior performances of selected half-sib families retained in a seed-orchard plantation is inherited, and is fixed and capitalized upon in order to produce genetically improved seed.
3. The breeding scheme for its second cycle of improvement depends on half-sib family and half-sib progeny testing. Selection population for this cycle is partly derived from the best breeding stock identified in the screening process of the first cycle. In addition, new germplasm, derived by cross breeding a new set of parents identified to have high breeding value, is brought in to broaden the genetic base in order to sustain an appropriately high level of selection intensity.
4. The third cycle of selection and breeding is based on full-sib family selection, with selection population to be developed through appropriate mating designs employing controlled crossing of more promising breeding stock identified earlier.
5. Selection procedure, selection units (individual trees, families, etc), selection criteria, and selection intensity vary at different stages of the project. Initial emphasis of selection (mass selection in wild stands) is on selecting best trees following use of a subjective criterion (independent culling levels) which establishes sufficiently rigorous acceptance standards for various traits which a selected tree must possess. Most attention at this stage is placed on traits like form, crown, and branching characteristics. At later stages, selection is to be based on traits like height and diameter growth, wood density, and stability of performance through an objectively determined numerical score (selection index) calculated to reflect correct genetic merit of all these traits.

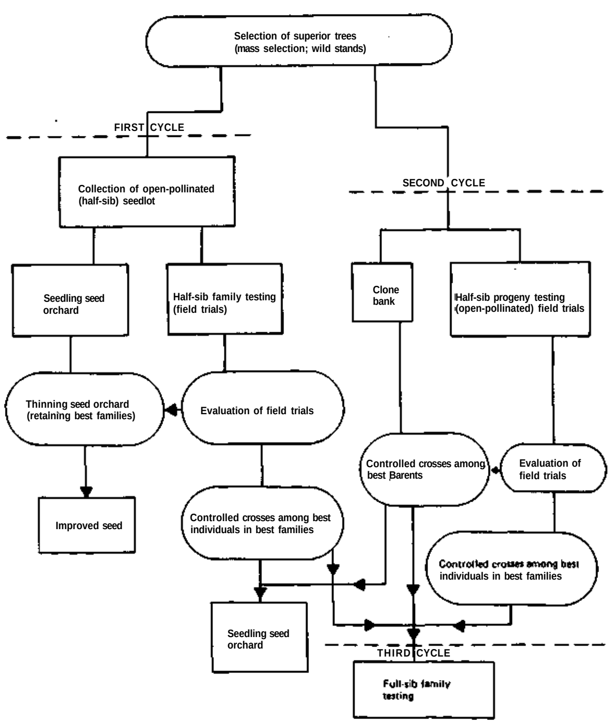

Figure 2.-Generalized illustration of breeding scheme.

CURRENT STATUS AND PROGRESS

The program for genetic improvement of lodgepole pine in Alberta is currently in its seventh year. Considerable progress has been made even though (considering the long-term nature of the program) most of the work can be characterized to be either in the planning or very early stages. A start has been made on the first cycle of genetic improvement of breeding regions Bl, B2, and C projects. Progress on these to date is described below.

Breeding Region Bl

This region contains 14,800 km^2 and covers parts of Grande Prairie and Whitecourt Forests, plains and lower foothills areas located in the general elevation range of 800 to 1,200 m. The work is done cooperatively with.B.C. Forest Products Ltd., Canadian Forest Products Ltd., and Procter and Gamble Cellulose Ltd.

The field work for selection of superior trees in the breeding region was started in 1976 and completed in 1978. The work was done jointly by all cooperators and a total of 324 selections were made by cruising forest stands located throughout the region. Selection intensity for field selection of superior trees was arbitrarily estimated to be at least 1:500. Qualifying criteria required that selected trees primarily possess: a) very good to excellent stem form; b) relatively low taper and superior natural pruning characteristics; c) desirable crown and branching characteristics; d) height superior to any dominant tree growing within a 300-m radius; e) freedom from any apparent disease, defect, or spiral grains. Cones were collected from each selected tree to provide a collection of 324 seedlots. An additional 76 seedlots collected from selected trees in the adjacent breeding region B2 were added to this collection to provide 400 seedlots for establishing half-sib family field trials and a seed orchard.

Half-sib family field trials were established in 1981 on four test sites (spread throughout the region) to determine field performance and genetic worth of individual seedlots for production of commercial seed in a seed orchard. The outplantings were done using 1-year-old container stock. The experimental design used was "blocks in reps design" which is a special case of randomized complete block design. The field design consisted of five replications per site and 4-tree row plots. The field trials will be evaluated at 5-year intervals starting in the fall of 1989 (10 years of age) to accumulate data on survival, height, and dbh. Data on wood density and fibre length will be recorded at 10-year intervals starting in the fall of 1999 (age 20). The families will be evaluated for resistance to western gall rust *(Endocronartium harknessii)* through artificial inoculation of seedling material in separate greenhouse/nursery experiments.

A farm site near Grande Prairie was recently purchased for establishing a seed orchard. The orchard will be jointly established and managed by the three cooperating forest industries, and the seed produced will be shared among the tree industries and the Alberta Forest Service. The planting of the seed orchard is expected to be completed in 1986. All 400 families will be initially outplanted in "blocks in reps design" complementary to the experimental design used in the half-sib family field trials where families are grouped into twenty-five independent sets of sixteen families each. Each set of sixteen families will be outplanted as a 4 x 4 block of single-tree family plots at 1.5 m s 1.5 m spacing. The orchard will be progressivley thinned based on 10-, 15-, and 20-year results from half-sib family field trials in such a manner that, respectively, 4, 2, and 1 trees corresponding to the best families are retained in each 16-tree block. It is expected that after the completion of the second thinning in 1995 (based on 15 years of results from field trials), the orchard will be at a development stage where commercial collection of cones can start to provide the first crop of genetically improved seed for reforestation in 1997.

Breeding Region B2

This region contains 12,200 km^2 covering the montane and upper foothills areas of parts of Edson and Grande Prairie Forests; the general elevation range is 1,200 to 1,600 m. The work is being done cooperatively with B.C. Forest Products Ltd. and Procter and Gamble Cellulose Ltd.

The field work for selection of superior trees was completed during the 1978 and 1979. A total of 428 selections were made. Plans for establishment of half-sib family field trials and a seed orchard are expected to be finalized in the near future.

Breeding Region C

This region contains 5,720 km^2 covering the Swan Hills general area of Whitecourt and Slave Lake Forests which has an elevation range of 1,000 to 1,400 m. The work is being done cooperatively with Blue Ridge Lumber (1981) Ltd.

The field work for selection of superior trees in the breeding region was started in 1977 and completed in 1980. **A** total of 240 selections were made following methods and procedures as described earlier. Four half-sib family field trials were established in 1982 using blocks in reps design, and plans for measurements and evaluation of field trials are similar to those described for region B1. No firm plans have yet been made for establishment of a seed orchard. The orchard will be located near Blue Ridge, and will be established and managed by Blue Ridge Lumber.

LODGEPOLE PINE GENETICS AND RELATED RESEARCH

In order to develop necessary scientific information to aid genetic improvement of lodgepole pine and mass production of improved seed in seed orchards, the Alberta Forest Service has started several research studies (Dhir et al. 1980; Schilf et al. 1982). The purpose of this work is to develop information on the Alberta lodgepole pine population with regard to genetic variability, inheritance, and genetic relationships of traits of importance in applied breeding. Several studies on early induction of flowering and enhancing cone and seed production using physiological and cultural treatments are also in progress.

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SEED PRODUCTION IN SEROTINOUS CONES OF LODGEPOLE PINE

A.K. Hellum

INTRODUCTION

Lodgepole pine *(Pinus contorta* Dougl. var. *latifolia* Engelm'.)is a steady (Crossley 1956) and heavy cone producer (Clements 1910, Bates '1930). Mature trees commonly bear hundreds of cones at a time. Reforestation after fire (Tower 1909) and site preparation (Crossley 1976, Lotan 1975) often leads to establishment of dense stands (Johnstone 1981, Smithers 1961).

It was the purpose of this study to demonstrate that not only is lodgepole pine a light cone producer, but that cone morphology precludes efficient seed production even in the few cones which are formed.

The only reason that lodgepole pine regenerates itself so densely after disturbances is its particular reproductive strategy which gives the species a momentary advantage of heavy cone and seed retention. Or is it a disadvantage?

METHODS

Data were assembled from a number of sources to establish the general relationship between tree age and size of cone crop in lodgepole pine (Clements 1910; Crossley 1956; Hellum and Barker 1981; Lotan 1967, 1968).

Because cones are retained on the tree for a number of years before they drop off, data were also analyzed to determine the rate of cone loss over time from standing trees (Crossley 1956, Hellum and Barker 1981, and unpublished data). Cone production was expressed as an annual percentage of the total cone crop on five trees on each of four sites in Alberta, two at 51°N (Crossley 1956) and two at 53°45'N (Hellum and Barker 1981).

The serotinous cone crop data and the cone loss data were then combined to calculate the total rate of cone production for a stand over 100 years of cone production, or until age 117 years.

Nonserotinous cones were excluded from these considerations because their seeds are shed as they mature and do not, as a rule, contribute much to stand stocking and bear no relation to stand origin after fire or logging.

The two stands at 53°45'N, near Hinton, (Hellum and Barker 1981) were analyzed further to evaluate:
a) total seed production by cone
b) total seed production by tree and stand and
c) seed retention in the cone even after vigorous attempts at seed extraction.

Five cones from each of the cones aged 3, 7, 11, 15, 19, 23, and 27 years (or as many of these ages of which there were representative cones present on individual trees) were "cracked open" at 180°C for 2 min. and then set into gravity-vented kilns at 60°C for **24** hours. They were subsequently tapped, 'tips down, against a table top fifteen times to release "all" seed, The cones were then picked apart by hand to yield the retained seed. A total of 238 cones were used for this test of total seed production and seed retention, representing five trees from each of two stands 110 years old.

An additional 70 cones from three trees (nos. **5**, 9, and 10) were picked apart to determine where the seed was held in the cone.

Photos were taken of a number of cones, split lengthwise, both in a wet and dry condition, to show different bending moments and scale types in different parts of the cone.

RESULTS

Cone production

About fives cones per tree accrue each year for 100 years. This relationships ($r^2 = 0.67$) could undoubtedly be improved upon

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Table 1--Total crop of closed cones on five trees in each of four stands of lodgepole pine in Alberta based on data from Crossley (1956). Helium and Barker (1981) and unpublished data.

Stand Notations	Tree	Total closed cones/tree	Percent of total crop
Stand at 51°N, open-grown trees, 61 years old on average (Crossley 1956)	1	12	2
	2	27	3
	3	1,102	55
	4	534	99
	5	183	98
	Average	372	51.4
51°N, closed canopy stand 69 years old on average (Crossley 1956)	6	221	76
	7	47	38
	8	116	25
	9	80	20
	10	376	94
	Average	168	50.6
5 3°45'N closed stand, flat, 110 years old (Helium and Barker 1981, in part)	1	721	94
	2	678	94
	3	241	100
	4	331	100
	5	598	100
	Average	514	97.6
53°45'N closed stand, N-facing, 100 years old, (Helium and Barker 1981)	6	540	75
	7	360	*96*
	8	352	70
	9	291	89
	10	160	90
	Average	341	84.0

by segregating stand data by stem density (table 1) and geographic origin (fig. 1), as well as by using many more observations than those available for this statement.

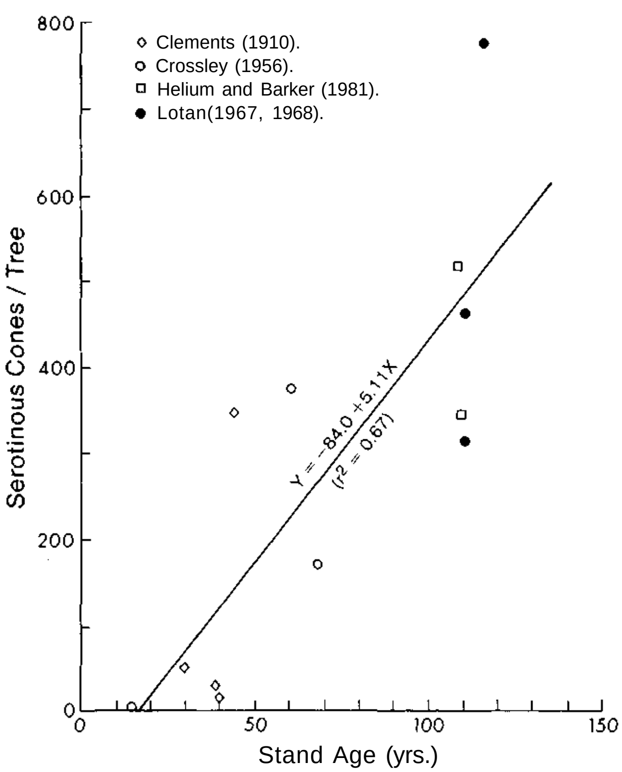

Figure 1. --Correlation between stand age and the number of serotinous cones retained by an average lodgepole pine tree.

The species produces closed cones every year without showing marked signs of heavy or light cone years. Individual trees can produce over 200 cones in a given year, but quantities less than 30 cones/year/tree are much more common even at full tree maturity.

The average cone stays on the tree for about 15 years and hardly any cones remain on a tree for more than 30 years, (figs. 2 and 3). Neither site productivity nor stand age, site aspect, or stand density seem to alter this linear trend of cone loss. Squirrel feeding does not alter this trend either, because the feeding is confined exclusively to new cones.

This means that about 3% of the cones on a tree fall off each year. Combining the data from figure 1 and figures 2 and 3, assuming a net annual eone accretion of 5 cones and a net annual loss of 3%, figure 4 indicates that a tree 117 years old

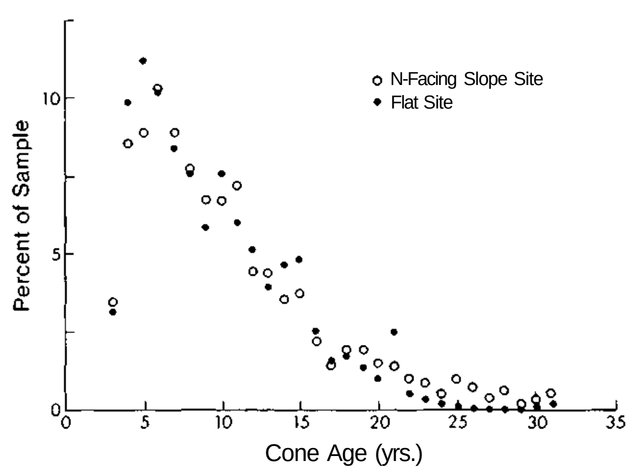

Figure 2. --Correlation between cone age on the tree and the number of retained cones, expressed as a percentage of all retained serotinous cones. Data represent two stands of lodgepole pine at 5 3°45'N, near Hinton, Alberta.

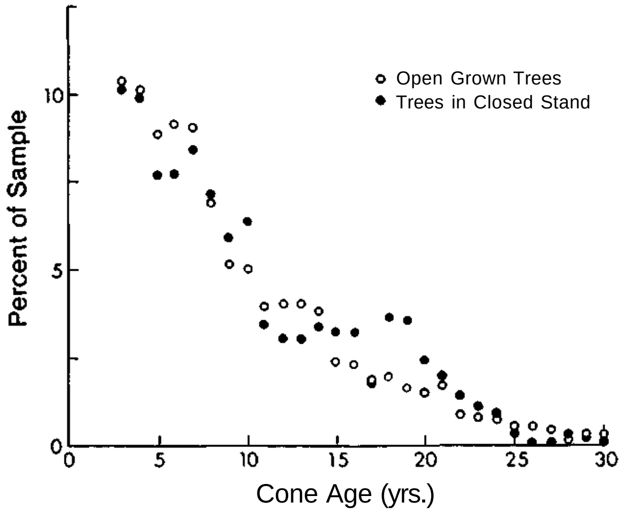

Figure 3. --Correlation between cone age on the tree and the number of retained cones, expressed as a percentage of all retained serotinous cones. Data represent two stands of lodgepole pine at 51°N, in the Kananaskis Valley, Alberta.

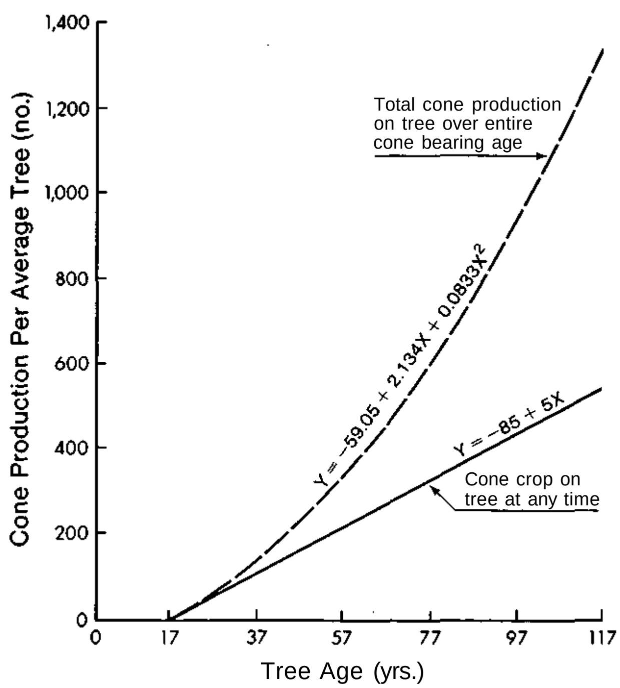

Figure 4. --Correlations between tree age and total retained serotinous cones and total cone production (serotinous) over the entire cone-bearing age of the tree.

could, on average, be expected to have produced 1,333 serotinous cones over 100 years, of which 500 still remain on the tree.

Nearly 38% of all the closed cones ever produced by the average tree over 100 still remain on the tree at harvest time or at 117 years.

Both the stands at 51°N (60-70 years old) and at 53°45'N (110 years old) produced 10-11% additional cones each year, but the effect on cone accumulation on the tree was reduced to a linear rate of five cones/year because, as more cones were retained year by year, more also fell off.

Seed release

It was reported earlier (Helium 1978) that an average bushel (36.37 1) of lodgepole pine cones might contain 1,487 cones judging by ten bulk samples from the major part of the species range in Alberta.

An average bushel yields 23,500 sound seeds (Krugman and Jenkinson 1974) or 15.8 sound seeds per cone using 1,487 cones per bushel. Yields between 13 and 29 seeds/cone (average 21) have been reported for Alberta based on careful seed extraction techniques (Wang 1978), but 15.1 (Lotan 1967) seeds is probably a good operational average for Alberta as well as Montana.

The 10 trees near Hinton produced from 16 to 33 full seeds/cone and tree (average 24) after cleaning (table 2).

These data suggest that about 35% of the full seed produced by an average cone of lodgepole pine may be retained and may not contribute to stand stocking after disturbances unless the retained seeds germinate within the cone and somehow are able to give rise to successful germinants.

Seed location in the cone

The average lodgepole pine cone appears to have three basic scale types judging by trees 5, 9, and 10 from near Hinton:

1. A basal scale which regularly has (a) a thick apophysis and sharp umbo, (b) comprises between 64 and 72% of the total weight of all cone scales, and (c) numbers between 70 and 115 scales per cone, depending on the tree.
2. A middle scale type which is wide and flat makes up from 20 to 27% of the scale weights and numbers between 17 and 25 scales per cone, depending on the tree.
3. An apical set of scales, bent lengthwise, one scale overlapping the next in closed cones, makes up from 8 to 9% of the scale weights and numbers between 10 and 12 scales per cone.

Category 1 scales appear to be sterile. They are attached to the cone axis by a narrow stem or a somewhat wider base. They are attached to the cone axis from the base of the cone to the point at which the pith section of the axis is at its widest. These

Table 2 --Average seed yield per cone based on five cones each 3, 7, 11, 15, 19 and 23 years old (where available) per tree , for lodgepole pine from 53°45'N near Hinton, Alberta, and average percent empty seed.

Tree No.	Total seed per cone (± 1 SD)	Sample size (cones)	% empty seed (± 1 SD)	Tree No.	Total seed per cone (± 1 SD)	Sample size (cones)	% empty seed (± 1 SD)
1	20.3 ± 4.2 .	18	19.6 ±19.6	6	36.0 ± 12.6	30	28.3 ± 18.7
2	31.1 ±15.3	25	21.8±12.6	7	31.4 ±.9.3	20	19.5 ± 9.8
3	28.0 ±15.9	20	25.9 ±18.6	8	30.1 ± 6.2	35	38.3 ± 38.6
4	35.4 ±11.2	20	10.0 ± 7.6	9	29.8 ±11.9	25	43.7 ±13.6
5	27.8 ±11.3	25	14.4 ±13.9	10	42.2 ± 12.2	20	22.8 ± *6.9*

. Grand average full seed/cone: 23.6
Grand average total seed/cone: 31.2

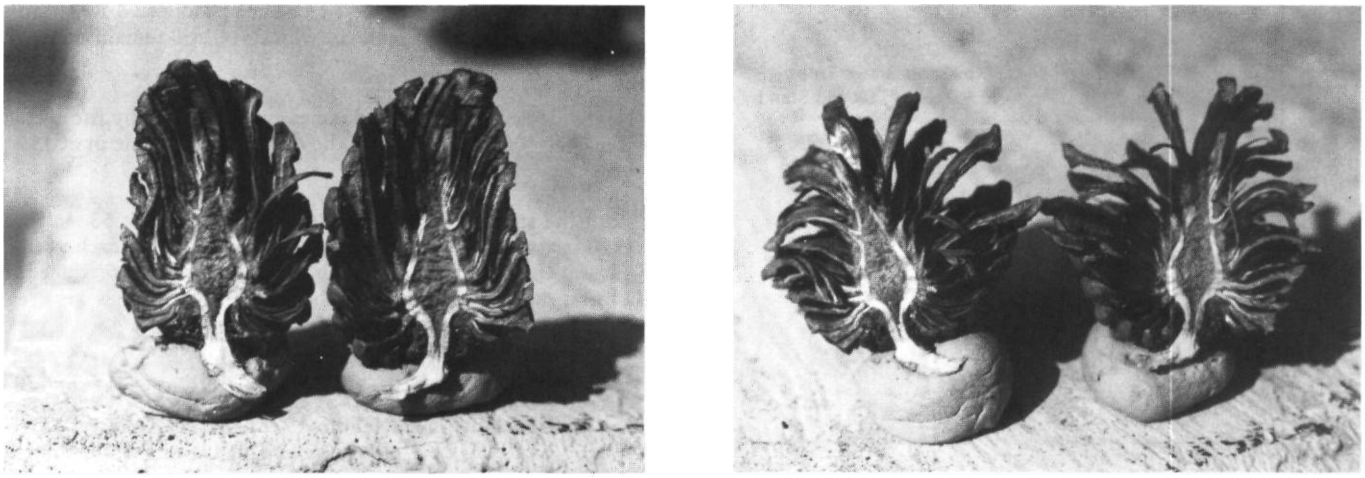

Figure 5.--These photographs show cross sections of lodgepole pine cones before (left) and after (right) opening. Cones of lodgepole pine have three district scale types which flex differently as cones open: a basal scale which bends in an elbow, a middle scale which bends along its entire length, and an apical scale which bends only at its base.

scales flex, during cone opening, by bending in an elbowjoint some distance from the cone axis. The scales are too thick to bend anywhere else (fig. 5). These scales also contain more acetone-extractable materials than the other scale types (Hellum and Loken 1982), thus making them slower to take up water and to flex than more apical scales.

Category 2 scales appear to produce between 75 and 85% of the seeds in the cone with an average of 1.3 to 1.5 seeds per scale, according to the three sample trees and cone ages. These scales flex along their entire length.

Category 3 scales appear to produce the remaining 15 to 25% of the seed with an average of 0.6 to 0.8 seeds per scale, depending on the tree and cone age. These scales flex backwards only from their bases during cone opening. They are folded lengthwise and can not bend anywhere else.

By the above analysis of scales, trees 5, 9, and 10 produced between 59 and 70% of the seeds that could have been produced for the cone ages 3, 7, 11, 15, 19, and 23 (table 2).

Seed production per hectare

The average tree 100 years old on the flat site near Hinton bore 11,601 full seeds in serotinous cones, the sloping site had trees with an average of 7.938 seeds (table 3). At a maximum seed-

Table 3--Total full seed by tree and stand near Hinton, Alberta.

	Tree No.	Total closed cones	Total sound seed/tree
	1	721	11,752
Flat	2	678	16,475
Site	3	241	4,989
	4	331	10,559
	5	598	14,232
	Average		11,601
	6	540	13,932
Sloped	7	360	9,108
Site	8	352	6,547
	9	291	4,889
	10	160	5,216
	Average		7,938

seed-retention rate of 35% in the cone, this still amounts to between 12 and 18 times more seed per fully stocked stand than that needed in Alberta to establish a stand with about 800 stems/ha after logging and site preparation.

DISCUSSION AND CONCLUSIONS

Lodgepole pine trees between 60 and 110 years old produced about 10-11% more cones each year than they retained from past years' production. At the same time, cones drop off at the approximate rate of 3% per year for every year, so virtually no cone remains more than 30 years. Cones fall off the tree because branches die and fall off, cone meristems die, and/or branches grow faster in diameter than cone meristems – thus forcing the cones to drop off.

The net effect of this accretion and loss is that an average tree bears only 5 more cones each year than the year before or about 500 cones after 100 years (serotinous cones only). This is nearly 40% of all the cones ever produced by an average tree.

Even if 500 cones/tree can shed between 12 and 18 times more seed than that needed for optimum stand development after fire or logging (one third of the seed is retained in the cones and cannot easily be extracted), it took the tree 100 years of cone production to accumulate this amount. This surely is not to be considered "heavy cone production."

In addition to such modest annual cone production, this study has shown that the cone of lodgepole pine produces few seeds, or only about one full seed per 4-5 scales because three quarters of the average cone is sterile.

The tendency of serotinous cones to produce excessive amounts of stored seed at tree maturity, their tendency to produce overstocked stands after disturbances, and the low seed production per cone seem to work in opposite directions regarding optimal species adaptation to site.

Has the species been a much more prolific seed producer in the past as the large sterile part of the cone suggests? Is high seed retention in the cone, even after cone opening, also a sign of cone inefficiency? Both factors certainly help to reduce the potential danger of stand stagnation from overcrowding after disturbance. But, trees can produce enough seed every 4-5 years to regenerate themselves once they reach the age of 22 years or more, and this can therefore lead to serious stand stagnation problems later in the life of the stand because 30-year-old cones contain as many viable seed as new ones (Wang 1978).

Lodgepole pine may also have adapted its seed and cone production to accidental fires occurring soon enough to prevent overstocking and stagnation. At an average stand age of 67 years (Day 1972), or 77 years today in Alberta's southern foothills of Rocky Mountains, the average tree has six to nine times more seed (or 8.5 to 11.5 times more in a 77-year-old stand) than that needed for regeneration. This could mean that cone serotiny is poorly matched to current fire history (Givnish 1982, Perry and Lotan 1979) especially in Alberta.

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SITE PREPARATION FOR NATURAL AND ARTIFICIAL REGENERATION OF LODGEPOLE PINE IN ALBERTA

S.I. Ferdinand

INTRODUCTION

Lodgepole pine is one of the most valuable commercial trees in Alberta. It is the dominant forest tree along the foothills and the east slopes of the Rocky Mountains. Its range extends from the Canada-U.S. border in the south to 56° latitude north. Small, remote populations can be found further north but these are of limited economic value. By area, lodgepole pine types occupy approximately 3.37 million hectares, which represent 40.0 per cent of the coniferous forests and 22.3 per cent of the total productive forest land.

Approximately 70 per cent of the allowable annual cut in lodgepole pine has been committed to the wood-processing industries to date. The area harvested annually varies between 7,000 and 10,000 hectares. Harvesting is carried out in clear-cut patches, ranging between 16 and 80 ha in size.

In Alberta, all forest land is owned by the province. However, wood-harvesting rights are granted to members of the wood-processing industry through long-term (20-year, renewable) Forest Management Agreements, long-term Timber Quotas, and through short-term (mas. 1 year) timber permits. Regardless of the type of tenure, the forest industry is directly responsible for the cost of reforestation. However, quota holders can elect to transfer the actual reforestation work to the Alberta Forest Service through payment of a reforestation levy. Thus both the Alberta Forest Service and members of the forest industry are actively engaged in reforestation of logged areas.

The reader should note that this report is intended to be a statement on operational practices presently employed in regenerating lodgepole pine. Most of the presentation is based on the personal observation and experience of the writer and on statistical data compiled by the Alberta Forest Service.

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REFORESTATION POLICY AND STANDARDS

Both the reforestation policy and standards are supported by legislation and are applied to permanent forest land. A summary of each is presented here in order to provide the reader with a frame of reference for scarification.

Reforestation Policy

a. All cutover forest land must be satisfactorily regenerated within 10 years after harvest.
b. Artificial reforestation treatment, where required, must be completed within 2 pears following harvest.
c. Reforestation success must be measured through a standardized regeneration stocking survey by the end of the 7th year following harvest.
d. Unsatisfactorily stocked areas identified by the survey must be retreated in the 8th year and resurveyed 3 years after treatment.

Reforestation Standards

a. All cutovers must be restocked with a minimum of 800 evenly distributed, established seedling trees per hectare of specified species, age, and quality.
b. Acceptable species include all native conifers with some limitation on alpine/balsam fir and hardwood on the coniferous regeneration sites.
c. Minimum age for established seedling trees: 2 years for pines, 3 years for all other species, and 3 years on site for all planted stock.
d. Satisfactorily restocked cutover blocks cannot contain understocked areas larger than 4 hectares.

REFORESTATION STRATEGY FOR LODGEPOLE PINE

The strategy adopted in Alberta for regenerating lodgepole pine includes, to the greatest degree possible, the utilization of the usually abundant seed supply in the cone-bearing logging slash and tree tops through scarification. This strategy was adopted at the time the compulsory reforestation policy was introduced (1955-1966) and is still in widespread use today. Consequently, site-preparation techniques that allow the utilization of the natural seed source were developed and are favored in operational reforestation. Planting is used only on those areas where satisfactory stocking was not obtained following scarification, or where scarification was not done for some reason. This strategy has served us rather well in meeting the stated reforestation objectives. Only relatively recently are some of the shortcomings, such as limited control over density and distribution of regeneration, being recognized.

As forest management develops and is intensified, a new reforestation strategy will probably replace the existing one. In the next step, a much greater reliance on stand establishment by planting is envisaged. In this phase, preference will be given to techniques that will limit and discourage seedling establishment from the slash-borne seed source and will accomodate large-scale planting operations.

Although the benefits of stand establishment by planting can be recognized readily on the theoretical level, in practice the advantages may not be so clear-cut. In 1982, stand establishment by site preparation and planting cost between 2.4 to 3.0 times (240-300 per cent) than that by scarification and the natural seed source. The advantages in increased growth and yield and in the value of the end product will have to be significant in order to offset the differences in initial investment. In spite of the cost difference, a large increase in planting of lodgepole pine is expected to take place when genetically improved seed becomes available, in or about 1997. It is expected that, until that time, large-scale planting of pine will be more a topic of discussion than action. Presently, only 10-20 per cent of the pine cutovers are regenerated by planting. The bulk (80-90 per cent) are regenerated by scarification and natural seeding.

THE ROLE OF SITE PREPARATION IN REFORESTATION

The term *site preparation* is applied to activities that are conscientiously designed to modify forest site conditions in order to make them more favorable for seedling establishment and growth. On the operational level, site preparation in Alberta is synonymous with mechanical scarification. Controlled burning has not been used here for site preparation to any significant degree.

In common usage, scarification denotes the disturbance (modification) of the forest floor, sometimes during but generally after harvesting by mechanical means to various degrees and depth. It can mean intermittent or continuous disturbance of the duff layer alone, total removal of the duff and logging debris, mixing of the duff and humus with mineral soil thus combining the "A" and "B" soil horizons.

The purpose of scarification is the creation of a favorable environment for the establishment and continued growth of the germinating seed and planted seedling. If done with care and with a thorough understanding of the factors affecting growth, scarification can accomplish the stated objective by allowing warming of the generally cold soils; by improving the water, oxygen and nutrient leveles in the soil; and by lessening competition from unwanted vegetation, thereby providing the aerial part of trees with more favorable light and temperature regimes. While this statement is correct in general terms, quite often not all of the growth factors can be optimized or even improved with scarification. On some sites, one factor may be improved at the expense of another. Consequently, the actual scarification should be and, in most cases, is preceded by a detailed site evaluation.

The pretreatment site evaluation is known by a number of different names such as: Post-Harvest Surveys (P.H.S.) or Management Opportunity Surveys (M.O.S.). The process and degree of sophistication may vary from one district to another or from one organization to another, but the primary objective of each unit is the identification of the biologically and economically most efficient reforestation method. All take into account the most important site parameters, the availability of reproductive material (seed), and the physical limitations of specific scarification equipment. The final result of the post-harvest survey is a site-specific treatment prescription.

SITE PREPARATION FOR NATURAL REGENERATION OF LODGEPOLE PINE

The opportunity to utilize the seed stored in logging slash was recognized at about the same time formal forest management was adopted in Alberta (1955-1966). Crossley (1956) and Ackerman (1962) established the basic relationship between scarification and natural seeding of pine. Operational foresters quickly adopted these principles and applied them to practical reforestation. After a short period of experimentation with equipment and techniques, the anchor-chain drag scarifier was adopted for general use.

The anchor-chain drag is a relatively simple piece of equipment. It is comprised of three to seven pieces of heavy, stud-link, anchor chain, each approximately 6.0-7.5 m long. Opposite the stud on each link, one D8/D9-class crawler-track pin (used) is welded. These pins are approximately 25-30 cm long and 50-57 mm in diameter and project out at 90° from the chains. The individual chains are then attached to a sturdy spreader bar at 0.75- to 1.0-m intervals thus forming a flexible, spiked, harrow-type unit. The largest drags in use by the Alberta Forest Service weigh approximately 6.5 tons and need D7- to D8-class crawlers for towing. The smaller drags (3 to 4 chains wide) are usually towed by D6-class crawlers. Drag scarification is the treatment of choice on all accessible, dry to moist, pine cutovers where an adequate seed source exists.

When properly used, drag scarifiers create a good variety of favorable microsites for seed germination by mixing the duff with mineral soil, by exposing mineral soil, and by removing some of the unwanted competing vegetation that may be present.

The quality objective for drag scarification is:

a. 40 per cent mineral soil exposure (M.S.E.) as measured by the line transect method perpendicular to the direction of travel (of drag), or
b. between 60 and 65 per cent M.S.E. as measured by the milacre-plot method. M.S.E. is satisfactory when 60 per cent of the milacre (0.001 acre) sample plots contain at least 1 ft^2 of exposed mineral soil (in metric measurement, this would correspond to approximately 0.23 m^2 M.S.E. in each 10-m^2 sample plot).

Seed availability from the logging slash is quantified during the post-harvest assessment prior to scarification. The requirements may vary some from one organization to another. The Alberta Forest Service considers the seed supply adequate to achieve 80 per cent stocking on most "dry" sites when a minimum of 25,000 evenly distributed, closed pine cones per hectare are present. On moist sites, more cones per unit area are desirable as the quality of scarification may be below 40 per cent, competing vegetation maybe more abundant, and lower soil-surface and air temperatures may result in reduction in seed release from the serotinous cones.

The anchor-chain scarifier usually does an adequate job on areas with shallcw duff (up to 7.5 cm deep) and light to moderate slash loads (to 50 tons/ha). On areas with deeper duff and heavier slash loads, the prime mover must also be equipped with the special toothed blade or a brush rake-type blade to increase the effectiveness of the chain scarifier. Coverage is contiguous on most areas, meaning 100 per cent of a particular cutover block is scarified whenever possible.

Timing scarification to follow logging, as well as timing it seasonally, can significantly affect the regeneration success. Drag scarification should be completed within 1 year after completion of harvest, preferably during the first summer season after the needles in the logging slash turn brown.

In Alberta, pine cones north of 53° lat. appear to be less serotinous and open more readily than those to the south. Delay in scarification in the northern part may result in seed loss and regeneration failure. In the southern part of the province, scarification may be delayed to the second year following harvest without serious loss of seed or detrimental effects on regeneration.

Presently, between 80 and 90 per cent of the pine cutovers are drag scarified. Only those located on steep terrain (>30 per cent slopes) and inaccessible areas are not scarified.

Regeneration success from drag scarification has been very good to date. Between 80 and 90 per cent of the scarified areas meet the minimum (80 per cent) stocking standard 7 years after harvest. Since only one tree per sample plot is recorded during the stocking surveys, no information on the density of regeneration is collected. Because of the pattern and quality of site preparation and the pattern and quantity of cone distribution, seed cast, and variations in site, regeneration densities significantly exceed the minimum requirement of 800 per hectare (Crossley 1976, Johnstone 1976, Bella 1976) at the 80 per cent stocking level. Densities vary between 2,000 and 40,000 per hectare, with averages falling in the 8,000 to 15,000 range at 10 years of age.

The high densities obtained to date are the result of the technique itself and the "over-kill" approach taken toward drag scarification in the past. In order to be safe, quite often more mineral soil than necessary has been exposed, even on areas with an over-abundant seed supply. Further refinements in the technique are feasible and are being implemented through improvements in quantifying the volume and distribution of the available seed and through adjustments in M.S.E. (by removal or addition of chains as needed). More recently, the anchor-chain drags have been replaced by the "shark-fin" barrel scarifiers in some areas in order to reduce M.S.E. and stand densities.

A number of professional foresters in Alberta are apprehensive about the high regeneration densities, fearing reduced growth through excessive competition and outright stagnation as happens in some fire-origin stands. 1 do not share this concern at this time. While the possibility for overcrowding and stagnation does exist, the probability is believed to be low.

Dense regeneration originating from drag scarification is significantly different from fire-origin stands in at least two aspects. First, these stands start at much lower densities than most fire-origin stands, and, second, the range in the age of the trees is increased. Because of the relatively slow release of seed, ingress up to 11 years is reported by Crossley and Johnstone (1976) following scarification in west-central Alberta. Together with variation in microsites and the genetic variability in the population, these factors will enhance the expression of dominance by potential crop trees and will reduce the probability of stagnation. Perhaps a moderate amount of competition pressure is more beneficial to the developing lodgepole pine stand than is presently recognized.

SITE PREPARATION FOR ARTIFICIAL SEEDING

When and where site conditions are favorable (shallow duff, light to medium slash volume), the drag scarifiers, with or without the brush rake-type blades, are used to scarify for broadcast seeding. The objective in this case is the creation of high M.S.E. and diversity of microsites in both the horizontal and vertical plane. Seeding rates are inversly related to M.S.E. and vary from 70,000 to approximately 250,000 seeds per hectare depending on site conditions and on the natural seed source. Artificial seeding quite often only supplements the natural seed source.

On deep duff sites with heavy slash loads, more-drastic site-preparation techniques are used. These include the various plows (Marttiini; Cazes & Heppner; Craig-Simpson), brush rakes, and dozer blades. The disturbance with these machines is quite extensive, with M.S.E. usually exceeding the 40 per cent standard.

In the past few years, the Alberta Forest Service has experimented with seeding of spot-scarified areas. One of the spot scarifiers (Bracke) imported from Sweden is able to seed on the scarified spots during scarification. The results on a 300-ha area treated in this manner are not encouraging. Two thousand. spots per hectare, each seeded with an average of eight lodgepole pine seeds per spot (75 per cent or more germination capacity) resulted in only 30 per cent stocking. The reasons for failure could not be identified on this project. More work is needed in this area.

SITE PREPARATION FOR PLANTING OF LODGEPOLE PINE

The scarification techniques vary according to site conditions and the type of planting operation. Two types of planting are generally recognized. The first and largest is the fill-in planting, followed by establishment planting.

Fill-in planting is usually required on areas where only partial stocking results from scarification. The most suitable equipment in this instance are the spot scarifers such as the Bracke and the Leno. With the proper prime movers such as rubber-tired skidders, these machines do minimal (15-20 per cent) damage to existing young regeneration, provided its height does not exceed 1.0 m. The scarification results in improvements not only in the microsite but in planting quality and productivity as well. Quite often, the cost of scarification is recovered through reduction in the planting costs.

The spot scarifiers may also be used in site preparation for establishment planting. Typically, the objective is to create between 1,250 and 1,600 plantable spots per hectare. Planting may be carried out with container-grown or conventional, bare-root seedlings. However, none of the spot scarifiers are satisfactory for scarifying areas of very heavy competition from tall grass and shrubs.

The most difficult sites, those with deep duff, heavy slash loads, or those taken over by dense grass and brush, usually require and receive a more intensive scarification than can be accomplished with spot scarifiers. The equipment used in such areas include brush rakes and the various plows mentioned previously. All of these require relatively large crawler-type (D6-D8 class) prime movers. Care must be exercised in their use in order to avoid soil erosion.

Anchor chain drag scarifier.

Toothed blade. **A** companion to the anchor chain drag.

Fifteen-year-old lodgepole pine regeneration. The result of drag scarification and natural seeding.

Lodgepole pine plantation on scarified ground.

SUMMARY

Scarification has played an important role in the regeneration of lodgepole pine in Alberta during the past 20-25 years. It has successfully supplanted the role of wildfires in regenerating pine. Many of the man-made stands are already believed to be superior to those originating from wildfires. Further refinements in scarification techniques are possible and will undoubtedly be made as scarification is expected to be part of lodgepole pine management for a long time to come.

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INSECT AND DISEASE PESTS AND ALLIED PROBLEMS AFFECTING LODGEPOLE PINE IN ALBERTA

W.G.J. lves

INTRODUCTION

Records compiled by the Forest Insect and Disease Survey over a 25-year period (Anon. 1953- 1977) indicate that lodgepole pine, *Pinus contorta* Dougl. var. *latifolia* Engelm., is relatively free of catastrophic insect and disease pests and allied problems along the east slopes of the Rocky Mountains in Alberta. There are a few serious pests, however, and a number of other organisms that cause appreciable localized damage. Some pests are of minor concern only.

Although I shall discuss insects, diseases, and allied problems separately, it should be realized that this is an artificial separation. One often finds individual trees affected by all three types of damage.

1 shall not attempt to describe the life histories or taxonomic characteristics of the pests involved, as these are covered in the literature. Papers by Hopping (1962), Nordin (1962), and Davidson and Prentice (1967) are particularly relevant.

INSECT PESTS

Bark Beetles

The mountain pine beetle, *Dendroctonus ponderosae* Hopk., is one of the most serious forest insects in western Canada at the present time (Cerezke 1981, Van Sickle 1982). Historically, this insect has not been considered a problem in Alberta. The only outbreak reported in this province between 1906 and 1965 consisted of an infestation covering 4000 ha in 1940 along the Bow and Spray rivers (Hopping and Mathers 1945, Powell 1966). Selective cutting and cold weather in January 1943 apparently were responsible for terminating the outbreak.

The above outbreak history, when related to research on the effects of climate on brood development and overwintering survival, led researchers to believe that there was little likelihood of the mountain pine beetle's becoming a problem along the east slope in Alberta, even though areas of moderate hazard extend as far north as Jasper on the British Columbia side of the continental divide (Safranyik et al. 1974, Safranyik 1978). In general terms, the hazard map presented by Safranyik et al. (1974) is probably still fairly meaningful, but there is currently an outbreak in southern Alberta in an area to which they had assigned a very low hazard rating.

The Alberta outbreak was first observed at scattered locations along the east slopes between the United States-Canada border and the Carbondale River in 1977, and probably started in 1976 (Wong and Petty 1978). By 1980 it had expanded and intensified: over 79 km^2 were infested and over one million trees had been killed (Hiratsuka et al. 1981). Extensive sanitation cuttings were undertaken by the Alberta Forest Service in late 1980 and in 1981 in an attempt to limit the spread of the outbreak. These efforts appear to have been partially successful. The outbreak has not been arrested, but the amount of spread and population increase are both less than might otherwise have occurred (Hiratsuka et al. 1982).

We still believe that lodgepole pine stands on the east slopes north of the Trans-Canada Highway should be safe from attack by the mountain pine beetle. A combination of cool summers and unfavorable winters is believed to be a sufficient climatic barrier to prevent the build-up of populations. In light of the experience in southern Alberta, however, it is impossible to state categorically that an outbreak will not occur. Sources of infection may develop to the west of the Continental Divide, and these could conceivably initiate outbreaks on the east slopes, provided that suitable climatic conditions (hot summers and favorable winters) occurred simultaneously in both areas.

Several other species of bark beetles attack lodgepole pine, but these are usually of minor importance in Alberta. l'he lodgepole pine beetle, *Dendroctonus murrayanae* Hopk., sometimes kills trees weakened by fire or the climatic damage known as "red belt." Many of these trees might recover without the beetle attacks. The pine engraver, *Ips pini* (Say), occasionally kills healthy lodgepole pine when beetle populations reach large numbers on slash or other suitable material (Bright 1976, Furniss and Carolin 1977). Usually, however, the insects seem

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to attack only trees that have been weakened by drought or some other cause. Other *Ips* species breed on lodgepole pine slash, but rarely cause a problem with living trees.

Woodborers

A number of woodborers in four taxonomic groups (cerambycids, buprestids, scolytids, and siricids) attack standing lodgepole pine and other coniferous tree species after fires, thus shortening the period during which salvage operations may be conducted. In Alberta, a common woodborer is the white-spotted sawyer beetle, *Monochamus scutellatus* (Say). This species can become a problem during logging operations, especially if summer-cut logs are left in decks for prolonged periods following exposure to ovipositing female beetles. Logs cut during early winter are less vulnerable to attack (Raske 1973). The volume loss in logs destined for use as pulp is less than 5% (Prentice and Campbell 1959), but the borer damage is more detrimental in lumber production (Prebble and Gardiner 1958). The damage is particularly important in logs intended for use as power poles because rigid grading standards allow virtually no sawyer holes (Cerezke 1975).

Weevils

A number of weevils cause damage to lodgepole pine in Alberta. Infestations of Warren's collar weevil, *Hylobius warreni* Wood, are widespread at lower elevations in the foothills and in the Cypress Hills. The feeding damage girdles and kills smaller trees and may provide ports of entry for disease organisms on larger trees (Cerezke 1970a). The numbers of weevils were found to be directly related to tree size, stand age, and duff thickness, and inversely related to stand density (Cerezke 1970a, 1970b). The weevil is considered to be an important insect in thinned and planted young pine stands (Hiratsuka et al. 1981).

The lodgepole terminal weevil, *Pissodes terminalis* Hopping, kills the current year's terminal growth on young trees (Drouin et al. 1963), and the white pine weevil, *P. strobi* (Peck), kills the previous year's terminal growth. Attacks by either species may result in multiple leaders and crooked stems (Johnstone 1981), while repeated attacks may cause the formation of "cabbage-topped" trees of little or no value. Neither species seem to have caused much damage in Alberta, but observations in Ontario (Anon. 1961-1972) indicate that the white pine weevil may become a serious problem in widely spaced plantations. The lodgepole pine weevil also prefers open-grown young stands (Drouin et al. 1963, Furniss and Carolin 1977, Stevenson and Petty 1968), so there is a danger that it may become a more serious pest as thinning of young stands becomes more prevalent. The strawberry root weevil, *Otiorhynchus ovatus* L., has caused heavy losses of coniferous seedlings in nursery beds, but this appears to have been an unusual occurrence (Anon. 1967).

Pitch Twig Moth

The northern pitch twig moth, *Petrova albicapitana* (Busck), and the metallic pitch nodule moth, *P. metallica* (Busck), both attack young lodgepole pine in Alberta (Miller 1978). *P. albicapitana* has a 2-year life cycle (Turnock 1953). Feeding by first-year larvae causes little damage, but second-year larvae sometimes kill the terminals. The feeding damage usually causes the formation of crooked and weakened stems. Turnock (1953) considered lodgepole pine to be particularly susceptible to attack by this insect, but little damage has been reported in Alberta (Anon. 1953-1977, Stark 1957). However, a several-fold increase has been observed in mechanically thinned stands in recent years (Sterner and Davidson 1981). Larvae of *P. metallica* feed more on the cortical tissue than on pith and xylem (Miller 1978). Because both insects are pests of young trees, it is conceivable that they may become more important in the future when large areas of young pine become more common.

Defoliators

The lodgepole needle miner, *Eucordylea starki* (Free.), reached outbreak proportions in the 1940s over an area of about 1200 km^2, primarily in Banff and Jasper national parks (Stark 1951). Little mortality is caused even by prolonged attack, but there is a danger that weakened trees may be vulnerable to attack by the mountain pine beetle (Stark 1954). However, the present mountian pine beetle outbreak has occurred in an area not infested by needle miners in recent years. *E. biopes* (Free.) reached moderate to high population levels in the Banff area in 1981 (Hiratsuka et al. 1982).

The jack pine budworm, *Choristoneura pinus pinus* (Free.), and the sugar pine tortris, *C. lambertiana* (Busck), cause top-killing of their hosts. The jack pine budworm is a major pest of jack pine in Manitoba, central Saskatchewan, northwestern Ontario, and the Lake states (Brandt and McDowall 1968, Cerezke 1978, De Boo and Hildahl 1968, Dixon and Benjamin 1963). The sugar pine tortris has caused heavy defoliation of lodgepole pine in Idaho and Montana (McGregor 1970). Neither species has caused damage to lodgepole pine in Alberta.

Neodiprion nanulus contortae (Ross) has been reported in Alberta (Furniss and Carolin 1977), but has not caused any significant damage. Other defoliators attack lodgepole pine but are of minor importance.

DISEASE PESTS

With the esception of foliar diseases, tree diseases fluctuate less from year to year than forest insects. Any fluctuations are more likely to be spatial or of a long-term nature, often related to stand age and history. Consequently, the information on diseases collected by the Forest Insect and Disease Survey (Anon. 1953-1977) tends to reflect the intensity of effort as much as the importance of a particular disease, In total, however, these records provide a reasonably accurate picture of the importance of the various disease organisms, especially when supplemented by information contained in a number of research papers.

Dwarf Mistletoe

Dwarf mistletoe, *Arceuthobium americanum* Nutt. ex Engelm., is a parasitic plant that principally attacks lodgepole and jack pine in Alberta, causing an estimated annual loss of more than 270,000 m^3 (Haranyay 1970). It is considered to be one of the most destructive diseases of lodgepole pine in Alberta, and affects trees of all ages (Nordin 1962). Studies of factors influencing the damage caused by dwarf mistletoe (Baranyay and Safranyik 1970) show that there are no simple relationships, although volume losses in lodgepole pine are affected by site, duration of infection, and age of stand when first infected. Trees infected when young will not reach merchantable size. Heavily infected trees suffer considerable volume loss, particularly in the upper portions of the crown on dry sites, because height growth is reduced. "Witches' brooms" may be small or nonesistent in dense stands, but are quite noticeable on open-grown or thinned stands (Nordin 1962). Attempts to control the disease by repeated sanitation cutting and pruning were unsuccessful (Van Sickle and Weggitz 1978). Complete removal of infested trees before reforestation is probably the only practical solution, and the cut-over areas should be relatively large to minimize the amount of reinfection from the residual stand. Baranyay (1970) indicated that mistletoe infection from one parasitized residual in a stand of young trees could spread more than 45 m in 80 years.

Red Stain and Decay

Red stain is the early stage of decay associated with a number of different fungi (Nordin 1962). Forest Insect and Disease Survey records (Anon. 1953-1977) give little indication of its importance because specialized assessment is required. One study conducted in 85-year-old stands near Nordcgg, Strachan, and Water Valley revealed that more than 80% of 183 trees were infected with red stain fungi (Nordin 1962). A much larger survey in the upper and lower foothills section of the boreal forest in Alberta indicated that 45% of 2436 trees had red stain, while 7% had measurable advanced decay (Robinson-Jet trey and Ionian 1963). Decay was found to be unimportant in stands less than 100 years old (Loman and Paul 1963). In older stands, most of the decay occurred in a few trees and *l-'omcs pun* (Thore) Lloyd was the most important trunk-decaying organism. *Pemophova pseudo-pini* (Weres. and (iibson) was associated only with red stain, while *Coniophora pulcana* (Schum ex Fr.) Karst. was isolated from brown cubical root and butt rot. Other organisms were associated with root and butt rots.

A widespread root rot, *Annillana mellea* (Vahl ex Fr.) Quel., sometimes causes mortality in young lodgepole pine stands (Anon. 1954, Baranyay and Stevenson 1964, Nordin 1962). Older stands are also affected, however, and 31% of the trees in a 73-year-old stand of' lodgepole pine near Flinton were killed by the disease (Anon. 1964).

Atropellis Canker

The cankers caused by the fungus *Atropellis ptmphila* (Weir) Loman and Cash are widespread on lodgepole pine in the foothills area of Alberta, and some stands are heavily infected (Anon. 1960, 1971). Surveys conducted in the Coalspur-Robb area in 1954 and 195 5 (Anon. 1955, 1956) showed that over 70% of the pine were infected in an area covering about 325 km^2. Forty to 70% of the trees in an area of 470 km^2 surrounding the heaviest infection were also infected. Smaller areas of moderately to heavily infected lodgepole pine were noted elsewhere on the east slopes (Anon. 1957). The cankers do not seem to kill the trees very quickly, but they and their associated blue-black stain degrade both pulpvvood and lumber.

Stem Rusts

Several species of stem rusts attack lodgepole pine in Alberta. Most have life cycles involving alternate hosts, but one species can spread from pine to pine (Ziller 1974). Western gail rust, *Endocronartium harknessii* (J.P. Moore) Y. Flirat., has no known alternate host in Alberta, and is "the most common, most conspicuous, and most destructive stem rust of hard pines in western Canada" (Ziller 1974). It is recognized as being "one of the most important disease problems of man-made and man-assisted, young, hard-pine forests" (Hiratsuka et al. 1981). Damage is compounded by rodents and insects (Wong 1972), which frequently feed on the galls. The disease is widely distributed in Alberta (Anon. 1960).

Stalactiform blister rust, *Cronartium coleosporioides* (Arth.), is also widely distributed in Alberta, and moderate to severe infections on lodgepole pine have been reported at a number of' locations (Anon. 195 3-1977). These infections have occasionally caused severe mortality among lodgepole pine saplings. Commandra blister rust, *Cromirthtm commandrae* (Peck), and sweetfern blister rust, *(.'. comptonae* (Arth.), arc both common in Alberta. *(.'. commandrae* occasionally causes serious injury (Anon. 1960, 1965).

Foliar Diseases

A number of organisms cause needle diseases on lodgepole pine (llepting 1971). Several needle cast fungi, particularly *Lophodermella cor/color* (Dearn.) Darker and */.. montivaga* (Petr.), have occasionally caused moderate or severe damage to lodgepole pine foliage at a number of' locations in Alberta (Anon. 1953-1977). The diseases cause foliage discoloration and premature needle drop, but do not affect tree growth unless the infection is unusually severe. Another needle cast disease, *lilytrodcnna dejormans* (Weir) Darker, is known to infect trees systemically and infections survive within the trees, eventually deforming them. The importance of this disease may be underestimated at the present time.

Needle rusts on lodgepole pine are caused by a number of organisms (Hepting 1971), but the western pine-aster rust, *Coleospnrhim asterum* (Diet.) Syd., is the only species reported to cause infections in Alberta (Anon. 1953-1977). It causes only moderate or minor damage (Ziller 1974).

ALLIED PROBLEMS

In addition to insect and disease pests, lodgepole pine trees are adversely affected by a variety of biotic and abiotic environmental factors. I shall not attempt to discuss all of these, because little information on their overall importance is available, but climatic and mammal damage occur so frequently that a brief discussion is warranted.

Climatic Damage

Drought, flooding, spring frosts, and hail all affect lodgepole pine adversely: damage is usually sporadic, although it may occasionally be extensive. Winter injury of lodgepole pine, commonly known as "red belt", is much more common (Anon. 1953-1977). The exact cause is unknown, but it is generally believed to be due to sudden temperature change in late winter or early spring (Robins and Susut 1974). The damage sometimes occurs in belts along hillsides, hence the name "red belt," but it may also occur in irregular patches. Injured trees usually recover, though they may lose much of their foliage. 'There may occasionally be extensive mortality, if the climatic damage is severe. Thousands of hectares of lodgepole pine in the upper foothills were destroyed in this manner in 1971, and more than 5000 ha were killed in the Cadomin area alone (Robins and Susut 1974).

Mammal Damage

Several groups of animals damage forest trees (Johnstone 1981). The snowshoe or varying hare, *Lcpus americamis* (Erxleben), has peaks in populations approximately every 10 years. Extensive damage to stands of young lodgepole pine have often been observed in areas where there is adequate cover for the hares. Normally, small saplings have been considered to be most vulnerable, because the hares clip off saplings up to 2 cm and girdle those larger than this. It was believed that the trees should be relatively immune to further attack if they escaped damage in one hare population cycle (Sullivan 1980). This is not always true, however. Some trees more than 10 cm in diameter at the base have been partially or completely girdled, usually just above the ground level. There is some disagreement among various "experts" as to what animal is causing the damage: some claim that it is attributable to porcupines, while others suggest that it is caused by squirrels. I do not profess to be an expert, but I have seen enough circumstantial evidence to convince me that the damage has been done by snowshoe hares. Some people have actually seen them chewing at the trees, but were unable to photograph the event. The extent of damage during the current peak in hare populations has not been adequately assessed, but it seems to be extensive.

Other mammals also cause damage by girdling or browsing on trees or saplings, but are of relatively minor importance. Porcupines, *Erethizon dorsatum* (L.), sometimes damage groups of trees, and meadow voles, *Microtus pennsylvanicus* (Ord), occasionally cause serious damage to trees in young stands, especially if there is extensive cover (Cayford and Haig 1961). Red squirrels, *Tamiasciurus hudsonicus* (Erxleben), frequently feed on rust galls and, in so doing, they sometimes girdle the stems or branches. They sometimes clip leaders or branches as well. Large game animals occasionally browse the tops of trees in young stands.

DISCUSSION

Lodgepole pine grows faster at a relatively wide spacing, and dense stands respond well to thinning, provided it is done when the trees are relatively young. The amount of thinning has therefore been increasing in recent years, **as** the management of pine stands intensifies. There is no doubt that this practice increases the growth rate if the trees have been too crowded, but unfortunately it is not without a certain amount of risk. Any significant amount of tree mortality between thinning and harvesting may nullify the increased yield that the thinning was intended to achieve, and this mortality can occasionally be appreciable.

Throughout this paper I have noted that there is accumulating evidence that certain organisms seem to be a greater problem in open-grown stands. At the moment, much of the evidence is circumstantial. Future strategy concerning management of young lodgepole pine stands may need to be modified, however, should the trends be corroborated by further observation. Spacing may require modification to achieve some form of compromise that will avoid undue suppression of tree growth without favoring the build-up of pest populations. Adoption of this approach should help to reduce the need for costly pest-suppression measures without seriously affecting ultimate yields.

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LAND-USE CONFLICT IN WEST-CENTRAL ALBERTA, PARTICULARILY WITHIN THE ST. REGIS (ALBERTA) LTD. FOREST MANAGEMENT AREA

Raymond Ranger

INTRODUCTION

St. Regis (Alberta) Ltd., with its manufacturing facilities and head office in Hinton, is the producer of high-quality bleached kraft pulp and, more recently, has entered the field of railroad-tie and kiln-dried stud production.

The government of the province of Alberta is the custodian of our provincial forest resources and, as such, was granted the first management agreement to the company in **1954.** The history of the company's association with the' governmentand the Department of Energy and Natural Resources, has been one of mutual cooperation in the development of a forest-management program suited to the province's particular needs. While details might differ from one government administration to another, the principles underlying a good forest-management program are virtually the same everywhere.

Our formal aggreement with the crown includes three main clauses designed specifically to protect the public's interest in the resource that the company manages as well as provide for overall resource development within the province.

The main context of these clauses are as follows:

1. Our agreement is for intervals of 20 years, with automatic renewals depending upon adequate performance.
2. Multiple use of the land is mandatory but, in this context, it is recognized that the growing of timber is its ***prime*** use.
3. The company is obliged to "Follow sound Forestry practices with the objective of achieving and maintaining a perpetual sustained timber yield from the productive forest land." This means that our yearly harvest of timber shall not exceed that which can be replaced by the annual growth.

The forest-management area is not only an area of prime timber but is also rich in coal deposits and petroleum and natural gas resources. The exploration and development of these reserves contributes greatly to the province's economy, and, while these activities are not without certain irritants to the successful management of the land for timber production, ways must be found to accomodate the nonrenewable-resource industries in their quest to develop these subsurface resources.

Thus, the stage is set for the frequent irritation, reluctant accomodation, or downright continuous conflict which can and does occur when activities involving the use of renewable and nonrenewable resources are allocated equal rights on the same acre of ground.

CONFLICTS

The three more common conflicts that we experience, on a day-to-day basis, are:

a) conflicts associated with coal exploration and development (strip mining),
b) conflicts associated with the exploration and development of oil and natural gas, and
c) conflicts associated with usage and/or disruption to our existing or planned infrastructure.

Coal Exploration and Development

The forest management area, which covers some 2 million acres of wild land on the east slope of the Rocky Mountains, is contained within fixed boundaries; and its harvesting and production operations are restricted by an allowable annual cut which is based on the capacity of its fixed land base to produce or grow timber of a certain species, size, and quality.

Underlying this land base are ribbons of rich coal seams which await development, it would seem, at the whim of foreign markets. Fully one third of our forest management area 'contains coal leases which are-so located and.which contain enough volume to be deemed viable future mining prospects. As such, they are held under lease to be stripmined or developed in the foreseeable future.

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If, in fact, the total or, for that matter, any appreciable amount of these proposed strip mines are developed with a short period of time (and I speak here of a period of, say, one rotation of 80 years), then it is easy to see that a program of sustained yield could not be maintained without a considerable addition of forested lands to augment our forest land base.

In addition to the loss of a considerable amount of land base, the strip mines have an additional adverse effect: their elongated form of development cuts timber operating areas virtually in two, thus dictating that two or more access and haul routes are required where formerly one would do. Further, aboveground overland conveyor belts planned to deliver the coal to major railroad marshalling points again pose considerable logging, roading, and other logistic problems.

Exploration and Development of Oil and Natural Gas

In addition to the rich reserves of coal underlying the forest floor, in the late fifties large amounts of oil were discovered, as well as an even larger quantity of natural gas which is distributed pretty much throughout the entire forest management area. These reserves have been discovered beneath the surface at both the 6-8,000- and 14,000-foot levels, and make up part of the overall reserves that class Alberta as the Oil Capital of Canada.

Subsequently, between the commencement of geophysical activity within the forest management area in the late 1950s and the end of 1981, some 6,600 miles of seismic exploration lines have been established by the petroleum industry, involving over 20,000 acres of timberland. The straight-line nature of these exploration lines ignores land contours, thus making it difficult to salvage any significant amount (1% to 5%) of merchantable timber encountered. The loss of harvestable wood constitutes a significant reduction in the annual amount of wood that is available for use in the company's mills.

Wellsites, access roads, pipelines, etc. (which are linked to the development stage of the oil and gas scenario) have resulted in permanent deletions from the forest management area in the amount of 9,000 acres during the same time.

Only quite recently have agreements been finalized between St. Regis (Alberta) Ltd. and the various oil companies that provide for salvage of a substantial amount of the merchantable timber contained within these permanent deletions. However, there still remain considerable losses in respect to the destruction of immature timber as well as the inherent reduction of our land base.

Possibly the most-important, long-term irritant that the oil and gas development will impose on the forest industry is the segregation of its forest operating units by the hundreds of miles of pipelines. Due to safety hazards and government regulations, these pipelines cannot be traversed by heavy logging or site-preparation equipment. Consequently, each pipeline, whether it be a major export line or a simple gathering line, becomes an effective operational barrier around which the forest manager is forced to work and plan.

Conflicts Associated with the Existing Infrastructure

For administrative purposes, the forest management area is partitioned into five working circles. Each working circle is further divided into several compartments with each compartment accomodating one age class or a group of similar age classes and is of a size which can accomodate harvesting over a 20-year period. These 20-year periods are termed "cutting cycles," thus, there are four cycles in the 80-year rotation under which we manage our forest management area.

The various compartments are further allocated to the four cutting cycles based on the actual age of timber contained within the compartments with the older or senior age classes of declining vigor having immediate priority. Since the first-cycle compartments are widely disseminated over the forest management area, this has meant that, in order to operate these compartments simultaneously, the total primary infrastructure of roads and supportive works had to be developed in the early stages of operations and have subsequently been utilized and maintained throughout the years.

With the concept of shared usage of such roads by other agencies, including the Alberta Forest Service, Department of Highways, and oil and gas companies as well as the general public, it is not difficult to imagine the irritation and incompatabilities that exist. Indeed, the latest surveys conducted on the major roads within our forest management area indicate that 60% of the total usage of these roads is, in fact, attributed to the oil and gas industry.

This type of heavy usage during all weather conditions (oil companies do not generally stop operations due to bad weather) considerably increases the maintenance costs associated with these roads and usually puts the holder of the forest management area in the distasteful position of "badgering" the other users for repair monies. Worse yet, the holder finds that the roads in question are suddenly unusable for its own operations.

As irksome as it may seem, the only other alternative would be to duplicate or parallel the existing extraction routes. This would have a further adverse effect on the forest land base as well as increase the number of operational barriers that now exist due to such things as pipelines, railroads, and high-voltage power lines.

Partial Solutions to the Above Problems

In order to minimize losses and inconveniences to our existing land base and infrastructure, St. Regis (Alberta) Ltd. has taken or is proposing to take the following steps:

1. Create a separate "land-use" section to deal exclusively with other user demands on our forest management area.
2. Implement an improved, land-base information-retrieval system that readily identifies existing **and** proposed infrastructure.
3. Provide supervision and/or manpower to salvage effectively an increasing amount of merchantable timber that would otherwise be lost due to the activities outlined above.

It should be understood however, that these steps will not, in themselves, provide a solution to the threat of the heavy development of nonrenewable resources. It is for this reason that St. Regis (Alberta) Ltd. now finds itself looking to the government of the province of Alberta for replacement lands that will be required for this company to meet its commitment of sustained-yield management and to otherwise remain a responsible, viable entity in its community.

A NEW METHOD FOR IMPROVEMENT OF THE QUALITY OF *PINUS CONTORTA* SEEDS

Milan Simak

INTRODUCTION

The precision sowing methods for production of forest plants, that is, the sowing of single seeds, demand seeds of the highest quality. However, in practice, a quantity of seed often contains, in addition to viable seeds, many that are dead or of low quality. These inferior seeds have to be removed before a precision sowing can be performed. **A** method, the so-called IDS method, for removing filled but dead seeds from a quantity of *Pinus silvestris* seeds was recently presented by Simak (1981). The method is based on the principle that viable seeds, after incubation and subsequent drying, lose absorbed water at a much slower rate than the dead seeds. This causes a distinct differentiation in weight and other physical properties between viable and dead seeds during a particular period of drying. These differences can be used for separation of the two types of seeds (fig. 1). Through removal of dead seeds, one can obtain a quantity of seeds which is virtually 100% germinable.

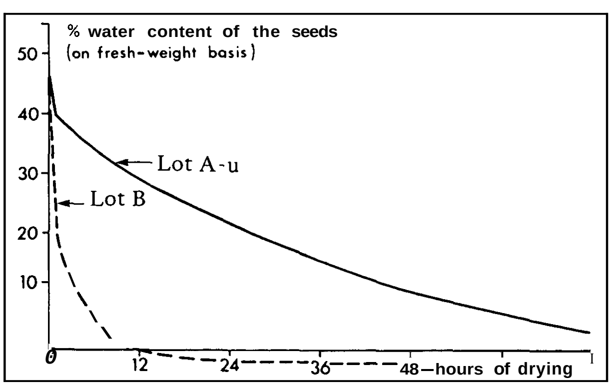

Figure 1.--The IDS principle.

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The IDS method was also successfully applied on *Pinus contorta* seeds in laboratory and greenhouse experiments. Some of these results are presented here.

MATERIALS AND METHODS

The laboratory and greenhouse experiments were carried out with a provenance of *Pinus contorta* seeds used in a reforestation program in Sweden. The low quality of the seeds would prohibit plant production in containers (table 1). Two seed lots of different quality (lot A = nearly all seeds viable, lot B = nearly all seeds dead) were laid out for germination at 15°C. Directly after 3 days incubation both lots contained approximately **45%** water. No visible germination occurred during this incubation step. When the seeds were subsequently dried, the water evaporated faster from seed lot B than from seed lot A. Thus, after about 12 hours of drying, the weight of the seeds in lot **B** decreased to the value which they had prior to incubation (6-7%), whereas the viable seeds in seed lot A still contained approximately 30% water (see fig. 1).

Table 1--Description of the material. The percentage of the dead seeds was determined by a cutting test at the end of germination analysis.

Orig.	Lat.	Elev.	Imported to Sweden	Germination 7 days	Germination 21 days	Dead seeds	Mechan. damage
				----------	%	----------	
Teslin, Canada	60°10'	750m	1978	13	68	29	4

It follows then, that seeds in lots A and B, if mixed together, could be effectively separated from each other, after an incubation period and after about 12 hours drying, by flotation, gravity separation, or other methods. This method for removal of filled but dead seeds from a bulk sample is called the IDS method, according to the three main steps of the process: I = Incubation, D = Drying, **S** = Separation.

The method can be modified for different species. For example, in the case of lodgepole pine, stratification of the seeds can be substituted for incubation (I step). After the stratification process, the seeds should be dried (D step) and separated (S step) according to the description above.

For separation of the seeds, these two alternatives of the IDS method were used and are outlined below:

a) IDS method (about 30g seeds were treated):

Incubation: 3 days between moistened blotters at +15°C, 100%RH, with light.

Drying: 12 hours at +15°C, 35%RH, with light

Separation: Flotation in water. After about 5 minutes the buoyant seeds on the water surface were removed (dead seeds). The seeds on the bottom of the vessel were the viable seeds.

After-drying: After separation, the seeds were dried at +20°C to the moisture-content level which they had before their incubation (6-7%). The dried seeds were stored for several weeks at -5°C before being sown in the greenhouse experiment.

b) IsDS method (about 30g seeds were treated)

Incubation (Is): The seeds were stratified for **30** days at +4°C in a plastic bag. (The index "s" means stratification during the incubation step.)

Drying, separation, and after-drying: The same procedure as in the IDS method above.

The laboratory experiment was carried out on a Jacobsen's germinator at +20°C, 1,000 lux constant, over 21 days. Seeds were used at the rate of 3x100 seeds/treatment. The greenhouse experiment was carried out under conventional conditions for plant production used in Sweden. Seeds were sown in paper-pots with peat at 3x100 seeds/treatment.

RESULTS

In the laboratory experiment, the germinability of the stratified (Is) as well as IDS-treated and IsDS-treated seeds from bottom ("viable") and surface fractions ("dead") was compared with that of the control seeds (fig. 2). Differences between the germination values of the control (C) and treatments were tested by a t-test.

In the greenhouse experiment, the germinability of the control seeds was compared with that of the stratified and IsDS-treated seeds (fig. 3).

DISCUSSION

The experiments carried out in laboratory and greenhouse show that it is possible to effectively remove the filled but dead seeds from a sample by the IDS method. Using this method in combination with stratification (IsDS treatment), the improvement of the % germinability of the lodgepole pine seeds became so obvious that they may well be used for containerized plant production by single-seed sowing. Such a sowing method would of course be uneconomical using the untreated seeds, as it would result in as high as 34% empty containers. There is no technical hindrance to separating a large amount of seeds for practical use by the IDS method. However, the procedure has to be adjusted for this purpose. Thus, the drying time can be cut down using higher temperature and lower RH%; the separation can be performed by other methods than by flotation water, etc. Technical equipment for this purpose is presently under

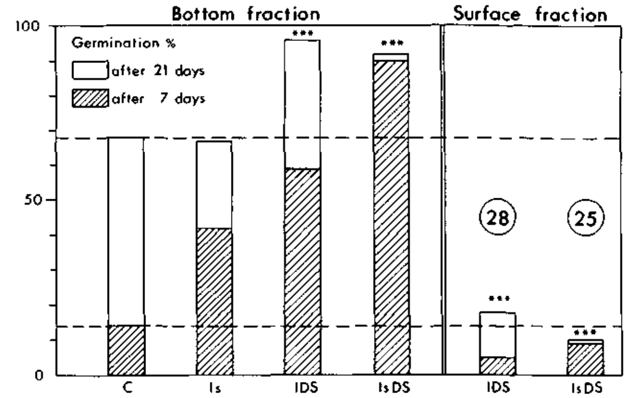

Figure 2. --Laboratory experiment. NOTE: The levels of significance: * = 0.5, ** = 0.01 and *** = 0.001. The encircled figures indicate the percentages of seeds removed from the original sample during the separation (= surface fraction) NOTE: **Is** = Stratified, unseparated seeds showed a faster germination than the untreated control seeds. IDS = After removing the 28% of the seeds which proved to be dead from the sample, the germination capacity of the remaining seeds increased significantly, IsDS = By substituting the I step (3 day incubation) with the Is step (30 days stratification) and after removing the 25% dead seeds from the sample, nearly all remaining seeds germinated within 7 days. "Dead" seeds = The 18% and 10% germinated seeds of the surface fractions represent only 7% and 4% plants respectively, if recalculated for the total amount of plants produced in the IDS and IsDS treatment, respectively.

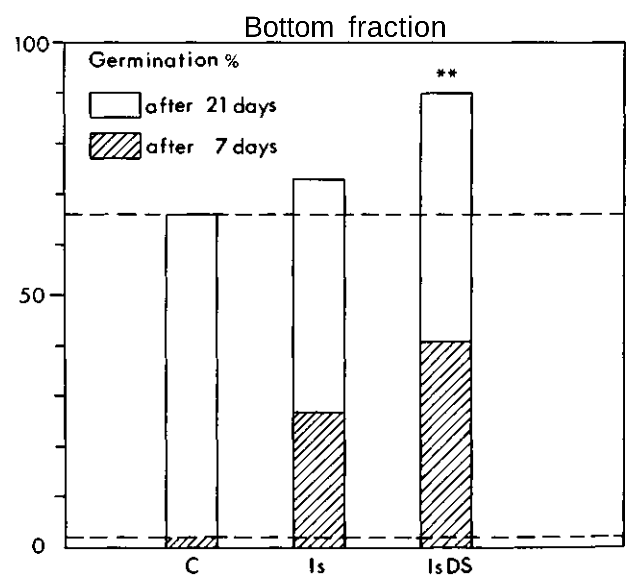

Figure 3. --Bottom fraction. For explanation of the figure, see figure 2. NOTE: Is = Stratified seeds germinate faster than the control seeds. An increase in the final germination was not expected, as the sample contained 29% dead seeds (cf. Material). IsDS: The germination after 7 and 21 days of the treated seeds was significantly better than that of the control seeds. For this considerable improvement of the seed quality, 4% of the plants were sacrificed. They were removed together with the "dead" seeds in the surface fraction.

development at our laboratory. A valuable aid in this connection is the x-radiography technique by which the IDS-procedure can be continuously checked on the treated seeds. An additional improvement of the germinability of the seeds used in the present experiments could be attained by removing the mechanically damaged seeds, which usually sink in the water to the bottom together with the viable seeds.

The positive effects of IDS and IsDS treatments which are presented in this paper were confirmed in several other experiments on seeds of *Pinus contorta*. The trials were carried out in different greenhouses and under various conditions. One of the results is worth mentioning: the IDS-treated seeds can be stored for several months in containers or in a dry organic substrate such as peat without loss of the effects achieved through the treatment. This is, of course, of great advantage to nursery culture.

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POTENTIAL OF LODGEPOLE PINE AS A COMMERCIAL FOREST TREE SPECIES ON AN UPLAND SITE IN INTERIOR ALASKA

John N. Alden and John Zasada

INTRODUCTION

Lodgepole pine, *Panus contorta* Dougl. ex Loud., is one of more than ten exotic species from high latitudes with potential for management in interior Alaska. The natural range of lodgepole pine extends to about 110 kilometers of the Alaska-Yukon border at 64° north latitude (fig. 1). Seed sources from the northern range of lodgepole pine are well adapted to short growing seasons and the extreme cold of subarctic winters north of 60° latitude in Europe and western North America. Juvenile growth is rapid, and seed production is prolific and begins at an early age. Lodgepole pine is easily managed in short-rotation, even-aged stands, and genetic variation in desirable traits within and among provenances is extensive (Critchfield 1980). The extensive genetic variation provides versatility for adaptation of lodgepole pine to a wide range of habitats both within and outside of its natural range.

A wide-range provenance trial with twenty-nine lodgepole pine seed sources and one jack pine, *Pinus banksiana* Lamb., seed source within the range of jack X lodgepole pine hybridization was planted at the University of Alaska's T-field Arboretum at Fairbanks in June 1974 to evaluate the potential of lodgepole pine on a productive upland forest site typical of southern exposures in interior Alaska.

Differences among provenances in height growth, survival, and seed production after 10 years are reported here. The T-field plantation is the only provenance test in Alaska; and results have been used to sample lodgepole pine in Yukon and northern British Columbia for studying genetic variation in survival, growth, and reproductive success on a wide range of sites.

Before extensive provenance research is indicated, however, lodgepole pine must first be found to be more productive than native conifers, and markets must be developed for small logs in Alaska.

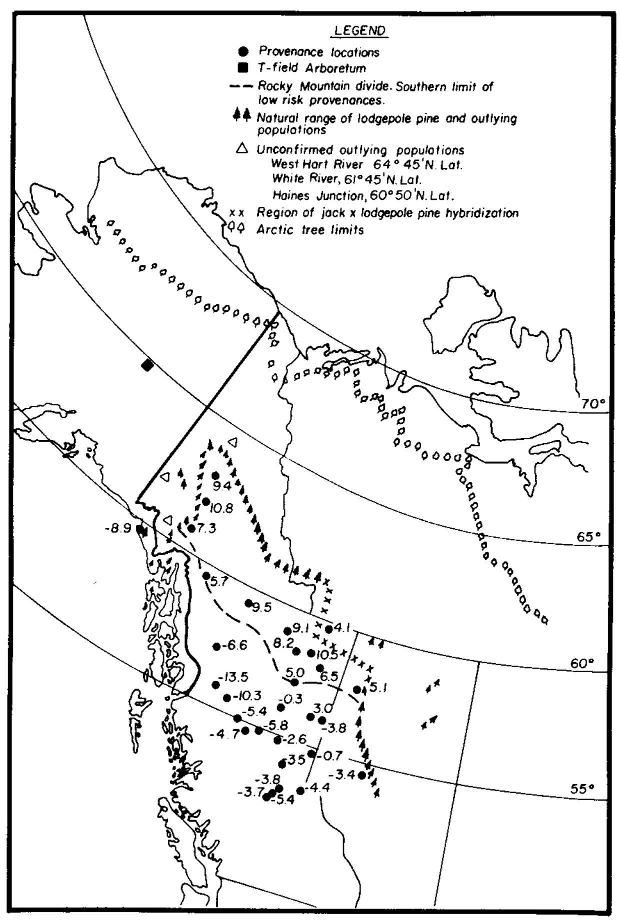

Figure 1.--Natural range of lodgepole pine at high latitudes and relative height growth. index of 30 provenances at T-field Arboretum.

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PROCEDURES

The lodgepole pine provenances trial was established at T-field Aroboretum, Fairbanks, Alaska, in June 1974. The seedlings were supplied by Keith Illingworth, British Columbia Forestry Service, Victoria, B. C., and were planted as 2-1 bareroot stock grown at Red Rock Nursery, Prince George, B. C. Seed sources were from wide-range provenance collections in southeast Alaska, northern British Columbia, Yukon Territory, and Alberta (table 1). Two replications of nine tree plots for each provenance were planted 6 feet (1.8 meter) apart. Performance of outstanding provenances after seven growing seasons at the T-field is compared with earlier outplantings of lodgepole pine from Whitehorse, Yukon, approximately 60' 40'N latitude, 135°30'W longitude, 750 meters in altitude; and Teslin Lake, Yukon, 60' 11'N latitude, 132°43'W longitude, 825 meters in altitude; and jack pine from Fort Simpson, N. T., 61°48'N latitude, 121°18'W longitude, 150 meters in altitude. The earlier outplantings at the T-field Arboretum were made with 5-year-old seedlings from Whitehorse in September 1964 and 1-0 seedlings from Teslin and Fort Simpson in August 1966.

The climate at Fairbanks is continental subarctic with a mean annual temperature of -3.5°C and 275 mm of precipitation. Maximum rainfall occurs during summer and peaks at about 60 mm during August. The T-field Arboretum is located at 64' 52'N latitude, 147°52'W longitude and 150 meters above sea level. The growing season produces about 1100 growing degree days' (C) and extends from mid-May to late August or early September.

[1] Growing degree days = Number of heat units, Celsius scale, above a mean daily temperature of 5'.

Height growth, survival, and winter injury were recorded annually from 1975 to 1981 for the provenance study. Pollen and seed-cone production was recorded for all outplantings in 1981. Two cones were collected at random from each of four seed-producing trees per provenance (two per replication) in October 1981. The cones were air-dried overnight at 58°C, and the seed was extracted, x-rayed, and germinated at room temperature to evaluate viable seed production. Data used to compare differences among species, provenances, and outplantings were either transformed to normal distribution before statistical analysis or analyzed by nonparametric methods.

RESULTS

Height Growth

Height growth of all outplantings increased exponentially during the first 7 years after outplanting. Mean height of the provenance trial and two superior provenances was 1.84 and 3.02 meters, respectively (table 1). Differences among provenances in 1980 and 1981 were highly significant at less than .001 probability of type I error. Mean height growth of the best twelve provenances was 2.59 meters. Height growth rates of Teslin and Whitehorse, Yukon, provenances after fourteen and sixteen growing seasons, respectively, are 0.7 and 0.8 meters which indicate that the superior provenances will continue to grow rapidly at least until crowns close at 12 and 15 years of age. The superior provenances are expected to average 9 meters in height at 15 years of age although they were inferior in height 1 year after outplanting (fig. 2). Growth rates for 3 to 5 years after outplanting reflect seedling age and size differences at planting and reaction of the provenances to change from nursery to plantation. environments.

Table 1--Location, survival, growth, seed cone yields, and winter injury to thirty lodgepole pine provenances T-field Arboretum, Fairbanks,-Alaska.

Plot Number	Provenance area	Latitude	Longitude	Altitude (meters)	1981 Survival, (percent)	1981 Height (cm)	Rank	Height[2] growth index	Winter[3] injury 1977-78. 79	# of cones per tree
19	Nithi R.	54'03'	125'05'	968	66	113	27	-4.7[b]	XX	
21	Doris L.	54'59'	126' 33'	960	84	131	23	-5.4[b]	XX	
24	Finlay F.	55°57'	123'48'	686	84	176	16	-0.3[b]	XX	
25	Hudson Hope	56'02'	122'05'	725	84	166	17	-3.0	XX	
26	Tower L.	56'01'	120'37'	792	88	184	14	-3.8[b]	XX	0.1
27	Pink Mt.	57°	122'24'	1112	100	2U9	12	5.0[a]	X	0.2
28	Tetsa R.	58'40'	124'10'	762	89	302	1	10.5[a]	X	8.8
29	Muncho L.	59'03'	125'46'	853	78	272	4	9.1[a]		8.0
32	Carmacks, Yukon	62° 14'	136' 18'	670	84	253	8	10.8[a]		9.1
33	Ethel L., Yukon	63' 18'	136'28'	875	84	246	10	9.4[a]		8.0
34	Takhini R.	60'41'	136'11'	746	61	250	9	7.3[a]		3.8
35	Atlin	58° 48'	133'47'	788	72	210	11	5.7[a]	X	3.2
36	Kinaskan	57'29'	130'13'	807	84	150	19	-6.6[b]	XX	
37	Cassiar	59° 06'	129'44'	792	84	264	5	9.5[a]	X	4.2
38	Jackfish Cr.	58° 32'	122'42'	457	94	302	2	6.5	X	5.4
39	Redwillow R.	54'56'	120'15'	954	94	183	15	-0.7	XX	
40	McLeod R.	54'49'	122'51'	697	100	148	21	-2.6	XX	0.2
62	McKale	53'25'	120° 20'	701	76	116	26	-4.4[b]	XX	
64	Wendle Park	53° 07'	121'30'	1280	78	145	22	-3.7[b]	XX	
65	Lynx L.	53'39'	122'58'	823	61	150	18	-3.5	XX	
66	Stone Mt.	58'39'	124'46'	1173	89	257	6	8.2[a]		10.5
88	Yakutat, AK	59' 30'	139' 10'	45	67	51	30	-8.9[b]	XX	
101	Kispiox	55'38'	127'54'	610	50	65	28	-10.3[b]	XX	
102	Nass R.	55'31'	128° 38'	305	39	52	29	-13.5[b]	XX	
103	Kalder L.	54'49'	124'16'	945	100	148	20	-5.8[b]	XX	
105	Bowron R.	53° 54'	122' 00'	671	78	126	24	-3.8[b]	XX	
106	Wells	53° 08'	121'33'	1112	73	123	25	-5.4[b]	XX	
141	Hawk H., Alb.	57'23'	117'33'	716	100	257	7	5.1	X	0.7
142	Swan H., Alb.	54° 18'	116' 35'	823	84	187	13	-3.4	XX	0.3
163	Petittot R.[1]	59° 54'	122'05'	396	89	291	3	4.1		9.4
				Mean	81	184				

[1] Jackpine. [2] Provenances with significantly faster (a) and slower (b) growth rates than the plantation average.
[3] - No apparent injury, **X** = Less than 10% of ail trees injured, XX = 25 to 100% of all trees injured.

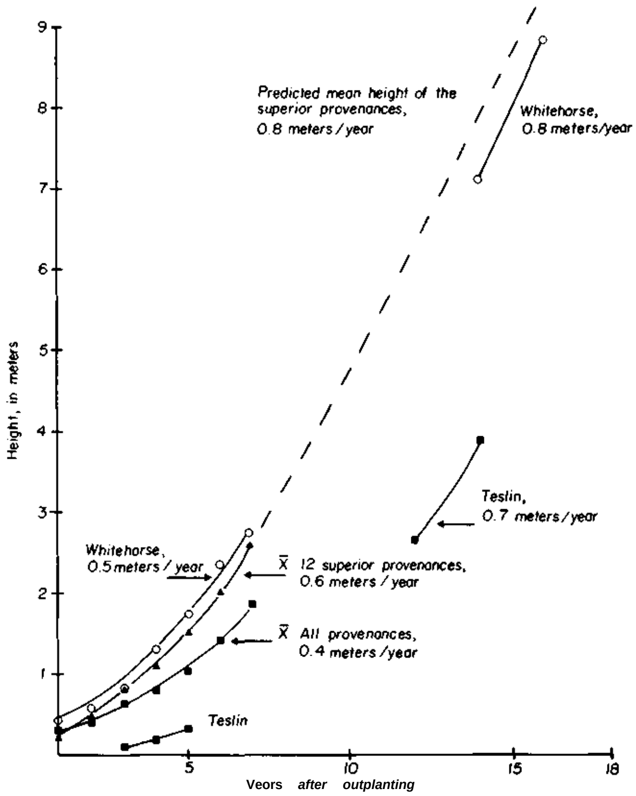

Figure 2.--Actual and predicted height growth of the 12 superior provenances and actual growth of 14- and 16-year-old lodgepine outplantings at T-field Arboretum. Lines are fitted curves. Symbols along lines are observed values.

A relative height growth index (HGI) for predicting early provenance performance was determined from a simple regression of mean annual provenance height as a percentage of mean plantation height on years of plantation development:

$$y = a + b\ x$$

where

y = x provenance height/x plantation height
x = number of growing seasons after outplanting
bj = height growth index (regression coefficient).

Height growth index is the change in provenance height relative to the plantation mean height per unit of time. Provenances with positive HGIs are growing faster than the plantation mean.

HGIs of the twelve superior provenances averaged 7.6 after seven growing seasons at T-field Arboretum. These provenances are located in the Yukon River, Liard River, and lower Peace River drainages. Provenances located in the upper Peace River region and rivers flowing southwest into the Pacific Ocean averaged -5.0 HGI. The Rocky Mountains divide that separates rivers flowing north and southwest is apparently the southern limit of lodgepole pine provenances that grow well on typical southern exposures in interior Alaska (fig. 1). High-altitude provenances at Wendle Park (1280 meters) and Wells (1112 meters), B. C, south of this divide, also grew slower than the plantation mean. Experiments in Sweden indicate that periods and rates of lodgepole pine growth are more closely related to latitude than altitude of seed source (Hagner 1970).

Growth rates (HGIs) of all fast-growing provenances except Jackfish Creek south of Fort Nelson, B. C.; Hawk Hills, Alberta; and jack pine on Petittot River, B.C., were significantly greater than the plantation mean (table 1). Provenances with large HGIs that lack significant departure from the plantation mean have variable growth rates. Although the lodgepole pine, Jackfish, provenance (#38) and the jack pine, Petittot R., provenance (#163) are among the three tallest after seven growing seasons, their relative growth rate is variable and declining (fig. 3). HGIs of the northern Yukon Territory provenances, on the other hand, show continued improvement and are more stable. These provenances may be superior after 1985, while most trees in provenances with negative HGIs will undoubtedly succumb to environmental extremes and competition from adapted neighbors (photo 1).

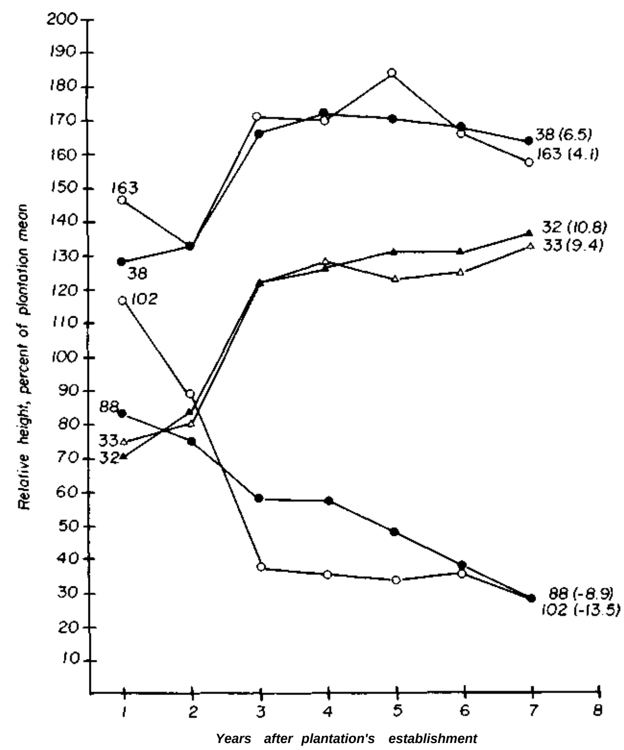

Figure 3.--Relative performance and height growth index of the tallest (38, 163), highest latitude (32, 33), and least adapted (88, 102) provenances.

Survival and Winter Injury

Eighty-one per cent of all trees in the provenance study survived seven growing seasons after outplanting. Average survival ranged from 39% for Nass River, B. C, 55°21'N latitude, to 100% for Mcleod River, 54°49'N latitude; Pink Mountain, B. C. 57°N latitude; and Hawk Hills, Alberta 57°32'N latitude. Average survival of the superior provenances did not exceed the plantation average until 3 years (1977) after outplanting (fig. 4). Number of replications and trees per provenance are too few for testing hypotheses concerning survival differences among provenances. For this reason, average mortality rates for the plantation and superior provenances were compared. Predicted mortality rates from environmental extremes, e.g., winter injury, are only 1.9% per year for all provenances and 1.0% per year for the twelve superior provenances (fig. 4). This difference is highly significant and indicates that survival will be truly different among provenances in time.

Photo 1.—Excellent height growth of the Ethel Lake, Yukon Territory provenance, 63°18'N. Lat. at T-field Arboretum (HGI=9.4). The two outstanding trees in the background averaged 3.2 meters in height after seven growing seasons. The provenance in the foreground is Nithi River, British Columbia, 54°O3'N. Lat. (HGI=4.7). The center tree is 1.6 meters in height. Terminal shoots failed to elongate after severe winter injury in 1981-82. The trees were photographed on 7/30/82.

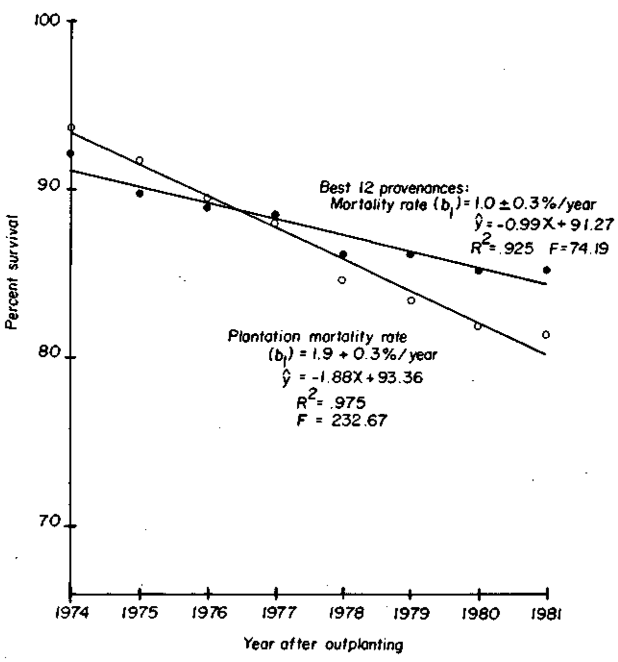

Figure 4.--Predicted mortality rates for the T-field provenance study and 12 superior provenances. Differences in mortality rates are significant at less than 0.05 probability of Type I error.

All provenances from Yukon and three provenances from northeast British Columbia escaped winter injury in 1977-78 and 1978-79 (table 1). More than 90% of the trees among the remaining six fast-growing provenances escaped apparent winter injury while 25 to 100% of the trees in provenances south of the Rocky Mountain crest in northern British Columbia were injured. Provenances south of this general area are apparently highly susceptible to winter injury on productive southern exposures in interior Alaska. The Whitehorse, Yukon, provenance was also injured in 1966, 2 years after outplanting. Thus, even northern provenances present some risk of winter injury, and parents should be carefully screened before their progenies are widely outplanted.

Time of injury was not determined; but brown needles and dead buds and twigs apparent in late spring suggest that high-risk provenances lose hardiness in early spring and become susceptible to late frosts.

Seed Production

Sixty-one of the trees in the eleven tallest provenances produced seed cones, and 59% of the trees produced pollen cones in seven growing seasons after outplanting. Number of seed cones and clusters of male strobili averaged 6.3 and 24.9 per tree. Only the number of male clusters was significantly different among provenances (table 2). Jack pine and lodgepole pine provenances near the range of hybridization in northeast British Columbia produced more male strobili than the two northern provenances in Yukon and Hawk Hills in Alberta. Atlin, B. C, at the southwest limit of low-risk provenances produced only 1.7 male clusters per tree. Pink Mountain, B. C, and the eighteen slow-growing, high-risk provenances produced from 0 to 0.3 cones per tree each (table 1) and could not be sampled for seed analysis.

Only 7.8 fully developed and 5.5 filled seed were recovered from an average of thirty-six seed-bearing scales per cone in the provenance trial. Differences among provenances in total seed yield and seed-bearing scales per cone were not significant, but filled seed yields differed significantly. Filled seed germination averaged 88.2% for jack pine and 99.2% for all lodgepole pine provenances after 10 days of cold stratification and 14 days at room temperature (23°C).

Low pollen production, timing of dehiscence and receptivity of male and female cones, and variation in pollen dissemination undoubtedly contribute to poor seed recovery from young trees. Cone production, total seed yield, and filled seed yield per cone increased significantly with tree and plantation age. These results are summarized in table 3 with an estimation of seed production of lodgepole pine from nothern provinces on a warm site in interior Alaska.

Applying Results of the T-Field Arboretum Provenance Study

Interior and southcentral Alaska contain 43 million hectares of forest land of which only 9 million hectares is currently producing commercial quantities of wood[1] (Hutchinson 1967). Many areas are occupied by slow-growing noncommercial tree, shrub, and grass species. These species produce deep organic layers that insulate underlying soils causing permafrost and poor soil drainage. The productivity of forest area in Alaska can be substantially increased with site preparation, introduction of rapid growing tree species such as lodgepole pine, and maintaining optimum stocking levels through applied management practices.

Large quantities *oiPinus* pollen found in pre-Wisconsin strata of eastern Alaska indicate that lodgepole pine may have been a major component of forests west and north of its present range more than 80,000 years ago (Matthews 1970). However, lodgepole pine macrofossils have not been discovered in Alaska

[1] Forests producing less than 1.4 m^3 of wood per hectare per year are considered noncommercial in Alaska.

Table 2--Average number of pollen strobili clusters per tree for the eleven fastest growing lodgepole pine provenances in T-field Arboretum.

Provenance	Provenance Number	Average number of seed cones per tree	Average number of pollen cluster per tree*
Atlin, B. C.	35	3.7	1.7
Ethel Lake, Yukon	33	8.0	15.5
Hawk Hills, Alb.	141	0.7	15.5
Carmacks, Yukon	32	9.1	15.8
Cassiar, Yukon	37	4.2	17.0
Takhini River, Yukon	34	3.8	19.4
Jackfish Creek, B. C.	38	5.4	29.3
Tetsa River, B. C.	28	8.8	31.7
Stone Mt., B. C.	66	10.5	32.4
Muncho Lake, B. C.	29	8.0	37.0
Petittot River, B. C. (jack pine)	163	9.4	52.0

*Provenances enclosed by a common line are not significantly different at .05 probability or less of type I error as determined by non-parametric multiple comparisons using the Mann-Whitney U-test statistic (Sokal and Rohlf, 1969, pp. 388-397).

Table 3--Biennial seed production for northern jack and lodgepole provenances at T-field Arboretum. Estimates are from age-related differences in cone and seed yields.

		Age in years		Yields					
Species	Provenance	Trees	Plantation	Cones/ tree[1]	Filled seeds/cone[1]	Trees/ hectare	Seeds/ hectare	Grams/ 1000 seed[1]	Kilograms/ hectare
Jack pine	Petittot River, B. C.	10	7	20.9 ab	2.8 a	2000	1.2×10^{5}	3.37 ab	0.4
Jack pine	Fort Simpson, N. T.	15	15	38.7 bc	17.2 b	1000	6.7×10^{5}	3.91 ab	2.6
Lodgepole pine	Northern B. C., Yukon	10	7	6.3 a	6.2 a	2000	7.8×10^{4}	4.10 b	0.3
Lodgepole pine	Teslin, Yukon	15	15	15.9 ab	24.9 b	1000	4.0×10^{5}	3.00 a	1.2
Lodgepole pine	Whitehorse, Yukon	23	17	88.1 c	22.8 b	625	1.3×10^{6}	3.52 ab	4.6

[1] Values with a common letter are not significantly different at .05 probability or less of a type I error as determined by the Student-Newman-Keuls multiple-range comparison procedure (Sokal and Rohlf, 1969, p. 239).

and east-prevailing winds often deposit Pinus pollen from Canadian forests over a wide area beyond present Arctic tree limits in the Brooks Range (Walker et al. 1981). Thus, evidence that the range of lodgepole pine extended west of about 143° longitude in recent geological time is lacking. Nevertheless, results of the T-field provenance trial show that lodgepole pine from the northern part of its range is winter resistant and grows rapidly at a warm upland site in interior Alaska.

The ability of Yukon populations to develop early winter resistance while maintaining a long growing season is unique. Northern and western populations develop high winter resistance without early lignification of phloem cells (Hagner 1970). The latter trait is characteristic of shore pine, variety 'Contorta' (von Rudloff and Nyland 1979). Recent electrophoresis analysis of polymorphism in wide-range, lodgepole pine collections provides evidence that populations from Yukon and northern British Columbia had different refugia than southern populations during the Wisconsin glaciation (Wheeler and Guries 1982). These studies suggest that the Rocky Mountain summit in northern British Columbia is a greater barrier to migration of lodgepole pine after Pleistocene glaciations than are the coastal mountains of southeast Alaska and northeastern British Columbia. Coastal populations are more variable genetically than interior populations (Wheeler and Guries 1982) and may produce greater change in population structure of lodgepole pine in Yukon refugia as a result of natural selection during Pleistocene interglacial migrations and introgressions.

Although lodgepole pine is of commercial importance worldwide, its natural range north of 60° latitude is largely unknown. Most northern populations in Yukon Territory are small, isolated stands that are less than 100 years of age. These populations are incapable of competing with more-tolerant black spruce, *Picea mariana* (Mill.) B. S. P., especially on permafrost sites and in the absence of fire. Results of the T-field provenance study indicate that only the northern range of lodgepole pine may contribute substantially to the genetic base introduced into interior Alaska and perhaps other high-latitude countries. An international effort to locate and sample the northern populations for provenance research and gene-pool conservation should be considered.

Plans for Evaluating Lodgepole Pine in Alaska

Two hundred and twenty-five unrelated, open-pollinated families from approximately fifteen provenances in the low-risk region of figure 1 have been collected and mapped for provenance research in interior Alaska. Stands within provenances were sampled with at least two families each where stand differences were apparent. Additional provenances from northwest and coastal British Columbia will be evaluated in the maritime climate of Kenai Peninsula and southcentral Alaska. Plans are to randomize each provenance, family within provenance, and trees within family in four to six replications per plantation within provenance test regions. This design will allow us to evaluate all sources of genetic variation in lodgepole pine on a range of sites within each provenance test region. Provenance test regions have been delineated by grouping locations with similar climatic factors that affect tree growth, e.g. , growing degree days, dates of early and late frosts, etc., with multivariate statistics. The provenance test regions will be modified into seed zones on the basis of provenance and family stability in survival and growth characteristics for several test sites and dates of establishment. The test plantations will also provide a source of genetic material for selecting future breeding populations adapted to seasonal climatic extremes, pests, and soil characteristics of each seed zone.

The number of seed zones and breeding populations will depend on how well provenances and families are adapted to the wide range of site conditions in Alaska. Future tree-breeding and improvement strategies should be designed to incorporate rapidly growing families into breeding and seed-producing populations for each seed zone. These strategies will maintain a broad genetic base for adaptation of lodgepole pine to environmental change in time and among sites.

Potential Risk of Lodgepole Pine Management in Alaska

Mammals that feed on woody tissues in winter, including hares, moose, voles, and squirrels, pose the greatest immediate threat to introduction of lodgepole pine in Alaska. Small mammals are serious pests. Snowshoe hares girdle the stems and clip branches of young seedlings. Hare populations fluctuate from 0.1 to 6 animals per hectare in 10-year cycles in interior Alaska (Wolff 1980). Severe losses can be expected where alternating dense and open habitats favor population buildups. Voles frequently cause large losses during the winter in young Swedish plantations (Hagner and Fahlroth, 1974). Local populations of the taiga vole reach 100 animals per hectare for 10- to 20-year periods in interior Alaska (Wolff and Lidicker 1980). The taiga vole obtains 10 per cent of its winter diet by foraging away from food stored in nesting areas. Red squirrels feed on the phloem of young lodgepole pine when other sources of food are unavailable. Red squirrel populations average about 2.5 animals per hectare in Alaska but they are not considered serious threats because mature forests are preferred habitats[1].

Moose populations seldom exceed one animal per square kilometer in interior Alaska but local concentrations may reach eight to twelve animals per square kilometer in winter.[2] Each animal consumes about 18 kilograms of fresh browse per day and may cause severe damage in wintering areas where lodgepole pine is the only major nutriment available. The range or population densities of caribou and buffalo are presently more limited than moose in Alaska, and these animals should pose no serious threat to lodgepole pine management.

The rust fungi are a second group of potential pests of lodgepole pine in Alaska. Alternate hosts of sweetfern blister rust, *Cronartium comptoniae* Arth. (*Myrica gale* and *Comptonia* spp.), and stalactiform rust, *Peridermium stalactiforme* Arth. and Kern (*Castilléja* and *Melampyrum* spp.), serious diseases of lodgepole pine, are widely distributed in Alaska (Hultkn 1968). The western gall rust, *Peridermium harknessii* Moore, does not require an alternate host to complete its life cycle. Mesic summers of interior Alaska could enhance inoculum buildup and widespread infection of the rusts. The comandra rust, *Cronartium comandrae* Peck, is the only serious rust pathogen that does not have alternate hosts in Alaska and presents no impeding threat to management of lodgepole pine. A small population of the alternate host, bastard toad flax, *Comandra umbellata* (L.) Nutt., survives at Steward Crossing, Yukon (Hultén 1968), however.

The rust fungi are not as widespread and infections are not as severe in the northern range of the lodgepole pine, but northern populations are more susceptible to infection when they are transferred south than are southern populations (Martinsson 1980, British Columbia Forest Research Review 1979-80).

[1] Mowrey, R. A. 1982. Personal communication. INF, Fairbanks.

[2] Van Ballenberghe, V. 1982. Personal communication. INF, Fairbanks.

Root systems of lodgepole pine, especially trees grown from containerized seedlings, are unstable in fine textured soils (Martinsson 1982). Plantations grown on silt-loam loess soils of interior Alaska may be susceptible to windthrow in regions where high winds are prevalent.

CONCLUSIONS

The potential of lodgepole pine as a commercial species in Alaska is revealed by the rapid juvenile growth and winter resistance of northern provenances at the T-field Arboretum. Short-rotation yields of provenances from the Yukon and Liard River Watersheds may compare favorably with many commercial species in temperate forests of southern Canada and the United States in spite of potential pest problems. Support for provenance research is necessary to discover superior genetic sources of lodgepole pine and to evaluate their productivity on a wide range of sites in interior and southcentral Alaska. The future of lodgepole pine in Alaska will depend on how well it competes with native white spruce, *Picea glauca* (Moench) Voss, and other exotic species , the effectiveness of provenance introduction and tree-improvement strategies, and development of a small-log market for high-latitude forests in North America.

Acknowledgments

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LODGEPOLE PINE IN THE SWEDISH REFORESTATION – PROBLEMS AND PROSPECTS

Owe Martinsson

INTRODUCTION

Lodgepole pine has been used in Swedish forestry since the end of the 1960s. Small, experimental plots of this tree species were already established at the beginning of this century.

During the past few years, about 50 million seedlings have been planted annually; this is approximately 10% of the total nursery stock. The total area of lodgepole pine plantations in Sweden today covers 180,000 hectares (Nellbeck 1982, Hagner 1982); **30%** of this area was planted in 1980 and 1981. Lodgepole pine is used by the forest companies primarily in the northern part of the country. It is being substituted for Scots pine and is used mainly on poor sites at relatively high altitudes. The primary reasons for introducing lodgepole pine are:

- Its superior volume production. Compared to Scots pine on equivalent site class, lodgepole pine is expected to produce 40-60% more wood per hectare.
- Because of the rapid growth and a shorter rotation period, lodgepole pine is expected to reduce the significant wood shortage anticipated in Sweden in about 40 years.

Two more conditions speak in favor of lodgepole pine:

- There is a lack of Scots pine seed for the most northern part of Sweden, and
- Logdepole pine has shown a better resistance to some of the most common diseases of Scots pine.

The seed demand

The lodgepole pine seed supply has so far been entirely imported from Canada. About 600 kg of seed has been imported annually during the last years. Some **30** hectares of seed orchards of lodgepole pine were established in the beginning of the 1970s. In 1977, a coordinated project was started to meet the future Swedish demand for lodgepole pine seed. Seed lots were collected from twelve selected trees from fifteen stands in each of six seed regions in B. C., western Alberta, and up to the northern limit of distribution in Yukon. Together with earlier collections, we now have progenies from more than 1,300 selected trees. Based on this materials, another 80 hectares of seed orchards are being established. When they are in full production, we expect to harvest about 400 kg per year (Rosvall 1982).

Establishment

The most common method for establishing lodgepole pine stands has been planting 1-year-old containerized seedlings with 2x2-m spacing, i.e. the same as that used for Scots pine. The seedlings' growth is very rapid and the lodgepole pine plantations are generally better in terms of survival and growth than plantations of native tree species, despite the fact that lodgepole pine is commonly used in areas with harsher climate.

VOLES AND STABILITY – THE TWO MAIN PROBLEMS

The two main problems we have seen so far are attacks of voles in young stands and instability of the trees against snow and wind pressure. Lodgepole pine is more frequently attacked by voles than our native pine (Hansson and Lavsund 1982). **A** useful property of the lodgepole pine is, however, its ability to survive and recover even after serious attacks. In provenance trials we have also observed that some northern provenances are attacked less than others, a situation which could eventually provide some information useful in controlling the animals (Karlman 1982). The damage also seems to be less serious in depressions and north slopes than in wind-exposed south and west slopes.

The lack of stability against wind and snow pressure is not due primarily to bad root development but to the relationship between the root and the shoot (Martinsson 1982b, Martinsson and Lundh 1982). Especially when planted as a containerized seedling, the young tree produces heavy, wide branches, and the relationship between the root and crown becomes very detrimental to stability. I think that this might be a consequence **of** the wide spacing and the rapid growth. In natural growing conditions, the spacing is very close, and the extension of the

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crown is reduced by competition for light. The distribution of the root is not limited in the same way. In the Swedish stands, the stability is further reduced in winter when the wide crown with its long needles collects wet snow and sometimes ice. In that situation the tree falls over easily. In contrast to the root system of Scots pine, that of the lodgepole pine is more concentrated and has a greater proportion of thin roots, which probably means a more efficacious uptake of nutrients and rapid growth, but the stability of the tree would probably have been favored by thicker roots with a wider extension (figs. 1 -4).

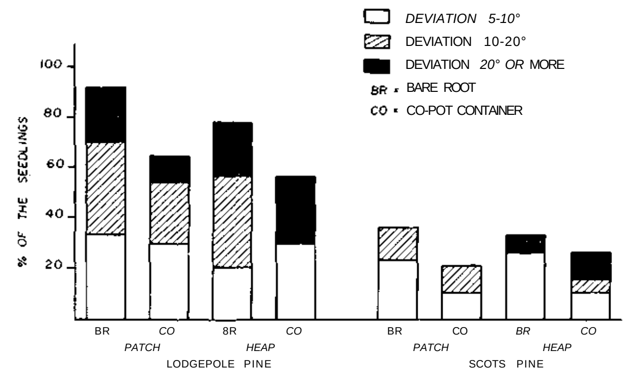

Figure 1.--Basal sweeps.

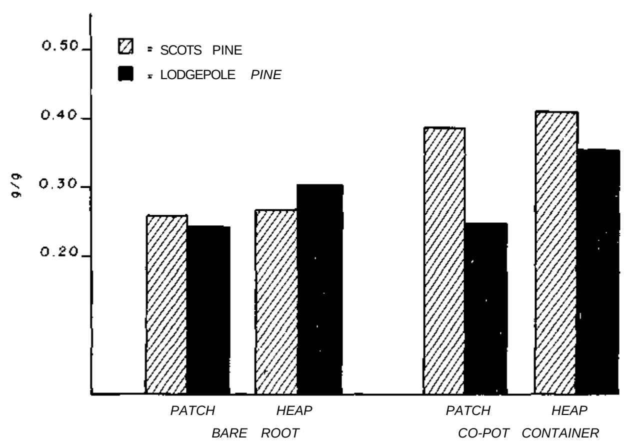

Figure2. --Root weight/crown weight.

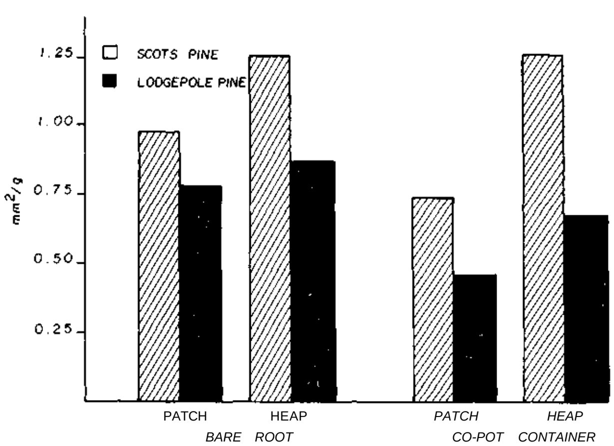

Figure 3. --Root area/crown weight.

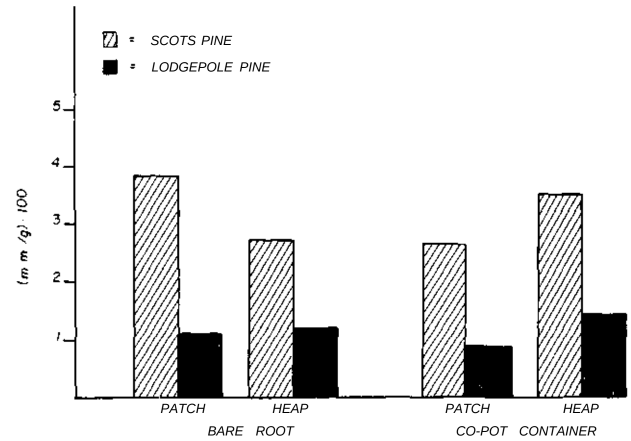

Figure 4. --Average root diameter/crown weight.

The seedling container used in the nursery has a lengthy negative influence after the planting of the seedling in the field. The roots are deformed for several years and consist, to a large extent, of a central burl. In comparison to Scots pine and Norway spruce of similar size, the lodgepole pine roots have a bigger central burl and smaller lateral roots. Seedlings growing after direct seeding develop an almost ideal root form; that is, with no central burl and with stabilizing roots in vertical and horizontal directions. Direct seeding also gives a slower start to the seedling which improves the root/shoot relationship in young trees. As an adult tree, lodgepole pine may have developed a deep, heavy root system. In spite of that, it falls over easily, especially on windy sites or when the soil is fine textured.

PRODUCTION AND QUALITY

The evaluation of Swedish lodgepole pine forests is partly based on provenance trials established in the 1960s and 1970s and partly on 75 small experimental plots established between 1920 and 1935 in Finland and Sweden. The provenances used are generally from a more southern origin than is recommended today. Those older plots are generally smaller than 1 hectare, and in most cases are growing on above-average sites. The stands have been thinned several times.

Even though the provenances were not the most suitable, the average volume production exceeds that of Scots pine by 40-50%, depending on site quality class (Hagglund 1980) (fig. 5). The average annual increment reaches the maximum earlier on high-quality sites than on poor sites and earlier with a high number of stems per hectare than with a low number (fig. 6).

In the younger provenance trials, the investigations are not completed. Considerable differences in volume production between provenances are indicated however (Lindgren et al. 1980). In southern Sweden, the growth seems to be somewhat less in provenances originating from areas north of latitude 56° In northern Sweden, provenances originating from areas north of latitude 62° are slower growing compared to provenances south of these latitudes. The survival of the trees increases with latitude of the provenance origin. The optimal combination of survival and growth in central and northern Sweden is therefore achieved in provenances from Yukon. However, the relationship between the latitude and the production properties in provenances of lodgepole pine is, in many cases, difficult to distinguish.

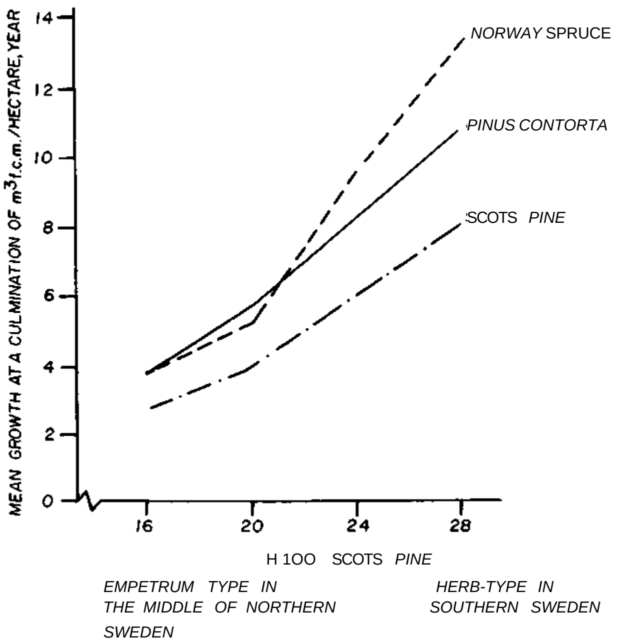

Figure 5.

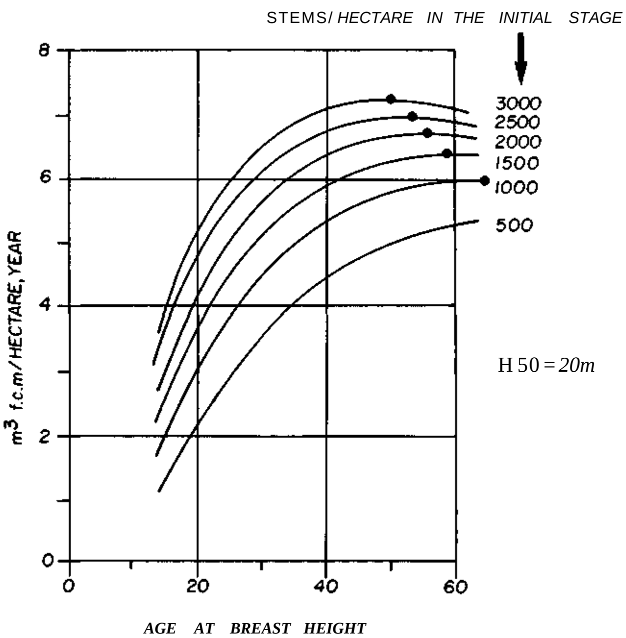

Figure 6. --Mean growth excluding natural thinning.

The properties of lodgepole pine make the wood useful for sawmill products as well as pulp and paper production. The quality of the boards produced is similar to board qualities of Scots pine grown in plantations (Andersson 1976). In order to achieve a good-quality board, it is necessary to use Scots pine grown through natural regeneration. The Swedish lodgepole pine will primarily be used in production of pulp and paper. Its wood properties for pulp and paper production are as good as or better than the properties of Scots pine. In addition, it can be used in processes other than those possible with Scots pine. The wood quality of lodgepole pine will probably be considerably improved through genetic breeding, which has not started yet (Persson 1982).

DAMAGE FROM FUNGI AND INSECTS

Upon introduction of a new tree species, there are always risks that the introduced tree species will be damaged by indigenous or introduced insects and diseases. These risks are probably the most important reasons why precautions have to be taken. Within its native habitat, lodgepole pine is one of the most attacked tree species. The most serious diseases are caused by rust fungi closely related to European stem rust fungi. None of these North American rust fungi have yet been found outside the North American continent, even though natural conditions conducive to their propagation exist in Europe and Asia. If some of these fungi were transferred into Europe, a very dangerous situation would develop, since not only lodgepole pine but also Scots pine is susceptible to these diseases (Martinsson 1980). Scots pine has existed in northern Europe since the last glaciation, and none of the North American rust species have appeared so far. A natural spread without human participation, therefore, seems unlikely.

Damage from indigenous diseases on the Swedish lodgepole pine have so far been rather limited (Karlman 1981, Martinsson 1982a). The most common diseases from which our native tree species suffer have generally caused less damage on lodgepole pine. None of the European rust fungi, such as *Melampsora pinitorqua* or *Endocronartium pini,* seem to attack and damage lodgepole pine under field conditions. Needle diseases like snow-blight *(Phacidium infestans),* pine needle cast *{Lophodermium seditiosum),* or grey needle cast *(Lophodermella sulcigena)* have generally caused less damage on lodgepole pine than on Scots pine. Damage from root rot fungi such as *Hetorobasidion annosum* and *Armillariella mellea* might appear as a problem. Lodgepole pine is, however, not intended to be used on sites where those diseases are prevalent.

With regard to insect pests, lodgepole pine is perhaps not so superior to Scots pine-, but there is on the other hand no big reason to worry as yet (Eidmann 1982). About sixty species of insects have been observed on lodgepole pine in Sweden. Among the species which have caused damage, of practical importance are the large pine weevil *(Hylobius abietis),* the European pine sawfly *(Neodiprion sertifer),* the European pine shoot moth *(Rhyacionia bouliana),* the pine cone weevil *(Pissodes validirostris),* and the six-toothed pine beetle *(Pityogenes chalcographus).* The last-mentioned species has, in a few places, caused serious damage after cleaning in adjacent stands. Its ability to propagate seems to be limited in the stem of lodgepole pine, however.

ECOLOGICAL QUESTIONS

Investigations on the influence of lodgepole pine on the forest flora, fauna, and soil conditions are in progress and only preliminary results exist. These indicate that the litter decomposition may be somewhat slower in a lodgepole pine stand than in a Scots pine stand. The pH value of the litter and the humus layer can be a little lower in a lodgepole pine stand. This could, however, be a direct consequence of the higher litter production in the lodgepole pine stand and it is not evident whether these differences have any practical impact on the soil condition (Lundmark et al. 1982).

FUTURE RESEARCH ON LODGEPOLE PINE

The species *Pinus contorta* is and will remain a foreign tree species for a long time in Sweden. This means that the knowledge and experiences with this tree species is more restricted than with our indigenous trees. Research on lodgepole pine has to be pursued with a high intensity. The genetic research has been most intensive. Other fields in which research is especially important include methods to minimize risks for ecological instability which may show up as damage from wind, snow, fungi, voles, and other animals. Another field which must be investigated is the suitability of lodgepole pine for different habitats. The silvicultural practices have to be better adapted to this tree species, and the economic impact for the regional and national forestry has to be analyzed.

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