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CHARACTERISTICS OF SUBALPINE SPRUCE IN ALBERTA

by
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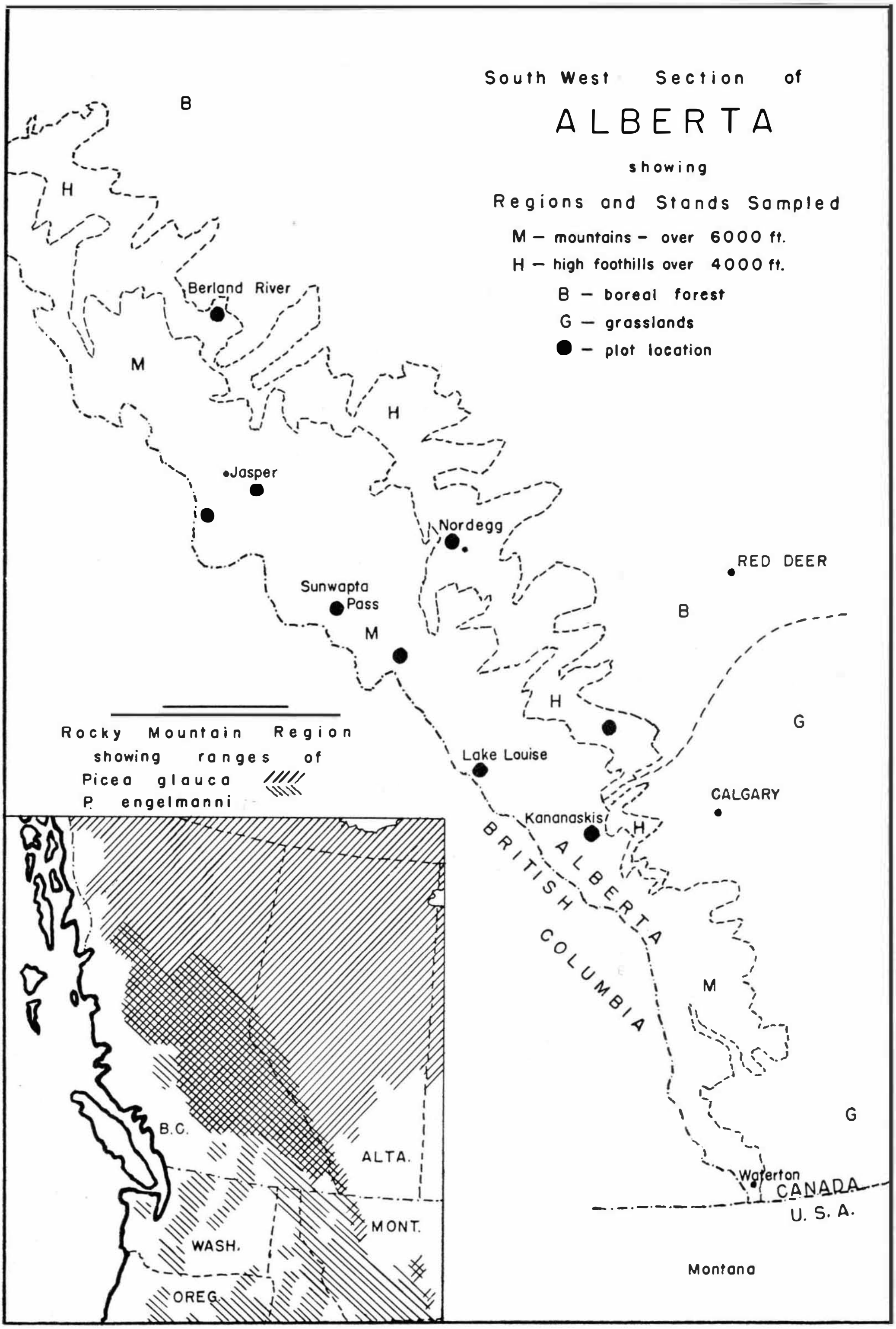
South West Section of
ALBERTA
showing
Regions and Stands Sampled
M — mountains — over 6000 ft.
H — high foothills over 4000 ft.
B — boreal forest
G — grasslands
● — plot location
Berland River
Jasper
Nordegg
Sunwapta Pass
RED DEER
Lake Louise
CALGARY
Kananaskis
BRITISH COLUMBIA
ALBERTA
Waterton
CANADA
U. S. A.
Montana
Rocky Mountain Region
showing ranges of
Picea glauca
P. engelmanni
B.C.
ALTA.
MONT.
WASH.
OREG.

Characteristics of Subalpine Spruce in Alberta

by K. W. Horton*

INTRODUCTION

The spruce forests of the Canadian Rocky Mountain region are particularly interesting and particularly problematical. They are interesting ecologically because they represent the most stable natural forest association, and interesting commercially because they comprise the most important source of saw timber in the region. They are problematical in their taxonomy, involving a complex of two species, and in their silviculture, especially concerning cutting methods regarding which some controversy exists.

It is the aim of this report to describe these forests as they are represented in western Alberta, to assess some of the practical features of their ecology, and to examine important silvicultural implications.

The background is provided by a fairly extensive though largely disjointed literature, particularly on silviculture of the spruce-fir type in the west, and by a study the writer made in 1955-56 on the taxonomy, distribution and general ecology of white spruce (*Picea glauca* (Moench) Voss) and Engelmann spruce (*Picea engelmanni* Parry) in Alberta.

The front map shows the area involved, the east slope of the Rocky Mountains in Alberta, including the adjoining high foothills. Spruce is the dominant tolerant forest species from the elevation of 4,000 feet at the edge of the plains to timberline at 6,500-7,000 feet. As the inset map indicates, the ranges of the two species, white and Engelmann spruce, overlap in the mountainous portion of this region. Generalizing, white is the typical spruce of the foothills at these latitudes, Engelmann being confined to the higher ranges. However, previous observations (Horton 1956b) pointed to some degree of altitudinal zonation of the two species within the mountains, white occupying the lower valley sites, Engelmann the upper slopes and a complex of the two between.

METHODS

This distribution suggested the field study approach—sampling stratified primarily on a taxonomic basis. Accordingly, discrete examples of white, Engelmann and intermediate spruce stands were selected, the white generally from the high foothills and outer ranges, the Engelmann from the higher forested passes and the intermediate stands from intervening mountain areas.

To facilitate comparison further, an effort was made to standardize site. Sampling was restricted to three easily definable extremes of site, considering local climate and soil drainage—hot and dry (D), normal and fresh (N), cool and moist (M). It is realized that there would be climatic differences associated with the altitudinal zonation, so that a dry site in the white spruce zone might not be the same as in the Engelmann zone, but a relative comparison was the objective.

Stand history is another major variable requiring consideration in ecological comparisons, but in this case the problem was minimized. There is in this region a relatively straightforward succession from lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) to spruce-fir (the fir being *Abies lasiocarpa* (Hook.) Nutt.) It was a simple matter to confine the sampling to undisturbed spruce-fir stands with this background, which were all more than 200 years of age.

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Sampling was thus carried out on three sites within historically comparable stands of the three taxonomic types. Sample plots varied in size from $\frac{1}{5}$ to $\frac{1}{20}$ acre and were replicated in each condition. Within a plot the aim was to obtain a complete picture of the gross characteristics of stand and site. All trees over 1″ d.b.h. were tallied and bored to ascertain age and growth trends. Data on basal area and dominant height were obtained. A belt transect (1/100 acre) was established along the centre line of each plot for the assessment of reproduction and subordinate vegetation. The soil profile development, texture and moisture were described together with topographic and local climatic features influencing the site.

DESCRIPTIVE COMPARISONS OF THE SPRUCE TYPES

Taxonomy and Distribution

The morphological complex of the two spruces has been problematical for many years. In recent years three comprehensive studies relating to the problem were carried out, more or less simultaneously. The most general is that of Wright (1955) which involved the phylogeny of the whole genus *Picea*. Wright proved by morphological and genetical evidence a close affinity between white and Engelmann spruce, and concluded that *Picea glauca* var. *albertiana* (S. Brown) Sarg. was the product of their hybridization.

Garman (1957) assessed the problem as it pertains throughout British Columbia. From a review of past minor studies made in that province, plus an extensive sample of the morphological variation, he presented a broad picture of the complex geographical distribution of the species.

In Alberta the situation is probably more clear-cut than in British Columbia owing to the more distinct altitudinal zonation from high mountains down to boreal plains. A morphological appraisal by the writer (Horton 1956a), stressing the altitudinal variation, pointed to introgressive hybridization of the two spruces. White spruce was found to predominate in valleys generally below 5,000 feet, Engelmann spruce above 6,000 feet, and a complex gradient resembling a hybrid swarm on the intervening slopes. There appears thus to be an ecotypic response, connected probably with climatic differences, with Engelmann spruce preferring the cooler, moister conditions, and white spruce the warmer, drier.

Wright's (1955) point that *Picea glauca* var. *albertiana* is a result of this hybridization seems to have some justification. A comparison of an extensive sample of white spruce cones and foliage collected throughout its entire range failed to show any consistent diagnostic differences between northwestern specimens and any others, *except* within the hybrid region. Most of the reported differences between the variety and the type form are characteristically intermediate between *P. glauca* and *P. engelmanni.* These include more resinous terminal buds, longer needles and sterigmata, more pointed bracts, and a conflicting variety of shapes and margins of the cone scales (Horton 1956b). The cones of the variety were described as shorter, broader and darker than those of typical *P. glauca* in Stewardson Brown's (1907) original type description, but this distinction was not noted in this study either in a sample of white spruce specimens from the immediate area of the type specimen, or in an extensive comparison of western, eastern and far northern white spruce material at large. There remains crown form; var. *albertiana* is described as having a characteristically narrower form than *P. glauca* (as has *P. engelmanni*). In western Alberta both narrow and broad-crowned spruce can be seen growing together, although the former certainly predominate. Northwards in the Territories, however, far beyond the recorded range of Engelmann spruce, the white spruce is typically narrow. Thus there may be a western variety *or form* of white spruce but if so the distinction is minor, and in the mountain region of Alberta the issue is certainly overshadowed by the fact of introgression between white and Engelmann spruce.

In the process of introgressive hybridization there is repeated backcrossing of the hybrids to one or both parents (Anderson 1949). In this case the individuals vary morphologically all the way from typical white to typical Engelmann. Each character will vary from the one extreme to the other and innumerable combinations of the characters of the respective taxa will occur. This makes categorizing of the hybrids difficult and arbitrary at best, but it is nonetheless necessary in a comparison such as this.

Fortunately the most useful diagnostic features of the two spruces are in the cone. There are differences in the flower, shoot and needle but those in the cone are most easily assessed. Five possible categories of cone scales found in western Alberta, progressing from typical *Picea glauca* (G) to *Picea engelmanni* (E) with three intermediate (I) classes are shown in Figure 1. The main criteria used in differentiating the two extremes are in the cone scale. In G the widest part of the scale is $\frac{1}{3}$ (of the total length) back from the apex, which is either broadly rounded or truncated. In E the widest part is close to the middle and the apex is narrow and often wedge-shaped. Other differences: G has stiff entire scales whereas those of E are thin, wavy and erose of margin. In a proportion of samples E has acuminate-tipped bracts; acute or rounded bracts are not diagnostic.

The half-way intermediate (I) presents a compromise in all or some of these characteristics, usually having a fairly broad scale with an ovate apex, more or less serrated and sometimes wavy. Then there are the intermediates inclined to G or to E, possessing some typical and some slightly hybrid features.

On an individual tree all cones are similar in such qualitative characteristics, so that one cone is enough for this taxonomic assessment. To extend it to a stand basis, one has merely to collect widely scattered cones from the ground, preferably during the year after a good cone crop. This assumes that the ground sample would be representative of the tree distribution, a possible weakness but usually the only expedient approach.

This procedure was carried out on the sample plots. A sample of 20-40 cones was collected on each plot and categorized as above. Then, for a crude evaluation of the degree of hybridity of a plot, an index was devised by assigning values to the 5 cone scale categories as follows: G=0, GI=1, I=2, EI=3, E=4. The percentages of the total cone sample represented by each category were calculated; these, weighted by the appropriate value and aggregated, gave the hybridity index for the plot. Pure G stands should, by this method, total 0, and E should total 400, with hybrid stands ranging anywhere between. However, with introgression occurring in the mountain region, consistently pure stands are difficult to find, some slight contamination being present even at the outskirts. Thus these extreme values do not apply; still there are *relatively* typical stands, and the index is convenient for indicating these as well as for differentiating the complex hybrid stands.

To facilitate comparison the plots were grouped into five taxonomic types, the same as the cone scale categories. The range in hybridity index of each type is shown in Table 1, together with the corresponding altitudinal distribution.

The distribution pattern supports the previous description, the types occupying overlapping altitudinal zones with intermediate hybrid stands commonest at intermediate elevations.

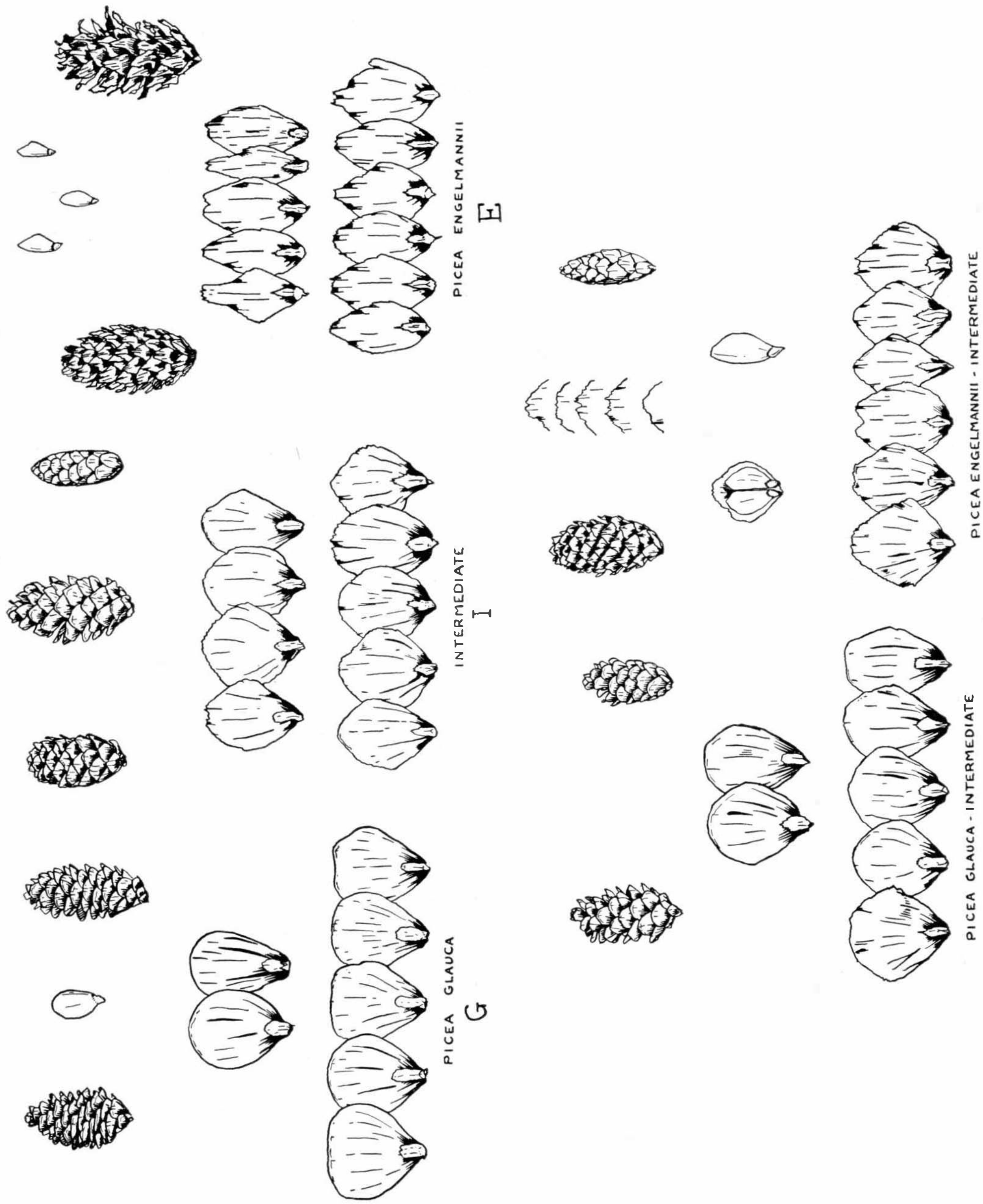

Figure 1. Representative samples of five cone scale types—Alberta.

In any given type the plot hybridity indices ranged in value as widely within as between sites, so that no local (soil moisture) site preferences can be shown for the different types. But, since different altitudinal zones are occupied by the two extremes, ecological differences attributable to change in climate might be expected.

In the succeeding comparisons the three intermediate types will be combined for simplification and strengthening of the sample, and designated type I.

TABLE 1.—SPRUCE TYPES—DEGREE OF HYBRIDITY AND ALTITUDINAL OCCURRENCE.

Type	Glauca G	Intermediate			Engelmann E
		GI	I	EI	
Hybridity Index Range	0–40	51–138	171–245	264–320	328–384
Theoretical Value	0	100	200	300	400
Elevation Class (ft.)—	Occurrence (No. of Plots) by Type				
4000–4500	5		2		
4501–5000	11	2	4		
5001–5500	1	6	5	5	
5501–6000		3	3	2	8
6001–6500			1	1	1
6501–7000					2

Stand Composition

Tree Cover

A general comparison of the quantitative stand features of the spruce taxonomic types appears in Table 2. It involves only summaries of silviculturally significant points such as relative stocking, the proportions of spruce to fir and of large spruce to small. For more details the reader is referred to DeGrace (1950 a&b) who presents stand and stock tables and considerable growth data for comparable spruce forests of the same region.

TABLE 2.—STAND COMPOSITIONS—AVERAGE VALUES PER ACRE, ALL SITES.

Type	No. of Plots	Total B.A.	B.A. of Spruce	Per Cent Spruce by B.A.	No. Stems 1″+DBH	No. of Spruce	Per Cent Spruce 9″+DBH	No. of Fir	Per Cent Fir by No.
G	17	184	168	91	531	440	27	15	3
I	34	224	198	88	652	390	38	235	36
E	11	247	223	90	723	356	41	363	50

Certain consistent differences between types are apparent. Considering the typical taxa, Engelmann spruce stands are more heavily stocked, having both a greater basal area and total number of trees. The latter is due to the far greater proportion of fir to be found in the E plots. There are, in fact, fewer numbers of spruce on the E plots than on the G, yet those fewer trees have a greater basal area. This points to larger trees in the E type, which is substantiated in the column showing proportion of spruce over nine inches d.b.h.

Thus a general picture of each type evolves. The G plots have a comparatively large number of spruce and few or no firs, whereas the E plots have fewer but bigger spruce trees and an abundance of small firs. The I plots are, accordingly, more or less intermediate in these respects. In all types the proportion of spruce by basal area is about 90 per cent; other species are of minor importance.

Reproduction

Table 3 is a summary of the status of natural reproduction in the different types. Data representing a complete tally of seedlings and advance growth under 6 feet high were obtained from 1/100-acre transects located within the larger plots. A standard of adequate stocking was arbitrarily set at 400 trees per acre. On this basis spruce reproduction is inadequate in all three types, and is negligible in the E stands. Fir reproduction, on the other hand, is frequently abundant, particularly in the higher I and E stands. It is often lacking in the G type, being replaced locally sometimes by black spruce.

TABLE 3.—NATURAL REPRODUCTION—FREQUENCY PER CENT OF ADEQUATELY STOCKED PLOTS.

Site	Type					
	Spruce			Fir		
	G	I	E	G	I	E
D	25	25	0	25	43	75
N	17	31	0	33	85	100
M	33	15	0	14	77	50

Subordinate Vegetation

The ground flora often provides clues useful in ecological comparisons. Certain limited descriptions of species associated with the spruce-fir cover types of Alberta have already been published and these have been synopsized by Moss (1955) who suggested that a more comprehensive investigation is needed, particularly in the Engelmann spruce-alpine fir type. In Table 4 the species encountered on the sample strips of this study are listed according to type, site and strata by frequency classes. Uncommon species, those found only once or twice, have been excluded.

It is evident from Table 4 that there is more similarity than difference between the taxonomic types in floristic structure. The distribution of species into the various strata corresponds closely. There are many ubiquitous species, occurring sometimes with comparable frequency in all three types. There are some specific differences, but few are exclusive to either the G or the E types. Practically all the non-ubiquitous species frequent the I type as well as one or the other "typical" types. Thus certain subalpine shrubs are confined to the E and I types, i.e., *Menziesia glabella, Vaccinium scoparium* and *V. membranaceum*. On the other hand, several western boreal plants do not extend as high as the E type; these include *Juniperus horizontalis, Mertensia panisulata, Equisetum sylvaticum, Delphinium brownii,* and *Galium boreale*.

Table 4 also shows the relative site indicator value of the species within a taxonomic type. This is particularly applicable here because of the uniformly contrasting nature of the sites sampled and the similarity in background of the stands. It is clear that most species are not confined to any particular site. Many occur on every site, some to different degrees. A few are reasonably reliable indicators of site extremes. On the dry side these include *Arctostaphylos uva-ursi, Juniperus horizontalis, Antennaria* and *Hedysarum* spp.; on the moist, *Betula glandulosa, Achillea* and the wet mosses, *Camptothecium, Aulacomnium* and *Sphagnum*. Not considered are the rarer species which are more exact in their site requirements, hence in their indicator value.

Stand Structure

Age Structure

The commonest way of representing stand structure is by size class distribution. With a tolerant species such as spruce, however, every degree of suppression among individuals is likely to be encountered so that size bears no relation to age. In this study the age of every tree on each plot was determined, to provide as accurate information as possible on the age class distributions of the different taxonomic types. Within a plot the trees were grouped for convenience into 20-year age classes. An appraisal of all plots showed that four age structure categories existed, as follows:

Growth Trends

Notes were made of the lifetime increment history of every tree on each plot to give information on the relative incidence, according to type and site, of the following features:

1. Steady growth (uniformly well-spaced annual rings).
2. Suppression at any period after seedling stage (crowded rings).
3. Extreme suppression at any time (requiring magnification to differentiate rings).
4. Recent release following suppression (increased outer ring spacing).
5. Decadence (presence of butt rot).

TABLE 4.—LESSER VEGETATION OF THE SPRUCE-FIR COMMUNITY BY TYPE AND SITE.

—	Site								
	Dry			Normal			Moist		
	G	I	E	G	I	E	G	I	E
TALL SHRUBS—									
Rosa acicularis	C	C	S	F	S	—	C	S	S
Ledum groenlandicum	—	—	F	F	S	F	S	S	C
Shepherdia canadensis	F	C	S	S	—	S	—	—	F
Menziesia glabella	—	—	—	—	S	S	—	S	S
Juniperus communis	C	C	F	S	S	S	—	S	F
Salix spp.	—	S	F	S	S	S	C	F	C
Alnus crispa	—	—	—	—	S	—	—	S	—
Lonicera involucrata	—	—	—	S	S	S	—	F	S
Ribes lacustre	—	S	—	S	S	S	S	F	—
Vaccinium membranaceum	—	—	—	—	—	—	—	—	—
V. scoparium	—	S	C	—	S	C	—	F	C
Potentilla fruticosa	S	—	—	—	—	S	—	—	S
Betula glandulosa	—	—	—	—	—	—	F	—	F
GROUND LAYER—									
Vaccinium vitis-idaea	F	S	S	F	S	S	F	S	S
V. caespitosum	—	S	C	—	S	C	—	F	C
Juniperus horizontalis	C	—	—	S	—	—	—	—	—
Arctostaphylos uva-ursi	S	F	S	—	—	—	—	—	—
Empetrum nigrum	—	—	S	—	S	S	—	S	C
Linnaea borealis	C	C	C	C	C	F	C	C	F
Mitella nuda	—	S	—	F	F	S	C	C	S
Equisetum scirpoides	—	S	—	F	F	F	C	C	C
Hylocomium splendens	C	C	C	C	C	F	F	C	C
Calliegonella schreberi	F	C	C	F	C	C	C	C	C
Hypnum crista-castrensis	C	S	S	F	C	F	C	C	F
Thuidium abietinum	S	S	—	F	S	—	S	S	—
Rhytidiadelphus sp.	F	—	—	S	S	—	—	S	—
Timmia austriaca	—	—	S	S	S	S	—	S	S
Dicranum spp.	C	C	C	F	F	F	S	C	C
Polytrichum juniperinum	S	—	S	F	S	S	F	S	S
Mnium spp.	—	S	—	S	—	—	F	C	C
Aulacomnium palustre	—	—	—	—	—	—	F	F	F
Camptothecium nitens	—	—	—	—	S	—	F	S	C
Sphagnum spp.	—	—	—	—	—	—	S	S	F
Fire mosses	S	S	F	—	—	S	S	—	—
Peltigera apthosa	C	C	C	F	C	C	F	C	C
Cladonia spp.	C	C	C	—	S	C	F	F	F
Leafy liverworts	S	—	S	—	S	F	S	F	S

(Cont'd.)

TABLE 4 *cont'd.*

	Site								
	Dry			Normal			Moist		
—	G	I	E	G	I	E	G	I	E
TALL HERBS—									
Epilobium angustifolium	F	F	F	C	S	S	F	F	—
Aster conspicuus	F	C	F	S	—	S	—	S	—
A. ciliolatus	S	S	—	—	—	S	—	—	F
Hedysarum sulphurescens	S	S	—	—	—	—	—	—	—
Mertensia paniculata	—	S	—	S	S	—	C	S	—
Stenanthium occidentale	F	S	—	S	S	S	S	S	F
Zygadenus elegans	F	F	—	—	—	—	S	—	—
HERBS—									
Elymus innovatus	C	C	F	C	F	F	C	F	S
Calamagrostis spp.	—	—	—	S	—	S	—	S	S
Other grasses	—	—	—	—	—	S	S	S	—
Cornus canadensis	F	S	C	C	C	F	F	C	C
Arnica cordifolia	F	F	F	F	F	C	S	S	F
Petasites palmatus	—	S	—	F	S	—	C	F	F
Fragaria glauca	S	F	F	F	S	S	S	S	F
Pyrola secunda	S	C	C	F	C	F	F	F	F
P. asarifolia	—	F	—	F	S	—	F	S	F
Achillea millefolium	—	—	—	—	—	—	F	S	S
Senecio indecorus	—	S	—	—	—	S	S	—	F
Pedicularis bracteosa	—	S	—	—	S	S	—	S	F
P. labradorica	S	—	—	—	—	—	S	—	—
Galium boreale	C	S	—	S	—	—	S	S	—
Rubus pubescens	—	—	—	—	—	—	S	F	—
Habenaria spp.	—	—	—	S	S	—	S	S	—
Osmorhiza obtusata	—	S	—	S	S	S	—	—	—
Delphinium brownil	—	—	—	S	—	—	F	S	—
Anemone parviflora	—	—	—	—	—	S	S	—	F
Listera borealis	—	—	—	—	—	—	S	S	S
Antennaria spp.	S	S	—	—	—	S	—	—	—
Lycopodium annotinum	—	—	S	—	—	S	—	—	—
Equisetum sylvaticum	—	—	—	S	—	—	S	S	—
E. pratense	—	—	—	S	S	S	S	F	F
E. arvense	—	—	—	—	S	—	S	F	—
Carex spp.	S	C	S	S	F	F	C	C	C

Frequency scale: C = common, 67–100%
F = frequent, 34–66%
S = scattered, 0–33%.

No attempt is made to compare the taxonomic types as to growth features such as dominant height because of the restricted, selective nature of the sample and because individual trees measured in hybrid stands do not necessarily match their plots taxonomically.

It was ascertained from preliminary tabulations of the data that absolute stand age did not apparently affect the amount of suppression or release in the senses just described. The plots having the largest proportion of "suppressed" trees and those containing the highest incidence of "released" trees occurred through the whole range of absolute stand age, from 200 to more than 400 years. Comparisons of growth trends between sites within each type showed no consistent relations. Thus the way was clear to compare in these respects the types themselves, as is done in Figure 2.

The differences between the types in these growth features are not pronounced, particularly in the E and I types. The G type is to some extent superior in that extreme suppression is less frequent and response to release more common; a reflection, likely, of its somewhat less dense stocking as shown in Table 2.

Of chief interest is the reasonably high frequency of released growth in these stands where natural mortality provides the only disturbance.

Category	Term	Average Age Range	Remarks
A	even-aged	40 years	Maximum of 20% of total age range represented.
B	broadly even-aged	120 years	Maximum of 50% of total age range, but large majority of trees in oldest classes.
C	two-aged		Two distinct age ranges present, each in A or B category.
D	uneven-aged	practically whole range	Single age classes may be absent and the youngest classes represented by advance growth, often suppressed.

Data from other studies by this writer were available to supplement this and the combined analysis (Table 5) shows the current age structure categories of plots representing different types and sites scattered throughout the region. Although category C, the two-aged stand, was occasionally encountered, it is not included in this frequency table because disturbed conditions, the usual cause of this structure, were avoided whenever recognizabe in the sampling.

The significant feature is that the even-aged stands outnumber the uneven 3 to 1, irrespective of type or site. The reasons for and silvicultural implications of this finding are discussed later.

TABLE 5.—FREQUENCY OF STAND AGE STRUCTURES.

Age Structure Category	No. of Plots by Type (all sites)			No. of Plots by Site (all types)		
	G	I	E	D	N	M
Even-aged — A	9	11	7	11	13	3
Broadly even — B	19	26	10	12	22	21
Uneven-aged — D	12	11	5	9	12	7
D in %	30	23	23	28	26	23

Discussion

There are differences in the spruce taxonomic types distinct enough to affect silvicultural treatment---differences such as the higher proportions of fir in the E type, and its paucity of spruce reproduction. As would be expected, the taxonomic intermediate stands show intermediacy through the whole behavioural pattern. Yet there are many general similarities among the three types, similarities in structure and growth which justify their grouping for the broad ecological and silvicultural considerations which follow.

ECOLOGICAL HIGHLIGHTS OF THE SPRUCE FOREST

The emphasis of this study has been mainly on description. Undisturbed stands provided the material, the object being to probe natural tendencies. Though there were no organized investigations of basic ecological processes or of practical silvicultural effects, some of the factual findings do have a bearing in these respects. It seems appropriate to examine these findings in the light of pertinent literature. A brief review of existing silvicultural information and its ecological background, together with a discussion of possible applications in the region under study, follows.

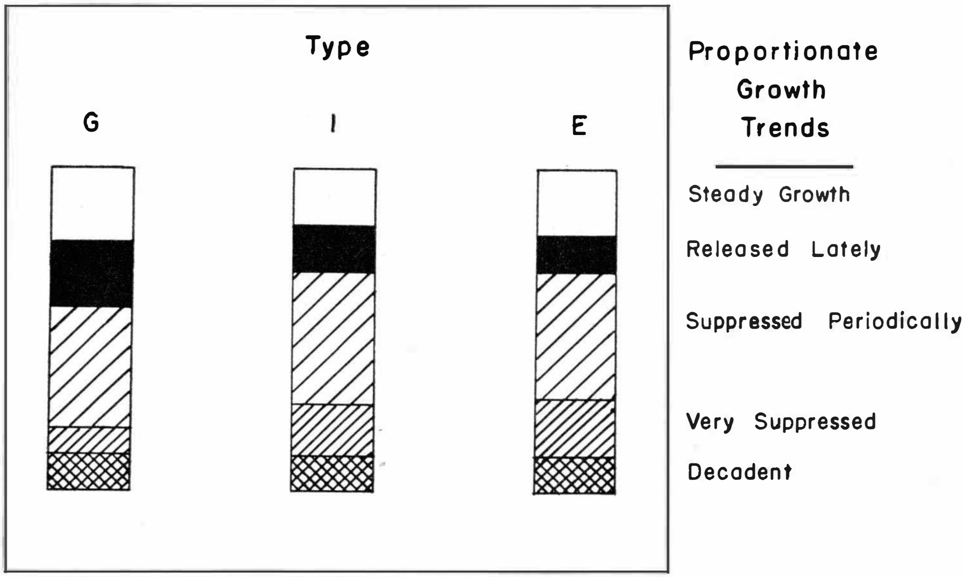

Figure 2. Relative percentic incidence of certain radial growth tendencies in the three spruce types.

Origin and Development

Concerning stand origin and development, fire is the keynote. Three variously detailed accounts of its role in this region exist: Bloomberg (1950), Cormack (1935), and Horton (1956). Following fire a dense stand of lodgepole pine will become established. This takes ten or more years, during which time spruce will seed in, providing a seed source is reasonably close. After this only occasional individuals will germinate and survive. If the site is adverse, spruce seedlings will evolve only in rare years when conditions are optimum. After about 150 years the spruce will begin to replace the pine as dominants. Thus in an old spruce stand there is usually an overstorey which is to all intents even-aged (Bloomberg found that it comprised more than 80 per cent of the trees), with smaller size classes being composed mainly of old trees suppressed to varying degrees. Even advance growth was often found to be well over 100 years old. Hence, appearances may well be deceiving, seemingly uneven-aged stands actually being preponderantly old. This is the explanation for the majority of practically even-aged stands.

The uneven-aged stands that were found probably originated in understocked conditions with a ready seed source from scattered residual trees. Barnes (1937) described the structure of an uneven-aged Engelmann spruce cover type in central British Columbia which was apparently virgin (fire excluded). He suggested a cyclic development resulting in the uneven-aged condition. Older age classes develop rapidly, suppressing the younger. Maturity is marked by a short period of slow but constant growth, followed by decadence, which opens up the stand to release the understorey and renew the cycle. Oosting and Reed (1952) found that extreme unevenness of ages and sizes of *P. engelmanni* and *A. lasiocarpa* with numerous standing dead trees, characterized virgin forests in Wyoming. This condition, which implies great stand age, would be exceptional in Alberta according to the present survey.

Growth

Growth in these forests is relatively slow because of the rigorous subalpine conditions. Dominant height at overmaturity averages around 90 feet. The general diameter growth trend of dominant trees is shown in Figure 3, the curve representing the average of close to 200 samples. The outstanding feature here is the persistence of reasonable growth at advanced ages. This concurs with a report by Lebarron and Jemison (1953) on Engelmann spruce farther south.

The ability to recover after long periods of suppression is a well recognized trait of spruce and, in some cases, fir (Hodson and Foster 1910, Pearson 1931, Betts 1945, Pogue 1946, DeGrace 1950 a&b, Oosting and Reed 1952, Horton 1956b). There was no evidence in this study that the response to release decreased with age. It was encountered in some of the oldest trees—almost 400 years of age, and it was found in trees of all sizes. However, some recent workers have suggested that it cannot be relied upon in older trees (Smith 1955, Alexander 1956).

The total amount of suppression in old spruce stands may seem discouraging but the proclivity towards release compensates and often ensures the continuation of the species in stands where natural reproduction is scarce.

Natural Reproduction

Conditions in the fully developed spruce-fir stand do not encourage natural reproduction of spruce. The origin and seedbed medium of all the reproduction sampled in the present study was assessed, with the following results:

TABLE 6.—SEEDBED ORIGIN OF REPRODUCTION.

Species	Relative Per Cent—All Types and Sites				
	Rotten Wood	Moss Duff	Needle Duff	Mineral Soil	Unknown
Spruce	64	16	3	6	11
Fir	41	23	25	4	7

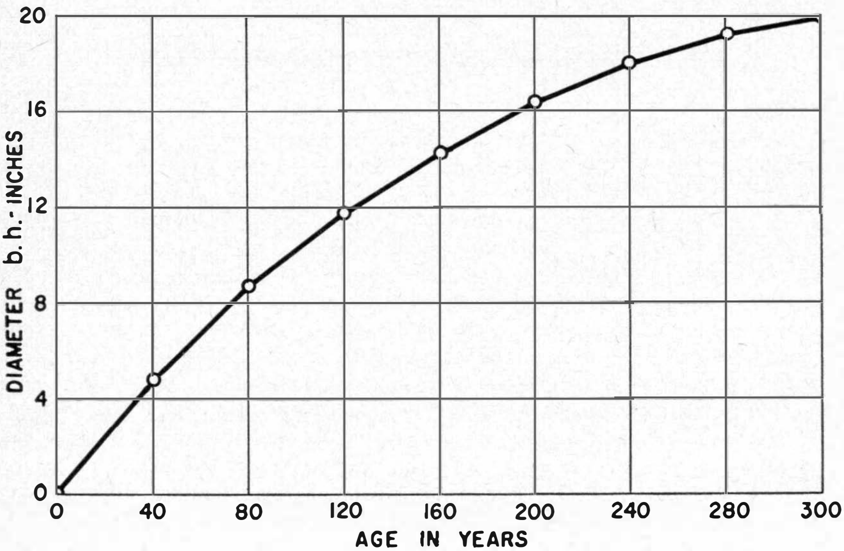

Figure 3. Average radial growth curve of dominant spruce, all types and sites.

Two-thirds of the spruce seedlings originated on rotten wood, an occurrence which has frequently been noted elsewhere in spruce stands and has been described in detail by McCullough (1948) for Engelmann spruce and by Rowe (1955) for white spruce.

Fir reproduction well outnumbers spruce in all taxonomic types except the G, where it is often entirely lacking, being replaced sometimes by black spruce. Almost one-half (44 per cent) of all fir reproduction originated as layers (a conservative estimate considering that only one member of each layer clone was tallied). Moreover, fir seedlings appear better adapted to establishment on moss and needle duff than spruce. Thus fir exhibits more reproductive versatility and a wider tolerance for seedbed conditions than spruce, both distinct ecological advantages.

The data of Table 6 concur with the findings from an intensive survey of the spruce-fir understorey in a hybrid spruce stand at Kananaskis, Alberta (Horton 1956b). They also agree, in effect, with Smith's (1955) figures for an Engelmann spruce-alpine fir forest in interior British Columbia, although in that case all spruce seedlings were confined to rotten wood and mineral soil seedbeds. Opinion is virtually unanimous that these two media provide the best natural seedbed for spruce in both Engelmann and white spruce types. Exposed mineral soil is rare in the undisturbed forest but invariably supports both spruce and fir reproduction. Humus, of both moss and litter origin, is usually too thick to be penetrated by spruce seedling roots before the upper layers dry. Fir seedlings, however, by virtue of their fast initial root growth, can survive on this medium (Hodson and Foster 1910, Lowdermilk 1925, Westveld 1931, Long 1947, Place 1953, Smith 1955).

A large numerical superiority of fir over spruce in natural reproduction and advance growth appears to be characteristic of overmature spruce-fir stands. The fir understorey content apparently increases with stand age (Bloomberg 1950, Horton 1956b). According to Oosting and Reed (1952), relatively few Engelmann spruce seedlings become established but their survival rate is high, whereas the reverse is true with fir. In western white spruce stands the amount of reproduction is somewhat greater than in Engelmann spruce by the present sample, but not necessarily to the extent of satisfactorily perpetuating the spruce content as DeGrace (1950 a&b) indicated.

DISCUSSION OF SILVICULTURAL METHODS

Regeneration

The usual inadequacy of natural reproduction of spruce in the old stands is attributed to its inability to germinate and survive satisfactorily on moss and litter seedbeds. Some form of seedbed improvement is necessary to obtain acceptable stocking in regeneration when these stands are logged. Both broadcast burning and mechanical ground scarification have been advocated for this purpose by workers in various regions throughout the ranges of white and Engelmann spruce. Because of the hazard of burning, scarification is favoured in Alberta, and several trials have been initiated to develop efficient techniques (Crossley 1952, Quaite 1956, and Ackerman 1958). Scarification may, as Smith (1955) points out, be the simplest way of favouring spruce over fir by synchronizing the operation with a bumper seed crop of spruce and a poor one of fir.

Fir is at present considered a weed species in this region. Since it thrives on practically all seedbed conditions in the Engelmann and intermediate types, it may be necessary to undertake cleaning operations to favour the spruce. However, fir is valuable locally in parks and for protecting watersheds. Some day, also, it may acquire the marketability of its counterpart in the east. Thus it should not be discounted, particularly in view of its high regenerative capacity even on extreme sites. It may be that a combination of methods—natural regeneration of fir plus selective planting of spruce—is the most efficient way to regenerate some cut-over conditions.

In any case, if planting of spruce is visualized, attention should be paid to the genetical variation in the region—the introgression pattern of the two species. Progeny tests should be carried out to determine the best suitability of spruce type (species or hybrid) to habitat.

In certain stands, mainly more open-stocked, often disturbed by a light patchy ground fire, spruce reproduction was observed sometimes in abundance. DeGrace (1950a) reports satisfactory reproduction in partially logged stands in the region after some years, although his standard of adequacy, about 300 trees per acre, seems low. The point is that there will be some stands where present advance growth is already acceptable for restocking the area; in such cases harvesting should be planned so as to conserve it.

Cutting Methods

Considerable controversy has developed in the west concerning the most suitable cutting system for the spruce-fir cover type, both clear and selection cutting being advocated. The disagreement has arisen largely because of actual differences in age class structure, between regions and between stands. There are many factors involved but age is primary, since most spruce-fir stands are over 200 years old and, according to a study by Etheridge (1956), the incidence of decay in spruce after 100 years increases rapidly, particularly on the moist sites. Considering the potential loss from decay and from windfall incurred by decay, it is evident that some form of clear cutting is required for the 75 per cent of stands in western Alberta which are essentially even-aged.

Lebarron and Jemison (1953) made this contention for Engelmann spruce-fir stands in the United States, pointing out other advantages of clear cutting over partial cutting, i.e., that it results in simultaneous treatments for slash, unwanted alpine fir advance growth, and seedbed conditions by enabling the efficient use of heavy machinery such as crawler tractors.

Flexibility may be achieved through partial clear cutting, using various techniques suited to different conditions of stand distribution and size, terrain, wind susceptibility and so forth. Irregular clear cut blocks of about 40 acres are recommended by Lebarron and Jemison (1953) for the Northwest States, together with seedbed scarification for natural regeneration, or planting or seeding if necessary. In the Colorado Rockies, the group selection method, removing 50 per cent of the merchantable volume in clear cut areas of about one chain in diameter, has produced good results in that windfall damage was low and spruce regeneration exceeded that of fir (Love and Dunford 1952), but logging costs and damage to residuals proved to be high. Alternate clear cutting in strips of one chain width is favoured over group selection and single-tree selection when all factors are considered (Alexander 1956). Logging damage to residual trees is the main silvicultural objection to selection systems, particularly in this era of heavy mechanization.

For all-aged stands the single tree selection method of harvesting is generally advocated. Adequate advance growth and protection against windfall are prerequisites to this system. The reproduction aspect of Alberta's east slope forests has already been dealt with; as to windfall, according to DeGrace (1950 a&b) it is not a serious problem if a reasonable residual stand is left.

DeGrace maintains that selection cutting is admirably adapted to stand conditions and logging economics in the region. His arguments are not applicable to the even-aged stands but they hold well for the uneven or more irregular-aged stands. A full description of the implementation of a true silvicultural selection method is contained in DeGrace's papers, and further details on marking techniques for spruce stands may be found in DeGrace, Robinson and

Smith (1952). The approach was designed to supplant the economic selective cutting based on a diameter limit which has been a general practice in the spruce forestry of Alberta and British Columbia.

In order to decide on the most suitable silviculture for any spruce stand it is essential that the stand be judged on its individual characteristics. Smith (1955), in discussing the relative applicability of clear and partial cutting, gives some helpful criteria for choosing between them through size class distribution. He states that even-aged stands more than 150 years of age should be clear cut because in British Columbia few of the smaller trees of that age respond well to release. Age structure certainly seems to be the primary consideration in the question of clear versus selection cutting in Alberta. Before the decision on actual cutting technique for any particular stand is reached, however, a balance must be struck between all local considerations, the economics of logging and regeneration, the protection of residual timber against wind, fire, insects, and disease. Then, reference to experience is required—to past cutting experience in the locality, and to the experiments of others in similar conditions elsewhere, such as those outlined above.

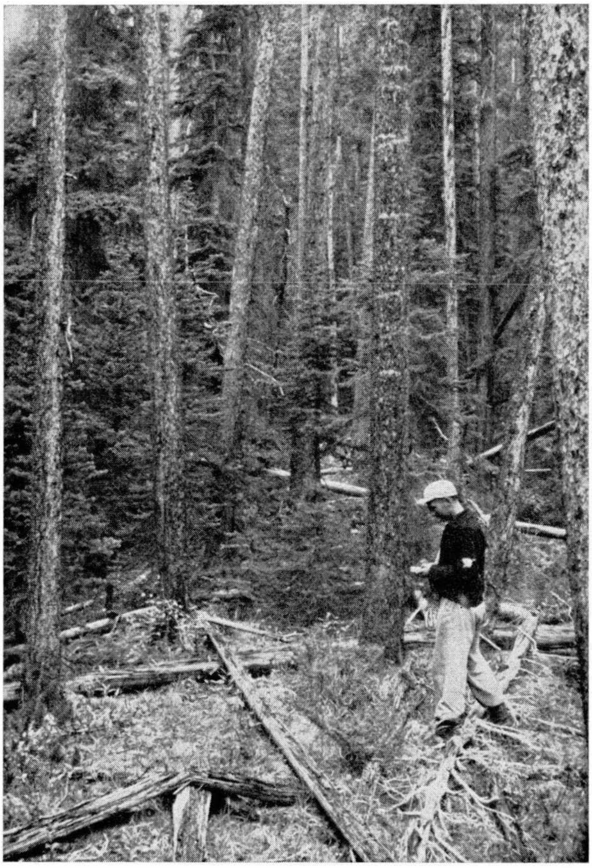

Figure 4. Interior of overmature hybrid spruce-alpine fir stand, showing abundant fir reproduction.

SUMMARY

The spruce forests of the Alberta Rocky Mountain region are examined as to taxonomy, ecology and silviculture.

Introgressive hybridization apparently exists, with white spruce occupying lower elevations, Engelmann upper, and a hybrid swarm (intermediate) between. A method of assessing the degree of hybridity of any sample is shown, an index based on cone morphology.

Typical and intermediate spruce types are compared by standardized samples and are shown to be generally similar in such points as age structure and growth. Differences include a higher incidence of fir and scarcer spruce reproduction in the Engelmann stands.

Ecological and silvicultural highlights of the spruce-fir type in general are reviewed. In structure, 75 per cent of stands are thought to be largely even-aged; for these, some form of clear cutting is considered most suitable. Uneven-aged stands are best suited to the single tree selection system on which references are given. Spruce natural reproduction is shown to be inadequate in most undisturbed stands; the advantages of scarification as a remedy are discussed in brief.

The emphasis is on treating each stand according to its individual characteristics, avoiding generalization.

REFERENCES

Ackerman, R. F. 1958. The effect of seed crop periodicity on the reproduction of subalpine spruce after clear cutting and scarifying. Canada, Dept. Northern Affairs and National Resources, For. Br., For. Res. Div. Unpub. Report.

Alexander, R. R. 1956. A comparison of growth and mortality following cutting in old-growth mountain spruce-fir stands. Rocky Mt. For. and Range Expt. Stn., Res. Note No. 20.

Anderson, E. 1949. Introgressive hybridization. 108 pp. John Wiley and Sons, New York.

Barnes, G. H. 1937. The development of uneven-aged stands of Engelmann spruce and probable developments of residual stands after logging. For. Chron., 13 (3): 417-457.

Betts, H. S. 1945. Engelmann spruce. U. S. Dept. Agric. For. Serv., American Woods Series.

Bloomberg, W. J. 1950. Fire and spruce. For. Chron., 26 (2): 157-161.

Brown, Stewardson. 1907. Torreya 7: 126. *Quoted by* Sudworth, G. B. 1916. The spruce and balsam fir trees of the Rocky Mountain region. U. S. Dept. Agric. Bull. No. 327.

Cormack, R. G. H. 1953. A survey of coniferous forest succession in the eastern Rockies. For. Chron. 29 (3): 218-232.

Crossley, D. I. 1952. White spruce reproduction resulting from various methods of forest soil scarification. Canada, Dept. Resources and Development, For. Br., For. Res. Div. Silv. Res. Note No. 102.

DeGrace, L. A. 1950a. Selective logging of spruce in subalpine Alberta. Canada, Dept. Resources and Development, For. Br., For. Res. Div. Silv. Res. Note No. 96.

———1950b. Management of spruce on the east slope of the Canadian Rockies. Canada, Dept. Resources and Development, For. Br., For. Res. Div. Silv. Res. Note No. 97.

DeGrace, L. A., E. W. Robinson and J. H. G. Smith. 1952. Marking of spruce in the Fort George Forest District. British Columbia Forest Service, Res. Note No. 20.

Etheridge, D. E. 1956. Decay in subalpine spruce on the Rocky Mountain Forest Reserve in Alberta. Can. J. Bot. 34: 805-816.

Garman, E. H. 1957. The occurrence of spruce in the interior of British Columbia. B. C. Forest Service Tech. publ. T. 49. 31 pp.

Hodson, E. R. and J. H. Foster. 1910. Engelmann spruce in the Rocky Mountains, U. S. Dept. Agric. For. Serv., Circ. 170.

HORTON, K. W. 1956a. A taxonomic and ecological study of *Picea glauca* and *Picea engelmanni* in North America. Thesis for Dip. For., Oxford University.

———1956b. The ecology of lodgepole pine in Alberta and its role in forest succession. Canada, Dept. Northern Affairs and National Resources, For. Br., For. Res. Div. Tech. Note No. 45.

LEBARRON, R. K. and G. M. JEMISON. 1953. Ecology and silviculture of the Engelmann spruce-alpine fir type. Jour. For. 51 (5): 349-355.

LONG, H. D. 1947. The prevention of regeneration failure of pulpwood species. Pulp and Paper Res. Inst. of Canada, Woodlands Section, Index 27 (F-2) 6 pp.

LOVE, L. D. and E. G. DUNFORD. 1952. The Fraser Experimental Forest—its work and aims. Rocky Mt. For. and Range Expt. Stn., Paper No. 8.

LOWDERMILK, W O. 1925. Factors affecting reproduction of Engelmann spruce. Jour. Agric. Res. 30 (11): 995-1009.

McCULLOUGH, H. A. 1948. Plant succession on fallen logs in a virgin spruce-fir forest. Ecology 23: 508-513.

MOSS, E. H. 1955. The vegetation of Alberta. Bot. Rev. 21 (9): 493-567.

OOSTING, H. J. and J. F. REED. 1952. Virgin spruce-fir forest in the Medicine Bow Mountains, Wyoming. Ecol. Monog. 22: 69-91.

PEARSON, G. A. 1931. Forest types in the south west as determined by climate and soil. U. S. Dept. Agric., Tech. Bull. No. 247, 143 pp.

PLACE, I. C. M. 1955. The influence of seedbed conditions on the regeneration of spruce and balsam fir. Canada, Dept. Northern Affairs and National Resources, For. Br. Bull. 117.

POGUE, H. M. 1946. Regeneration and growth of white spruce after logging. British Columbia Forest Service. Bull. T 29.

QUAITE, J. 1956. Survival of white spruce seedlings resulting from scarification in a partially cut mixedwood stand. Canada, Dept. Northern Affairs and National Resources, Forestry Br., For Res. Div. Tech. Note No. 44.

ROWE, J. S. 1955. Influence of litter and humus on spruce reproduction in a cutover mixedwood stand; Riding Mountain, Manitoba. Canada, Dept. Northern Affairs and National Resources, For. Br., For. Res. Div. Tech. Note No. 3. 27 pp.

SMITH, J. H. G. 1955. Some factors affecting reproduction of Engelmann spruce and alpine fir. British Columbia Forest Servicc, Tech. Pub. T. 43.

WESTVELD, M. 1931. Reproduction on pulpwood lands in the north east. U. S. Dept. Agric. Tech. Bull. No. 223. 32 pp.

WRIGHT, J. W. 1955. Species crossability in spruce in relation to distribution and taxonomy. For. Sci. 1 (4): 319-349.