FORESTRY COMMISSION

BULLETIN No. 25

Studies of North-West American Forests in relation to Silviculture in Great Britain

BY R. F. WOOD

LONDON: HER MAJESTY'S STATIONERY OFFICE

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R. F. WOOD, B.A., B.Sc.
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1955

FOREWORD

During 1952 and 1953, Mr. R. F. Wood, one of the Commission's forest officers, who had been awarded a Travelling Fellowship by the Nuffield Foundation, visited the forests of British Columbia and the neighbouring territories, to carry out field studies. This region is the home of several trees, such as the Sitka spruce and the Douglas fir, which have become important in British silviculture, but few comparative studies of the two environments, in relation to tree growth, had hitherto been made. The purpose of this Bulletin is to examine and discuss the growth of these timber trees, as observed in North-West America, with particular reference to its implications for forestry practice in the British Isles.

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I. INTRODUCTION

This report arises out of a nine-months visit (between June, 1952 and April, 1953) to British Columbia and adjacent regions of the Pacific Coast, which was made possible by the award of a Civil Service Travelling Fellowship of the Nuffield Foundation. The principle object was " .... to study in their native habitat, a group of coniferous species which have been widely planted in Great Britain .....", and a secondary object "..... to make personal contacts with foresters and research workers in the Forest Service, and by so doing obtain unpublished information about the trees concerned and make provision for future exchange of knowledge".

Grateful acknowledgments are due to the Nuffield Foundation; and to the British Columbian Forest Service under Dr. C. D. Orchard (Deputy Minister) for facilities and much kind assistance.

I was fortunate in being invited to join the Forestry Commission delegation to the British Commonwealth Forestry Conference for the tour arranged by the British Columbian Government. This tour provided a good cross section through the southern part of British Columbia from the Rockies to the Pacific. Apart from this my visits were largely confined to the Coastal Forest, and since this extends south of British Columbia through the States of Washington and Oregon and also to the north into Alaska, I thought it desirable to extend my visits to regions outside British Columbia which are close enough to Britain in climate to be of special interest.

A further advantage was the opportunity to see something of the field studies on Sitka spruce and its associates conducted by Mr. W. R. Day of the Imperial Forest Institute, Oxford. His interesting work in the Queen Charlotte Islands and the Skeena River region, and that of Mr. Ralph Schmidt of the British Columbian Forest Service Research Division, provided some very stimulating ideas. This report, however, deals with more general topics, and designedly avoids any serious comment on the edaphic factors such as can be expected to follow Mr. Day's investigations.

The range of territory "sampled", (I hasten to disclaim covering it!) extended from Juneau in Alaska to the Columbia River. I based myself in Victoria, and I am greatly indebted to Mr. R. H. Spilsbury and his staff in the British Columbian Forest Service Research Division for their hospitality and assistance.

During my stay I visited other principal Research establishments dealing with coast forest conditions, such as the Pacific North West Forest and Range Experimental Station at Portland, Oregon, U.S.A., the Alaskan Forest Research Centre, Juneau, and the University of British Columbia; and in addition I met numerous interesting people connected with forestry and the forest industries. The contacts made have been most valuable.

The first thing that strikes the visiting forester travelling from the east into and through British Columbia is the great variety of forest types through which he is passing. He may (I personally admit to it) have some vague idea that on passing through the Rockies into British Columbia some approach to Western European conditions will become apparent. He will be quickly undeceived, and on turning to the authorities on the climate of British Columbia he will find the climatic conditions of Kamloops and Prince George likened by Chapman (1952) to those of Saratov and Moscow (Russia), respectively. The range of climate in British Columbia is in fact enormous.

The British forester will already be aware that his chief interests lie in the Coast Forest, as defined by Weaver and Clements (1938) and Halliday (1950). There is a good deal of misconception about the term "coastal". In the above sense the Coastal Forest is one of the primary ecological divisions of the North American Continent, typified by the climax dominants *Thuja plicata* and *Tsuga heterophylla*, other important species such as Douglas fir and Sitka spruce occurring in association. This "formation" or forest region extends to a very great length along the Pacific coast. Its depth is variable; roughly speaking the inland boundaries are the British Columbian Coast Mountains, and further south, the Cascade Mountains of Washington and Oregon, which are unrelated geologically but physically almost continuous.

This is a very great region containing much physiographic and climatic variation. We in Britain are chiefly interested in the northern part of it, the area indicated on the map (see central inset). It is desirable to have some broad classification of the tract for descriptive purposes.

The following scheme is a mixture of political and physiographical divisions, but without begging certain questions to be later discussed, it is sufficiently "natural" for our purpose.

South East Alaska
- Outer Islands
- Inner Islands
- Coast

British Columbia, Canada
- Queen Charlotte Islands
- North Coast (from Alaskan boundary to opposite northern tip of Vancouver Island).
- South Coast (coast opposite Vancouver Island)
- Georgia Straits Islands (Straits between Vancouver Island and South coast)
- Vancouver Island
  - East
  - West

Juan de Fuca Straits Islands (Straits between Vancouver Island and Washington North Coast)

Washington, U.S.A.
- North Coast (Cape Flattery to Puget Sound)
- West Coast (Western drainage of Olympics and Coast Range)
- Olympics
- Cascades
- Puget
- Sound of Puget (the low level basin from the Puget Sound to the Columbia River).

During this tour I have tried to look at the various species as if seeing them for the first time, and to avoid merely searching for confirmation of what we think we know. Of course, it is neither possible nor desirable to put home experience altogether out of mind, but I have written the report so far as practicable from the North-West American coast view point rather than the home one.

II. NORTH-WESTERN AMERICAN COASTAL AND BRITISH ISLES ENVIRONMENTS

This chapter is concerned almost entirely with climate; the word 'environment' may be excused by reason of some meagre remarks about other site factors.

An effort is made to bring out the main features, similarities and dis-similarities, of the various climates represented in the two regions; it relies entirely on published accounts, though some data have been worked up and presented in an original manner to illustrate particular points.

Meterorological data for the Pacific coast are available in the various British Columbian and United States Government publications listed in the bibliography. A valuable recent account of the climate of British Columbia is that of Chapman (1952). Bilham (1938), and Manley (1952) have been the main guides for the British climate.

No attempt will be made to describe the climatic controls operating in the two regions, but it should be pointed out that there are considerable differences in this respect, and that similarities in climate are due to the interplay of different factors. Hence it is very common to find that similarities are more apparent than real—similar means arise from different distributions. Since we usually have to work with rather crude means it is as well to keep this in mind at all times.

The North Pacific Coastal region of North America (as defined above), although only a relatively narrow fringe of the territory west of the Rockies, contains a much greater variety in climate than we experience in Britain. Chapman (1952) has compiled a climatic classification and mapped British Columbia following the system of Köppen. Most of Vancouver Island (except the dry south-east corner and certain high ground), the Charlotte Islands, and a coastal belt of width not usually exceeding 100 miles (widest at the main fiords and "through valleys") is included in Köppen's "Cfb" class. This is defined as follows:—

> "Mean of coldest month less than 64.4°F, but more than 26.6°F. Mean of warmest month over 50°F. No distinct dry season, driest month of summer exceeding 1.2 ins. of rainfall. Mean of warmest month less than 71.6°F."

Outside of British Columbia this class would include most of Washington west of the Cascade Mountains; but an area shadowed by the Olympic Mountains in the Puget Sound region would link up with the south-east corner of Vancouver Island, falling into the "Csb" or Mediterranean type with less than 1.2 ins. in the driest summer month. Northwards, most of South East Alaska would fall into the "Cfb" type. Inland it is limited by increasing continentality, the winter means falling below 26.6°F. It is in fact a very coarse class but on a map of continental scale looks very like Weaver and Clements' "Cedar-Hemlock association of the Coast forest" (Weaver and Clements 1938). The whole of Britain at reasonable elevations would fall into it. Köppen's classification is now chiefly of historic interest; but since his "Cfb" class does with reasonable success define a broad zone which is regarded as having considerable ecological unity, it is of some value to recognise that the range of our conditions is less.

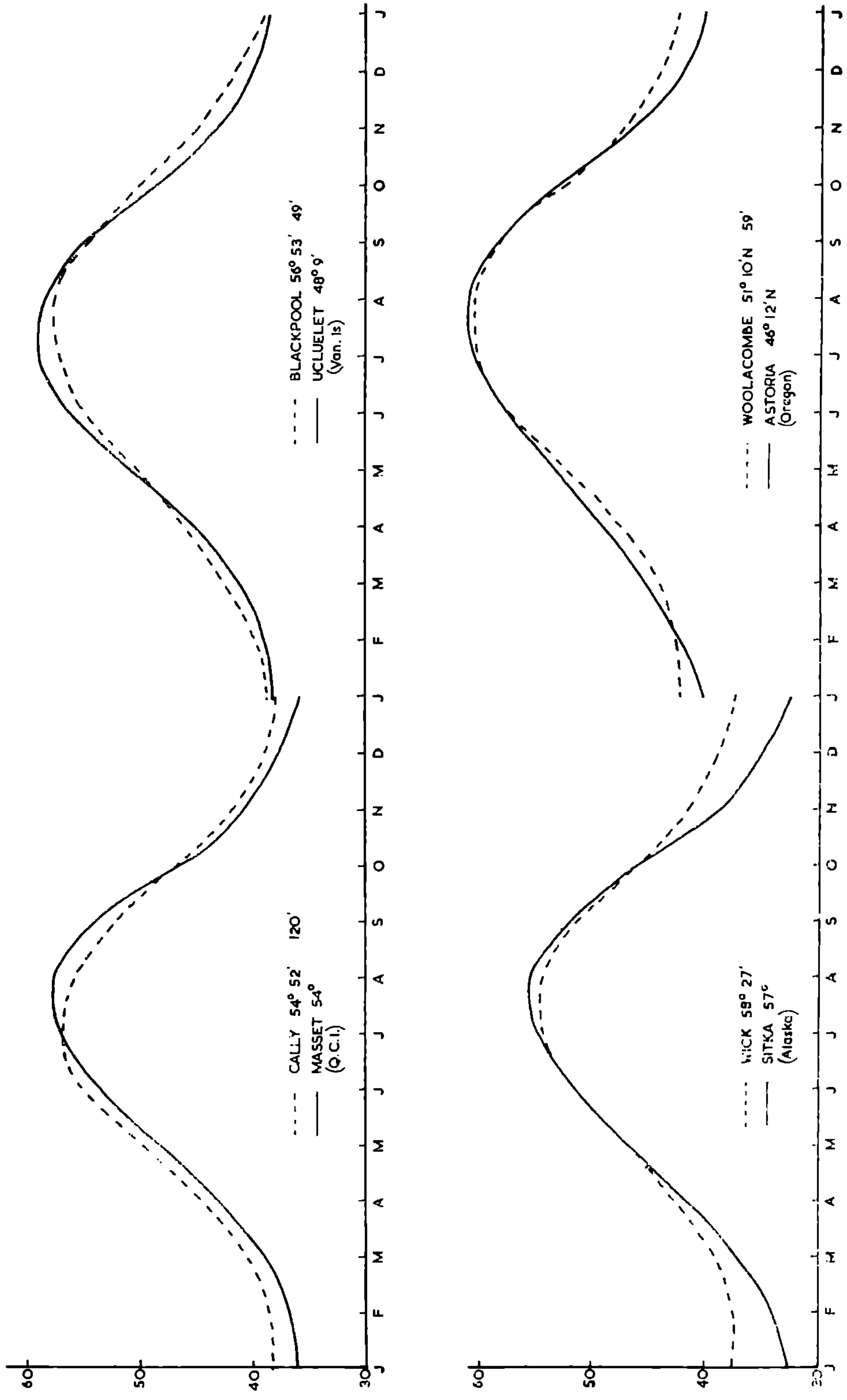


Figure 1 Mean Monthly Temperatures for Pacific Coast (—) and British Isles (- - - -) Stations.

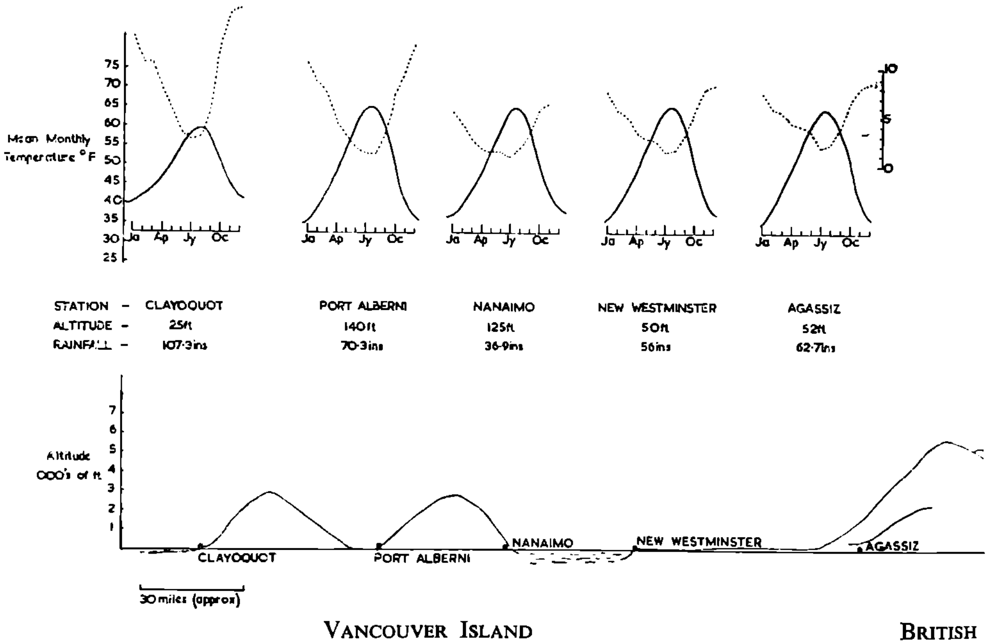


Figure 2 Temperature and Rainfall Diagrams

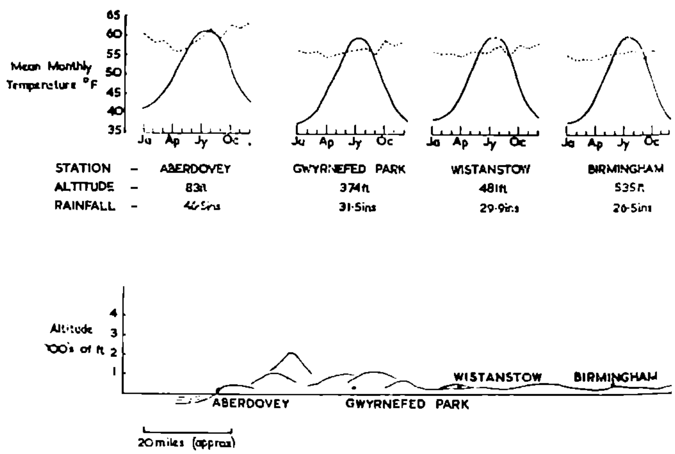
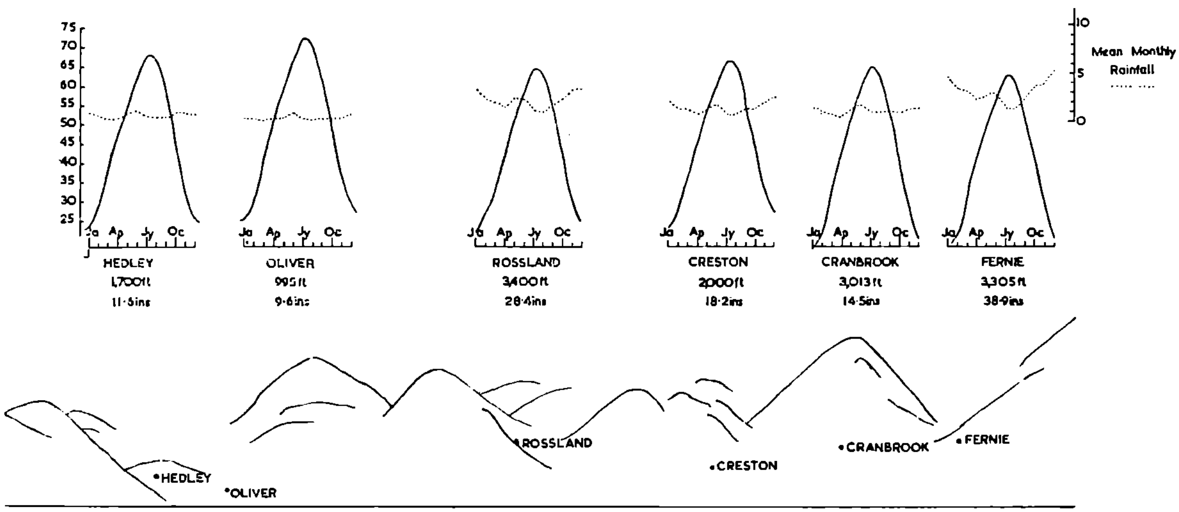
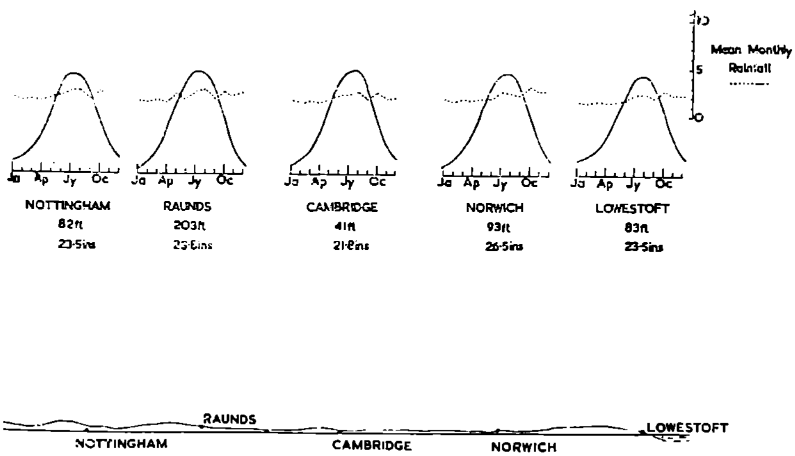


Figure 3 Temperature and Rainfall Diagrams for a Section



Columbia Coast Mountains Rocky Mountains

for a Section across British Columbia near 49°N.



across England and Wales between 52°5N. and 52°50N.

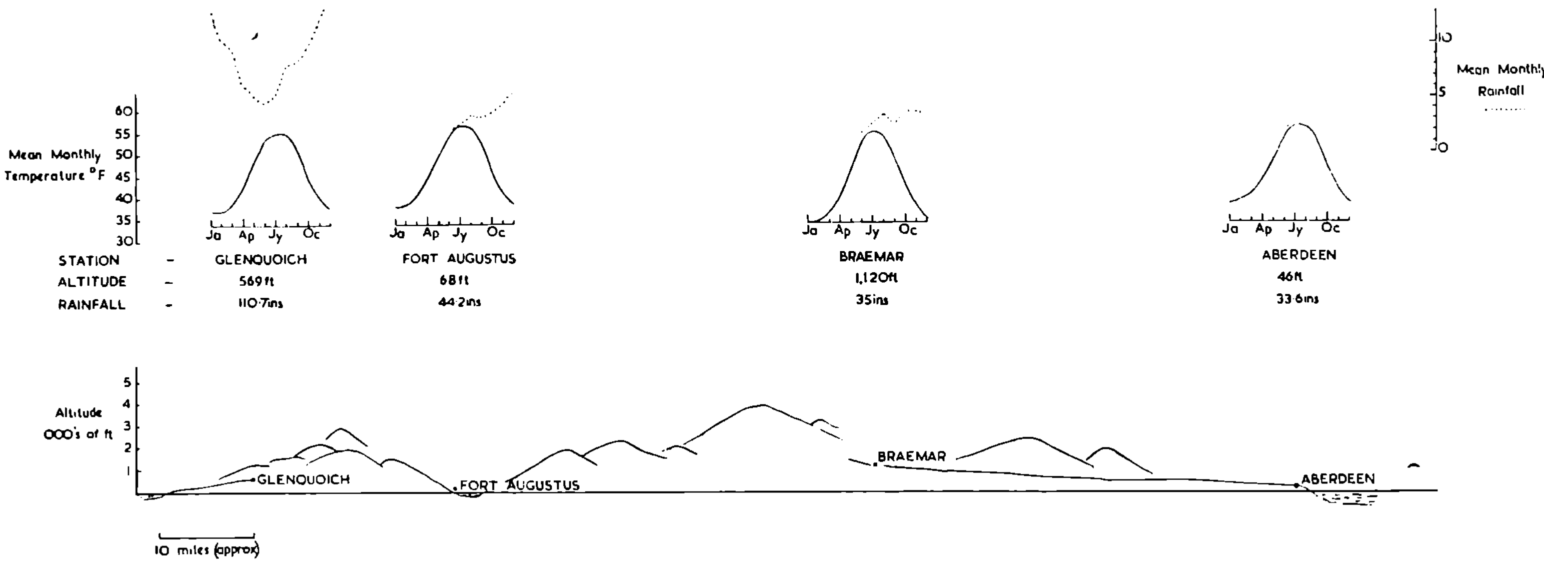


Figure 4 Temperature and Rainfall Diagrams for a Section across Scotland between 57°N. and 57° 10'N.

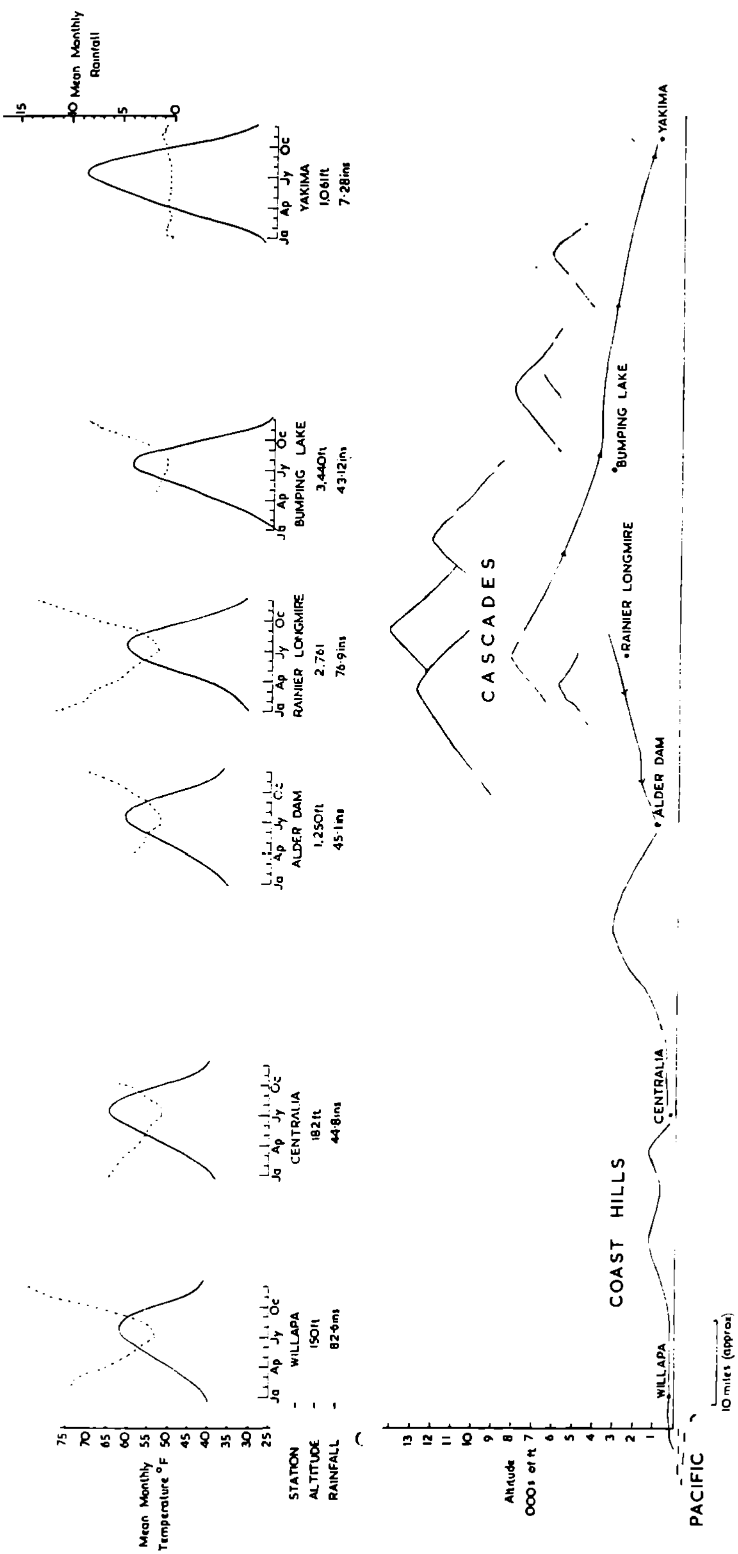


Figure 5 Temperature and Rainfall Diagrams for a Section across Washington, U.S.A., near 47°N.

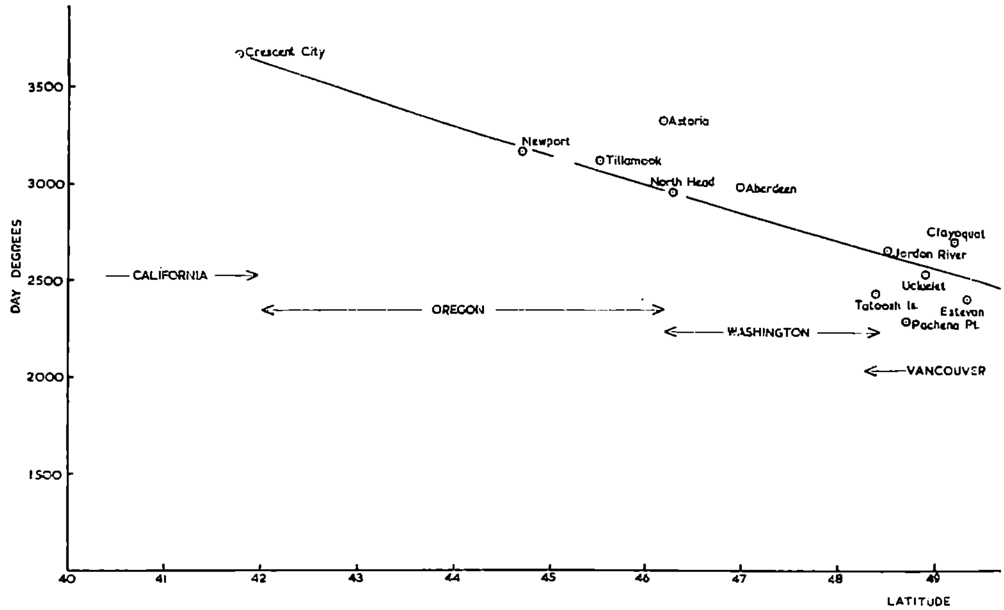


Figure 6 Summer Warmth—Day Degrees over 42°F. Pacific Coast (full line

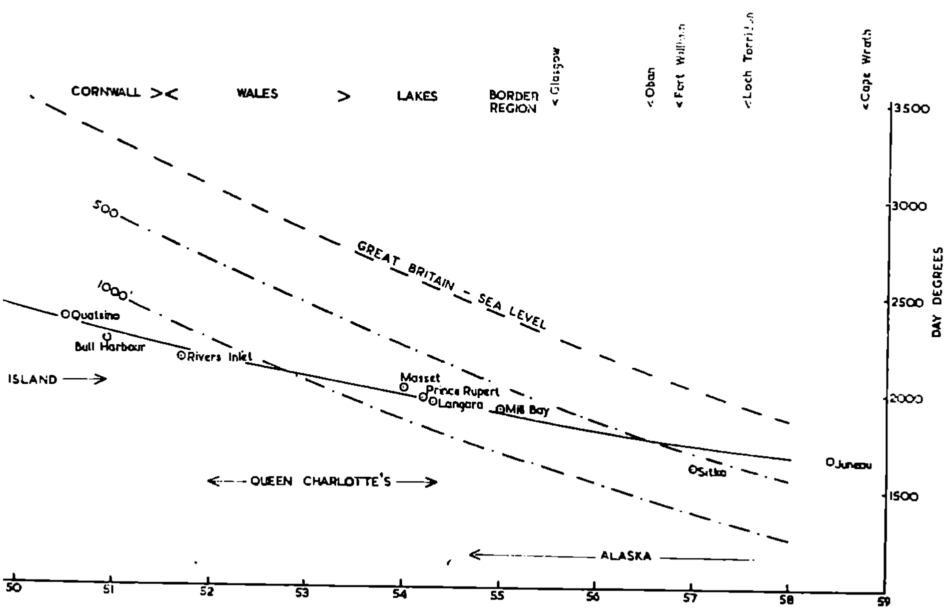
Temperature regime

Mean monthly temperature curves of truly coastal stations on the North Pacific seaboard of North America differ more one from the other in respect of their lengths above a given temperature (say 42°F) than in their summer or winter means. All have of course the mark of an oceanic temperature regime, a low annual range of mean temperature. British west coast stations have very similar curves, the four pairs of curves (American and British) shown in Fig. 1 have been chosen on their approximately equal area above 42 degs.

The whole of Britain experiences a more or less oceanic temperature regime, only a small area in the Thames Estuary has a mean annual range exceeding 24°F. (Bilham 1938). But on the Pacific coast of North-West America a comparatively shallow penetration inland is sufficient to produce a mean annual range much greater than this. Thus Ucluelet on the west coast of Vancouver Island has a mean annual range of 20°F. whilst Alberni at the head of the fiord nearby has a mean annual range of 30°F. (Chapman 1952). Hence we can match the British temperature regime only in a very restricted zone on the American Pacific coast, and as the extreme oceanic fringe is left behind, each successive barrier gives rise to increasingly continental conditions, with higher summer temperatures, lower winter ones and shortened growing season. Figs. 2 and 5 illustrate the effects of the main ranges in British Columbia and Washington in this respect; for the sake of interest the sections are taken well beyond the limits of the coast forest. They may be compared with Figs. 3 and 4, which illustrate the much less dramatic patterns across Britain.

Inside the coastal region of British Columbia, Chapman (1952) recognises four divisions, namely Outer Coastal, Inner Coastal, Fiords, and Through Valleys. Of these, the Outer Coastal is the one to which we approach nearest in temperature climate. Chapman's Inner Coastal division, regions in the lee of the Vancouver Island Mountains, is an area one step removed from the strictly oceanic temperature regime of the Outer Coast. The Fiords and Through Valleys according to Chapman provide more extreme temperatures and shorter frost-free periods. They may be subject to sharp reversals of temperature due to the drainage of cold air from the mountains. Certain Through Valleys provide more or less continuous transitions from oceanic to continental climates.

Quite similar divisions could be made for South East Alaska, where the outer islands are analogous to Chapman's Outer Coastal division, and the inner islands and coastline to his Inner Coastal. In Washington, the transition between the extreme coastal fringe and the more continental conditions in the broad basin south of the Puget Sound is probably rather gradual, the low Coast Hills not providing a very prominent barrier.



for sea level) and Great Britain (broken lines for three different elevations).

Summer Warmth

It is useful to have some better measure of summer warmth than is provided by July mean temperatures. "Accumulated temperature" calculated by the abbreviated procedure suggested by Miller (1950) (monthly mean temperature — 42°F. × days in the month) has been used for this purpose. This has the advantage of giving some credit to the length of the vegetative period. It has been calculated for as many stations as possible in British Columbia, South East Alaska, and Washington west of the Cascades, and an effort has been made to map the distribution (See Map). Owing to the absence of high level stations in British Columbia no attempt has been made to suggest the distribution other than at sea level or thereabouts. But in Washington there are sufficient stations along the slopes of the Cascades to get some idea of the fall-off with increasing altitude. The principal point illustrated by the map is the rise in growing season temperatures accompanying any removal from the full oceanic influence. Thus a considerable area in South East Alaska in the protection of Prince of Wales Island is as 'warm' as the Charlotte Islands, the east side of Vancouver Island is warmer than the west, and there is a very warm zone in Washington southwards from the Puget Sound which is only bounded on the east by the rise of the Cascade Range. Accumulated temperatures for purely coastal stations on the Pacific have been plotted against latitude, and a corresponding curve for the coast, with derived curves for the 500 foot elevation, and the 1,000 foot elevation in Britain have been superimposed (see Fig. 6).

It will be noticed that we are warmer, latitude for latitude, than the Pacific coast—due to our higher sea temperatures; the difference naturally diminishes northwards. On this measure of growing season temperature, the coasts of Britain experience a range of between 3,000 and 1,500 day-degrees, which is roughly equivalent to the difference in warmth between Sitka (Baranoff Island, S.E. Alaska) and the mouth of the Columbia River.

While there is some increase in continentality inside Britain, particularly to the south-east, this is not accompanied by any marked increase in accumulated temperature, the longer growing season on the west coast balancing the higher summer temperatures experienced inland.

We are more concerned with the climate in the hills than at sea level. Manley (1952) discusses the effects of increased elevation on growing season temperatures in an oceanic climate. Regarding the *area* of the mean temperature curve over 42°F. as some indication of the heat energy available to plants in the vegetative period, he shows that this *area* is reduced to a greater degree by a given ascent in an oceanic climate than in a more continental one, assuming the normal lapse rate with altitude to apply in both cases.

It is particularly important for us to have some idea of the reduction in growing season warmth with altitude in Britain, since it is such a large factor in our oceanic climate. An effort has been made to suggest the probable range of accumulated temperature to be found in a given altitudinal range in Britain by applying the normal lapse rate for altitude (1°F. in 280 feet) to monthly mean temperatures typical of low level stations over our latitudinal range. The curves for 500 foot and 1,000 foot elevations in Britain, shown on Fig. 6, are derived in this way. The procedure is admittedly rough, but probably gives a reasonable idea of how our summer warmth in Britain up to moderate elevations compares with that of the American Pacific coast at sea level.

Extreme temperatures

We are probably not greatly concerned with winter minima and summer maxima; it is sufficient to note that any penetration inland on the American Pacific Coast will give a greater range of extremes than we experience at comparable latitudes. The "frost-free period" is more important, but not an easy feature to compare between the two regions. The statistic used in the United States and British Columbia is the period between the mean dates of occurrence of the latest and earliest frosts (a reading of 32°F. or less in the Stevenson Screen). This has been mapped for Washington (Climate of the States) but not for British Columbia, where the physiography is too complicated and the meteorological stations too sparse. For Britain, *The Climatological Atlas of the British Isles* (1952) maps the *mean dates* of occurrence of earliest and latest frosts.

It is quite clear that the frost-free period as charted for Washington is closely connected with continentality, relatively high values being experienced in the truly oceanic fringe (up to 300 days), dropping quickly in the lee of this Coast Range to values of 200 days. The period shortens again as the Cascades rise, falling to 150 days at about 2,000 feet elevation.

British Columbia does not record any frost-free periods quite as long as 300 days, but most of the exposed west coast stations exceed 200 days. "Fiord" and "through valley" stations may have much shorter periods; Bella Coola shows only 144 days, as against 229 days for a station to seaward in the same fiord system. Terrace, 90 miles up the Skeena River from Prince Rupert, has only 132 days against the latter's 198.

In South-East Alaska the frost-free period probably varies between 200 days for some of the outer islands in the south, and 100 days in some of the northern fiords.

The main objection to the use of this statistic as a measure of length of growing season is that it equates rather different kinds of "length". In a climate of some degree of continentality the rise of temperature in the spring is much steeper than in a more oceanic climate, and the growing season is more sharply defined and more easily measurable. In an oceanic climate, frost-free period is not to such an extent an attribute of the shape of the curve, but rather of the frequency of significant deviations from the normal march of temperature.

The longest frost-free period on the mainland of Britain is just under 300 days in the tip of the Cornish peninsula. The *Climatological Atlas* (1952) shows that this decreases rapidly inland; and also from the plains to the main mountain masses. It probably does not much exceed 200 days over most of low-level England away from the coast, or 150 days in the Central Welsh Mountains or Border Hills. And as is well known the effects of local topography are often far more important than the broad regional distribution of this factor. Bilham (1938) shows that the night climate of a certain Hertfordshire valley station at 183 ft. above sea level is almost exactly that of Braemar, nearly 1,000 ft. higher and about 450 miles further north!

Inland stations in Britain with curves of mean monthly temperature almost identical to those of American Pacific coastal stations do not necessarily have the same distribution of extreme temperatures. For instance Buxton in Derbyshire has a very similar mean temperature curve to Prince Rupert (Fig. 7). But the mean extreme minima for the periods are substantially different, Buxton experiencing lower temperatures, on occasion, throughout the growing season. To generalise, the comparatively narrow zone on the American Pacific coast which has an oceanic temperature regime similar to our own (so far as the march of mean temperature is concerned) is probably more favoured as regards frost-free period than the greater part of inland Britain. To match frost-free period without moving into a substantially different temperature regime may not always be easy, but it is clear that the modified climates of the fiords provides a part of the answer.

Unfortunately there are few fiord meteorological stations. Bella Coola (British Columbia, North coastal) is one of the few examples. It is interesting to compare its mean and extreme low temperatures for the month of May with those of Clayoquot (Vancouver Island), a typical "Outer Coastal" station.

	Mean Temp. May	*Mean of Extreme Minima. May (Over 50 Yrs.)*
Bella Coola	52°F.	24°F.
Clayoquot	51°F.	38°F.

Obviously, in addition to some gain in continentality (mean annual range of Bella Coola 33°F.

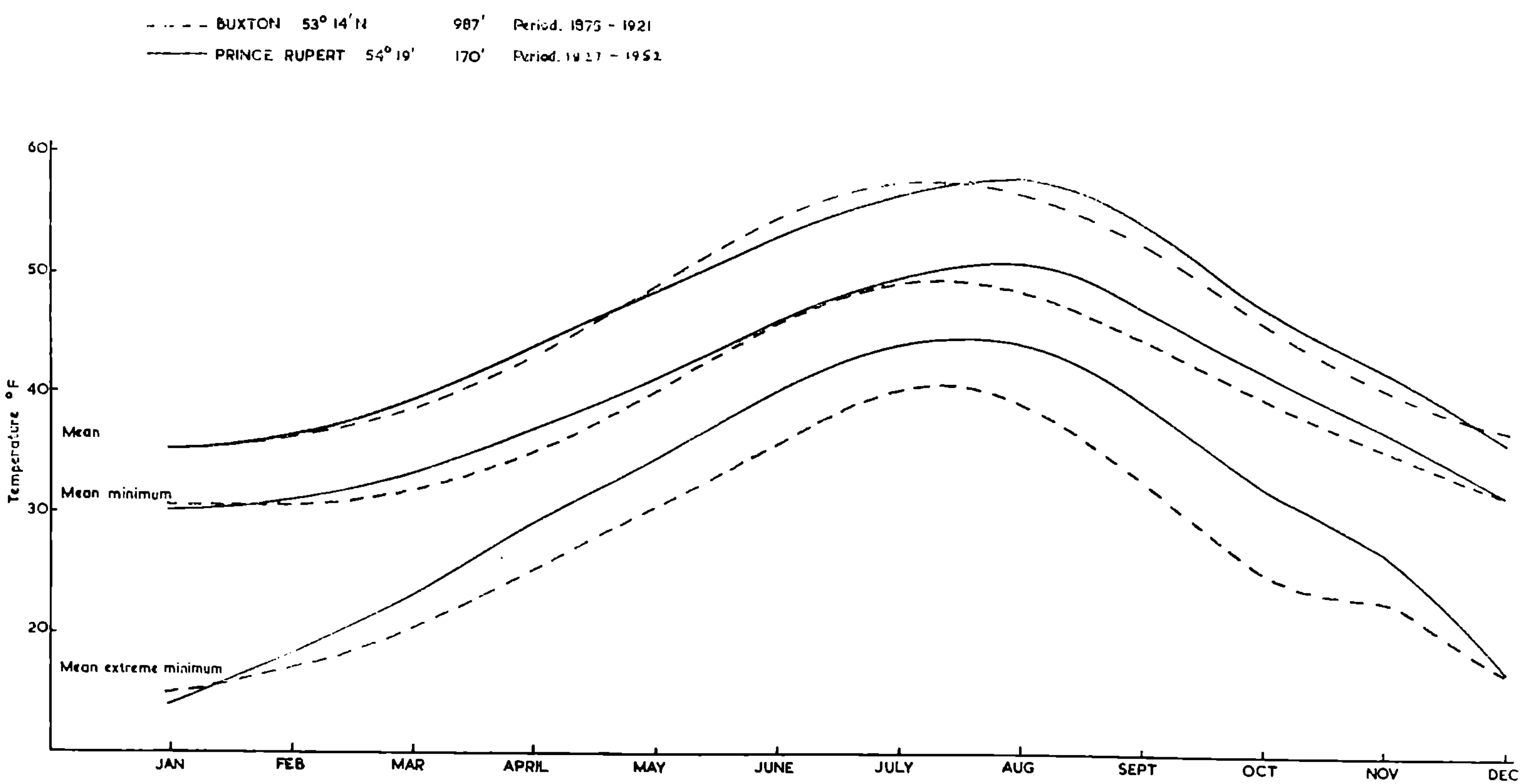


Figure 7 Monthly Temperatures at Prince Rupert, British Columbia, and Buxton, England.

against Clayoquot's 18°F.), the fiord station has a much more variable spring temperature.

It is hardly safe to compare means of extremes devised from different periods, but it is of interest to note that the Book of Normals (1919-1924) gives May mean extreme minima higher than 38°F. for only such favoured places as Anglesey, Wales, and Falmouth, Cornwall.

At the other end of the scale, a high level station (Buxton, 987 feet) and a low level but notoriously frosty place (Cambridge), have mean extreme minima of 30°F. for the month of May.

Precipitation

One safe generalisation can be made about the Pacific Coastal region under consideration; there is no part of it which has a seasonal distribution of rainfall exactly similar to any part of Great Britain, and the greater part of the area has a distribution extremely different from any found in Britain.

While all areas west of the Cascades and the British Columbian Coast Mountains have a winter type of rainfall distribution, this becomes increasingly more marked the further south one goes. This is illustrated in Fig. 8, which shows the percentage of total precipitation falling in the summer quarter and the six months April—Sept., for a number of Pacific coast stations, plotted against latitude.

Bilham (1938) gives figures for the mean percentage of total rainfall in Britain occurring each month of the year in each of the principal regions. These figures summed for the winter, spring, summer and autumn quarters are reproduced below.

Rainfall of Each Quarter Expressed as Percentage of the Total

	Winter (Dec.Jan.Feb.)	*Spring* (Mar.Ap.May)	*Summer* (Jun.Jul.Aug.)	*Autumn* (Sep.Oct.Nov.)
	Percentages			
Scotland (North)	32.0	20.2	20.0	27.8
Scotland (West)	29.7	19.4	22.6	28.3
Scotland (East)	25.3	21.0	26.1	27.6
England (North-east)	22.2	21.3	28.5	28.0
England (East)	23.4	20.8	27.2	28.6
England (Midlands)	25.0	21.1	26.6	27.3
England (South-east)	26.4	19.7	23.9	30.0
England (North-west & North Wales)	26.2	19.4	25.5	28.9
England (South-west & South Wales)	29.5	19.3	21.8	29.4

For comparison, figures are given below for a fair scatter of Pacific Coast stations, both salt water and inland. They are grouped North to South, and total rainfall is given to show that there is little connection between the pattern and the amount.

Rainfall of Each Quarter Expressed as Percentage of the Total

Station and Region	*Winter*	*Spring*	*Summer*	*Autumn*	*Total Ins.*
		Percentage			
Juneau, S.E. Alaska, coast	24.6	19.1	19.7	36.6	84.2
Sitka, S.E. Alaska, Outer Islands	26.7	17.9	16.9	38.5	88.6
Massett, Queen Charlotte Islands	31	22	14	33	55.5
Quatsino, Vancouver Island, West	37.6	20.2	8.6	33.6	95.6
Estevan, Vancouver Island, West	39	22	10	29	108.9
Ocean Falls, British Columbia, North Coast	32.6	20.1	13.2	34.1	166.1
Nanaimo, Vancouver Island, East	44	16.5	9	30.5	37.7
Vancouver (airport), Lower Fraser	40	20	9.5	30.5	57.4
Agassiz, Lower Fraser	34.6	22.4	12.5	30.5	62.7
Tatoosh Island, Washington, West Coast	41	21	8	30	77.3
Willapa, Washington, West Coast	43	23	7	27	82.6
Centralia, Washington, South of Puget	41	22	8	29	44.8
Rainier Longmire, Washington, Cascades	42	22	8	28	76.9

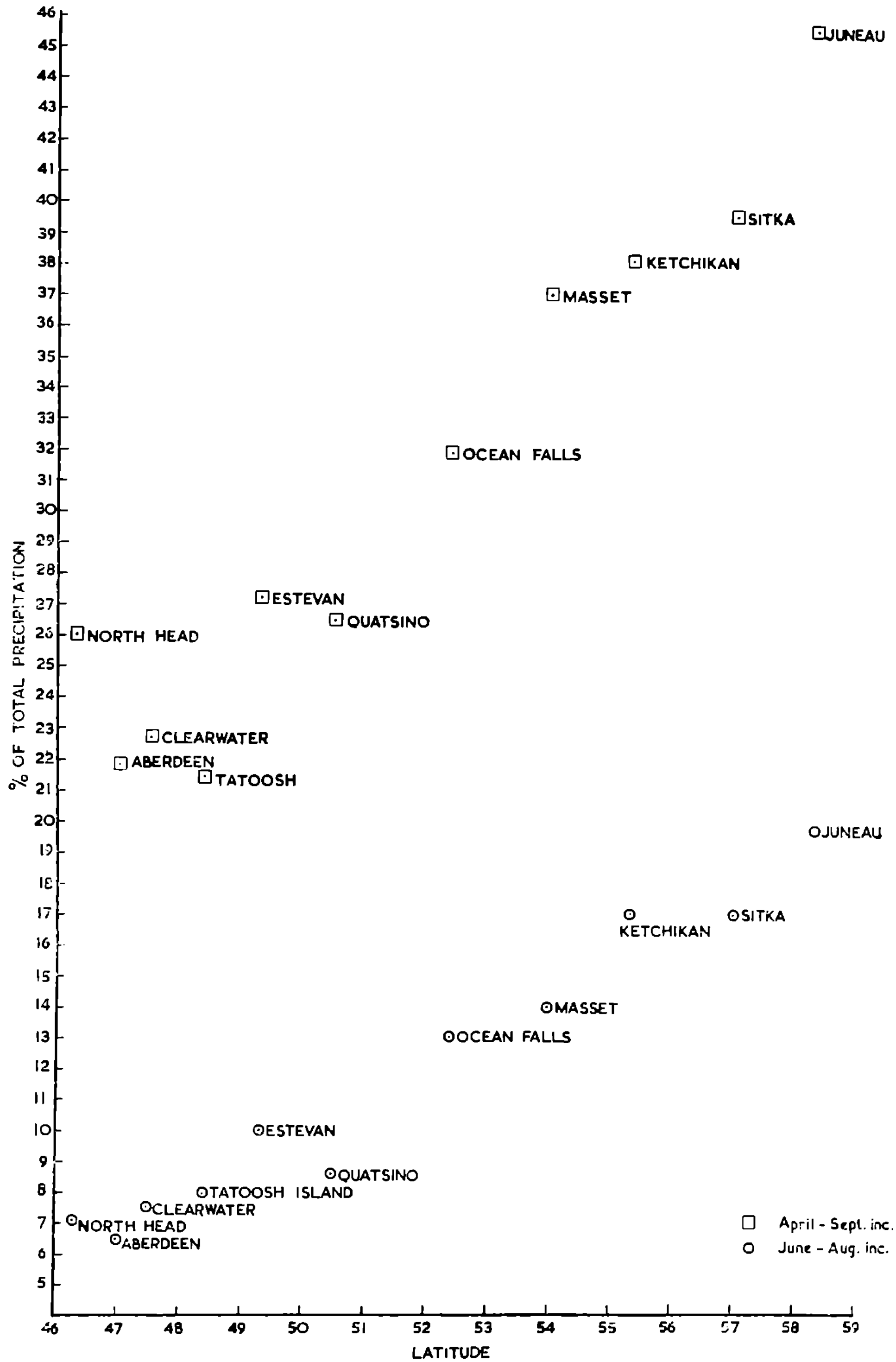


Figure 8 Pacific Coast—Percentage of Summer Rainfall and Latitude. The upper series of points refers to the period April-September inclusive, the lower series to June-August inclusive.

The most important difference between Britain and the Pacific Coast which is indicated by these figures is in the summer rainfall. No special virtue is claimed for the use of the quarter in comparing the effective rainfall for different sites; Isaac (1949) uses the April to September (inc.) total, while Löfting (1951) uses the "pentaprecipitation", the May to September (inc.) total. In making comparisions between climates the period during which rainfall is of critical importance will vary with a number of circumstances; the actual amount, the soils, the temperature, the response of the species, etc. and it may well be necessary to have a different yardstick for each purpose.

Areas experiencing annual rainfalls of 50 inches or less in east Vancouver Island and in Washington are drier in the summer than any we have. A dry area in England may have 24 inches of rain a year, more than 6 inches on the average falling in the three summer months, whereas areas in the former regions with twice that annual rainfall are not likely to average more than about 5 inches in the three summer months.

In Britain there is a tendency for the drier areas of the country in the East to have a higher proportion of their rainfall in summer than do the wetter western areas. There does not seem to be any such trend west of the British Columbian Coast Mountains and Cascades. It probably merely reflects the relatively greater importance of cyclonic rainfall in Britain during the summer months.

The distribution of rainfall is illustrated graphically in the sections across England and Wales, Scotland, British Columbia and Washington, Figs. 2, 3, 4, 5. The driest period in Britain, except in the north-west of Scotland, is apt to be centred round the spring, certainly before the summer peak of temperature. On the American Pacific Coast the dry period is centred pretty well on the warmest period. In Britain rainfall usually increases markedly from May to August, the latter month usually showing as a subsidiary maximum, and over considerable areas of lowish rainfall in the east it may be *the* maximum. The Pacific Coast distribution is very symmetrical, rainfall increasing steadily from the end of August to December, but in Britain the relatively wet August is followed by a relatively dry September and a relatively wet October; the latter month being the common peak of rainfall in the areas of moderate or small amounts. But in the wettest parts of the country and particularly in the north-west of Scotland, the pattern smooths out considerably and winter and autumn rainfall dominates the picture, reflecting the importance of orographical as against cyclonic rainfall in these parts.

The closest resemblances between British and Pacific Coast rainfall distributions are provided by the north-west of Scotland and the northern parts of South-East Alaska. The trend on the Pacific Coast towards increasing summer rainfall northwards partly accounts for this; also there is in northern Scotland a tendency for the "dry" spell to occur rather later than it does in the rest of the country. The figures for Juneau and Sitka (Alaska) and Glencarron (Inverness-shire) illustrate this; since the three stations happen to have rather similar mean annual totals the figures have not been reduced to any common basis. (See foot of page.)

It will be noticed that the figures for the months April to August are in all three cases very similar, and also that in each case June has the lowest rainfall.

Along the coast all stations fully exposed to the Pacific record very heavy rainfall, many of them 100 inches or more. As they are nearly all at low elevations they give little idea of the extremely heavy precipitation experienced in the mountains facing the sea, only occasionally have gauges been exposed to get the full effect. Henderson Lake in Vancouver Island is credited with the figure of 250 inches which is said to be the highest recorded on the American continent (Denison 1932). The main mountain features cast very perceptible rain shadows; the Vancouver Island mountains leave the east side of the Island and the Straits of Georgia with much less rainfall than the west of the island; the Puget Sound region is also shadowed by the Olympic mountains. The Charlotte Islands are markedly drier on the east side, particularly in Graham Island; but the island system of South-East Alaska seems too broken to render the inner regions markedly drier. Fairly adequate rainfall maps exist which give a reasonable idea of mean annual rainfall over most of the area.

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun.*	*Jul.*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Year*
Juneau	7.2	5.5	5.5	5.4	5.2	4.0	5.1	7.4	10.2	11.4	9.2	8.0	84.1
Sitka	8.0	6.5	6.2	5.5	4.1	3.3	4.4	7.2	10.7	13.0	10.3	9.2	88.4
Glencarron	10.1	7.4	7.6	6.0	4.5	4.1	5.3	6.9	7.5	8.3	9.5	10.5	87.7

There is one further point which requires mention and that is the question of the variation in precipitation. We may know that two areas, British and Pacific Coast, have the same mean precipitation for a given period, but we should also wish to know what variation there is likely to be about this mean, particularly on the low side of it. Longley (1952) discusses this for British Columbia; and gives figures for the co-efficient of variation (standard deviation/mean) for a number of stations. He has mapped the expression for British Columbia and concludes that variability tends to be greatest where precipitation is least, though the relationship is not very close. Glasspoole (1921) examined the variability of rainfall in Great Britain and mapped the relative variability (mean deviation/mean). Longley's figures for stations of most interest to us, approximated to relative variability by taking four-fifth's of his co-efficient of variability, are as follows:—

	Mean Annual Rainfall	*Relative Variability Percentage*
Alberni	66.5	14.9
Bella Coola	54.9	17.4
Massett	55.2	13.6
Nanaimo	37.9	16.3
Prince Rupert	99.9	11.5

Glasspoole's map shows a small pocket of relatively high variability in the lower Severn Valley, exceeding 16 per cent. A considerable area in England embracing the south-western peninsula and the West Midlands exceeds 13 per cent, as does a big patch covering part of Durham and the East Riding of Yorks., and a small pocket over Edinburgh. None of the rest of the country exceeds 13 per cent, and certain of the driest areas in the east of Scotland and in East Anglia have figures of 11 per cent or lower. Glasspoole did not find any relationship between total precipitation and variability of rainfall. It can perhaps be concluded that British Isles rainfall is on the whole more reliable than British Columbian coast rainfall, and it does not become less reliable in the areas where it is of the most importance, as appears to be the case in British Columbia.

Humidity

Humidity datas are published for only a few stations in British Columbia (Boughner and Thomas). Chapman (1952) states that the "whole (Outer Coastal) region is characterised by high relative humidity".

So far as one can judge British Columbian Outer Coastal stations are in the same class throughout the year as our west coast stations. In Britain, humidity falls off quite markedly from the coasts inland (Bilham, 1938), but I think that in America humidity almost certainly declines faster on leaving the Pacific coast. I do not think we need worry about a humid 'fog belt' whose conditions we cannot match. Most of the places I visited in the Outer Coastal regions in the summer of 1952 have a drier feel about them than I expected. There was certainly no marked atmospheric humidity.

Wind Velocity

Boughner and Thomas (1948) give figures for average monthly wind velocity for a few scattered stations along the British Columbian Coasts. It is noticeable that none of these stations, however exposed, is in the same class of 'windiness' as out extreme western stations; e.g. such places as the Scilly Islands, Holyhead, Butt of Lewis, etc. They vary greatly among themselves, but in the main the variation might be contained among a set of British Isles stations not exceptionally exposed.

It is also of interest that the prevailing winds on the British Columbian coast are north westerly in summer and south easterly in winter (Boughner and Thomas) i.e. more or less parallel to the coast itself and to the backbone of the main mountain features; whereas in Britain prevailing winds are westerly to south-westerly and so at right angles to the main mountain features. This may accentuate the effects of the prevailing winds. There is no doubt about the observed fact that exposure is of far less significance on the Pacific coast than it is with us.

Evaluations of Climate and Site

An obvious question is whether we can evaluate climate as a whole to obtain a better comparison between growing conditions in American Pacific coastal regions and in Britain. There have of course been a number of attempts to use climatic lines ranging from simple isotherms and isohyets, through remainder indices and arbitary formulae based on temperature and rainfall, to more complicated expressions based on the theoretical response of plant life to temperature. Reasonable success in demarcating the limits of certain types of vegetation has sometimes been achieved with quite simple expressions, and the more advanced systems such as that of Thornthwaite (1948) have proved of value for some purposes; but this has usually been on the continental scale of climate.

In Britain we have a relatively small range of climate; and though the range of annual rainfall is considerable, we do not have such great differences in moistness between regions as can be perceived in moving comparable distances on the American Pacific Coast. Also, British foresters are well aware that certain factors which are not contained in the commoner climatic classifications are often of more importance, at least temporarily, than those which are. It is, however, of some interest to see whether Thornthwaite's methods do help us to understand certain important points in the relationship between British and Pacific coastal climate.

He has developed an exponential function of temperature which is not only a measure of the response of plant growth to temperature, but is also a measure of the water required for growth at that temperature, and is expressed in the normal units of precipitation. This "Potential Evapo-transpiration" calculated from the mean temperature for each month of the year is regarded as the out-goings in a water-balance account, the precipitation in each month being the income, and an arbitrary amount equivalent to 4 inches of rainfall being regarded as a storage bank which can be drawn on when potential evapo-transpiration exceeds rainfall. This balance being completed for the year, the monthly deficiencies and surpluses are summed. Thornthwaite's "moisture index" for a station is:—

$$\frac{100 \text{ surplus} - 60 \text{ deficiency}}{\text{need (or potential evapo-transpiration)}}$$

His full definition of climate has four terms :— (1) a scale of values of this moisture index; (2) an index of seasonal variation in effective moisture; (3) a measure of thermal efficiency, a scale of values of potential evapo-transpiration; (4) and an index of summer concentration of thermal efficiency.

Thornthwaite has mapped his indices for the United States and Marie Sanderson (1948) has applied his methods to Canada. On the continental scale, good agreement has been found between Thornthwaite indices and the natural provinces. Climatic data for British Columbia are at present being worked up on this system at the University of British Columbia.

In the east of Canada use is being made of certain of the indices to provide the basic climatic background for site classification on the Hills system (Hills 1952). For this purpose lines of common potential evapo-transpiration are used to bound the summer heat provinces, and lines of common deficiency (or surplus) to bound moisture provinces. For our purposes, something similar might prove useful.

Unfortunately, Thornthwaite's potential evapotranspiration calculated from British data may be a rather unsafe estimate of the water need under our conditions. Penman (1950), using a formula which includes additional average factors for cloudiness, humidity, and wind velocity, has mapped evaporation over Great Britain, and his estimates usually agree well enough with actual observations of evaporation from reservoirs. His estimates of moisture requirement are lower than, but reasonably close to, those derived from Thornthwaite's formula for the extreme south of England; but are considerably lower for the North. Since we cannot even be sure that Thornthwaite estimates are reliable on the Pacific coast, it is clear that this means of comparison cannot be taken too far. But it is of interest to compare Thornthwaite's determinations for our driest region (the old Meteorological Office District 5, England South-East) with those for a Vancouver Island station of similar warmth and moderate rainfall. The station chosen (Cumberland) lies on the east side of the island and has a rainfall of 57.4 inches, reasonably typical of the Douglas fir forests on that side of the island, and not too dry to exclude *Tsuga* entirely.

The figures are illustrated diagramatically (Fig. 9). It will be noticed that though the water-need at the Vancouver Island station is slightly less than that estimated for South East England, and though the rainfall at the former place is twice as great, it still shows a much greater deficiency than the English region.

The method has the great advantage of bringing into account the linkage between temperature and moisture requirement and it also illustrates very clearly the importance of the distribution of precipitation. Where the summer rainfall is 12 per cent of the total rainfall or less, e.g. south of Vancouver Island, it is evident that the total precipitation has to be very high indeed if considerable deficiencies are not to occur during the summer, and this is assuming normal rainfall.

With such distribution, summer droughts are apt to be much more drastic affairs than in Britain; a logging operation which I visited in the north of Vancouver Island had some thousands of acres of 200-year-old Douglas fir destroyed by fire in the summer of 1952. The annual rainfall in this locality exceeded 80 inches. It is hardly possible to conceive of a crown fire in mature timber in the driest part of Britain. Consideration of the water-need also suggests that the relatively dry British spring may not be a very important adverse feature in comparing the two climates. During the greater part of this period the water-need is quite low, and deficiencies are slowly accumulated.

The suggestion is that moisture is a more vital element in site classification on the Pacific coast, at least in regions south of Alaska, than it is with us. It might be put that the gradient is both steeper and longer. Confinement of species on the grounds of moisture will be more sharply defined on the Pacific coast than in Britain. If such confinement is not clearly observable there in any species we should be

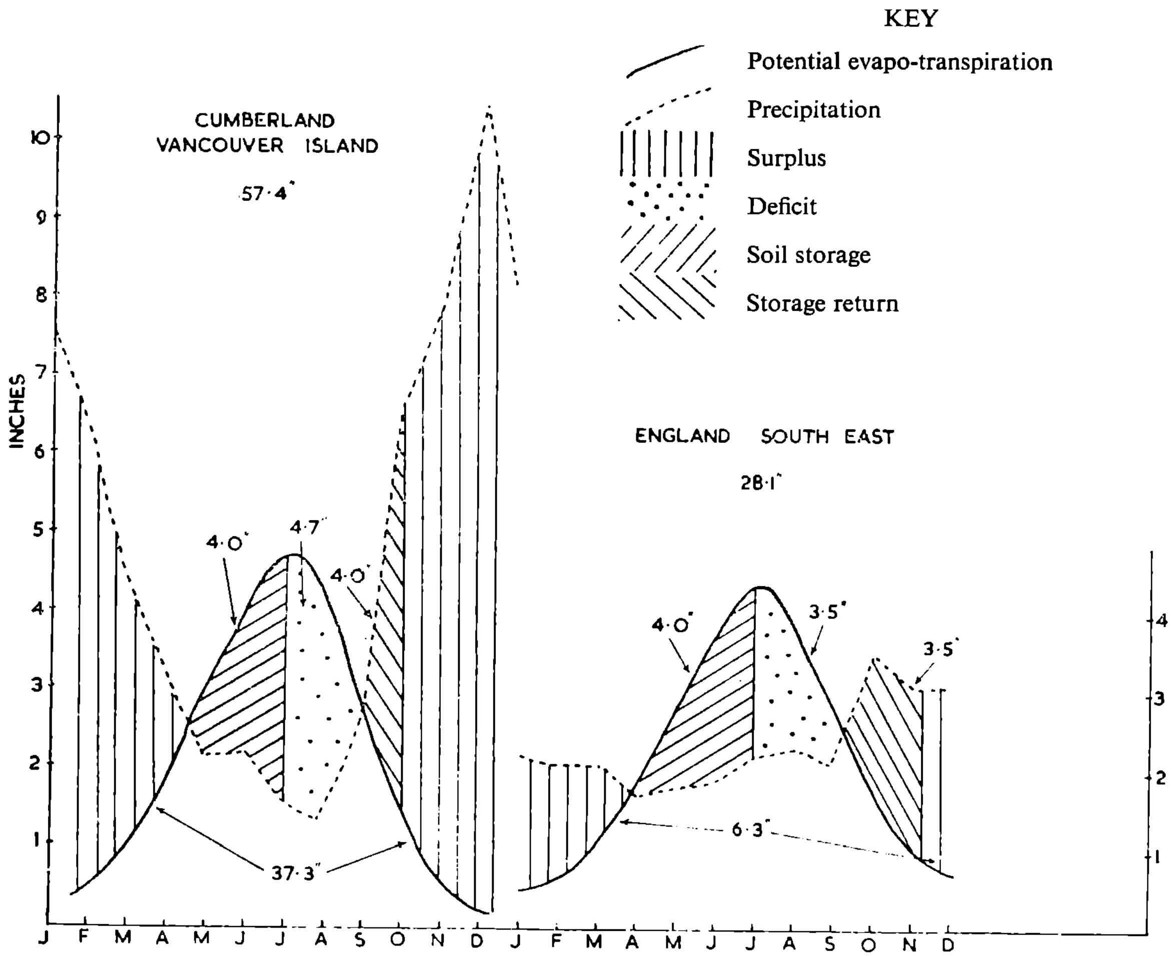


Figure 9 Potential Evapo-transpiration (Thornthwaite's Formula) and Annual Precipitation, for Cumberland on Vancouver Island, and an average station in South-East England. All figures are in inches of rainfall, or its equivalent. Total annual rainfall at Cumberland, Vancouver Island, is 57.4 inches; that for South-East England is 28.1 inches.

able to conclude that the species can tolerate very considerable 'stresses', and we should not expect to have to confine it at all strictly on the grounds of moisture in this country.

The British Columbia Forest Service is very actively engaged in ecological surveys and a provisional site classification of the Pacific North-West has been prepared by Spilsbury and Smith (1947), using a number of indicator plants that are widely distributed through the area and have sufficient sensitivity for the purpose. Their principal types are labelled from the chief dominants in the ground vegetation; in descending order of quality—*Polystichum* (Swordfern), *Polystichum/Gaultheria* (Salal), *Gaultheria*, *Gaultheria/Parmelia* (Pale green lichen), *Gaultheria/Usnea* (Bearded lichen). Spilsbury and Smith recognise five climate subdivisions which call for some modification in the floral composition of the types. They were able to show a very reasonable relationship between their types and the mathematical quality classes of McArdle (1949) for Douglas fir. Work now proceeding on the coast will probably break down the area on a climatic basis and will recognise a series of types for each subdivision.

Whatever other aspects of fertility these types indicate, it is quite evident that available moisture plays a big part in the scale, and that the moistest is the most productive. It is interesting that it was apparently not found necessary to recognise any important type, extensively developed, in which moisture could be considered to be in excess.

In eastern Canada where summer precipitation is relatively more plentiful it is possible to recognise important types where moisture is in excess, and where the quality class of certain species has fallen accordingly (Bedell and Maclean, 1950). On much of the Pacific Coast, moisture in excess means impeded local drainage and muskeg formation, the boundary of the muskeg being usually sharp. This is of course quite a different phenomenon from that caused by the (normal) excess of rainfall over evapo-transpiration throughout the summer, which encourages blanket peat formation.

In South-East Alaska, where the distribution of rainfall is much closer to our own, and where total amounts are usually rather large, I was informed that a site classification on the lines of Spilsbury and Smith is hardly applicable. This is understandable on the assumption that moisture is the most important factor in their scale; in South-East Alaska I was told that it would be difficult to find any widespread limitation from lack of moisture, and species or communities which are separated largely on their moisture requirements are not so easily discernible.

Taylor (1932) has used plants which indicate a range of acidity or nitrophile status (or both), such plants as *Oplopanax* (*Fatsia*) (devil's club) and *Rubus* sp. being typical of good sites, *Cornus occidentalis* and *Vaccinium* sp. of poorer ones. But since the *Tsuga* climax forest in South-East Alaska is a blanket which tends to equate the surface conditions for lesser vegetation, more reliance is placed on some of the easily observed soil characters such as drainage and free-rooting depth (to the bedrock or gleyed horizon).

The classification of the soils of the coastal forest does not seem to have reached a very advanced stage, and the regions most studied are those which have the least similarity to our conditions. Some difficulty seems to have been found in fitting the soils into the great soil groups.

Nikiforoff (1937), writing about coastal Washington, says that the high winter precipitation alternating with pronounced dry periods favours soil formation processes akin to laterization, though the coniferous vegetation favours podsolisation.

Marbut (1936) places the soils of the Coastal Forest in the Grey-Brown Podsolic group, but comments that the podsolic character is generally poorly expressed. One will look in vain for the very mature British heath podsol. Marked leached horizons can be seen on infertile sands and gravels, but without continuous pans, perhaps a few ordstein nodules.

All the region northward from just south of the Puget Sound has been heavily glaciated, and tills are among the most important and widespread parent materials. In general, I was not impressed by the depth of the soils seen. Even in the potentially deep soils (usually alluvial) various forms of impedance were common.

A widespread phenomenon on the tills of Vancouver Island (which constitute perhaps the most important parent material in the Douglas fir forests) is the occurrence of a strongly cemented horizon at about 24 inches from the surface. Spilsbury (1944) has made a survey of the soils of south-east Vancouver Island and the following typical profile is quoted from him.

"A_2	0-2 inches.	Dark brown fibrous organic mat, partially decomposed and derived from coniferous debris.
A_3	2-3 inches.	Ash grey and grey brown sandy loam with soft platy structure.
A_3	3-5 inches.	Brown grey sandy loam with with an indefinite soft crumb structure. A few hard concretions occur.
B_1	5-12 inches.	Light brown sandy loam with an indefinite soft crumb structure. Horizon loose and porous and contains frequent hard brown concretions and a fairly heavy iron coating on sands and gravel.
B_2	12-20 inches.	Yellow brown sandy loam, single grain structure, denser than in B_1, yet still freely porous.
C_1	10-24 inches.	Brown grey sandy loam, containing fragments of partially weathered till. In some cases these are strongly cemented.
C_2	24 inches +	Grey sandy loam till, the top few inches are generally very strongly cemented and have a platy structure. The lower part is massive, extremely dense, but only slightly cemented."

The cemented layer is a complete barrier to deeper rooting, and seems also to be a considerable hindrance to water movement, certainly water can be seen streaming out above this horizon in the wet season where road cuttings, etc. have exposed it. No doubt the cemented layer is often useful in allowing water to creep down from higher elevations. It is encouraging to see trees 200 feet tall with a root system no more than 24 to 28 inches deep. Such soils do not provide the best Douglas sites, but they may be in the upper third. It is noticeable that when one moves off them to adjacent glacial outwash material the quality of forest falls off very markedly. Rooting in such coarse material is often very deep, live Douglas roots can be traced down to 8 feet or more, but the greater depth of root-run does not fully compensate for the poorer retentivity and fertility of the medium.

Discussion

What we ideally require is a set of measures which will allow us to discuss the limits and behaviour of species in Britain in terms which will have some application to their observed characteristics on the Pacific coast. The trouble is however that while it can reasonably be assumed that the species will have the same responses in Britain to the basic factors, the supply of heat and moisture, we have certainly different limits to tree growth. Macdonald (1951) discusses limits in Britain, and states that the dominating factor at the upper limit of tree growth is undoubtedly exposure to wind. This is a factor which is hopelessly compounded with that of summer warmth. Exposure increases as summer warmth falls with increasing altitude—not of course in any simple relationship—and since the general limit to tree growth is exposure and not insufficiency of summer warmth, the latter factor becomes difficult to evaluate, and we should not expect to see it in operation with any sharpness. However, this should not encourage us to pay any less attention to the summer warmth factor, since we have in fact quite a wide range of it, equivalent to a great latitudinal range on the Pacific coast.

Precipitation in Britain has been shown to follow a substantially different pattern to that on the Pacific coast, the main difference lying in the greater relative proportion of summer rainfall in Britain. Dissimilarity increases to the south on the Pacific coast. It seems likely that this will tend to smooth out the moisture factor in site differences, and to make it more difficult in Britain to draw plausible climatic lines distinguishing moisture provinces. Also we lack the dry end of the moisture range represented on the Pacific coast. Perhaps we have a relatively greater proportion of the wet end of the range.

The wide variety of soils in Britain arising from the complex geology can make climatic classification appear very unreal. There is obviously more difference between the Chalk and the Lower Greensand—perhaps a mile away, than there is between the latter and some acid infertile soil 400 miles north. One can perhaps look at the more obvious gradations of moisture and fertility on the Pacific coast and hazard a guess that the species will respond in the same sort of manner to analogous trends in Britain.

The regrettable unreliability of the spring climate in much of Britain is another factor which often overshadows the more basic site qualities. To some extent this is an overestimated handicap; spring frosts are rarely a permanent limitation; most arise from quite shallow inversions and they provide a particular (often very difficult) climate for the tree only in the early years of its life. Spring frost is a special curse for the pioneer planter, our successors may pay less attention to it.

Again the emphasis on plantation in Britain makes us sensitive to the ecological conditions which have developed on long disafforested sites, and while these often indicate certain important site characteristics very effectively, they can also obscure basic factors. To some extent the communities *are* the sites: remove *Calluna* and what is left of "heath"?

The Pacific Coast is a relatively easy forest region to understand with the aid of expert local exposition. The broad picture of the forest communities does on the whole seem explicable in relatively simple terms of climate and local gradations. But Britain is not a good place for simplifications, and the difficulty is not so much in understanding the behaviour of species in Pacific Coast conditions as in interpreting it in terms which will mean something in Britain.

III. DISTRIBUTION AND LIMITS OF SPECIES

Since the majority of the coastal species do not find their limits inside the part of the tract which is closest to Britain in climate, and since the general limitations to tree growth in Britain are in any case different, we can only obtain rather general ideas about their requirements and sensitivities by looking at their distribution against the background of climate. They have also reached their present habitats by diverse routes, and it is reasonable to suppose that their make-up as they are today must owe something to the climates they have occupied in the past as well as to the climate they happen to be experiencing at present. In this context it may be of interest to summarise briefly what has been written about reinvasion and subsequent succession in the Coastal Forest following the Pleistocene glaciations.

Hultén (1937) regards a number of the coastal conifers as Boreal species which have invaded North America from centres in the neighbourhood of the Bering Sea. Before the maximum glaciation they had established refugia mainly south of the greatest extension of the Cordilleran ice-sheet, which, forming in the western mountains, glaciated the entire coast north of the Puget Sound. There is evidence that some small areas, such as the north-west corner of the Charlotte Islands, may have escaped, and there may have been a number of "nunataks" left above the ice, to serve as local refugia.

Hultén says that Sitka spruce, *Tsuga heterophylla*, *Thuja plicata* and *Abies amabilis*, are associated with a centre in the south of the Bering Sea area. He calls them "West Coast Radiants". *Pinus contorta*, another Boreal species, he terms a "Continental Western American Radiant". The other two important coast species, Douglas fir and *Abies grandis*, are not Boreal species but emanate from southern centres.

Hansen (1947, 1950) and Heusser (1952) have applied the method of pollen analysis to the problems of forest succession and chronology of the coast. Hansen, working in Washington and Vancouver Island, and Heusser in Alaska, both found that *Pinus contorta* was the principal pioneer involved in the re-establishment of forest following the retreat of the ice. In the Puget Sound area Hansen gives 20,000 years as the approximate period since the retreat of the ice, Heusser gives a figure of 8,000 years for S.E. Alaska.

In the Puget Sound region Hansen found that Douglas fir expanded rapidly to supersede *Pinus contorta*, *Tsuga* increasing more slowly. On the subsequent relative abundance of these three species, he was able to suggest some long term variations in climate; the general picture being that after an initial cool moist period of some 4,000 years there was a period of some 7,000 years during which conditions became warmer and drier, and a period of some 4,000 years which have again been cooler and moister. Hansen of course assumes that the behaviour of the species has been the same as it is now, that *Tsuga heterophylla* will expand in a cool moist period and Douglas fir in a warm dry one, which is certainly what one would suppose from their present distribution. In the extreme Pacific coastal zone he was not able to see signs of major climatic changes since the ice recession, Sitka spruce and *Tsuga heterophylla* succeeding *Pinus contorta* at an early stage and not apparently varying much in their relative proportions up to the present time. This was also the case in the east of Vancouver Island, where following the initial succession from *Pinus contorta*, the species seem to have taken up roughly the positions one would expect under the present conditions of climate. In South-East Alaska, Heusser estimates a period of some 2,000 years of cool moist climate, which was followed by 1,000 years of gradual improvement. The next 3,000 years embraced a period of maximum warmth and dryness; the last 2,000 years have been cooler and wetter, except for the very last 200 years which have seen a fairly general recession of the glaciers in the vicinity. During this penultimate cooler and moister period there was a re-expansion of *Pinus contorta*, which is an interesting indication of its almost purely "muskeg" or bog status in this region. It has not there its other common refuge, the dry, frequently burned site, and only an increase in the area of muskeg can increase its incidence.

Apart from these important species, many other trees now present in the coastal forests are represented in these pollen analyses. On the whole it does not appear that there have been any very revolutionary changes in their status. So far as the method of pollen analysis can take us, the composition of the coastal forest does not seem to have altered much since the initial successions; and climatic modifications seem to have been only big enough to have marked effects in regions where there has always been a rather fine balance, particularly in the moisture factor.

Halliday and Brown (1943) have examined the distribution of the principal Canadian species with particular reference to their relative abundance inside their botanical range. They consider that relative abundance gives a better impression of the response of the species to the main climatic controls than does mere occurrence; it may also suggest the routes of reinvasion and the presence of refugia. (The latter points may be of some importance in the consideration of provenance problems).

Some attempt is made below to apply this very generalised kind of information to British conditions in order to guess whether the various species are likely to meet with any limitations in Britain of the kind which appear to confine them in their own habitat. The remarks naturally refer to the best adapted variant of the species in respect of any particular limiting factor. In no case are we concerned with the southern limits of a species.

Sitka spruce. The distribution clearly suggests a high moisture requirement for the species as a whole. It is only generally distributed where rainfall is high, and increases regionally in abundance to the north where rainfall is relatively more plentiful during the summer. It is confined to climates of a considerable degree of oceanicity, (unlike its close associates *Tsuga heterophylla* and *Thuja plicata*), but certainly occurs in climates which are a good deal more continental than anything we have. We need not look for any specific limitation in Britain on the grounds of extreme temperatures, nor for that matter on the grounds of low atmospheric humidity. In fact its

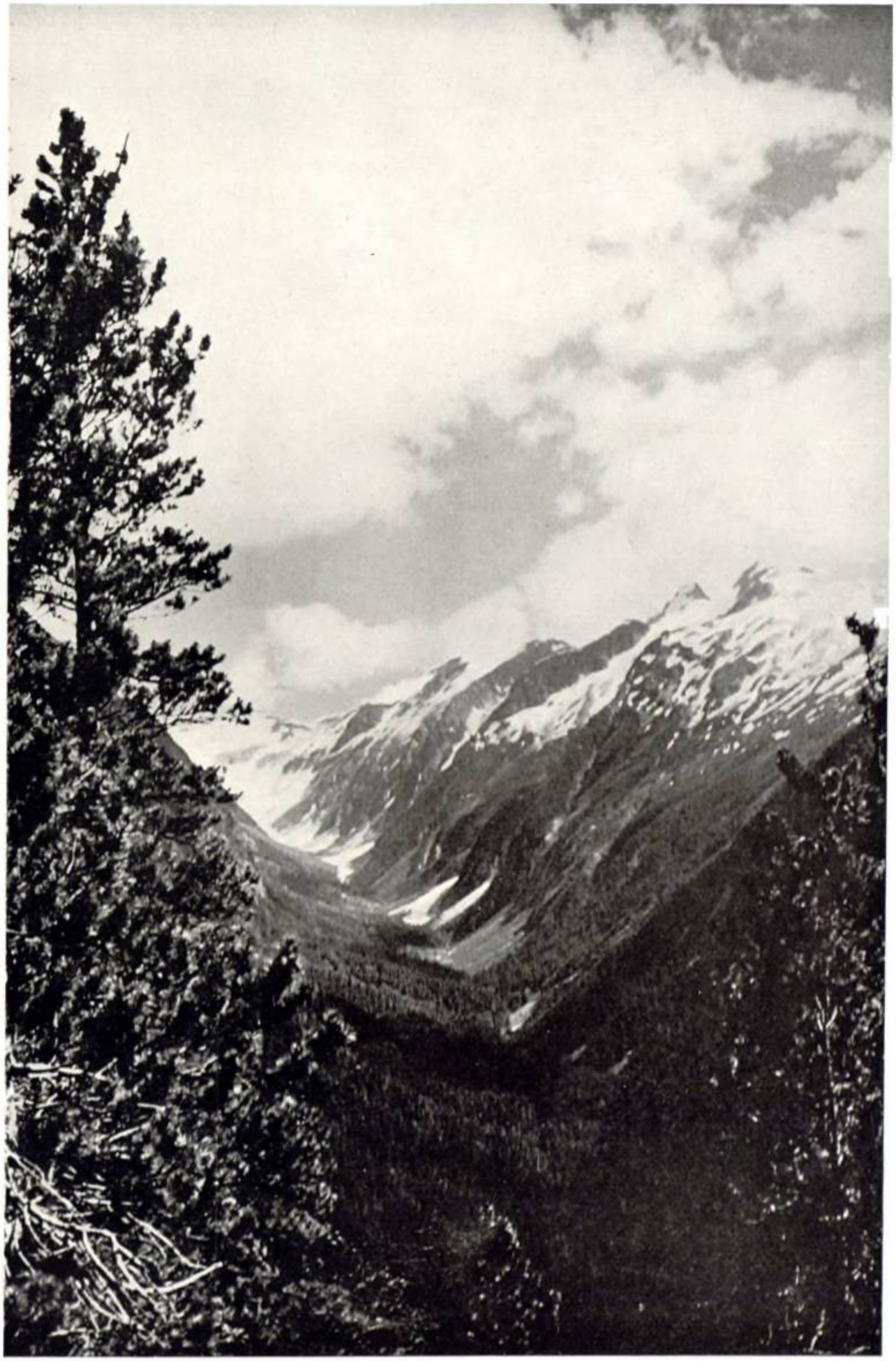


Photo. 1 Skeena River. Kitsumkalum Lake. Looking up Glacier Creek from about 3,500 feet. Lodgepole pine, *Pinus contorta*, on left.

Photo. 2 Queen Charlotte Islands. Sitka spruce *Picea sitchensis* (60 inches diameter at breast height) dominating western hemlock, *Tsuga heterophylla*. Note windfalls.

Photo. 3 Skidegate Inlet, Queen Charlotte Islands. Small inlets densely forested to tide line.

Photo. 4 South East Alaska. Juneau. Outfall of Mendenhall Glacier.

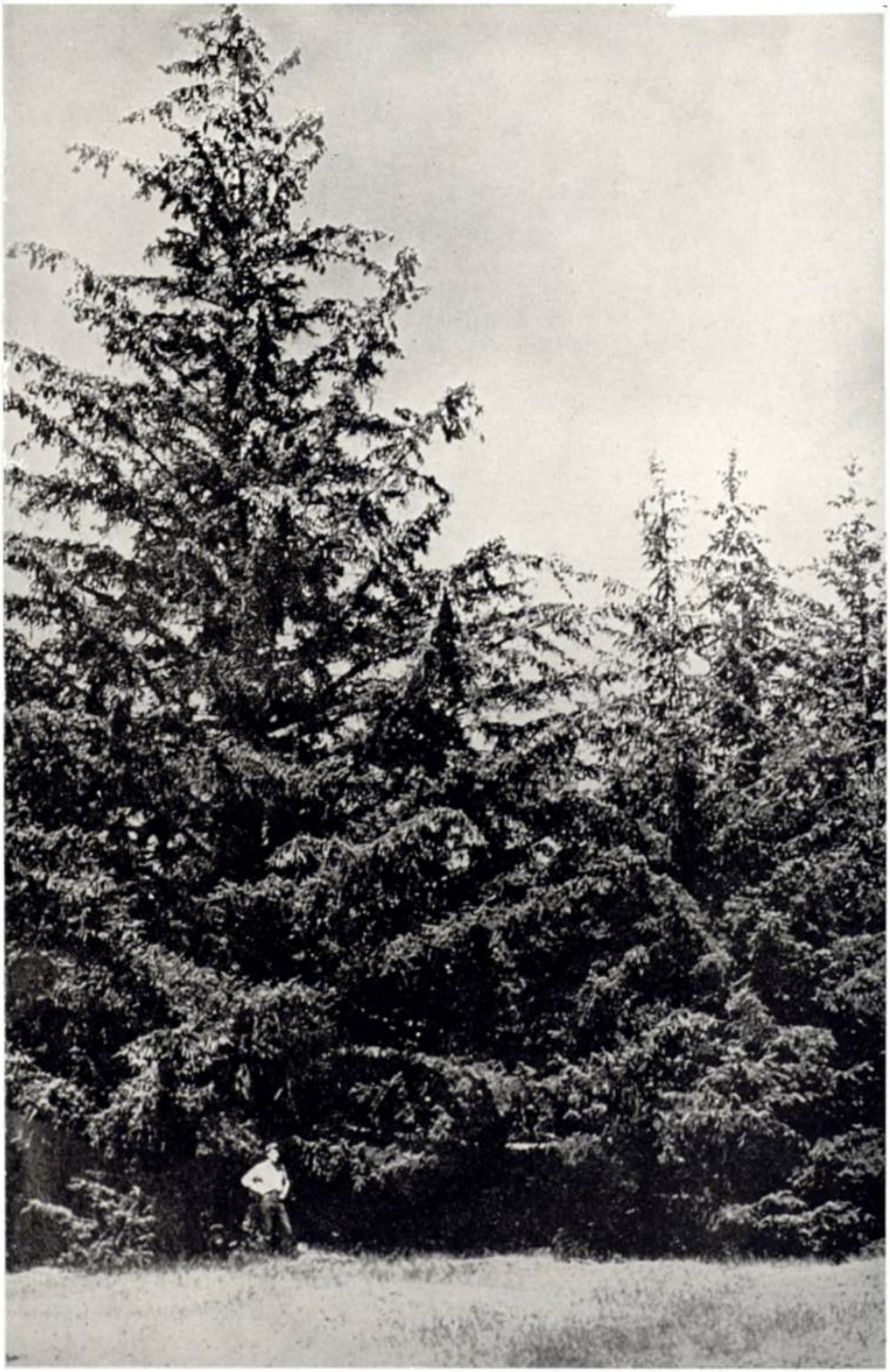


Photo. 5 Queen Charlotte Islands. Tlell. 80-year-old pioneer Sitka spruce on a dune. Note heavy coning.

Photo. 6 Queen Charlotte Islands. The Tlell-Port Clements road. Lodgepole pine, *Pinus contorta*, regenerating after burn in western red cedar, *Thuja plicata*.

Photo. 7 Queen Charlotte Islands. Close to the scene in Photo 6. A few Sitka spruce of poor chlorotic appearance may be seen. Lodgepole pine, *Pinus contorta*, is vigorous. Note Sitka spruce in right foreground.

Photo. 8 Queen Charlotte Islands. Tlell. A practically pure pioneer stand of Sitka spruce on coastal dunes. An important seed collecting area.

Photo. 9 Queen Charlotte Islands. A stand of red alder, *Alnus rubra*, which has pioneered a disturbed site, now much degraded; succession to spruce well advanced.

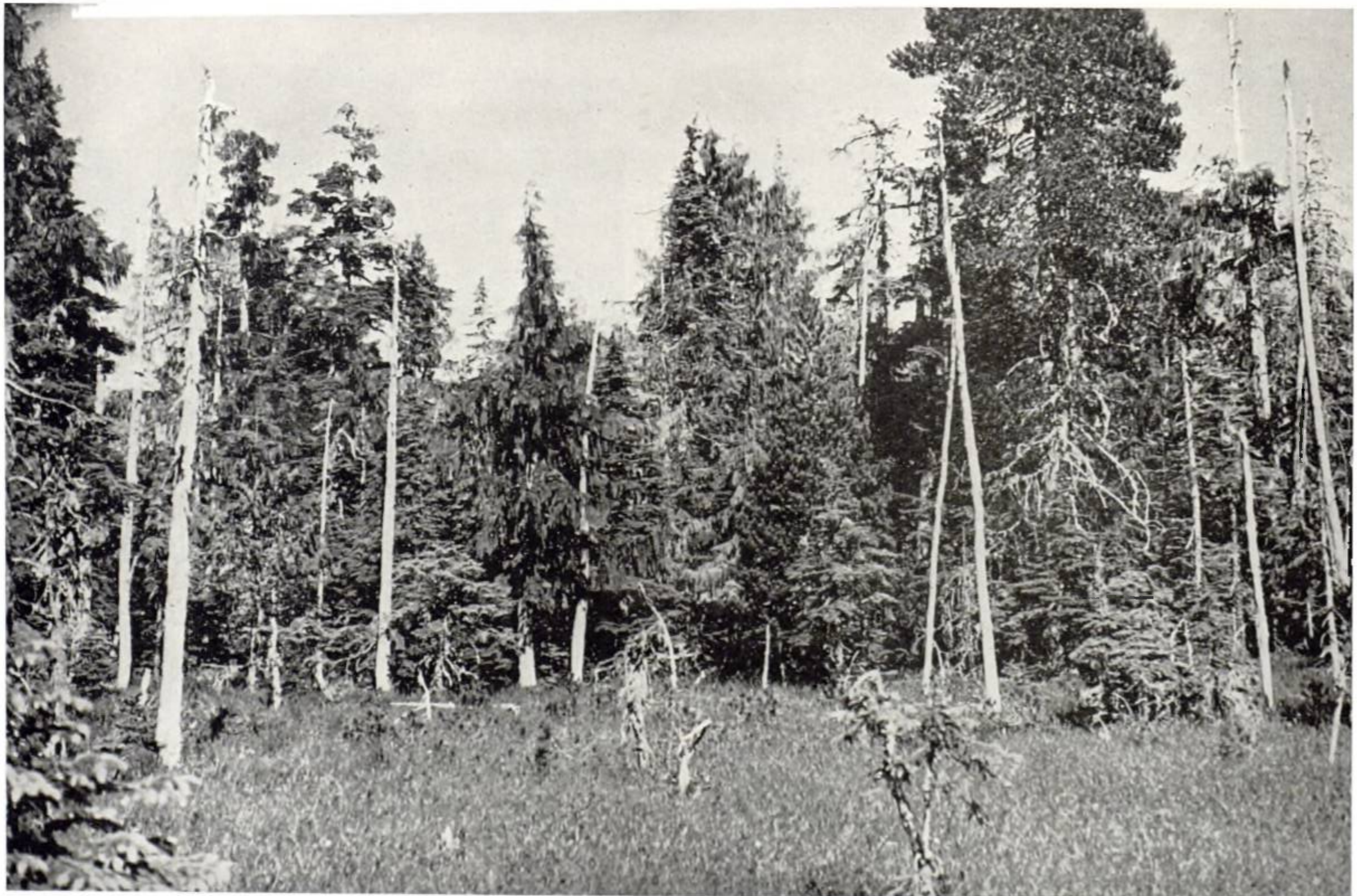


Photo. 10 Queen Charlotte Islands. A muskeg at 1,000 feet elevation. Lodgepole pine, *Pinus contorta*; western red cedar, *Thuja plicata*; and Nootka cypress, *Chamaecyparis nootkatensis*. Moribund sitka spruce in foreground. Tree (a) is a shapely Nootka cypress; Tree (b) is a tall lodgepole pine. *Kalmia* and *Ledum groenlandicum* in shrub layer.

Photo. 11 Queen Charlotte Islands. Hemlock, *Tsuga heterophylla*, regeneration on the remains of a big Sitka spruce.

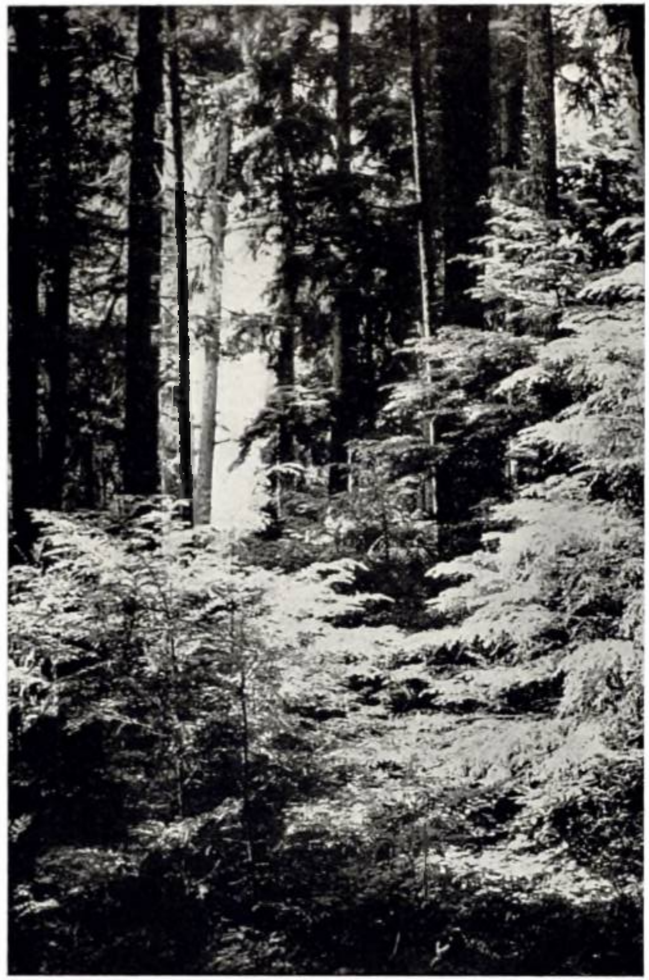


Photo. 12 Queen Charlotte Islands. Western hemlock, *Tsuga heterophylla*, regeneration. Near climax conditions.

Photo. 13 Queen Charlotte Islands. Hemlock, *Tsuga heterophylla*, almost pure. The collapsed stem is Sitka spruce.

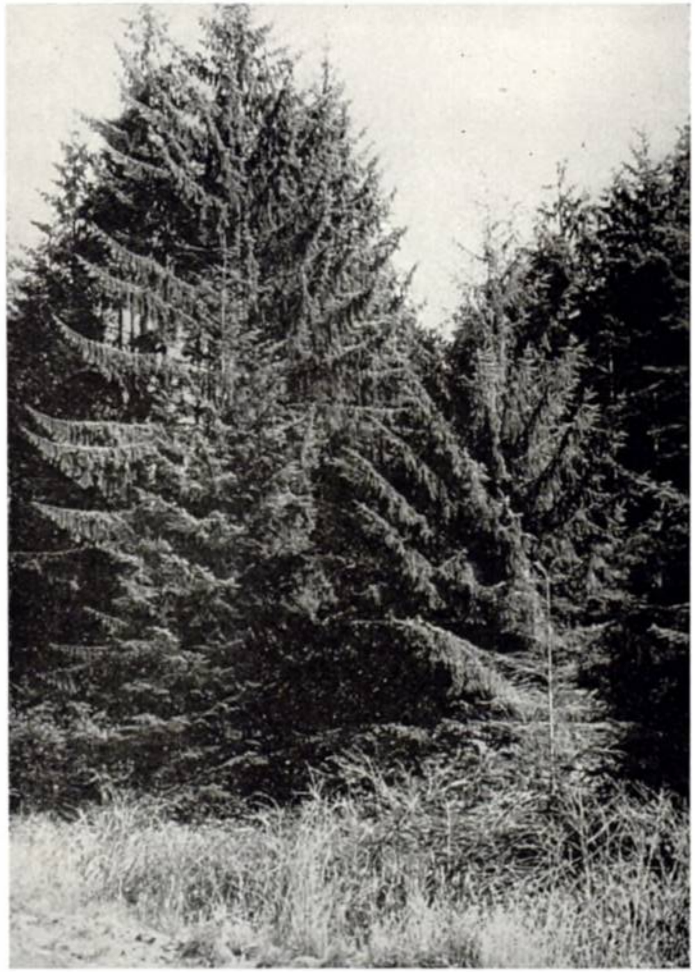


Photo. 14 Washington. Clallam County. Even-aged regeneration of Sitka spruce and hemlock showing similar early growth rates.

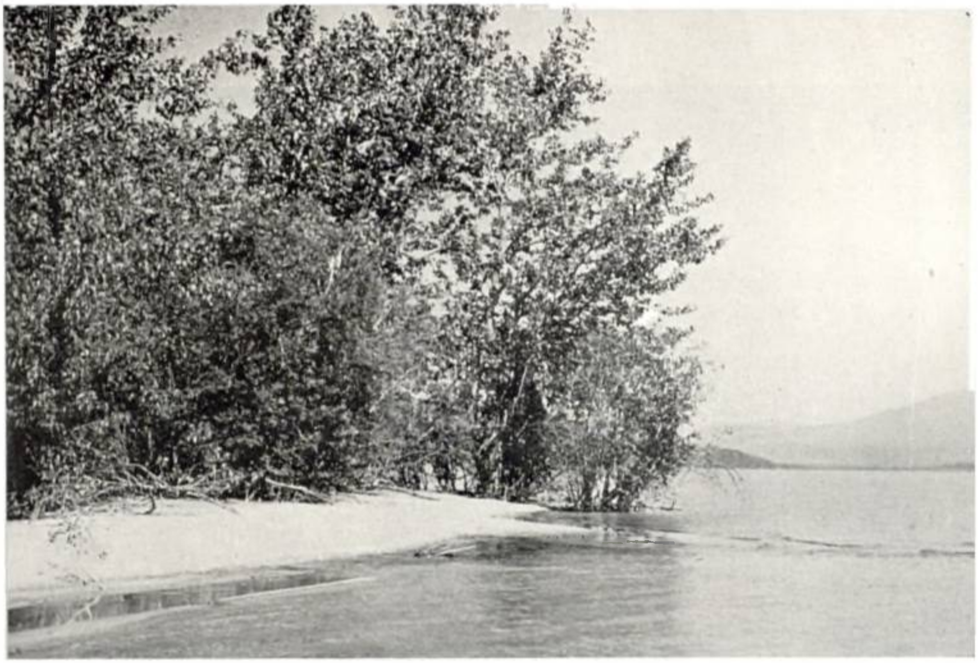


Photo. 15 Skeena River. Kitsumkalum Lake. Balsam poplar, *Populus trichocarpa*, and willows, *Salix* sp., colonising mudbanks.

Photo. 16 Washington. Common associates of Sitka spruce in the shrub layer. *Fatsia horrida*, *Rubus spectabilis* and *R. parviflora*.

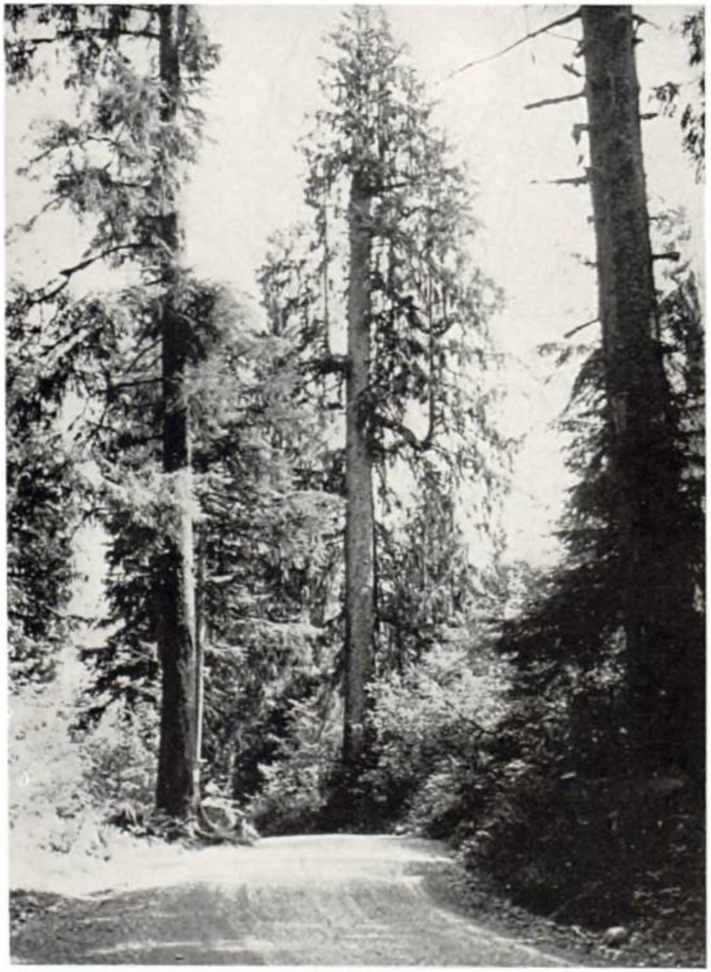


Photo. 17 Washington, Hoh River. Sitka spruce (10 feet diameter at breast height) on "Swordfern" type. Vine maple, *Acer circinatum*, in underwood.

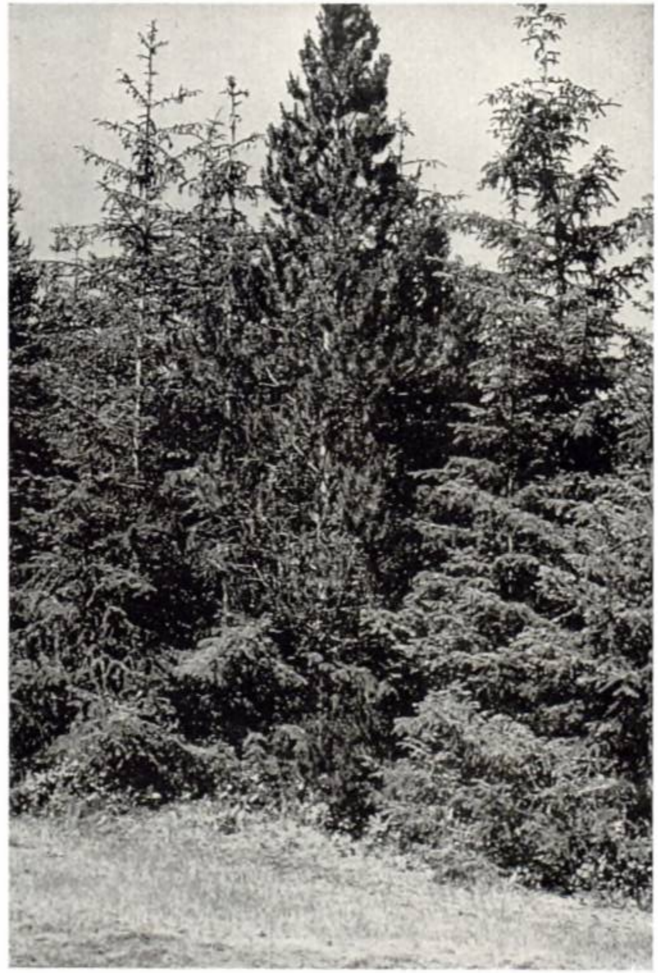
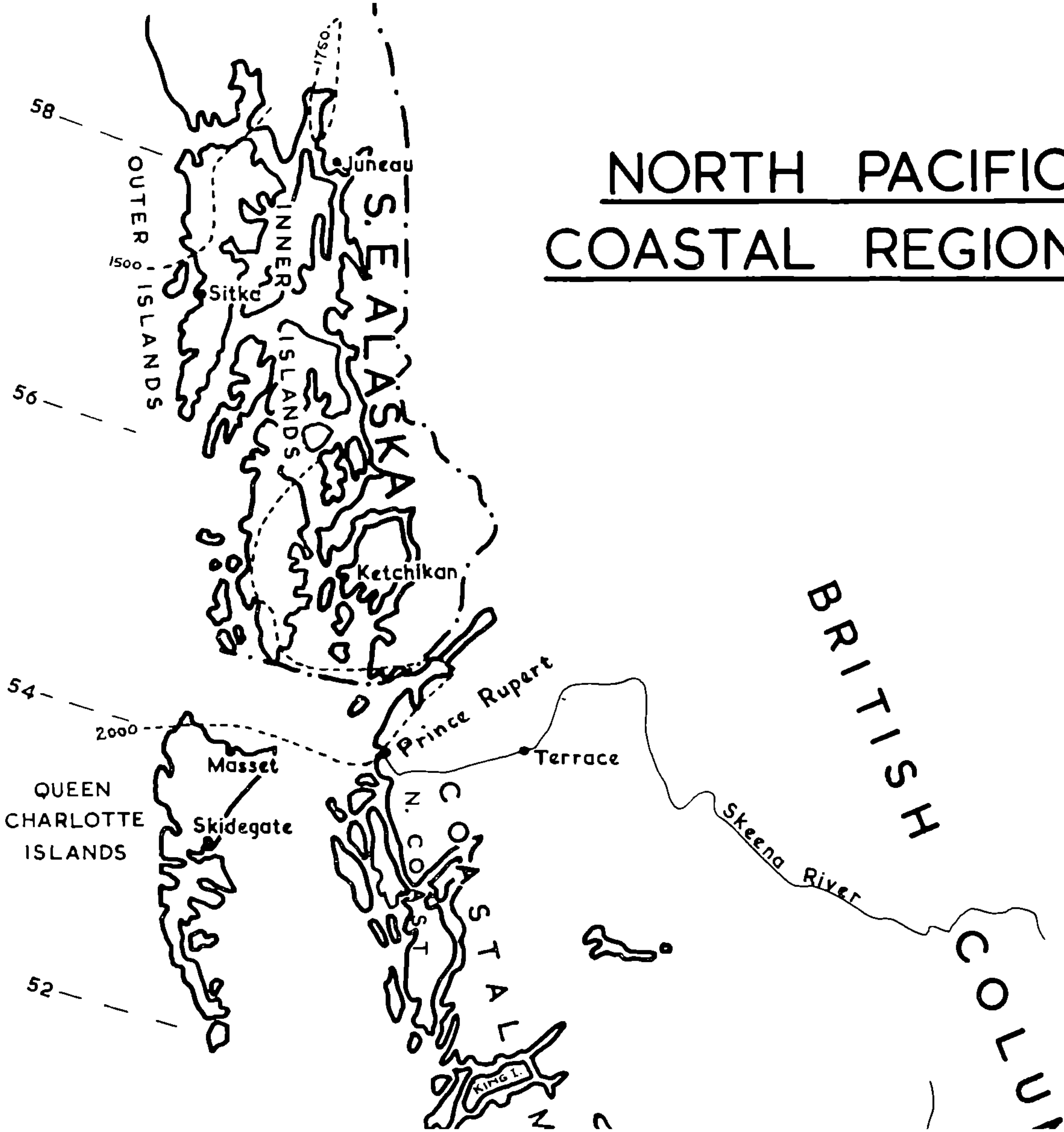


Photo. 18 Queen Charlotte Islands. Lodgepole pine, *Pinus contorta*, and Sitka spruce about 30 years of age exhibiting equal rates of growth on a site which is rather dry for the latter. Note form of coastal *Pinus contorta*.

Map

NORTH PACIFIC COASTAL REGIONS



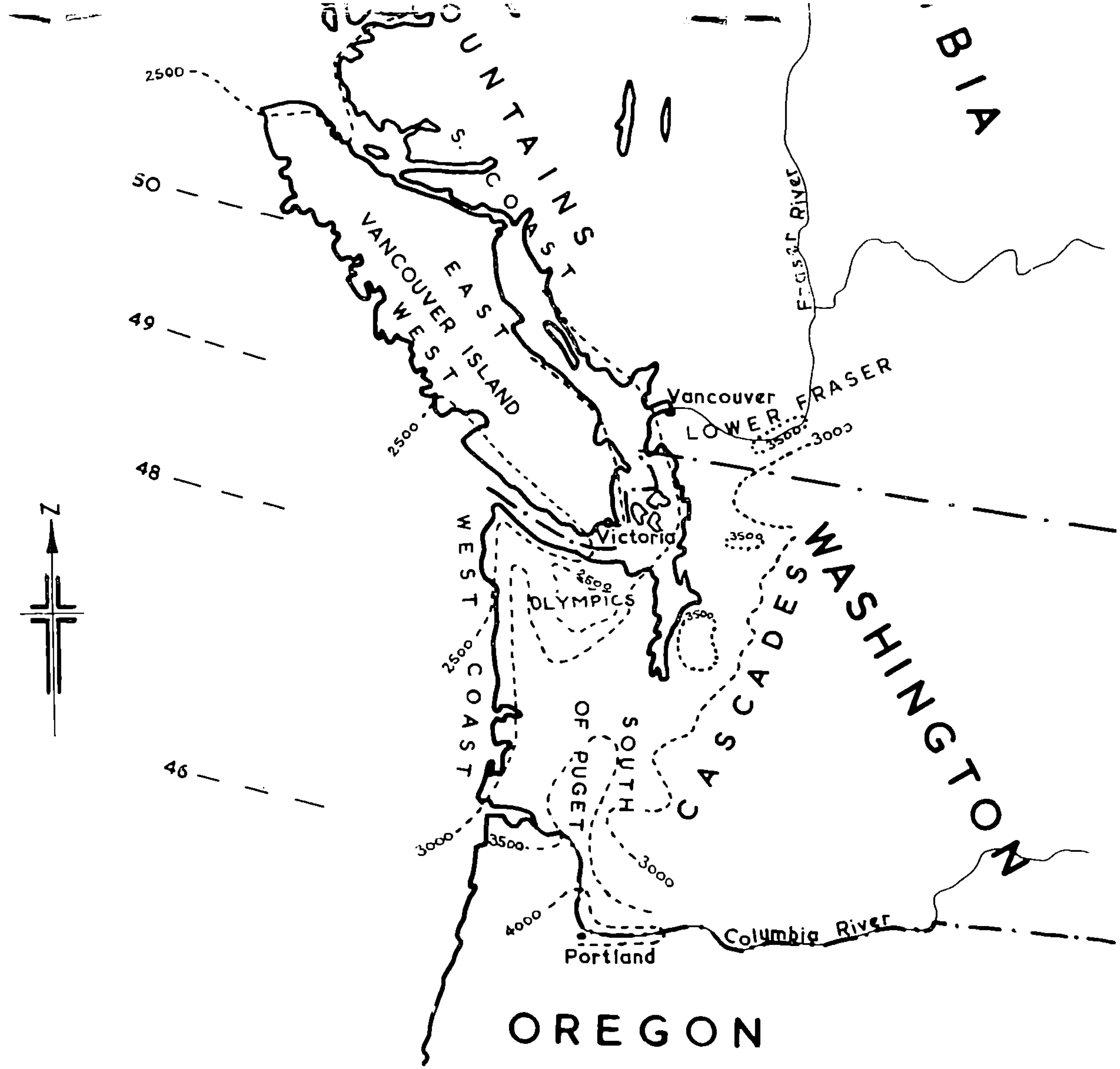

BIA
UNTAINS
S. COAST
EAST
VANCOUVER ISLAND
WEST
Fraser River
Vancouver
LOWER FRASER
Victoria
OLYMPICS
WEST COAST
SOUTH OF PUGET
CASCADES
WASHINGTON
Columbia River
Portland
OREGON
50
49
48
46
2500
3000
3500
4000
N

Photo. 19 Skeena River. Kitsumkalum Lake. Open stand of mountain hemlock, *Tsuga, mertensiana*, at 3,000 feet.

Photo. 20 Washington. Lodgepole pine, *Pinus contorta*, near Olympia on dry site where it is associated with Douglas fir. Note crown form.

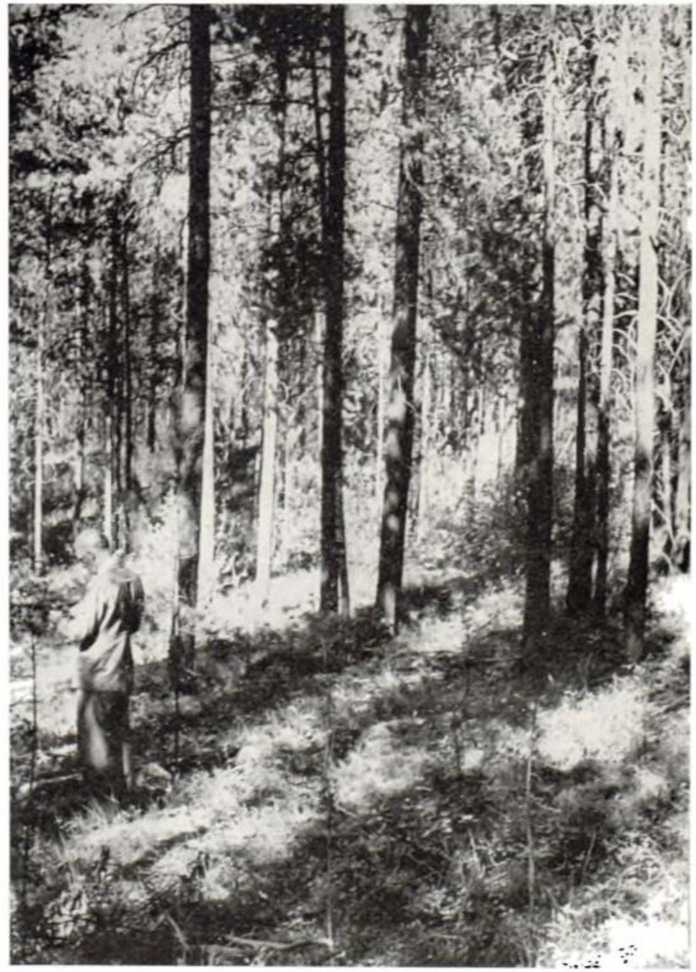


Photo. 21 Okanagan Valley. Lodgepole pine, *Pinus contorta*. This is true interior lodgepole pine, but compare Photos. 27, 28 which show good stem form also.

Photo. 22 Skeena River. Lake Lakelse. 100-year-old balsam poplar, *Populus trichocarpa*, in intimate association with Sitka spruce.

Photo. 23 Vancouver Island. Franklin River. Old Douglas fir, now sparse on the ground, over hemlock. The two storied effect has probably been brought about to some extent by fire.

Photo. 24 Vancouver Island. Qualicum Park. Douglas fir in dry coastal climate typified by the Pacific madrone, *Arbutus menziesii*, seen in centre.

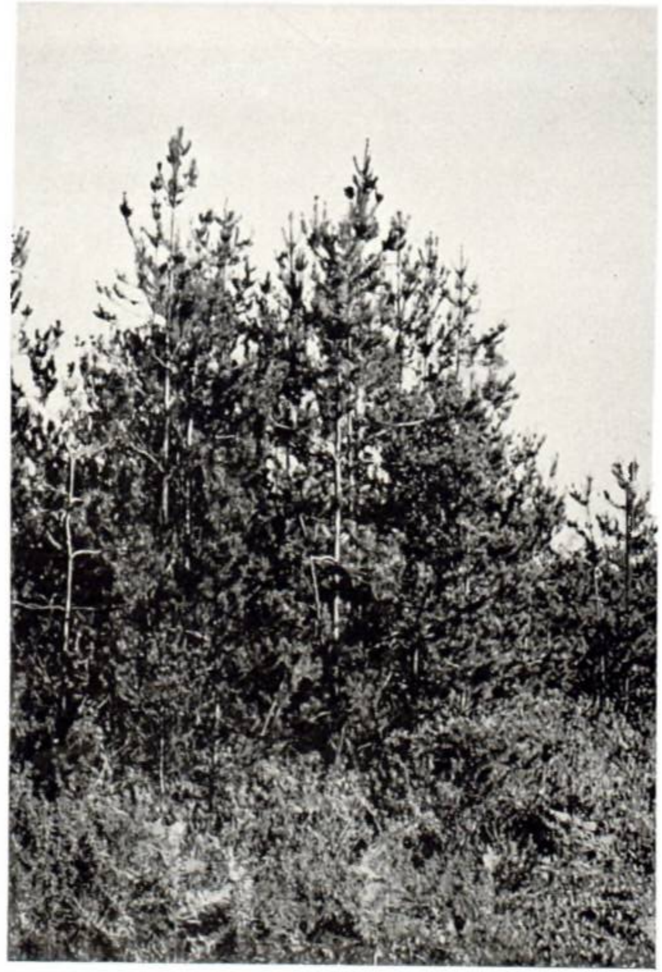


Photo. 25 Lulu Island, Fraser River Estuary. Lodgepole pine, *Pinus contorta*. These stands have been a common source of coastal lodgepole pine seed.

Photo. 26 Vancouver Island. Nimpkish Valley. Near the northern coastal limit of Douglas fir. A 250-year-old stand of Douglas dominant over western hemlock, *Tsuga heterophylla*, and western red cedar, *Thuja plicata*.

Photo. 27 Skeena River. Lake Lakelse. A fine stand of lodgepole pine, *Pinus contorta*. Hemlock taking over and regenerating freely in gaps. A rather better site than that below.

Photo. 28 Skeena River. Kitsumkalum. Hemlock invading 90-year-old lodgepole pine, *Pinus contorta*, on poor gravels.

Photo. 29 Vancouver Island. Cowichan Lake. Fire break in almost pure second growth of Douglas fir, 50 years of age.

Photo. 30 Washington. Olympic National Forest. "Staggered set" working in Douglas fir. Disturbance favours Douglas, and seed source is maintained by avoiding complete clearance.

Photo. 31 Washington. Olympic Park. Douglas fir under moist conditions dominant over western red cedar and western hemlock. Vine maple, *Acer circinatum*, in foreground.

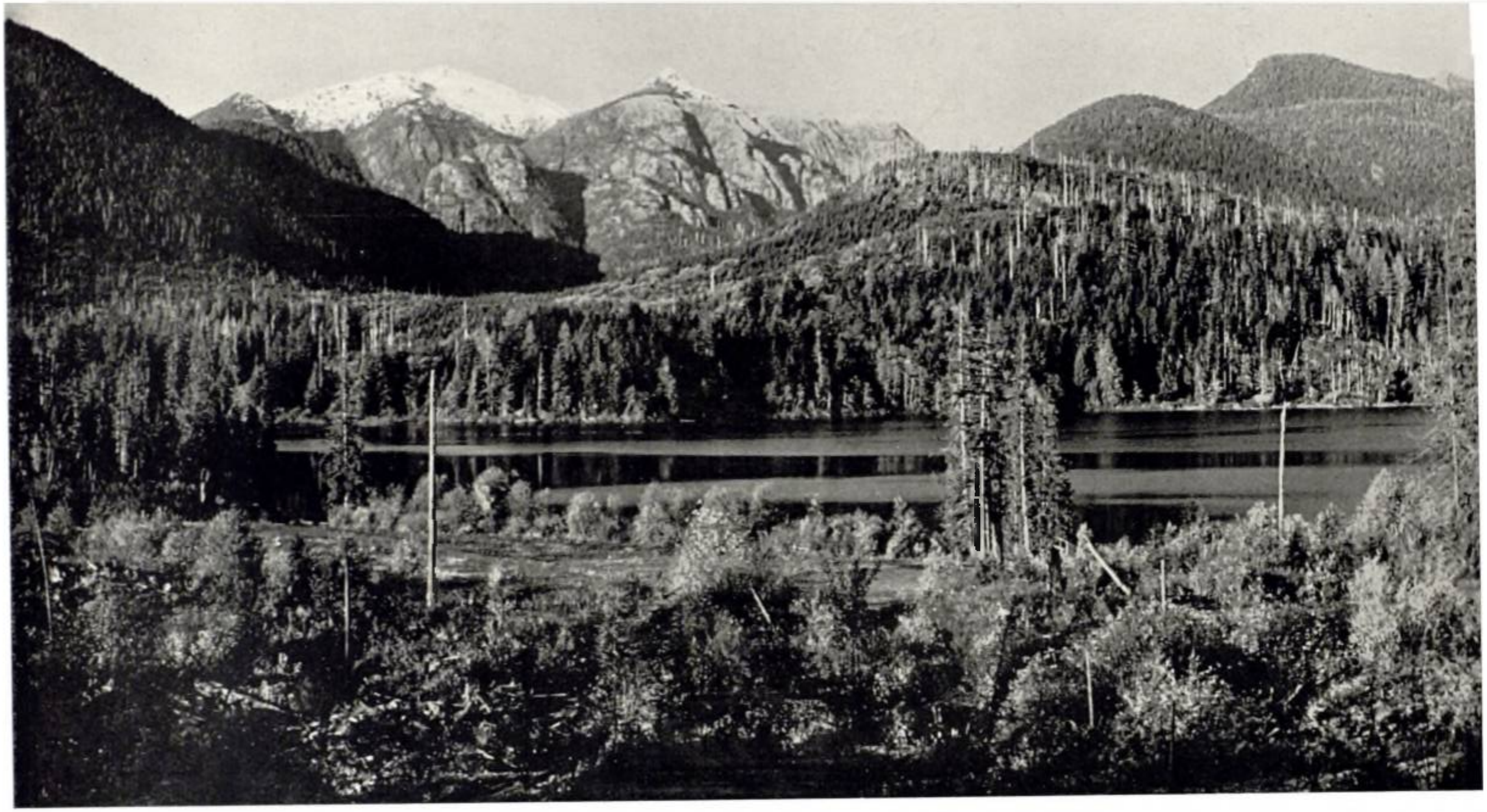


Photo. 32 Vancouver Island. Nimpkish River. Anutz Lake. Logged-over forest of Douglas fir. Fires have destroyed regeneration; red alder taking over.

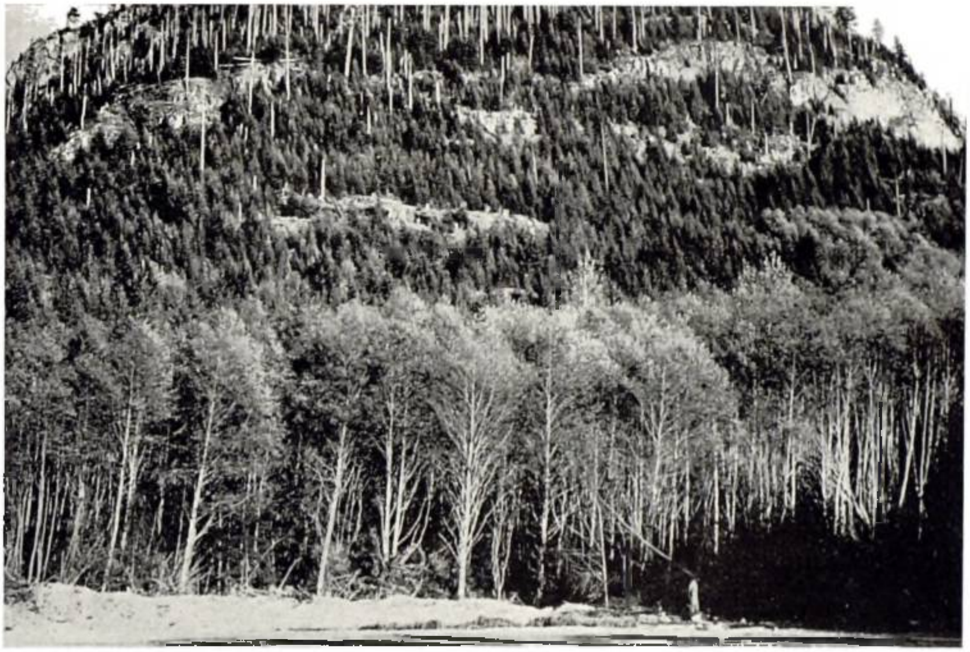


Photo. 33 Vancouver Island. Nimpkish River. Red alder, *Alnus rubra*, stands on lower slopes of logged-over hill. This effectively precludes Douglas fir.

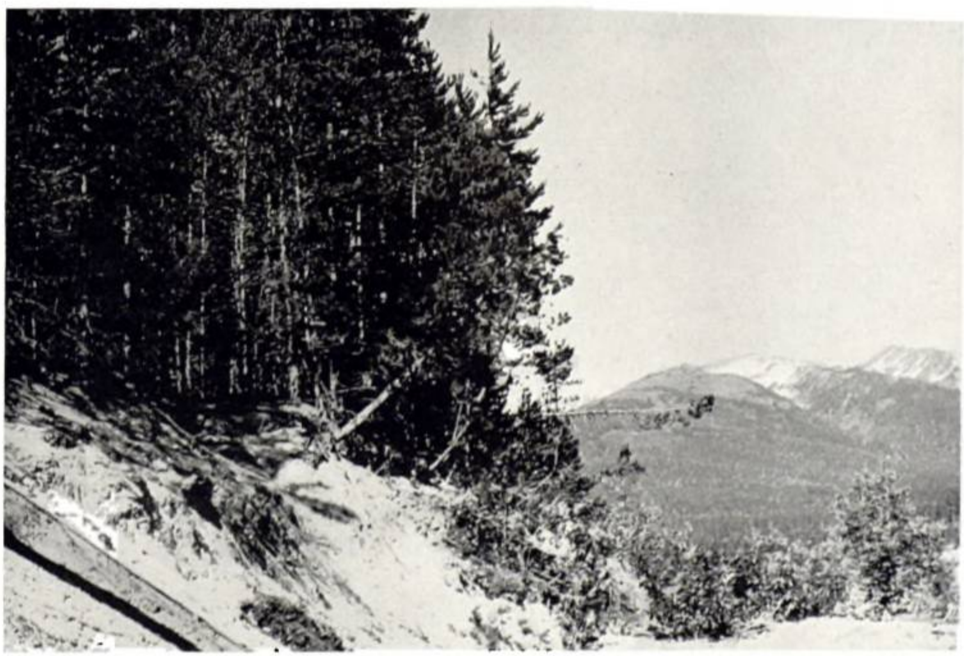


Photo. 34 Skeena River. Kitsumkalum Lake. Lodgepole pine, *Pinus contorta*, on gravel terrace.

Photo. 35 Kicking Horse Pass, Canadian Rockies. Douglas fir in extremely continental climate. The light coloured foliage is American aspen, *Populus tremuloides*.

confinement to the Coastal Forest and non-appearance in moist interior environments, where its associates *Thuja plicata* and *Tsuga heterophylla* recur, simply suggests that it has not been able to cross certain intervening dry belts.

As a species its summer temperature requirements are low. Griggs (1934) shows that it is not stable at its northern limit on the Pacific coast, but is pioneering actively in Kodiak Island. Here it will have something over 1,500 day degrees F. of accumulated temperature, (not much cooler than the northernmost mainland of Scotland); but since Griggs concludes that it is not at a summer warmth limit, it is hardly worth speculating whether it would find a summer temperature limitation *inside* the general tree limit in Britain.

We are left with high moisture requirement as the one important specific character indicated by its broad distribution. It is tempting to draw some climatic line in Britain to limit the species, but this is hardly possible on Pacific Coastal evidence.

Tsuga heterophylla. For this species as a whole it is not possible to suggest any broad climatic limitation which is likely to operate in Britain. It obviously exceeds the range inside which we operate. Plainly its abundance distribution shows that moisture is a big factor with it, but the climatic moisture limit is probably not to be found in our conditions. No doubt its sensitivity to moisture in the site might be more noticeable in our drier east.

Thuja plicata. On broad climatic ground there is little to separate *Thuja plicata* from *Tsuga heterophylla*, except that it stops short of the latter in South-East Alaska, south of a line which might be demarcated by 2,000 day degrees F. This may or may not indicate a somewhat higher requirement for summer heat; it can be said that it does not run through our range of summer warmth. Like *Tsuga heterophylla* it recurs under moist conditions in the interior.

Abies amabilis. Like *Thuja plicata* it terminates in South-East Alaska. It probably hardly runs through our range of summer warmth, but one would not expect to find any great sensitivity in Britain on these grounds. It does not recur in the interior of British Columbia. On its general distribution one would hardly separate its moisture requirements from *Tsuga heterophylla* and *Thuja plicata*.

Douglas fir. The limits of Douglas fir are probably more closely connected with the natural incidence of fire than with its response to any individual climatic factor.

The northern limit of Douglas fir might be demarcated by the 2,500 day degrees F. line on the coast; in the interior it runs much further north and summer heat may be a little less than 2,000 day degrees F. Thus it is not a species which runs through our range of summer heat, and the great weight of its distribution is towards warmer conditions than we experience. While it is not suggested that any sharp summer temperature limit can be drawn for Douglas fir, we might reasonably expect that it would exhibit increasing sensitivity towards the colder end of our range. It has plainly, as a species, no dry limit that means anything to us. Halliday and Brown (1943) remark that its abundance distribution is almost the exact reverse of that for *Tsuga heterophylla*, but this interesting observation applies to the broad picture of the two species, whereas we are concerned with only a restricted part of their range.

Abies grandis

On the coast the limit of *Abies grandis* is similar to that of Douglas fir. It also does not run through our range of summer heat, and might find some handicaps at the colder end. Its moisture requirements are not easy to suggest from its broad distribution, they are obviously greater than those of Douglas fir, but not probably such as to find any marked climatic limit on these grounds in Britain.

Other Species. There is obviously no point in looking for any generalised climatic limit in Britain for *Pinus contorta*. *Tsuga mertensiana* and *Chamaecyparis nootkatensis* appear, like Sitka spruce, to run right through our range of temperature. *Abies nobilis* is only just a native of the region under consideration. Although a sub-Alpine species, one would imagine that it might strike a summer temperature limit somewhere in the British Isles.

To repeat, this sort of information is of very limited value in the interpretation of the position of the species in Great Britain. It may be summed up that no climatic limits (with any clear meaning in Great Britain) can be ascribed to a group of species (*Tsuga heterophylla*, *Tsuga mertensiana*, *Pinus contorta*, *Chamaecyparis nootkatensis*, *Abies amabilis*, *Thuja plicata*); Sitka spruce has a distinct moisture limit but no temperature limits; and Douglas fir and *Abies grandis* have probably no moisture limits on the dry side but may have summer temperature limits. In the following section the principal species and associations will be re-examined with more attention to their relative responses to site and climate.

IV. SILVICULTURAL NOTES ON THE PRINCIPAL SPECIES AND THEIR ASSOCIATES

We can most easily think of the coastal forest as essentially a forest of the western hemlock, *Tsuga heterophylla*. The great intolerant dominants Sitka spruce and Douglas fir occur with it in associations which slightly overlap, and are not easily separable on any simple formula; but clearly the division is on the following lines:— moist, cool, oceanic for the former, and drier, warmer, more continental for the latter. Without begging the questions discussed in this section, it seems logical to think of some such division in Britain also, always bearing in mind that the greater part by far of the truly vast range of Douglas fir lies in climates quite dissimilar to ours, and we have only a range perhaps equivalent to the northern coastal section of the Douglas fir forests of North America.

Sitka Spruce and its Associates

The main feature of Sitka spruce is high moisture requirement; if the rainfall is low it is sharply confined to sites of adequate ground water supply, high retentivity or both. This factor will remain highly important with us, but it will be somewhat softened by our better rainfall distribution. Nevertheless, it seems such a strong feature of the tree that one might expect to have local sites too dry for it even in quite high rainfall areas. It is not easy to separate its fertility requirements from its moisture demands—it often fades out on what might be either a fertility or a moisture gradient, as the finer grained more fertile soils are also the more retentive. It obviously dislikes stagnation more than does any other of its close associates, and probably tops the group in both its nutritional and moisture demands.

Whilst its penetration inland up river valleys gives it a quite surprising list of contacts, its intimate and inseparable associates over most of its range are *Tsuga heterophylla* and *Thuja plicata*. Some impression of the relative requirements of these species may be obtained where even-aged stands have developed following disturbance on sites with marked quality gradients. The best examples of these are given by dense pole crops or middle aged stands where the various species have had time to show their respective degrees of dominance.

Where there is a moisture gradient, e.g. a steady slope with drier conditions higher up, Sitka spruce will usually be dominant over the other two on the moister parts, but on the drier parts will be dominated and disappear from the stands before *Tsuga heterophylla* has shown much signs of falling off in vigour. It is not so easy to trace any equivalent trend to the muskeg condition, because the edge is usually very sharply defined. It can however at least be said that between the last reasonably vigorous spruce and the muskeg proper there are likely to be some reasonably vigorous *Tsuga heterophylla* and *Thuja plicata*. In the muskeg itself everything is miserable, but *Thuja plicata* and *Pinus contorta* may make a fair show on the edge; in South-East Alaska *Tsuga mertensiana*, *Chamaecyparis nootkatensis* and *Pinus contorta* compete for the honour of surviving these conditions. If Sitka spruce is present and making any show in a muskeg, it will usually be found beside the edge of a runnel, or slightly elevated on a local rise, even an old log. On the other hand it does not seem to have any objection to salt water in moderation and is often found with its root system in a position where it must get periodically inundated by the tide.

I do not think any altitudinal limit can be traced for Sitka spruce which has any meaning for British conditions. It usually falls out on mountain sides because of poor site, often the soils become too shallow and cannot retain enough moisture for it. If better conditions recur higher up, Sitka spruce may reappear. It is not very clear what governs the change over from species like Sitka spruce, *Tsuga heterophylla*, and *Thuja plicata* to *Tsuga mertensiana*. It has been suggested that the tolerance of young regrowth to deep snow may have something to do with it. One would not imagine that it had much to do with summer warmth, as Sitka spruce has in fact the most northerly range of the coastal conifers.

The relationships between Sitka spruce and *Tsuga heterophylla* have probably received most attention from R. F. Taylor and his colleagues at the Forest Research Centre, Juneau. In South-East Alaska they are confronted with a *Tsuga heterophylla* climax forest which has (of course) no useful net increment and also possesses very poor value due to the low standing volume and prevalence of defective timber. Sitka spruce is poorly represented in much of the forest, but there are usually sufficient spruce present to allow a reasonable stocking in the second growths following clear felling. Such second growths have been shown to be capable of producing twice the merchantable volume of the climax type in eighty years, (Taylor, 1934). This is not accounted for purely by the superior yield of the spruce. Taylor found that there was little between Sitka spruce and

Tsuga heterophylla in height growth for about 100 years, and spruce dominants only exceeded hemlock dominants in diameter by about 7 per cent. He was able to construct useful preliminary yield tables for such second growth stands, without concern as to the exact proportion of spruce, which varied between 10 per cent and 75 per cent by basal area. Clear felling in the hemlock climax is a cultural measure allowing the litter to break down; soil temperature is very low in the forest on this part of the coast, and it rises very markedly on clearance.

Pure stands of Sitka spruce occur under special conditions; they may occur in the wake of receding glaciers following a stage of poplars, willows and alders (Cooper 1942, Taylor 1932); on fresh alluvial flats; or on earth slides. In fact they are favoured by radical disturbance. A pure spruce forest is advancing quite briskly over Kodiak Island, where there has been no coniferous forest since the end of the Pleistocene. (Griggs 1934). But the intimate mixture with hemlock is the common condition in second growth stands.

The factors influencing the proportion of the two species in regeneration have been studied from various angles. Taylor (1935) investigated the condition of the forest floor. He found that litter or mull which would produce high nitrate nitrogen on incubation favoured a high percentage of Sitka spruce in regeneration. On the other hand where ammonia nitrogen was high, *Tsuga heterophylla* regeneration was favoured. He found the mull of alder and brambles high in nitrifying power, Sitka spruce duff medium, and *Tsuga heterophylla* duff low in this respect. High nitrate nitrogen went with less acid, high ammonia nitrogen with more acid conditions. Allen (1953) found that the optimum temperature for hemlock germination was considerably lower than that for spruce. Taking into account the greater shade tolerance of hemlock, it seems clear enough that many of the things which go with closed forest conditions favour hemlock against spruce, and a moderate degree of disturbance such as a small windblow will also favour the hemlock.

But I do not think that the behaviour of *Tsuga heterophylla* suggests that its use in Britain need be confined to that of a successor species. Its greatest sensitivity, which is presumably to humidity as a young seedling, is probably exhibited in a period which may be roughly covered by the nursery stage. We have of course to consider the factor of exposure, to which it is undoubtedly more sensitive than Sitka spruce. Apart from the problem of establishing *Tsuga heterophylla* in open conditions on which we probably get little guidance from its behaviour in nature, its main advantages would seem to be that its requirements are distinctly lower than those of Sitka spruce, and one would expect it to make a better showing than the latter species both under drier conditions and on sites of lower fertility.

Second growth stands of spruce and hemlock can be seen anywhere in the common range of the two species, and the relationship between the two species seem pretty constant. In Alaska they are preferred to stands of either species pure. Pure Sitka spruce are considered very coarse and limby. Actually the only pure spruce I saw was rather open grown, resulting from sparse regeneration. But there is no reason to doubt that the mixture provides the better spruce. They also find that dense stands of pure hemlock "stagnate", or are sometimes snow broken. It is claimed that mixed stands are more yielding than either species pure, and while this may well be the average result in South-East Alaska where yield from thinning is not contemplated, it does not follow that it would be with us. The mixture is to some extent self thinning, in the later stages spruce is making ground at the expense of hemlock. This is of course an advantage where intensive management cannot be contemplated, but has little bearing on conditions in Britain.

On the whole, and without going into the diverse arguments as to whether mixtures are a "good thing", the spruce/hemlock even-aged stand looks to be a very practicable proposition, which might well be managed under our conditions with an eye to larger dimensions of spruce and smaller assortments of hemlock. It does, however, seem likely to me that we have many sites for which Sitka spruce would be our present choice of species, where hemlock might very well outgrow spruce in even-aged mixture. There is no evidence that an admixture of hemlock will improve the site.

The common habit of spruce of succeeding red alder, *Alnus rubra*, should be mentioned. Disturbances which expose the mineral soil frequently seed up with alder. Spruce often seeds in with the alder, and is left behind almost at once by the much more rapid early growth of the latter. However, it seems able to hang on surprisingly well, and retains sufficient vigour to take over when the short-lived alder declines. The process is very common and reliable, though, seen in its early stages, it does not look at all inevitable. The old process of "A-frame" logging, in which lumber from a narrow sector of hill-side is drawn down to the salt water, has often left its traces in belts of alder which are in various stages of succession to spruce.

The question of beginning the diversification of British Sitka spruce plantations where opportunity has been provided by windblows, group deaths, etc., has recently come to the fore. If the analogy with the Pacific Coast of North America is sound, and it is difficult to see why it should not be, there does not seem to be much doubt about the answer. The obvious species is *Tsuga heterophylla.* We might also have a place for *Abies amabilis* here. It seems very probable that these climax species will be easier to establish under these conditions. It is a pity that red alder has been so disappointing with us; otherwise one could certainly have recommended a limited use for it in the larger accidental clearings.

Pinus contorta

Pinus contorta is of very minor importance in the moister associations in the Coastal Forest. It is practically confined to refuges such as muskegs, shore-lines, etc. from which it spreads out in the event of fire to occupy sites which it can only hold for a very short time. During this stage it can be seen in even-aged mixture with Sitka spruce, hemlock and western red cedar. Its contact with spruce under these conditions is however rather ephemeral; if spruce is able to grow with any vigour, the site is several degrees better than that on which *Pinus contorta* can exhibit its low requirements to dominate any of the group; and it is soon likely to be separated from spruce by zones containing hemlock and red cedar. It is however, a very difficult species to generalise about. As *the* pioneer following the recession of the ice sheets it had an almost general distribution. It is now (in the Coastal Forest) greatly diminished and exists in a number of special habitats which have only the one thing in common, they are too poor for anything else. It still acts as a general pioneer for spruce and hemlock in the colonisation of certain coastal dunes, but that is rather a special case. There is nothing to be seen analogous to our use of *Pinus contorta* as a nurse for Sitka spruce on moorland (but then there is nothing analogous to *Calluna* on the coast). One would feel that if we succeed in keeping Sitka spruce and *Pinus contorta* in balance for any length of time, this can only be because we have Sitka on much poorer sites than it is accustomed to; there is nothing very natural about the mixture. (More will be said later about *Pinus contorta* in relation to drier conditions.)

Thuja plicata

Some mention must be made of *Thuja plicata* if only because it is such a widespread and typical species in the Coastal Forest. But I found it very difficult to understand its status in the forest. It seems to be present in all conditions from the best to the worst. It makes often the best showing on poor sites bordering on muskeg conditions, on the other hand it is almost certain to be present also on the best alluvial sites. Its one obvious advantage on the latter lies in its longevity, which includes the power of surviving gross injuries from fire and other causes. Hence a few individuals scattered about can provide a seed source for a very long time indeed, during which mere chance may get some of their progeny into a favourable position. But it is only at the poorer end of the scale that it is likely to *dominate* its associates by a better general response. One would guess that its fertility requirements are slightly lower than those for hemlock, but its moisture requirements appear rather higher. On the whole it is a species which one would *expect* to be of real importance in British forestry—sited on the poorer parts of the present range of Sitka spruce, but not with the same degree of confinement on the grounds of moisture.

Douglas Fir and its Associates

It has already been mentioned that Douglas fir even in its coastal range occupies whole regions climatically much drier than we have. Löfting (1952) thinks that a close analogy can be drawn between Douglas fir and Scots pine. From the Western European point of view, he says, Douglas should be regarded as drought resisting; as with Scots pine there should be no problem in meeting its water requirements. This is certainly the impression I obtained myself.

Except in the belt from the south-east corner of Vancouver Island to south of the Puget Sound, where there is a possibility that Douglas might be present in the climax as conditions are too dry for *Tsuga heterophylla* Douglas fir, is always represented by substantially even-aged disturbance stands, dominant over *Tsuga heterophylla*, *Abies* spp., *Thuja plicata*, etc. The fact that it can only be present where the incidence of past fires permits, makes it difficult to estimate its limits in other terms. Presumably it reached certain climatic limits in its advance north to succeed *Pinus contorta* after the retreat of the ice, but since then further succession, bringing in the tolerant *Tsuga heterophylla* and *Abies* species, has complicated the position.

Though as a species its moisture requirements may not be high, it is perfectly capable of growing to fine dimensions on sites where Sitka spruce is equally at home, and we may be sure there is ample moisture there. In fact in Washington it is obvious that the distribution of Quality Class I sites is very much related to moisture supply, there being a marked concentration of them on the low coastal hills which experience very heavy precipitation (Isaac 1949). Round Aberdeen and Hoquiam (Washington) Douglas fir experiences 100 in. rain a year, which sounds a lot, but the distribution is such that on average only about 23 inches falls from April to September (inclusive) and about 7 inches in the summer quarter. It is difficult to give the exact equivalents in Britain. A station in the South-west of England with 60 inches of annual rainfall might have about 23 inches in the April-September period, but a station of only 30 inches annual rainfall with the same distribution would give 7 inches in the summer quarter. Taking into account also the moisture need, which will be higher in coastal Washington than in most of Britain, it seems likely that these wettest Douglas sites in Washington are no moister, climatically, than areas in Britain receiving 45 inches annual rainfall. Perhaps we might put it that (i) we have no regions climatically too dry for Douglas as a species, (ii) we should however see in Britain some response to increasing rainfall, other things being equal, but (iii) we ought not to expect any further response beyond a quite moderate rainfall figure of perhaps 45 inches in the South and markedly less in the North. Löfting thinks that Douglas is likely to be sensitive to soil temperature, and that this may be one of the factors limiting to it in an oceanic climate. He considers that this is an important point to observe both in the siting of Douglas and in questions of provenance.

Over the moister part of its coastal range Douglas is inseparably associated with *Tsuga heterophylla*, and all stages of the succession from young stands following fires to near-climax conditions are to be seen. Munger (1940) describes a very advanced stage in the process in Washington. He gives the following analysis of an old Douglas stand:—

	No. of Stems Per Acre	*Height ft.*	*Breast Height Diameter ins.*	*Age*
Douglas fir	5.8	250—275	60—100	590±25
Tsuga heterophylla	21.9 (over 16 in. B.D.H.)			
	of which 28% are in age class			100—200
	25%			200—300
	44%			300—400
	3%			over 400

No. of Trees Per Acre

Diameter Class	*Douglas*	*Tsuga heterophylla*	*Thuja plicata and Abies species*
16-20″	—	4.62	.09
21-40″	.06	14.44	—
41-60″	1.34	2.81	.06
61-80″	3.41	—	.19
Over 80″	.97	—	.03
	5.78	21.87	.37

While this is a late stage, Douglas fir has been found over 1,000 years of age. The younger stages are of more interest to us, and here the relationship between Douglas and hemlock seems to be very much a matter of moisture. Under drier conditions the second growth stands are often to all intents and purposes pure Douglas, any hemlock that may regenerate in with the Douglas being hopelessly dominated; and it is only later in the succession when no doubt a suitable micro-climate has been provided, that hemlock becomes a significant feature of the stand. On moister sites the position is quite different. Hemlock regenerates with Douglas and grows in intimate mixture with it for many years. The degree of dominance of the Douglas may not be very marked for the first 100 years, there are many stands older than this with hemlock still in the upper canopy; but probably by 150 years at the latest there will be a significant difference in the rates of height growth in favour of Douglas, and by 200 years Douglas will hold the upper canopy. But with short rotations and intensive management hemlock would obviously become an important component of the crop. From our point of view Douglas/hemlock mixtures look a practical proposition. The impression seems to be general among coast foresters that Douglas is less limby therein. There is little available evidence on the yield of such mixed stands, what there is does not suggest that there will be any advantage to the mixture in this respect.

It is difficult to predict whether such mixtures would "work" in Britain. I think it is not very likely that we have whole regions where the mixture would fail due to the hemlock being hopelessly dominated, but there is quite a possibility of the reverse occurring in the west. In our wetter regions one would expect the degree of dominance of Douglas to be quite small, and any attention from its pests (*Phaeocrytopus*, *Adelges*, etc.) might well tip the balance. (We have experience of this sort of thing in the Douglas/Thuja mixtures in the Forest of Dean).

Apart from hemlock, American Douglas stands may contain a number of other species. Except on the driest sites *Thuja plicata* is sure to be present.. On the moist oceanic fringe Sitka spruce may overlap Douglas; *Abies amabilis* may be associated with it on the higher slopes; and *Abies grandis* is to be found rather sporadically in stands usually on valley alluvia.

On many of the drier Douglas sites in Vancouver Island and Washington *Pinus contorta* is a common associate of Douglas fir. These are areas where fire is frequent and this serves to maintain a high but shifting population of *Pinus contorta*. The two species may regenerate together and grow in intimate mixture till the pine is inevitably suppressed, or another fire starts the process again; or if Douglas fir has failed to come in initially through seed shortage or other cause, there may be a long successionary process to Douglas fir which will not be able to take charge till the pine has begun to deteriorate and open out. There do not seem to be any half measures in the process. Something similar is to be seen north of the Douglas limit on dry sites where *Pinus contorta* is the common pioneer after fire, and the succession is to *Tsuga heterophylla*. Here if the site is too dry for hemlock initially, or regeneration fails for other causes, *Pinus contorta* may hold the site for many years, hemlock taking charge gradually as the stand declines. If however, the site is rather better and hemlock can establish itself with the pine, the two may grow harmoniously together till the rate of height growth of the pine begins to fall off, when the pine is quickly suppressed. Generally speaking if the pine is in at the outset, it is going to make its full height growth. The succession may be 'telescoped', but it is probably rare on dry sites for *Pinus contorta* to be suppressed by the successor species before it has completed its main surge of height growth.

It has been suggested that Douglas is more shade-tolerant on dry sites than on moist. Certainly some approach to uneven-aged conditions can be seen in the driest coastal conditions. This has been ascribed to the "need" for Douglas to transpire at a high rate (Krajina 1953) which it can achieve under canopy in a dry climate but not in a wet one. However that may be, the general impression is of a highly intolerant tree, rather more so than Sitka spruce. The latter manages to exist under alder for the relatively short life of that species, but Douglas fir does not seem able to do this. Many of the high quality Douglas sites in Washington have regenerated heavily to alder and are regarded as lost to Douglas where silvicultural measures cannot be undertaken early enough.

Abies species

Not enough was seen of *Abies grandis* to make any very worthwhile observations about its use in Britain. It would appear to be rather particular about site, having a liking for finer grained soils. It does not seem to be nearly so concerned about rainfall or atmospheric humidity. *Abies amabilis* occupies a zone above Douglas in Washington, but descends to low elevations in the north of the coastal forest. One would expect it to have lower warmth and site requirements and rather greater moisture requirements than *Abies grandis*, and of the two species one would guess that it would be the easier to satisfy in Britain. It is absent from the Charlotte Islands and most of South-East Alaska. It is slightly more tolerant than hemlock. Hanzlik (1932) considers that in parts of the Olympic National Forest it constitutes the climax following a succession through Douglas and *Tsuga heterophylla*. We might do well to give it a trial; I should think the better mountain soils of Western Britain are indicated.

Broadleaved species

At first sight broadleaved trees appear to play an extraordinarily small part in the coastal forest. Species such as Garry oak, *Quercus garryana* and the Pacific madrone, *Arbutus menziesii* are essential components of the forest in a rather special climate (the dry 'Mediterranean' Cfb zone of Köppen might nearly define it); but most occupy stages in the succession to a coniferous climax after the disturbance of the forest, or find some niche as sub-dominants in the unevenly stocked climax forest. So far as one can judge they are hardly ever an essential part of any succession; exceptions being the colonisation of new or freshly exposed soil material such as river deposits and recently uncovered glacial tills.

No doubt the temporary occupation of sites by broadleaved species has some effects, but they must be very limited; the broadleaved species are ephemeral compared with the conifers, and in any case broadleaved species are simply not present in significant quantity at any stage in the greater part of the forest. They become of more importance in the transitional parts of the Coastal Forest, and intimate mixtures with conifers occur which most foresters would admire. A good example of this was seen at Lake Lakelse near Terrace. An even-aged 100-year-old stand on a mountain side, resulting from fire, contained *Tsuga heterophylla*, *Thuja plicata*, Sitka spruce, *Abies amabilis*, *Populus trichocarpa*, *P. tremuloides*, birch and red alder. The most complex part of the stand with all the foregoing species in intimate mixture, was only developed on the lowest part of the slope, ascending which conditions became progressively poorer; the main change appearing to be a steady decrease in moisture. The broadleaved species and Sitka spruce dropped out early, followed by *Abies amabilis* and most of the *Thuja plicata*. A zone of almost pure hemlock merged into a mixed stand of hemlock and *Pinus contorta*, the latter species occurring almost pure further up the slope. Since the whole series occupied quite a short distance, and since dead or suppressed individuals of the more demanding species were to be seen in higher zones, it could be taken that the stand did in its varied composition represent the possibilities of the site at any level. There was no doubt that the soil conditions in the mixed broadleaved zone were much pleasanter than in the pure conifers, there being a distinct trend from a mull type litter with little obvious leaching to a tough mor with marked leaching under the pure *Pinus contorta*. The example is not of course necessarily analogous to any British condition, but there is probably some generality in it; where broadleaved species are most desirable for the improvement of the site may be the place where it is most difficult to maintain them in mixture with conifers.

Of the principal broadleaved species, red alder, *Alnus rubra*, is the most important in the extreme oceanic fringe, and a tree of quite respectable stature and timber quality. It really is an extremely close associate of Sitka spruce, and it is a pity that it has proved so disappointing with us. If we knew why it had failed we might have some idea whether it would be worth while experimenting with introductions from other parts of its range. Apart from an obvious requirement of mineral soil for germination, it does not appear too fussy about site. It has certainly not the degree of confinement to valley sites which our own alder exhibits, and on the more retentive soils it does not seem to be unduly high in its climatic moisture requirements. Our failure to grow this tree would not, I think, be expected on any observations of its distribution and habits, and it warrants further trial and study.

Exceptionally fine stands of the black cottonwood, *Populus trichocarpa*, were seen on recent fluvial deposits in the Skeena valley. It was noticeable also that the poplar was not so closely confined to alluvium as one might expect, it reached large dimensions on much poorer materials, provided the moisture was there. Dense stands of it on flood plains are often succeeded by Sitka spruce. It might be worth looking into the provenance question in the search for canker resistance, which is at present the main impediment to the use of a species which is very well suited to western Britain. It is quite a vigorous tree as far north as Juneau in Alaska.

The American aspen, *Populus tremuloides*, is hardly a typical species of the coastal forest, but it does occur in Washington west of the Cascades and is very well developed in the transitional area round Terrace. The latter might be a good place from which to introduce this aspen if we want to try a West American form.

Acer macrophyllum, the big-leaf or Oregon maple, can reach large dimensions but is usually a coarse tree far inferior to sycamore. It is much more closely associated with Douglas fir than with Sitka spruce, and if anyone wants to grow it, there is no need to give it 60 inches of rainfall in Britain. I doubt if we have any obvious place for it.

The other common maples, *Acer glabrum*, the Rocky Mountain maple, and *A. circinatum*, the vine maple are little but shrubs. The latter might be a useful species for autumn colour.

The principal birches attaining tree stature in the coastal forest seem now to be considered varieties of the Canadian white or paper birch, *Betula papyrifera*. I saw some quite good birch near Terrace, and it might be worth introducing a western form of *B. papyrifera*, but there is no reason to expect that this will provide any solution to our birch problems, this is more likely to lie in the hands of the geneticists.

High elevation species

A question of special interest in British forestry is whether we can lift the economic limit of planting by some change in our choice of species. Unfortunately increased elevation in Britain means, above everything else, greater exposure to wind. This is coupled with a short cool growing season. There is little point in hoping for good results from timberline and high elevation species which grow in more or less continental climates, e.g. *Picea engelmanni*, *Abies lasiocarpa*, *Pinus albicaulis* etc. These may be adapted to a short growing season, but it is a *definite* one. Our main hope would appear to lie in the species which are found above Sitka spruce in the oceanic fringe, such trees as mountain hemlock, *Tsuga mertensiana* and Nootka Cypress, *Chamaecyparis nootkatensis*. Both are slow growing species of low requirements, they are capable of reaching considerable dimensions and the latter, at least, is known to provide high quality timber. They appear well worth trial, particularly where conditions are not *completely* dominated by exposure. However, in my opinion a more promising line is to try for northern provenances of Sitka spruce.

Discussion

The Pacific Coastal group of species is by no means our only source of exotics, and in current practice only Sitka spruce appears quite irreplaceable by species from other regions. All the other species in the group have to be compared with one or more of the other principal coniferous exotics—Norway spruce, Japanese and European larches, Corsican pine; and also with our native Scots pine.

From their distribution and broad climatic preferences however, one might well conclude that the Pacific species could easily cover the British range of climate. There has been a strong tendency to confine them to western Britain, largely I think on the assumption that they are all moisture-loving species. Except in the case of Sitka spruce this seems to be quite unwarranted, and while it is of course true that most of our afforestation must be in western districts, there is no climatic basis for passing over the American Pacific Coast species for the drier regions. That is of course only a part of the strory, difficult sites will often cancel out climatic possibilities. By and large our only advantage over the Pacific coast lies in our better balanced rainfall. While we ought to be able to profit by this in using highly productive Pacific species throughout our range of rainfall, we may not find them easy to establish in the first rotation on the poorer sites. Probably none of them has the competitive power of Scots and Corsican pines, except *Pinus contorta* which will not stand comparison with the foregoing on sites suitable to them.

The choice between certain of the Pacific species has in the past been influenced to some extent by their reputation as timber producers. But since these reputations have been built on old growth timbers, whilst we shall grow the trees on comparatively short rotations in different environments, I doubt if it is worth paying any attention at all to them. The fact that in the past Douglas fir was valued and western hemlock was not appreciated seems to have little bearing on our choice between them. The Douglas fir we grow are only the knotty cores of the 300-500 year old coastal giants—perhaps our hemlock might be less knotty at eighty years than our Douglas, which would outweigh a considerable difference in basic strength. Or perhaps our Sitka spruce may fail to live up to its reputation, and produce something worse than the despised *Abies* species, or *Pinus contorta.* We shall have to find out for ourselves. In any case the view-point on the Pacific Coast is (perforce) altering rapidly, and virtue is being found in species which a couple of decades ago were considered valueless.

Sitka spruce. The present trend to confine this species still further to the higher rainfall areas appears to be justified. But it seems likely that many sites even in high rainfall areas will prove eventually to have been too dry for it. Also, there is no encouragement for its use on sites of very low fertility, and I feel that we may be in the habit of expecting too much from this species—perhaps placing over much weight on its ease of establishment and rapid early growth and too little on its apparently high site requirements.

In present practice, many of the most favourable valley sites available for Sitka spruce are planted to Norway spruce, the latter being more reliable where spring frost is an important factor. There is no reason to regard frost tenderness as a specific characteristic in Sitka spruce, and it is important to realise that this custom certainly deprives Sitka spruce of most of the logical sites in mountainous country.

Sitka spruce is almost always seen in young stands in intimate even-aged mixture with western hemlock, and in older growths dominant over uneven-aged hemlock. This has undoubtedly some bearing on the production of clean timber, and while we might expect some gain in that direction by mixing it with hemlock, our short rotations would decrease the effect. Also, since it is undoubtedly a choosy species in its own habitat, I do not think its reputation as a timber producer should be put forward as an argument for using it as a general plantation species.

Tsuga heterophylla. It is difficult to see good reason why we should not make greatly increased use of this tree. While certainly expecting a marked response to increasing rainfall, I should not expect to find conditions regionally too dry for it in any part of Britain. While like most other climax species it may be easiest to establish it in some degree of shelter, there does not seem to be any good reason to confine it entirely to use as a successor.

With us, it should have the advantage over Sitka spruce in its markedly lesser fertility and moisture requirements, and ultimately I should expect its logical extension to encroach on our present Sitka spruce sites. It might also prove a most useful species under much drier conditions, where we are at present establishing pioneer crops of pines. Generally speaking, its rather low site requirement appears to be the key to its usefulness. It may be an excellent species to use for the conversion of western oak coppice and birch scrub, but there seems no reason to confine its use to such productive sites.

Douglas fir. My impression is that we have tended to keep Douglas fir too far west, on an over-estimation of its moisture requirements. It is difficult to believe that it could fail anywhere in Britain purely on account of the dryness of the site; but without postulating any simple limits, it does look as if Douglas stops short of the cool/moist end of our range of climate. As with other predominantly continental trees exposed to moist oceanic conditions, symptoms of such displacement are usually pathological.

I should expect its peak development in Britain to lie in regions of quite moderate rainfall, perhaps not over 45 inches, and in the Southern half of the country. Apart from an obvious dislike of excessive moisture in the soil (it will not stand temporary inundations whereas Sitka spruce will), it is difficult to say much about its site requirements. It seems to be separated from hemlock chiefly on its lower moisture requirements, and cannot be so easily separated as Sitka spruce from hemlock on fertility requirement. I think that hemlock might well prove a more reliable species than Douglas in our higher rainfall areas. Douglas fir at present may be planted on a range roughly corresponding to that of the two larches combined, but there is no climatic reason why it should not be considered for sites where Corsican and Scots pines are the customary selections. Its usefulness in comparison with these species may well be restricted by other factors, inability to compete with heather, frost tenderness, dislike of highly calcareous soils, etc., but where temporary adverse conditions are remediable by silvicultural treatment there does seem to be a reasonable case for its extension onto what are usually considered to be pine sites.

It is curious that Douglas fir in its native habitat appears, if anything, less shade-tolerant than Sitka spruce. The average forester in the British Isles would rank it much more tolerant.

Thuja plicata. It is not easy to suggest a range in Britain very different from that of *Tsuga heterophylla*. The temptation is to recommend it for the poorer peats on the evidence of its tolerance of muskeg conditions, but the analogy may be deceptive. Its extreme longevity on good sites and power of recovery from injury are perhaps characteristics of little value in our forestry. Like hemlock, one might expect it to surpass Douglas fir in our wettest areas.

Pinus contorta. The main feature of *Pinus contorta* is plainly low requirement both for moisture and nutrients, and the tree has no climatic preferences, of any importance to us.

An important characteristic of such a notable pioneer is its early surge of height growth; on sites which do not unduly favour its more demanding competitors it is likely to attain the greater part of its possible height growth before suppression. My impression after seeing something of the tree in nature is that we are apt to underestimate the difference in its requirements from those of Sitka spruce, and are thus too optimistic about the possibilities of maintaining a balance for any length of time. Mixed stands containing both species are very local, ephemeral phenomena. A much lesser gap exists between the requirements of *Pinus contorta* and *Tsuga heterophylla*, or even Douglas fir on dry sites, and on the face of it one would expect more manageable stands to result from the use of *Pinus contorta* as a nurse for hemlock or Douglas fir on certain heathlands, than from its use as a nurse to Sitka spruce on peatlands. But it would also appear highly logical to utilise its extremely low demands to the full by planting it pure on our most infertile sites, whether wet or dry. One practice which certainly has no basis in nature is the introduction of successor species into rapidly growing *Pinus contorta*.

Other species. There seems little basis for the restriction of the range of *Abies grandis* in Britain on the grounds of climate. I should *expect* its best behaviour to be in the warmer half of the country, and would certainly not expect very high moisture requirements. On the other hand, it seems to have some degree of confinement to soils of more than average fertility. *Abies amabilis* would appear on its distribution to be a species more suited to Britian, but it is difficult to suggest any particular niche where it would prove more valuable than, say, its close associate *Tsuga heterophylla*. But possibly it might have a place at high elevations in not unduly exposed localities. *Tsuga mertensiana* and *Chamaecyparis nootkatensis* are two species of low requirements which are worth trial both at high elevations (particularly the former) and on poor peats.

Of the broadleaved species, I feel that red alder, *Alnus rubra*, warrants further trial as a most intimate associate of Sitka spruce and a tree of reasonable stature itself. *Populus trichocarpa* is impressive, and since it has not the exalted tastes of the "hybrid blacks", but is quite happy on well watered sands and gravels, we should be able to make more use of it (provided a canker-resistant strain can be isolated).

V. PROVENANCE QUESTIONS

It is our experience that we are able to establish introductions of many of the American Pacific Coastal species from widely separated parts of their range, even from those regions which do not lie in the Coastal Forest proper. Our oceanic climate does not provide quick tests with survival as the prime criterion; we are rather concerned with varying growth rates and the less dramatic symptoms of unfitness.

Our provenance experiments and general experiences have taken us far enough to be able to identify certain broad regions from which we can import seed with reasonable certainty of successful establishment and early growth. These regions vary greatly in definition, some happen to be quite circumscribed, others are vague geographical expressions, no doubt containing much variation of which we have no measurement.

We have, in the main, little idea of the patterns of adaptive variation in the chief species—we cannot usually forecast what will be the behaviour of an unfamiliar provenance, though in certain cases we may hazard a good guess. Hence our ideas about the general behaviour, range and value of these species in Britain are somewhat restricted, and we are not clear what margins exist within which further provenance studies can hope to pay dividends.

It would be out of place here to attempt a review of the provenance problems in Britain of our chief species, the intention is to limit these notes to what seems apparent from the 'other side'. I feel that the time is ripe for a general review of the behaviour of Pacific coast species in Britain. A number of the more important ones have now been established throughout the length and breadth of Great Britain, and we ought now to be able to gather some valuable information on the sensitivities of the species and of their stock provenances. Such an investigation, by analysing our 'discontents', would give direction to further provenance studies.

The general approach to provenance is to find the best possible climatic match, taking into account significant minimum temperatures, summer temperature, quantity and distribution of rainfall, latitude, etc. It is usually assumed that we shall best succeed in our introduction if we can use seed from the part of its range which is closest in climate to the planting region.

In fact we have always a very considerable freedom, and can often take our seed from regions further south and a good deal warmer than our own, thereby getting faster growth than if we confined our attention to equivalent latitudes. The limits of this are not clear; we should, I think, pay special attention to timber properties in relation to summer warmth and perhaps latitude. We certainly plant the Pacific Coastal species through a considerable range of summer temperatures in Britain; it is not a factor to which they appear particularly sensitive, but it seems feasible that it may express itself in summer wood development. It is usually practicable to vary our collecting areas considerably to match regional temperatures in Britain, and it would, I think, be surprising if there were no benefits to be obtained from this.

The matching of climates is of course only a part of the story. We may not know that the variations in the species which interest us most are in the main responses to the existing climate. The history of the species, its origins and movements through climates different to the present, the junction of long separated strains, other selective pressures related to its habits and relations with its associates: all these may enter into it. Also we are not concerned with introducing seed from point A to point B, but with seed from a general district, which may or may not be easily defined climatically, and in mountainous country may contain much variation in climate inside small compass; and we are introducing it to serve whole regions of Britain. Hence the most important quality to be looked for is adaptability. It may be that we shall find this sufficiently developed in seed from the region of best climatic match, but the quality of adaptability (whatever it is) seems to be somewhat capriciously distributed and we may find it better developed in regions where the climate is less like our own. Again climatic resemblance is easy enough to see when it is really close, but often the problem is to guess which of several climates varying in different respects from our own is most likely to have selected the adaptive characters we desire. The resemblance is after all only 'skin deep'; the Pacific coast has only a relatively narrow belt of oceanic climate as we understand it. In this we certainly get the closest resemblances to our kind of climate, but may miss one feature of our own climate, its essential unreliability.

There is no substitute for an adequate series of provenance collections, which should (ideally) sample the range with which we are concerned thoroughly enough to present some picture of the pattern of variation. This may require to be carried out at two different levels. By sampling fairly extensive districts of some climatic uniformity which represent practical collection zones it should be possible to find out whether there are better seed sources for general or special use in Britain; and this should give as good a picture of the variation as we can in fact use in arranging for comparatively large-scale imports. This however would not be sufficient to discover local strains of outstanding quality or even to show that they exist. But the work of searching for such strains entails effort of quite a different order. We might however at least get a useful clue to the regions of greatest variability in the species by sub-sampling the main collection zones.

It is usually clear enough where we should collect seed if we wish to get the closest climatic match for any region in Britain, though it may not be easy to obtain it in quantity from the indicated zone. It is more difficult to estimate what we stand to gain by any major shift in our collecting zones.

Sitka spruce

This species should exhibit the simplest provenance problems of the group. According to Halliday and Brown (1943) it survived glaciation to the south of the greatest extension of the ice and subsequently re-invaded northwards to Alaska.

These authors do not mention the possibility of refugia in the Charlotte Islands or on the mainland opposite, though they do for its associate *Tsuga heterophylla*. In any case the long south-north distribution of Sitka spruce, and its relatively shallow inland penetration, are the most obvious features; one would expect a steady clinal type of variation in response to the photo-period and to the length and warmth of the growing season. This should be an easy pattern to establish, (and indeed our limited provenance experiments already suggest it).

The Queen Charlotte Islands have throughout the life of the Forestry Commission provided easily the greatest quantities of seed, some 85 per cent of imported seed having come from this source.

Growing season temperatures are intermediate in the British range (Fig. 6). They can be matched quite closely on a month to month basis at points in Britain from Central Scotland at sea level to mid-Wales at about 1,000 feet elevation. The principal collecting areas in the Charlotte Islands are quite circumscribed; a narrow strip along the north shore of the Skidegate Inlet, especially about Tlell; round Massett; and at Sandspit opposite Tlell across the Skidegate Inlet on Moresby Island (see Map). All the sites are at very low elevations, and collection is from young second growths or pioneer stands on dunes. It will be difficult to distinguish these on climate; usually the figures for Massett have been applied for Charlotte Island collections in general. A new climatic station has recently opened at Sandspit which should also represent Skidegate satisfactorily; the figures for the first three years are extremely close to those of Massett. The collecting areas as a whole should have a fairly uniform temperate climate; they are on low ground close to salt water, backed by gently undulating conditions. I should doubt if there is much chance of cross-pollenisation with trees occupying very different environment, and the topography does not suggest that sharp reversals of temperature are at all likely. This may be the main disadvantage of these areas; the spring climate is likely to be rather too reliable, and our ideas of the susceptibility of Sitka spruce to spring frost may therefore be rather biased. Otherwise there can be little doubt that the temperature regime is a good match for most of our principal spruce regions, though we have certainly considerable areas where summer temperatures are lower than those of the Charlotte Island collecting grounds.

Apart from the question of climatic suitability, it might be asked whether the Charlotte Island sources provide a reasonable sample of the genetic possibilities of the truly magnificent spruce of the Islands. I think it is doubtful whether they could fail to do so, since no selective processes can have proceeded for any length of time to degrade the strain, even though some of the sites are of poor quality. There is, however, a good deal of observable variation in the second growth and pioneer stands from which collection is made, and there may well be some adverse selection in seed collection.

The collector fills his bag as quickly and easily as possible and thus regularly chooses precocious trees, heavy coning trees with wide crowns, and trees with large cones. Insofar as any of these may be connected with undesirable silvicultural characteristics, the sample is likely to be biased in that direction. But it would be unrealistic to give undue weight to this; our Sitka spruce plantations in the British Isles do appear to have reasonably good form; and any other sort of collection e.g. from old individuals or from logging operations, is not practicable on any scale.

The only other seed source of any importance has been the Washington coast, principally the lower parts of the valleys north of Grays Harbour. This is a considerable jump from the Charlotte Islands. The regions concerned have accumulated temperatures in the 2,500-3,000 day degree F. range, which is rather high for us; such figures would only apply to low elevations in the southern third of Britain. Washington spruce has been in some disfavour due to late and early frost damage in the nursery, and in some forests also. There might well be some variation in respect of date of flushing in the Washington collection areas; one would look for late flushing in the valleys draining the Olympic Mountains (Hoh River for example) rather than in the gentle undulating country immediately north of Grays Harbour. The most northerly point in Washington is 2 degrees south of Dartmoor, Devon, which is about as far south as we have used Sitka spruce, and a full 6 degrees south of the Scottish Borders. These latitudinal differences are pretty considerable, and if the tree shows any photoperiodic responses they might at least account for a tendency to harden off late. One would not, purely on climatic evidence, choose Washington spruce for areas other than South Wales and southwest England.

While it is only in the last ten years or so that any considerable quantities of Washington seed have been imported by the Forestry Commission, it seems quite likely that some of the older trees and plantations in Britain may have originated from Washington, since these regions would have been more accessible to travellers and seed merchants. It is a point which should be kept in mind when assessing the quality of timber produced by the older trees in the British Isles.

Seed sources on the coasts of Oregon and the northern tip of California can be dismissed; though it is of some interest, as indicating the adaptability of the species, that spruce from these regions has grown in Britain.

We have practically no experience of Sitka spruce from areas between Washington and the Charlotte Islands. The west coast of Vancouver Island has only recently become the scene of logging operations, and there are consequently few areas of second growth spruce. It is also somewhat inaccessible and is certainly not an area of any importance for large scale collections, and it does not seem likely that it would have any advantages over the Charlotte Islands. Some of the fiords and through valleys on the north coast of British Columbia are worth attention, as it is in these situations that sharp reversals of temperature in the early growing season are likely to occur, which may select out strains with a late flushing tendency. Again, no extensive areas of second growths are available, and collections of the scale carried out in the Charlotte Islands are not possible. But significant quantities could be obtained near Terrace on the Skeena river, an area where spruce is close to the limits of its inland penetration, and in a climate of some continentality.

North of the Charlotte Islands, lies South-East Alaska, a chain of mountainous islands lying off an even more mountainous and fiord-intersected coast line. The nearest point to the Charlotte Islands is only about thirty miles north thereof. There is no marked discontinuity of climate between the Charlottes and the outer islands, merely a steady falling off in temperature and an increase in the proportion of summer rainfall. On the other hand some parts of the mainland coast have undoubtedly very special climates.

Seed collection on a commercial scale is possible at a few centres in South-East Alaska, and is to some extent organised at Ketchican and Juneau. It should also be possible at Sitka itself. Of these three centres Ketchican is the southernmost, and its temperatures are very difficult to distinguish from those of Massett. Being on one of the inner islands, it is slightly less oceanic than Massett; winter temperatures are rather lower. Ketchican does not seem sufficiently distinct in climate from the Charlotte areas to be likely to give rise to any very different attributes; it might however be a useful substitute in case of failure of seed supply in the Charlottes. Sitka is on one of the outer islands, it is distinctly cooler than Massett; with an accumulated temperature value of 1,700 day degrees F. it has about the same summer warmth as Wick (Caithness coast) or Kingussie (Inverness, 840 feet elevation). (It is of interest that its mean monthly temperature curve fits much more closely to Kingussie's than to Wick's). Though I understand that seed has not been collected there in any quantity, there should not be any insuperable difficulty in getting moderate amounts, but not hundreds of pounds. It is a far more highly developed place than any settlement in the Charlotte Islands, but there are no extensive areas of second growth.

Juneau lies on the mainland with the Alexander Archipelago between it and the Pacific. It is consequently more continental in climate than Sitka, and though more than a degree further north has about the same accumulated temperature value. Close behind Juneau is a large permanent icefield with glaciers reaching down to salt water on the nearby Taku Inlet. Though Juneau normally derives its weather from the Pacific, the ice cap is apt to unload its cold air seawards from time to time, causing very sharp falls in temperature. This situation seems to have the essential unreliability likely to select out a population which will be hardy to spring frost, probably through a "late" response to the rise of temperature in the spring.

Collection of reasonable amounts should be quite practicable as there is a good deal of second growth in the area. Juneau is the capital of the Territory and a very thriving place; there are plenty of people about but it is understood that wage rates are astronomic and it would be difficult and expensive to attract collectors.

One curious feature of South-East Alaska as a whole is that coning of Sitka spruce is out of phase with that in the Charlotte Islands. Thus, in the autumn of 1952 there was no coning in South-East Alaska worth mention, but a good crop in the Charlottes. But in 1951 the reverse occurred, and coning seems to have been general in South-East Alaska, e.g. heavy coning occurred at both Ketchican and Juneau. One would have said that Ketchican was far closer to the Charlotte Islands in every way than to Juneau, and it may be speculated whether the phenomenon indicates a genetic discontinuity.

None of the Alaskan spruce seen appeared distressingly slow in growth. We should be very satisfied with the growth rates of the spruce at Juneau on our more difficult sites. The main argument for the use of some Alaskan seed in our plantations is that we can get much closer to the growing season temperatures which we experience in Scotland and at high elevations. How much this matters requires to be evaluated. I think it may matter most when site conditions are poorest, and that when difficulties multiply, the provenance that will do best is the one which is, at least, adapted to the growing season temperatures. Recently attention has been drawn to certain abnormalities in the wood of Sitka spruce growing in Britain; stem crack, failure of late summer wood, etc. (Day 1950). The extent and cause of such phenomena are at present under investigation. I could find no-one who had seen such troubles on the coast; Lutz (1952) reports stem crack in white spruce from the Kenai Peninsula, Alaska, but it seems to be a rare thing in Sitka spruce. A number of cores taken from rapidly growing young spruce ranging from Washington to Juneau showed no suggestion of any direct connection between fast growth and poor summer wood production. I think it is worth bearing in mind in this connection that almost all of our Washington spruce and perhaps half of our Queen Charlotte Island spruce is planted in British localities with summer temperatures lower than in the seed collecting regions.

Further provenance studies on Sitka spruce should take the obvious course of sampling the north-south range of Sitka spruce from Washington to Sitka (roughly corresponding to the British summer temperature range); and in addition spruce from special climates such as those provided by fiords and "through valleys" should be examined.

No immediate change in the major collecting area appears to be called for, but it might be worth while importing sizeable quantities from Alaska specifically for the extreme north of Scotland and for high elevation planting further south in Britain.

Sitka spruce appears to cone with reasonable regularity—perhaps one heavy crop in four years on the average, though it may be economic to collect twice in four years in the same area. As has been mentioned above, it is possible to get a bumper crop in one region and not in another. But the heavy crop is regional, not purely local.

Douglas fir

Douglas fir presents varietal and provenance problems very different to those of Sitka spruce. The enormous geographic and climatic range of the species, of which relatively little falls within our set of conditions, gives a wide field for variation. We should be very content to know something of the variation in a fraction of the range.

According to Halliday and Brown (1943) Douglas fir, which is a species of southern origin, re-advanced northwards at the end of the Pleistocene by two main routes; (i) following the base of the Rockies and perhaps thus repopulating the interior plateau of British Columbia, and (ii) via the coast and perhaps thence up the Columbia River.

There has been much discussion about the possible subdivision of Douglas fir. It is common to speak of the 'Rocky Mountain' and 'Intermediate' types as botanical varities. Peace (1948) however, was not able to find sufficiently well marked discontinuities in gross morphological characters to support this. The point is relatively unimportant from the British foresters' point of view since our interest is almost entirely centred on the Coastal type. A question which is less academic is whether all the Douglas in the Coastal Forest has reached its present position by reinvasion northwards along the coast, or whether there has been some outward penetration of the Coast Range by interior populations; from the interior of British Columbia across the island-studded Johnstone Straits to Vancouver Island for example. Were this so (and those best placed to judge appeared unwilling to deny the possibility), we should have to be prepared for something other than relatively simple clinal variation.

Provenance experiments in Britain have not proved as informative as we could wish. We can at least dismiss the 'Rocky Mountain' type on the grounds of slow growth and susceptibility to the fungus *Rhabdocline*. We cannot entirely dismiss the 'Intermediate' or 'Fraser River' type, since we have cases where this has behaved better than 'Coastal' Douglas. But this probably points to the inadequate sampling of the regions west of the Cascade Mountains. It is obviously very misleading to cover all this area under the one description, containing as it does a very wide range of site and climate. It is however safe to say that 'Coastal' Douglas in this broad sense has established itself as the best section of the species for Britain; and when successful it is one of the most high yielding trees we have.

After a phase of very extensive planting in the early 1920's, Douglas fir lost favour considerably. The reasons for this are not simple, but probably unsuitable siting on cold wet soils has been an important element. Instability, susceptibility to the fungus *Phaeocryptopus* and *Adelges* insect attack, coarseness of form are all common complaints against Douglas; it would be rash to guess how much is specific and how much racial.

A general survey of the species in Britain might well tell us something of the conditions under which Douglas exhibits various disabilities, and in addition to improving our choice of site for the species, might suggest the directions in which further provenance enquiries should be pursued. If we find, for example, that certain disabilities multiply in the colder, wetter environments, the obvious direction is to the Pacific oceanic fringe or as near to it as we can get.

I have nothing to add to Peace's account of the appearance of the tree in the regions visited, except some rather negative remarks on 'form'. I was left wondering where some of our seed had come from, since I never saw any reasonably well stocked stands with the grosser faults which have turned up frequently in British plantations. It was impossible to decide, on an area basis, where the best-formed trees were to be found; nothing was seen which gave the impression that tendency to extreme coarseness of branching or waviness of stem might be attributable directly to race. It seems more likely that certain strains have it in them to develop such characteristics on certain sites, perhaps sites much moister than they are used to. There is no doubt that we have had a great deal of seed from some extremely dry areas of deep gravel soils (the glacial outwash plains just south of the Puget Sound), and it does not seem far-fetched to imagine that the phenotype developed under these conditions will be very different from that we shall see on moist sites in the British Isles.

Some guidance on the adaptive variation in coastal Douglas fir can be obtained from the classic experiment laid down in Washington and Oregon by the U.S. Forest Service in 1911-12. This compares progenies from 18 different sites in Washington and Oregon west of the Cascades, and is greatly enhanced in value by the extreme differences between the five sites at which the series have been laid out. Isaac (1949) summarising the results of this experiment says, "there are strains .... that make superior growth in their own environment and also over a considerable range (A); others that make poor growth in their own environment and also over the range tested (B); others that make good growth in one environment or locality and very poor in others (C); and still others that make average growth over a considerable range (D)"; (letters inserted). From our point of view it would have been nice if there had been more oceanic provenances and planting sites in the experiment, there was only one of each. The one truly oceanic lot did well on a similar site but poorly elsewhere. The "A" lots, which appeared to have great flexibility, were none of them from strictly oceanic sites. It is not possible to define their common characteristics in such a way that any zone or region can be recognised which is likely to reproduce such attributes. In fact the suggestion has been made that such sites are meeting places of rather diverse conditions. Löfting (1952) considers that they contain highly heterogeneous populations brought about by the ease of cross-pollenation in small compass from very distinct environments. Referring specifically to Darrington (one of the four such sites mentioned by Isaac) he remarks on the quick change from the dry warm sands of the valley to the cool fresh mountain slopes above, where Douglas is under pressure from hemlock and *Abies amabilis*. Perhaps one should also not lose sight of the possibility that such sites may sometimes mark the meeting place of long-separated strains.

Munger and Morris (1942) observed the order of flushing in the various lots, and were able to rank them approximately according to the climate of origin. "The first class is formed of stock from low altitude plains and valleys having relatively warm spring days and nights, the second of stock from high altitudes where both days and nights are cold until late in the season; the third, of stock from the foothill valleys where in spring the days are warm, but, owing to cold air drainage, the nights are cold". The various lots maintained this sort of order in different seasons and at different sites, though the whole flushing period was shifted earlier or later according to the spring weather and the altitude of the site. Hence strains with different flushing responses to temperature appear to be selected by the night temperatures in the environment; in particular unreliable climates with sharp reversals of temperature select late-flushing strains.

The main point suggested by this experiment is that highly adaptable strains are not necessarily to be sought for in the climate closest to that of the planting site. I think our own problem is in the choice between regions of the greatest degree of oceanicity and those which are clearly one step removed from this but which may contain populations of special flexibility. The Douglas fir at present in Britain is quite diverse in origin. There will be some profit in studying the behaviour of the principal introductions as well as the actual provenance experiments, but the information arising from this must be regarded with caution and interpreted in a very broad way. Douglas's original collection cannot be accurately sited. His journal (Douglas, 1914) only once makes definite mention of the collection of *seed*; in his entry for the 17th Oct., 1826 he records that he "exposed some of the last gathered seeds and cones of *P. taxifolia*". He was then on the Umpqua River in Oregon about 120 miles south of his base in Fort Vancouver (near Portland), and it is difficult to see why he should have troubled himself with it on an arduous and dangerous journey if in fact it had coned nearer his base that season or the previous one. Douglas's introduction is considered the best material of the three importations made up to 1853 (Matthews 1953). Whether it came from Fort Vancouver or the Umpqua, it was from a good deal further south and also further inland than one would recommend on purely climatic evidence, but Douglas may have struck a 'flexible' strain.

It seems likely that introductions from Washington did not take place on any scale till the 1890's, when the firm of Manning moved from Oregon to Roy near Tacoma. During the Forestry Commission's lifetime the principal importations have been made from the generalised areas of

Coastal Washington, Oregon and the Lower Fraser Valley; the respective proportions being in the order of 7, 1, 5.

It would now be difficult to say where the main weight of seed imported to Britain has come from. Probably, however, the glacial out-wash plains near Fort Louis south of the Puget Sound in Washington have contributed largely in the early 1920's, and also the foothills of the Cascades in King and Pierce Counties. It is almost certain that the quantity of seed obtained from the strictly oceanic belt has been quite small.

The very considerable importations from the Lower Fraser River were confined to the early 1920's, during which period the Dominion Government administered the forests in the Railway Belt and maintained a seed extraction plant at New Westminster, B.C. I was informed that it was likely that much of this seed was obtained from high quality sites. This general origin should be relatively easily identified in our plantations, since at least one large lot formed the only importation for its year. The Lower Fraser is not now an important source of seed, though small quantities are collected from farmers' "wood-lots". It will be noticed that Oregon has provided very little seed; and Vancouver Island has been almost completely neglected.

We can find the closest match with British temperature regimes in the strictly oceanic belt where Douglas frequently gives place to Sitka spruce in the associations. It is also easiest here to find considerable areas at low elevation which have the very large annual rainfall necessary to give summer figures comparable with our own. In Washington, the area immediately north of Aberdeen and Hoquiam draining to the Chehalis River and, further north, the lower slopes of the Olympic Mountains draining west to the Pacific are regions of markedly oceanic climate and high precipitation. A very close match can be made between the conditions here and in the south-west of England. It is also an area of very vigorous growth, with a considerable concentration of Class I sites (Isaac, 1949). Since a great deal of logging has been done in the area there are considerable quantities of second-growth stands which facilitate seed collection. The form and vigour of the young Douglas seen in the area was generally very satisfactory. Against such an area it might be said that the conditions are too uniform for the development of any "flexibility". But it does seem very unlikely that we should run into serious trouble, though it is possible that some degree of frost susceptibility might be encountered.

The west coast of Vancouver Island has a similar type of climate with decreasing summer temperatures. Extremely high rainfall figures have been recorded, and it is safe to say that this is, by and large, the area in which Douglas fir experiences the greatest rainfall. It is not a good area for large scale seed collection because of poor communications and scattered settlement; also logging operations hardly commenced before the mid-1930's and there is a scarcity of second-growth. However it is a zone that should certainly be sampled, as in it we can find the coolest oceanic conditions under which Douglas fir grows.

Leaving the narrow belt of strictly oceanic conditions, we are at once up against the difficulty that the climate is different from that which we experience in Britain, and while we can still match individual measures, we cannot match the whole set. Prediction on the basis of climate becomes very much guesswork. We can however presumably ignore the dry south-east corner of Vancouver Island and the continuing dry belt south of the Puget Sound on the grounds that these conditions are out of reason removed from our own. This leaves us still a very wide field including the Cascade foothills in Washington, a large part of the east side Vancouver Island, the lower Fraser River and British Columbian coastal islands and fiords, etc. In Washington, the general area of Skagit and Snohomish counties and the north part of King county looks attractive. Here the western slopes of the Cascades are more exposed to oceanic influence than those further south. In this zone we should collect at reasonable elevations, probably not less than 750 feet, and in areas of considerable rainfall in which hemlock is an important constituent of the forest.

In Vancouver Island, which is a relatively untested field, I should prefer some of the mountain valleys to the rather constant undulating sites along the east coast. Possibly the conditions which, it has been suggested, promote flexibility in the population might be found in some of the bigger cuts into the backbone of the island, such as the Cowichan Valley, the Alberni Inlet, and the Nimpkish Valley. Some of the mainland coast inlets should also be interesting, perhaps particularly the Bella Coola valley, a place which is subject to sharp reversals of temperature.

In spite of the evidence of some of our experiments, I doubt if there is a good case for any large scale introductions of the "Intermediate" or Fraser River type, which we have usually had from the vicinity of the South Thompson River. I feel that there is bound to be sufficient variation to meet our requirements in much more probable climates.

On the whole, and till further evidence is available, I feel that the oceanic zone in Washington is the most logical choice of seed source, perhaps followed by the northern Cascade foothills. If any pronounced sensitivity to growing season temperatures could be demonstrated it would of course be logical to make for Vancouver Island, but at present I doubt if there is any evidence to support this.

It seems likely that variation in Douglas fir is rather complicated, and that the comparison of samples representing large areas may not be very rewarding. In future provenance work, I would suggest that we sample a few relatively uniform zones strung on some logical axes—e.g. north-south in the oceanic fringe and along west-east sections from moist oceanic to drier more continental climates. Such collections may or may not show some pattern; at the same time we might well look for élite strains very much on speculation, being content with small point collections wherever we can hear of or deduce the possibility of obtaining interesting genetic material.

Coning in Douglas fir is less regular than in Sitka spruce. Considerable efforts have been made to obtain correlations with seasonal conditions, but the picture seems to be rather complicated. The important point is that quite long periods (six years or more) may elapse during which coning is poor almost throughout, and in partial crops the yield of seed per cone is quite disproportionately reduced by insect damage. Bumper crops, when they occur, are very generally distributed, the yield of seed is good, and collection is far more economical. The tendency on the Pacific Coast is to rely on very heavy collection in good years, storing enough seed to avoid uneconomic collection in the poor years. Storage up to seven years in optimal conditions is accepted with confidence.

Pinus contorta

Halliday and Brown (1943) say that *Pinus contorta* had reached well south of the 40th parallel before maximum glaciation. By the last glaciation a more or less continuous area had been re-established "doubtless only split into a number of elementary areas by the Cordilleran ice sheets". These elementary areas were readily able to fuse together again, and this picture suggests a highly complicated pattern of variation.

There has been a good deal of discussion amongst taxonomists about this species, some authorities being inclined to give the principal variant sub-specific rank or even to construct two species. The British Columbia Forest Service (Garman 1953) separates "shore pine" (*Pinus contorta* Douglas) from "lodgepole pine" (*P. contorta latifolia* Engelmann var.) on length and colour of leaf, and also on cone obliquity. "Shore pine" is said to have leaves 1 to $1\frac{1}{2}$ inches long and $\frac{1}{10}$ inch broad, which are dark green in colour; its cones are very oblique. "Lodgepole pine" has leaves $1\frac{1}{2}$ to 3 inches long and $\frac{1}{8}$ inch broad, which are pale green; its cones are less oblique. Garman gives the range of "shore pine" as the Coast Forest, and mentions intergrading with "lodgepole pine" at the divide (Cascades—British Columbian Coast Mountains).

This is certainly where one would expect to find the boundary if any exists; but from the point of view of the forester in Britain it may be begging the question to assume that the most important variation (to us) does follow this pattern.

Also the names "shore pine" and "lodgepole pine" are quite commonly used to distinguish bushy dune or marshy (muskeg) phenotypes from the more upright dry-site form of the Coast Forest. It seems probable that the use of the name "shore pine" by British purchasers of seed has directed the attention of seed collectors largely to the bushy dune types. It would, I think, be better to deal with the matter simply as provenances of *Pinus contorta*, without introducing confusing nomenclature; and if we desire a common name to cover the whole species (in the broad sense) there is very little objection to calling it "lodgepole pine"; this is quite common practice on the Pacific Coast.

We have derived the impression from our plantations that the Coastal tree is more spreading in habit of growth, is a darker green, has on the average more branches in the whorl, and has a shorter, straighter, needle than the interior tree. It surprised me that we had been able to construct any such picture, since the variation between individuals at some places seemed to embrace all these and other characters, and I found it difficult to see much relationship between them. The needle characters appeared the best; the broad, long twisted needle of the interior did seem to offer a fair regional contrast with the shorter, straighter needles of the Coast.

It is in any case reasonable to assume that the main break in *Pinus contorta* follows the physiographic divide of the British Columbia Coast Mountains-Cascade Mountains; and this is confirmed by the behaviour of the tree in provenance experiments in various countries. *Pinus contorta* west of this divide has a rather different status to the interior tree. In the interior it exists in large populations and, whilst always a pioneer many of the successions from it are slow. By contrast, west of these ranges *Pinus contorta* has a more strictly refuge status. It is up against much more vigorous competitors, and in general is absent from extensive high quality sites, since it cannot maintain itself sufficiently long on these to take advantage of the incidence of fire. Hence it has to exist in a number of refuges where its low requirements give it an advantage and allow it a relatively long life. From these refuges it will spread in the event of fire, but its hold is ephemeral and most of the selective pressure on the tree is for fitness to exist in its particular refuge. One such refuge is the muskeg, and there are areas where the tree has no other of any importance. Hence one would imagine that only fitness for such sites would be of much value to the tree, stature would be of relatively little importance. In its brief excursions from the muskeg it might not even be able to reproduce itself outside, so variants in the direction of better stature would have no special survival value. Another refuge is the coastal dune, and here again the emphasis is on fitness to survive in a rather special environment.

Its most important habitat in the Coastal Forest however is on poor dry sites where fire is relatively frequent, and where better species grow slowly to succeed it. Here the selective pressure ought to be rather different, it is not only an advantage to the tree to live as long as possible under difficult conditions, but it is the successful competitor with its neighbours and (temporarily) with other species (often Douglas fir) which supplies the seed source for the next burned area. Hence one would expect a tree of better stature on such sites.

The muskeg and dry habitats mentioned are distinct and recognisable forest types, and in a recent classification of Vancouver Island they are designated "*Pinus contorta-Ledum-Sphagnum*" and "Douglas fir-*Pinus contorta-Gaultheria-Peltigera*". It seems likely that there will be a tendency to the development of ecotypes in *Pinus contorta* for these sites. However, *Pinus contorta* is undoubtedly an extremely adaptable subject, and there is no reason to suppose any strict specialisation, particularly in those areas where both habitats occur within short distances.

There is no doubt at all that there is finer pine in the interior than anything to be seen in the coastal forest. I doubt if it is sound to use it in Britain's oceanic climate. It is interesting that at the Wind River Experimental Station, which is in the western slopes of the Cascades close to the Columbia River, interior *Pinus contorta* has succumbed to needle disease after growing well for years. The climate there is only moderately oceanic by our standpoint; it has a far drier summer than anything we experience. *Pinus contorta* of local origin is growing quite healthily nearby. Similar troubles have been observed both in Britain and Ireland, and there is sufficient evidence that we shall be safer to confine our collections to the coastal forest; it is doubtful whether we have had anything approaching the best so far.

What do we want *Pinus contorta* for? If we want it to suppress heather on wet moorland—and thus to act as a nurse for Sitka spruce, it would seem logical to use a seed source where the tree has a predominantly muskeg status. And what is probably more important, it is over-optimistic to expect a harmonious mixture if we get the spruce from the Charlotte Islands and the pine from 400-500 miles further south. The too vigorous growth of *Pinus contorta* in such mixtures has been the main source of difficulty in their management. The source of pine seed should be *at least* as far north as that of the spruce.

There seems to be no reason why we should not in fact obtain our seed for this purpose from the Charlotte Islands. The tree there is principally muskeg in status, but has colonised drier sites fairly extensively following fire, on which it exhibits quite respectable form of growth. Prince Rupert on the mainland opposite would be a very easy place to obtain seed of *Pinus contorta*; there it is emphatically a muskeg tree, as it is throughout South-East Alaska. It would be interesting to see whether we could obtain *Pinus contorta*, from Juneau perhaps, which would be markedly slower in growth than Charlotte Island Sitka spruce, thus forming a self thinning association.

If on the other hand we want a tree of better stature to plant pure, then the dry coastal sites suggest themselves. Very considerable areas of young pole stands of *Pinus contorta* are to be found along the east side of Vancouver Island. In the main this general area represents the dry habitat. Another considerable area of dry sites is round Terrace in the Skeena valley, which is one of the few places where interior and coastal populations have had a chance to come together. In this sense the pine there might have the 'intermediate' characters we are looking for, and its mixed origin might well confer on it an extra measure of adaptability. I understand that the geneticists working in eastern Canada are interested in *Pinus contorta* from Terrace from this point of view, it has already shown some promise in their experiments.

It may be of interest to give a sketch of two individuals growing within fifty feet of each other at Terrace. (Fig. 10). They have had ample room to develop, so their very different crown forms are truly representative of their innate habits. Tree B would probably pass anywhere on gross characters as a "lodgepole" pine, tree A as a "shore" pine; it is in fact quite likely that they have one parent, at least, in common; they are almost certainly part of one breeding population.

If we wish to use *Pinus contorta* pure as a substitute for Scots pine on sites of low quality, or if we want it as a nurse for Douglas fir or *Tsuga heterophylla* on the drier heaths, the two general areas mentioned above would seem to be logical seed sources. But though the stands of *Pinus contorta* in these regions

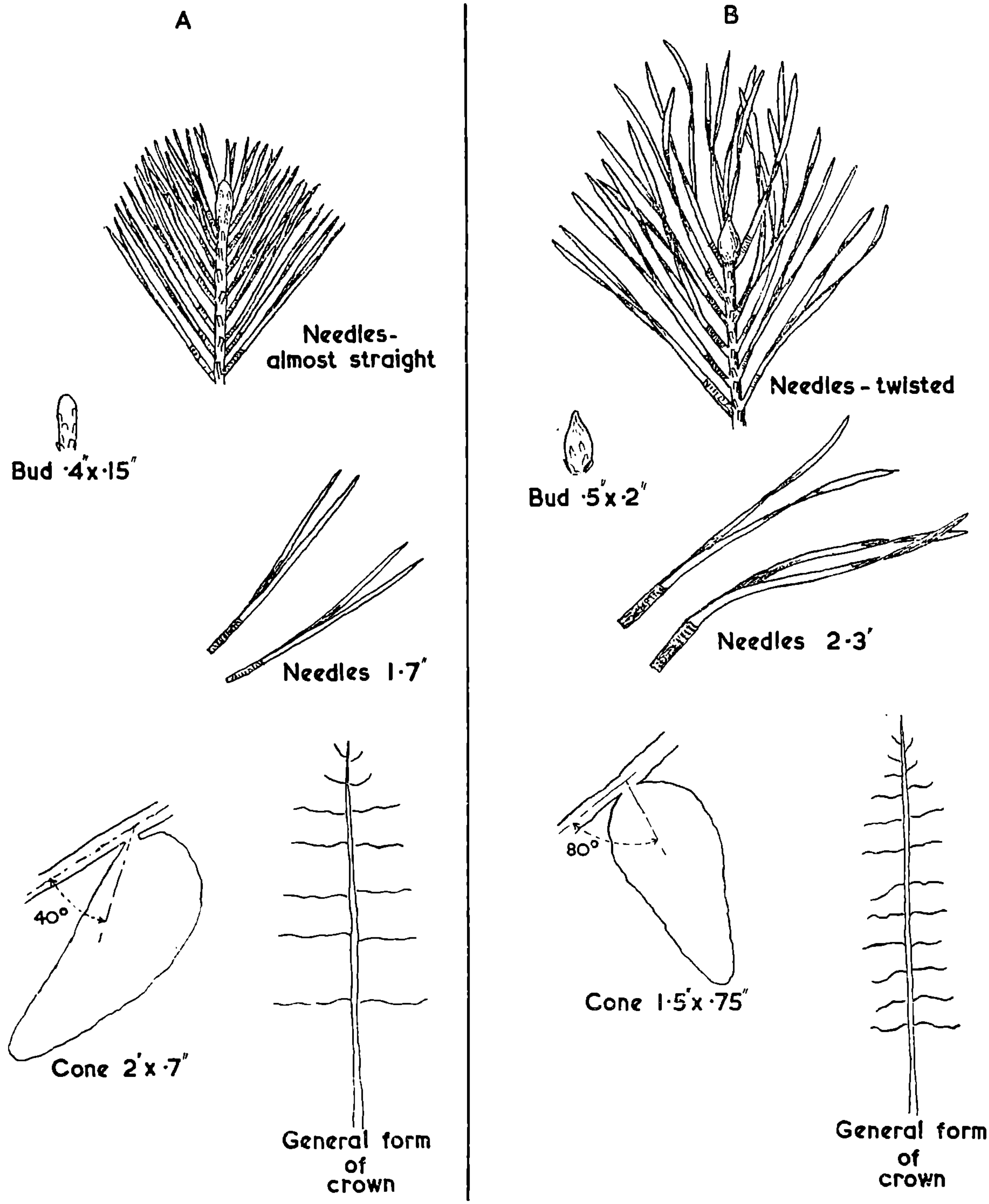


Figure 10 Two *Pinus contorta* Variants at Terrace, British Columbia.

often exhibit quite good form with which we should be very satisfied, it is by no means certain that we shall get the same results under our moister soil conditions. I think there is no doubt that on the Coast the dry site (plus of course the dense regeneration typical of such sites) makes the 'lodgepole' form, and the muskeg site or windswept coastal dune the "shore pine" form.

It was frequently noticed where invasion had taken place from muskegs to better ground, that the form of young crops was much better than expected. I did get the impression that the tree of the dry sites in Vancouver Island and about Terrace was better than its counterpart in Washington. The latter seemed rather constant in its characteristics, and appeared to become very coarse on the least provocation. The pine on Lulu Island, a convenient source of 'shore pine', looked terrible; but the site is poor. The pine population here may be quite ancient (Hansen 1947) and if it has never had the chance to grow better than it does now there cannot have been much selection for desirable silvicultural characters.

Other Species

We have little knowledge of what characters can be related to provenance in the lesser used Coastal species. Accidental comparisons occasionally provide evidence of variations, but we have little to guide us except choice of climate. It is probable that we shall find that the climax trees *Tsuga heterophylla*, *Thuja plicata*, and species of *Abies*, etc. do not vary quite so much as the early succession species, since they are not so exposed to climate "in the raw"; much of the selective pressure on them must take place on seedling populations in forest micro-climates.

Tsuga heterophylla. There seems little reason why the Charlottes should not prove a suitable source of seed. It would be of interest to study parallel sets of Sitka spruce and hemlock provenances. With hemlock, we can however consider moisture requirement; the range of the species suggests that there might be quite appreciable differences in this respect. Insofar as cold is a part of exposure, we might also be able to extend the upward limits of hemlock by introducing Alaskan material.

An observed fault of hemlock in Britain is stem fluting; I could find no evidence that it has any regional distribution, nor did it appear to be particularly common. It is quite likely that some small seed imports have had an undue proportion of seed from a few individual trees, that is assuming the defect to be inherent.

Thuja plicata. Most of the above remarks might apply to western red cedar, *Thuja plicata*, but we can get all the seed we want for our present limited usage at home.

Abies amabilis. A good concentration of the species is required before one can get respectable quantities of seed from any of the silver firs; this, together with questions of accessibility, will limit the practicable collecting zones for the Pacific silver fir, *Abies amabilis* considerably, in spite of its considerable range. For instance it may be difficult to get quantities of seed from Vancouver Island, though the tree is common enough. Possible sites are the Western slopes of the Olympic Mountains, also the western slopes of the Cascade Mountains in Whatcom, Skagit and Snohomish Counties, all in Washington. There is a considerable abundance of the tree in the Skeena Valley round Terrace, and this should be a very practicable place to collect. Halliday and Brown (1943) think that there may have been a refuge hereabouts during the last glaciation. There are also reasonable quantities of accessible *A. amabilis* in some of the valleys off the lower Fraser. In particular, there is plenty of it on the University of British Columbia experimental forest at Haney. So far as I know the seed merchants on the Coast have at present no markets for *A. amabilis*, and hence no organised collection areas. It should be easier on the whole to obtain than *A. grandis*.

Abies grandis. The district round Courtenay in the east of Vancouver Island appears to be one of the best centres at present for the grand or lowland fir, *Abies grandis*. It is agricultural country, and *A. grandis* occurs in small rather open stands. Recent purchases from Roche came from here. Otherwise the Cascade valleys are the main source; here it is usually collected from squirrel caches.

Mountain hemlock, *Tsuga mertensiana*, and Nootka cypress, *Chamaecyparis nootkatensis* are hardly in the "trials of species" stage. If it is intended to do something with them, I suggest we at least provide one rather sweeping contrast, perhaps between seed from low level northern muskeg sites and high level sites in Washington.

I think we should do some provenance work with the red alder, *Alnus rubra*. So far most of our seed has come from the lower Fraser Valley, though we have had one considerable import from the Charlotte Islands, which might possibly afford useful information if its progeny can be traced in the field.

A few other species which have received no detailed mention in this report penetrate to the Coastal Forest from more continental regions.

All are in cultivation in Britain, and though none of them appears likely to fill any essential place outside arboreta, it is almost certain they have not been introduced from their most westerly extension. So it may be of interest to try some of them again from better chosen seed sources. (I do not think that we need regard it as axiomatic that the western limit of species with near continental ranges is the best source of seed for us). Of these trees, the western yellow pine, *Pinus ponderosa* occurs south of the Puget in Washington in a much more suitable climate than the interior of British Columbia, whence we have previously taken seed. The western larch, *Larix occidentalis* breaks through the Cascades near Wind River in Washington, and thrives there in a climate in which trees of interior origin have failed—this is perhaps a promising pointer. The alpine silver fir, *Abies lasiocarpa* can be found in Vancouver Island, and on the Skeena River; there is even said to be an outlier of it in South-East Alaska. The Engelmann spruce, *Picea engelmanni*, just touches Sitka spruce on the Skeena River. The white spruce, *Picea glauca* reaches the Pacific in the Kenai Peninsula in Alaska. The whitebark pine, *Pinus albicaulis*, is found at high elevations in Vancouver Island.

Discussion.

We have plainly a good deal of freedom in the choice of seed collecting zones, and perhaps our most urgent problem is to determine how far timber quality is influenced by seed source. This may be the only criterion which will enable us to draw the southern limit of our collecting areas, which is at present quite vague. We do not know in fact how important growing season warmth may be. We have had some trouble with southern (Washington) seed of Sitka spruce, but this has been due to growing-season frosts, and the discovery of late-flushing strains is not an impossibility. Otherwise I do not think we have experienced any penalty to show that growing-season temperature or latitude are important factors, we can break down our planting areas into appropriate zones and choose seed sources for particular conditions.

At present I think any effort to do this would be somewhat unrealistic. It is easy enough to say that South-East Alaska provides growing season temperatures closer to those of British northern and elevated regions than do the Queen Charlotte Island collecting areas, and that therefore we should use Alaskan seed for these regions. But we should have some first-hand evidence that it is advantageous to match the growing season temperatures.

Choice of seed source is often governed by the extreme temperatures in the planting regions, and here we are fortunate in that our winter temperatures seem to confer very little restriction on this group of species. Spring frost incidence in Britain is too locally distributed to form the basis for any zonation; but it is certainly possible to obtain seed of both Sitka spruce and Douglas fir from environments which are likely to give rise to late-flushing strains. It might not be possible to obtain such seed in quantity, but it will be worthwhile to get small amounts as material for later breeding work.

With Sitka spruce, we are not much concerned with matching the kind of climate, for it is largely confined to regions of some oceanicity. But Douglas fir, even in the coastal forest, occupies areas which are far more continental than Britain, and with this species there are obviously questions of moisture and temperature regime. It is simple to find the regions which approach most closely to Britain in these respects, but again we lack first hand evidence of the advantages to be gained from closer matching, and perhaps there are hints that flexibility in Douglas fir is most likely to be found in regions one step removed from the most oceanic conditions.

Pinus contorta is usually thought of as involving varietal problems, but it seems likely that this has obscured the question of seed source in the Coastal Forest. Here it seems likely that there may be some ecotypic differences principally between the dry-site and muskeg pines, and it is the former which we should expect to produce reasonable form of stem, coupled with the vigour and fitness for our oceanic climate which we associate with Coastal *Pinus contorta* generally. There is a distinct possibility of types intermediate between interior and coastal pine.

In conclusion, it is an important fact that most of the species from this general region have been introduced with success from very diverse parts of their ranges. Their provenance problems are not acute or clearly defined, and the positive advantage of this rather negative situation is that if we can find evidence of sensitivities in any of them in any particular direction in Britain, we can attempt to remedy this by appropriate change of seed source without fear of disaster. It will be strange also if we cannot in time break down our planting regions and diversify our seed sources with profit. At present the necessary evidence may be lacking, but some part of it can no doubt be obtained by a survey of the existing plantations of known origin.

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LIST OF SCIENTIFIC AND COMMON NAMES OF TREES MENTIONED IN THE TEXT

Pinus contorta Douglas (and varieties)	Lodgepole pine
P. ponderosa Laws.	Western yellow pine
P. monticola Douglas	Western white pine
P. albicaulis Engelm.	White-bark pine
P. flexilis James	Limber pine
P. sylvestris L.	Scots pine
P. nigra Arnold var. *calabrica* (Loud) Schneid.	Corsican pine
Larix occidentalis Nutt.	Western larch
Picea sitchensis Carr.	Sitka spruce
P. glauca (Moench) Voss.	White spruce
P. engelmanni Parry	Engelmann spruce
Pseudotsuga taxifolia (Poir) Britton.	Douglas fir
Tsuga heterophylla (Raf.) Sarg.	Western hemlock
T. mertensiana (Bong.) Carr.	Mountain hemlock
Abies amabilis (Dougl.) Forbes	Lovely fir
A. grandis (Dougl.) Lindl.	Grand fir
A. lasiocarpa (Hook.) Nutt.	Alpine fir
Thuja plicata Don	Western red cedar
Chamaecyparis nootkatensis Don	Spach. Nootka cypress
Populus tremuloides Michx.	American aspen
P. trichocarpa Torr. and Gray	Northern black cottonwood
P. tacamahaca Mill.	Balsam poplar
Betula papyrifera Marsh. var. *commutata* (Regel) Fern.	Western white birch
Alnus rubra Bong.	Red alder (Oregon alder)
Quercus garryana Dougl.	Garry oak
Acer macrophyllum Pursh.	Broadleaf maple
A. circinnatum Pursh.	Vine maple
A. glabrum Torrey. var. *douglasii* (Hook.) Dipp.	Douglas maple
Oplopanax horridus (Sm.) Mig.=*Fatsia horrida*	Devil's club
Cornus occidentalis (T. & G.) Coville	Western dogwood
Arbutus menziesii Pursh	Pacific madrone
Ledum palustre L.	Wild rosemary
Gaultheria shallon Pursh.	Salal

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