FORESTRY COMMISSION

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SITKA SPRUCE IN BRITISH COLUMBIA

A Study in Forest Relationships

BY W. R. DAY, B.Sc., M.A.
IMPERIAL FORESTRY INSTITUTE
OXFORD

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Foreword

In the spring and summer of 1952 Mr. W. R. Day, Lecturer in Forest Pathology at the Imperial Forestry Institute, Oxford, visited British Columbia with the aid of a grant from the Forestry Commission. His object was to examine the forest relationships of the Sitka spruce in its natural homeland. This introduced tree has been planted on a large scale in Great Britain, and these studies are likely to have considerable practical application in British silviculture.

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Author's Preface

The work described in this bulletin was carried out in two small regions of the coastal forest in British Columbia, viz., in part of Graham Island (one of the Queen Charlotte Islands), and around Terrace in the watershed of the Skeena River. These regions are situated between 53.5 and 54.5 degrees, north latitude. Any descriptions or discussions apply to the forest as seen within these restricted regions, unless mention is made otherwise. The chief interest throughout is in Sitka spruce ; but it is impossible to consider one element in mixed forest adequately without taking its associated species into consideration. The latitudinal range of the coastal forest of which Sitka spruce forms an element is very great, and both the structure of the forest and the topographic and edaphic preferences of the various species must change throughout the considerable difference in climate which occurs over the whole latitudinal range. Nevertheless the general character of the various species will not alter essentially, and the preferences and interrelationships demonstrated within a relatively restricted latitudinal range will illustrate what is likely to occur elsewhere.

The studies on which this work is based were necessarily limited and brief, and they are not intended to be more than a reconnaissance of a large subject, insofar as this could be carried out in four and a half working months. Only brief indications of the general vegetation are given. The only point of doubt with regard to the identification of tree species concerns hemlock in skunk cabbage areas around Lake Lakelse. These mostly appeared to be mountain hemlock, but confirmation of this is needed. It should also be noted that *Pinus contorta* is always referred to as lodgepole pine and that no attempt has been made to recognise " shore pine ", or any other variety which may occur.

The soil profiles described will be dealt with separately. A great deal is due, in all this work and particularly with regard to the soil descriptions, to Mr. S. H. Lok, who acted as my assistant. The soil profile descriptions were all made by him ; this enabled the maximum degree of consistency in description to be attained.

Much also is owed to Mr. R. L. Schmidt, of the Research Branch, British Columbian Forest Service. The writer was entirely unacquainted with the forests of the Pacific coast and without Mr. Schmidt's expert guidance very much less would have been achieved. A full examination of the flora in these forests was made by him and he also made mensurational estimates of the forest standing.

This paper has been written directly on the basis of the field work as it seemed essential to complete it while the matter was still fresh in mind. There has therefore been no attempt to refer to other work, or opinion, which might be relevant ; actually published studies referring to the forest concerned are slight, except for those of Drs. J. E. Bier and R. E. Foster and their associates, who have paid special attention to the causes and development of decay in forest in the Queen Charlotte Islands (Bier, Foster and Salisbury, 1946). It is hoped that what has been written will throw some light on the relationships in natural forest between Sitka spruce and its associated species and, in particular, that it will interest foresters in the British Isles who have made such wide use of Sitka spruce in the establishment of new forests. The writer's interest in soil conditions as providing the basis for the development of much disease in the forest, or actually causing it, provided much of the stimulus to carry out this work, which may be summarised, perhaps, as an attempt to make some preliminary observations on the origins and effect of limitations in soil conditions, on the growth of trees as seen in association in mixed forest.

It is not possible shortly to summarise a long paper such as is this. Those who have no time to study the whole of what is written may read the introduction and the final discussion. The former will, it is hoped, help those who have never been into the forest on the Canadian Pacific coast to obtain some idea how parts of it are constituted.

It is desired to acknowledge with thanks the help of Mr. Tchapliansky, Mr. J. Shaw and Mrs. Allington who drew the diagrams, and Mr. H. F. Woodward who was responsible for the printing of photographs.

Introduction

The Purpose of the Work

1. The work in British Columbia, on which this Report is based, is the culmination of interest in the development of Sitka spruce in plantations in Britain, stimulated by a variety of problems in which its susceptibility to disease, whether of a non-parasitic or parasitic nature, necessitated attention to the factors of environment which determined the manner of its growth (Day, 1946-1954). The problems raised in this manner compelled attention to conditions of soil, or of climate, as often basically determining presence or absence of disease, rate of growth, quality of wood made or length of time over which rate of growth was likely to be efficient, whether from a biological or an economic point of view.

It is one of the difficulties of afforestation in a country such as Britain, which is poor in tree species of economic value for the production of timber, and in which the native forests have largely been destroyed, that there is very little to indicate what will be the eventual course of development of any exotic species which is used in new plantings. The youth of present new plantations reflects but a very limited past experience ; the future is largely a matter of speculation. Under these circumstances opportunity to study unexploited natural forests to which a species of interest is native is a great advantage, for from the variety of situations which occur in these with regard to soil and climate and from the relationship of the species in which interest is concentrated with those with which it is associated in growth, much may be learned, even though the climatic and edaphic situations differ in some respects from those in the region to which the species has been introduced. It was with this in view that it was planned to spend as long a period as possible, of one growing season, in the coastal forests in western North America, in which Sitka spruce forms one of the important species. The main purpose was to study Sitka spruce as an element in the mixed forests in which it naturally occurs, in relation to soil and topographical situation, and if possible in somewhat contrasting climatic regions. This study was made possible mainly by the cooperation and help of the Forest Service of British Columbia, to whom, and especially to the Chief Forester, Dr. Orchard, and the Forester in Charge of Research, Mr. R. H. Spilsbury, a considerable debt of gratitude is owed. Thanks for aid are also due to the Forestry Commission and to Oxford University. The work attempted eventually resulted in a study of :

(*a*) The rooting in depth of Sitka spruce in varying edaphic situations ;

(*b*) the changes which occur in the constitution of the forest, with special regard to Sitka spruce, as edaphic situations vary ;

(*c*) The effect of varying edaphic situations on the health and development of the root and crown of Sitka spruce ;

(*d*) the conditions under which Sitka spruce has an advantage in production relative to its associated species.

It is plain that in the short space of four and a half working months only a preliminary reconnaissance could be made with regard to these things, and the report which follows does not pretend to any other status.

The Regions Worked In: Their climates

2. Under the advice of the British Columbian Forest Service two regions were worked in : one was the Queen Charlotte Islands, where work was carried out in the central and south-eastern part of Graham Island, the largest and most northern island in this group ; the other was around Terrace on the Skeena River, in the Coast Range mountains. The climate of Graham Island is maritime and equable ; that of Terrace is still oceanic, though removed about 100 miles from the coast ; but it shows in its colder winters and hotter summers the influence of this geographical position (see Table 1). The region with a climate most like that of Britain is Graham Island. The average figures for the meteorological station at Masset, on the north coast, show monthly mean temperatures which are almost identical with those for Buxton, in Derbyshire, at an elevation of 1,000 feet, and the data for this and four other selected stations in Britain, for mean monthly maximum and minimum temperatures, are given in Table 2. These show the tendency for the first half of the year to be cooler, relative to the latter half, in Masset, as compared with the British stations. The mean monthly averages for Aberdeen (37 feet elevation) are also close to those for Masset (Tables 1 and 2) : this city is three degrees of latitude north of that place.

If the temperatures at Masset are taken as being sufficiently similar to those in the centre and on the east coast of Graham Island, it may be said that the indications are that the climate is rather cooler than that in most of Britain, for equivalent latitudes and elevations, especially during the first half of the year. The coolness of the latter part of the spring in 1952 was very marked to the writer as a visitor from England. Terrace, on the other hand, with its slightly continental type of climate, has average temperatures below freezing point during the three winter months, but higher average summer temperatures than are usual in Britain, in situations similar in latitude and elevation (Tables 1 and 2). The region in Graham Island is in the latitudes of the north Midlands in England and that around Terrace in those of the North of England ; i.e., together, within the range, 53.5 and 54.5 degrees north latitude.

3. A few observations from experience may help the reader to realise the differences in climate between these regions and Britain better, perhaps than meteorological averages. Thus, in 1952, snow still occurred in late August in the western mountains in Graham Island, in much greater quantity than is usual much earlier in the year, on hills of equivalent elevation, in the Highlands of Scotland, two or more degrees of latitude further north. May and June were cool damp months : warm clothing was usually needed if one was not to get chilled when out in the forest all day ; the experience was much what would be expected when out on field work in England, at similar elevations, in the latter part of March or in April. Cloudless weather in the beginning of July at Tlell on the east coast was accompanied by a cool northerly wind ; this is stated to be usual ; the result is, however, the absence of the oppressive summer heat, which is commonly felt in Britain and may be experienced also at Terrace, differently situated at a low elevation among high mountains. It is apparent that Graham Island has a cooler climate, latitude for latitude, than Britain, though probably one which is equally, or perhaps in some ways, more equable. For instance no sign of frost injury was noticed on young regeneration of Sitka spruce, or western hemlock, in topographical situations in which it would have been reasonable to expect such injury in Britain ; no injury of this type was in fact seen anywhere in the parts of Graham Island worked in. Terrace differs in having a colder winter than is usual for the same latitude and elevation in Britain, but a rather hotter July and August. Thus in 1952 snow still lay deep at Lakelse, near Terrace (240 ft. elevation) in April, and the ice on Lake Lakelse is said not to have broken up until the beginning of May. In contrast, the afternoons became so oppressive, in hot August weather, that it was profitable to be up early and to cease work early. There were indications around Terrace that winter injury, perhaps late in the winter, may not be uncommon on spruce, hemlock and pine; but this needs further investigation.

4. The chief difference in distribution of precipitation between Masset and Terrace is that, at the former place, the period of lower precipitation extends from June to August, while at the latter it extends from April to August. This is reflected in the experience that well-drained sites, for equivalent situations, are drier in the region of Terrace than in Graham Island ; an important factor affecting the growth and distribution of tree species is to be found here, especially when the higher summer temperatures which prevail at Terrace, are taken into account. The regions of Britain in which the distribution of precipitation is most like that in either of these places, occur in the more hilly and the western part of the country. The period of lower precipitation is not only shorter, but it also begins later at Masset, or even at Terrace, than is typical of the eastern and south-eastern parts of Britain ; where also the amount of autumn and winter precipitation is much less than that in those places. The indications from temperature and precipitation, in so far as this very limited examination goes, are thus that the west of Britain, perhaps especially in the north, is likely to provide a climate which is most like that of Graham Island. There are no situations which have at all a similar climate to that of Terrace, taking the year as a whole.

5. Another matter worthy of notice is the general lack of marked evidence of serious blasting by wind to tree crowns. Blasting by strong winds is said, understandably, to be serious on the western exposure of the coastal range of mountains in Graham Island ; but in the centre of the island there was no great evidence of this, even on hill tops of 2,000 feet elevation, which were completely clothed with forest. In the same way above Kitsumkalum Lake, on the side of Mount Garland, no serious wind-blasting occurred in forest, at 3,500 feet above sea level, on a point which stands out from the main mass of the mountain and has a western exposure. It would appear that neither the forest-clad mountains of central Graham Island, nor the undulating muskeg region which lies to the east of this, is seriously affected by wind-blasting ; nor yet are the forest-clad lower and middle slopes of the Coast Range mountains around Terrace. An illustration of wind-blasting as it affects the outer strip of trees on the east coast of Graham Island is shown in Photo 1. This general freedom from persistent strong winds stands in marked contrast to the conditions which prevail in many parts of Britain and is, of course, markedly in favour of forest development in the coastal regions and mountains of British Columbia.

6. The wetter aspects of the west coast forest are sometimes referred to as temperate rain forest, and this is an important reflection on the climate within which they occur. The relative coolness of the climate and not merely the amount of precipitation needs to be considered in relation to this. The character of the soil water reservoir has always to be taken into account in considering the importance for the growth of trees of a particular type of climatic regime. This importance, in the case of the two regions under consideration, is best seen by a consideration of the forest growth which is typical on the less water-retentive soil types. It is to be noted that in the region of Terrace, lodgepole pine and western hemlock combine to form the forest on the more dry situations at the lower elevations ; but western hemlock and western red cedar (or on some of the sandy soils on the east coast side of Graham Island, Sitka spruce with some western hemlock and lodgepole pine) form the forest. This may be taken as an indication that, for soils of equivalent make-up and topographical situation, the resultant supply of available water is likely to be greater in Graham Island than in the region of Terrace during periods of minimal precipitation.

7. One of the more difficult questions relating to available water supply, is to determine the relative importance of precipitation as rain or snow, as compared with that received in the form of condensation from fog or mist, or as dew. It has been shown that condensation on the crowns of trees, from mists, may form quite an appreciable part of the total precipitation under some circumstances (Grunow, 1955), and it has also been estimated that moisture received from dew may also be appreciable (Staubing, 1955). There is a very great lack of information regarding these things, relating to the regions discussed here, and under these circumstances all that can be done is to interpret the vegetation as indicating some important aspects of the meteorological conditions which prevail. The more important aspect of the vegetation in this connection appears to be the mosses. These necessarily absorb water through the thallus, and in order to do this have to be wetted. Mosses which occur on the ground have an advantage in that they tend to form a water-retentive cover ; they are also relatively little exposed to drying winds. This is not so true of mosses on the branches of trees, and it is characteristic in Graham Island to find tree branches moss-covered (Plates 7, 8, 11, 21, 30, 40) and sometimes bearing long hanging lichens, often to a considerable height in the air. This is much less true round Terrace, and it seems to imply that in Graham Island the wetting of branches and leaves by precipitation, of whatever origin, is sufficiently frequent and long maintained to enable a relatively abundant moss growth to take place even in what appear to be well ventilated situations.

8. These indications for a wet, "dripping" climate, as contrasted with one that is merely humid, seem to be of particular importance when estimating the conditions under which Sitka spruce tends, the more generally, to be site-tolerant. It would appear that a relatively general site tolerance which is, perhaps, exhibited as well in Graham Island as anywhere else, is dependent in part on the frequent occurrence, within a cool climate, of damp conditions under which leaf and twig surfaces are actually wetted. These periods are times when the rate of evaporation from the wetted surfaces is low. In this way they provide a contrast with the conditions which so often prevail, for example, in many parts of Britain, in which in spite of a high relative humidity, there is a sufficiently high rate of evaporation to cause leaf and twig surfaces to dry quickly, as a general rule. Common mosses in low elevation forest in Graham Island, occurring on the ground, or on fallen logs, often in great abundance (e.g., as in Plate 23), are *Plagiothecium undulatum*, *Rhytidiadelphus loreus*, *Calliergonella schreberi* and *Hylocomium splendens*. The indications for Britain are that these mosses occur in abundance as part of the ground cover, in the upland country in the north and west. This is the part of Britain in which wetting conditions occur the more frequently and are maintained the longer, and they are, it would seem, the parts of Britain which have a climate which approaches relatively nearly to that of Graham Island. Even here, however, the branches of trees in forests are not typically heavily moss-covered, and it would appear from this that, on the whole, a higher rate of evaporation from leaf and branch surfaces prevails and so a higher rate of transpiration. The indications appear clearly to be, thus, that the possession of general site tolerance in Sitka spruce depends on the occurrence of a climate which is relatively cool and damp in the sense of being actually wetting, and that as temperature rises there will be an increasing dependence on soil water supply, or on locally favourable climatic conditions such as occur in cloud zones. This will be accompanied by a loss of general site tolerance, especially as a dominant in mature forest ; and in its native forests this seems to be what actually occurs.

9. The climatic situation may be summarised as follows : Graham Island has a not dissimilar climate to that of Britain : it is, however, cooler, latitude for latitude ; it has a different distribution of precipitation, especially as compared with the less wet parts of Britain, in that the period of relatively low precipitation is shorter and occurs later in the year ; there is less evidence of persistent strong winds capable of damaging leaves and shoots ; and there

is no sign that frost during the growing season is an appreciable cause of injury, at least at the lower elevations in which work was carried out. There are also clear indications that the climate is not merely more humid, but that it is characterised by longer periods during which a low rate of evaporation prevails : the greater coolness of the climate probably plays an important part in this.

10. The region round Terrace differs in having a cooler winter and a hotter summer than in Graham Island, with its markedly maritime climate ; it also has a longer period of relatively low precipitation during the spring and summer : for these reasons its climate is less humid and, in general, drier. There is again no evidence of appreciable frost injury during the growing season ; but it is much less certain here that winter frost injury, including damage to bark and not merely frost crack, does not take place. There is a suggestion of continental influence in the climate which probably makes this an unsuitable region as a source of seed for Britain.

11. The British forester should note that no perfect fit of climate with climate is likely to be found, and that in the search for sources of seed he will have to be content with that climate which is likely to produce the more adaptable strains for his purpose. Thus, if the mean temperature curve is reasonably equivalent in the source and the site of usage of seed, the deviations from the mean may yet be significantly different ; or if length of day is the same, temperature conditions may vary appreciably, and so on. Also it is not sufficient to consider purely meteorological measurements. Conditions which are the resultant of a climatic condition and some factor relating to land structure must also be taken into account if the full resultant effect of change of site upon a species is properly to be estimated : the effect of physiographical structure of land on exposure to wind or of soil structure on availability of water, provide examples of this.

The Composition of the Forest Within the Two Regions

12. The differences in composition of the forest within the two regions is determined, apart from treatment in utilization during modern times, partly by the differences which occur in conditions of climate and soil and partly by the more simple flora which has resulted from the isolation of the Queen Charlotte Islands, from colonisation from the mainland. Thus in Graham Island only Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), lodgepole pine (*Pinus contorta*) and Oregon, or red, alder (*Alnus oregona*) are of account as forest trees at the lower elevations. (No attempt has been made here to recognise different strains of *Pinus contorta*.) Yellow cedar (*Chamaecyparis nootkatensis*), mountain hemlock (*Tsuga mertensiana*) and the usually bush-like Sitka alder (*Alnus sinuata*) occur at the higher elevations, but are of no very appreciable economic importance. All these species occur around Terrace ; but there are also *Abies amabilis*, the red or lovely silver fir, *A. lasiocarpa*, the Alpine silver fir (principally at the higher elevations) ; *Betula papyrifera occidentalis*, the western paper birch, *Populus trichocarpa*, the black cottonwood, and *P. tremuloides*, the American aspen.

The differences observed in the forests of the two regions are caused partly by this difference in species, but also, and probably much more fundamentally, by differences in climate, in physiographical structure and soil condition. Thus within the regions investigated in Graham Island no sites were seen, other perhaps than rocky outcrops and limited areas of coarse gravel, which could be considered " dry " on the basis of soil texture and the possession of very free open drainage. On the other hand, on the terraces from which Terrace takes its name, there are areas of sandy and sometimes coarsely gravelly soil, some of which at least would always be considered to be dry, simply because of low water retentive capacity. One consequence of this is the much greater prominence of lodgepole pine in the Terrace region, as compared with Graham Island. The greater height of the mountains around Terrace and the related much greater occurrence of long, steeply sloping hill-sides, in addition to the locally extensive terrace formations, all help to provide forest sites which are different physiographically, edaphically and climatically from those in the centre and east of Graham Island.

13. The characteristic forest composition for physiographically well-drained sites on Graham Island is western hemlock, Sitka spruce, with a little western red cedar ; for moist, water-receiving, but not wet sites, Sitka spruce with western hemlock and perhaps some cedar ; for less well-drained wet sites with moving water, western red cedar, western hemlock, Sitka spruce ; for ill-drained sites with more or less stagnant ground water, western red cedar and lodgepole pine, with no, or only scrubby, hemlock ; for physiographically dry sites with shallow soil over rock, western red cedar with western hemlock. The spruce-hemlock forest of the moist well-drained soils and the cedar-hemlock forest of the wetter, less well-drained soils may be said to be characteristic of the country : as much of the hilly parts of the island consists of moist well-drained sites, spruce-hemlock forest tends to predominate there ; it is economically the most valuable and it is often the type of forest which creates the greater impression.

14. Conditions around Terrace are quite different. The higher elevation forest is not referred to here. The steep mountain sides are covered with forest consisting of western hemlock and red or lovely silver fir (*Abies amabilis*) as the principal species, especially on the convexities as the physiographically drier situations : Sitka spruce and western red cedar are found in concavities in addition to these species and along spring lines ; that is, in the more moist situations. Lodgepole pine has a definite place on dry rocky outcrops. On the more gently sloping foothills of the mountains red silver fir seems to be much less common, but otherwise the forest is similarly composed, and for the same reasons ; so that spruce, cedar and hemlock, usually with more or less black cottonwood, are characteristic of the more moist, but well-drained sites. Hemlock, usually with a fair amount of cedar, is characteristic of the rather drier, but not very dry sites, and hemlock with lodgepole pine of the really dry sites. The distribution of species on the terraces is similar, and is likewise determined largely by soil moisture conditions ; the same is true of other situations, e.g., the large ancient alluvial fans exposed on the eastern side of Lakelse Lake.

15. Wet sites around Terrace differ, on the whole, from those found in the parts of Graham Island worked in. Those seen were mainly of two types : there are the wet alluvial sites, subject to flooding and silt deposition. They provide a relatively rich variety in vegetation, in which eventually aspens and cottonwood, with alder, cedar and spruce, together with some pine in sandy places, are the first forest formers. Hemlock seems to enter only after a drained soil has been built up, and in the earlier stages to be uncommon or absent. Providing silt deposition continues, and the silt is of good texture, these alluvial sites eventually provide some of the more fertile land, and carry high quality forest consisting of spruce, cedar and black cottonwood. The other type is, characteristically, skunk cabbage swamp. This is extensively developed around Lake Lakelse on what was, at one time, lake bed. The terrain consists of larger or smaller wet and often peaty areas, with drier ridges in between ; the forest stands principally on these ridges, and its composition and quality is determined largely by their fertility and area relative to the wet places. The characteristic dominant species on the more fertile types are western red cedar and Sitka spruce ; hemlock usually occurs abundantly, but as a smaller tree : birch may be present and alder is usually so. Shrubs typical of the wetter patches, if not too wet, are *Rubus spectabilis*, the salmonberry ; *Oplopanax horridum*, devil's club ; the guelder rose, *Viburnum trilobum*, and the dogwood, *Cornus stolonifera* ; on the more dry places *Vaccinium ovalifolium*, the oval-leaved bilberry, and *Menziesia ferruginea*, the false azalea, are common.

16. Neither of these wet types was characteristic of the part of Graham Island worked in, though similar sites occur with similar vegetation. Similarly the ill-drained peat-bogs, or muskeg, which are so well-developed in parts of Graham island were seen only in local patches around Terrace. *Sphagnum* is the typical moss of these ill-drained places, and in the worst areas its bright pink provides one of the principal colour shows of the island. Other typical plants are deer grass (*Eriophorum* spp.), crowberry (*Empetrum nigrum*) and reindeer moss (*Cladonia rangiferina*). Woody plants are sparse in the worst places and consist of small junipers (*Juniperus sibirica*) and pines, which grow on *Sphagnum* humps. Typical shrubs of this muskeg, as the depth of drained rooting material increases, are Labrador tea (*Ledum groenlandicum*) and mountain laurel (*Kalmia polifolia* subsp. *occidentalis*). Oval-leaved bilbery and false azalea eventually come in, but the typical shrub of the little hills which form the better drained parts in these areas is salal, *Gaultheria shallon.*

17. If a general view is taken of the forest in the two regions under discussion, it may be said that whereas in the Graham Island region spruce, with hemlock as the more abundant species, form the characteristic forest of the average site with reasonably good drainage ; around Terrace, on the lower slopes of the mountains, the characteristic forest consists of hemlock and red silver fir, while on the foothills and terraces (on loams and loamy sands) it consists of hemlock, with western red cedar and Sitka spruce as the soil becomes more moist, or with pine, but also often with some cedar, as the soil becomes more dry, in terms of water-retention. Hemlock is usually by far the more numerous species in both regions, though not necessarily the highest volume producer. This distribution of species must be interpreted as indicating that, soil and physiographical situation being equivalent, conditions at Terrace are drier than in Graham Island : for evidence will be brought forward later which shows that Sitka spruce is less adapted to compete as a dominant, as soils become drier, than is hemlock ; red silver fir has not been studied as much as hemlock, but as it occurs as a co-dominant with this species over large areas of mountain side, it is often plainly adapted to compete on similar situations.

18. This difference in the general moisture supply available is seen if the constitution of the forest is studied on areas burned within about the last one hundred years. The species most prominent in the east of Graham Island, where there are extensive areas burned about one hundred or one hundred

and twenty years ago, are hemlock, cedar, spruce, pine and alder, and among these lodgepole pine is ordinarily the least prominent conifer. This predominance of other species than pine, in forest regenerated after fire, seems clearly to be determined by the presence in most situations of moist surface soil conditions ; there is much evidence to suggest that, given these conditions, in the absence of a raw humus covering, and an adequate supply of seedlings, lodgepole pine has no advantage over the other species in the regeneration of burned areas, at least within a maritime climate and in these latitudes.

19. Regenerated burned areas are extensive in the region of Terrace, both on the terraces within the valleys and on the mountain sides. It requires but a very superficial examination to show that in their regeneration lodgepole pine was by far the predominant species. It is here, especially, that examination of regeneration now sixty to one hundred years old, that is of an age when pines which became established as dominants would still be alive, shows most clearly the relationship between soil moisture conditions and the species composition of forest regenerated after fire. These old " burns " occur chiefly on well-drained sites on which, eventually, western hemlock in association to varying degree with red silver fir, western red cedar, or spruce, will become the predominant species in most cases. The failure of these eventual dominants to regenerate effectively after fire must be ascribed to the conditions provided for the germination and establishment of seedlings, rather than to any lack of seed. Climatic factors plainly play an important role in the development of these conditions, and the conclusion seems to be inescapable that in the region of Terrace the resultant edaphic effect of climate is to produce soil surface conditions after fire which are much more adverse to the establishment of the more shade-tolerant species than is the case on similar soils and physiographic sites in Graham Island. This resultant edaphic effect would seem to be interpretable largely in terms of available water supply, and it will be seen that there is an appreciable amount of evidence in favour of this conclusion.

20. In order that there may be some clearer conception as to the nature and composition of these forests the following points may, finally, be made :

(*a*) The forests in both regions are typically of mixed species, with conifers forming the bulk of the trees and doing this increasingly as the forest advances in age. The broad-leaved species which occur, chiefly alder and poplar, are associated chiefly with the more moisture-receiving, or moisture-retentive, sites.

(*b*) Local, but usually not large, stands of single species may be regenerated as e.g., of Sitka spruce on special exposures of silt or sand ; the only extensive pure or practically pure regenerations are those of lodgepole pine, after fire. Any such stands are to be regarded as successional stages towards mixed forest.

(*c*) Locally pure stands of western hemlock tend to occur as the forest matures, on freely draining loams, owing to the difficulty which Sitka spruce, or even western red cedar, then find in regeneration. This is part of the normal successional development towards the climax on such sites. It will be shown that this tends continually to be broken down : also red silver fir, at least on the mountain sides where it is most numerous, is equally as efficient in regeneration as is hemlock, and there maintains the mixed nature of the forest.

(*d*) The relative size to which trees of different species grow is determined largely by the fertility of the site in relation to their requirements ; but on sites of moderate or good general fertility, Sitka spruce makes the larger tree in height. Western red cedar rarely reaches the same height, but becomes as large, or often larger, in diameter. Western hemlock is nearly always a shorter tree, age for age, than is Sitka spruce, but tends to exceed western red cedar in height, though it is nearly always smaller in diameter than both. Red silver fir is a smaller tree than any of these on sites which really suit them ; though on the mountain sides on which it is numerous it grows as the co-dominant and equal of hemlock. Of the broadleaved trees alder and birch are relatively short-lived, but the former, at least, may grow to be well over one hundred feet in height. Black cottonwood forms a tree of very great size, the equal or very nearly so of Sitka spruce in height. It lives to an age of well over two hundred years, and for this reason specimens of it are usually found in forest on the more moist soils on which it tends to become established. It is, in fact, the longest-lived as well as the largest of the broad-leaved trees ; but it does not occur in Graham Island. Lodgepole pine is smaller than any other conifer, though it may reach a height of well over 100 feet on favourable sites. Both aspen and birch occur most numerously on recently regenerated sites of fair fertility : neither are apparently very long lived trees.

(*e*) Of all species of conifer, western hemlock is the most numerous in both regions. The next most numerous species in Graham Island is probably western red cedar, and after that, among conifers, Sitka spruce. But hemlock is most numerous as a dominant on well-drained sites and cedar on those tending to be poorly drained. Sitka spruce is most numerous as a dominant on moist sites which are intermediate between these.

(*f*) Around Terrace, red silver fir is most numerous on the mountain sides, but much less so on the lower hills or in the valleys, where it is often rare. Black cottonwood may occur on any drained but moist soil which will support spruce or cedar ; but it forms characteristic stands, at first as the sole dominant, on the alluvia of the river valleys around Terrace and especially westward along the River Skeena. Spruce and cedar always invade these poplar groves and often grow to great size ; hemlock may eventually dominate if the site rises to be above flood level.

(*g*) Lodgepole pine is a comparatively rare tree on Graham Island except in the muskeg, where it grows poorly, and on some of the sandy soils along the east coast, where, so far as seen, it is not usually numerous. It covers large areas of ground around Terrace ; largely because of its efficiency in colonisation after fire, under the conditions which prevail there in many places.

(*h*) The shade-tolerant conifers of the Coast forests are all potentially long-lived trees. More or less even-aged forests occur only when regeneration has taken place after some catastrophe, such as fire or wind-throw ; even then eventually the forest becomes uneven-aged. The age to which the older dominants will live in maturely developed forest depends partly on the frequency of occurrence of such catastrophes and partly on the nature of the site as determining the size, for any particular rate of growth, and so the age, up to which trees of any particular species can remain alive : on the whole, catastrophes permitting, the shade-tolerant species in these forests are long-lived.

(*i*) It is well for British foresters to realise that the trees in these forests regularly attain a larger size than do those native to European forests, or to the forests of the same latitudes in eastern North America. This difference in size results partly from the nature of the tree species, but partly also from the type of climate in which they grow and the resultant effect of this on soil conditions. This difference in size is mainly caused by the great height growth : a tree which reaches a total height of one hundred to one hundred and twenty feet at maturity is small, whereas in Britain it would be considered to be of considerable size. Not only, however, is such a tree relatively small, it will also show in its condition all the indications for poor site conditions : e.g., the early onset of root disease and development of a poor debilitated crown. This difference in the size of the trees which constitute the forest, perhaps, is the thing to which a British forester finds it difficult to become accustomed and to make allowances for. It is very doubtful whether identical physical land conditions in Britain with identical species would yield an identical forest in size and condition, except over limited areas, usually in the more western parts of the country. This difference in size is, perhaps, more striking in Graham Island than around Terrace, and this again seems to be an indication of the difference in environment for tree growth provided by the two regions.

TABLE 1

Temperatures (°F.) and Precipitation (inches) for Masset, Graham Island, and Terrace, on the Skeena River, by months

		Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	
Masset	*Daily Temperature* (°F.)													*Average*
53° 58′ N.	Maximum ..	41	42	45	49	56	61	64	66	61	54	47	43	52
	Minimum ..	30	31	32	36	40	45	50	51	46	40	35	33	39
	Mean ..	36	37	39	42	48	53	57	58	53	47	41	38	46
Near Sea level	*Precipitation* (inches)													*Annual Total*
	Total ..	5.59	4.40	3.98	4.57	4.05	2.43	3.07	2.73	4.17	6.66	7.18	6.89	55.72
	Snow ..	10.5	5.8	4.8	1.3	Tr.	—	—	—	—	0.3	1.7	7.2	31.6
Terrace 54° 33′ N.	*Daily Temperature* (°F.)													*Average*
	Maximum ..	28	34	44	54	63	69	73	74	65	52	40	32	52
	Minimum ..	20	23	29	34	40	46	50	50	44	39	32	24	36
	Mean ..	24	28	36	44	51	58	62	62	55	45	36	28	44
About 200-250-ft. elevation	*Precipitation* (inches)													*Annual Total*
	Total ..	4.80	3.89	3.19	2.01	1.71	1.88	2.08	1.88	3.23	6.07	7.40	7.03	45.17
	Snow ..	17.9	13.0	4.7	0.5	—	—	—	—	—	1.2	4.8	13.9	56.0

Temperatures (°F.) and Precipitation (inches) at five British stations, by months, for comparison with Masset and Terrace (Table 1)

TABLE 2

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Buxton 53° 16′ N. 1.007 ft. elevation	*Daily Temperature* (°F.)													*Average*
	Maximum ..	41	41	44	49	57	61	64	64	59	52	45	41	52
	Minimum ..	32	32	33	36	41	46	50	50	46	41	36	33	40
	Mean ..	36	37	39	43	49	54	57	57	53	47	41	37	46
	Precipitation (inches)	4.5	3.8	4.1	2.9	3.1	3.2	3.9	4.4	3.2	4.9	4.7	5.7	*Annual Total* 48.4
	Snow ..	8	8	8	3	1	—	—	—	—	0.9	3	6	37.9
Aberdeen 57° 10′ N. 37 ft elevation	*Daily Temperature* (°F.)													*Average*
	Maximum ..	43	43	45	48	53	59	62	62	58	52	46	43	51
	Minimum ..	35	35	36	38	43	47	51	51	47	43	38	36	42
	Mean ..	39	39	40	43	48	53	57	56	53	48	42	40	47
	Precipitation (inches)	2.2	2.1	2.4	1.9	2.3	1.7	2.8	2.7	2.2	3.0	3.0	3.2	*Annual Total* 29.5
	Snow ..	7	7	7	3	0.8	—	—	—	0.1	1	3	5	33.9
Liverpool 53° 24′N. 198 ft. elevation	*Daily Temperature* (°F.)													*Average*
	Maximum ..	45	44	47	51	58	63	65	65	61	55	48	45	54
	Minimum ..	37	36	37	41	46	51	55	54	51	45	40	38	44
	Mean ..	41	40	42	46	52	57	60	59	56	50	44	41	49
	Precipitation (inches)	2.1	1.7	1.9	1.6	1.9	2.2	2.6	3.1	2.4	3.3	2.5	2.6	*Annual Total* 27.9
York 53° 57′ N. 57 ft. elevation	*Daily Temperature* (°F.)													*Average*
	Maximum ..	44	45	48	53	61	66	69	68	64	56	48	44	56
	Minimum ..	35	35	36	39	44	49	53	52	48	43	38	35	42
	Mean ..	39	40	42	46	53	57	51	60	56	50	43	40	48
	Precipitation (inches)	1.8	1.5	1.7	1.6	2.0	2.1	2.5	2.5	1.6	2.7	2.1	2.2	*Annual Total* 24.3
Fort William 56° 49′ N. 171 ft. elevation	*Daily Temperature* (°F.)													*Average*
	Maximum ..	44	44	47	51	58	63	65	64	60	54	47	44	53
	Minimum ..	35	35	35	37	43	47	50	50	47	42	37	35	41
	Mean ..	39	39	41	44	51	55	57	57	53	48	42	40	47
	Precipitation (inches)	9.6	7.4	6.6	4.4	3.9	3.5	4.8	6.1	6.3	7.0	8.1	10.1	*Annual Total* 77.8

CHAPTER 1

Soil Conditions in relation to the Growth and Root Development of Sitka Spruce and to the Constitution of the Forest

Soil Forming Materials and Soils—The Graham Island Area

This section refers principally to Graham Island. The forests investigated in Graham Island lay principally within the watershed of the Mamin River, and that of the Yakoun River, in its middle reaches. The Mamin River flows into Juskatla Inlet on the south side of Masset Sound and the Yakoun River into this Sound on the same side, some miles further to the east.

The next principal regions of investigation were in the vicinity of Port Clements, on Masset Sound and near Tlell, on the east coast. A week was also spent at Queen Charlotte City, on the south coast of the island, on Skidegate Inlet and over the hills to the south of Juskatla.

1. These areas fall topographically into two groups. The country to the south of Juskatla Inlet, which includes the Mamin River valley, part of the Yakoun River valley and the region round Queen Charlotte City, is made up of rounded forest-clad hills which rise to a maximum elevation of about 2,500 feet (Plate 2). This type of country is characteristic of much of the centre of the Queen Charlotte Islands, taking a line running from north to south, and the valleys and lower slopes of the hills include much of the better quality forest. It is, accordingly, in this type of country that much of the felling has been carried out up to the present. The country around Port Clements and Tlell is outside the mountainous region and within the large area of more flat, undulating country which occupies the north-east of the island. The hills here are always low, the slopes usually gentle ; and it is within this part that large areas of muskeg and poor scrub forest occur. It is this flatter part of the island which hitherto has principally attracted settlement, usually not with any great success, probably because of the rather infertile soil conditions which prevail over large areas.

2. The central hill country consists of glaciated hills, geologically of Cretaceous and Jurassic age (Mackenzie, 1916), but including some basaltic intrusions. The glaciation has resulted in the deposition of a very generally occurring layer of till, which is highly compacted and impervious : this (or, if it outcrops, the underlying bedrock) provide a basic root-restricting substratum in many of the soils. Water-lain layered sediments of much more recent geological age are exposed both in the Mamin and Yakoun River valleys. They appear to be the first sediments deposited in these mountain valleys, and to be continuous with similar and much more extensive strata which extend into the low-lying north-eastern part of the island. They are often irregularly stratified and layered and of variable texture; usually they are, as seen, compacted and impervious to water. There is evidence that these beds are tilted and that accordingly appreciable earth movements have taken place since they were laid down. Their deposition preceded the present river system, and the Mamin River, for example, has cut through these formations in part of its course. These sediments are overlaid in parts by gravels which are apparently of fluvio-glacial origin (Photo 3). The best exposure seen of this material is behind Juskatla Camp, where it provides a moderately good forest soil (Plate 4). The sediments seem also to be covered in places with glacial till, and if this has provided the parent material for soil formation, the result is a shallowly rooted rather poor soil. The remaining major source of soil forming material in the hill country is the alluvium of the river valleys : this is complex in nature and age and is discussed in greater detail later.

3. The soils discovered in this hill country are mainly acid loams, varying in texture from heavy to light. Clays occurred in places, but were not found to be extensive : sands and gravels occur usually in connection with alluvia and glacial or fluvio-glacial material. High base or neutral soils seem to be absent in the district worked in, but this naturally needs much closer investigation than was possible within the short time available.

4. The parent material of the soils of the hill-sides seemed usually not to be the, ordinarily, underlying compact till. More probably much of the soil in these places has been derived by the weathering of bed-rock outcrops higher up the hillsides ; that is, it is essentially colluvial in nature. The soils on the valley alluvia, the gravels, the newer sediments, where exposed, and the glacial till in the more gently sloping or flatter areas, are derived from *in situ* material and their character is largely determined by the nature of this. Organic soils occur, e.g., round the edges of lakes and overlying the more flat

exposures of glacial till and of some of the water-lain sediments ; but at least at the lower elevations, they were not found to cover any great area in this part of the country.

5. The flatter part of the island extends from the south-eastern edge of Masset Sound and the lower reaches of the Tlell River northwards. The solid formations, where exposed in the regions worked in, consist of layered sediments and gravels similar to those which have been noted as occurring in the valleys of the Mamin and Yakoun Rivers. The indications plainly are that at one time the whole area was under water. These strata are best exposed in the low cliffs which extend up the east coast from Tlell northwards (Plate 3). They are frequently covered with glacial drift, but whether the superficial soil forming material is glacial drift of some sort, or is the solid formation, it is usually of such a character that shallow soils are formed which have highly impeded drainage in the subsoil. According to the few places sampled, the shallowly rooted surface mineral soil is usually a loam or heavy or clayey sand.

6. There is abundant evidence that the depressions of this undulating north-easterly region at one time formed shallow lakes; some few such lakes still remain, though none are of any great size. The peat bogs, of which the muskeg in this region largely consists (Plate 27) have been formed by the filling up of these shallow waters with peat, and in this the remains of reeds and other water plants occur abundantly. The forests of the muskeg are of considerable interest ecologically and are shortly mentioned below.

7. The most difficult soils for tree growth are found in the wetter parts of the muskeg. There are, however, extensive areas of shallow peat overlying, where sampled, compact glacial drift on which forest of low quality usually occurs. This forest is also worthy of attention ecologically, although it is, probably, of no immediate economic value in this particular geographical situation.

8. There is a narrow belt of sandy soil along the east coast in some places. This is well developed in the region of the Tlell River estuary, where much of it is plainly windblown in origin. This provides ecologically interesting, though not economically important sites, at least in the limited region investigated.

9. All the soils examined appear to be acid, with the exception of limited areas of coastal sand ; and it is usual for there to be a well-developed organic surface covering. The function of this in the edaphic economy of the forest is of considerable interest and is referred to later. The mineral soils in general seem clearly to belong to the podsolic group ; if any appear as brown forest soils, such as some of the alluvia still subject to silt deposit, this is because they are still immature. True mull soils seem to be of very restricted area and to occur only in special places, e.g., moist, water-receiving sites.

10. It seems to be clear that the earth movements which resulted in the tilting of the water-lain sediments also caused the formation of raised beaches. The soils of these beaches were not examined in any detail, but in some cases they form very stoney gravels. Calcareous soils containing shells can still be found on some, as e.g., at Queen Charlotte City. The gravelly soil of Plot 22, Yakoun Bay, may possibly be derived from such a beach. These sites are not of any considerable economic importance. (A list of plots observed, with summary information, is given in Appendix I.)

11. It may be said in conclusion, that the most common type of mineral soil is an acid loam, which at maturity forms a podsol with a well-developed covering of organic material ; that the deeper mineral soils are found in alluvia, or in the lower slope colluvia, the deeper rooting often taking place where they are of a sandy nature ; that in most mineral soils there is a restriction to rooting in depth, usually owing to the occurrence of compact coherent material, the drainage of which is highly impeded. Peat soils are commonly developed in that part of the island where the topography is flat, or gently undulating ; the peat may be shallow, or deep. The deep peat has formed, in so far as seen, on the site of shallow lakes and contains in itself evidence of the water plants from which it was formed.

The Soil-forming Materials and Soils in the Terrace Region

12. The work done around Terrace falls into several fairly well defined sections. Three plots were examined on alluvial fan material, deposited by Goat Creek and in Kitsumkalum Park (Plate 5). Then, just outside the Park, a transect was examined which began on clay, an old lake bed deposit, and then ran uphill across a series of raised beaches, the material of which was sandy or gravelly. Work was done next mainly on lake bed deposits around Lake Lakelse : the soils discovered included organic soils, clay and loams. One plot was examined here on morainic material just outside the limit of the old lake bed deposits and at the foot of the steep rise up the mountains on the east side of the lake. Two plots were also examined which stood on Skeena alluvium, one being near Terrace and the other by the Exstew River bridge. Two further plots were examined in the little hills which lie at the foot of the mountains on the east side of the Kitsumkalum River and to the north of Terrace. One

of these was on clay, presumably deposited in a one-time glacial lake, and the other on colluvial loam overlying glacial till. A certain amount of time was spent examining one of the large ancient alluvial fans which occur on the east side of Lakelse Lake : the soil-forming materials were sands and gravels or, in places, mainly rounded boulders with a little sand or grit in their interstices. Some of the forest on the terraces to the north of Terrace was walked over, but not worked in, partly because it has been subject to general selective exploitation for some-time past. The soil-forming materials vary from clay to coarse gravel made up of large rounded boulders and stones, mixed in with sandy gritty material.

The general tendency in this area in the valley sites which mainly were examined, seems clearly for well-drained soils to be either podsolic brown earths or clearly developed podsols with a shallow leached horizon. The conditions for humus accumulation and development seem to be appreciably different in this region from those which occur in Graham Island, and possibly the hotter and drier summer climate has something to do with this. The visitor to Terrace is struck with the extent of the geologically recent sediments which form the terraces on one of which the town is built. There are also extensive alluvial deposits, especially in the valley of the Skeena River ; locally these are important and bear valuable forest. The main forest is, however, on the mountain sides, but this was not examined to any appreciable extent, mainly for lack of time. It would appear, however, that water received by lateral drainage is of more importance here than in Graham Island ; presumably because of the longer period of relatively low rainfall and the hotter summer. Because of this, situations which would ordinarily be called dry are of much more frequent occurrence. This tendency to summer dryness seems to raise the importance of soil texture, as well as of site drainage, as factors determining local soil water supply, and through this affecting the constitution of the forest. This is, thus, a region in which Sitka spruce becomes a tree found chiefly on water-retaining soils or in water-receiving sites ; indeed one of the ways to find a spring on a mountainside is to look for spruce. The valley, which runs roughly from north to south, down the Kitsumkalum River through Terrace and over towards Kitimat, marks the eastern limit for the distribution of Sitka spruce in this region. One of the advantages of work here was that, in this situation, it was possible to obtain some idea of the factors which are limiting for the successful growth of this species.

CHAPTER 2

Alluvial Soils, the Forest Carried and its Type of Rooting

The Character and Importance of the Valley Alluvia

1. The importance of the valley alluvia lies largely in the fact that they bear some of the more fertile of the soils, and that because of this, sites occur on them in which trees tend to approach the optimum growth for the species in these latitudes. Such highly fertile sites were the ones chiefly investigated, and the remarks made here apply principally to these ; but the alluvial soils are of sufficient interest for something of a general character to be said with regard to them.

2. The soils of the valley alluvia vary greatly in type and fertility, depending on the nature of the material of which they are composed and the stage of development in deposition and in soil genesis which has been reached. The water-lain sediments which have been subject to earth movements in reality form the more ancient of the alluvia in the Mamin and Yakoun River valleys ; but their deposition must have taken place under lake or estuarine conditions and they have little relation to the present river system which, in part, has been cut through them (Plate 3). The next oldest alluvial material is perhaps to be seen in beds of large pebbles, making a very coarse gravel and through, or over which the present rivers sometimes run (Plate 6). Although these rivers when in flood may move stones of appreciable size, no evidence was seen for the current deposition of heavy gravel such as is this : it would appear, therefore, that this gravel is relict from a time when a much heavier volume of water was carried downstream than at the present. These gravels may, however, be held to form part of the present alluvial system in that they are less clearly distinguished from modern depositions than are the older sediments, and tend to be united with them with regard to soil constitution and root development. Succeeding and sometimes on top of this heavy gravel, but sometimes covering the water-lain sediments or other material, are the more or less modern alluvial deposits. These are made of finer materials and, so far as seen, never become more coarse in texture than rather fine gravel ; usually they are loams or sands. It is upon

this finer material that some of the finest of the forest of the present day grows, or did so before felling ; but it may be pointed out, as a matter of interest, that it is possible to find fragments of wood and bark of conifers and cones of Sitka spruce buried in some of the heavier textured of the water-lain sediments with which the river valleys first began to be filled. The forest must, therefore, be regarded as extremely ancient.

3. The modern alluvia may be divided according to their stage of development in deposition and, related to this, their position in soil genesis ; they can, of course, also be divided according to texture and structure. The type of forest carried varies, however, not only with texture and structure, but also according to stage of development in deposition and soil genesis. This will be discussed with regard to the limited aspects investigated.

4. **Meadow Forest.** The first stage in the development of alluvium is seen at the present day, within the valley of a river such as the Mamin, in the exposure of gravel as the bed of the stream slowly shifts its position by the erosion of its banks. Various plants develop on this gravel in quiet places, and among them may be found red alder and willows (and also in the Terrace region poplars and especially black cottonwood). The proper development of a woodland awaits the deposition of silt, however, and after this has taken place to a sufficient extent, the soil surface becomes entirely covered with vegetation unless subject to erosion during floods. On the well-drained alluvia studied in Graham Island, the characteristic vegetation of this stage may be called Meadow Forest, in that it consists of more or less scattered groups of trees in between which are little meadows filled with grasses and herbs (Plate 7). Meadow Forest exists on a soil, the level of which is steadily being raised by the deposition of silt, and the evidence is that, so long as this is actively in progress, this open condition of forest tends to be maintained. Meadow Forest seems to be much less a characteristic of this stage in the development of alluvia, in the region of Terrace, and probably mainly because of the ability of black cottonwood to colonise and afforest these developing soils.

5. The species of tree characteristic of Meadow Forest are Sitka spruce and red alder : western hemlock occurs, but is infrequent characteristically ; while western red cedar is often completely absent. The regeneration of trees in Meadow Forest, in its typical stage, is undoubtedly difficult and would seem to be almost impossible in the dense herbage of the meadow patches. The development of seedlings of Sitka spruce seems to take place either on logs, or branches which fall to the ground, or are stranded there after floods ; or, much less often, on silt patches. Biotic factors may help to prevent regeneration. No evidence of grazing by deer was seen, but the cutting-back of shoots of seedling spruce by some sharp-toothed animal is not uncommon. This browsing of spruce seedlings occurs commonly in Graham Island and may be done by deer which, in Europe, are known to be responsible for such damage. It would appear, however, that any such factor is of secondary importance to the difficulty of seedlings becoming properly rooted on germination.

6. The well-drained alluvia, in the valley of the Skeena River near Terrace, have not been studied closely, but the process of forest development is appreciably different to that on corresponding soils in Graham Island ; also these alluvia are much more extensive and correspondingly of greater economic importance. The forest first appears as a more or less closed canopy of broad leaved species in which black cottonwood eventually becomes the sole dominant. Groups of western red cedar and Sitka spruce have appeared by the time this broadleaved forest is in high canopy. Their rate of growth for the first decades seems often to be moderately slow, perhaps not more than six to twelve inches a year, but eventually trees of great height may be produced, and some of the finest spruce and cedar in this region grow on these soils. Western hemlock occurs, but is not typical and never seems to become abundant so long as active silt deposition is in progress : it may, however, eventually become the more numerous conifer.

7. **Transitional Meadow Forest.** The character of the forest changes as the soil surface is raised by deposition of silt so that it is covered only by the higher floods, or perhaps in patches hardly at all. There now develops what may be called Transitional Meadow Forest. In the Mamin River Valley the principal difference in the trees is that alder becomes less frequent, or disappears entirely, and that western hemlock becomes common, or abundant, as an understorey to the older and larger Sitka spruce (Plate 8). Sitka spruce still regenerates, however, though apparently always in smaller numbers than western hemlock. Open places in the forest are still common, but plants capable of withstanding partial shade become more or less abundant in them ; thus in one such place there occurred in decreasing order of abundance, *Mnium insigne*, *Hylocomium splendens*, *Dryopteris linneana*, *Tiarella trifoliata* and *Streptopus amplexifolius*. Regeneration in these mossy meadows continues to be poor, and it is evident that conditions for the establishment of seedlings are very adverse, for the amount of seed which falls on such places must be very large.

8. Shrubs are rather infrequent in either Meadow, or Transitional Meadow Forest ; but in the latter *Vaccinium* species begin to occur. The salmonberry, *Rubus spectabilis*, and also the dogwood, *Cornus stolonifera*, may form communities in some of the wetter places on alluvial flats where sometimes thickets of alder also occur ; these are not, however, typical Meadow Forest sites.

On the whole the well-drained alluvial soils in the region of Terrace stand in contrast to this. Shrubs such as salmonberry, dogwood, guelder rose and devil's club may occur abundantly, filling up open places in the canopy or forming an understorey under black cottonwood (Plate 9). This is, perhaps, one of the reasons for the absence of any type of meadow here.

9. The soil in Transitional Meadow Forest is still immature and typically shows no leaching. Humus accumulation is definitely beginning under the more dense thickets of trees, and here at least indications of a change towards a mature forest soil are to be seen.

10. **Closed Forest.** The final stage in this development is seen in the formation of Closed Forest on alluvial flats or benches which are now above flood level. Plate 10 shows such a forest on a bench near to the Yakoun River. The typical stage of this forest is marked by the development of a leached soil : there is a well-developed organic surface covering and a clear, but usually narrow, grey leached horizon which is compact and not usually abundantly rooted. This type of forest consists of Sitka spruce and western hemlock. The hemlock are by far the more numerous and are usually to be found, more or less, in all ages ; but the spruce form the larger trees, the outstanding dominants and those that are of the greater age, probably. Spruce regeneration is absent or sparse ; it only occurs in the more open places and often only on fallen logs on which, however, hemlock regeneration is also abundant. The large dead snags, as well as the large fallen logs, in this type of forest, seem clearly to be spruce ; and the impression given is that this species has been the longer established on the site, though this may not always be true. The shrubs in this type of forest are principally *Vaccinium* species : Devil's club may occur in the more open places. The ground vegetation is usually sparse, but may be abundant in the more open places. (Plate 11.)

11. The sequence in development from Meadow Forest to Closed Forest is plainly related to a development in soil character from the immature soil of an alluvial flood bench which is being continually built up by fresh depositions of silt, to the mature podsol of the Closed Forest with its well-defined and often thick, organic surface covering. It would be wrong to think of an alluvial bench in any stage of its development as a regularly flat area. On the contrary such areas tend to be irregular in relief owing to the presence of backwater channels, used mainly, or only, in time of flood, and to various hollows and humps excavated or cast up during such times : in addition there may be the occasional wind-throw which, in the course of time, leaves its not inappreciable hump and hollow owing to the earth carried up on the root plate. The irregularity in successional development which occurs on such a relief is largely determined by the related effect of these variations in relief on soil depth, drainage and structure. The large spruce dominants usually stand on the higher and better-drained parts, and on air photographs these are sometimes to be seen marked by the grouping of the large spruce crowns. The loosening and general disturbance of soil which occurs in the formation of humps, whether from flood or wind-throw, is particularly important in its effect on conditions for regeneration. Such humps are marked by the absence of surface leaching, or by its presence only to a very superficial degree, and by their loose porous structure : there is usually either no, or only a trace of, raw humus on their surface. Their characteristic vegetational covering is the moss *Pogonatum alpinum* together with *Dryopteris linneana*. (Plate 11.) In Closed Forest, such as that illustrated, such humps obviously provide quite different conditions for regeneration as compared with the typical leached soil surface with its thick organic covering. Their importance in the regeneration of the forest and in connection with soil genesis is discussed later, in connection with hill-side sites where they are often much more common.

12. **Discussion.** Some of the more interesting problems in connection with these alluvial soils relate to the history of their development, and the change in opportunity for growth during the course of this development. It is plain that the nature of an alluvial soil must depend largely on that of the materials from which it is formed by deposition, and it does not follow necessarily that this must be favourable to the development of a fertile soil. An example is provided by a soil on which stands a small community of Sitka spruce on the edge of one of the water-meadows through which the Tlell River meanders before it becomes tidal. This consists of about six inches of drained sandy loam overlying grey, compact, coherent, stinking sandy material. This subsoil stinks even where it is exposed in the bank of a running backwater and where some efficient drainage might be expected. The horizontal runners of the spruce root systems

stand high above the soil surface, indicating the great shallowness of their development. Plainly the soil is intractable and incapable of ever carrying high-grade forest, and it would appear that this must be because of the type of materials deposited by this river. It is, however, of more interest to consider soils which bear trees of great size and which often, at least, are capable of carrying high-grade forest.

13. One of the more interesting and important of these problems is that of the development throughout much of the profile of a coherent soil having a massive structure. Such soil may be penetrable by the deep-going sinker roots, but does not favour the formation of a well branched root system. It is, therefore, inefficient from the point of view of root development and tree growth. Reference to the data given for the alluvial soil profiles (Table 3) will show that in these relatively deeply-rooted soils, the tendency is for there to be two zones of abundant development of roots : the one is in the surface soil layers ; the other on the lower part of the root system. The intervening zone of relatively sparse root development is that in which the soil is more or less coherent and shows a massive structure. The depth of this intervening zone was usually greater, for any given total rooting depth, the heavier the texture of the soil (see Table 3). Profile T3 in the Skeena alluvium, near to the Exstew River Bridge, provides a marked exception, however, and is a warning against facile judgements in this matter, for the soil is mainly sand. It is characteristic of this zone that, if the texture is a loam and especially a heavy loam, it is coherent in consistency and massive in structure. This coherent material is probably always fissured, though sparsely and in such a manner that the fissures tend not to be noticeable in the wall of the profile, and may only become exposed on breaking down the soil. They are often occupied with fine roots which descend from the upper zone of abundant rooting, and they may be stained darkly with humus should the soil be a podsol. It is characteristic of this coherent loam that it sticks, more or less, heavily to the spade, and for this reason is heavy to excavate. One of its markedly interesting characteristics is that it is interpenetrated with the channels of fine roots, apparently long since dead, and which seem to have no connection with the root system as it exists or has recently existed. Traces of bark, or even of wood, may be found in these channels. The fact that they have continued to exist is a tribute to the consistency and structure of the soil ; and the existence of organic remains points to the very slow rate of decay which takes place within it. The, often abundant, presence of such channels is clear evidence that this coherent massively-structured soil was once abundantly rooted, and it compels the question as to why its character with regard to root development should have changed. It has to be remembered that most of these soil profiles on alluvium were dug within the root systems of spruce which were at least four to five hundred years old, and that, even within the lifetime of the trees concerned, there has been a not inconsiderable time for physical changes in the structure of the soil to take place.

Loamy sands or pure sands, among the profiles examined, differ from the heavier loams in that they show much less or no coherence, though sometimes a considerable degree of compaction (Profiles 18 and T3, Table 3). Old fine root channels do not seem to occur, at least in the sands, even if there is a considerable degree of compaction ; but this may be due to difficulty of observation in material of coarser texture.

14. Observation of the root system as seen in the excavation of the single soil pits showed that die-back of secondary roots up to a ¼-inch in diameter has been not uncommon in the abundantly rooted upper zone ; and in one case, on a gravelly soil, it was observed that quite large roots had been affected. Variations in soil condition induced by the occurrence of extreme seasons, at least seem to be the chief factors responsible for the initiation of this type of disease. The deeply descending sinker roots excavated were mainly living for the first several feet excavated ; but in all cases some, and in some cases all, of their ends were dead. The conclusion come to from such evidence, and from examinations of the root plates of wind-thrown trees, was that death of roots usually occurred to a considerable extent in the lower part of the root system of these large trees. The healthiest root system examined at depth, with the most abundant development of live feeding roots in the lower, and under normal development in the abundantly rooted zone, was seen in Plot 5, Mamin River (Table 3). These roots had developed over porous gravel with moving water, and it may be assumed that in this, at about seven feet below the soil surface, conditions for water supply and aeration were relatively favourable and constant.

15. There seem to be two possible reasons why this often extensive death of the lower part of the root system takes place. One is that, during the long life of the trees, soil conditions vary sufficiently, owing to climatic variations, for healthy root development to be possible at one time, but not at another. It would be very wrong to dismiss this as an impossibility ; indeed field experience indicates that such variations may be one of the important causes of root disease even at these lower levels : they are, of course, difficult to prove by direct observation. The other explanation is that, during

the long life of the tree, a physical change has taken place in the structure of the soil and that this has brought about conditions which favour the dying of roots. The occurrence of abundant empty fine root channels in the now sparsely rooted coherent, massively structured zone in the loams, suggests that such a change has taken place. There is, indeed, some geological evidence to suggest that the fate of the lower layers of these still deeply rooted alluvial soils may be to develop a compaction which makes them useless for root development. There is exposed, for example, in a low cliff in the bank of the Yakoun River, beneath two to three feet of coarse gravelly drift, some grey, hard, extremely compact fine textured material, presumably originally clay, which is patterned in rust with fine root channels. This material is part of the water-lain sediments which appear first to have been deposited in these valleys : it must, at one time, have born vegetation, and, judging from the appearance of the root channels, this was forest.

Perhaps both these suggestions have to be taken into account in explaining the condition of the root systems of these large trees : on the one hand the occurrence of considerable variation in soil conditions because of the irregular seasonal, as well as periodic, variation in climate ; on the other the slow advancement in physical genesis towards rock formation of the alluvial material itself. A third point may be added to these. Sinker roots penetrate downwards because it is their nature to do so, and not because there are guaranteed good conditions for root development in the soil material towards which they advance. It is inevitable that they must sometimes meet the fate possible for pioneers and be unlucky ; it is actually not difficult to prove this by the examination of roots in any forest. Difficulty is raised, however, by the size of the dead ends of these deeply penetrating roots. The time necessarily taken for roots, finger, or thumb thick, to have developed, means that an appreciable number of years must have occurred in which conditions were favourable for root development.

16. According to the suggestions just put forward, the foundation of root disease of the type described is to be found in the physical make-up of the soil as influenced by climate and the local physical formation of the land. Given a particular basic soil character, certain types of disease may confidently be expected, and at an age appropriate to the manner of development of the trees. Biotic factors, and particularly root-infecting fungi, play their part : but they do so on this foundation. The effect of this root disease is to be seen in the development of the tree, as it becomes appreciable, and is most obvious in the condition of the crown. Photo 15 shows the crown of one of the dominant Sitka spruce in Closed Forest on an alluvial bench by the Yakoun River. It will be seen that the top is extremely thin, and this is principally to be attributed to the death of a large proportion of the roots in the lower rooting zone : it is not merely a consequence of old age nor, on appropriate sites, is it necessary for trees to grow to the size of this one to show similar symptoms. Plate 16, taken by the Mamin River, shows a variety of crowns of large trees growing in Transitional Meadow Forest ; the differences in crown density are plain, and it may be taken that the amount of root disease is proportional to this.

17. It is characteristic of the larger roots of spruce which are affected by disease in this way, that they show a development of false heart wood and also, very often and within limited zones, are heavily impregnated with resin. False heart and resin heart were almost constantly observed when large roots had to be cut through ; but they do not occur necessarily, and are undoubtedly symptoms of a diseased condition. It is obvious that the conditions which make this type of disease possible must be favourable to the entry of root and butt rotting fungi. It was impossible to make an assessment of the frequency and severity of butt-rot in any of the plots since no felling had been carried out. The tree examined for stem analysis (Plot STAI, Table 3) showed early signs of butt-rot, however, and was on the edge of a recently made felling in which heart rot in general was fairly severe.

18. Data for soil profiles and rooting depth relating to these alluvial soils appear in Table 3, p.16. The shallower depths of rooting in the upper zone occurred in Plots STAI and 4 (Plate 12), in which the soil was a heavy loam and in Plot T3 (Plate 13), in which there was a shallow depth of loam overlying a compact sand. The greater depths are on the lighter loams and loamy sands (Plots 5, K2 and T1 (Plate 14)). The middle zone of sparse rooting is best developed in the heavy loams (Plots STAI and 4) : it has to be remembered in connection with this that in Plot 4, within the lower 24 inches within which fissure rooting was abundant (though many of the roots were dead), the quite large structural elements showed little or no sign of rooting internally. Plots 18, K2 and T3 show, however, that where a lighter-textured soil is coherent or compact there may also be a well-developed middle zone of sparse rooting : this is related to the occurrence of an unfavourable consistency and structure. The most satisfactory soil in terms of distribution of live roots seems clearly to be that for Plot T1 (Plate 14) : Plot 5, with its relatively narrow and, actually, not well-developed middle zone and deep upper and lower abundantly rooted zones, also appears as one of the more satisfactory soils (Plates 8 and 16).

TABLE 3

Data Relating to Root Development of Sitka Spruce on Alluvial Soils

Plot No.	District	Forest Type	Total Rooting Depth (inches)	Soil Group	Depth (in.) of Rooting Zones: 1 Upper Abun.	1 Upper Freq.	2 Middle Sparse	3 Lower Freq.	3 Lower Abun.	Texture of Rooting Zones 1	2	3	Consistency of Rooting Zones 1	2	3	Condition of Ends of Sinker Roots
S.T.A.1	Graham Island Yakoun River (Br. 40 ; Juskatla)	Transitional Meadow	80	B.F.S. Gley (Immature)	7	—	53	11	9	Lm	Lb	sC	l-f	c-vc	vc-vsc	All dead.
4	Yakoun River (South of Gold Creek)	Closed Forest	64	Podsol	—	5+1	35	24 (in fissures)	—	Om+Lb	Lb	Lb-sC	f+vc	vc	c-vc	All dead.
5	Mamin River	Meadow Forest	80	B.F.S. (Immature)	—	32	14	28	6	Lm	ls-sL	S over Gr.	f-l	f	l	Live feedings roots locally abundant—some dead ends.
16	Gold Creek Valley ..	Transitional Meadow (on Alluvial fan)	41 (probably deeper in parts)	Degraded B.F.S. (Immature)	13.5	—	12.5	15.5	—	La+gr	Gr+sL	cL+L	l	l-sc and compressed	c	Very large dead roots ; live newer, roots.
18	Mamin River	Transitional Meadow	69	B.F.S. (Immature)	22	—	36	11	—	lS+S	sL	sL over Gravel	l-vsc	vsc (compact)	vsc	All dead (Live smaller roots occur).
Saw Mill	Queen Charlotte City	Transitional Meadow	22	B.F.S.	—	20	—	—	—	La	Gr	—	loc.l loc.c	indurated gravel		None seen, probably dead.
					(a very variable soil more deeply rooting in places)											
Kitsumkalum Park K1	... .	Closed Forest	32	Immature (B.F.S.)	2	16½	4	—	10	fS+Om +fS	Om (buried) H	Sb-Lb over Sb	f-c	c	c	All dead (many zone 3 roots dead).
K2	..	Closed Forest	90-96	Podsol	2+5	40	33	—	13	Om+Sb	sL-L	S with Gr	l+c	vc	vc	Dead (some large dead roots occurred throughout profile).
					Root distribution irregular.											
K3	.. ..	Closed Forest	19	Podsol	3+5	1+1	8	—	—	Om+Sb Om+Lb	Om+Lb	sL-S	l+c	vc	cemented	None exposed : probably all dead.
T3	*Skeena Alluvium* Exstew River Bridge	Closed Forest	57	B.F.S. (Immature)	9	—	24	24	loc 3	cL	Sm	Sm	l-c	compact not coherent		Dead or dying (new living roots abundant).
T1	Terrace	Closed Forest (Young S.Sp. and W.R.C. under poplar)	48	B.F.S. (Immature)	48	—	—	—	—	La	L	—	l			

Symbols for Texture and Consistency : L=loam, C=clay, Gr=gravel, S=sand, Om=organic matter, B.F.S.=Brown Forest Soil, a=light, m=medium, b=heavy, c=clayey, s=sandy, l=loose, f=friable, v=very, c=coherent, s=slightly, loc=locally.

Average heights for dominants and co-dominants for the plots in Table 3 are given in Table 3A. The information given is insufficient to be really conclusive. It is suggested, however, that the deeply-rooted plots have an advantage over the shallowly rooted ; but there is very little to show that a relatively great depth of well-rooted soil is of any great advantage as regards height growth. Actually a careful analysis of increment in relation to age would be needed before anything effective could be said with regard to this. The frequency with which coherence or compaction had developed in the middle and lower part of the deeply-rooted profiles will be noted, together with the general occurrence of disease. There is no doubt that, as far as examined, more live and apparently healthy feeding roots were seen where the deeper zone of rooting was in material of light texture and porous, showing little coherence, than where the material of this zone was of heavier texture and coherent. It will be seen from Table 3A that differences in shape of the upper crown were noted : this is a matter of some interest and is discussed in Chapter 8, p. 80.

19. The examination of root development and soil profiles in the field compels an acknowledgement of ignorance in the history of development of trees on these relatively fertile alluvial soils. Something of this has been indicated already. One of the reasons for the carrying out of increment studies is to obtain indications as to what this past history was, together with suggestions of what one may expect to happen in the future. It is quite impossible adequately to discuss efficiency in production in relation to site conditions until growth data are available, through the interpretation of which the life history of these trees can be known.

Total Rooting Depth, Soil Texture and Average Height of Dominant and Co-Dominant Trees on Alluvial Soils

TABLE 3A

Rooting Depth (inches)	Plot No.	Soil Texture	Average Height of Dominant and Co-Dominant			Crown Development in Height of Dominant Sitka spruce	Shape of Crown top
			Western Hemlock	Sitka spruce	Western Red Cedar		
64	4	Lb/sC	192	227	—	Complete	Broad.
80	S.T.A.1	Lm/Lb/sC	—	§165	—	Incomplete	Broad.
80	5	Lm/sL/Gr	—	237	—	Complete	Broad.
69	18	lS/sL/Gr	170	205	—	Probably complete ..	Broad.
41 (at least)	16	La/sL/Lm with gravel	169	227	—	Complete	Broad.
96	K2	Sb/La/S with gravel	170*	192*	154*	Probably complete ..	Narrow
57	T3	shallow/cL/Sm	—	†193*	—	Incomplete	Broad.
32	K1	Sa/Sb and Lb	—	158*	—	Probably complete ..	Narrow.
19	K3	Sb/sL/S and gravel	161*	178*	129*	Probably complete ..	Narrow.

* Approximate estimates.

† With Black Cottonwood : average height 197 ft. ; age of dominants 180-200 years.

§ At about 139 years—one comparatively young tree.

Note.—Except where stated the age of the dominant class was probably not less than 300 years.

Texture Symbols—L = Loam. C = Clay. Gr = Gravel. S = Sand. a = light. m = medium. b = heavy. s = sandy. l = loamy. c = clayey.

CHAPTER 3

The Soils and Forest on the Hill-sides in the Central Hilly Region of Graham Island

The Type of Forest in relation to Site Drainage

1. It is proposed here to say something with regard to the hill-side sites investigated. Most of these, as in the case of the alluvial soils discussed, lie in the watersheds of the Yakoun and Mamin Rivers in the district which lies to the south of Juskatla Camp and is served by the road system developed from there ; the remaining three sites were in the hills on the north shore of Skidegate Inlet. The value of this discussion is, of course, limited to those parts where similar conditions prevail to those investigated ; but it is believed that such may not be uncommon.

2. The sites mostly occurred at elevations of less than 600 feet and on moderately to steeply sloping hill-sides. They refer, thus, to the lower, or lower middle, slopes of these central mountains, and probably to that range in elevation within which most of the more productive forest occurs in this type of country. They included none of the more poorly drained situations ; nor any of the knolls on which the drier and better drained sites tend to occur. Only one of the mountain tops was visited. It is, of course, well recognised that the type of forest in a mountainous region is determined largely by such factors as elevation, aspect and wind-exposure, as determining the climate locally experienced within that general for the region ; and the physical formation of the land as influencing conditions of drainage topographically and tendencies in naturally occurring erosion ; so that convexities and steep slopes tend to be soil-losing situations, but concavities and gentle slopes, situations in which soil is retained or accumulated. These generalities apply to the region under discussion and, while little can be said as to the importance of variations in local climate (for this needs detailed study for which there was no opportunity), something must be said as to the relation between the type of forest and the physical formation of the land.

3. The type of forest occurring, in terms of proportional occurrence and relative development in size and condition of species, is largely determined by the prevailing site drainage conditions. There are three general factors of appreciable importance in determining these. There is firstly, and perhaps of predominating importance, the general shaping of the land surface into convexities and concavities of varying steepness of slope and size ; secondly, there is the occurrence of a root-restricting horizon and its position as largely determining the volume locally of rootable soil ; thirdly, there is the character of this soil, as influenced by drainage conditions determined by the physical land formation and the position of the underlying restricting horizon. The freely-draining horizons in these soils, as examined, are acid loams, which show a leached horizon when mature. They have a tendency to show coherence and a massiveness in structure (Plates 17 and 18) which has already been noted as characteristic of some alluvial loams ; but usually the tendency is not so highly developed as in these. It would appear that the hills in this region, almost entirely, have been glaciated ; the underlying root-restricting horizon is usually till, or fluvio-glacial drift (Plate 18); where this is not so, it is ordinarily the hard bedrock. The appearance of well-drained or ill-drained places is largely determined by the nearness to the surface of this impermeable horizon, as determining the level at which drainage laterally and downhill takes place through the soil (Plate 19). The deposition, in the more gently sloping concavities, of fine-textured silt, is also important. This silt has been deposited, in the course of time, by surface drainage water running downhill in the form of permanent, or temporary, rivulets fed by the laterally moving underground drainage as well as by surface run-off. A hill-side thus usually forms a complex pattern of relatively well-drained and ill-drained places, and the type of this pattern is of considerable importance in determining the quality of the forest which develops.

4. It has been said that on these hill-sides the convexities and steep slopes tend to be well-drained relative to the concavities and gentle slopes. If the forest which they carry is examined with this in mind, it will be seen that there is a species distribution in proportionate composition and in quality which is related to this. The species of tree with which one is concerned are western hemlock, Sitka spruce and western red cedar. Generally speaking, it is characteristic that the convexities, as the better-drained and usually least water-retentive places, are covered with forest in which western hemlock is the most abundant tree among the dominants, as well as being much the more common species in the smaller trees beneath those (Plate 20). Sitka spruce is apparently always represented, though often sparsely, and it is usually, age for age, of greater height and larger diameter than the hemlock. Western red cedar is often

present, though less certainly ; it may be, and often is, as a dominant, of greater diameter than either spruce or hemlock ; but in height it is no taller and may be rather shorter than hemlock.

5. The more ill-drained concavities or, if ill-drained, the gently sloping shelves which are so characteristic of some of these mountains, carry forest in which western red cedar is the characteristic dominant. Western hemlock occurs, though as a smaller and sometimes relatively scrubby tree : frequently it shows a defective crown (Plate 21). Some Sitka spruce always occur ; they may be as tall as, or taller than, the cedar ; but compared with those spruce that grow on better drained sites, they are comparatively poor trees. It is characteristic of them that they show a defective crown development (Plate 21). The cedars of these sites are smaller and less well-developed trees than those which occur on better drained places, and they characteristically are spike-topped. This dying of the upper crown is related in cause to the defective crown development of spruce, already referred to, and will be discussed in connection with the general problems of crown development (Chapter 8, page 80).

6. Sites which are water receiving, by topographical drainage, but are nevertheless, generally speaking, well-drained, are those which bear forest in which Sitka spruce is found most abundantly as a dominant (Plate 22). Western hemlock occurs still, usually as the most abundant tree and as the most common species in the understories ; it is usually shorter than the spruce, as a dominant, and almost always smaller in diameter, age for age. Western red cedar often occurs on these sites, apparently almost always only as a dominant ; it forms a large fine tree of about the same total height as hemlock, but attaining, as is characteristic, much greater diameters. These characteristic spruce sites are found in folds on slopes ; or on gently sloping shelves on the mountain side, providing the soil is deep enough and adequately drained ; or on lower slopes, especially if these are concave. It is on the comparatively deep moist soil of these concave lower slopes that some of the finest forest occurs (Plate 22).

7. There is one other type of situation, besides the relatively ill-drained places, in which western red cedar seems to occur as the prevailing dominant : this is the well-drained position, often with rather shallow and markedly leached soil, which is found on knolls, or in water-losing positions on slopes. Cedar may occur as the chief dominant on such sites, with western hemlock as a co-dominant and understorey tree : Sitka spruce seems to be absent, or rare ; in any case it is unlikely that it would make a very worth-while tree in such places. This type of situation seems to be of no great importance as judged by area. It would appear from the little seen at the higher elevations that, at least up to about 2,000 feet elevation, western hemlock is the prevailing dominant on well-drained rocky hill-tops, slopes and ridges. Yellow cedar is an accompanying dominant, often reaching a larger diameter than the hemlock, while in some places Sitka spruce occurs (e.g., Plot 10, Table 23). A certain amount of mountain hemlock was also seen, but no typical forest composed of this species, though such forest may occur at higher elevations than those reached. The crowns of the trees on these hill-tops seem to be much more subject to breakage, presumably by wind, than are those in the valleys ; but no evidence was seen of any considerable crown-shaping by wind blast : the quite appreciable height of the dominants, e.g., 110 feet total height for Sitka spruce in Plot 10 on a hill top at 1,900 feet elevation, is consistent with this observation.

8. The above general description of the distribution of the three principal species which form the forest in this region suggests that there are important differences between them in tolerance of site conditions. Problems relating to regeneration and establishment, as affecting species distribution, may be overlooked for the time being, though some suggestions will be made later with regard to these (See Chapter 7, page 74). Taking, therefore, the mature forest as it stands on these hill-sides, and referring to the abundance of a species among the dominants, the following may be said : firstly, Sitka spruce appears as the least site-tolerant species in that its appearance in relative abundance as a dominant in closed forest is associated with sites which are water-receiving by topographical position, but which, nevertheless, have a sufficient depth of well-drained soil. Western hemlock is much more site-tolerant, especially in that it is able to form mature forest on the more shallow and better-drained soils ; it will be shown below that it is also more effective on some wet sites than is spruce (See page 35). Western red cedar appears as the most site-tolerant, particularly as sites become less well-drained ; but there are indications, as suggested above, that it is also tolerant of rather shallow soils on well-drained sites. Further evidence is needed from other types of situation before this question of site tolerance can be discussed effectively, but it will be shown that the indications for tolerance suggested here are maintained elsewhere, to a very great extent (See Chapter 6, page 62).

9. Accidents of Nature as Determining Soil Conditions

Two things are impressive, in traversing these forests, and considering the factors which have helped to determine the proportions in their present specific composition ; the first is the common tendency for the regeneration of Sitka spruce to be much in the minority as compared with other species, except in certain favoured situations ; the second is that, given the appropriate general conditions of soil and drainage, Sitka spruce may always be expected to occur in an appropriate proportion among the dominants in the forest. Conditions in the mature hill-side forests are worth considering with regard to these things. The tendency for spruce to be replaced as a dominant by hemlock, on well-drained sites, is often quite obvious. A very good example was provided by Plot 1 (Table 23), near to Queen Charlotte City. There were within, or on the border of, this plot two large dead snags, plainly the remains of large dominant Sitka spruce ; yet none of the present dominants of any class, and only a very few insignificant seedlings among the considerable amount of regeneration which was coming up in groups in this area, were spruce ; their number could be counted on the hands and, judging by their small size relative to the surrounding hemlock, there was every likelihood of their becoming suppressed. The evidence in and around Plots 7 and 8 (Centre-page Figure, Table 23), in the watershed of the Yakoun River, was entirely similar and examples could easily be multiplied. Yet the evidence is that, given future conditions which are at all like those in the past, Sitka spruce is likely to maintain its place in the forest as a dominant, more according to conditions related to soil drainage and depth than according to the indications for succession given by the structure of the complex canopy in present mature forest. Part, at least, of the explanation of this is to be found in the influence on site conditions of what are called here "accidents of nature".

10. The accidents referred to here are three, namely, fire, erosion and windthrow. There are considerable difficulties in assessing the influence of these things in regard to the forest as it has existed up to the present : these difficulties originate in present ignorance of its historical development. It is not unfair to put the term of life of a tree, which attains the position of a dominant in mature forest on an averagely good site on one of these hill-sides, at not less than 500 years ; evidence for a greater age could easily be brought forward. Heusser (1952), referring to forests in southern Alaska, gives 8,000 years for the age of the forest since the last Ice Age in this part of the world. The glacial history of Graham Island is likely to be related to that of this part of Alaska and, if this estimate is to be accepted, not many tree lifetimes have past since the ice retreated. It is necessary to remember this slow process in the passing in the forest of generations of dominant trees, when considering the problem of the maintainence of specific composition.

11. The evidence for the action of accidents of nature is to be obtained from examination of soil profiles and the relief of the soil surface. The occurrence of fires will first be discussed shortly. A very good example is provided by the profile of Plot 3 (Table 23), situated in the hills behind Skidegate Mission : there were abundant pieces of charcoal in the base of the humus, giving indication of the fire which took place before the present stand was regenerated ; then between depths of 27 and 47 inches there occurred an horizon which contained, especially in its upper part, numerous pieces of charcoal. There is evidence here, thus of two fires ; one occurred about 100 years ago and the other at some unknown time in the long past ; the depth at which this ancient charcoal was buried undoubtedly indicates the subsequent occurrence of erosion. Plot 1 (Table 23) near to Queen Charlotte City provides similar evidence ; there were traces of charcoal on the surface ; there was a buried charcoal layer with the remains of a burned soil surface, at a depth of 37 inches ; one piece of charcoal was taken out of the till, the surface of which occurred at a depth of 52 inches. The evidence for a fire on the present soil surface also occurred elsewhere in this locality. There is, thus, again the evidence for a comparatively recent fire, and for a much more ancient fire followed by erosion ; the piece of charcoal in the till would appear to indicate the occurrence of some still more ancient fire. The mineral soil in these burned surfaces shows a peculiar reddish-brown colour which is the typical consequence in soil of exposure to fire. The occurrence of charcoal in the profiles examined is listed in Table 4. This is likely to be an understatement of occurrence rather than otherwise. The very ancient date of some of the fires from which this charcoal originated is sufficient to show that periodically and independently of anything that modern man may have done, the forest in these regions has been liable to be burned. Also, the frequency and depth of buried "A" horizons (Table 5) is in itself sufficient indication of the periodic occurrence of serious erosion.

12. This evidence, of course, does not mean that the forest in Graham Island is, or ever has been, especially fire-susceptible or that, similarly, there is, or has been, a high risk of erosion. But it does mean that fire and erosion have happened, and with appreciable consequences as to the condition of the soil surface and the opportunities for regeneration of the forest. It is here that the slow process of generations in the forest, apart from these accidents, has to be taken into account. It is, perhaps, not too much to say that a big fire once every 300 to

600 years would, in the past, have been quite sufficient seriously to upset the progress of any theoretical succession based on the relative competitive power of species and the development of the soil surface under conditions of assumed lack of disturbance. Of the two factors, fire should be regarded as having the more extensive influence, though edaphically the influence of erosion is much greater where it occurs.

13. No evidence was seen that the forest in Graham Island, in the parts investigated, has been especially susceptible to wind-throw, but there is much evidence for the extensive, though not necessarily intensive, occurrence of this. This is provided by the widespread occurrence of " hump and hollow" surface relief. It is plain that this type of surface relief might arise from more than one cause : e.g., from erosion by torrents running down hill ; or through the scouring of alluvial benches by floods with subsequent deposit of silt ; and in this hill region of Graham Island it could be shown that both types of erosion had operated in this way, though not to any appreciable extent. Typical hump and hollow relief, as it occurs commonly in these forests, is caused by the tearing up of a mass of soil through its attachment to the root-system of a wind-thrown tree. A hollow is left as a result. The root, and eventually the whole tree, decay and entirely disappear, leaving a heap of soil on the site where the upturned root-system stood. Plate 23 (Plot 12, Table 23) illustrates this : it shows a windthrow seventy-five years old, with the over-turned stems still in position: on the still steeply-sided humps stand trees of about this age ; these are Sitka spruce in the main, but some hemlock occur. The Centre-page Figure* illustrates the soil profiles in humps and hollows in various plots. (See central inset of plates.)

14. It is, perhaps, necessary here to distinguish between different types of wind-throw, i.e., the overturn of trees at their base, as seen in these forests. There is wind-throw which occurs owing to the decay of the great roots at the base of the tree : there is no upturn of the root-system ; the tree breaks off at the base and falls over. Cases of this were seen in Plot 16 (Tables 3 and 23), in the Gold Creek area of the Yakoun River watershed (near to Branch 44, Juskatla), in a grove of very tall overmature Sitka spruce which stood on a soil of light texture and free drainage derived from alluvial fan material. Then there is the case in which the sinker roots die and decay owing to adverse conditions in the subsoil such as, e.g., the development of coherence and a massive structure : this is illustrated in Plate 24, taken by Plot 13 (Table 3), in a tall stand of Sitka spruce and western hemlock which stood on a deep colluvial soil on a lower slope. A root plate is thrown up in this case, as the photograph shows, and accordingly a hump and hollow relief develops : the slope on which this plot stood demonstrated this. Some of the approximately 300 year old trees stood on such, now ancient, humps ; the tree shown in Plate 25 is one such. Lastly, there is the case of trees which stand on shallow soil which overlies a layer of material impenetrable to roots or unfavourable to their continued development : these trees commonly and naturally develop root disease owing to the restricting conditions for root growth ; but even if they were to escape such disease they still would be liable to be wind-thrown because of the relatively shallow root system. Much of the hillside forest is on soil of this nature, and on such sites hump and hollow relief is particularly liable to develop. The proportional area of land which shows this relief must be quite considerable ; both poorly and well drained areas are affected ; indeed, its importance in the development of the forest is particularly great in poorly drained areas, for the humps provide the better drained sites for root development.

15. Information regarding plots surveyed, which showed hump and hollow relief, is given in Table 6 and Centre-page Figure ; these plots were situated in the central hill region, except No. 23 and Tlell I and II, which were in the southern end of the north-eastern plain. The soils concerned are all medium quality loams. The important characteristics, as affecting the growth of the forest, are the relative wetness of the hollows as indicating one important characteristic of the root-restricting surface down to which the root-systems extend ; the average rooting depth as indicating the relative volume of soil available for root development, and the topographical position as indicating the character of the situation with regard to topographical drainage. The relative area covered by the humps and hollows is of importance as regards the density of stocking of the forest ; thus in Plot 14 (Centre-page Figure, Table 6) the hollows were swampy and large and occupied most of the area ; the stocking was accordingly poor ; for trees of any size only

* *Note on Centre-page Figure*

The profiles represented illustrate the variations in rooting depth which occur in areas characterised by a surface having " hump and hollow " relief, owing to windthrow. The terms, wet and dry, used to characterise the type of hollow, refer to the surface appearance. The depth of rooting indicates the degree of drainage below the surface, so that a dry surface with shallow rooting, as for one of the profiles in Plot 8, indicates that soil conditions soon become wet and stagnant, whereas a wet slope with deeper rooting, as in Plot 9, indicates the occurrence of wet, but aerated conditions unless, as in Plot 14, there is a note that the roots had died. The humus was consistently of a type favourable to root development except in the case of the water-logged material in Plot 14.

occurred on the humps. In Tlell II, the distribution of humps is irregular (see Figure 3) ; the dominant Sitka spruce occur mainly on them, however. There is an irregular distribution of species accordingly, and also of standing volume of timber, for the spruce are the taller trees and have much the greater basal area per acre within the plot area. Wet hollows permit only of very superficial rooting on the part of trees (Plate 25) ; whereas with better drained hollows, the whole depth of soil down to the basic restricting material may be occupied by roots. This is a great advantage and it is one of the factors which have helped to make possible the great height growth in Plot 13 (Table 6, Plate 22). The position of this site on a water-receiving lower slope is another advantage. The occurrence of a slope is, within limits, an advantage in that it ensures that topographical drainage shall be active and not stagnant.

16. The importance of hump and hollow formation in the development of the forest is fairly plain. It results in the local heaping up of soil, thus giving a greater rooting depth and enabling a more normal root-system to be formed, at least within the limits of the humps. Much will depend on the size of the humps, of course, and there is evidence that in dry seasons and perhaps especially on sites which topographically are not water-receiving, trees may die simply because of lack of water within the restricted rooting volume available. Strong suggestions that this had taken place were seen in the Tlell plots. Hump formation also results in a periodic working of the soil, breaking up and destroying the more or less elluviated and often compacted soil surface, burying or thoroughly disturbing the organic surface covering, and, in effect, forming what is largely a new and certainly a much less mature soil. Its ultimate volumetric advantages, or disadvantages, as affecting volume and quality of soil available for root development, need quantitative investigation and cannot be effectively commented on here. Its effect on conditions for the regeneration of the forest is obvious and especially, perhaps, its tendency to favour the regeneration of Sitka spruce. This was shown particularly plainly in the comparatively recently wind-thrown area in which Plot 12 was situated ; but was also demonstrated in Plots 13 and 23 (Table 6) and the Tlell Plots.

17. The rate at which trees are wind-thrown over an area of forest is a matter of some interest. The evidence seems to be that the rate is usually very slow and also that wind-throw may occur sporadically and not affect great blocks of forest at one time ; though, of course, exceptions must occur with regard to this. The age to which the dominants in old-growth forest normally live has to be taken into account when considering the effect of wind-throw as a means of soil regeneration. Not many wind-throws per acre per year are needed during the lifetime of one long-lived tree in order to have a considerable edaphic effect. The length of time over which the edaphic effect endures has also to be considered. Centre-page Figure (Plot 23) illustrates this. Some of the lower humps in this plot have a shallow leached surface : they are of great age and not less than several centuries old. Some of the higher humps, however, were formed as the consequence of at least two wind-throws. In the profile illustrated the surface of the earlier is now buried about 24 inches below the top of the present hump and it has a leached surface which may be of the same age as the surface of the lower hump. The present surface shows no leaching, however, and the 24 inches of soil beneath it and above the buried leached horizon are highly porous and very thoroughly rooted ; even the anciently disturbed lower part of the hump is still porous and well-rooted. The upper part of the hump is not less old than the age of the trees standing on it ; i.e., about 100 years. This difference in age, between humps, seems to be of common occurrence. Thus, the hump cut into for one of the soil profiles examined in Plot 7 (Centre-page Figure), showed no leached horizon ; whereas that in the adjacent Plot 8 showed clearly the shallow grey leached horizon which is typical of mature soils in this region and because of this is to be considered much the more ancient.

18. It may be noted finally that both erosion and wind-throw are determined by climatic factors, rain and wind being the active agents ; fire may also be included here, at least in part, since the occurrence of lightning fires cannot be excluded. It is shown thus that, whereas under the influence of temperature, precipitation and humidity, as these prevail in this region, the tendency in soil genesis is towards the development of a humus elluviated surface, and because of this towards a change in the constitution of the forest towards the species which are able to regenerate on such a surface. The effect of other characteristics of climate, namely wind, precipitation as an eroding agent, and lightning as a fire producing agent, is towards a reconstitution of the soil surface so that an earlier stage in soil genesis is reverted to. The complex cyclical process through which the character of the soil surface, that is the regenerating bed of the forest, is determined, has to be considered in relation to the great age to which dominants live if allowed to do so, as in the unexploited forest. The effect of secular changes in climate, such as those described by Heusser (*loc. cit.*), for Alaska, will affect not so much this cyclical determination of the soil surface, as the suitability of the site, in terms of general supply of soil needs for particular species of tree. There may be considered, thus,

TABLE 4

Position of Charcoal in Plot Profiles

Topographical Position	Hill-side	Hill-side	Alluvial Flat	Hill-side	Alluvial Flat	Alluvial Flat	Hill-side	Hill-side	Edge of sea	Undulating Plain		Plain		Plain (old lake bed)			Irregular small hills		Alluvial Flat	Hill-side
District	Queen Charlotte City	Queen Charlotte City	Queen Charlotte City Sawmill	Skidegate Mission	Yakoun River	Yakoun River	Mamin River	Gold Creek	Juskatla Inlet	Port Clements	Port Clements	Tlell	Tlell	Lakelse	Lakelse	Lakelse	Terrace	Terrace	Kitsumkalum	Kitsumkalum
Plot No.	1	2		3	4	STA1	12	16	17	19	20, 21, 23 and 24	I and II	III	L6	L7	L8	T2	T4	K2	K4, 5 and 6
Horizon Ao	Present			Present					Present		Present	Present	Present					Present		None recorded but regarded as regeneration after fire
A		Layer 0-1$\frac{1}{2}$ in.	Layer 0-1$\frac{1}{2}$ in.						Layer 0-1 in.	Scatter 0-6 in.		Scatter 0-22 in.		Scatter 0-12 in.				Layer 0-$\frac{1}{2}$ in.		
B	Scattered between $\frac{1}{2}$ and 36 in.		Scattered between 3-20 in.		Very sparsely scattered 12-36 in.	1$\frac{1}{2}$ in. scatter		Scatter 4-12 in.												
Buried A	Layer at 36-36$\frac{1}{2}$ in.			Thick scatter			2-5 in. Layer												Buried H; Layer at 6 in.	
Buried B			Scattered 24-47 in.	22-24 in.		3 in. scatter														
C											In Compact Till				Scatter 38 in. to more than 48 in.	Scatter 23-30 in.	Scatter 13$\frac{1}{2}$-30 in.			
D	Occasional pieces in till below 48 in.																			

TABLE 5

Situations and Depths of Buried Horizons

Plot Number	1	3	12	16	23	K1	K2	K3	STA1
District of Plot	Queen Charlotte City	Skidegate Mission	Mamin R.	Gold Creek Juskatla	Port Clements	Kitsum-kalum Park	Kitsum-kalum Park	Kitsum-kalum Park	Yakoun River
Topographic Position ..	Hillside Lower Middle Slope	Hillside Lower slope Raised valley	Hillside Middle Slope	Lower Slope	Plain (Escarpment edge)	Alluvial Fan	Alluvial Fan	Alluvial Fan	Alluvial Flat
Character of Buried Horizons	A_2 and B	Reconsti-tuted B material	Burned Ao A_2 and B	A and B	Ao+A+B	Ao+A+B	Ao+A_2+B	Ao+A_2+B	Ao+B
Depth of Buried Horizons (in.)	36	Below 27 ins.	Ca. 24	39	25	18	6	5	22

TABLE 6

Details of Plots showing "Hump and Hollow" Relief (Graham Island)

Average Rooting Depth	Plot No.	Age	Per-centage Slope	Character of basic root-restricting material	Character of Soil Surface in Hollows	Average Total Height of Dominants (feet)			Topographical situation
						Hemlock	Spruce	Cedar	
Very shallow ..	14	All ages	Nil	Till or fluvio-glacial drift	Swampy	51	—	88	Flat hollow in valley.
Shallow	9	All ages	5	Till	Wet—very wet	114	132	—	Hillside shelf with reverse slope.
Moderately Shallow	7	All ages	18-20	Till	Wet	149	152	145	Lower middle slope of mountain.
Moderately Shallow	8	All ages	45-50	Till	Moist—wet	148	160	132	Lower middle slope of mountain.
Moderately Shallow	12	75	33	Till or Bedrock	Moist	114	132	—	Lower middle slope of mountain.
Moderately Shallow	23	97	5	Till or fluvio-glacial	Moist—dry	137	134	(Alder 115)	Edge of plain (near Masset Sound).
Shallow	Tlell I and II	Ca. 100	Nil—1	Impervious layered sediments	Dry—moist	85-90	110	85-90	Edge of plain (near the sea).
Deep or Moderately Deep	13	295	33	Coherent colluvium, Till or Bedrock	Dry	203	219	—	Lower slope in mountain valley.

to be three general types of process in the development of the soil: firstly a cool moist climate determines progression in development towards a humus elluviated soil with the accumulation of an organic surface covering; secondly climatic factors acting catastrophically determine an irregular reversion in condition of soil surface towards a less advanced stage in its genesis; thirdly the secular swing of climate towards hotter or colder, wetter or drier conditions determine a change in general conditions of soil supply in any site. The maintenance of the specific composition of the forest is to be seen mainly in relation to these processes as determining the conditions under which regeneration must take place on the one hand and as affecting the conditions of general supply from the soil, according to its physical and chemical structure, on the other. This argument has, of course, a more general application than to the hill forests; but these are, perhaps, particularly favourable for consideration of its implications.

19. There are inevitably many situations in the hill-side mountain forests which cannot be discussed here because of lack of opportunity for investigation. This is particularly true of the wetter aspects of the forest in which western red cedar is usually the principal dominant. Certain observations with regard to forest sites of this type were made: they will be discussed, however, in the next section, which is concerned principally with the forest as it is found in the undulating country round Port Clements and Tlell, in relation to changes in drainage conditions and soil type.

CHAPTER 4

The Site Tolerance of Sitka Spruce, Relative to its Associated Species, as Marginal Forest Sites are Approached

The Regression Towards Ill-drainage in Graham Island

1. Reference has already been made to the fact that the abundance of Sitka spruce as a dominant in the hill-side forests, is largely associated with the character of the site in relation to soil water supply and drainage. Sites which favour abundance are water-receiving, but at the same time reasonably well-drained: as these characters are departed from western hemlock, or western red cedar, tend to become the prevailing and characteristic dominants, according to the conditions. These site characteristics, though not the only ones which determine the abundance of Sitka spruce, are of such importance that an examination of other situations is necessary, bearing them in mind. This it is proposed to make in this section, referring to different series in regression of site character. Those immediately to be discussed were observed in Graham Island, in the region of Port Clements or Tlell; subsequently others in the region of Terrace will be mentioned.

2. The undulating plain of eastern and north-eastern Graham Island includes many areas in which the hollows were once filled with shallow lakes, but are now the site of swamps, or peat bog; while the eminences are low gently sloping hills, covered with forest which is usually of mediocre or low quality as judged by the accepted Site Index range (Plate 27). Country of this type occurs also on the southern side of Juskatla Inlet; and areas of bog which give similar regressions in forest type, as mineral soil is approached, are to be found round Marie Lake and probably the other lakes in the hills to the south of Juskatla Inlet. A considerable variety of edaphic types occur in this large area, and all that is attempted here is to refer to a few sequences in soil type in order to illustrate the variation in dominance in species as this changes.

3. Western red cedar with western hemlock, together with salal (*Gaultheria shallon*), may be considered as typifying large areas of forest, much of which is poor and often, in a stage of full development, no more than scrub. The changes in the character of this forest, as one progresses from the wetter to the drier parts, depend largely on the drainage conditions which prevail. It may be said generally that a shallowly rooted forest always occurs, whether the soil is organic, and derived from some type of peat, or whether it is mineral, with a thicker or thinner surface organic covering. The root restricting horizon in mineral soil always shows a high degree of impedance in drainage; it is often, though not necessarily, extremely compact glacial drift. It may be concluded that it is this material, or the impervious clayey sediments which, in the north-eastern plain, appear often to underlie it, which were responsible for the occurrence in ancient

times of the many shallow lakes, by the filling up of which the present peat bogs have been formed. The poor quality of forest which usually occurs in this type of country is plainly determined largely by this restriction on root development in depth based on poor topographical drainage, or the occurrence near to the surface of impervious mineral soil horizons.

Cedar-Hemlock-Salal Forest near Juskatla on Deep and Shallow Peats

4. One series of sites was briefly examined to the west of Juskatla Camp. The wetter aspect began in what may be called Cedar Swamp Forest. This is an open, poorly stocked forest of very poor height growth. The open glades are characteristically wet, with broad-leaved grass, between the stems of which green *Sphagnum* moss is abundant : pools or channels of water occur frequently, and the impression gained is that there is, on the whole, some lateral drainage from these. The most numerous tree of any size, and the prevailing dominant, is western red cedar, which is characteristically found in all ages, though small seedlings seem difficult to find (Plate 28). Western hemlock commonly is also numerous, but makes a much poorer tree than the cedar. All trees commonly stand on slight eminences which in this case were entirely organic, and the roots are found mainly in the slightly better drained soil in these. Sitka spruce occurs as a small tree no more than a few feet in height : it seems to be of younger age than either the hemlock or cedar, and the indications are that it does not live so long. The dominant cedar are in this type all spike-topped, and dead cedar poles occur locally. The mosses *Hylocomium splendens* and *Calliergonella schreberi* occur on the tree-inhabited humps and often, on these drier places, a little poor salal.

5. The Cedar Swamp Forest just described occurs on what is essentially a fen peat of an acid nature, on which a thin layer of drained material has been built up locally. The remains of the plants from which this peat has been formed are preserved perfectly within it. Plot 6 occurred on a site adjacent to that in mind, in which this fen peat is covered with about six to eight inches of fibrous decomposed peat which is drained, though still wet, and is very abundantly rooted (see Table 7). Grass-covered wet areas are of slight importance, and there is a more or less closed canopy. The forest now consists of cedar dominants (up to about 50 ft. in height and at least 170 years of age) standing over hemlock and cedar co-dominants and sub-dominants (the hemlock about 45 to 24 feet total height and 160 to 100 years of age), with a small number of Sitka spruce (about 15 feet in height and up to 50 years of age). The small size of many of the trees can be seen in Plate 29 : this also gives a view of the ground vegetation. Some of the more obvious plants noted here, apart from these trees, were :

Trees : Yew (*Taxus brevifolia*) and red alder (*Alnus oregona*).

Shrubs : Dogwood (*Cornus* spp.) ; oval-leaved bilbery (*Vaccinium ovalifolium*) ; false azalea (*Menziesia ferruginea*) ; Labrador tea (*Ledum groenlandicum*), and salal (*Gaultheria shallon*)—abundant but poor.

Herbs : Coptis asplenifolia and *Veratrum viride.*

Mosses: Hylocomium splendens and *Calliergonella schreberi.*

Cedar is still the principal dominant in this type of forest, though hemlock may be the most numerous tree species. The dominant cedar are characteristically spike-topped. It may be noted that the deeper water-logged peat is anaerobic and stinks on excavation, and that the tree root systems are confined to the very shallow surface covering of aerated material (Table 7). *V. viride*, in contrast, sends down its thick white roots quite deeply.

6. A change in forest type becomes obvious, from what has been described for Plot 6, as soon as the deep wet peat of the one-time lake is left ; the soil is formed by a shallower organic covering with mineral soil within reach of roots of trees. The most striking thing to the walker is the increase in height and density of the shrubs and especially of salal, which is dominant among these. This salal bush may now be man-high and difficult to push through. The mature forest is still irregularly and poorly stocked, but the trees grow to a much bigger size. A variety of situations occur here : the only one examined in any detail is that for Plot 11 (Table 7). One of the principal differences between the vegetation on this area and that for Plot 6, was not its specific composition, which in many ways was very similar, but its luxuriance, which was considerably greater (Plate 30). The absence of *Ledum groenlandicum* and *Veratum viride* is, perhaps, of considerable significance with regard to specific composition ; that of the former especially indicating the different conditions of drainage prevailing here.

Things to be noted are the poorness of stocking (Plate 30) with the death of trees of no very great size, in spite of this ; the poor crown development of dominant spruce and dead tops of cedar (Plate 31) and hemlock (in the background of Plate 30) ; but nevertheless the quite considerable height of dominants (an average total height of 135 feet for spruce and cedar—Table 7). The explanation of these things is to be found in rooting conditions and drainage. The soil (Plate 32) consisted of about six to eight inches of organic material which overlaid a hard compact extremely coherent coarsely textured till, the top three inches of which were capable of being rooted. There was, thus, at the most about twelve inches of rooting depth, and this was in material which is of low base status. There was free, though perhaps somewhat slow, drainage laterally down an incline of about 4 per cent. The live roots of the trees proved mainly to be in the top six to eight inches of organic material (Plate 32). Sinker roots had penetrated into the upper few inches of mineral soil and then mostly died. The explanation of the present condition of this area of forest is to be found in the restricted and probably very variable supply to the roots which these soil conditions offer. It will be suggested later that forest on this type of site may be much more densely stocked in its earlier stages, as for example, when regenerated after fire. (See page 43).

7. General observation shows that chlorosis indicative of nutrient deficiency is common on sites of this nature. The dominants commonly show stag-headed, or poorly developed crowns ; root disease is always appreciable and heartrot usually common. The density of stocking seems clearly to increase in proportion as root development takes place in mineral soil, but this cannot be adequately discussed owing to lack of data. These few observations indicate one end of a site regression, the dominant characters of which are related to shallow rooting in a wet soil with poor, but probably never stagnant, drainage and possibly associated with poor conditions for nitrification. The prevailing dominant throughout is western red cedar, which eventually always becomes spiked-topped, though it may live for a long time. Western hemlock is usually the most numerous tree, especially if all sizes which occur are taken into account. It is, however, a smaller tree than either spruce or cedar on the better sites (Plot 11), and an inferior co-dominant or subdominant on the poorer, such as Plot 6 and the adjacent Cedar Swamp type. Sitka spruce, in the type represented by Plot 11, grows to be as large a tree as cedar, but occurs less frequently : in Plot 6 it was the least frequent of the three species and quite insignificant in size. Its growth was much inferior still in the Cedar Swamp type : that this is normal under such conditions was confirmed by its growth in Plot 14 (Table 6), also a Cedar Swamp type, but with shallower peat, and humps composed of mineral soil on which, if anything, growing conditions should be less severe. The indications are, thus, that spruce is the most susceptible of the three species to increasingly poor soil conditions ; that hemlock is somewhat less affected by them and that cedar is the most tolerant of them. Plainly the poorer sites form economically worthless scrub forest.

Cedar—Hemlock—Spruce on Shallow Peat and Hill Side Swamp

8. Plot 15 (Table 7) on heavy alluvial silty clay covered with shallow peat and Cedar Swamp areas adjacent to Plot 7, represent sites with which Plot 11 may most profitably be considered. There are some superficial edaphic similarities between Plots 11 and 15. The rooting medium in Plot 15 is shallow peat, having the total depth of about 16 inches. The total rooting depth is about 12 inches and the depth of abundant rooting about 3 or 4 inches (Table 7). Water is ponded in the lower few inches of the peat, in which the undecayed remains of swamp plants are to be found ; there is, however, some lateral movement of water, sufficient to prevent stagnant conditions from arising in the main layers rooted. One principal difference from Plot 11, is the failure of roots to reach mineral soil. The site of Plot 15 is by the side of the Mamin River, on a small plain : probably it receives but little water by topographical drainage, and in this resembles Plot 11. There is, however, a big difference between the two plots in the type of forest carried : that on Plot 11 is, as stated, of the open type, poorly stocked, which is associated with shallow wet soils in Cedar-Hemlock-Salal Forest when fully developed ; but the canopy in Plot 15 was more or less closed. The mean height of the dominants in Plot 15 is the lower, being 115 feet average total height as compared with 135 feet—but the crowns of the hemlock and the very few dominant spruce showed the signs of narrow restricted development which is characteristic of these trees on shallow wet soils, while the cedars were spike-topped. There was little ground vegetation, however, under the canopy in Plot 15 ; there were a few very small skunk-cabbage plants and these may be taken to suggest that this plot belongs to a different vegetational type from Plot 11, and one that possibly indicates a different nutritional status.

The small Cedar Swamp areas adjacent to Plot 7, though in a very different position, are possibly related vegetationally (Table 7). These differ from Plot 15 in that there are truly wet swampy areas, though because of the slope on which they are situated, the water in these is always moving. The trees grow on humps standing out of these areas. Small skunk cabbage plants (*Lysichiton camtschatcensis*) are to be found here also. Associated plants in very moist, but not actually watery, places were :

Broadfronded liverworts (*Pellia* spp. ?) locally dominant.

Sphagnum moss, locally dominant.

Mnium punctatum, often abundant.

Pogonatum alpinum.

Dryopteris linneana, locally frequent and small.

Maianthemum dilatatum, locally frequent and small.

Coptis asplenifolia, locally frequent and small.
Listera spp., occasional and small.
Narrow-leaved grass, abundant locally.
Small seedlings of western red cedar, western hemlock and Sitka spruce, frequent.

Such a flora is not that associated with strong development of salal, and it seems to imply a much improved nitrogen status, at least in the surface soil, to what might be expected where salal occurs. This may account for the relative frequency of tree seedlings in these patches : Plate 33 shows one of them, actually in Plot 7 ; the small size of the ferns and herbs gives it the rather bare appearance. Where these wet places cover an appreciable area, as below Plot 7, Sitka spruce occurs sparsely, but grows to an appreciable height and age : it shows the poor type of crown development (Plate 34), which has already been noted, the cedar dominants are always spiked topped and hemlock with thin or dead tops are frequent.

It would appear from these brief observations that there are at least two different regressions to be observed in Cedar-Swamp Forest. One is that in which salal becomes dominant in the ground vegetation as conditions become drier : the other that in which plants such as skunk cabbage, *Pellia* and *Mnium* occur and eventually *Maianthemum* and *Dryopteris*. Further, conditions are more favourable for the growth of Sitka spruce in the skunk cabbage than in the salal type. (See Chapter 6, page 62).

The Development of the Forest on Proceeding from Sphagnum-Juniper-Lodgepole Pine Bog

9. This may be studied in many places in the region between Port Clements and Tlell. Plate 27 shows one of these : in the foreground are enclosed more or less stagnant pools of water overlying deep peat ; with small stunted, but quite old, lodgepole pines scattered thinly on the higher places. These are formed chiefly by the accumulation of raised peat through the growth of *Sphagnum*, the pink colour of which is one of the striking characteristics of the bog. Small juniper bushes (*Juniperus sibirica*) are quite common, poking their branches with wax-covered needles out of the pink *Sphagnum* clumps. An appreciable range of plants occurs in these places, which there was no time to list or study, though ecologically this type of bog is of considerable interest. The regression in forest constitution now briefly described, proceeds in the main from the wet foreground shown in Plate 27 up to the top of the hill beyond : Plot 19 (Table 8) was situated on the crest of this.

10. The forest on the hill is approximately even-aged (ca. 90 years) and was regenerated after fire. The larger pines in the bog are older. The regression in species composition of dominant trees can be described very simply :

(*a*) If the bog has a wet centre, as shown above, there are enclosed pools of water surrounded by sedges and grasses with stunted pine and juniper growing surrounded by humps of *Sphagnum* moss. Reindeer moss (*Cladonia rangiferina*) may be common ; there may be some poor Labrador tea (*Ledum groenlandicum*) and poor growth of bearberry (*Arctostaphyllos uva-ursi*) ; crowberry (*Empetrum nigrum*, may also occur. If the wet centre is occupied by a stream, as in another part of this bog, the vegetation changes significantly, though this change cannot here be stated in detail. New species of grass and sedge appear ; *Eriophorum* spp. may be abundant ; woody plants, such as Labrador tea or bearberry, show much greater and more vigorous growth ; western red cedar appears as a small, but not unhealthy looking, tree and small Sitka spruce may also occur. The pines by the stream side lose their extremely stunted appearance and, if there is enough raised peat, a woodland of short pine and cedar is formed with a closed canopy. These changes seem clearly to be related to the influence of the stream as a drainage channel.

(*b*) If one proceeds across the bog towards the rising ground there is no change of significance until the foot of this is reached when, still on fairly deep peat, a closed but stunted woodland of pine with cedar is formed ; the trees stand on small humps of peat in which there may be some small rather depressed junipers still occurring : the hollows between are decidedly wet.

(*c*) Proceeding towards the rising ground, the cedar and pine improve in height growth and crown development, and small stunted hemlock appear under their canopy. This is a characteristic stage in the regression, and the hemlock are not likely appreciably to grow out of their stunted suppressed condition. The ground surface is more dry, but wet hollows still occur.

(*d*) The next stage is for a taller and better formed woodland to develop in which cedar, pine and hemlock form co-dominants. Sitka spruce now appears occasionally as a small suppressed tree ; often these small spruces have been killed by suppression. The peat is now shallow and roots are within reach of mineral soil, although they penetrate it very little.

(*e*) Proceeding further uphill, the pine become sparse or disappear and a cedar-hemlock stand occurs in which the hemlock seem usually to be the more numerous trees : occasional spruce now appear as co-dominants or sub-dominants. This is the stage typical for Plot 19 (Table 8), though no spruce actually occurred in it : it is also typical for Plot 24 which occurred in a similar position and in the same district ; there were a few spruce in that plot. Details of the profiles for Plots 19 and 24 are shown in Table 8.

(*f*) The regression on the site illustrated in Photo 27 proceeded no further ; but under some circumstances a further stage occurs in which forest of this type, regenerated after fire, develops as a spruce-hemlock stand with a few cedar, perhaps, but no pine. Plot 20 (Table 8) illustrates this : it is to be regarded as the climax of the regression and is referred to below (para. 13).

11. There are, of course, many variations on this regression, which it would be tedious here to attempt to describe and, indeed, impossible effectively to do so owing to lack of information. However, if the regression proceeds from peat bog into mature forest, as frequently in the large area of scrub forest to the west of Tlell, it now proceeds somewhat after the following fashion.

(*a*) There is, first of all, the *Sphagnum*-Juniper-Pine association, already noted.

(*b*) This changes into Cedar-Hemlock-Salal forest as rooting conditions improve. This is more or less open forest, much as in the area round Plot 11, near Juskatla (page 27, para. 7). The hemlock appear at first as scrubby bushes with short, but much taller cedar dominants ; the latter are always spiked-topped. The ground is covered with rather poor salal and there may be much Labrador tea. Spruce have not been noticed in this stage, but may occur at some time during its development, as poor plants.

(*c*) If soil conditions continue to improve, the forest improves in height growth and density ; the hemlock in particular show this, though they are still often poor trees. Spruce may occur not infrequently as very and almost bushy poor trees. The salal/false azalea/oval-leaved bilberry bush which covers the ground, may be as high as a tall man, or higher and extremely difficult to penetrate, so that in places it is easier to go on all fours and crawl under the bushes.

(*d*) Continued improvement in site conditions leads into Hemlock-Cedar-Spruce forest, which gradually increases in density and height growth. The end of this change will depend on the progression in site conditions : in the region of Tlell, one end is to be seen in the small area of tall forest which contains many large spruce dominants, and which stands by the side of the Tlell River about a mile beyond Experimental Plots 416 and 417. Such good growth cannot, of course, take place unless appropriately good soil conditions prevail.

12. In this analysis lodgepole pine is shown as the species of tree most tolerant of wet, more or less stagnant peat bog ; western red cedar follows, with western hemlock as a poor third. Both these species, and also to a greater degree Sitka spruce, are shown to need at least some few inches of drained peat. The soils were purely organic, as in the deep peat ; or shallow peat which overlay a compact mineral substratum in which drainage was entirely impeded ; or podsols with a fairly thick covering of raw humus, but in which some very shallow root development took place in the mineral soil. The growth of the forest improves in the order given for these soils. Sitka spruce does not appear as a strong dominant on these poor shallowly-rooted peat or podsolic gley soils.

A Regression in Regeneration, after Fire, from Poor Cedar-Hemlock Forest to Spruce-Hemlock Forest

13. About a quarter of a mile on the north side of the tidal outlet of Kumdis Creek, along the road which was at one time to have proceeded from Port Clements to Masset, a steep bank rises to a height of about 40 feet. The area sampled in Plot 20 is on the top of this bank, which is composed of irregularly layered sandy clay, sand and silty sand of a grey colour : this material probably underlies the whole of the small area now referred to. The ground surface near the edge of the bank, in Plot 20, is slightly convex, but approximately flat ; thereafter there is a very slight slope downwards. Details of the soils, as sampled in three places proceeding on a line through this area, are given in Table 8. They are derived from drift which overlies the above-mentioned grey sediments. The soil in Plot 20 is a podsolic brown earth which overlies a water-retentive subsoil and has an appreciable covering of raw-humus ; the depth of rootable material is about 19 inches. Profile 20A, taken some 30-40 yards beyond the plot boundary, is plainly a podsol ; the depth of rootable material is about 19 inches also, but it overlies a hard cemented iron pan. Profile 20B, taken a short distance further on still, is a well-developed podsol, also with a hard iron pan, and with a rooting depth of about eight inches. The constitution of the forest changes according to the soil on which it stands ; Plot 20 consisted of spruce dominants with hemlock co-dominants ; Profile 20A was dug in a stand of cedar and hemlock dominants with an occasional spruce, and 20B was dug in a stand with poor scrub hemlock co-dominants beneath sparse short cedar dominants ; but with occasional poor, sub-dominant or suppressed spruce occurring also. There was a continuous decrease in height and diameter on proceeding from Plot 20 to Profile 20B. A comparison may be made with the profiles for Plots 19 and 24, which are characteristically cedar-hemlock stands, though a few spruce and some pine also occurred in Plot 24 (Table 8).

The gleyed horizons in all these soils are characteristically hard and compact, at least in the upper part ; that in Plot 20 was the least severely compressed or cemented, and the one in which capillary transference of water to the rooted horizons probably is most efficient. The specific constitution of the forest and the vigour of growth shown in these even- and equal-aged stands is to be regarded as mainly determined by the character of the rooting profile, and particularly, perhaps, by the volume available for rooting and the water supply to this. It is very doubtful indeed whether distribution of seed supply has been of any appreciable importance in determining proportionate distribution of species. The sparsity of cedar among the dominants of any class in Plot 20 is a plain case where this explanation cannot hold, for there are, in this area, a few large cedars which survived the fire which preceded its regeneration, and which obviously must have provided an adequate supply of seed. One is thus left to the conclusion that the constitution of the forest in these areas has been determined principally by the locally occurring edaphic supply of the sites in relation to the needs and competitive power of the various species. This being so, then plainly spruce appears as the least tolerant of adverse conditions of supply as they occur in this region.

14. **The Influence of Water Movement on the Constitution of the Forest.** It was mentioned above, in paragraph 9, that the passage of a stream of moving water through stagnant peat bog exerted a favourable influence on the growth of trees and other woody plants standing along its banks. This same influence may be seen on a peat soil of higher fertility and capable of bearing Closed Forest. It was exemplified well in the forest within which Plot 21 (Table 9), near Port Clements, was situated. This area of forest stands on deep peat within which the remains of water plants are abundant ; plainly it is on the site of one of the lakes which, at one time, must have been abundant in this region. A small stream runs through the area, often passing under the great roots of the larger spruce. The plot was situated within the spruce on the banks of this stream. The soil was examined within the Plot, and also in two other places directly in line with each other and away from the stream. Details of these profiles and the constitution of the forest which surrounded each are given in Table 9. The main difference between this peat and that of the open muskeg referred to in paragraph 9(*a*) is the appreciable depth of decomposed and more or less drained peat which consistently overlies the water-sodden fossil peat of the old fen. These two zones in the peat are distinguished by their colour ; the upper and rootable material is almost black ; the lower and water sodden, a dark brown which, however, turns almost black on being dug out and exposed to air. This is the common oxidation phenomenon which occurs on the exposure to air of peat which has lain under anaerobic conditions. The upper black peat is divided into two zones ; there is an upper superficial zone of four to five inches in depth within which root development is intense, and a lower one which varied in depth from 13 to 9 inches, within which roots were much less abundant (Table 9). The roots were mostly alive in the upper zone, though much dead root occurred ; but the number of dead roots in the zone below increased proportionately very greatly. It is to be noted that, within the Plot, by the stream side, the whole of this lower zone was occupied by roots, but further away from the stream, only the upper part of it. The constitution of the forest in relation to this is of considerable interest ; it varied as follows :

(*a*) By the stream in Plot 21
Sitka spruce was chief dominant, with western red cedar and some red alder and western hemlock.

(*b*) 50 yards beyond the Plot :
Western red cedar, western hemlock, Sitka spruce and lodgepole pine, in that order of frequency as dominants ;

(*c*) 100 yards beyond the Plot :
Western red cedar as sole dominant with an understorey of poor hemlock and a few suppressed, dying or dead Sitka spruce.

No measurements were taken of height and diameter except in the Plot ; but there was a decrease in both, as one proceeded away from the stream much as has been indicated above for Plot 20 and the associated profiles. The stand on the site furthest from the stream was, in fact, very like that at site 20B (Table 8 and page 29, para. 13), though the soils in the two sites are very different. It also bore resemblances to Plot 6 (page 26, para. 5), but was more dense. The association of relatively good growth with nearness to running water may be observed consistently in places such as this, and the conclusion seems to be inevitable that this is mainly because of the occurrence of aerated conditions to a greater depth in such sites than in those more distantly situated. Also there is in this example a clear demonstration of the relative failure of Sitka spruce to tolerate the more difficult soil conditions as compared with western hemlock and western red cedar. Moreover, cedar appears clearly as the most site-tolerant of the three species under these conditions.

15. It is plain from what has been said above that, if one considers the shallowly rootable gleyed soils and the peat soils which occur in the muskeg region between Port Clements and Tlell, that the four species of conifer which occur here and principally

make up the forest, appear in the following order of site tolerance, beginning with that which is most tolerant : lodgepole pine, western red cedar, western hemlock and Sitka spruce.

It is easier to state this than to say what are the conditions which are tolerated or avoided, but plainly there is a sequence in which soil aeration, soil depth available for rooting and the character of the soil water supply are of very great importance. It would appear that Sitka spruce, as the species least tolerant of poor conditions, is in greatest need of an aerated rooting space supplied reasonably constantly with water. Only when these are available can its great powers of growth be developed. It must not be assumed that excess of water, and consequent lack of air, is always the principal adversity, apart from nutrient status and soil volume, which is experienced on these sites. It is in every way possible that one of the difficulties in shallowly rooted gley soils in which cedar-hemlock or cedar-pine dominate is, at least periodically, lack of water, and it will be shown later that, where such clearly must occur, Sitka spruce is unable to compete with these species (Chapter 5, page 48).

A Regression from Lake-side Sedge Meadow to High Quality Forest

16. A fuller picture of the regression in dominance of species is obtained when sites of high fertility are included in the area surveyed. The best example seen in this work was along a transect walked from the borders of Marie Lake in the hills south of Juskatla, westward towards, and then beyond, Plot 13 (Tables 3 and 6) to the top of the hill on the slope of which it stood. (The site is shown on Plate No. 2.) The sequence in appearance of the forest as one proceeded from the lake edge towards the hills was as follows :

(*a*) In the shallow water at the lake edge a community of water-lilies (*Nymphaea polysepala*).

(*b*) On the lake edge, open sedge meadow, very wet, with shooting star (*Dodecatheon* spp.) and a large pale *Viola*, in bloom, in June ; small sickly lodgepole pine occurred at the inner edge, occasionally.

(*c*) *Ledum groenlandicum* then became dominant in the ground vegetation, and lodgepole pine occurred as a small tree of perhaps fifteen feet in height ; *Sphagnum* was an abundant moss and the ground wet.

(*d*) The ground became drier, on the average ; mosses such as *Hylocomium splendens* covered and coloured the slightly raised humps ; *Sphagnum* still occurred in the wetter hollows. Salal (*Gaultheria shallon*) appeared sparsely and was of poor growth ; the most abundant tree was western red cedar ; pines were sparse or absent ; there were some poor and rather yellow-foliaged western hemlock, and a very occasional extremely poor Sitka spruce. The cedar dominants were spike-topped.

(*e*) Proceeding further from the lake, the ground became drier, but wet peaty hollows were frequent. Salal grew much more strongly, and grass occurred in the drier open places. All the trees were much taller, though still not large. Cedar was decidedly the dominant species, but the hemlock appeared green and healthy: there were some few Sitka spruce. The larger cedar were spike topped. Up to now the soil had consisted of peat which permitted only shallow or very shallow rooting.

(*f*) The ground now became much drier and had a " hump and hollow " relief, and there was mineral soil, at least in the humps. The forest was, on this transect, now almost entirely pure cedar. The trees were situated entirely on the humps, but their root-systems spread over all situations. Their height growth and condition appeared to be moderately good. Some of them were spike-topped.

(*g*) The ground now began to rise up from the level of the peat bog, on the one side, on to a small rocky knoll, covered with a shallow podsolised soil ; on the other, up the slope of the hill on which Plot 13 was situated (see Plates 2 and 22). The knoll, an obviously well-drained situation topographically, was covered mainly with cedar. These were good-looking trees, but not so fine as the better of the trees in the cedar noted under (*f*). A few hemlock occurred also ; no spruce were seen.

The foot of the rise towards the main hill had partly been cleared. It had, plainly, carried a stand of cedar, hemlock and spruce.

Some fine cedar still occurred and there is no doubt that a stand of moderately good quality in terms of Site Index, occurred here.

(*h*) Proceeding uphill, the slope became moderately steep, to steep ; cedar disappeared and the forest consisted of tall spruce and hemlock. This is the situation of Plot 13. The soil was a moderately deep, to deep, colluvium ; there was little ground vegetation other than mosses ; e.g., *Plagiothecium undulatum*. The ground surface showed the signs of an anciently formed hump and hollow relief, but the hollows were dry (Table 6). This is a water-receiving but well-drained situation. The average total height of dominants and co-dominants in Plot 13 was for spruce, 219 feet ; and for hemlock, 203 feet ; diameters ranged from about 36 to 60 inches. These trees were nearly 300 years in age (Table 23).

(*i*) The soil became shallower and more rocky on the upper slope and top of the hill. Most of the forest at the top had been felled, but the remaining trees and those on the upper slope showed that cedar had once again appeared. Hemlock had been abundant,

TABLE 7

Details of Plots Illustrating Site Tolerance of Sitka Spruce

Profile Details	Plot 6			Plot 11			Plot 15			Wet Areas near Plot 7§					
	Horizon			Horizon			Horizon			Horizon			Horizon		
	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture
L+F	2	i	o.m.	1	i	o.m.	1	i	o.m.	Tr	f	—	Tr	—	—
H1	3*	i	o.m.	3½	i	o.m.	2½	i	o.m.	½	S	o.m.	8	f-nil	o.m.
H2	3*	ab	o.m.	3	loc. f.	o.m.	9	vs (dead)	o.m.	—	—	—	—	—	—
H3	Unknown	*nil	o.m.	—	—	—	4†	nil	o.m.	—	—	—	—	—	—
G1	—	—	—	3	loc. f. (dead)	L+Gt	8	nil	sC	‡(A)2½	nil	cL	‡(AG)3	nil	sL
G2	—	—	—	Unknown	nil	C+Sa	Unknown	nil	sC	Unknown	nil	cL	(B) Unknown	nil	Hard till
Soil Type	Deep Peat			Shallow Peat/Gley			Shallow Peat/Gley			Gley			Shallow Peat/Gley		
Dominant Ground Vegetation	*Gaultheria shallon* (short). *Ledum groenlandicum.* *Veratrum vivide.*			*Gautheria shallon* (2·5 ft.). *Vaccinium ovalifolium*			Mosses ; occ. very small skunk cabbage			*Mnium punctatum*			*Mnium punctatum*		
Main Tree Spp.	Cedar, Hemlock, Spruce.			Cedar, Spruce, Hemlock.			Hemlock, Cedar, Spruce			On nearby humps in dry areas : Hemlock, Spruce; in wet areas : Cedar, Spruce, Hemlock.					
Average Ht. of dominants and co-dominants (feet)	Cedar—64			Cedar—135 Spruce—136			Hemlock—118 Cedar—114 Spruce very occasional and of much same height.			Heights not less than Plot 15.					

*Smell badly, H3 especially.
H3 fossil peat.

Profile Symbols :
L = Litter ;
F = Fermentation Layer ;
H = Humus ;
G = Gley.

†Fossil peat : no bad smell.
‡Horizon Symbols.

§Hill-side sites with hump and hollow relief.
Symbols : o.m.=organic matter ;
s=sandy ; L=loam ;
C=Clay ; S=sand.
Soil : Gr.=grit; c=clayey; a=light.
Roots : i=intense ; ab=abundant ;
f=frequent ; s=sparse ;
loc=locally.

Age—These are plots having trees of all ages.

TABLE 8

Profile and Crop details in Areas Regenerated after Fire—near Port Clements

Plot No.	19			20 (Profile 1)			20 (Profile 2)			20A			20B			24(1)			24(2)		
	Horizon			Horizon			Horizon			Horizon			Horizon			Horizon			Horizon		
Profile details	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture
L+F	½	—	o.m.	1	—	o.m.	1	—	—	½	—	—	½	—	—	½	—	—	½	—	—
H	6	i	o.m.	7	i	o.m.	5	f to i	o.m.	1½	i	o.m.	2½	i	o.m.	3	vi	o.m.	3	vi	—
A1	—	—	—	—	—	—	—	—	—	—	—	—	(A21)2	i	sL	2	i	L	—	—	—
A2	6	ab(d)	sC	0-1	—	—	0-1	—	—	1½	i	sL	(A22)4	S	sL	(A21)2	f	cL	5	loc. s or f	cL/C
B1	—	—	—	(B)12	loc. f to s(d)	L	(B)8	ab	L	15	i	L	—	—	—	(A22)5†	s	C	—	—	—
B2	1+	nil	C+ Gr	—	—	—	—	—	—	½	nil	iron* pan	½	nil	iron* pan	—	—	—	—	—	—
G	Un-known	nil	C+ Gr	17	nil	sC+ Gr	G1 6½ G2 Un-known	s(d) nil	cL-C Sb	Un-known	nil	+ Gr	Un-known	nil	+ Gr	Un-known	nil	C+ Gr	Un-known	nil	Gt+ Gr
Spp.	Cedar, Hemlock, Spruce, Pine			Spruce, Hemlock			As 20(1)			Cedar, Hemlock, Spruce			Cedar, Hemlock, Spruce			Cedar, Hemlock, Spruce, Pine			Cedar, Hemlock, Pine		
Av. ht. of dom. and co-dominants (ft.)	Cedar .. 74 Hemlock .. 74			Spruce .. 120 Hemlock .. 108						Ca 80-90 (by eye)			Ca. Cedar .. 60 Hemlock .. 40 Spruce .. 30			Hemlock .. 92 Cedar .. 84 Spruce .. 82 Pine .. 79			As 24(2)		

* Cemented. (19) * Cemented. (20A) * Cemented. (20B) † Free water here. (24(1))

Note :

The G horizons were all hard and compressed except in 20(1) and 20(2).
Slopes—always gentle or nil.
Elevations—all less than 100 feet m.s.l.
Age—Ca. 90 years.

Rooting : ab=abundant.
i=intense.
f=frequent.
v=very.
s=sparse.
d=dead.

Texture : L=loam.
sC=Sandy clay.
C=Clay.
cL=Clay loam.
Gt=Grit.
Gr=Gravel.
o.m.=organic matter.

TABLE 9

Details of Soil Profile and Root Development in Plot 21 and Subsidiary Profiles in Deep Peat

Horizon	Depth (in.) in Profiles			Rooting Intensity in			Condition of Roots
	a (Plot)	b	c	a (Plot)	b	c	
L + F	1.0	0.75	0.75	f	f	f	
H1	4.5	4.5	4.0	i	i	i	Mostly living, but numerous dead.
H2	13.0	12.0	9.0	loc.a.	loc. f. in upper half	as (b)	Many dead ; often most.
Transitional zone	5.0	5.0	5.0	Nil	Nil	Nil	
Fossil Peat	Unknown			Nil	Nil	Nil	

Note : There is probably a little fine mineral matter in H2.

Symbols : f=frequent ; i=intense;
a=abundant ; loc=locally.

but there had been fewer spruce. None of the cedar showed spiked tops. Growth here was good, but less fine than on the slope below. This brief description of the change in composition of forest with change in edaphic situation serves to summarize what has been shown before in the several regressions in type of forest already described. Sitka spruce appears clearly as the least site-tolerant species, lodgepole pine as the most, with western red cedar following it closely. It is to be noted that any well-drained, water-losing situations favour the occurrence of cedar and not merely the less-well-drained. Hemlock appears as a widely tolerant species, but not able to cope with the wetter situations as well as either cedar or pine can do. It would appear that no situation in this hill country, on well-drained sites, is sufficiently dry to be so adverse to cedar or hemlock as to enable pine to survive as a dominant.

A Comparison of the Relative Growth of Sitka Spruce, Western Hemlock and Western Red Cedar on Soils of Different Types

1. It was felt, in view of the observations with regard to the relative site tolerance of spruce, hemlock and cedar, that it would be of interest to collect data relating to their growth on a site on which there was some clear change in soil type. It was necessary to choose this site in the region of Tlell since that, at the time, was the centre worked from. Eventually two adjacent transects were chosen in the strip of relatively good forest in which are Experimental Plots 417 and 416. This is situated on the left or western bank of the lower and tidal part of the Tlell River ; it is separated from it by a sand dune, now naturally fixed and forest covered. The dune, on its western side, falls to the base of a low cliff of about forty feet in height. This cliff doubtless faced the sea at one time, before the building up of dunes parallel to the shore diverted this part of the river into its present northerly direction. The situation resembles that of Plot 20 (page 29, para. 13), near to Kumdis Creek, in many ways. The cliff consists of grey coloured sandy clays and gravels which are ordinarily impervious and show a layered structure ; they are part of the sediments which occur so largely in this part of Graham Island. There is at the top of the cliff a strip of more or less flat land which is narrow in the more northern part, but widens on proceeding southerly. It is three to four chains wide in the part investigated ; i.e., in and just to the

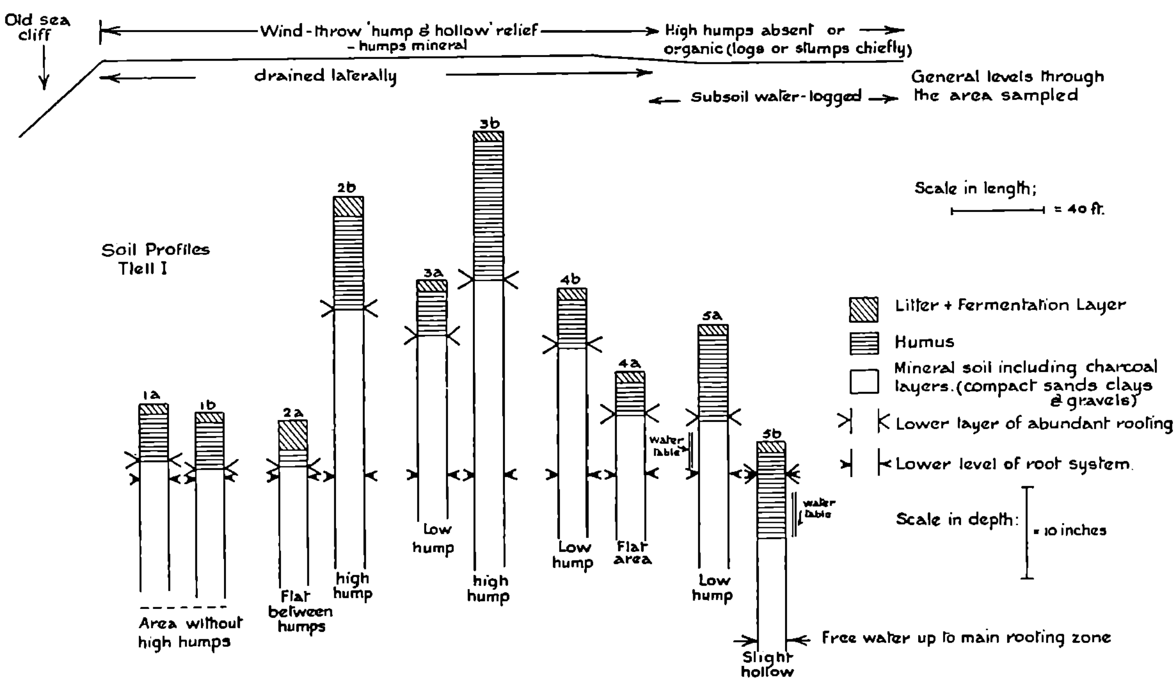


FIG. 1

This illustrates the variations in rooting depth within the transect plot, Tlell I. The greater depths occurred in the humps; the shallower, at the base of humps, or in the hollow or flat areas between them. The humus was consistently favourable to root development, unless water-logged, as in sub-plot 5b. It should be noted that the zone of abundant root development was confined almost entirely to it (compare with the adjacent transect, Tlell II, Fig. 2).

north of Plot 417. Proceeding further from the river and westerly, the ground falls a few feet and a wet type of forest is entered. The two transects chosen proceed from the cliff edge into the edge of this wet type. This cliff edge strip was regarded as even-aged and of approximately 95 to 100 years old. It seems probable that it was regenerated after fire ; but it has also been markedly affected by windthrow in the past, for in many parts it shows a strongly developed " hump and hollow " surface relief, the hollows being dry. There is no doubt that before wind-throw occurred this area was burned, for charcoal occurs within the top foot of mineral soil in a number of places. The length of the transects was limited by the depth to which the even-aged regeneration occurred ; it was quite plain that only the edge of the wet type was so affected that it regenerated at the same time as that on the higher and drier part.

2. The soil in the hollows of the narrow cliff-edge plain is leached, its drainage is highly impeded, so that only an inch or two of it is occupied by roots and there is a thick organic surface covering (Fig. 2). The higher humps are brown podsols, or podsols with a narrow leached horizon : the lower humps are often much like the hollows. Little or no free water ran into the pits in this part of the transects, which seems to be adequately drained, as it is now under high forest, by movement of water laterally. The mineral soil in the lower part of the transect is of very similar constitution to that in the higher, but it is water-logged. Some idea of the effect of the humps on rooting depth can be obtained by a comparison of Fig. 1 with Fig. 2 : the latter represents profiles found in the second transect by consistently sampling hollows; whereas in the first transect humps also were investigated. Both these figures show plainly the very great importance of the organic surface covering as providing rooting space for the trees in this area. The soil in the hollows is a coherent, compact, dark grey coloured material, usually a sandy clay, fissured though not always obviously so, and with a hard compressed horizon at no great distance down. The larger spruce are practically always on or near humps, while the hemlock, on the whole, increase in proportion in the hollows, especially where these are extensive (e.g., see Fig. 3). It is to be noted that the organic covering is intensely rooted ; worms were found scattered sparsely through it.

3. The ground vegetation consisted almost entirely of mosses and small liverworts. Of the mosses, *Plagiothecium undulatum* occurred in relative abundance, usually, but not necessarily, on the higher places, and *Eurynchium oreganum* similarly in the lower places. *Rhytidiadelphus loreus*, *Hylocomium splendens* and *Calliergonella schreberi* also occurred ; this list is not intended to be an exhaustive one.

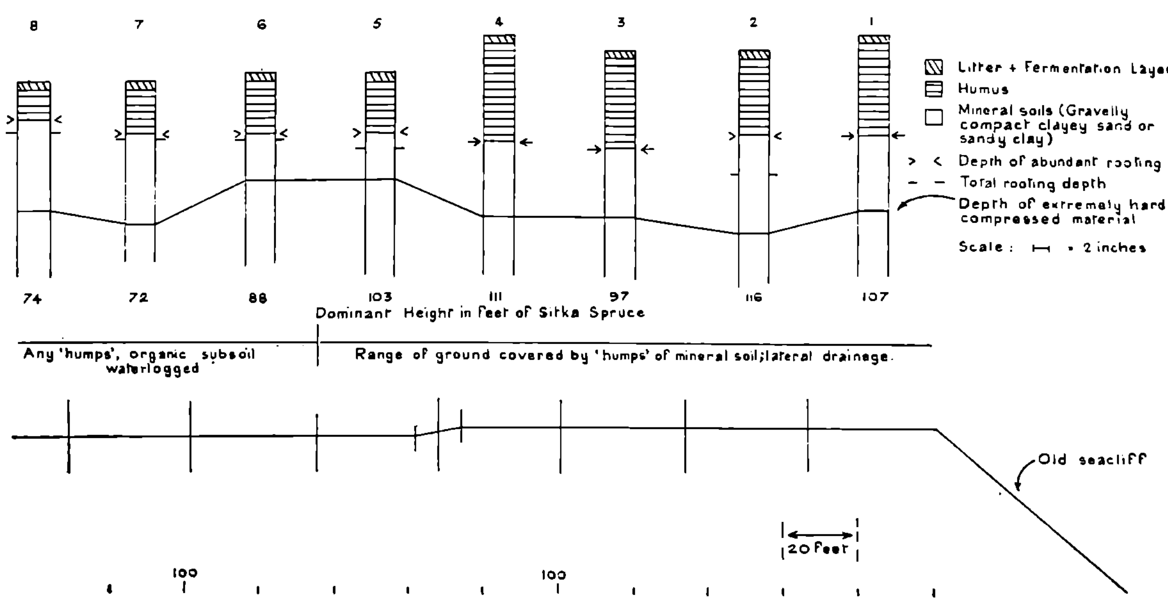


FIG. 2

Profiles showing root abundance in hollow, or flat, areas usually lying between wind-throw humps throughout the transect plot, Tlell II. Note that in these areas the organic material alone provides the effective rooting space. The humps, as illustrated in Fig. 1, thus almost alone provide the space for root development in mineral soil.

There was an occasional small plant of *Menziesia ferruginea* and occasional fern (*Dryopteris* spp.). The finer fronded liverworts of the *Scapania* type were often abundant on logs and humps ; while in the wetter areas broader fronded species (probably *Plagiochila asplenioides*) were locally the dominant ground cover. The proportion of ground covered by mosses and liverworts varied from about 40 to 90 per cent. ; the moss layer was usually thin. Tree seedlings were sparse or absent, but a few hemlock and a very few spruce were seen. Sitka spruce and western hemlock formed the forest on the higher parts, except for a very few western red cedars. Red alder had once been present here and of appreciable size. Hemlock and then cedar were most numerous in the wetter part : some spruce occurred and a very few lodgepole pine. It can be seen from Table 14 that the trees in the higher and drier part were much larger than those in the lower and wetter.

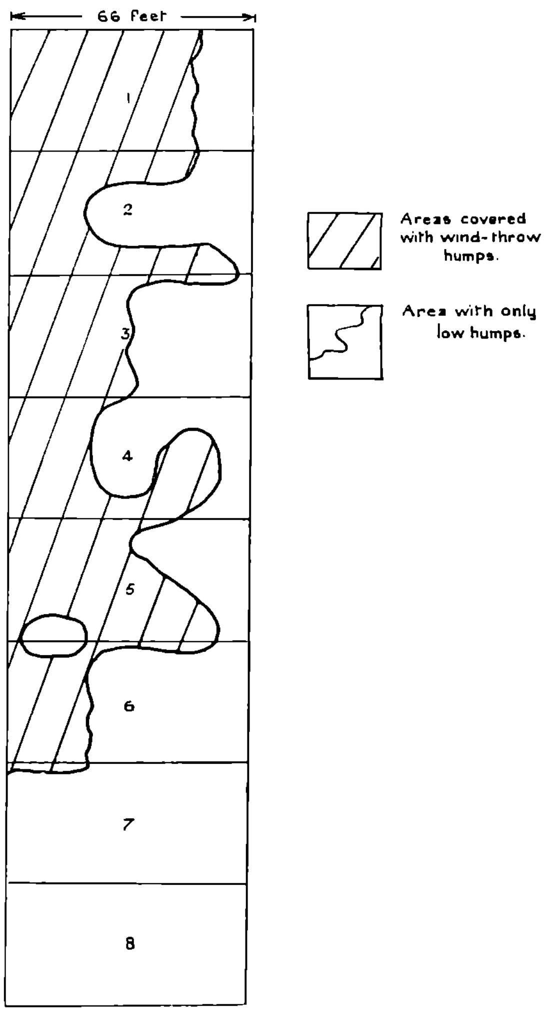


FIG. 3

Plan showing the area in transect plot Tlell II within which the larger wind-throw humps occurred. The distribution of these determined the distribution of the larger Sitka spruce. The rooted soil was purely organic in sub-plot 8, nearly all of sub-plot 7 and part of sub-plot 6.

4. The first transect examined was half a chain wide and five chains long ; it was divided into five plots, each a chain in length. The second transect was a chain wide and four chains long : it was divided into eight plots, each half a chain in length. Thirteen plots were thus measured, each half a square chain in area. The three first plots in the first transect were on the higher part, the fifth on the lower wet part, while the fourth occupied a transitional position, but was mainly in the higher. Similarly, in the second transect, the first five half-chains were in the higher part, the sixth was transitional and mainly wet, while the two last were in the wetter part. The data relating to these transects are given in Tables 10 and 11 ; while in Figure 3 a plan is given of the second transect, showing the area which was covered with relatively large humps, and the area in which the ground was flat or had only very low humps. The mean level of the ground in this transect is shown in Fig. 2. The levels for the first transect were similar : but the distribution of humps was not so one-sided.

5. The chief interest in this work lies in the comparison of the growth of the tree species. A simple comparison of the drier part of the transects, which had " hump and hollow " configuration, with the wetter (Table 12) shows that on the former the larger Sitka spruce, which were the stand dominants, are always bigger in diameter and usually appreciably greater in height than are the larger of the western hemlock. On the lower-lying ground, however, there is no significant difference between these species, either in height or diameter. This comparison is made more interestingly in Figure 4, in which the mean height and diameter of spruce in the half-chains is compared with those of hemlock. The curves show that, not only does hemlock fail to increase in diameter, or even in height, at the same rate as spruce, which is not very surprising ; but that the more vigorous growth of spruce is accompanied by a falling-off in size of the hemlock. The curves seem to reflect the effect of the relative site tolerance of these two species on their mutual competitive power. In the better positions spruce is the stronger grower of the two species, and it holds the hemlock in check to some extent. As the quality of the site for growth falls, however, hemlock becomes equal in competitive vigour, and there is every reason to believe that a point comes in which it possesses the advantage.

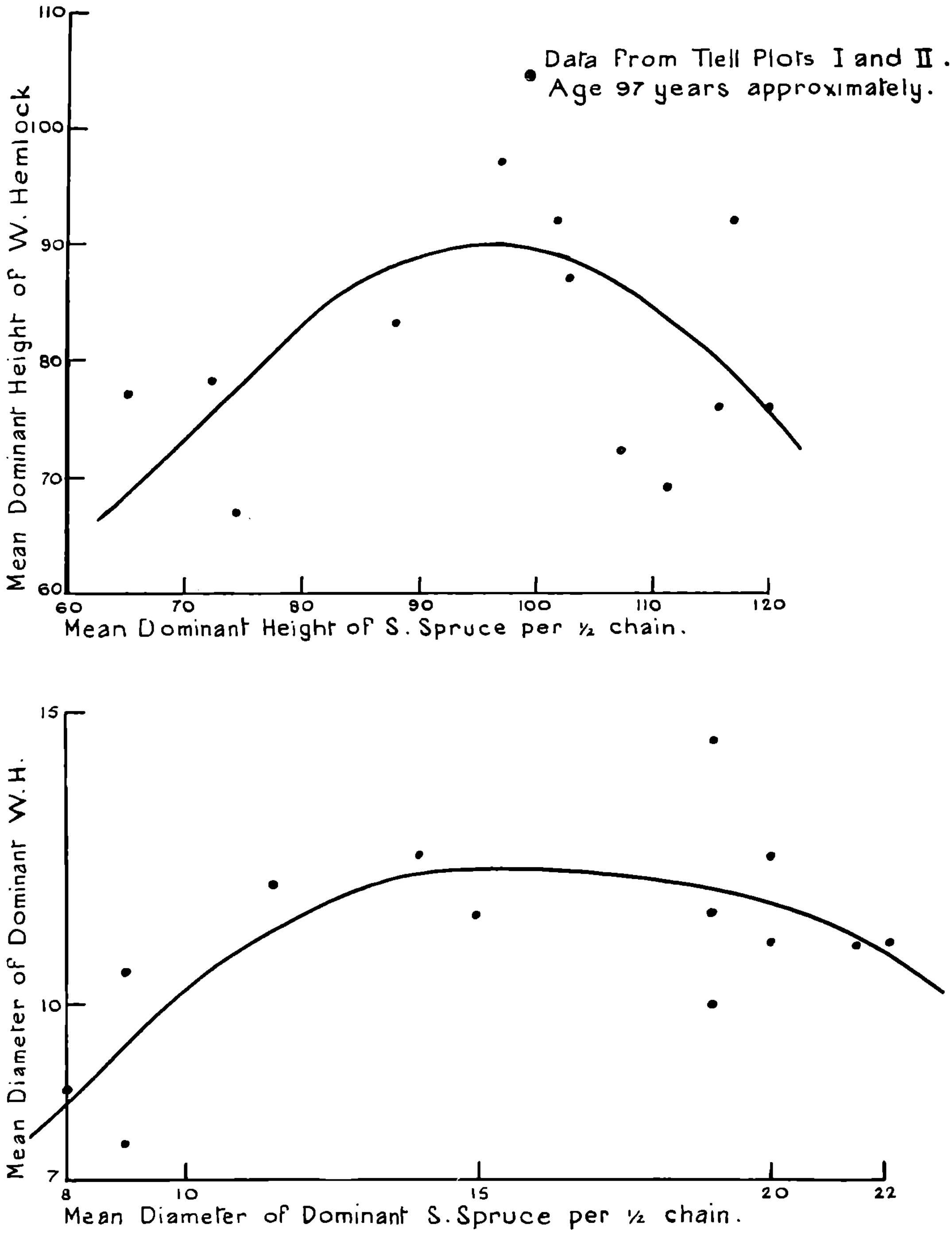


FIG. 4

Comparison, by sub-plots of mean height and diameter growth of Sitka spruce and western hemlock when grown in intimate mixture. The term "dominant" here means the taller class of tree for each species considered separately.

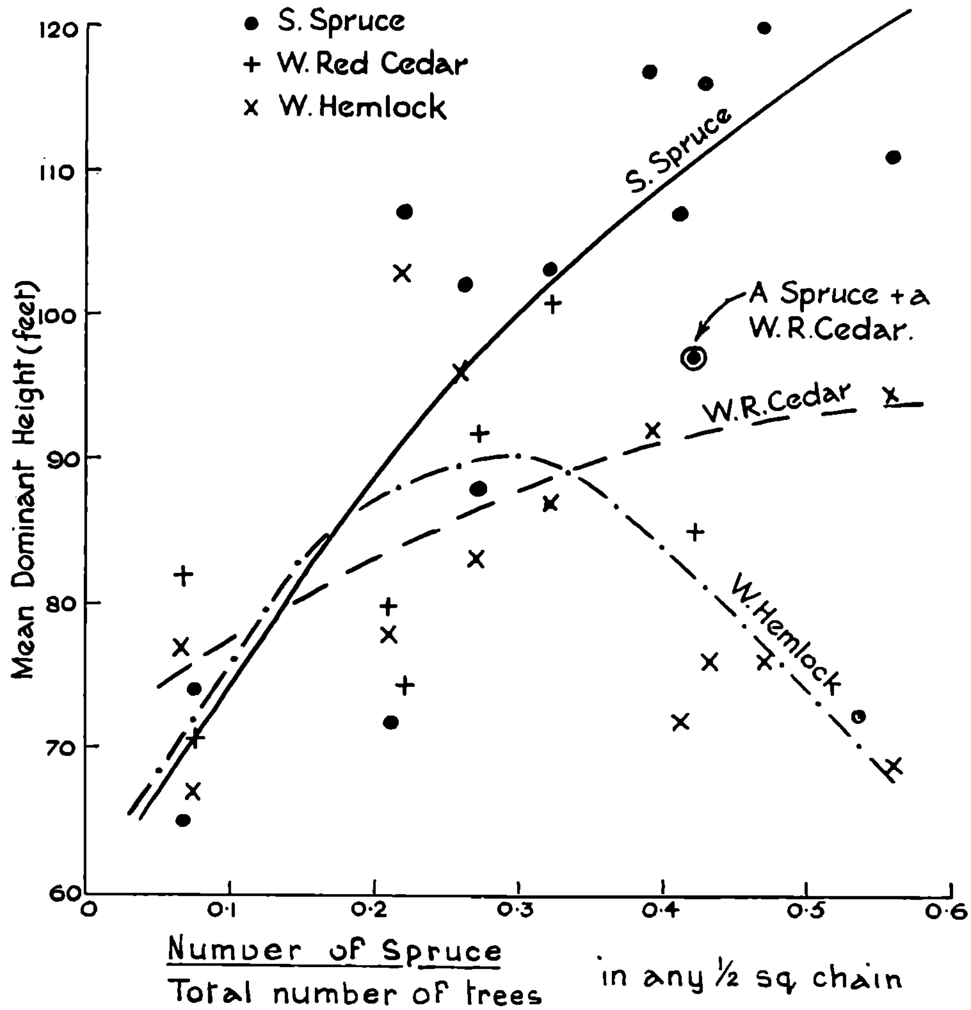


FIG. 5

Comparison by sub-plots, of mean dominant height with the proportion by number of Sitka spruce for Plots Tlell I and II.

6. This is illustrated further by a comparison of height, diameter and basal area, for the three principal species, with the proportion of spruce by number, in the total number of trees in any half-chain (Figures 5, 6 and 7). The curves for cedar can be no more than suggestive, because of the poor representation of this species on the better ground. The influence of an increasing proportion of successful spruce dominants, on the growth of hemlock in height and diameter, is shown plainly. The indication is that, when the quality of the site has risen beyond a certain point, spruce is able to use it more efficiently in terms of growth than is hemlock. On the other hand the very scanty data suggest that cedar is much less affected in this way, and that as conditions become poor it becomes relatively more vigorous in growth than either of the other species. If what has been said above about the relative site tolerance of these species is true, this is, of course, what should happen. The importance of spruce in determining total basal area, when the ratio of its occurrence is above 0.3, is obvious (Fig. 7), as also is that of hemlock, and especially of cedar, when the ratio of occurrence of spruce is low. This is, of course, merely a reflection of the fact that a higher ratio means that the site is relatively favourable to spruce, and a lower ratio that it is similarly adverse. These curves, thus, reflect the relative competitive power of these species in relation to their site tolerance, and suggest to some extent their relative biological importance in the forest.

7. This small study plainly should not be taken out of its immediate context in the forest. It does suggest that the relative productive power of these

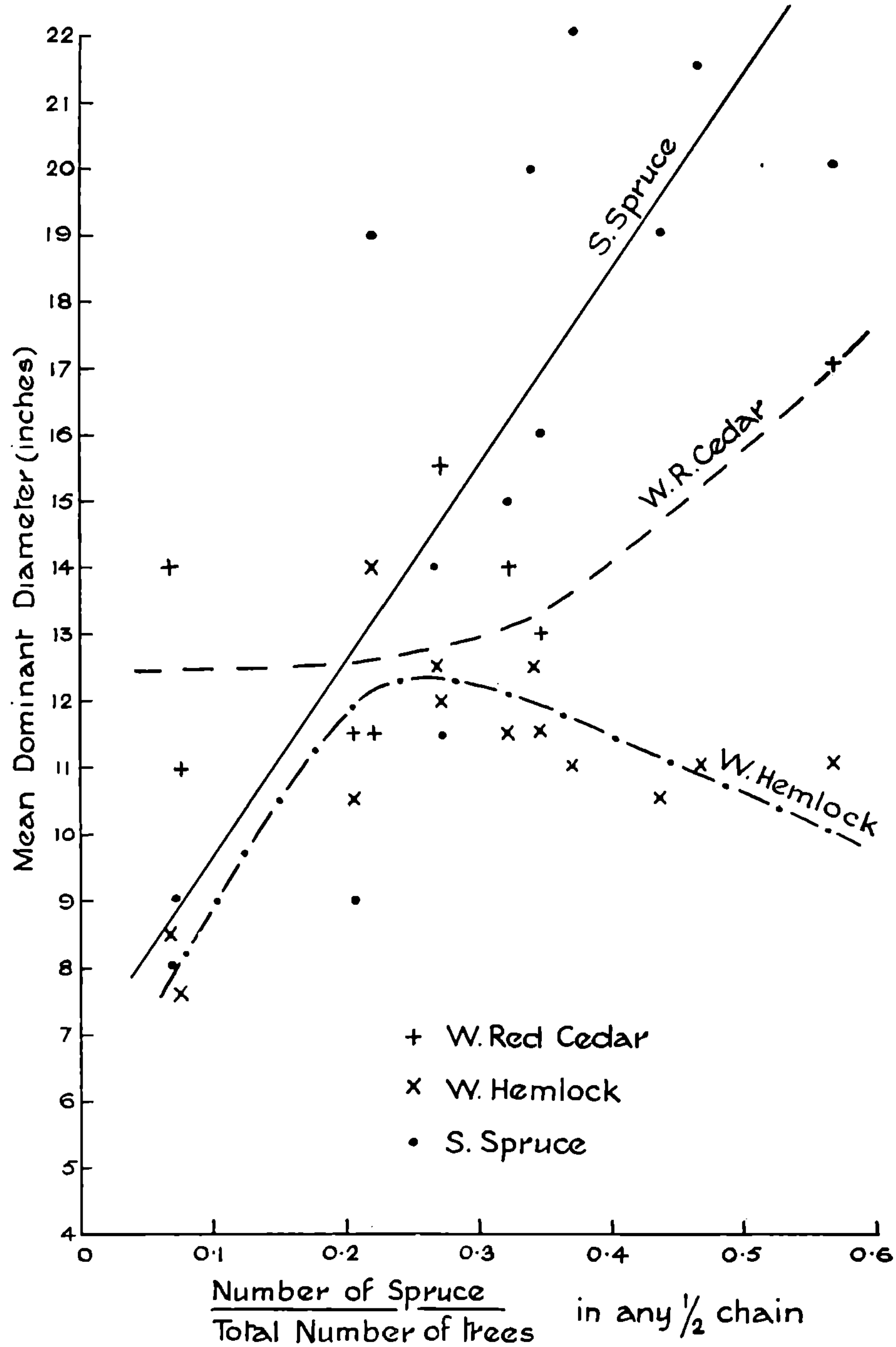


Fig. 6

Comparison by sub-plots, of mean diameter breast height of dominants with the proportion, by number, of Sitka spruce for Plots Tlell I and II.

three species, and especially of spruce and hemlock, might well be worth study in relation to their growth and competitive power as determined by site tolerance. Its main purpose here is to give some slight demonstration by measurement of what has been described above for a much wider variety of sites from general observation. What is suggested is that when the Site Index drops down to its lower limits for profitable economic utilisation, say between 80 and 100 feet as representing mean growth in total height in 100 years, Sitka spruce ceases to have any great advantage in volume production as compared with hemlock and cedar. The fact that these species appear as more tolerant of these poorer sites than is spruce is an added reason for their growth for, this being so, they are less likely to suffer loss from disease. This is perhaps reflected in the number of recently dead dominants standing in the two transects surveyed. The distribution of these is shown in Tables 10 and 11. It can be seen that there were fifteen dead large spruce in Transect I and five in Transect II ; but only one dead hemlock in each, and no dead cedar. Most of these spruce occurred either on the higher humps, where it may be suggested they died owing to excessive competition within a very limited volume of soil ; or at the beginning of the wetter area, i.e., in the lower part of the fourth half-chain in Transect I and in the sixth half-chain in Transect II. In the latter conditions especially, it is to be noted that it was the hemlock which survived and the spruce which died : this clearly seems to be consistent with the general trend in site tolerance for these species.

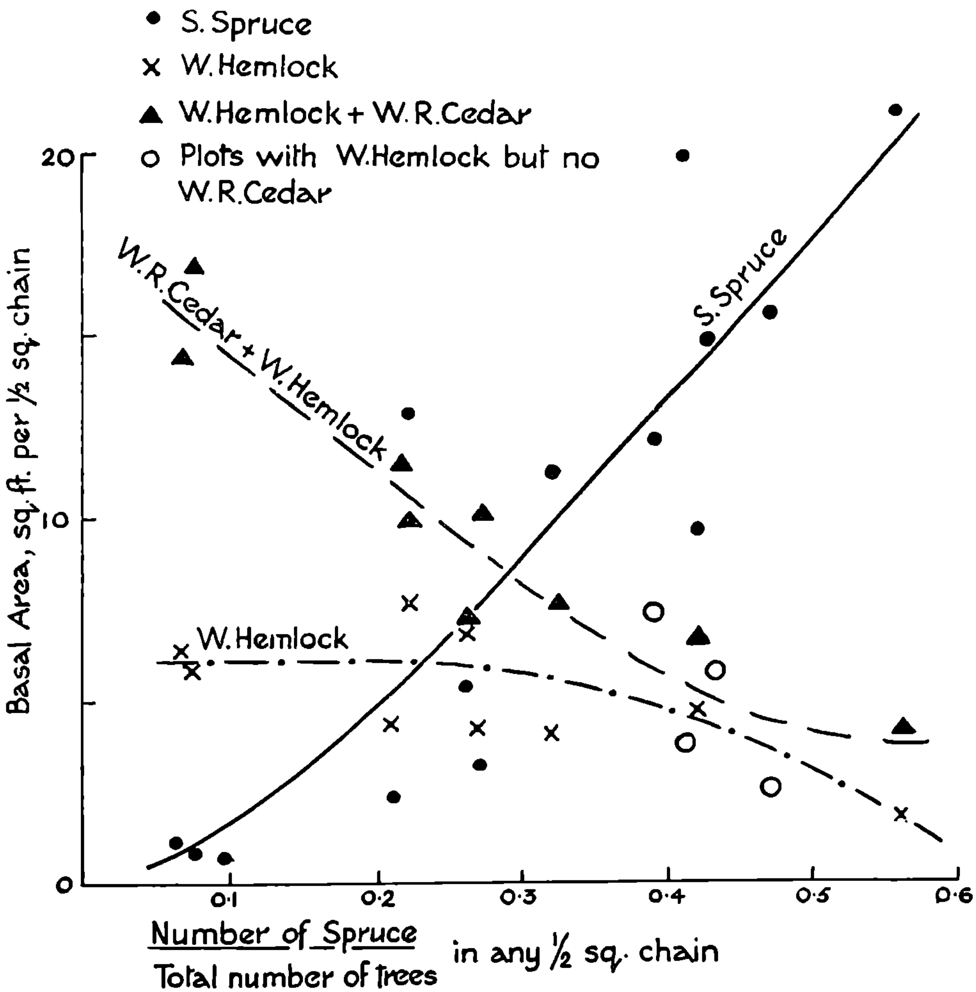


FIG. 7

Comparison by sub-plots, of basal area of the different species with proportion by number of Sitka spruce for Plots Tlell I and II.

General Table for Tlell, Transect I

TABLE 10

Chain No.	Species of tree	No. of trees	Mean Diameter (in.)	Mean Dominant		Basal Area per ½ chain (sq. feet)	No. of recently dead dominants	Ratio No. Spruce: Total No.
				Height (ft.)	Diameter (in.)			
1	S.Sp.	7	18.7	120	21.5	15.4	2	.47
	W.H.	8	6.9	76	11.0	2.5	—	
	W.R.C.	—	—	—	—	—	—	
2	S.Sp.	9	15.4	117	20.0	12.1	2	.39
	W.H.	14	9.0	92	12.5	7.4	—	
	W.R.C.	—	—	—	—	—	—	
3	S.Sp.	5	13.4	102	14.0	5.3	4	.26
	W.H.	13	9.3	96	12.5	6.9	1	
	W.R.C.	1	11.0	—	—	0.67	—	
4	S.Sp.	5	20.6	107	19.0	12.9	5	.22
	W.H.	14	9.2	103	14.0	7.7	—	
	W.R.C.	4	9.75	74	11.5	2.3	—	
	S.Sp.	4	6.25	65	8.0	1.0	2	
5	W.H.	38	7.64	77	8.5	6.4	—	.067
	W.R.C.	17	8.0	82	14.0	8.1	—	
	L.P.P.	1	12.0	78	12.0	0.79	—	

General Table for Tlell, Transect II

TABLE 11

1	S.Sp.	11	16.8	107	22.0	19.9	—	.41
	W.H.	16	7.8	72	11.0	3.8	—	
	W.R.C.	—	—	—	—	—	—	
2	S.Sp.	13	10.8	116	19.0	14.8	—	.43
	W.H.	17	8.2	76	10.0	5.8	—	
	W.R.C.	—	—	—	—	—	—	
3	S.Sp.	11	11.4	97	16.0	9.7	1	.42
	W.H.	13	7.5	97	11.5	4.7	—	
	W.R.C.	2	13.5	85	13.0	2.1	—	
4	S.Sp.	13	16.3	111	20.0	21.0	—	.56
	W.H.	7	6.6	69	11.0	1.8	—	
	W.R.C.	3	10.3	94	17.0	2.4	—	
5	S.Sp.	9	12.7	103	15.0	11.3	—	.32
	W.H.	9	7.6	87	11.5	4.1	—	
	W.R.C.	10	7.4	101	14.0	3.6	—	
6	S.Sp.	7	9.0	88	11.5	3.3	3	.27
	W.H.	10	7.7	83	12.0	4.3	1	
	W.R.C.	9	7.0	92	15.5	5.8	—	
7	S.Sp.	7	7.4	72	9.0	2.4	1	.21
	W.H.	16	5.6	78	10.5	4.4	—	
	W.R.C.	11	9.8	80	11.5	7.1	—	
8	S.Sp.	4	5.5	74	9.0	0.97	—	.075
	W.H.	38	4.9	67	7.6	6.0	—	
	W.R.C.	14	10.4	71	11.0	10.9	—	

Note: S.Sp. = Sitka spruce ; W.H. = western hemlock ; W.R.C. = wesern red cedar.

TABLE 12

Comparison of Heights and Diameters, Tlell I and II

	Higher drained part				Lower wet part			
	Dominant Heights (ft.)		Dom. diameter (in.)		Dom. Heights (ft.)		Dom. Diameter (in.)	
Transect	S. Spruce	W. Hemlock	S. Spruce	W. Hemlock	S. Spruce	W. Hemlock	S. Spruce	W. Hemlock
I	120	76	21.5	11.0	65	77	8.0	8.5
	117	92	20.0	12.5				
	102	96	14.0	12.5				
	107	103	19.0	14.0				
II	107	72	22.0	11.0	88	83	11.5	12.0
	116	76	19.0	10.0	72	78	9.0	10.5
	97	97	16.0	11.5	74	67	9.0	7.6
	111	69	20.0	11.0				
	103	87	15.0	11.5				

Development of Canopy in Relation to Site Conditions

1. It is apparent, on walking through the forest in the region of poor soils which prevails so largely between Port Clements and Tlell, that old growth forest tends always to be more or less open, with an undergrowth of salal bush or other appropriate vegetation. On the other hand if, on such soils, any of the areas which have been burned within the last one hundred years are encountered, a closed stand seems always to occur, the ground being free from undergrowth except possibly for mosses and liverworts. It is quite obvious that any densely regenerated stand must thin itself as the trees grow larger, and if an area of forest is walked through in which a series of fires at different times has resulted in the regeneration of stands of different ages, this process of natural thinning can be demonstrated very clearly. One tends, however, to expect that such thinning will leave a closed stand, and there is no doubt that on any sufficiently productive soil this is true, at least for a long time. There are many square miles of forest to demonstrate this (e.g., see Plates 10, 22 and 20).

2. Examples of three profiles taken from sites around Masset Sound on which open forest occurred are given in Table 13. One of them (Plot 11) is illustrated in Plate 30. These three examples are all taken from Cedar-Hemlock-Salal forest. Plot 11 is the most fertile, as judged by height growth of dominants, and Plot 20C the least fertile. Unifying characteristics are the shallowness in rooting depth determined by a layer of hard compressed material within a few inches of the surface of the mineral soil, and their low base status. It will be seen that there is no essential difference between these profiles and those given for fire regenerated stands in Table 8, all of which are of low base status and of shallow rooting depth. It would appear that the principal factors which determine the eventual development on such soils as these, of a more or less open forest from one which after regeneration developed a closed canopy, are firstly the low nutrient status per unit volume of soil ; and secondly, the very restricted rooting depth. These factors combine to produce several effects. A tree, if it remains at all healthy, must of its essential nature continue to grow in size. This means that its root system will continue to occupy a continually larger space, or disease in some form or other will appear. The only appreciable means of increasing rooting space on these shallow soils is by horizontal spread. It follows necessarily, therefore, that proportionately to size, a greater superficial area will be needed for each surviving dominant tree if it is to maintain an adequate degree of health for survival, than would be the case on deeper soils which otherwise were of the same general character. The opening of the canopy owing to root competition, however, admits sufficient light to permit of the growth of ground vegetation. This takes the form of salal bush, with the usually accompanying oval-leaved bilberry and false azalea, on sites such as the three under discussion. The salal bush is, of course, essentially part of the forest canopy, and takes its share of the limited soil supply, thus ensuring still further the need for a more or less open canopy of dominant trees.

3. The development just suggested is to be regarded as merely one aspect of the development of the complex canopy in a forest, its characteristics being determined by particular conditions of restriction in soil supply. If this is so, then one may expect to find similar types of development of canopy on sites in which soil supply is restricted, and it appears that this is so also. An example is provided by forest which occurs on the steep sides and the top of a minor point of the side of Mount Garland to the east of Kitsumkalum Lake, between elevations of approximately 3,000 and 3,500 feet. The dominants consist of mountain hemlock (*Tsuga mertensiana*), which are widely spaced so that there is no closed canopy of dominants. Beneath is a dense thicket which consists principally of oval-leaved bilberry (*Vaccinium ovalifolium*) and false azalea (*Menziesia ferruginea*). This forest stood on shallow soil either on a rocky hill top or a steeply sloping mountain side. Another example seems clearly to be provided by some of the riverside alluvial flats which are subject to flooding and have a high water-table, or develop impedance in drainage within a short distance of the soil surface. These sometimes bear a rather open forest which may consist of trees of great size, and which usually are Sitka spruce. The lower strata of the complex canopy are poorly represented, though some smaller trees and shrubs occur and there is a carpet of grasses, herbs and mosses. The soil supply for the needs of the trees is much greater on sites of this type than in those illustrated by the examples already given, but there is, nevertheless, a restriction in space considering the size of the trees, and this operates to produce and maintain the relatively open type of forest. A similar effect may be produced on soils which permit of comparatively deep rooting, such as the freely draining sandy soil in Plot 18 (Table 3), on an alluvial flat by the Mamin River. The relatively coarse texture of the soil and its freely draining nature provide the supply restricting factors in this case. Plate 35 illustrates this site : it may be compared with Plate 10 which shows equally old closed forest growing on a heavy loam on an alluvial bench by the Yakoun River (Plot 4). The difference in density of forest is obvious : Plot 4 bears the larger spruce (Tables 3 and 23).

4. Some examples to illustrate the manner in which a closed canopy becomes open can be given from forest which may be considered suitable for management as in a closed canopy. Plot 17 (Table 14) was situated at sea level, on a moderately steep but variable slope, on the west side of Juskatla Inlet. The soil consisted of a light loam which overlay fissured rock : it varied in depth from not more than 12 inches to at least 36 inches. The stand consisted of Sitka spruce with western hemlock ; it was regenerated after fire and was about 87 years of age. Plate 36 shows a rather dense part where the rooting depth was about 20 to 24 inches : a stand of equal density, but with trees of larger diameter, occurred where the rooting depth was deeper. Groups of very thin crowned or dying Sitka spruce or of red alder, occurred in places. The crowns of neither species were overshadowed ; but in all cases these groups occurred where the shallower rooting depths were found ; the data in Table 14 illustrate this. The drainage on this site is free topographically and vertically and, although it is at a low elevation above sea level, the site is so situated that no water is received by drainage from above. Plate 37 shows one of the groups of dying alder : the slightly stag-headed crown of a large dominant alder can be seen in the background also. It seems to be quite plain that this local dying in groups is caused basically by local shortage in soil supply.

5. A very similar case is illustrated by Plate 38 taken on the edge of Plot 23 and in or near Experimental Plot 414. There is a gap in the canopy on the edge of which is seen a small dead Sitka spruce, a large dominant red alder with a thin and dying crown, and a dominant Sitka spruce, the crown of which shows the dense clustering of twigs and foliage round the branches, which is the first sign, often, of appreciable loss in vigour of growth. This is an area in which rooting depth is fairly shallow (Table 14), except where the numerous wind-throw humps provide a greater depth of rootable soil. The root-restricting horizon is provided by extremely hard compressed glacial drift. A very similar case is provided by the spruce-hemlock stand on the borders of the Tlell River (Expt. Plot 417 and Plot Tlell I, Fig. 1), where there is, similarly, a shallow rooting depth increased locally through the occurrence of wind-throw humps. The dying of dominants, mostly spruce (Table 10) is here associated with either overcrowding on humps, or excessive density on shallow soil. Both these areas fall into medium Site Index classes—E.P. 414, S.I. 140 ; E.P. 417, S.I. 120. The main factor restricting height growth is restriction in rooting volume, considering the local conditions of supply to the site. The area on which E.P. 415 (Plot 22, Site Index 120) is situated provides further examples in this class of forest, but on a different soil type. Plate 39 shows a dead Sitka spruce in a gap in this plot ; it will be noted that the crowns of the dominants which surround the gap are thin at the top and have begun to die back slightly. This area has, ordinarily, a moderately shallow rooting depth with underlying root restricting material composed of very stony gravel which is freely draining (Table 14).

6. This evidence suggests that, whenever the supply from the soil of the needs of the forest is

appreciably restricted, as in all the cases cited above, death of trees with the development of an open high canopy is to be expected at the appropriate time. The consequences of this development depend on local soil conditions. In Plot 22 (E.P. 415) there is an understorey of hemlock ; in the neighbouring Plot 23 (E.P. 414) the gaps are largely filled with grass and herbs ; in Plot Tl.I there is a canopy of hemlock co-dominants sufficiently dense to prevent any appreciable ground cover developing up to the present. It would appear that on the very shallowly rooted sites such as are exemplified by Plots 19 and 24 (Table 8), the main consequence of the opening of the high canopy is invasion by salal ; and that once a dense low canopy of this and its associated shrubs has been formed, there is but little chance of reforming a high canopy until after the next fire has swept through the area. It would appear that there is a case here for controlled burning in aid of regeneration, if that could be successfully accomplished.

7. One matter of some importance arises in connection with this. It would appear that the efficient length of rotation, as determined by age, or size, of tree, will largely depend on the age, or size, up to which it is possible efficiently to maintain a reasonably complete high canopy. The length of time taken to reach this point in stand development will plainly be influenced not merely by volume of rooting space, but also by the conditions for root supply per unit volume within this space. It would appear, however, generally speaking, that the more shallow is the mean rooting depth the sooner, other things being equal, is the dominant canopy likely to become open. The operating factors are an undue restriction in supply in the soil, considering the demands of the high canopy, and the development of root disease, even in the surviving dominants, because of the pathogenic action of the conditions which cause the supply restriction. The opening of a high canopy under these conditions is ordinarily marked by a general reduction in growth vigour in the surviving trees, and not by an increase in vigour such as is to be expected as the result of a thinning made during the developmental period ; that is the youth of the dominants which form any high canopy. The great difficulty in discussing this matter is the lack of data and plainly there is great need for research in this connection.

8. Some comment may be advisable on the growth of salal in relation to canopy density, in view of references to its occurrence in poor forest. It seems to be quite plain that this plant is unable to withstand the shade of a dense canopy, for it seems consistently to be absent under dense stands regenerated after fire, even if it occurs abundantly immediately outside the area burned. It will exist and grow well under a complete canopy, providing this has become thin. Plate 40 provides an example of this. The stand is Sitka spruce of about 80 years of age and 80 feet mean dominant height ; the soil is a fairly moist sand, wind-blown in origin ; the rooting depth of the spruce is about 24 inches and the salal is about 4 to 5 feet in height. An equally dense growth of salal, of very nearly the same height, was seen under Douglas fir near Quilcene, in the Olympic Mountains ; it was accompanied by some sword fern (*Polystichum munitum*) and Oregon grape (*Mahonia nervosa*). The Douglas fir were about 80 years of age and probably in a Site Index class of medium quality : there were evident signs that the canopy was beginning to become thin. It is quite possible, of course, that in the latitudes of the Olympic Mountains salal withstands greater shade than in those of the Queen Charlotte Islands. A moist soil, with some movement of water, but not necessarily a deep soil, is needed apparently for strong growth of salal, and it would appear that poor growth is a sign either of bad drainage, or of, at least, a periodic deficiency in water. It seemed to the writer that it may legitimately be doubted whether any site may be called dry on which salal grows reasonably well. It seemed that salal, growing at least moderately well, is indicative of a site in which, probably, nitrification is poor, the base status is low, but in which there is at least a few inches of moist well-drained soil. It is these few inches which enable a Closed Forest to regenerate after fire, as in Plot 19, or Plot 24 ; but it is also this restriction in rooting space within a poor soil (Table 8) that determines that, in its mature form, the forest shall have a more or less open high canopy with a low shrubby undergrowth provided mainly by salal.

TABLE 13

Soil Profile and Rooting Details in Forest with Salal Dominant in Ground Vegetation

	Profiles in open mature Cedar-Hemlock-Salal Forest									Profile in 80 year old Sitka Spruce Tlell III		
	Plot 11			Profile 19a			Profile 20c					
	Horizon			Horizon			Horizon			Horizon		
	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting
Profile Details L+F	o.m.	1	i	o.m.	5	i	o.m.	Tr.	—	o.m.	2	i
H1	o.m.	3½	i	—	—	—	o.m.	3	v.l.	o.m.	3½	i
H2	o.m.	3	loc.f.	—	—	—	—	—	—	—	—	—
A1	—	—	—	—	—	—	L+o.m.	1	ab.	—	—	—
A2	—	—	—	sC	10	f	si.L.	3	v.s. or nil	S	½	f
B2	—	—	—	Ironpan	½	nil	—	—	—	S	13	f
B3	—	—	—	sC+Gr	9½	nil	—	—	—	(C) S	15+	S to nil
G1	L+Gr	3	loc.f. dead	sC+Gr	20+	nil	sC+Gr	8+	nil	—	—	—
G2	C+Sa	Unknown	nil	—	—	—	—	—	—	—	—	—
Dominant Ground Vegetation	*G. shallon* (2-5 feet) *V. ovalifolium*			*G. shallon* (dom.) (2-3 feet)			*G. shallon* (5-6 feet) *M. ferruginea* *V. ovalifolium*			*G. shallon* (4-6 feet)		
Main Tree Species ..	Cedar, Spruce, Hemlock			Hemlock, Cedar			Sparse Cedar, Scrub Hemlock and Spruce			Spruce		
Average Height of Dominants and Co-dominants ft.	Cedar—135 Spruce—136			Not measured Site Index about 80 or 90			Not measured Site Index below 80			Spruce—80		

Symbols :
Soil : o.m.=organic matter. C=clay L=loam. Gr=Gravel. S=sand. a=light.. Tr=Trace. S=Sandy. si=silty. c=clayey.
Roots : i=intense. f=frequent. ab=abundant. s=Sparse. v=very.

TABLE 14

Soil Profile and Rooting Details in Forest in which the High Canopy has begun to open out

Profile	Plot 17						Plot 23††						Plot 22		
	Shallower Soil			Deeper Soil			Hollow			Hump					
	Horizon			Horizon			Horizon			Horizon			Horizon		
	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting	Texture	Depth (in.)	Rooting
L+F ..	o.m.	Tr.	—	o.m.	¾	s	o.m.	¾	s	o.m.	½	s	o.m.	½	ab.
H ..	o.m.	2	i	o.m.	½	ab.	o.m.	3	ab-f	—	—	—	o.m.	4x	v.ab.
A ..	—	—	—	La.	1	m.ab.	L	5½	vi	—	—	—	(A2)Gr.†	1	s
B ..	La stoney	12	ab-i	La	17	loc. ab. loc.s.	L+Gr	14	s	sL-cL	56*	m.ab.	Gr†	5	s
C ..	Fissured rock	Unknown	f. in fissures	Fissured rock	Unknown	f. in fissures	L+Gr compressed	10+	nil.	L+Gr. cemented	Unknown	nil.	Gr§	42‡	nil.
Main Tree Species	Spruce, Hemlock, Alder.						Hemlock, Spruce, Alder.						Hemlock, Spruce.		
Average Heights of Dominants and Co-dominants (ft.)	Spruce and Hemlock—128						Hemlock—137 Spruce—134 Alder—119						Hemlock—151 Spruce—156		
Age (years ..	90						90						150		

†† A plot showing "wind-throw" relief, on surface of soil.

* Includes 4 inches of buried H+A2, 25 inches down.

† Compressed.
§ Loose, probably B horizon material.
x Much deeper in hollows.
‡ Roots penetrate this in places.

For Symbols—see Table 13.

CHAPTER 5

The Effect of Increasing Dryness of Site on the Proportion of Sitka Spruce in the Forest. Illustrations from the Region of Terrace

1. It has been shown above that, in the relatively cool, humid climate of Graham Island, Sitka spruce acts as the least site-tolerant of the principal species of conifer. None of the sites examined could, however, be considered as dry in any real sense, and it was not until work was begun in the region of Terrace, where the period of relatively low rainfall during summer is longer than in Graham Island and the summer temperatures are higher, though the latitude is slightly more northerly, that there was

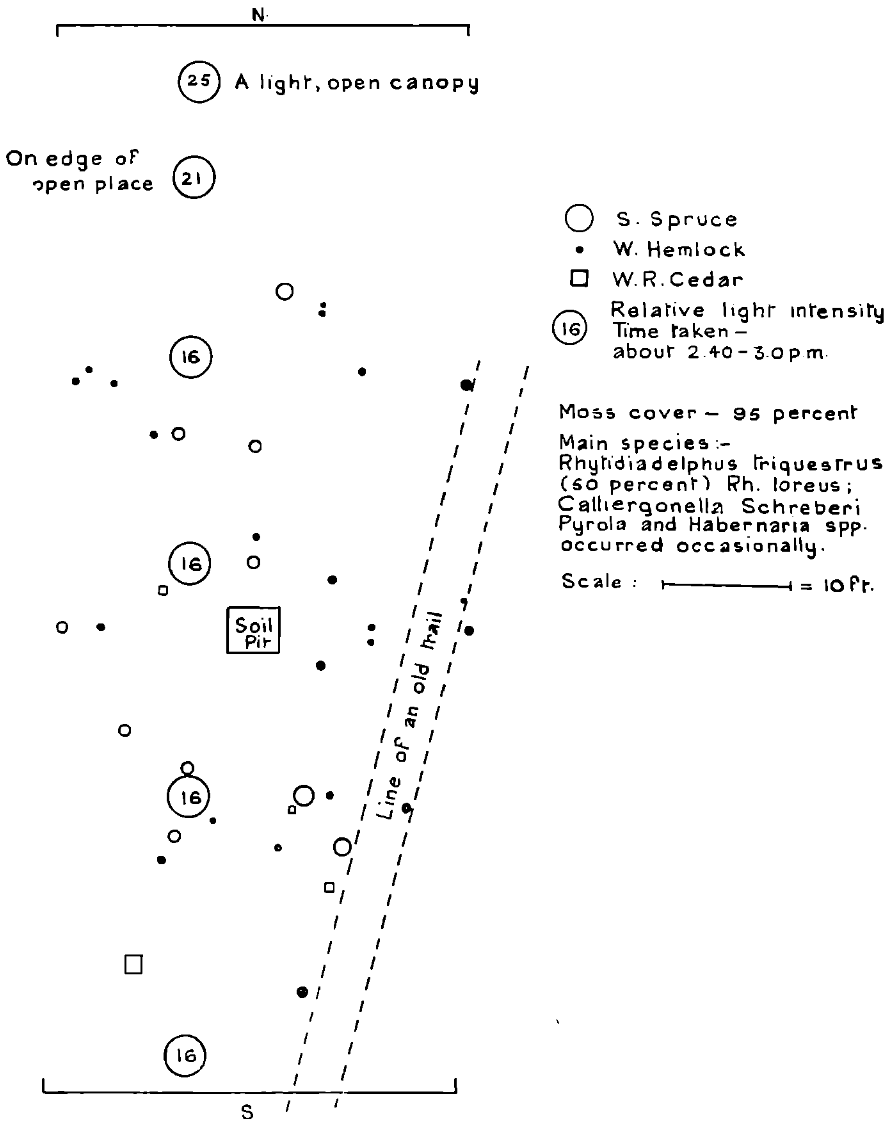


FIG. 8
Plot K4, situated at the foot of a long slope, in a water-receiving situation. The soil was a gley podsol with about 7 inches of gravelly sand over clay. The roots occurred mainly within the top 12 inches, including three inches of humus.

any opportunity of observing the change in the proportion of Sitka spruce in the forest as one moved from moist to relatively dry sites.

2. **Observations near Kitsumkalum Park.** This park is a more or less flat area at the south-eastern end of Kitsumkalum Lake (Plate 5) and about twenty miles north of Terrace. From its eastern boundary the ground rises in a series of benches which appear to be the remains of beaches left raised by the fall of the lake from one-time higher levels. At one point this slope is occupied by a mixed forest which is even-aged and of about 120 years : it appears to have been regenerated after fire. The species of tree occurring are Sitka spruce, western red cedar, western hemlock and lodgepole pine. The lower edge of this slope falls into the flood channels of Goat Creek, which flows across the southern edge of the Park into Kitsumkalum Lake : the soil here is derived from a grey clay, presumably a lake deposit, which is covered with a thin layer of gravel. The forest on this consists of spruce, hemlock and cedar, with a very few pine. Proceeding up the slope the soil changes to sand and then to gravel, eventually becoming very stony. The forest dominants now are pine, sometimes with hemlock as co-dominants, but sometimes only as an understorey. Some cedar occurs and a little very poor Sitka spruce. Three plots were examined in this area : particulars with regard to soil profile, rooting and ground vegetation are given in Table 15 and, with regard to diameter classes, in Table 16.

3. Tables 15 and 16 show that the productivity of these situations is related to soil conditions. Plot K5, with three feet of sand overlying clay, plainly bears the greatest volume of utilisable timber. The shallow soil overlying clay in Plot K4, and the deeper, but extremely stony coarse sand in Plot K6, are both markedly inferior sites. It is to be noted, however, that species composition is related, not to site productivity, but apparently to the moisture conditions of the soil surface. Thus the mosses present indicate K4 as the area with the more moist soil surface, and this is to be expected from its soil profile, which shows clay lying very near the surface ; also it is the lowest-lying of the three plots and so that which would receive most moisture by lateral drainage. This is the plot in which Sitka spruce form an important part of the dominant canopy. No spruce could, however, be found in K5 with its comparatively dense and consistent canopy, in which pines form the chief dominants and hemlock and cedar the co-dominants and subdominants. A very few spruce occurred in the area in which K6 was situated. These were trees of not more than 3 inches diameter, though of the same age as the stand dominants. This is the site which would appear to have the least satisfactory water supply within the upper layers of soil, and this condition is reflected in the constitution of the stand. It will be seen from Table 16 that this plot includes a considerable number of small shrub-like hemlock ; these small trees are of appreciable age, some, at least, being as old as the stand dominants. The stocking of the three areas is illustrated by Figures 8, 9 and 10 : the position of the small hemlock is indicated in Fig. 10. It will be seen that they tend to occur between groups of dominants, and the indication is that the establishment and growth of hemlock on this site beneath established pine dominants is at least very difficult. The controlling factor plainly is shortage of water ; the light readings given in the Fig. 10 indicate that it is very unlikely to be shortage of illumination. The crown condition of pine dominants in K6 was much poorer than that of those in K5 ; some had died recently and it cannot be doubted that others will die within a few years. This is to be observed in places where there is no dense hemlock understorey, and in itself indicates the supply difficulties of the site.

4. There is some interest in the height growth of the trees on these sites. There were no pines actually situated in K4, but one or two nearby on the same type of soil indicated that height growth of this species would have been at least as good as on K5. It is clear that the pines have been least affected in height growth by the changes in soil conditions. The hemlock, on the other hand, show by their height growth that they are adversely affected by conditions in K6, even if no note is taken of the shrubby understorey. Spruce only appears in appreciable numbers in K4 ; had it become established it would probably have made an equally tall tree on K5. As indicated it has survived sparsely in the K6 area as a small, scrubby, very slowly growing tree. The height growths in the various plots are illustrated by the curves in Fig. 11.

5. The evidence of these plots suggests two things of some importance. The one is that the successful establishment of spruce regeneration is governed largely by the moisture conditions of the soil surface, and that where these are adequately good, it, together with cedar and hemlock, will compete with and prevent the development of pine. The corollary of this is that, where the surface horizons have little water retentive power, the regeneration of pine, and then hemlock, is favoured strongly ; spruce, and to a less extent cedar, will tend to fail, even if their seedlings actually appear. The other is that at Kitsumkalum, as in Graham Island, pine appears as the most site-tolerant of the species concerned, though, in this case, in dry situations. Hemlock appears next in tolerance ; but is unable to cope very successfully with so freely-draining, stony and

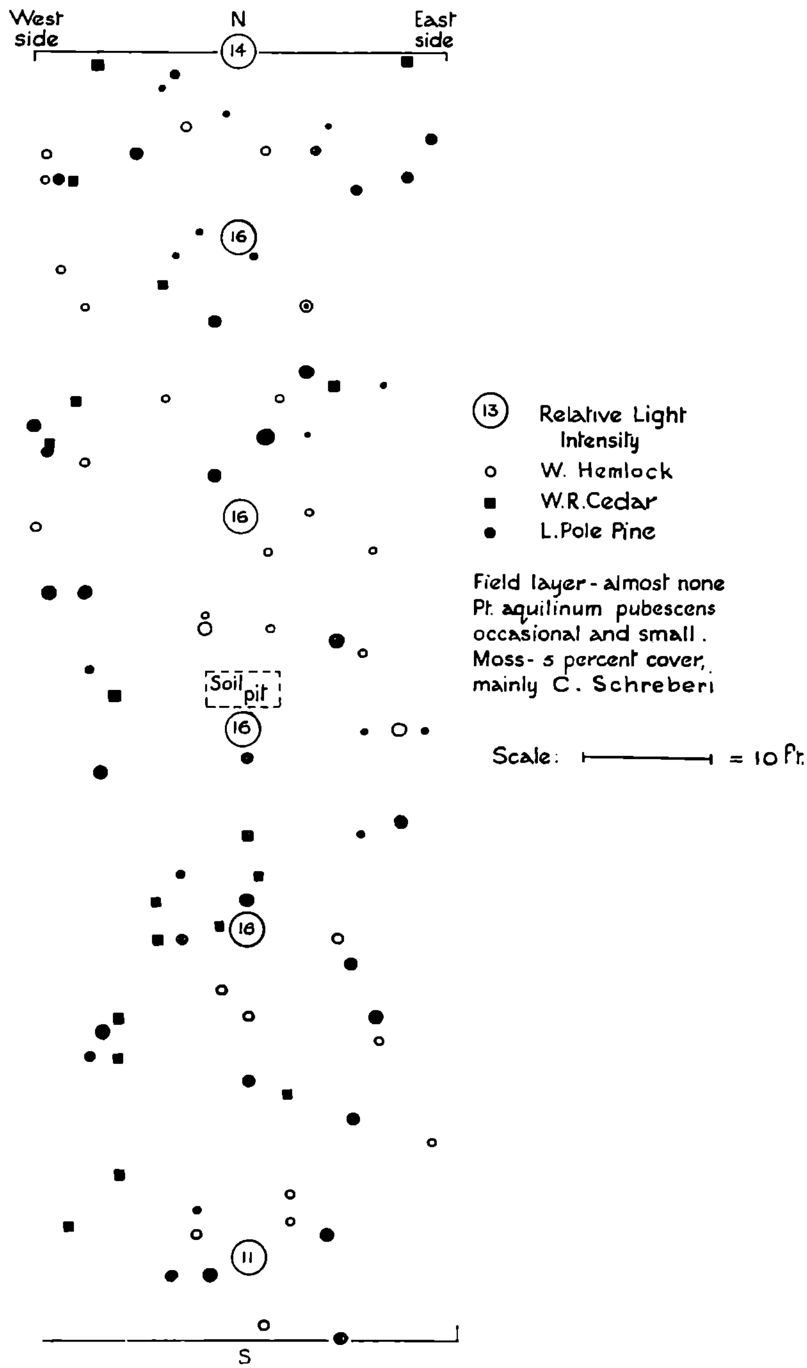


FIG. 9

Plot K5, situated a few feet higher than K4. The soil was a stoneless podsolized sand overlying clay at 37 inches depth (see Table 15). Roots extended down to the clay.

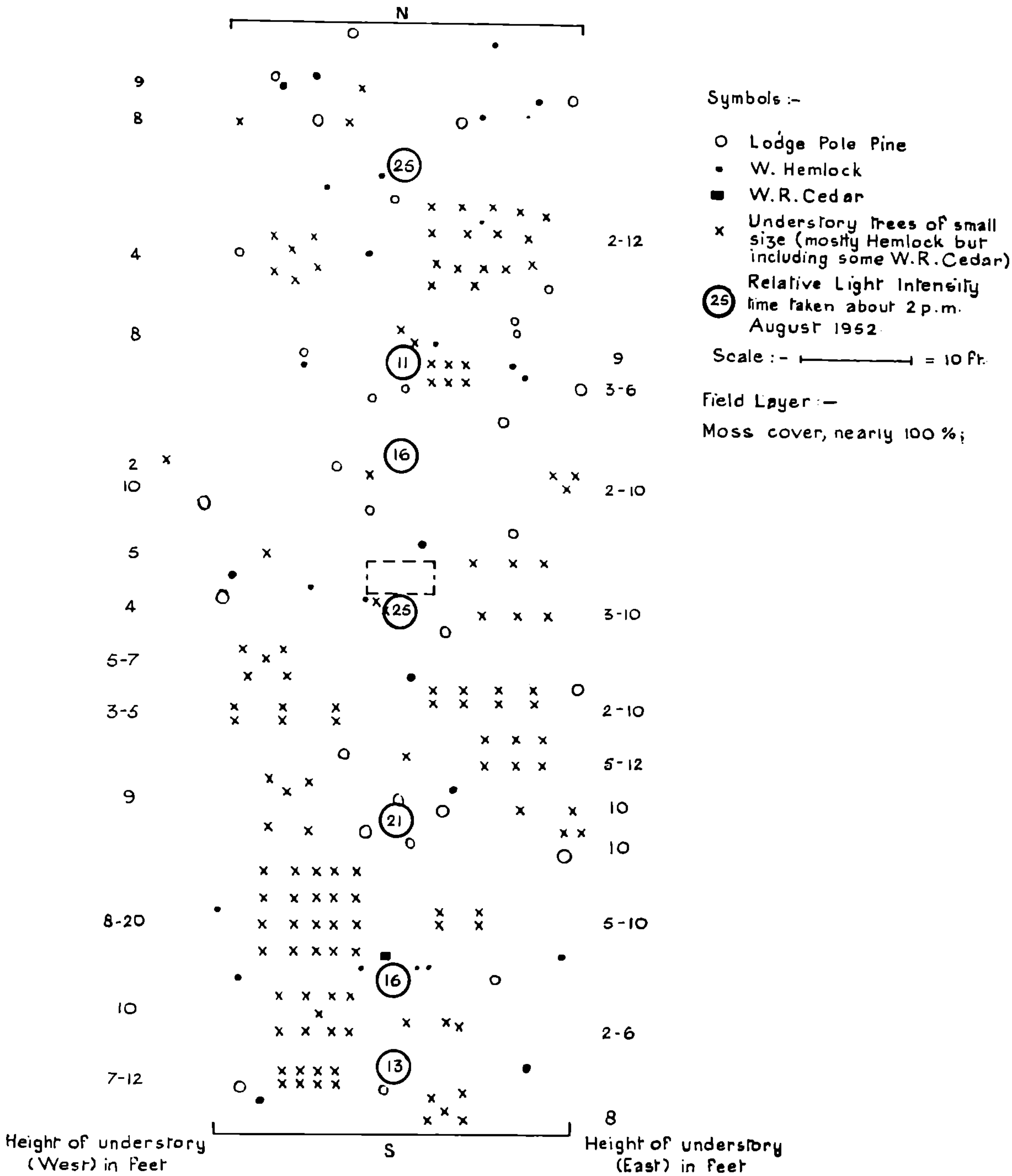


FIG. 10

Plot K6, situated on a raised beach, in a freely draining situation topographically, and with a very stony, coarsely sandy, podsolised soil (see Table 15). Roots descended to more than six feet in depth. Many, at least, of the under-storey trees were as old, approximately, as the dominant pines. These pines were of poor foliage density, many of the crowns being very thin.

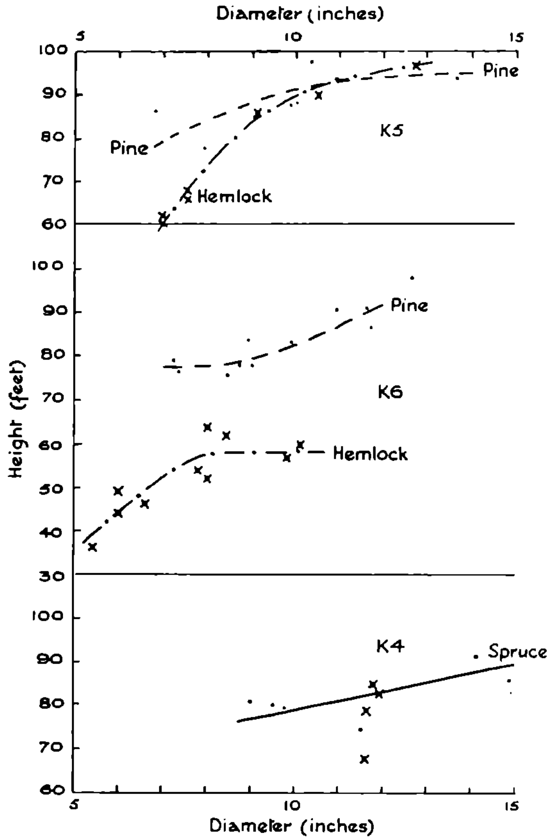


FIG. 11

Height/diameter curves for Plots K4, 5, and 6 ; Kitsumkalum Park. It should be noted that in K6 none of the many small understorey trees are included in the hemlock.

coarse-textured a soil as that in K6, at least in a climate such as that which occurs at Kitsumkalum. Cedar makes a poor third, and appears as less tolerant of dry sites than hemlock. Spruce, whether because of difficulties during the regeneration period, or of growth afterwards, appears clearly as the least site-tolerant of all.

6. A further example of this is provided by a transect taken through much older forest within Kitsumkalum Park : Fig. 12 illustrates this. The soil along this transect consists of two types : the one, from 0 to 220 feet, is in the main a fine loamy sand, which, where sampled at about 75 feet along the transect, is of more than ten feet in depth (Table 15). There was a water-table, at the time of examination, at about 10 feet down. This sand is irregularly layered alluvial material deposited in the fan of Goat Creek and is actually somewhat variable in nature ; it contains, in places, irregular layers of coarse sand and fine gravel mixed in with the general bulk of finer material. The soil from 220 feet to the lake edge, consists of a coarse sand mixed with more or less rounded stones and boulders ; material, in fact, very like the upper part of the profile in Plot K6 (Table 15). The surface of the ground lies three or four feet higher than that in the first part of the transect. No soil pit was dug ; but examination of the bank at the lake edge suggests that the coarse stony material is of some appreciable depth. It is probable that a watertable occurs within it. The ground vegetation on the loamy sand was characterised by devil's club, *Oplopanax horridum*, together with herbs and ferns ; that on the coarse sand consisted almost entirely of mosses, in which *Hylocomium splendens* and *Calliergonella schreberi* were the dominant species (Fig. 12). The distribution of diameter classes in the two parts of the transect is given in Table 17. It is plain from this table and from Fig. 12 that the forest on the two parts is very different in constitution. That on the first part of the transect is characterised by a few large co-dominant and dominant trees which consist of cedar, hemlock and spruce. There are open places in which devil's club forms most of the ground cover and attains a height of from two to seven feet. The remainder of the transect consists of Closed Forest in which hemlock is the principal species, though a few cedar and spruce occur among the dominants and co-dominants. Diameter growth has been much more slow on this part of the transect than in the first part, but the dominants in both are probably of similar age.

7. The important features of this transect are, firstly, the dominance of hemlock on the coarse sand, with its relatively dry surface soil conditions ; secondly, the absence of any herbaceous growth, or regeneration of trees on this sand. The light readings recorded along the transect suggest that this absence is most unlikely to be caused by insufficient light ; it is to be regarded as related to relatively dry surface soil conditions. Thirdly, there is the presence of a few relatively large spruce and cedar in this part of the transect. Plainly, if these species become established they are able to continue growth successfully : this suggests that conditions during the regeneration period and immediately afterwards are of great importance in determining the proportion in the stand among the species available, on such a site as this with dry upper soil layers, but with water in the subsoil. Fourthly, in contrast to the coarse sand, a cover of devil's club, herbs or ferns is present everywhere, except under dense shade, on the more moist loamy sand. The light reading at 125 feet suggests that the shade cast by devil's club may be as great as that cast by a high canopy of tall trees (the reading at 62 feet) and this may, in part, account for the

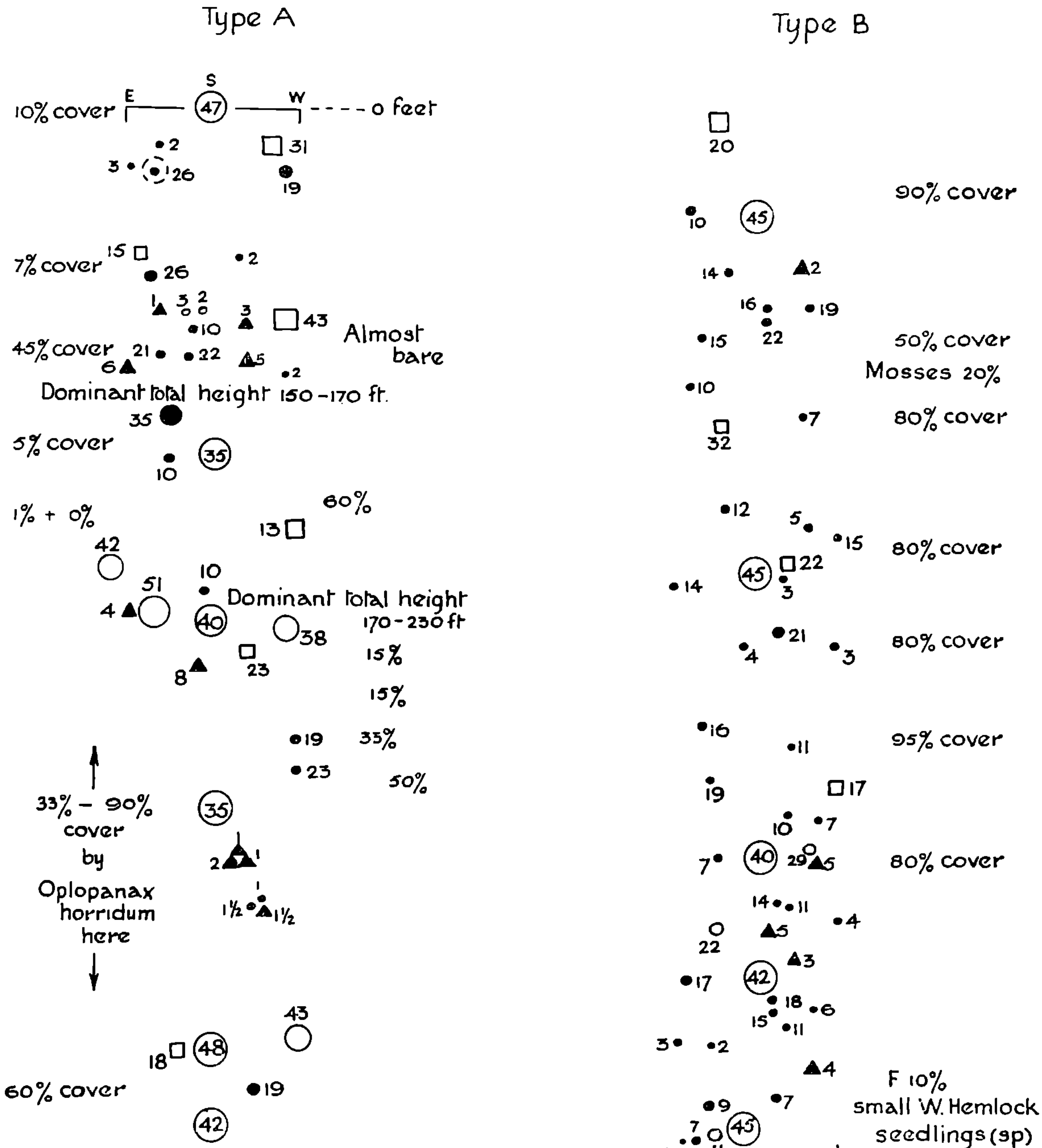
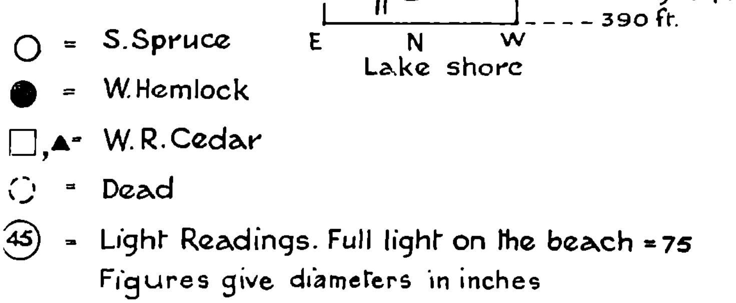


FIG. 12

Transect through part of Kitsumkalum Park. The first 200 feet crossed lay about three to four feet in level below the remainder: the soil was a deeply rooted loamy and often gravelly alluvial sand (see Table 15). The more northerly part of the transect crossed morainic material, very stony and coarsely gritty. The difference in vegetation is plainly related to the differences in the character of the soil.



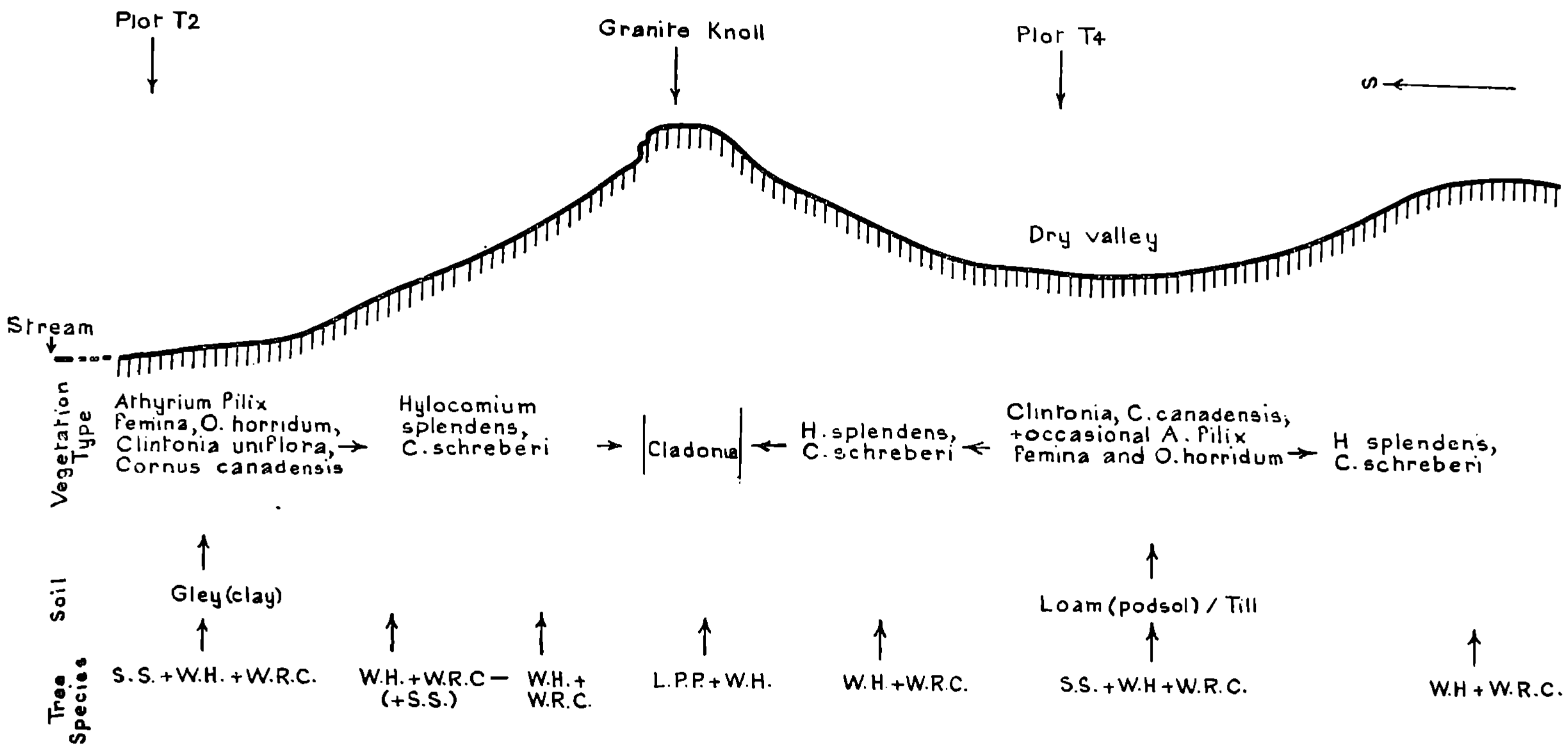


FIG. 13

Topographical section illustrating the relative positions of Plots T2 and 4: this is only diagrammatic. T4 was in a hanging valley and T2 on the site of the lake which lay below this and into which it emptied. Symbols: S.S. = Sitka spruce; W.H. = western hemlock; W.R.C. = western red cedar; L.P.P. = lodgepole pine.

absence of seedling trees between 100 and 150 feet along the transect where this plant grew especially strongly. Fifthly, the relative abundance of small cedar in this part of the transect is worthy of notice (Fig. 12 and Table 17). It would appear that the more moist surface soil conditions favour the establishment of this species as compared with the drier condition on the coarse sand, without in any way being adverse to hemlock. Sixthly, the complete absence of spruce in the smaller diameter classes is to be noted. The size of the spruce dominants suggests that the more moist aspect of the soils in Kitsumkalum Park is eminently good for spruce, as it grows in this district ; the absence of this species in the smaller diameter classes is evidently caused by adverse conditions for regeneration. Lastly, this site is too good, even in its drier aspects, to permit of the continued growth of pine, which survives only in special places, as on the edge of the low cliff in front of the Forest Service cabin in this park.

8. The evidence from this transect is thus that, of the three species, Sitka spruce, western hemlock and western red cedar, hemlock tends to become dominant on the drier soils on this flat lake-side ground, though it reaches the larger sizes on the more moist. Cedar does not appear as a good competitor on the drier sites though, in this park, fine cedar are often numerous on the more moist soils. General observation in this area undoubtedly shows the dominant spruce associated with moist, but not water-logged soils. These trees have the rather narrow spire-shaped crown so often seen in large spruce in this region. Plate 41 shows the spire-shaped crowns of the dominants as seen from the lake. The apparent rise of ground indicated by the outline of the crown tops is caused by differences in height growth related largely to soil conditions : the differences in level of soil surface are slight.

9. Observations to the East of the Kitsumkalum Road, near to Mr. Giggey's Saw-mill

This site is in the foothills to the high mountains which lie to the east of the road from Terrace to Kitsumkalum Lake and not far from Mr. Giggey's saw-mill. Two contrasting situations were examined in both of which Sitka spruce occurred. Their situation is illustrated by the diagram, Fig. 13. The terrain here consists of a scattering of rocky knolls with relatively fertile small valleys lying between them. Plot T2 was situated in the fairly narrow and moderately steeply sloping valley which leads uphill beyond the sawmill. This valley receives the inflow of several higher-lying valleys, in one of which, and directly over a knoll immediately above T2, Plot T4 was situated. The soil in T2 is derived directly from a grey clay ; this would appear to be a lacustrine deposit and it would seem that this main and lower lying valley was at one time occupied by water. The soil in the higher lying valley, in T4, is a stony loam which overlies a hard coherent gravel which appears to be till. The principal difference between the two situations lies in the nature of the basic root-restricting material : in the one case this is a hard compressed till which is of no great water-holding capacity ; in the other a clay which was still plastic within a short distance below the base of the rooted zone of soil. Details with regard to soil profile and rooting are given in Table 18. Plot T4 was certainly regenerated after fire ; the age of the stands is unknown, but the examination of local fellings suggests an age of about 200 to 250 years for the larger trees.

10. The composition of these plots in species is shown in Figs. 14 and 15. It will be seen that T2 is predominantly spruce with some hemlock and cedar ; whereas T4 is predominantly hemlock with some spruce and cedar. Table 18 shows that spruce is a taller tree in T2 than in T4 ; both hemlock and cedar in this plot tend to be sub-dominants. In T4, however, while the tallest species is spruce, both hemlock and cedar are well-established as co-dominants. The principal differences in ground vegetation between the two plots were the larger amount of bare ground in T2, indicating a more dense canopy ; the greater abundance of ferns (*Dryopteris linneana* and *Athyrium felix-femina*) and of devil's club, and in the local occurrence of the hepatic, *Plagiochila asplenioides*. The principal ground cover in T4 was *Clintonia uniflora* and *Cornus canadensis* (bunch berry or dwarf cornel), together with, locally, *Chimaphilla umbellata* (prince's pine). Seven plants of lady fern occurred and one small group of devil's club, as shown in Fig. 15. The soil in T2 is a gleyed clay which shows no surface leaching ; that in T4 is a freely draining podsolised loam.

11. The difference in species constitution between these two plots is to be regarded as determined by the different soil conditions, as affecting both the regeneration and establishment of young trees, as well as their later relative development in growth. The tendency for hemlock to be a sub-dominant in T2 recalls its position as this in the stronger growing parts of the Tlell transects, discussed above (Page 35 para. 1 and Figs. 4 to 7). This plot may, thus, be regarded as presenting another example of the ability of Sitka spruce to dominate and prevent the full growth of western hemlock when they grow together under appropriate soil conditions.The essential condition seems to be that the status of the soil as regards moisture supply and nutrition shall favour the development of spruce, at least during its developmental stage, and so enable it to develop its

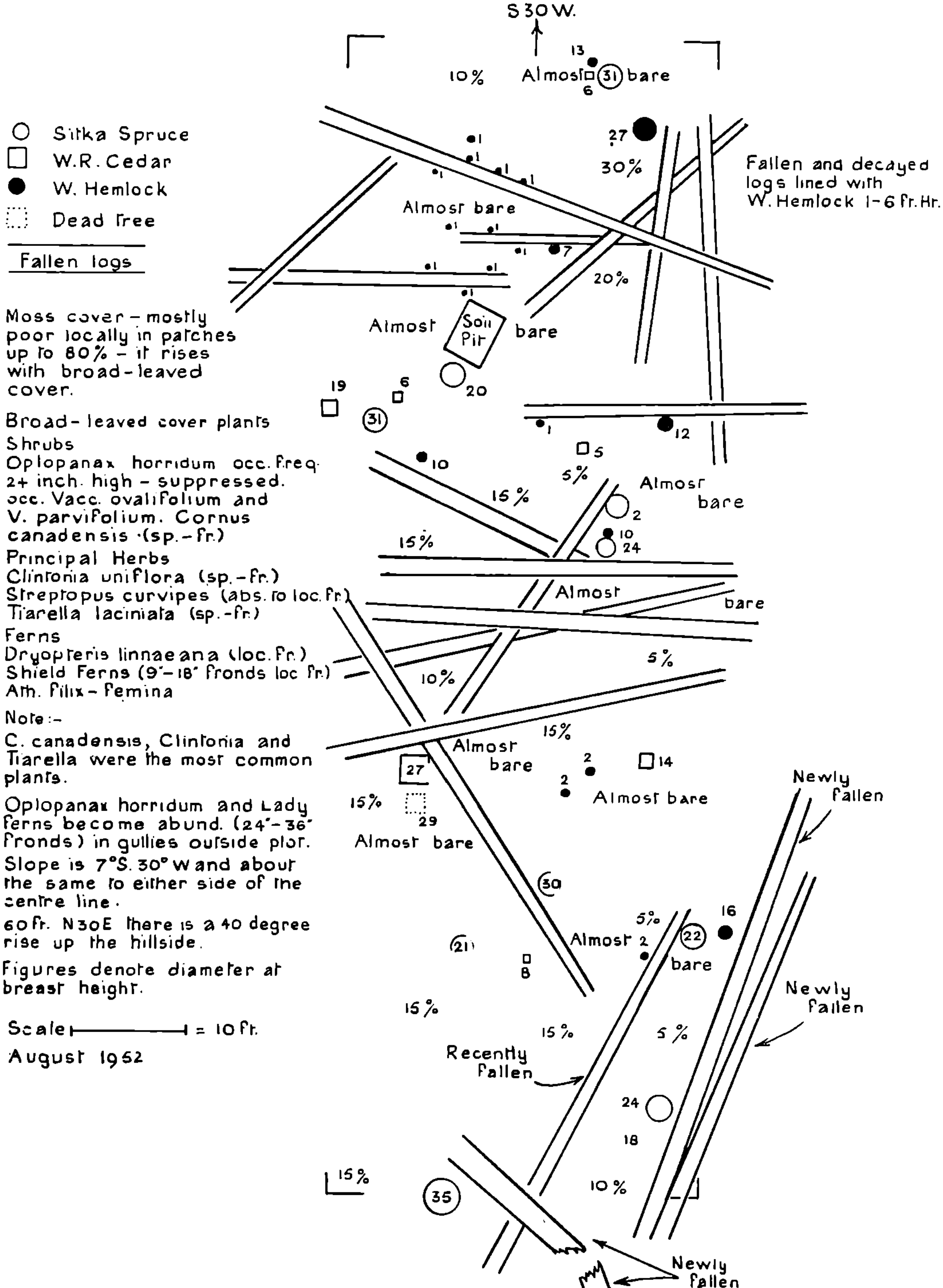


FIG. 14

Plot T2. The diagram shows an old growth stand with a high volume of standing timber and with Sitka spruce strongly dominant. The soil is a shallowly rooted gleyed clay (see Table 18). The sparseness of the field layer indicates the relatively high density of the canopy. Nevertheless root die-back had occurred, often severely, on the spruce dominants. This was a water-receiving, but slightly convex and well-drained site. The large number of fallen logs indicates that during recent decades this area had been passing through a period of natural thinning (compare with Plot T4).

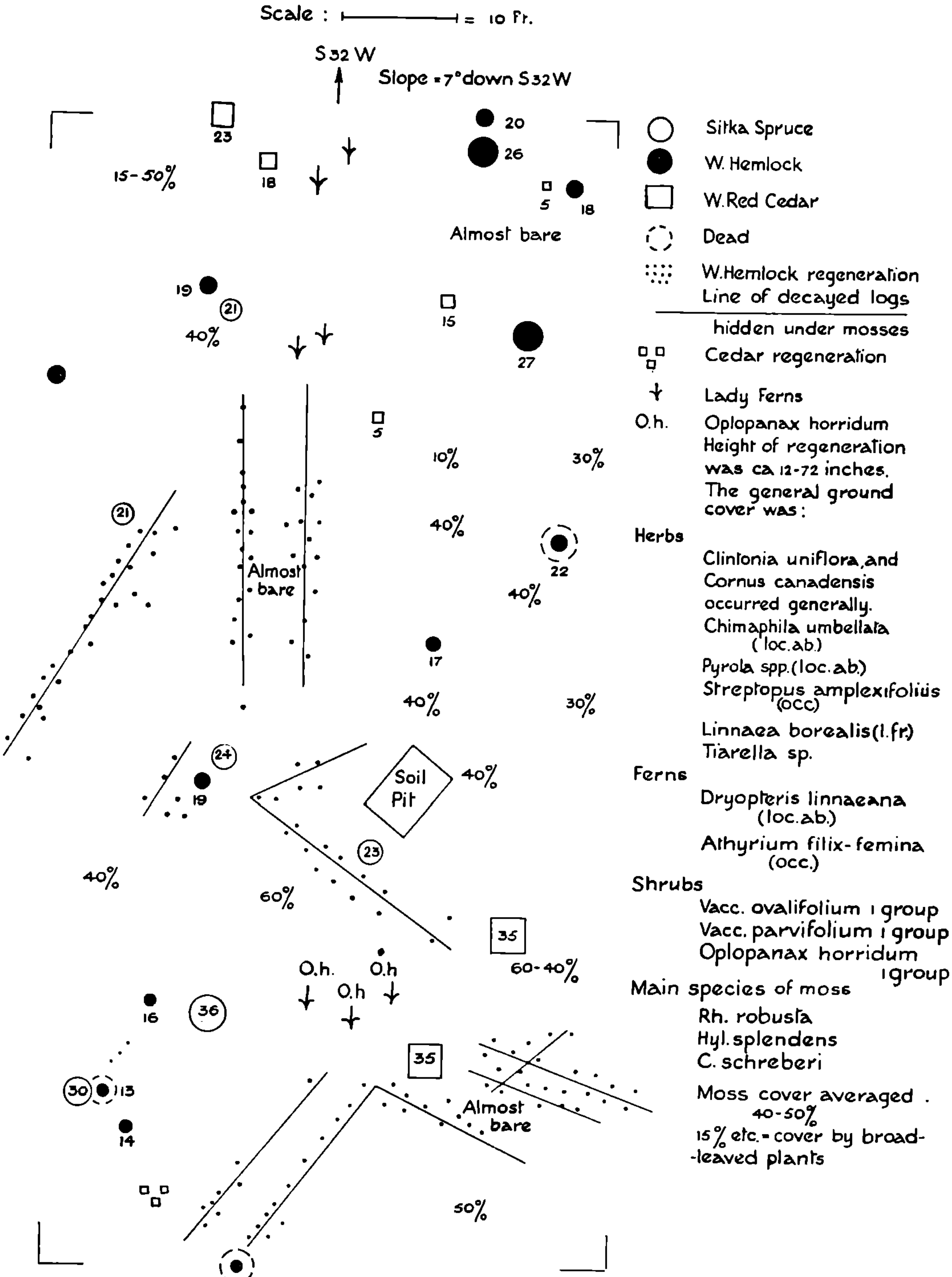


FIG. 15

Plot T4. This represents old growth forest standing on a shallowly rooted stony loam which overlay till (see Table 18). It should be compared with Plot T2, Fig. 14, which grew nearby on a shallowly rooted clay soil. This plot differed from T2 in having a more strongly developed field layer and a lighter high canopy, western hemlock and western red cedar forming most of the dominants and co-dominants, and in the entire absence of exposed, relatively undecayed fallen logs. A more dry and poor situation is indicated in which the process of natural thinning set in much earlier than in T2, with the result that the remains of fallen logs had to be sought under the moss covering the ground.

great growth potential ; but that the general soil supply shall be too deficient fully to maintain the growth of hemlock in competition with the dominating spruce. The supply deficiency is expressed in both cases in the shallowness of rooting depth (compare Figs. 1 and 2 and Table 18).

Plot T4 presents the reverse case. This plot and T2 are related in some respects ; both have shallow soils and both are related to some extent through their ground vegetation, which evidently indicates certain similarities in nutrient status and moisture condition. T4, however, has the lighter and much the more stony soil (Table 18). The indications are that, not only has this favoured a higher proportion of hemlock in the dominant canopy, but that also, because of its generally healthier crown condition, hemlock is likely to outlast the spruce, which may be expected entirely to disappear, leaving a forest composed of hemlock and cedar. There is, thus, a suggestion that the conditions in T4 are near the margin at which spruce ceases to have an advantage in volume production, and hemlock becomes equally or more advantageous in this respect.

12. The relative site tolerance of the various species is emphasised by the distribution shown diagrammatically in Fig. 13. Small lodgepole pine, with still poorer hemlock, occupy the dry, rocky, lichen-covered knoll tops. Hemlock occurs as a pure stand on the steep slopes from these ; proceeding downhill the stand composition grades into hemlock-cedar, the latter species always being in the smaller proportions. The concave valley bottom is occupied by spruce, hemlock and cedar. This is plainly a sequence in proportionate stand composition which reflects a change from dry to moist conditions ; as already indicated, the proportion and dominance of spruce rises with increasing moisture, providing the drainage of the surface soil horizons is maintained sufficiently ; also in the more moist places black cottonwood appears as a rather sparse constituent of the stand.

13. In summary it may be said that in this region, if a series of sites is examined which represent a change in soil supply from moist to dry, the upper soil horizons, at least, being well drained, an appropriate sequence in stand composition will occur. This will begin with spruce-cedar-hemlock, perhaps with some black cottonwood, in the more moist situations and end with lodgepole pine with some small hemlock and perhaps an occasional small cedar, on dry rocky lichen-covered positions. This sequence in stand composition is brought about, in sufficiently mature forest, not merely by differences in the colonising capacity of the different species during a regeneration period, but also by their relative competitive vigour as determined by the supply characteristics of the site and particularly of the soil. Most of the examples discussed here are regarded as having regenerated after a catastrophe, almost certainly fire, has prepared the ground for seeding ; the theoretical or actual complexities of successional regeneration are not thus entered into.

Plate 1. Sitka spruce at the mouth of Gold Creek, north of Tlell, east coast of Graham Island. The cliff shows a coarse gravel, probably fluvio-glacial, overlying geologically recent, layered, clayey sediments.

Plate 2. View from the hill above Plot 13, near Marie Lake, Graham Island, showing typical hill country of the central region. The hills are glaciated, except probably for the high angular points which reach 2,300 to 2,500 feet above sea level. They are entirely forest covered: the tree species are, almost entirely, western hemlock, western red cedar and Sitka spruce.

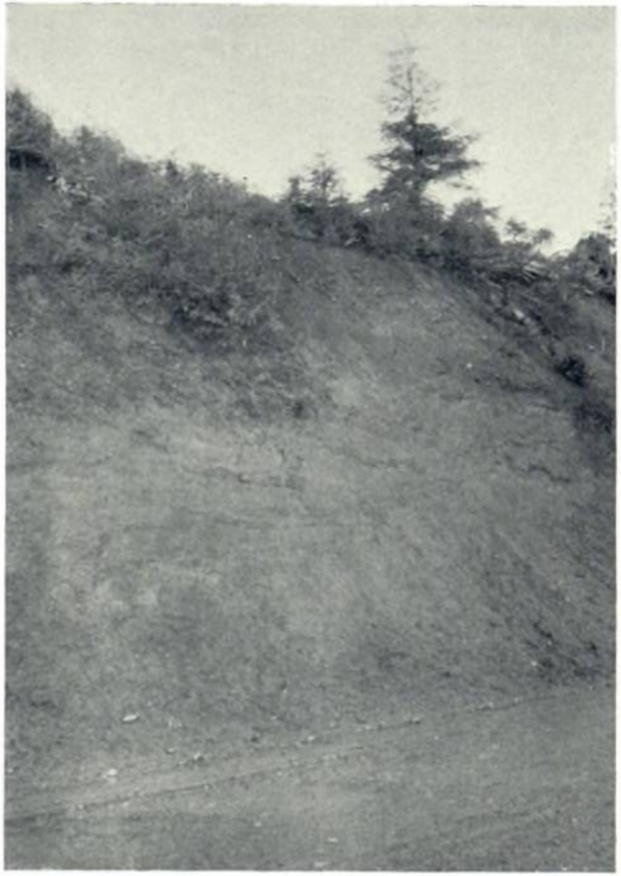


Plate 3. Cliff at roadside near Juskatla Camp showing coarse gravel (see Plate 4) overlying layered sediments. These sediments include, irregularly, gravel beds. They are mainly impervious to water (see also Plate 1).

Plate 4. Profile typical of the gravels at the back of Juskatla Camp. This is similar gravel and overlies similar sediments to those shown in Plate 1 (see also Plate 3). Forest carried was mainly western hemlock with Sitka spruce.

Plate 5. View from Kitsumkalum Lake, near Terrace, across Kitsumkalum Park (in the foreground) and down the valley of the Kitsumkalum River. The hills in the mid-distance, at the foot of the mountains, show the type of country in which Plots T2 and T4 were situated. The forestry cabin is hidden in trees on the left centre. The tall trees in the centre are Sitka spruce emergent from the main canopy which is composed of western hemlock, western red cedar, Sitka spruce and black cottonwood. The whole of the foreground is the practically flat area largely occupied by the alluvial fan of Goat Creek. The taller spruce are over 220 feet in height.

Plate 6. Coarse gravelly alluvium by the side of the Mamin River, near the two-mile post from Juskatla Camp. The forest consists of western hemlock and Sitka spruce with crowns now in poor condition (see Plate 49).

Plate 7. View across a small "meadow" by the side of the Mamin River and including part of Plot 5. The earth from the soil pit is shown on the left. The trees are Sitka spruce and western hemlock. The meadow is still flooded, but probably only at high water. Plate 45 shows also a part of "meadow" forest near the Mamin River.

The field layer includes *Mnium insigne, Hylocomium splendens, Dryopteris linneana Tiarella trifoliata,* and *Streptopus amplexifolius.*

Plate 8. View across part of Plot 5, near the Mamin River and looking in the opposite direction to Plate 7. The forest in the background is typical "meadow transition forest". It consists of large Sitka spruce, the taller of which rise to about 250 feet, with smaller trees both of this species and western hemlock. The dominated canopy is mainly hemlock. The soil is immature with layered humus typical of flooded areas.

(Plate 16 gives a view taken outside this area from across the river).

Plate 9. Forest on alluvium near the Exstew River Bridge where this river joins the Skeena River. The trees are Sitka spruce and black cottonwood, both rising to about 200 feet. The undergrowth in the foreground is devil's club (*Oplopanax horridum*). Dogwood (*Cornus*) bushes appear in the background. This is on an immature soil showing the layered surface humus typical of flooded areas. See Plate 13 for soil profile.

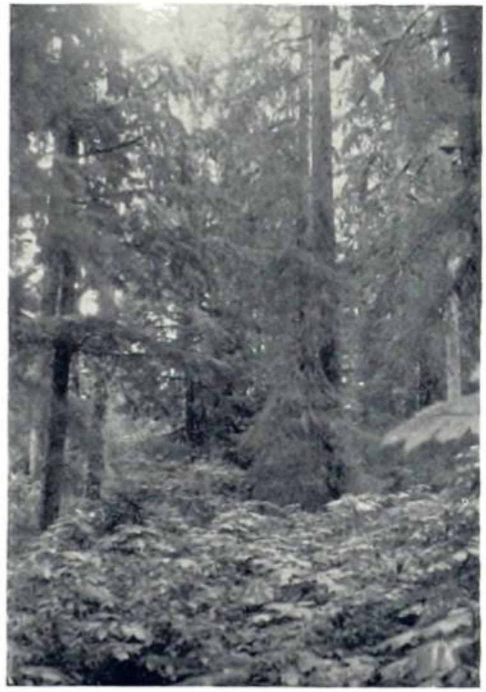


Plate 10. Part of Plot 4, by the Yakoun River, Graham Island. The trees are Sitka spruce and western hemlock; the latter are the more numerous. This forest stands on an old alluvial bench now above flood level. The soil is a heavy loam, podsolised where undisturbed and shows a clear leached horizon about 1½ to 2 inches in thickness. The trees are deeply rooted. See also Plates 11 and 12.

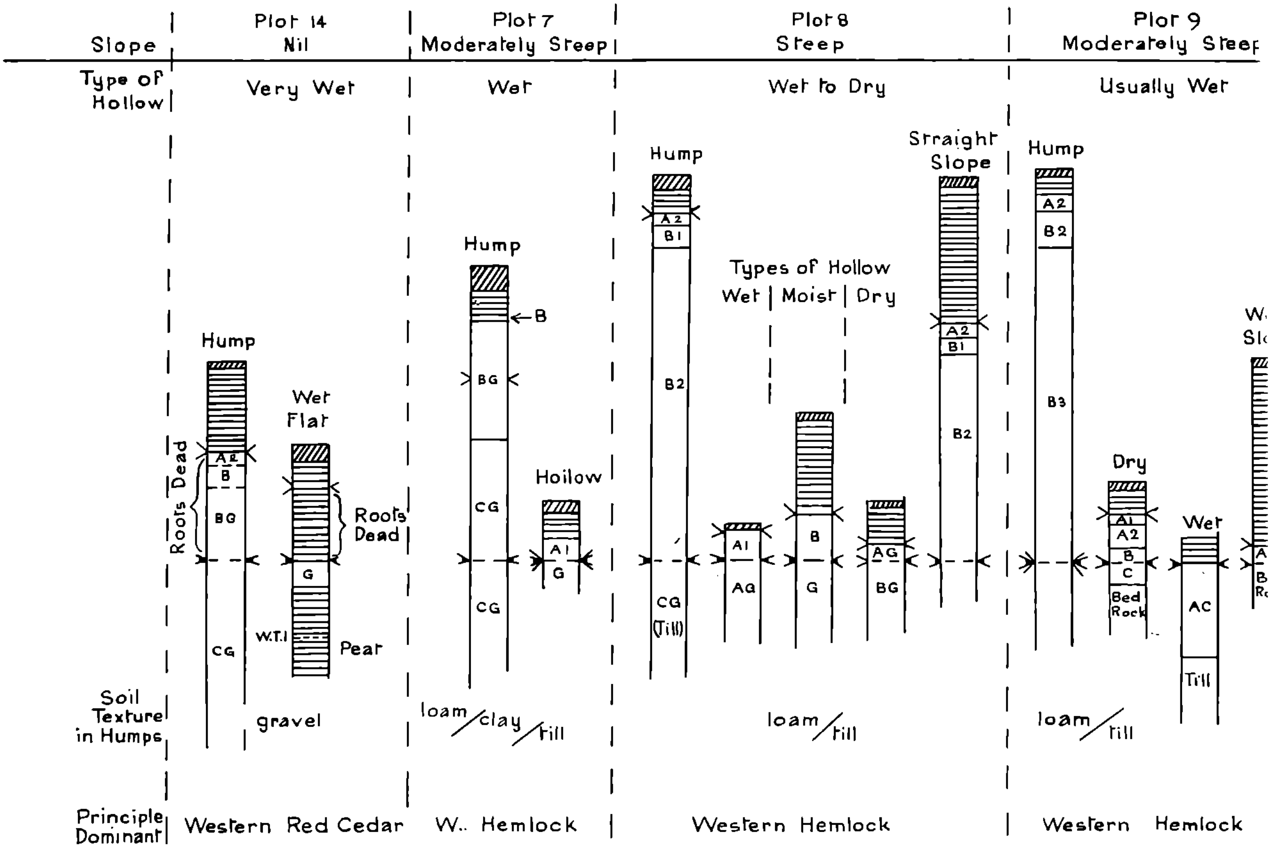
Plate 11. View just outside the limits of Plot 4, by the Yakoun River (see Plate 10). The trees shown are Sitka spruce, western hemlock and red alder (the branches on the left). The snag of a recently broken large dominant spruce is shown. The hump at the foot of this tree is covered with the moss, *Pogonatum alpinum*, in which are set numerous fronds of the fern *Dryopteris linneana*. The soil of this hump is leached only superficially; it is of relatively recent creation and may be an ancient flood bank.

The larger stems seen in the right centre are mostly Sitka spruce.

Note the heavily moss-covered branches of the centre tree.

Plate 12. The upper part of the soil profile in Plot 4. The soil is a fine textured loam, which in the main is coherent and has a massive structure. The dark surface layer is organic and is intensely rooted except where it consists of rotted wood of old logs; the roots are more sparse in these. Part of the leached A2 horizon shows. The remainder consists of B horizon material. Only the upper part of the mineral soil is at all frequently rooted; but the sinker roots penetrate to at least six feet. The lower part of these was consistently dead. No water table was discovered.

SOIL PROFILES IN 'HUMP AND HOLLOW' REL
GRAHAM ISLAND



Centre page figure

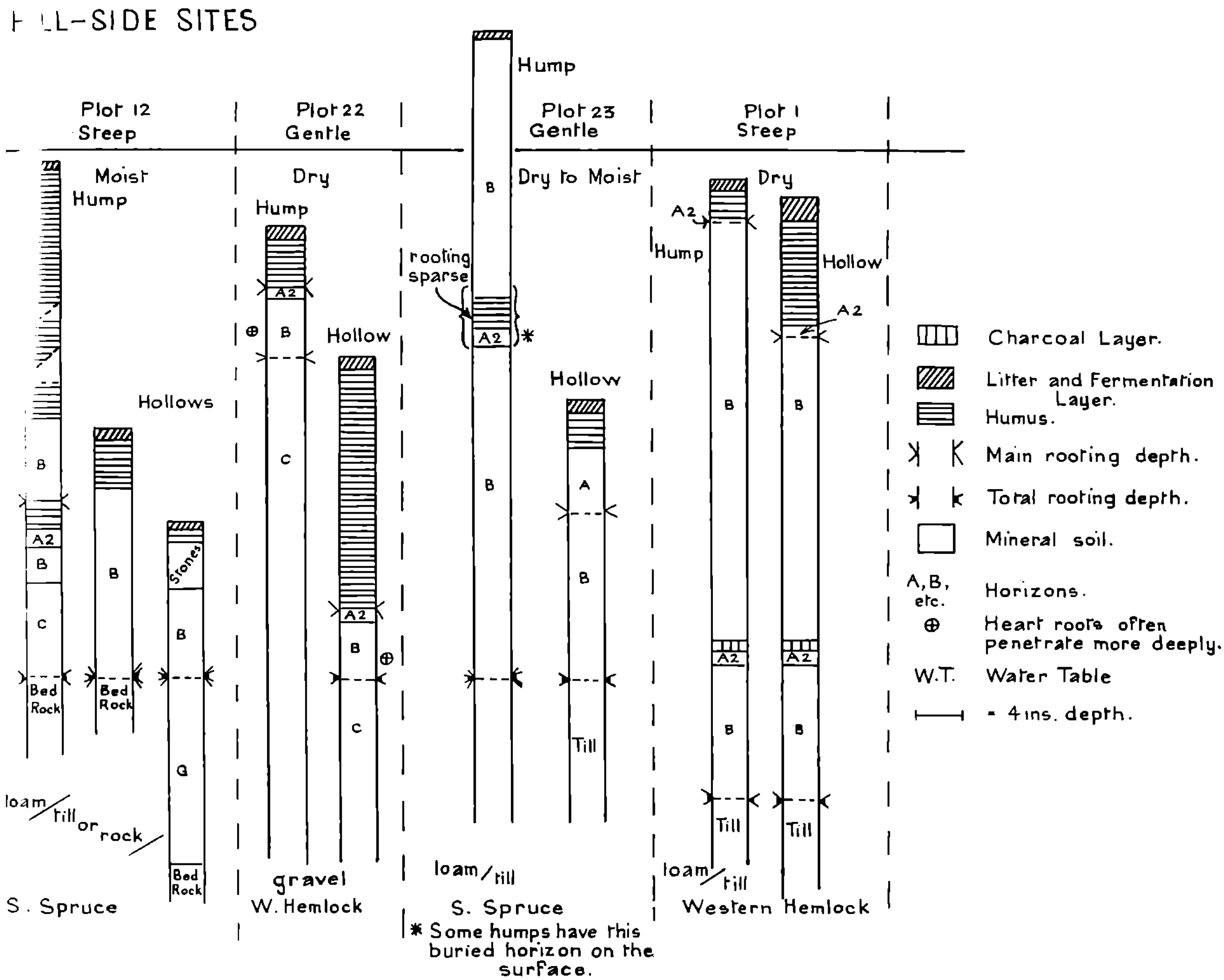


Plate 13. The soil profile for Plot T3 on alluvium near to the Exstew River Bridge (near the Skeena River junction). This is an immature soil still subject to deposition of silt. There is a shallow layer of loam which is intensely rooted. Below this is almost pure medium fine sand, which is adverse to a generally distributed root development. The base of a sinker root which has penetrated this sand is shown. Many of the lower ends of such roots were dead. See also Plate 9.

Plate 14. The soil profile for Plot T1, on alluvium by the Skeena River. The forest consisted of sixty to eighty year-old western red cedar and Sitka spruce under a high canopy of black cottonwood. The soil is immature. There is about 4 feet of fine sand, or sandy loam, which overlies rounded boulders some of which can be seen at the pit side. The even root distribution should be noted: it is typical of a porous light soil. Compare with Plates 12, 13, 17 and 18 for root distribution.

The roots shown are those of Sitka spruce.

Plates 15. The crown of a dominant Sitka spruce in Plot 4 (see Plates 10, 11 and 12). Note the thin condition of its apex; this is correlated with the dying of the lower part of the root system. The tree is about 230 feet in height.

Plate 16. " Meadow transitional forest " by the side of the Mamin River and near to Plot 5. The taller trees are Sitka spruce. The large rather thin-crowned tree on the right is probably over 230 feet high. The smaller trees are western hemlock and red alder. Note the variations in crown density between the two tall spruce. The dense top of the centre tree stands clear of the crown of any other. This difference in crown density is determined mainly by root condition.

(See Plates 7 and 8, taken within this area).

Plate 17. The upper part of the soil profile in Plot 3, Indian Reservation, Skidegate Mission. See also Photo 26. This is a brown podsolic soil with about 6 inches of intensely rooted humus. Only the upper part of the mineral soil shown is at all frequently rooted. The remainder consists of coherent compact material in which dead roots are frequent. Total rooting depth is about 55 inches to the surface of a hard sandy clay.

Plate 18. Soil profile for Plot 13, near Marie Lake (see also Plates 22, 24 and 25). This is a leached soil. The narrow A2 horizon shows intermittently beneath the humus. Rooting is sparse except in the humus, which is intensely rooted. The rooting depth extended to 67½ inches, to the surface of hard till (just below the large stone). The B horizon material is the lighter toned upper half and the C horizon, the darker toned lower half of the mineral soil above the till. The B horizon material is fissured. The soil is a coherent loam of massive structure and is sparsely rooted except where penetrated by sinker roots. The lower part of these roots was dead (see Plate 24).

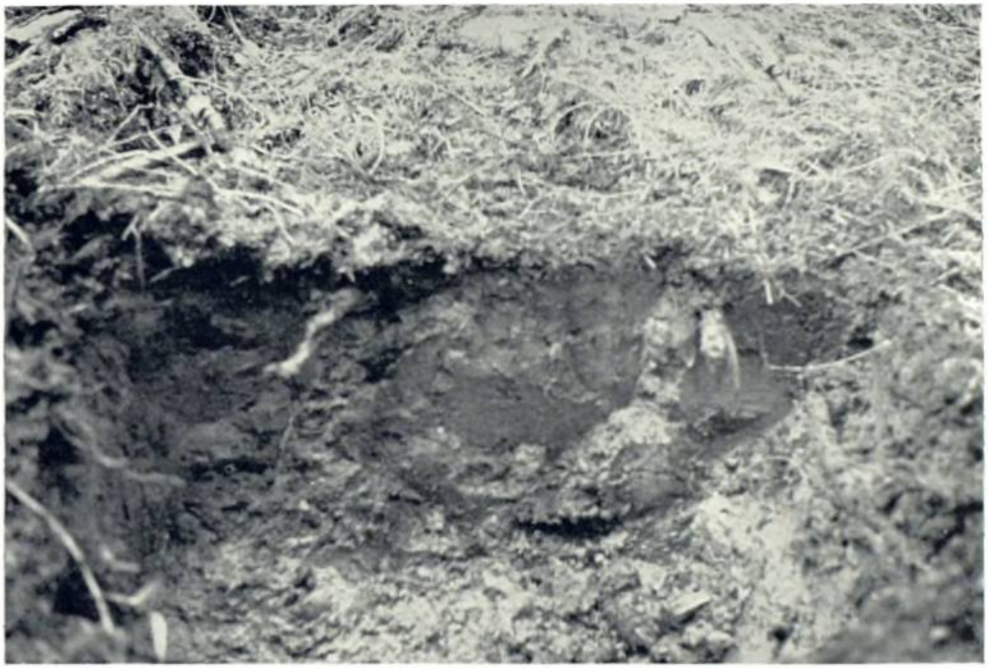


Plate 19. Soil profile in a wet hollow in a hillside site (Plot 7, Yakoun River basin). This is a grey, wet, sodden soil except in the top inch or two; here it is black. Roots are, as can be seen, confined to the black soil. These sites favour the development of quite small seedlings of spruce, hemlock and cedar; the soil conditions prevent any appreciable growth. See also Plate 33 which shows the undisturbed surface of such a hollow. The soil is a silt deposited, apparently, during surface run-off.

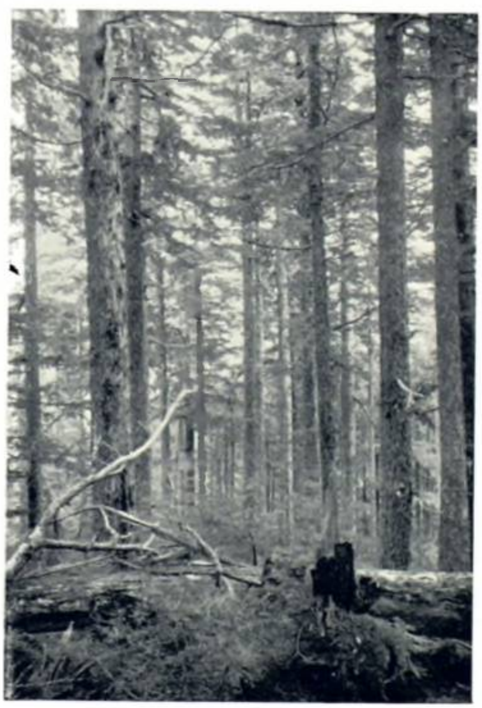


Plate 20. Forest which consists almost entirely of western hemlock on the hillside on which Plots 7 and 8 were situated (Yakoun River basin). A few Sitka spruce and western red cedar occur. This hillside shows marked hump and hollow relief, owing to wind-throw. The trees root mainly in the humps. The mean total height of dominants and co-dominants was about 150 feet. The canopy is more or less closed but is thin, and regeneration of hemlock can be seen forming a low understorey. (See Centre-page Figure for typical soil profiles, and also Plate 34).

Plate 21. Crowns of trees in a patch of cedar-spruce-hemlock swamp forest just below Plot 7 (compare with the normal stand in Plate 20). The trees grew on small humps; the hollows between are swampy. The spruce was clearly a dominant but has a very thin crown. There were hemlock, the crowns of which were dead or dying. The larger cedar, not seen in the photograph, were spike-topped.

Note that many branches are thickly covered with moss.

Plate 22. View of Plot 13. The trees are Sitka spruce and western hemlock of about 300 years of age. The mean height of dominants is well over 200 feet. This is a lower slope site with a deeply rooted colluvial soil. It is a hump and hollow site, the hollows being well-drained. See also Plates 18, 24 and 25.

Note the thin condition of many of the crowns; this is related to dying-back of root systems (see Plate 24).

Plate 23. View inside Plot 12, on a hillside in the Mamin River basin. This is a stand which consists of Sitka spruce and western hemlock regenerated on the site of a wind-throw which occurred 75 years previously. The old wind-thrown trees can be seen with moss-covered trunks. Two dominant Sitka spruce are seen in the centre, typically rooted on the root-plate of a wind-throw. The soil is podsolic and shallow, overlying hard compressed till, or hard bedrock; the slope is mostly steep. The hollows are moist but well-drained as a rule.

The moss shown was mainly *Rhytidiadelphus loreus*. It is sometimes collected in bulk and sent to florists in towns on the coast, further south.

Plate 24. The underside of a recent wind-thrown root-plate on the edge of Plot 13, Marie Lake (see Plates 18, 22 and 25). The ends of the protruding sinker roots were all dead and largely rotten at the time of wind-throw. The thin condition of the crowns of the dominants shown in Plate 22 is related to this.

Plate 25. The base of a large Sitka spruce dominant in Plot 13 (see also Plates 18, 22 and 24). The tree is about 300 years old. The site shows typical though ancient "hump and hollow" relief. This tree is on an old hump; the stilt-like nature of the large roots at its base is to be accounted for by the collapse of this as the wind-thrown root-plate decayed.

Plate 26. View in Plot 3, Indian Reservation, Skidegate Mission. The soil pit, Plate 17, was dug by the large spruce on the left. This was a 100 year old stand of Sitka spruce and western hemlock regenerated after fire. It was passing through a period of intense competition and many of the smaller trees were due to be eliminated. The soil is a podsolic loam, colluvial, on a lower slope. The stem-littered ground is typical for unutilised forest when passing through a period of natural thinning.

Plate 27. View from the centre of wet muskeg (deep peat) looking easterly towards Plot 19 which was on the top of the slight hill in the background. The trees in the bog are lodgepole pine. Western red cedar comes in at the foot of the hill and then western hemlock. Dead cedar poles can be seen. Spruce occur sparsely in places, but in the dominant canopy only towards the top of the hill and never on the swampy peat.

Plate 28. Cedar-hemlock swamp forest, on deep peat, on the western side of Plot 6 (see Plate 29). All the dominants were small; there were open swampy patches more or less bare. The trees tended to occur on slight humps. Cedar was the principal tree; hemlock was abundant but smaller; spruce occurred frequently but only as a quite small poor tree. The cedar dominants were all "spike-topped".

Plate 29. View in Plot 6 (see also Plate 28) situated on deep peat but with no significant swampy patches. This is an aspect of cedar-hemlock swamp forest. The principal dominant was western red cedar (mean height 64 feet); western hemlock occurred commonly but was much smaller; Sitka spruce occurred frequently but as a small insignificant tree. Yew (*Taxus brevifolia*), red alder and a dogwood (? *Cornus stolonifera*) also occurred. The field layer shown consists largely of salal (*Gaultheria shallon*), with the smaller broad leaves, and *Veratrum viride*, the plant with the large broad leaves. The figure in the background shows the small size of the trees; this is mature forest. The white line is the plot boundary string.

The main rooting zone was very shallow and superficial; but *V. viride* sent thick white roots deeply into the stinking badly aerated subsoil peat.

Plate 30. View across Plot 11, Juskatla, near Branch 1. Fully developed cedar-hemlock-salal forest on shallow peat overlying hard impervious till. There was a gentle slope with lateral movement of ground water. Sitka spruce occurred sparsely as a dominant with cedar. Dominant height of cedar and spruce was about 135 feet. The open condition of the forest is typical. Note the strong growth of salal (*Gaultheria shallon*) measured by the standing figure. All dominants have dead or thin tops (see Plates 31 and 32).

The depth of rooting was about 12 inches; all the larger trees have much dead root.

Note the heavily moss-covered branches.

Plate 31. View of tops of trees in the dominant canopy in Plot 11 (see Plates 30 and 32). Note the evident signs of crown die-back on the Sitka spruce in the centre and the two dead tops of cedar in the background. The smaller trees, at the sides, are western hemlock.

Plate 32. Soil profile for Plot 11 (see Plates 30 and 31). There was about 7 inches of intensely rooted organic material. This overlay a grey water-sodden gritty sand, the top three inches of which only was rootable. All the roots excavated in this were dead. The broad leaf is that of salal.

Plate 33. A moderately wet hollow in Plot 7 (see Plates 19, 20 and 21) in an area showing "hump and hollow" relief. The vegetation included small ferns (*Dryopteris linneana*), small *Maianthemum dilatatum*; *Coptis asplenifolium*; some very small plants of *Lysichiton camtschatcensis*; much liverwort (*Pellia*); locally much green *Sphagnum*; locally abundant *Mnium punctatum*; and frequent seedlings of western hemlock, Sitka spruce and western red cedar. It is shaded by the hemlock, which stand on the adjacent humps. Neither spruce nor cedar seedlings were seen on the humps.

Plate 34. Profile in a hump near to and below the trees shown in Plate 20. The roots are Sitka spruce. The soil is a brown podsolic gley. Most roots were in the surface organic covering and in the upper gley horizon. The light-toned unrooted material at the base of the profile is compact, impermeable till. (See also Centre-page Figure).

Plate 35. View in Plot 18 on the edge of the Mamin River. The soil is an immature alluvial porous sand, still subject to flooding. Mean heights of dominants and co-dominants were: spruce 205 feet; hemlock 170 feet. The spruce were plainly emergents in the canopy. Total rooting depth about 69 inches; the ends of large sinker roots were commonly dead. This is a dry soil in the upper horizons, with a water-table. Seedlings do not survive, apparently, in the small "meadow" shown. Many of the tree branches were heavily moss-covered.

Plate 36. View in Plot 17, showing 87 year-old Sitka spruce and western hemlock regenerated after fire. The soil is podsolic and of very variable depth overlying hard fissured rock. The site is a small slope down to the shore of Juskatla Inlet. See also Plate 37.

The rooting depth in the area shown varied between about 20 and 40 inches.

Plate 37. Dead and dying alder crowns, not suppressed by the conifers, in Plot 17. Sitka spruce was affected similarly in places. This phenomenon is associated with shallowness of soil. The rooting depth was about 12 inches (see Table 14).

Plate 38. View of edge of Plot 23, Yakoun Bay, Masset Sound, in a 97 year-old stand of Sitka spruce, western hemlock with some red alder, regenerated on an old hump and hollow wind-throw area. The crown of the dominant alder on the left is dying back though entirely free. The crown of the spruce in the centre has entered the stage when the upper branches are covered with short close twigs. The lower branches are still normally twigged. (See Table 14 and the Centre-page Figure; also Plates 50 and 51).

Plate 39. View of crowns in Plot 22. There is a gap in the canopy in which a dead Sitka spruce stands. Note the poor condition of the tops of the crowns in the background. The soil is a leached (A2 horizon 1 inch deep) gravel, freely draining but not generally deeply rooted. The stand is 150 year-old western hemlock and Sitka spruce. (See Table 14 and Centre-page Figure).

Plate 40. View across Plot Tlell III. This is an 80 year-old stand of almost pure Sitka spruce, probably regenerated after fire and on sand near to the Tlell River estuary. Note the dense tall growth of salal (*Gaultheria shallon*). The soil is a shallowly leached pure sand, probably of wind-blown origin from the nearby beach. It has a shallow leached horizon ; the rooting depth varies between about 18 and 30 inches. Dead roots occur very commonly and the canopy is thin, as the growth of salal testifies. Note the heavily moss-covered branches. (See Table 13).

Plate 41. View across Plot K1, in Kitsumkalum Park. This was a stand of western red cedar and Sitka spruce on an immature sandy soil subject to flooding and in the fan of Goat Creek. Rooting depth was about 32 inches to a water-table; most of the roots in the lower 10 inches were dead, including some 7 inches diameter. This is old-growth forest with dominant spruce as emergents and rising up to about 170 feet in height. The ground vegetation is principally *Equisetum* (80 to 90 per cent cover). *Dryopteris linneana* and *Athyrium felix-femina* were locally frequent. *Plagiochila aspleniodes*, *Rhytitiadelphus triquetrus*, and *Eurynchium* spp., occurred frequently under the *Equisetum*. Other woody plants included *Alnus*, *Rubus parviflora* (in foreground); *R.spectabilis*; *Rosa* and *Ribes* spp., *Viburnum trilobum; Oplopanax horridum*. (See Figure 22 and Tables 19 and 22).

Plate 42. Old-growth forest on shallow peat overlying lake silt on the edge of Lake Lakelse. Dominants are Sitka spruce (mean height 114 feet) and western red cedar (mean height 94 feet) with western hemlock as sub-dominant (mean height 77 feet) and as an under-storey tree with alder, dogwood (*Cornus*) and *Oplopanax horridum*. *Vaccinium ovalifolium* and *Menziesia ferruginea* occur on higher places. Principal herb cover in wetter places was *Lysichiton camschatcensis* (large leaf in foreground). On humps bunch berry (*Cornus canadensis*) occurred generally. Plot L 3-4. (See Figure 17 and Tables 19, 20 and 21).

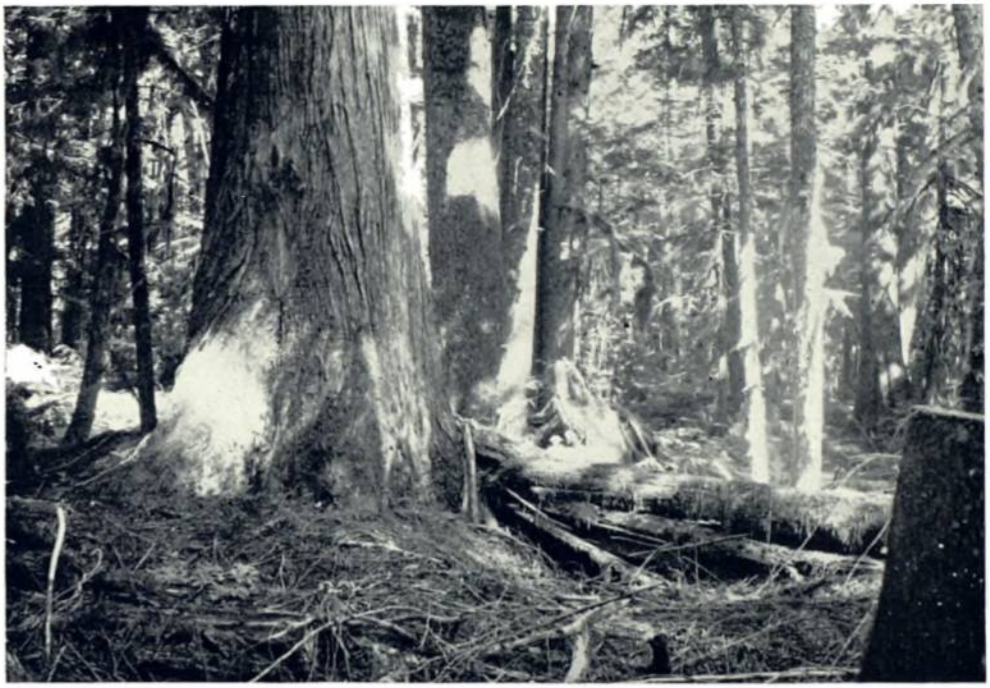


Plate 43. View across one side of Plot L 5-6, Lakelse. Western red cedar and Sitka spruce dominants are seen on one of the humps; the smaller stems are of western hemlock. Skunk cabbage (*Lysichiton camschatcensis*) with *Rubus* spp. and ferns occur in the hollow beyond. Soil is a gleyed clay; rooting depth on humps was about 20 inches. (See Figure 18 and Tables 19, 20 and 21).

Plate 44. View across and beyond Plot L7, showing pure Sitka spruce, about 125 years of age (at breast height) and 166 feet, mean dominant height. Soil was a silt with a shallow leached horizon; rooting depth 41 inches. The field layer is *Athyrium felix-femina* very tall, and *Oplopanax horridum*. The site is within the flood channels of a small creek. (See Figure 20 and Tables 19 and 22).

Plate 45. Large Sitka spruce with red alder in the background and western hemlock as sparse understorey, on alluvial soil subject to flooding by a backwater of the Mamin River not far from Plot 5. This is an example of the type of woodland which occurs as "Meadow Forest". (See also Plates 7 and 8).

Plate 46. Three dominant Sitka spruce with a black cottonwood crown on the left and a western hemlock crown on the right, behind them. Note the differences in crown condition: this is determined by the correlated condition of their root-systems.

Plate 47. Black cottonwood, in the Hoh River valley, Olympic Peninsula, with younger Sitka spruce growing up beneath them. Some red alder occurs also. The soil was a greyish black mull with only a very little litter. About one-third of the ground was bare. The field layer included sword fern, rushes, brambles (*Rubus*), broadleaved grasses and many herbs. Some of the spruce were badly infested with the long-galled *Adelges* but without this having any serious effect.

Plate 48. Sitka spruce on alluvial soil (loam and gravel) in the Hoh River valley. The soil is a mull with little or no organic surface covering. The large tree is about 200 feet in height. Note the differences in crown condition: this is related to the stoniness of the soil. Other trees were western hemlock, red alder, vine maple (*Acer circinatum*). Spruce seedlings occurred in open places. Other plants: *Symphoricarpus*; *Rubus spectabilis*; *Oxalis oreganum*; sword fern; *Tiarelia trifoliata*; *Ranunculus* spp. and *Eurynchium oreganum* and *Rhytidiadelphus loreus* on the ground. The *Oxalis* and ferns were the typical cover under canopy.

Plate 49. Forest consisting of Sitka spruce, western hemlock and red alder on the bank of the Mamin River. Soil is immature and subject to silt deposition. It is a shallow loam overlying a very coarse freely draining gravel. The poor condition of the crowns is related to the soil conditions. (See also Plate 6).

Plate 50. View on edge of Plot 23 (see also Plates 38 and 51). In the left centre at the back is a Sitka spruce crown, still in the main dense, but becoming thin at the top and edges. The dead alder on the left had its crown free from overshading.

Plate 51. View in Plot 23 (see also Plates 38 and 50). The light-toned thin crown in the centre is of a dominant Sitka spruce. The lower more densely crowned trees are western hemlock.

Plate 52. View on the shore of Juskatla Inlet from the lower edge of Plot 17. A stand including Sitka spruce, western hemlock and western red cedar is shown which grew on a seepage zone on shallowly rooted gravel. The tall spire-shaped crown of a spruce in the centre was typical for hemlock and spruce dominants on this site. Note the generally poor condition of the crowns. This is related to the soil conditions.

Plate 53. Sitka spruce with very narrow spire-like crowns growing on alluvium in the delta of a river flowing into Kitsumkalum Lake. The border shrubs are mainly willow. The shape and poor condition of the crowns is typical of spruce on sites such as this. The trees were shallowly rooted with a wet subsoil. (See also Plate 54).

Plate 54. Sitka spruce with some black cottonwood and bush consisting mainly of willows in the foreground. The stand is on alluvial soil near to Plate 53, on the shore of Kitsumkalum Lake. This is a slightly better site than that shown in Plate 53 and the crowns are better in shape and density.

Plate 55. Old-growth forest, including trees of all ages, on alluvial soil by the River Mamin. Sitka spruce, western hemlock and western red cedar are present; there is some red alder. The crown of a very large and old spruce is seen in the right centre.

Plate 56. Dense regeneration of western hemlock on the site of a felling, at the back of Juskatla camp. This area escaped burning subsequent to felling and most of the organic surface covering was left in position. Few spruce and no western red cedar occur within this clump. See Plate 57. The soil type is shown in Plate 4. In the front is an old dragging road.

Plate 57. Sitka spruce regeneration coming up among charred logs on the site of an old felling behind Juskatla Camp and quite near to Photo 56. The fire destroyed practically all the organic surface covering. The regeneration here is almost entirely spruce; but in many parts it consists of hemlock and spruce mixed.

TABLE 15

Profile and Vegetation Details for Four Plots near or in Kitsumkalum Park

	K4					K5					K6						K2				
	Horizon					Horizon					Horizon						Horizon				
	Depth (in.)	Texture	Consistency	Stoniness %	Rooting	Depth (in.)	Texture	Consistency	Stoniness %	Rooting	Depth (in.)	Texture	Consistency	Stoniness %	Rooting	Profile Details, K2	Depth (in.)	Texture	Consistency	Stoniness %	Rooting
Profile Details L+F ..	1	o.m.	matted	—	s	1	o.m.	very matted	—	s-ab.	1	o.m.	matted	—	i	L+F	2	o.m.	loose	nil	f
H	3	o.m.	soft	—	v.i.	tr.	o.m.	—	—	—	tr.	o.m.	—	—	—	H	1½	o.m.	loose	nil	i
A2	7	S.cS	close compact	50	loc.f	3	S	Sl. compact	nil	ab.	1½	Co.S +Gt.	loose	50	ab	A2	1	Si	very compact	nil	s
B	—	—	—	—	—	25	S	m. comp.	occ.	loc.f.	33	Co.S; S, Gt.	comp.	50	loc. ab-f.	B1B2	5	Sa	comp.-v.comp.	nil	ab.
C	—	—	—	—	—	9	S	v.comp.	nil.	v.s.	(C1)20 (C2)26+	S S†	v.comp. e.comp.	40 nil.	s-v.s. v.s.x	Buried H+A2	1	o.m. Si	comp.-v.comp.	nil	s
G1	10	C+ Gt.	coh.	1	f. in fissures	un-known	C	e.coh.	1	v.s. nil.	—	—	—	—	—	(B)*	32	sL, S Gr.	v.comp.	nil.	f-ab.
G2	Un-known	C	coh.	—	nil.	—	—	—	—	—	x Roots still descending sparsely. † Includes occas. narrow clay bands.					(C)	+60+	sL, S & Gr.	comp.-v.-comp.	Gr. loc.	s-ab ab at base
Tree Species ..	Spruce, Hemlock, Cedar and occasional Pine.					Pine, Hemlock, Cedar.					Pine, Hemlock, Cedar and occasional poor Spruce.					—	Spruce, Hemlock, Cedar.				
Approx. average height of Dominants and Co-dominants. ft.	Spruce—82. Hemlock—79.					Pine—89. Hemlock—76.					Pine—82. (Hemlock—50—all Sub-dominants)					—	Spruce—200. Hemlock—170. Cedar—155.				
Ground Vegetation	Moss cover—95%. *Rhytidiadelphus triquestris* (50 %). *Rh. loreus, H. splendens. C. schreberi.*					Moss cover 40—100%. *H. splendens.*					Moss cover nearly 100% *H. schreberi* (dominant). *H. splendens.*					—	*Fatsia horrida, Clintonia, Dryopteris, Linneana, Athyrium felix- femina.*				
Approximate age (years)	120					120					120					—	All ages. (Large Dominants probably about 300 years).				

Symbols : Soil—om = Organic matter; S = Sand; C = Clay; Gr = Grit; G = Gravel; Si = Silt; L = Loam; c = clayey; s = sandy; comp = compact; co = Coarse; coh. = coherent; e = extremely; a = light; occ. = occasional; m = moderately

Roots— s = sparse ; f = frequent ; ab = abundant ; i = intense ; v = very

+Water-table at about 55 inches.
* Horizon Symbols.
tr. = trace

Kitsumkalum Park

Distribution of Diameter Classes in three Plots—Age ca. 120 years

TABLE 16

Diameter Classes (inches)	K4			K5			K6		
	Spruce	Hem-lock	Cedar	Pine	Hem-lock	Cedar	Pine	Hem-lock	Cedar
1-2	—	—	2	—	1	5	—	103	4
3-5	2	10	1	—	17	7	—	20	—
6-10	4	10	—	22	25	2	26	8	1
11-15	3	2	1	11	2	—	5	—	—
15 +	—	—	1 (21 in.)	—	—	—	—	—	—
Total No. ..	9	22	5	33	45	14	31	131	5
Mean Diam.	8.8	5.9	3.2	9.1	6.4	3.4	9.4	5.2†	6†
Area of Plot (sq ft)	2,178			3,300			3,300		
No. Trees per sq. chain > 2 in. diam.	66†			113†			80†		
Basal area at b.h. (sq. ft.) per sq chain	23.1†			41.1†			24.5†		
Soil	7 in. sandy Gravel over Clay.			37 in Sand over Clay.			53 in. Coarse Sand mixed with rounded cobbles over Sand		

† Not counting trees of less than 3 inches diameter breast-height.

Kitsumkalum Park

Distribution of Diameter Classes on different Soil Types, along a Transect one half chain Wide. Old Growth Stands of All Ages

TABLE 17

Diameter Classes (inches)	0-220 feet			220-380 feet		
	Spruce	Cedar	Hemlock	Spruce	Cedar	Hemlock
1-5	—	11	7	—	4	6
6-10	—	2	3	—	—	11
11-20	—	4	3	1	1	16
21-30	—	1	4	2	1	2
31-40	1	1	2	—	1	—
41-50	1	1	—	—	—	—
51	1	—	—	—	—	—
Soil Texture	Sandy loam			Coarse sand and stones		
Ground Vegetation	*Oplopanax horridum*—herb-fern			Mosses, mainly : *Hylocomium splendens*, *Calliergonella schreberi*		

TABLE 18

Profile and Vegetation Details for Plots T2 and T4

	Plot T2					Plot T4				
	Horizon					Horizon				
	Depth	Texture	Consistency	%Stoniness	Rooting	Depth	Texture	Consistency	%Stoniness	Rooting
Profile details L+F	2	o.m.	closely matted	nil	ab-i	1½	o.m.	matted s. loose	nil	ab
H	Tr.	o.m.	—	—	—	3	o.m.	loose	nil	i
A2	—	—	—	—	—	2	gt L	—	nil	ab
B	13½	C+ occ. Gr and S	e.c.	nil	i-f	13	gt L	v. coh.	35	ab
C	—	—	—	—	—	23+	gt L†	e. coh. hard	30 (grit) 35 (stone)	s in top ; nil
CG1	11	C+ occ. Gr and S	e.c.	nil	nil	—	—	—	—	—
CG2	12+	C+ occ. Gr and S	e.c.	nil	nil	—	—	†Till	—	—
Tree species	Spruce, Hemlock, Cedar.					Hemlock, Spruce, Cedar.				
Approx. average height of Dominants and Co-dominants (ft.)	Spruce—172 Hemlock—136					Spruce—164 Hemlock—151 Cedar—151				
Ground vegetation ..	Suppressed by shade :— *Oplopanax horridum* ; *Dryopteris linneanna* ; *Athyrium felix-femina* ; *Rhytidiopsis robusta* ; *Hyl. splendens* ; *Cal. schreberi* ; *Plagiochila aspleniodes.*					*Clintonia uniflora* ; *Cornus canadensis* ; *Oplopanax horridum* (occas.) ; *Ath. felix-femina* (occas.) ; *Rhyt. robusta* ; *H. splendens* , *C. schreberi.*				

Symbols :

Soil : o.m.=organic matter; C=clay; S=sand; L=loam; gt=gritty; e=extremely; c=coherent; v=very; s=slighty

Roots : i=intense; ab=abundant; f=frequent; s=slight

CHAPTER 6

Sitka Spruce in Forest on Skunk Cabbage (Lysichiton camtschatcensis) sites

1. Lake Lakelse is situated about fifteen miles to the south of Terrace. It was at one time of appreciably greater area and around its sides the old lake bed now remains in the form of flat land which is wet and swampy in many places. These wet places are often occupied by skunk cabbage, sometimes as a pure community, but more often in association with other plants. A place on which skunk cabbage grows is not necessarily wet on the surface, but there is always a wet horizon quite near the surface of the soil. Often, however, it grows in more or less swampy places which occur as a series of shallow hollows between low ridges of better drained ground. The forest trees grow on these ridges, in the main ; but they send their roots across the surface of the wet places, never descending very deeply below this. Skunk cabbage itself often roots quite deeply into the underlying wet ill-drained soil. There are many variations in plant association in these skunk cabbage areas, and this plant itself grows to very varying size according to the nature of the site. A special study would be needed to characterise the many variations which occur and it is not intended to enter into these here. The better skunk cabbage plants occur in wet places in which there is moving water : here the leaf blade may be as much as three feet long and remain a deep beautiful green until the end of the summer. Red alder may grow strongly, and also *Rubus spectabilis*, *R. parviflorus*, *Viburnum trilobum* and large *Cornus* species (Plate 42). Such places give the impression that there is active nitrification, at least in the soil surface. The poorer sites are in relatively stagnant situations : the principal mosses are *Sphagnum* species ; *Drosera rotundifolia* and *Menyanthes trifoliata* may occur with these in the wetter places. Skunk cabbage usually occurs only locally and where there is some indication of less stagnant conditions. Its leaf blade may be no more than twelve to eighteen inches long ; it may be yellowish in colour and round the edges turn brown and die by the middle of August.

2. The quality of the forest varies largely according to the extent of the intervening ridges or humps, and the character of these with regard to soil texture and drainage : for example, some of the poorer sites round the settlement of Lakelse consist of an alternation of wet bog and masses of large stones deposited in time past in the fan of Granite Creek. Spike-topped cedars are the predominant trees in such areas ; a few equally tall or taller spruce, the crowns of which are very narrow and in poor condition, also occur. Hemlock is usually numerous as a sub-dominant of poor form and size. The more fertile skunk cabbage sites may show no alternation of wet and dry areas, and bear closed forest of moderately good site index value : the dominant species are cedar and spruce ; hemlock makes a good tree, but occurs mostly as a sub-dominant (Fig. 19). Skunk cabbage does not reach its finest development on such sites, the surface soil of which is too well-drained to favour its development to a large size. A few examples are discussed below to illustrate some aspects of this regression in fertility in terms of forest growth. Their interest here lies principally in the light they throw on the habits of Sitka spruce and its associated species. It should be realised that they illustrate only a few aspects of a very complex ecological situation.

3. The forest in a skunk cabbage area which consists of a reticulation of relatively well-drained ridges filled in with wet ill-drained hollows, is necessarily poorly stocked, from a forestry standpoint, since it is only on the drier parts that trees are able to grow satisfactorily. This is illustrated by Figs. 16, 17 and 18. The size of tree which develops is determined largely by the nature and drainage of the soil in the higher parts and by the extent to which the wetter can be utilised by the root systems. Thus, in the examples (data for which are given in Tables 19, 20 and 21), of the plots which show this reticulate pattern of ridges, Plot L12 (Fig. 16) on deep peat and with wet hollows, shows the poorest growth. The better growth is shown by Plot L56 (Fig. 18), in which the soil was clay, both in the humps and hollows ; the surface soil in the latter was much better drained. None of the plots, however, has a complete canopy because of the nature of the soil ; but Plot L8 (Fig. 19), in which there was an even distribution of moisture horizons and generally a well-drained surface, has such a canopy.

4. The nature of the vegetation in the hollows is often some guide as to the fertility of a site for the growth of trees. The size and condition of the skunk cabbage leaves are of some help in this matter. These leaves were green and in good condition in all the areas here discussed. The larger size of leaf occurred in Plot L34 (Plate 42, Fig. 17), in which the soil consisted of shallow peat overlying silt : this

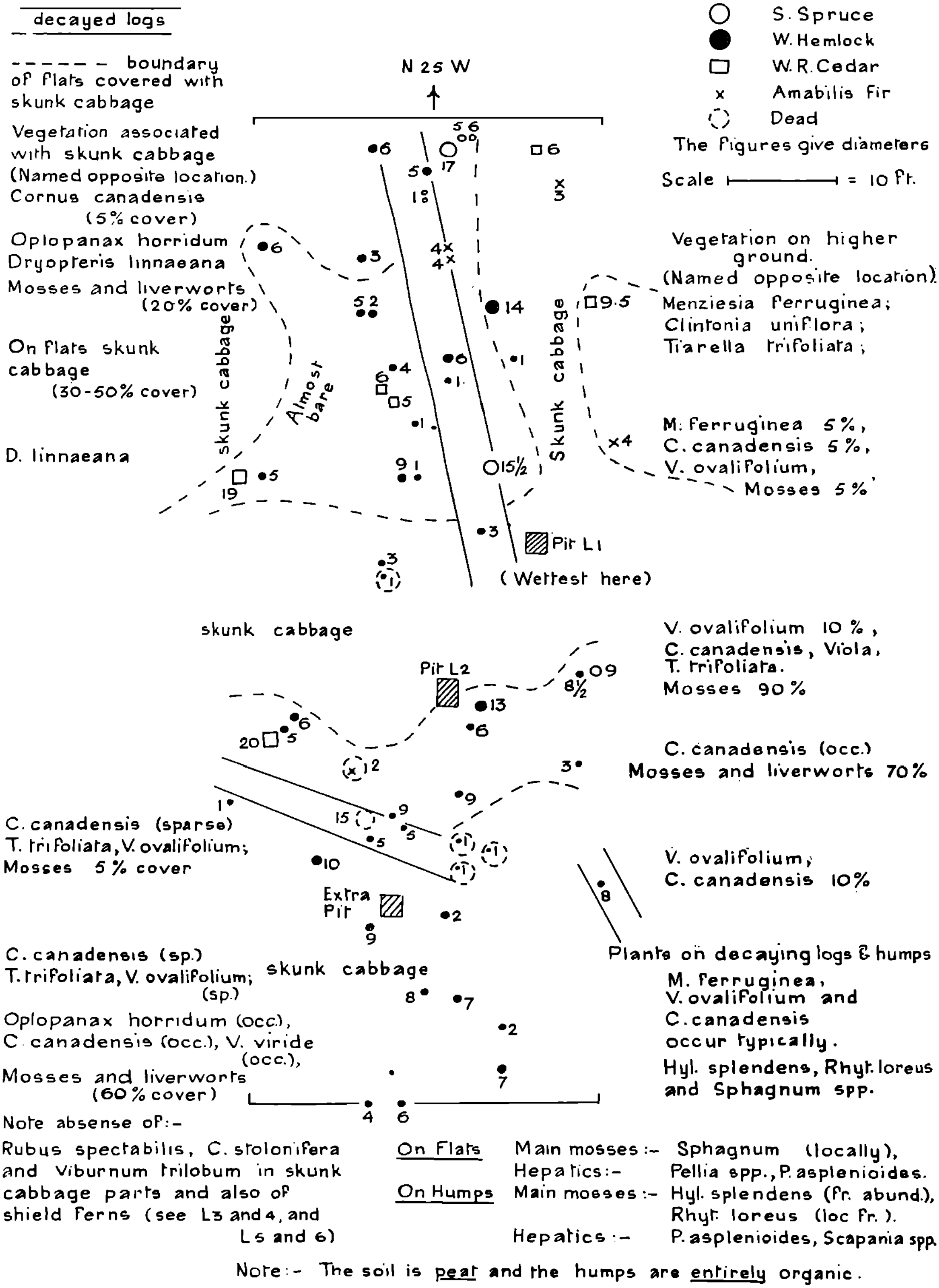


FIG. 16

Plot L12. An area of swamp forest characterised by skunk cabbage (*Lysichiton camtschatcensis*) is shown. The soil is entirely organic (Table 20). Characteristically the main dominant is cedar; the tallest dominant is Sitka spruce ; the most frequent species of tree and characteristically sub-dominant, is hemlock (Table 19). The skunk cabbage areas were wet and almost bare of other vegetation (compare Figs. 17 and 18).

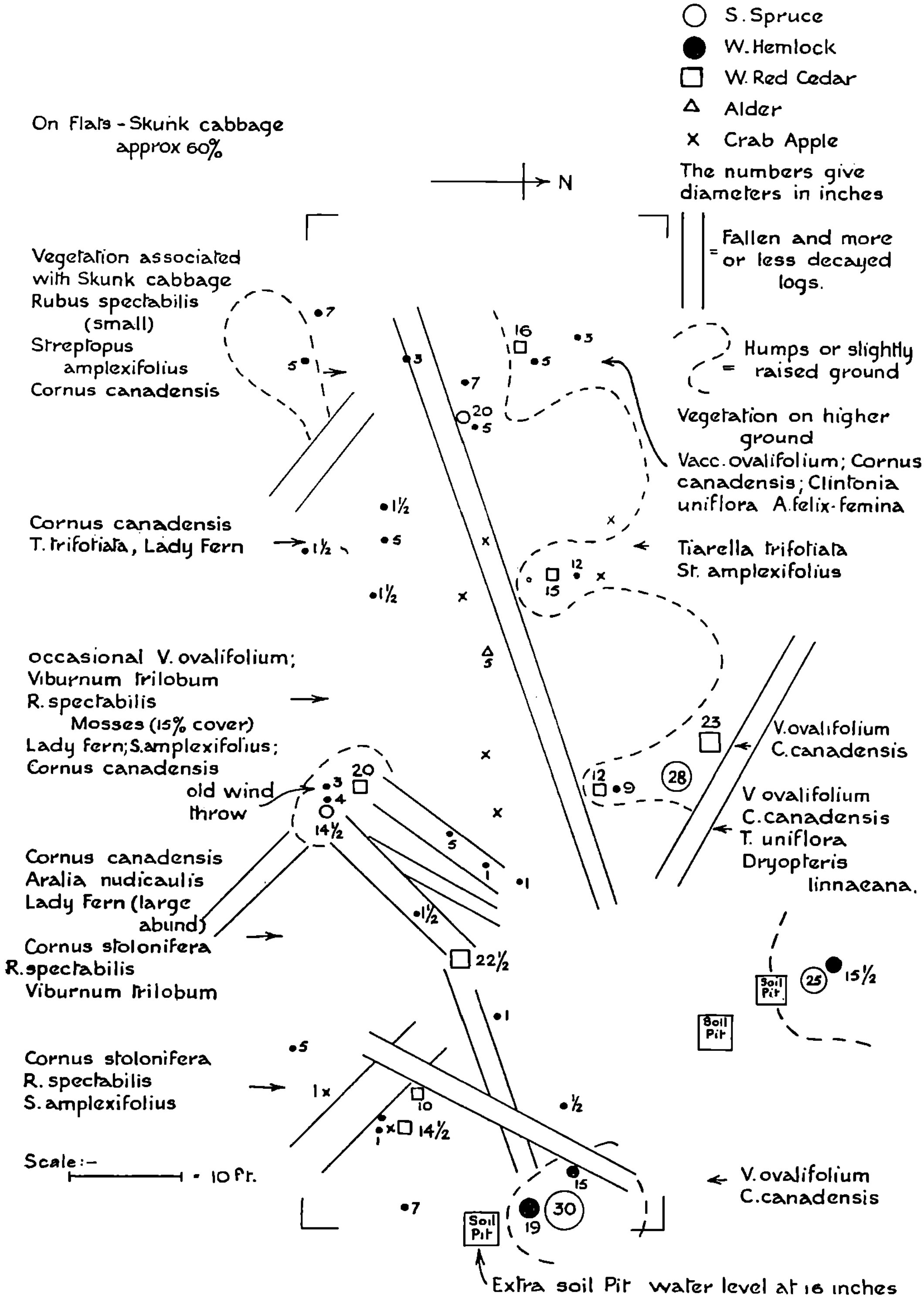


FIG. 17

Plot L34. An area of skunk cabbage swamp forest which grew on a shallow organic soil overlying a clayey silt (Table 20). It is of a slightly drier type than Plot L12 (Fig. 16). This is marked by the occurrence of *Athyrium felix-femina* and also *Rubus spectabilis* and *Viburnum trilobum* in the skunk cabbage areas. The trees are also taller than in Plot 12 (Table 19).

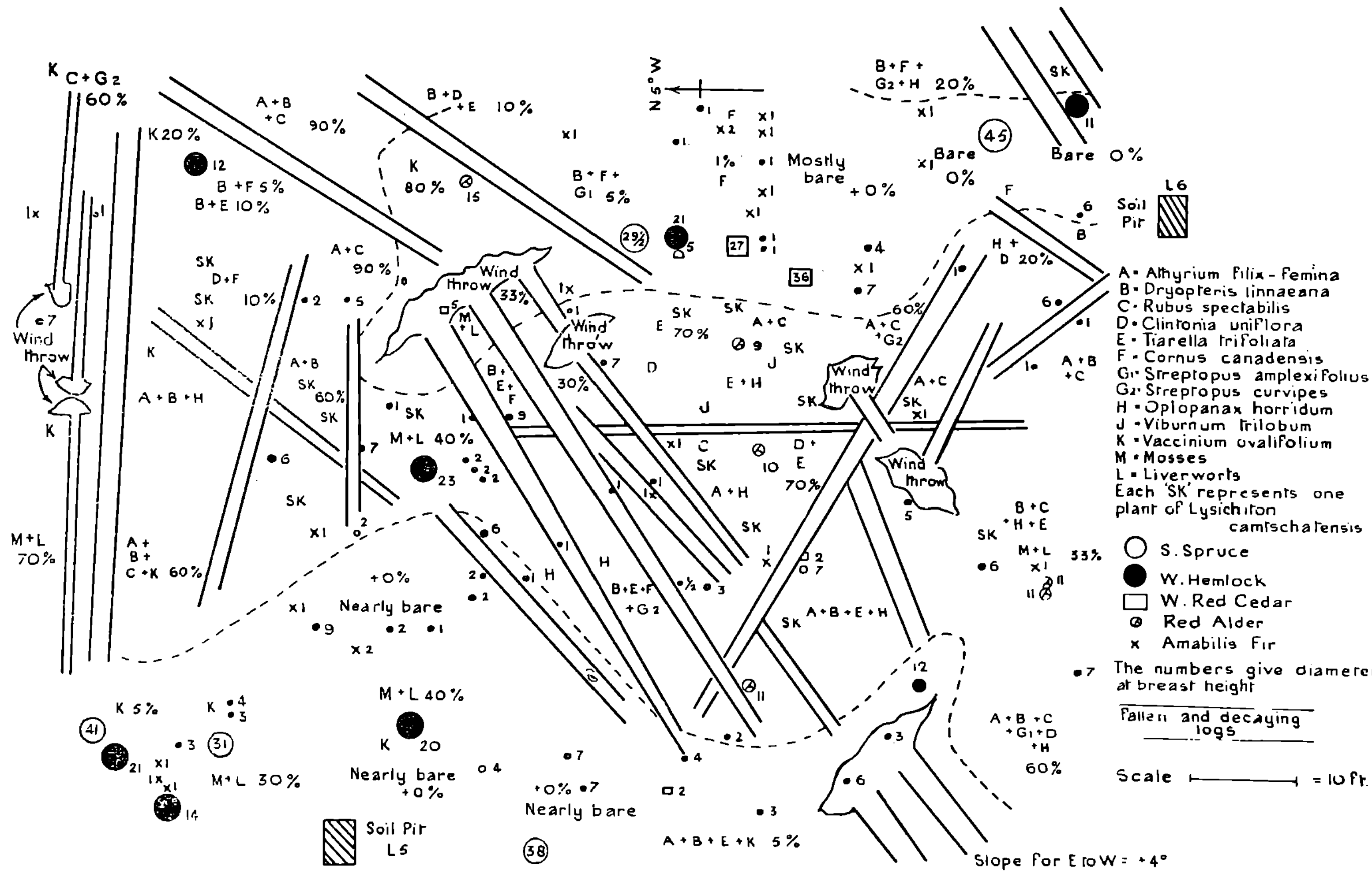


FIG. 18.

Plot L56. An area of skunk cabbage swamp forest in which both the wet hollows and the humps have a clay soil (Table 20). This is a relatively dry type in which the surface of hollows is not swampy during summer. Small trees and shrubs occur quite commonly in them, but skunk cabbage only as an isolated scattered plant. The spruce and cedar dominants are of large size (Table 19) : compare with Figs. 16 and 17. The frequency of wind-thrown trees reflects the shallowness of rooting ; but note that the trees turned over were consistently smaller than the large dominants.

coincided with the occurrence of a moderately dense and well-grown shrub layer which consisted of salmonberry, dogwood, guelder rose, crab-apple and alder. The hollows here were sufficiently drained to support this woody undergrowth, though not to act as the actual site of large trees, all of which grew on humps or ridges. Both the size of the skunk cabbage leaves and the condition of the shrub layer become poorer as conditions for the growth of trees become either better or worse. They are worse in Plot L12, on deep peat and with wet hollows covered almost entirely by skunk cabbage ; and in Plot 56 (Plate 43) where the hollows have a clay soil and skunk cabbage occurs only as a scattered plant (Fig. 18). It will be seen that in the hollow in Plot L56, shown in this figure, there is a scattering of small trees, mostly hemlock. Conditions here, in fact, approach, though they do not actually reach, the state in which the development of a closed high canopy is possible. The shrub layer is relatively poor in this plot ; but in Plot L8 it was practically non-existent. This area, in which there were no wet hollows, approaches the limit for the development of skunk cabbage as soil drainage improves, the soil itself being good. A comparatively slight increase in the depth of well-drained surface soil is sufficient to eliminate this plant. Plots K1, K3 and L7 (Table 22) illustrate this. Skunk cabbage grew near to or actually within each of these plots, though in ditches, or the flood channels of creeks, which were at a lower level than the actual forest floor (Figs. 20, 22 and 23). In the case of the area in which Plot L7 (Fig. 20) was situated, for example, a drop of about two feet on to an adjacent area was sufficient to change the type of ground vegetation from tall shield fern to skunk cabbage with short salmonberry bushes. The change in tree species was from dominantly Sitka spruce to dominantly western red cedar, both species being present in each place. A further drop in level brought one into the ridge and hollow type of surface relief, with skunk cabbage as the sole dominant in the wet hollows : a type very near to that illustrated by Plots L12 and L34 (Figs. 16 and 17), but more fertile because the ridges consisted of fairly good mineral soil.

5. Trees are, of course, an essential part of the vegetation type in any forest area and, in the type of area discussed, in which there is often an irregular distribution of widely differing types of ground vegetation, they act as a unifying factor, in that their roots spread both within the drier areas and over the surface of the wetter. The proportionate occurrence of tree species, as well as the size and condition of the dominants, varies according to the nature of the soil and the depth to which good drainage occurs, both in the higher and the lower parts.

An examination of Figs. 16 to 19 and Tables 19 to 22 will illustrate this. It may be said that in general western red cedar is the characteristic dominant in skunk cabbage areas : the poorer the site the more obvious are the cedar ; the poorer their condition, the smaller their height growth ; and the greater is the number of dead silvery spiked tops which occurs among them.

All species of tree improve in size and condition as soil conditions improve, but the proportionate constitution of the high canopy alters also. Thus, in Plot L12, which illustrates a moderately poor type, cedar is the prevailing dominant, though Sitka spruce is the tallest tree ; hemlock is entirely sub-dominant. Plot L34 (Plate 42) is a stage better : all species are taller, spruce is much more common, hemlock makes a sizable tree, but is still mainly sub-dominant ; but the most common dominant is still cedar. Plot L56 (Plate 43), in which the soil of the ridges and hollows is not organic, but consists of clay, shows a stage further in the proportionate change in species. All species are taller still, but spruce is the most common dominant, cedar being the other main dominant. Hemlock is still principally a sub-dominant, but makes a tree of moderately good size.

The next stage in old growth forest is really shown by Plot K3 (Fig. 23, Table 22), in which the better drained ridges are so large that the trees are independent of the wet hollows. The most common dominant here is hemlock, the next cedar, but the tallest dominant is still spruce. This plot is, in fact, in the main, an example of old growth forest on alluvial soil which is too well-drained to support skunk cabbage, but in which there is a water table fairly near the surface.

The neighbouring Plot K2 (Fig. 12, Table 15) provides a further example, but of one in which the water table is much deeper : the soil surface is mature in both cases. Plot K1 (Fig. 22, Plate 41, Table 22) provides an example of old-growth forest on alluvial soil which also is just too well-drained to support skunk cabbage, but the soil surface here is being continually renewed by silt during flooding. It is not improbable that the height of this has been raised appreciably during the lifetime of the present dominants which are spruce and cedar, and that these were established under conditions which were much nearer to those illustrated by Plot L8, in which the ground vegetation is skunk cabbage associated with strongly growing shield ferns.

6. Plots L7 and L8 also provide an illustration of difference in proportionate composition of the high canopy on transition from a site with a very shallow depth of well-drained soil to one that is deeper, with the consequent change in ground vegetation from a skunk cabbage-fern type (L8,

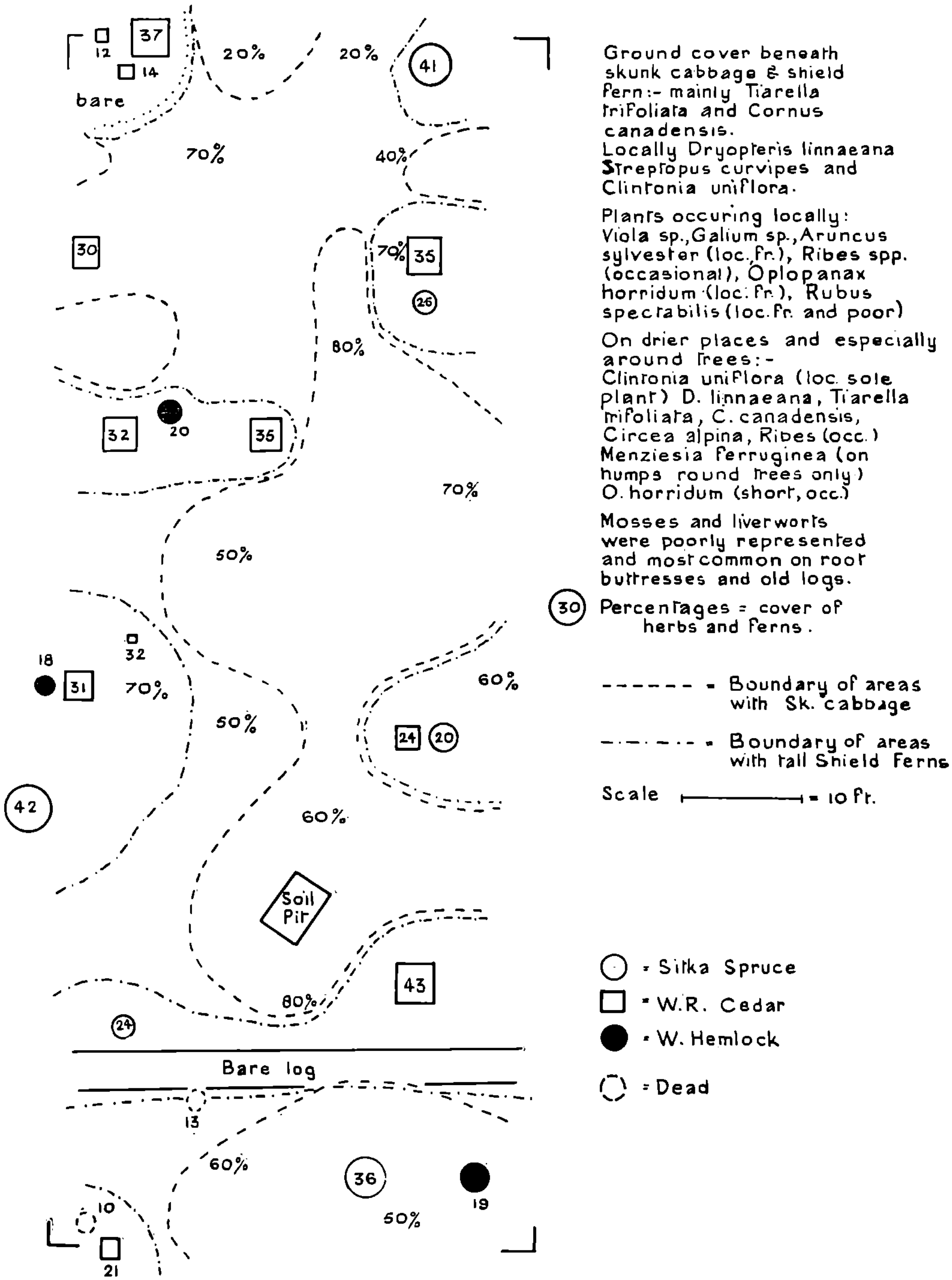


FIG. 19.

Plot L8. A flat area with a shallowly rooted ill-drained, alluvial soil. The presence of skunk cabbage is made possible by the occurrence of wet, sodden soil within a few inches of the surface of the ground. Features to be noted are, the relatively dense ground cover combined with an absence of tree seedlings and the absence of fallen logs. As the trees had clean boles, indicative of early suppression of branches, this implies that the natural thinning of the stand took place early (compare with Figs. 14 and 15 in which the dominants were much older). Fig. 20 shows an area on similar but better drained and more deeply rooted soil and in the same general situation. See Tables 12, 20 and 22 for other data.

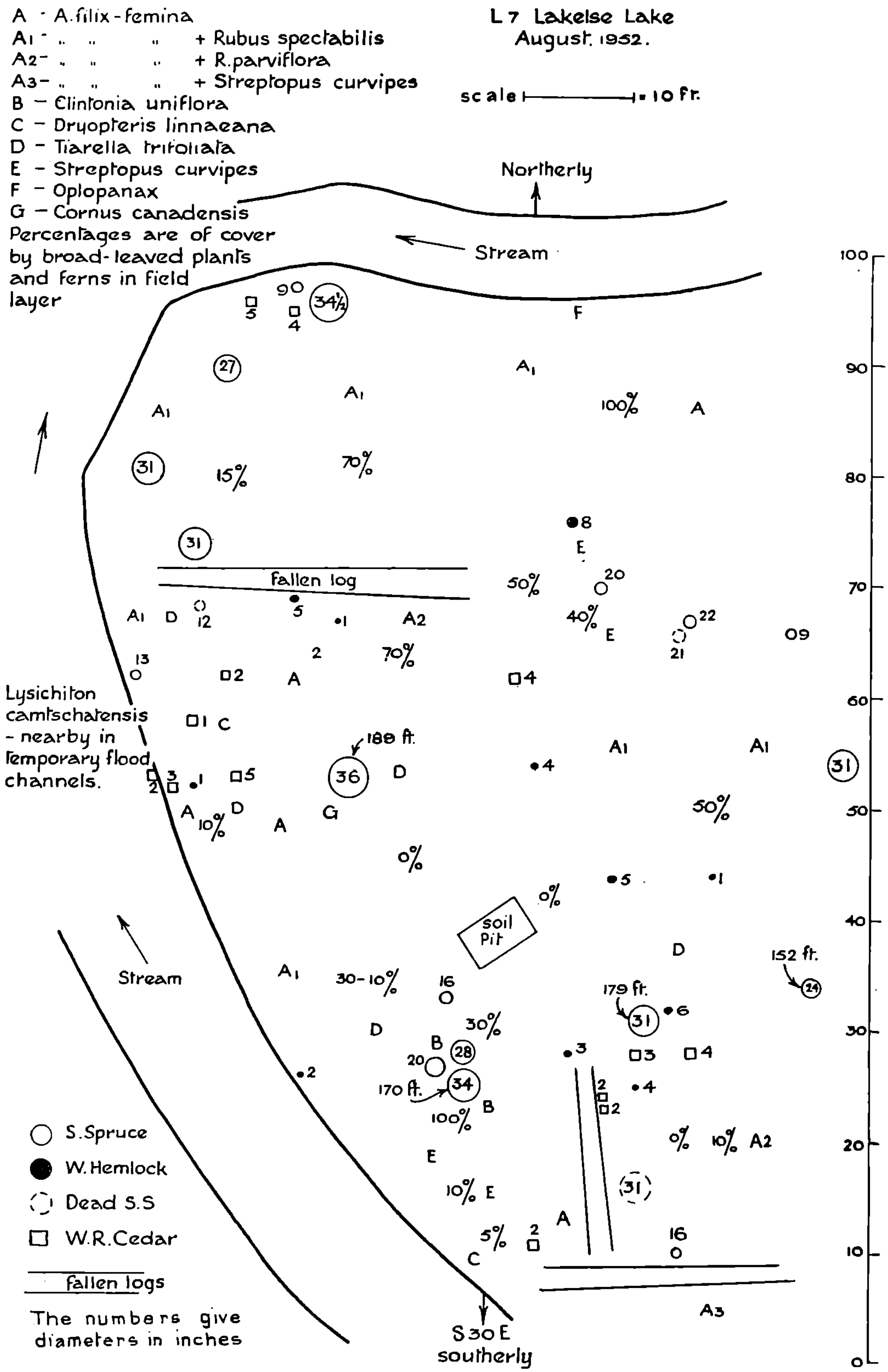


FIG. 20 (*caption opposite*).

Table 22) to a fern type (L7. Table 20). These two plots occurred near to each other ; they were both relatively even-aged and of about the same age (circa 125-130 years at breast height). The chief soil difference between them is that in L7 there is about two feet more of well-drained soil than in L8 ; also L7 has a leached surface, while the surface of L8 is a mull with a crumb structure. It will be seen from Figs. 19 and 20 that in L8 the cedar is the principal dominant, then Sitka spruce, while hemlock occurs relatively rarely ; but in L7 the stand consists entirely of spruce (Plate 44, Fig. 20). It may be taken that this plot is in a successional stage of development, and that the composition of the high canopy may be expected to change in the course of time. The change from predominantly cedar to predominantly spruce on passing from a relatively wet to a relatively dry site seems, however, to be typical of the forest on the alluvial lake-side flat on which these plots were situated. It would appear probable that both these plots regenerated after some catastrophe which destroyed the previous forest, this accounting for their even-aged composition. It appears that on any adequately moist surface on sufficiently well-drained soil, exposed in this manner, spruce tends to be the main dominant at first : Plot L9 (Fig. 21, Table 22) taken in a stand regenerated after fire illustrates this.

7. The conclusion of this examination of forest associated with skunk cabbage and of that on slightly better-drained sites on which this plant does not occur, is that there is a general trend in the proportionate specific composition of the forest which is related to drainage conditions. The general soil character in texture and structure is also important, though this is not specially illustrated here. The forest on the wetter skunk cabbage types shows western red cedar as the characteristic dominant, but Sitka spruce occurs sparsely as an equally tall tree. Hemlock, however, occurs mainly as a subdominant, or understorey, tree. The proportion of spruce in the high canopy rises as the soil becomes better drained ; hemlock, too, takes an increasingly important position, but so long as skunk cabbage is still a characteristic plant of the site, cedar still remains the main dominant species.

Cedar, however, ceases to be this usually, on transition to sites which are too well drained to bear skunk cabbage, even though still moist and with a fairly high water-table. Spruce now tends to be the main dominant, though cedar still may occur frequently as a dominant ; hemlock also definitely takes a place in the high canopy and with the development of a mature soil surface as determining the proportionate regeneration of species, may possibly become the main dominant. This sequence in development is not suggested as indicating more than a general tendency. Exceptions could be quoted quite easily, and plainly much more work is needed with regard to these things. It does, however, seem to be quite clear that the position of Sitka spruce in the complex of skunk cabbage types is quite different to that which it takes in the complex of types which occur in Graham Island in association with the progression from *Sphagnum* bog to salal bush. There spruce did not appear as a dominant until the more fertile sites had been reached : on skunk cabbage sites, however, it appears as a dominant, though sparsely, even on poor sites. The difference seems to lie in the different nutrient conditions suggested by the different types of vegetation which define the two progressions : on the one hand a progression to salal bush, from poor peat bog dominated by *Sphagnum* ; on the other from a wet swamp dominated by skunk cabbage, through types in which this plant is associated with shrubs (*Rubus*, *Cornus*, *Viburnum*, *Oplopanax*), or with ferns, to a moist, but at least superficially, well drained type characterised by devil's club, ferns and herbs. The one progression suggests a condition in which nitrification is at a minimum ; the other one in which it is appreciable ; it may be suggested that here, probably combined with other advantages, are to be found the factors which enables spruce to take a relatively prominent place as a dominant, as compared with hemlock, in what are admittedly poor types of forest. Obviously further investigation is needed and it would be tedious to attempt further analysis in face of a general lack of observations. However, the dominant height growths attained in the two progressions (compare Tables 8 and 9 with Table 19) suggest that the sites in skunk cabbage areas, on which trees are able to form forest, are more fertile than those found in the salal bush sites investigated in Graham Island. It has already been suggested that the ability of Sitka spruce to demonstrate its greater growth potential relative to that of western hemlock and western red cedar depends on there being an adequate degree of soil fertility. This short analysis of skunk cabbage types suggests that chemical, and not merely physical edaphic factors, are of considerable importance in determining this, and that on sites characterised by skunk cabbage these are more favourable than on those characterised by salal.

Plot L7. A flat area, moderately deeply rooted, but having a soil of very similar physical composition to that of Plot L8 (Fig. 19). The age of the dominants in the two plots is very similar, but the spruce in this plot are appreciably the taller. The greater height and the greater density of stocking seem clearly to be related to the greater rooting depth. The soil here is just too well-drained to permit of growth of skunk cabbage, which occurs only in flood channels of the stream.

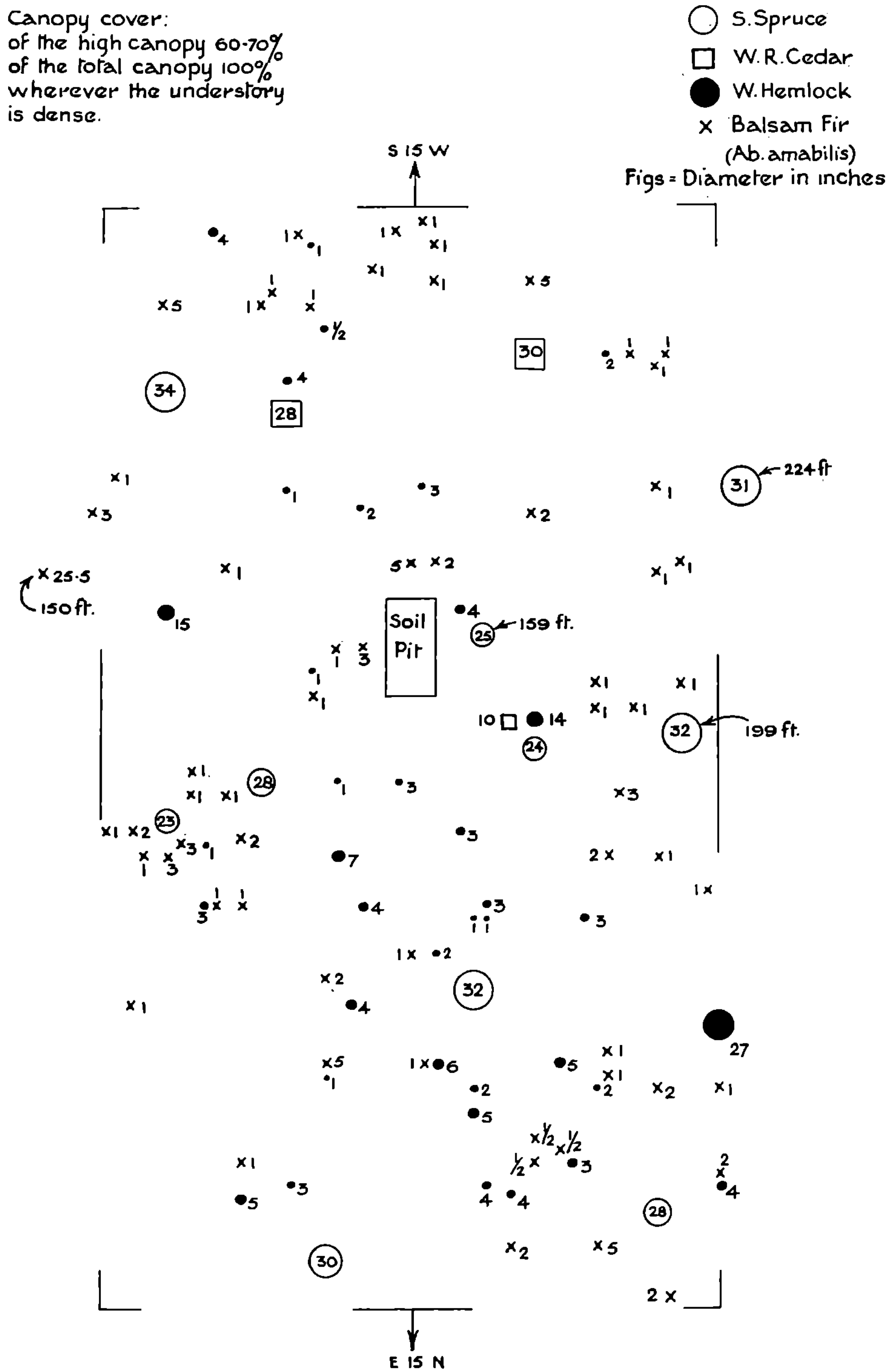


FIG. 21.

Plot L9. A stand dominated by tall spruce and growing on a soil which consisted mainly of broken rock (Tables 19 and 22), The site was on a side moraine, at the foot of a mountain slope and in a water-receiving situation. Plot L8 (Fig. 19) lay about ½ mile away to the west. This area was regenerated after fire. The great height of the spruce is related to the water passing through the rock debris which mainly formed the soil and the abundance of the understorey to crown debility caused by root die-back on the dominant trees. Some of the tall spruce here are younger than the large hemlock.

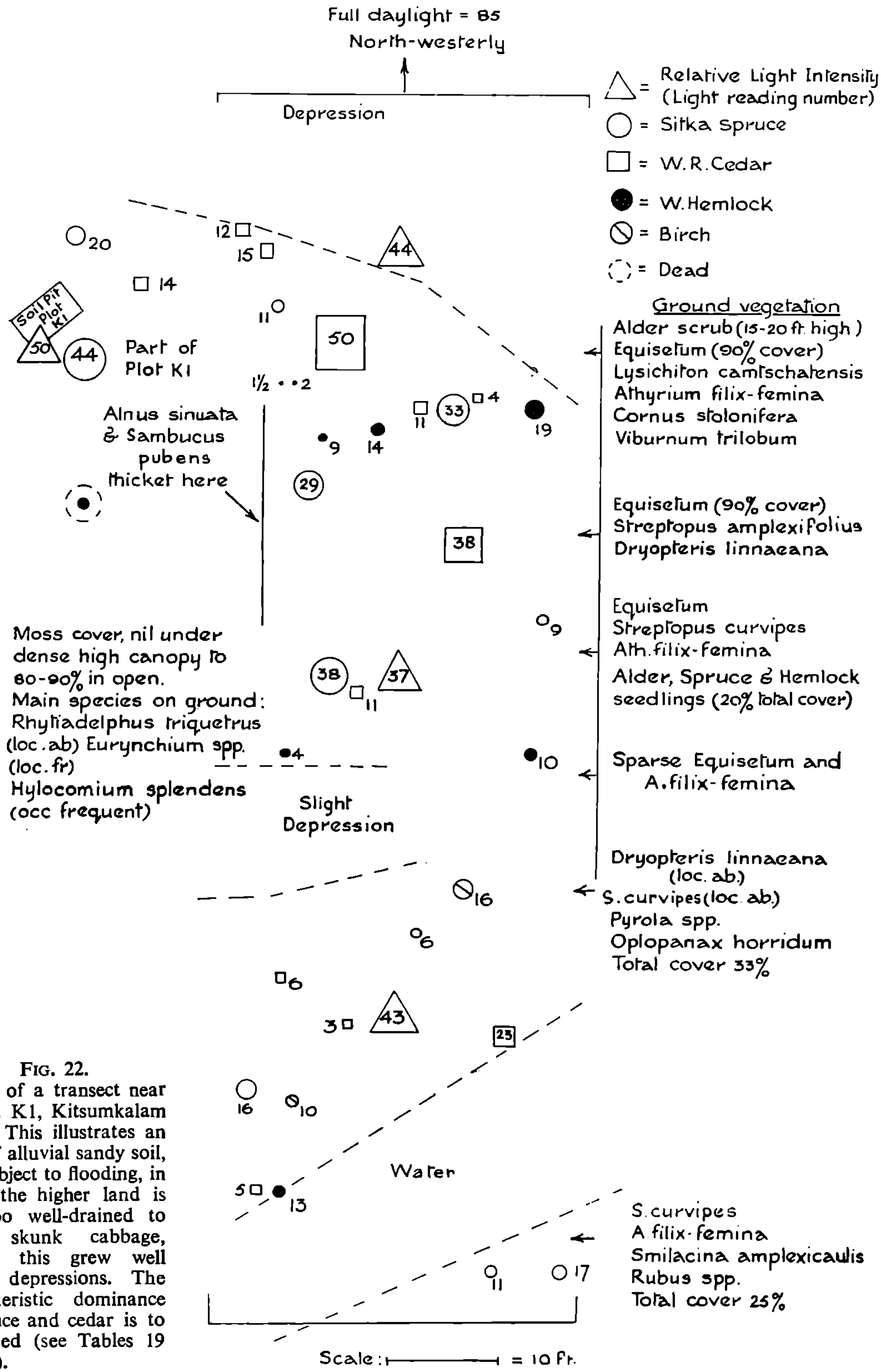


FIG. 22.

Part of a transect near to Plot K1, Kitsumkalam Park. This illustrates an area of alluvial sandy soil, still subject to flooding, in which the higher land is just too well-drained to carry skunk cabbage, though this grew well in the depressions. The characteristic dominance of spruce and cedar is to be noted (see Tables 19 and 22).

Heights and Diameters of Dominants and Co-dominants

TABLE 19

Plot No.	Age (years)	Approx. Mean Height (feet)			Height of Tallest Tree measured (feet)			Approx. Mean Diameter (inches)		
		Spruce	Cedar	Hem-lock	Spruce	Cedar	Hem-lock	Spruce	Cedar	Hem-lock
*L 12	All ages	101	89	70†	116	101	70	18	17.5	—
*L 34	All ages	114	94	77†	122	97	95	26	18	15.5
*L 56	All ages	160	133	117†	173	138	140	38	41	22
*L 8	130 (at b.h.)	150	120	114	165	114	125	30	29	20
§L 7	125 (at b.h.)	166	—	—	189	—	—	32	—	—
L 9‡	All ages	187	133†	169	224	133	171	33	26	27
§K 1	All ages	150	not measured	—	167	not measured	—	39	37	—
§K 3	All ages	178	126†	161	183	132	173	52	36	36

† All, or mainly, in the sub-dominant canopy.
‡ One *Abies amabilis* was 150 ft. high.
* Plots in skunk cabbage (*Lysichiton camtschatcensis*) areas.
§ Plots with skunk cabbage in channels passing through, or beside, them.

Soil, Rooting and Vegetation Details for Plots, bearing Skunk Cabbage, round Lake Lakelse

TABLE 20

Plot Number	L 12	L 34	L 56	L 8
Dominant Ground Vegetation	Sk. cabbage (24 in. blades)—60% cover *Pellia* ; *Plagiochila*	*Rubus-Viburnum-Cornus* (6-8 ft. high) Sk. cabbage (30 in. blades) Ferns ; *Rhytidiadelphus triquetris*; *Plagiochila*	*O. horridum-Rubus* (2-3 ft.) Ferns ; Sk. cabbage (scattered plants—18 in. blades); Occ. Alder and Hemlock	*F. horrida-Rubus* (loc. 4-5 ft.) ; Ferns (30 in. fronds)—30% cover; Sk. cabbage ; (24 in. blades—30% cover) ; *Tierella* ; *Clintonia*
*Soil Type	Deep Peat	Shallow Peat	Gley	Gley
*Main Rooting Depth (in.)	No large tree roots	10	7	5½
*Total Rooting Depth (in.)	12	10	12	15‡
*Rooted Soil	Peat	Peat	Clay	Silty sand
Unrooted Subsoil ..	Peat	Silt	Clay	Silt and Peat alternating
Material in humps or ridges	Peat	Peat	Clay	No appreciable humps
Approx. Mean Ht. (ft.) of Dom. and Co-dom. Spruce	101†	114†	160†	150§

† All ages present.
* Refers to the wet areas bearing Skunk cabbage in L12, L34 and L56 and not to the intervening humps which bear the forest trees (see Table 21).
‡ Very moist, becoming wet below 10 inches.
§ Aged 130 years at breast ht.

Soil, Rooting and Vegetation Details for the Ridges in Skunk Cabbage Plots (see Table 20 for Hollows)

TABLE 21

Plot Number	L 1-2	L 3-4	L 5-6 Mostly bare
Dominant Ground Vegetation	*Vaccinium ovalifolium* ; *Menziesia ferruginea* ; *Cornus canadensis* ; *Hylocomium splendens* ; *Scapania* spp.	*Vacc. ovalifolium* ; *Menz. ferruginea* ; *Cornus canadensis* ; *Rhytidiadelphus triquestris* ; *Hylocomium splendens*	*Vacc. ovalifolium* ; *Oplopanax horridum* (small and occ.) *Cornus canadensis* ; *Dryopteris linnaeana* ; *Rhytidiadelphus triquestris*; *Hylocomium splendens*
Soil Type	Peat	Peat	Gley
Main Rooting Depth (inches)	21	26	11
Total Rooting Depth (inches)	21	26	11
Rooted Soil	Peat	Peat	Humus + Clay
Unrooted subsoil	Peat	Silt	Clay
Approx. mean ht. of Dominant and Co-dominant Spruce (feet)	101	114	160

Trees of all ages occurred in all the plots.

Soil, Rooting and Vegetation Details for Plots near Skunk Cabbage Sites (K1, K3 and L7 and Plot L9)

TABLE 22

Plot Number	K1	K3	L7	L9
Dominant Ground Vegetation	*Equisetum* spp. (85% cover) ; *Rubus parviflora* ; Ferns	*Clintonia uniflora* ; *Cornus canadensis* ; *O. horridum* (loc.)	*O. horridum-Rubus* (3 ft.-loc.) ; Ferns (4 ft. fronds 60% cover) ; *Tierella*; *Clintonia uniflora* ; *Streptopus*	Mostly bare ground with understorey of *Tsuga* and *Abies* ; *F. horrida* ; Ferns ; *Clintonia uniflora* ; *C. canadensis* loc.
Soil Type	Immature (Alluvial Flood Bench)	Podsol	Podsol	Podsol
Main Rooting Depth (inches)	†19	†15	†41	over 65
Total Rooting Depth (inches)	33 (Roots dead below 19 inches)	27	41	over 65
Rooted Soil	Fine sand	Silty sand	Silt	85% angular stones with sand
Unrooted subsoil	Fine sand (water table)	Silty sand (water table)	Silt	Compact water-holding material probably starting at ca. 84 inches
Approx. mean ht. of Dom. Spruce (feet)	150	178	166	187
Age	All ages	All ages	125 years at b.h.	All ages

† Soil very moist or wet below this depth.

CHAPTER 7

The Conditions Affecting the Establishment of Seedlings Within the Forest

1. The conditions of the soil surface as affecting the establishment of seedlings are among the more important factors which determine what the proportionate composition of the forest shall be, through the extent to which they favour one or other of the species of tree, seed of which is distributed over the area. This is a complex matter with regard to which it is possible to offer only a few observations made within the restricted areas worked in. There is an historical aspect to this subject which it is not possible here adequately to discuss. It may be taken that the forests, in both the regions worked in, developed after the retreat of ice and that, with variations in constitution which can only be estimated, they have continued in existence for some thousands of years. It would appear that the specific composition during this time has been much what it is at present, taking the region as a whole. One is concerned thus, with the manner in which the proportionate specific composition of this forest has been affected by the conditions which determine the establishment of seedlings and especially with the evidence with regard to this offered by the forest standing at the present day.

2. The simplest conditions prevail when the forest has been cleared, as by fire or felling ; or destroyed, as by wind-throw. Observation shows clearly that, providing a source of seed is available, any of the tree species may be favoured by a disturbance of the soil surface. Thus the banks of soil pushed up by bulldozers at the sides of roads may make excellent seed beds : for example, some along Branch 1, at Juskatla, in places were covered quite thickly with Sitka spruce and western hemlock; western red cedar occurred to some extent. There was no organic covering to the soil in this case, but some shade was given by the neighbouring forest. Clear felling clearly also favours regeneration ; for example, thickets of alder become established in suitable sites and especially those which are water-receiving, as in the bottom and on the lower slopes of valleys. Thus the bright green of broadleaved trees, in the bottoms of valleys which had been cleared in felling, was very conspicuous, in the spring of 1952, when flying north from Vancouver. It is quite clear that, after a catastrophe such as a fire, alder may become much more widely distributed than it afterwards is able to maintain itself ; for the dead and rotting remains of alder stems can frequently be found in suitable sites, in forest which has been regenerated after fire, or if the stand is young enough, the trees themselves occur.

The felled areas in the Mamin River valley, behind Juskatla, are mainly on land with a well-drained soil surface. The regeneration almost entirely consisted of spruce and hemlock; both usually occurring in sufficient abundance eventually to form a closed canopy. The area behind the camp was cleared and partly burned in the early 1940's ; Sitka spruce was the principal seedling on the burned areas; but hemlock might be the only species on places where there had been no burning or great disturbance of the surface organic covering of the soil (Plates 56 and 57). It would appear that the exposure of the mineral soil favours all species; but that, in this region, retention of the organic covering favours hemlock against alder, spruce or cedar. It is, of course, difficult to be certain what has happened on such areas without knowing more with regard to their history and especially the original distribution of seed. Of the three main species of conifer, that which appeared least often as regeneration on felled areas with well-drained soil surface was western red cedar ; it was certainly suggested that in Graham Island such openly exposed areas presented conditions which were unfavourable to this species, which may require a more moist, or more shaded soil surface than they present during summer.

3. There was only slight opportunity to examine the conditions in alder thickets for the regeneration of conifers, in Graham Island. This tree always seems to grow faster when young than any of the conifers on soil which suits it. It seems to be quite certain that no species of conifer will become established where it occurs in really dense young thickets ; or if any is established concurrently with the alder, on a site which is suited for the rapid early growth of this species, the conifer will remain suppressed until the alders open out. Spruce, cedar and hemlock may be seen as seedlings under alder, however, providing the canopy is sufficiently light. It was certainly suggested that the density of colonisation by conifers under alder, and similarly under black cottonwood along the Skeena River, may be very irregular and probably, from the point of view of intensive management, often inefficient. The same

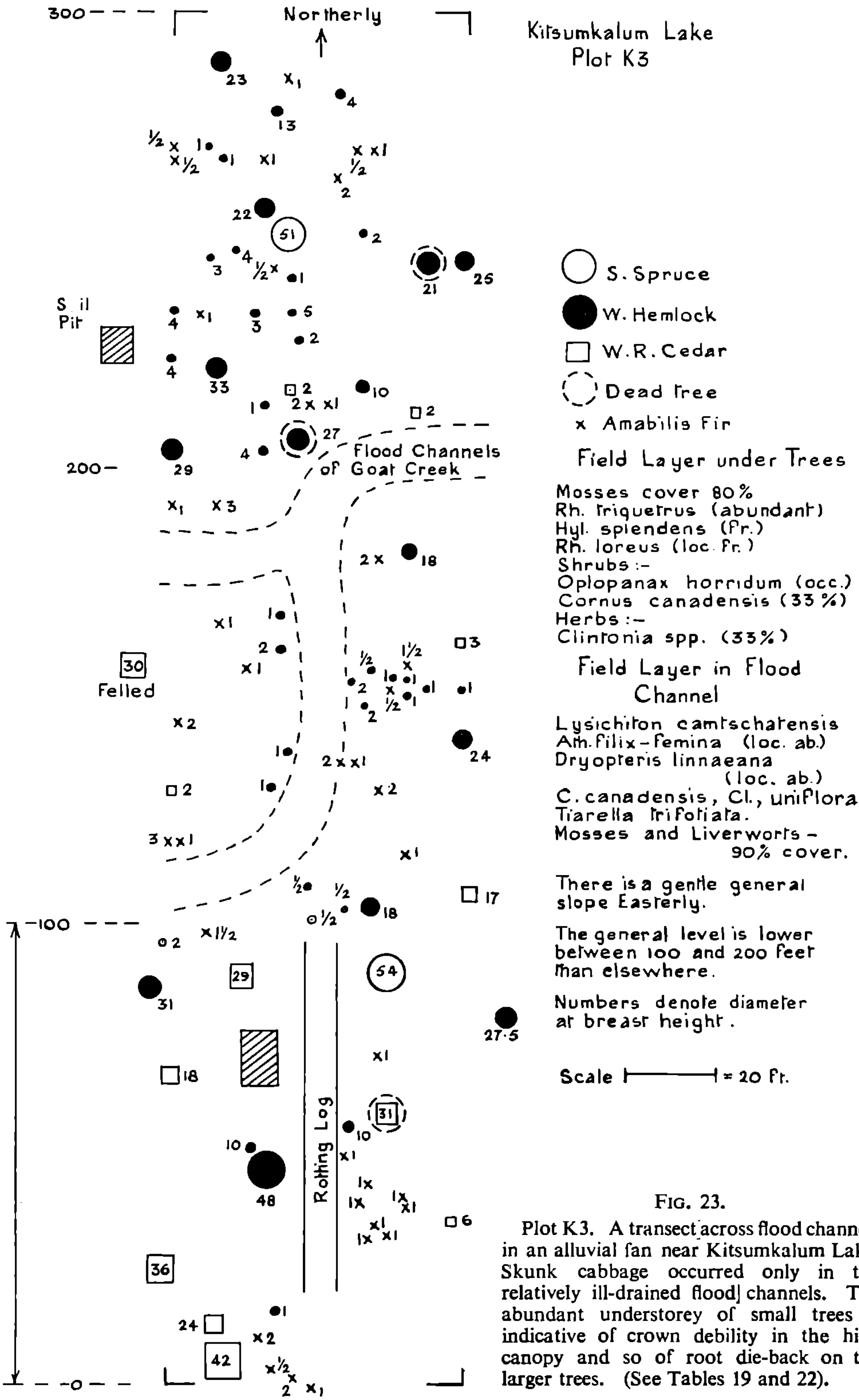


FIG. 23.

Plot K3. A transect across flood channels in an alluvial fan near Kitsumkalum Lake. Skunk cabbage occurred only in the relatively ill-drained floodj channels. The abundant understorey of small trees is indicative of crown debility in the high canopy and so of root die-back on the larger trees. (See Tables 19 and 22).

was true of much of the small area of conifer regeneration under alder, or cottonwood, seen in the Olympic Mountains (Plate 47); this could be very good as regards density of colonisation, but it could also be sparse and irregular. The principal species involved in the areas seen there was Sitka spruce, but western hemlock and Douglas fir also occurred in places. Density in successional regeneration, and form and length of clean stem, are matters of no great biological importance in a natural forest, but they are plainly matters with which future management for economic purposes may have to concern itself. The present appearance of forest now about 100 years of age and regenerated after fire, in Graham Island, in which red alder occurred or once formed a part, suggests that the original establishment was a more or less even-aged mixture of which this species formed a part, together with spruce, hemlock and often cedar, and that a successional stage did not occur. The same is true of spruce-hemlock-cedar stands in which black cottonwood occurs, or has occurred in the region of Terrace, on the terraces and in small valleys of the foot-hills to the mountains. These were stands in which regeneration was efficient as regards density from the economic standpoint; the evidence for this is found in the straight clean stems which exist at the present day.

4. It is very difficult without actual measurement to be sure of the ages of trees which look very similar as regards size. It is necessary to mention this because of the ease with which false deductions may be drawn. An example is provided by an area near Queen Charlotte City, in which Sitka spruce and western hemlock occurred as co-dominants. Sampling with a pressler borer at breast height showed that two Sitka spruce dominants were between 65 and 75 years of age at breast height; two similarly sized hemlock were, however, between 150 and 160 years of age. The evidence was thus that the spruce grew up some considerable time after the hemlock and that what looked like an even-aged stand was actually uneven-aged. A similar example occurred near Lakelse in which a spruce dominant was 125 years at breast height as judged by ring counting; whereas a neighbouring hemlock and also a cedar were about 200 years of age. Other examples were also seen in which Sitka spruce were the younger trees in a stand, the other species being stronger shade bearers. Cases such as these suggest that theoretical conceptions as to the order in which species will regenerate, which differ in shade tolerance, should not be used too rigidly in interpretation of the development of forest, of the past history of which there is no actual record.

5. It is of interest to speculate what will be the future course of regeneration in forests in which the surface of the soil is subjected to no catastrophic disturbance. This is, of course, largely an abstract exercise because the evidence is that the soil surface is eventually disturbed, in the course of the centuries. It is, however, one which should be of some interest to foresters who need, in practice, to consider regeneration over the relatively short periods of time necessarily allowed for in economic management and during which the catastrophes which affect the soil surface may not occur. There seem clearly to be significant differences, in this matter of successional regeneration between Graham Island, with its usually cool moist, summer climate, and the Terrace region with a rather drier and hotter summer. The former will be discussed first.

Regeneration in Graham Island in More or Less Closed Forest

6. Topographically well-drained sites, which are in a " water-losing " position, characteristically have " mor " soils with the typical horizon stratification into litter, fermentation layer and humus. Western hemlock regenerates on such sites providing there is sufficient light, often to the exclusion of all other species. It is thus the characteristic species in the dominated canopy. No western red cedar were seen; but Sitka spruce seedlings do occur, though usually rarely. Such spruce seedlings may root directly into the organic surface covering and not be connected with any decaying log or branch. A forest which regenerated in this way would consist almost entirely of hemlock and such stands can be found without great difficulty (Plate 45). The seedlings grow extremely slowly until the high canopy breaks up, as eventually it will owing to the effect of restriction in soil supply on the vigour of the dominants. If, however, a site is water-receiving and the soil moisture is not stagnant, one of two conditions seems to prevail. There may still be an appreciable organic surface covering to the soil, but it is more moist. These moist surfaces have an appropriate flora; e.g., species of *Mnium* occur commonly on them: on such surfaces seedlings of spruce, cedar and hemlock may occur with fair frequency. Alternatively a mull may occur: again all three species may regenerate. Such moist surfaces, favourable to regeneration, occur in hollows of sites characterised by wind-throw relief, along stream sides or on folds of the hillsides down which temporary streams flow. It would seem that they provide places in which spruce and cedar would maintain themselves in regeneration without the aid of any catastrophic disturbance of the soil surface. Red alder might be expected also to regenerate. The absence of a dense herbaceous or grassy field layer is probably necessary for successful regeneration in such places. The meadows of Meadow

Forest (see page 12, para. 4) seem to provide clear evidence of this ; but any factor which suppresses the development of such vegetation will favour the growth of tree seedlings. Herein, at least in part, lies the importance of the relatively light shade thrown by a high canopy of red alder, or black cottonwood (Plate 47). But if in spite of such shade the field layer forms a dense canopy, as for example is shown in Plate 9, tree seedlings seem always to be scarce.

7. It seems to be quite clear that on some sites the regeneration of trees occurs very slowly in the absence of a catastrophe such as fire, which prepares a seed bed. The meadows already mentioned provide examples : but the open stage of Cedar-Hemlock-Salal forest (Page 43, para. 1, Plate 30), in which salal forms a dense ground cover, seems clearly to provide another example, and the various types of swamp forest provide yet others. Much regeneration, in such places, occurs on special sites, such as fallen decaying logs, or windthrow humps, and not directly on the undisturbed ground. The provision of such sites depends, however, on occurrences which have the nature of catastrophe, such as the breaking of a large tree, or its overthrow.

8. It would seem, thus, in summary, that if the forest soil surface remains undisturbed for long periods the tendency will be for western hemlock to become the principal dominant on any site which is well-drained topographically and has a relatively dry surface. This follows the development of mor as the typical organic surface covering. On water-receiving, or other relatively moist sites with fresh water, the regeneration of spruce, cedar and alder seems to be possible, even if there is no disturbance of the soil surface. This would appear necessarily to be related to different types of decomposition within the organic surface covering.

These are, of course, only suggestions based on very limited observation : in any case they have a rather abstract value, since over any long period the chances are very high that a disturbance of the soil surface will take place. They are, however, consistent with the need proved by silvicultural experience, to break up a mor covering if regeneration of some species of tree is to be successful in any high proportion.

The Development of the Dominated Canopies in Closed Forest Illustrated by Examples Taken in the Region of Terrace

9. The total canopy of the forest, that is the total soil cover presented by woody vegetation in a forest, varies in composition according to changes in soil and climate, in species composition and in past history. The catastrophic conception in regard to the maintenance of the specific composition of the forest implies that periodically, but not necessarily frequently, the forest will be destroyed and that, in the regions discussed here, a relatively even-aged stand will develop subsequently (e.g., Figs. 9 and 14, and Plate 44). It is characteristic of such a forest that the canopy consists only, or chiefly, of the high, or dominating phases, and that the dominated phases, or understoreys, are more or less missing. The crowns in this high canopy open out with age and eventually begin to fail as deficiencies in site supply affect them appreciably. Light and moisture then become available which enable dominated canopies to develop, and the bare, or almost bare, floor of the earlier stages in the development of the forest disappears. The forest now gradually becomes uneven-aged and a canopy forms which has dominated as well as dominant phases. This may be regarded as the normal condition of the forest as a maturely developed entity, until the next catastrophe sweeps it away. A natural forest, not subject to exploitation or continued destruction, presents thus, a series of phases as the progression develops from the more or less newly developed even-aged stand, to one with a fully developed complex canopy in which all ages of trees are represented. These phases do not, of course, occur in any regular order in distribution throughout the forest, but according as accidents of nature, i.e., fire, windthrow, epidemic defoliation and the like have had their effect and after the manner made possible by the site charteristics.

10. A canopy composed of both dominant and dominated phases may develop in at least two ways. The forest may be even-aged, but mixed in specific composition, so that one species grows faster than the other. This results in the development of a storied forest : Plot K6 provides an example of this (Figs. 10 and 11) ; there was a pine overstorey and a hemlock understorey, but the whole can be regarded as, in the main, even-aged. This is a quite common phenomenon, after various fashions : e.g., Sitka spruce often appears as the emergent above the main canopy in mixed forest, which may be even-aged, or as in part of the Tlell transects may form the dominant canopy with a hemlock subdominant canopy of equal age. A dominated canopy, however, ordinarily develops by regeneration, and it is with this aspect of the matter that we are concerned here.

11. A plan of the distribution of trees of all sizes, all present being recorded except a very few small seedlings, is given in Fig. 23, representing Plot L9, near Lakelse. A fully complex canopy as regards both the dominant and dominated phases occurred here. This area was probably regenerated after fire, and so was originally even-aged. The dominant canopy is now made up of Sitka spruce emergents

which have attained a height of between 200 and 225 feet ; these stand above the main canopy of co-dominants, the height of which is about 170 feet, more or less, and consists of Sitka spruce and western hemlock ; there is beneath this a relatively sparse sub-dominant canopy which attains a height of about 130 to 150 feet and consists mainly of hemlock and western red cedar, though some few spruce also occur and an occasional red fir. The dominated canopy stood well below this. It consisted almost entirely of hemlock and red fir, but a very few maples occurred also. Trees of all heights from about six to fifty feet occurred in it. There were a very few seedlings of small size where the dominated canopy was least dense ; they included hemlock, silver fir, cedar and maple. This complex canopy is to be regarded as having developed beneath a high canopy which was originally more or less even-aged. This site is in a water-receiving position, but the soil is excessively stony and very freely draining (Table 22). It encourages deep and even root distribution, probably to a depth of about seven feet, and it may easily be this deep and relatively even distribution of the roots of the dominants which has made the development of the complex canopy possible. The relatively humid climate has also played a great part in this, of course.

12. There is evidence from this region that where root development is restricted in depth the more or less complete development of the complex canopy through regeneration by shade tolerant species may not occur. Thus in the transect shown in Fig. 21 (Plot K3), the emergents are spruce and hemlock, with a height of about 175 to 180 feet. The main canopy consists of hemlock and cedar the heights of which vary between about 120 and 160 feet, the cedar being consistently the shorter tree. There is hardly any dominated canopy at the southern end, where the dominant canopy is most dense, but rather more at the northern where it is more open. This area has a moist but moderately shallow soil (Table 3). Plot T4 (Table 18) had a not dissimilar rooting depth to Plot K3, but the soil and situation was drier.

13. The age of the older dominants is similar to those in Plot L9 discussed above ; that is about 200 to 250 years. This area also was regenerated after fire. Fig. 15 shows that there is practically no dominated canopy and that what is present consists of quite small trees which have regenerated along the lines of much decayed fallen logs. There were no true emergents from the main canopy in this case, but spruce and hemlock formed the upper part of the high canopy, and hemlock and cedar the lower : heights varied from 140 to 175 feet. Development on an equally, or rather more shallow, but heavier textured and more moist soil, is shown in Fig. 14, for Plot T2 (Table 18). Spruce here were clearly emergent with a height of about 190 feet ; the co-dominant canopy consisted chiefly of spruce, but included some hemlock and attained a height of about 170 feet ; the sub-dominant canopy was sparsely represented by hemlock and cedar, with heights varying between 100 and 140 feet. The dominated canopy in this case was represented by numerous hemlock of quite small size, most of which are not shown in the figure. They nearly all had germinated along the line of decayed fallen logs. The age of the larger dominants in T2 was at least 250 years.

14. These examples suggest that the more the root systems of the high canopy are concentrated in the superficial soil horizons, the less likely is the dominated canopy to develop ; the less moist the soil, the more is this likely to be true. Thus hemlock-cedar forest in which the field layer consists almost entirely of *Hylocomium splendens* and *Calliergonella schreberi* is common around Plot T4. It occupies topographically better drained positions and has shallower soil than this plot. The dominated canopy is almost completely absent : the age of the forest is similar to that of Plot T4. An example in which the dominated canopy is missing, and in which the rooting depth is very shallow, though the soil is very moist, is given by Plot L8 (Table 19). Fig. 19 shows that the dominated canopy was almost entirely absent, so far as trees were concerned : it consisted mainly of fern fronds and skunk cabbage leaves. A more complex but somewhat similar example is given by Plot T3, on Skeena alluvium (Table 3). There was, on this site, a shallow depth of intensely rooted loam which overlay deep sand in which root distribution was very irregular (Plate 13). Fig. 24 shows that here again the dominated canopy was absent insofar as trees were concerned : it consisted mainly of devil's club, large fern fronds and, locally, bushes of elder and dogwood (Plate 9).

15. It would appear thus that the complexity of the canopy, in forest which has achieved a mature age, is in this region largely a function of the supply capacity of the site in terms of rooting space and water. This relationship between the composition of the canopy and site characteristics can be demonstrated equally in other regions. Investigations made by the writer in central New Hampshire in 1951, in the northern hardwood-hemlock-white pine forest, showed, for example, that in mature forest the complex canopy was most complete on moist water-receiving, but fairly well-drained sites, and least on water-losing and relatively dry sites. This is a complex matter and warrants much more attention than has been possible to give to it here. There is a tendency in Britain at the present towards the development of forest with a more complex

canopy than that which occurs as the result of even-aged planting. Quite apart from its intrinsic ecological interest, some study of the factors which make possible the maintenance of a complex canopy are worth while, even if only because the manner of its composition will plainly be determined by the characteristics of the site, so that an abstract conception of what this composition should be, cannot be imposed against the influence of these.

The Importance of "Mor" in the Regeneration of Western Hemlock

16. It is a point of some further interest to note that, whereas in Graham Island, western hemlock

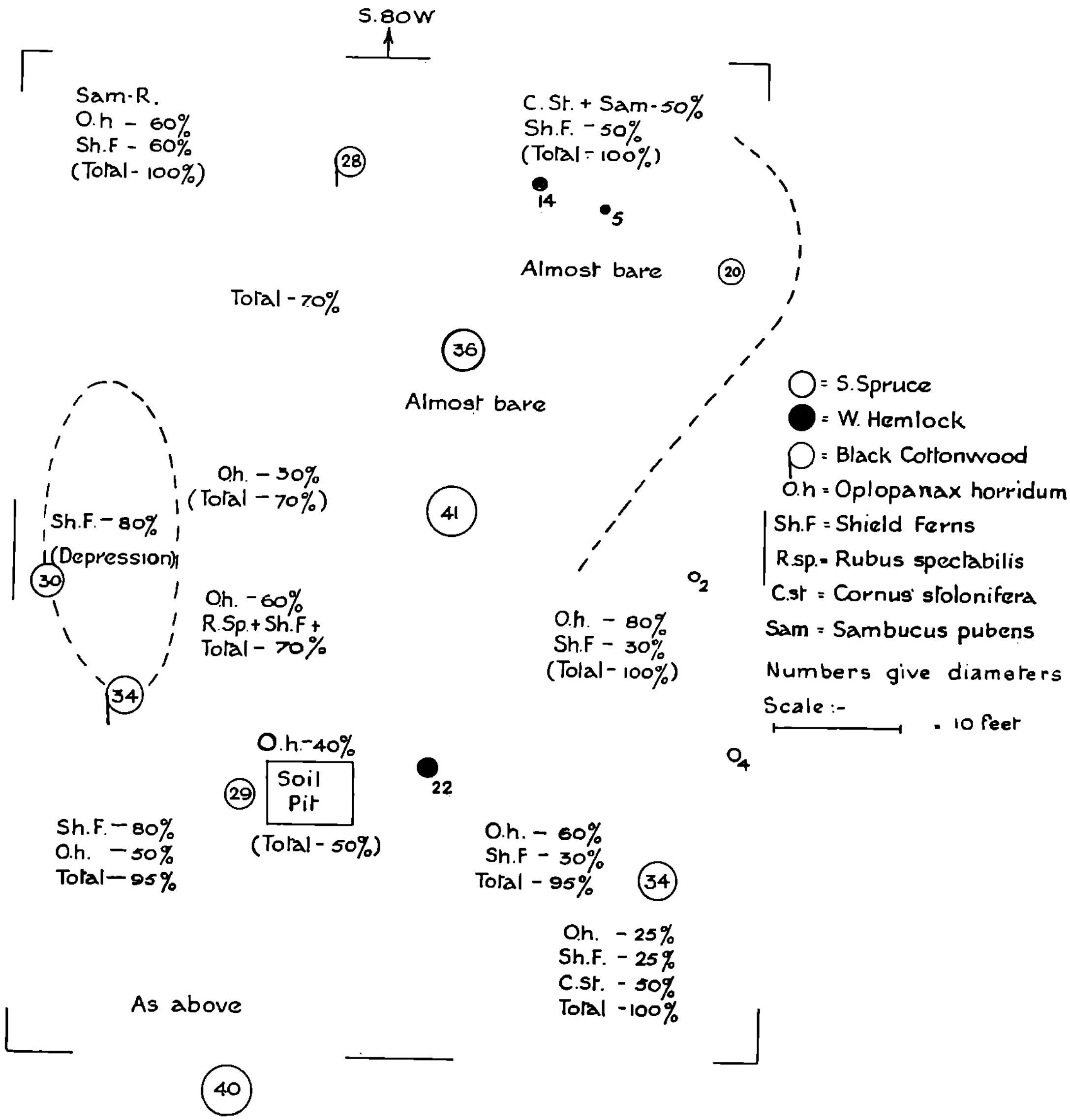


FIG. 24.

Plot T3 was situated on alluvium lying between the Skeena and Exstew Rivers. The soil consists of a shallow covering of loam which overlies compact, soft, almost pure rather fine sand (Plates 9 and 13 and Table 3). The dominant canopy consisted of black cottonwood and Sitka spruce. The sparsity of small trees in the understorey is characteristic of the area, as also is the general dominance of devil's club (*O. horridum*) and tall shield ferns as ground cover. The small size and sparsity of hemlock is characteristic. The shallow loam was intensely rooted, the upper sand poorly rooted, and many of the ends of the deep-going sinker roots were dead. (Plate 13).

regenerates with ease on an organic surface covering having the character of mor, given sufficient light and, probably, the moisture which accompanies this, around Terrace, as in Plot T4 (Fig. 15), its regeneration fails to occur, even in a moderately moist water-receiving situation, except along decayed logs, and failed almost completely on the drier slopes above. This seems to be quite typical. Thus in the rather drier region around Terrace, hemlock seems to react, in regeneration, to the organic surface covering, in much the same way as Sitka spruce does in Graham Island. An illustration can be given by reference to the forest on part of the ancient alluvial fan of Granite Creek at Lakelse. In the part in question the lower part of the fan is occupied by cedar-spruce-hemlock swamp forest, associated with skunk cabbage. A gentle slope rises from this up to the higher part of the fan. The lower part of the slope is occupied by mixed forest which contains hemlock, spruce, cedar and some black cottonwood and red silver fir. Passing up the slope the forest becomes almost pure hemlock, at first with a little spruce and then with some lodgepole pine. A little higher up the slope still, it becomes a mixture of hemlock and pine in which sometimes one species and sometimes the other predominates. The change in field layer is from *Clintonia uniflora* and *Cornus canadensis*, with *Streptopus curvipes*, *Rubus parviflorus* and *Oplopanax horridum* coming in where fellings have given increased light, to an almost pure moss cover composed mainly of *Hylocomium splendens* and *Calliergonella schreberi*, in which a few other plants such as *Vaccinium parvifolium*, *Linnaea borealis* and short *Pteridium aquilinium* may occur. The transition is from a relatively moist to a relatively dry type, though, of course, in a climate in which no excessively dry periods ordinarily occur. There was no complex dominated canopy in this forest. On the more moist lower slope hemlock and silver fir regeneration, about 5 or 8 feet in height on the average, gave about 50 per cent. cover. The same type of regeneration appeared in the middle zone dominated by hemlock and especially where there had been fellings. But on passing into the hemlock-pine zone, regeneration failed almost completely. There were a few small hemlock seedlings ; fewer cedar and still fewer pine. The number of seedlings of all these species rose greatly wherever mineral soil was exposed, as by the roadside and even though under the shade of trees. The soil on this slope is a podsol with a shallow but distinct leached horizon. Rooting depth of dominants is very irregular, but often mainly within the upper foot of soil. Root disease with butt-rot seems to be common, at least on the moist lower slope. The soil texture is sandy and locally very stony. The density of the high canopy in the hemlock-pine zone is often poor, and it is unlikely that a deficiency of light has been an important factor preventing regeneration : indeed, in the more moist parts this occurs under much more dense canopy. It would appear, thus, that within the relatively low elevation sites investigated, and in a water-losing situation with free surface drainage, hemlock, as well as other species, needs some assistance by disturbance of the organic surface covering, if its seedlings are to become satisfactorily established. This is the position of spruce in such situations in Graham Island, where the climate in summer is cooler and more moist.

CHAPTER 8

Crown Development and Soil Conditions

1. **The Shape and Density of the Crown in Sitka spruce in Relation to Site Conditions.** One of the real difficulties in diagnosis, in relation to the condition of the forest, is to make any reasonable assessment of the present condition and vigour of the trees. It is, of course, a great help if data relating to the rate of increment in growth throughout the life of typical trees are available ; but often this is not so. It is always of value, under these circumstances, to make careful observations of the condition of the crown, for plainly if this is unsatisfactory the condition of the whole tree will be also. It may be taken, too, that if the condition of the crown is unsatisfactory that of the root necessarily is, too, or if the condition of the crown is poor because of some sudden recent catastrophe, that of the root very soon will be, the condition of the two necessarily being closely related. The state of root systems is necessarily one of the more difficult things satisfactorily to observe. The digging of soil pits, in the work on which this discussion is based, showed clearly that in any forest as old as that investigated, that is from about 90 years to several centuries in age, die-back of roots owing to some temporary, or permanent, deficiency in soil supply may always be expected. The size at which a tree shows the effect of such deficiency will depend on its degree and kind, purely climatic

effects or those due to parasitic attack, being discounted. The symptoms may, thus, appear in Sitka spruce growing on ill-drained peat covered with *Sphagnum* moss before the tree is a foot high ; or on a good deep soil not until after it is two-hundred feet high ; but sooner or later they are to be expected.

2. The crown of a large well-developed Sitka spruce which is still vigorous is rather broadly conical and quite dense. It is difficult to isolate such crowns for photography, but one is to be seen in Plate 16. It is the tall central tree, the very tip of the crown of which is cut off. The top and the upper right hand side of the crown stand free from any other and it will be seen that the foliage is dense. This was a tall tree : its height was not measured, but it approached 200 feet and was still making appreciable growth upwards. The soil is a sandy loam which favours good and deep root development down to a water table. A somewhat later stage in crown condition is shown in Plate 48, taken in the Hoh River valley, in the Olympic Peninsula. The big spruce is about 200 feet high. The crown shape indicates a poor rate of height increment, and it is quite plain that the foliage is less dense than that of the tree indicated above. This tree grew on a moderately deep alluvial loam ; the smaller and thinner crowned trees behind grew on gravel. It may be taken as certain that the root system of this big tree has suffered appreciably ; but those of the trees behind still more. A similar but rather later stage in the thinning of a crown is shown in the tall right hand tree in Plate 16. This is a taller and older tree than that in the centre. It has practically completed its growth in height, not because this is the maximum possible for the species, but because of site deficiencies, and the root disease which depends on these. It has a broad crown, indicating growth on a site hitherto satisfactory, but the thinness of the foliage is obvious. This thin condition of the crown may set in, on poorer soils when trees are much smaller : an example is shown by Plate 49 of spruce and hemlock growing on shallow loam over coarse gravel by the side of the Mamin River. It is also well illustrated by the trees shown in Plate 22. These are 300-year old spruce and hemlock which grew on a lower slope fairly deep colluvial loam near Marie Lake, Graham Island. The dominants are well over 200 feet high ; they have broadly shaped crowns and obviously have thin foliage. The examination of wind-throws (Plate 24) showed that the lower part of the root systems was severely diseased and it may be taken that such signs of crown debility are always associated with root disease.

3. Most of the trees mentioned above were large and old, and grew on deep soil. It can easily be shown that when the soil is more shallow, even though of reasonably good quality, crown debility in the dominants sets in at a much earlier age. This can be illustrated from trees which grew in or on the border of Experimental Plot 414 (Plot 23). This plot has a Site Index of 140 feet at 100 years. At the age of about 97 years the mean height of dominants and co-dominants averaged approximately 135 feet. The soil is a rather shallow loam which overlies hard compressed till, but it has been cast up into humps by past wind-throws ; the trees grow mainly on these humps. Three crowns of dominants are shown in Plates 38, 50 and 51. In Plate 50 the crown is still dense, though the rate of height growth has probably slowed up very appreciably. In Plate 38 the crown is open, but shows short densely clustered twigs round the branches. This is one of the earlier signs of loss of vigour and is usually shown most markedly in the upper part of the crown. In Plate 51 marked deterioration in crown structure has definitely taken place, although, as can be seen, the tree is a dominant and in no way suppressed. Variations of this nature on one small area ordinarily reflect variation in soil condition, and certainly differences in degree of degeneracy of the root system. The smaller size of tree affected in this case, as compared, for example, with the large tree on the right hand side of Plate 16, is merely a reflection of the more limited supply by the soil to the root and especially probably of space and water.

Similar variations in crown condition can be observed in many places ; an example is shown in Plate 46. This shows the crowns of three dominant spruce in Kitsumkalum Park ; behind the centre one is the crown of a black cottonwood. The difference in condition of the spruce crowns is obvious. This thinning of the crown may become, more or less, general, even though the dominants are of no exceptional size for the species. Such a condition is shown for a hemlock stand in Plate 20, near Plot 7, Juskatla, and for a Sitka spruce stand at Tlell in Plate 40, although in this case the tree crowns are not shown. Such a general condition is always accompanied by the development of the lower stories of the canopy in some form or other : this took the form of hemlock regeneration in the former, and of salal in the latter case. Sampling of the root system in digging soil pits showed that in both cases appreciable die-back had occurred, especially of the deeper-going roots. These cases, in fact, illustrate one of the conditions in which the satisfactory development of an understorey becomes possible.

4. It is often to be observed, especially in the region of Terrace, that the crowns of mature spruce, and sometimes also of hemlock, are narrowly spire-shaped. A very good example of this is shown by

the tall tree in Plate 52. It can be seen that the larger trees on this site all tend to have poor crowns. They grow on shallow stony soil through which seepage water flows to the shore of Juskatla Inlet. The development of a narrow spire-shaped crown often occurs on soils which, though capable of supporting a tall tree, suffer from deficiencies in supply of the needs of the root system as the tree becomes large. Often, but not necessarily, the soil is moist but shallow. This is illustrated in Plate 53, which shows Sitka spruce growing on shallow alluvial soil with a high water table, on the delta of a river which flows into Kitsumkalum Lake. The narrowness and poor development of the upper crown is not caused by overcrowding. It finds its origin in restriction in growth of side branches, and is often accompanied by the dying back of these and of the twigs which they bear (see Plates 31 and 46). An improvement in soil conditions may show a marked improvement in crown shape. This is illustrated by Plate 54, which was taken quite near to Plate 53. Many examples of spire-crowned

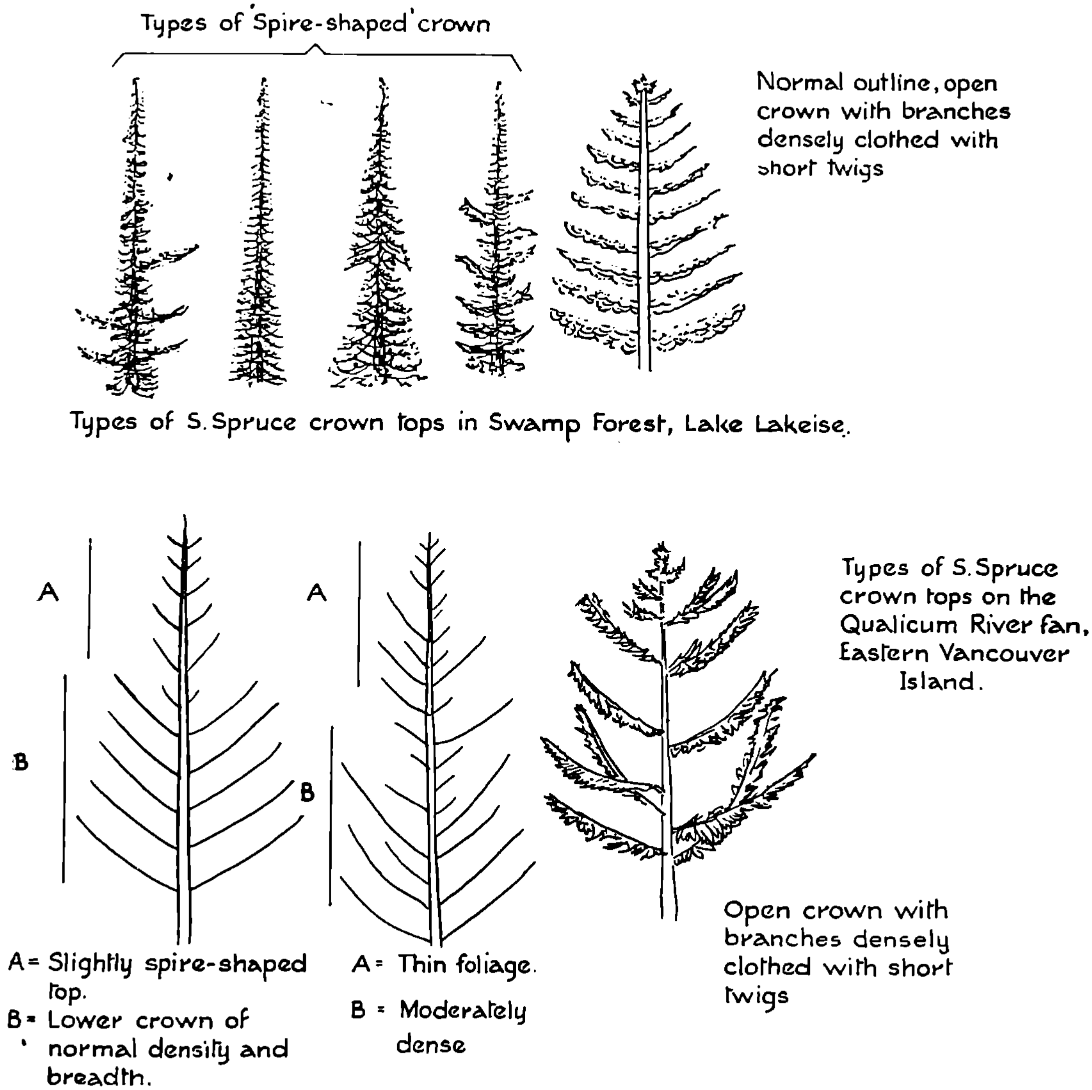


FIG. 25.

Diagrammatic representation of crowns of Sitka spruce which showed defective development (see also Plates 5, 15, 16, 21, 22, 31, 38, 46 and 48 to 55). This defective growth is related to defective conditions for root development.

spruce are to be seen in the wet types of forest round Lake Lakelse. A few examples are outlined in Fig. 25. Other species of conifer may be affected in this manner, though crown debility is less frequently shown in this way by either cedar or hemlock. There may be, and indeed probably are, strains of spruce which produce crowns of significantly different shape, even if growing perfectly healthily. It seems to be quite certain, however, that the production of spire-shaped crowns is, in general, a pathological phenomenon caused by supply difficulties for root development in soils which, up to a point, are favourable for growth. The exact processes which lead to the development of various crown forms, through injury to the root, need further investigation ; it is only possible to indicate here that their foundation seems clearly to be edaphic.

The Development of the Crown in Western Red Cedar

5. The crown development of western red cedar is of some interest in this discussion. Within the experience of the writer this species seems clearly to be associated, as the characteristic dominant, with water-retentive or wet soils. Other species seem either to have an advantage in regeneration, or to suppress it subsequently, or to hold it in check for long periods, on the more fertile but well-drained soils, so that although it may be present, it never becomes a characteristic dominant in the forest. The well-drained sites on which it occurs with hemlock as the less numerous dominant are not referred to here. Water-retentive or wet soils are notoriously root-restricting. Trees of great height may develop if there is a sufficient depth of well-drained material, but sooner or later the difficult conditions for subsoil drainage, whether caused by soil texture, or topographical position, limit root development and act as causes of root disease. It has been seen that here lies a fundamental condition determining the development of spire-shaped spruce crowns. The development of the crown of western red cedar is of particular interest because these are the conditions with which the tree so often has to contend. The ultimate consequence of this is familiar to everyone who has seen the Pacific Coast forest ; it is the development of a dead top to the tree. The young cedar grows a normal densely foliated crown, even if growing on a poor site, as shown in Plate 28. Sooner or later, according to the character of the site, the crown begins to thin, or only remains dense round the main stem. This thin condition of the crown apparently may persist for a long time, as it seems also to do, under appropriate conditions, in spruce and hemlock. Eventually the whole top of the tree dies and the dead spike top is formed. This form of crown die-back seems to be as characteristic of cedar as die-back of the branch ends and twigs is for spruce. The crown of a very old and large spruce is shown in Plate 55. Characteristically it is still alive to the top, though obviously very decrepit. A cedar of similar size would, inevitably, have had a dead top.

6. It is characteristic of many cedars that they produce a number of dead tops, as many as six or seven may often be counted, or perhaps even more. Accepting the principal that, unless there is clear evidence to the contrary, debility of the crown is to be regarded as a sign of debility in the root, the production of multiple dead spikes is clearly evidence of the variability of soil supply over the course of years. Any tree tends to develop up to the size made possible by conditions of maximum supply in the soil. Soil supply is variable, however, and therefore the maximum cannot be maintained. Thus, when in the course of development a tree reaches a size which only maximum conditions of supply can satisfy, any appreciable drop below this must mean a loss of health and condition for both crown and root. Fluctuations in supply will be responded to according to the vigour of the tree, and the development of multiple spike-tops in cedar is one of the consequences of this.

7. The importance of this experience with cedar is that it illustrates a general principle. All species of tree, after their kind, grow towards that size which only the maximum conditions of supply for the site can satisfy. This size depends, naturally, on the character of the site and the manner in which the tree is affected by any drop from the maximum, as well as on the manner in which variations in soil supply take place. There is, plainly, much to be found out with regard to this, but the matter is of some appreciable importance for, amongst other things, the size at which the demands of a tree approach the maximum supply possible for the site is that at which supply deficiencies will inevitably reduce vigour and health and begin that decline in growth rate which is the mark of biological inefficiency, even though the tree may continue to live for a very long time. This size may be well within economic rotations in the poorer sites, but the management of the better is not likely adequately to be understood unless this relationship between supply of site and condition of tree also is understood.

8. The above discussion has been concerned principally with soil deficiencies which arise mainly owing to inadequate drainage in the subsoil. It would be quite easy to show that a similar argument applies to any type of soil and particularly those which suffer from lack of water retention. Plot K6, discussed above (see Fig. 10 and 11, and Table 15)

provides an example of this. This plot was on a well-drained site topographically and the upper layers of soil were but little water-retentive. The poor condition of the high canopy of pines had been brought about because during good periods, that is wet years, the trees which formed it grew to a size which necessitated a demand which the soil was unable to supply during dry years. The decay of the high canopy and gradual death of many of its crowns is quite inevitable under such circumstances.

CHAPTER 9

Discussion

1. **Soils and Growth.** There are a number of problems to be solved before it can be stated what, in any particular situation, are the factors which favour the development of one species as compared with others. Suggestions that Sitka spruce is favoured, in comparison with its associated species, by conditions of relatively high nutrient status, seem to be found in several things. There is, for example, its fairly consistent association, as a well-grown tree, with a field layer containing broad-leaved, non-ericaceous shrubs, ferns and herbs and, conversely, its failure to maintain a satisfactory position, as compared with its associates, where the field layer falls into the salal, Labrador tea, *Sphagnum* progression in muskeg regions in Graham Island. Its association as an early successional species with alder and black cottonwood seems clearly to point in the same direction ; as also does its position as a dominant in the various skunk cabbage types around Lake Lakelse. The frequent occurrence of Sitka spruce as a seashore species, as on the coastal sands around Tlell, may be mentioned here. It is not impossible that this may have a nutritive basis, for such seaside situations must receive a relatively copious deposit of sea spray.

2. It is necessary, however, to remember that one is concerned with problems in which a number of factors interact, and which eventually involve complex correlation analysis. There is, thus, the clear evidence round Terrace that Sitka spruce cannot compete with western hemlock, western red cedar or lodgepole pine on the drier sites. There is similar evidence on Graham Island : thus, Sitka spruce seems always to occur on moist coastal seepage zones round Juskatla Inlet, usually together with western hemlock and often western red cedar ; but the outstanding tree of adjacent well-drained rocky knolls is cedar. This may grow poorly and show some chlorosis, but it forms forest in which, on such places, spruce is absent apparently, though hemlock may occur. It may be, thus, that one of the great advantages of sites which give indication of a relatively high nutrient status is that they are usually water-receiving and that this, given adequate drainage, is a factor which favours the growth of spruce relative to other species. The failure of spruce to maintain its competitive position on those poor sites which become dominated by cedar-hemlock-salal forest may also be related at least as much to type of water supply as to balance and amount of available nutrients. The impression given, in the examination of soil profiles, is that this is so and that spruce takes a prominent position in the dominant canopy of mature forest in any situation in which the supply of aerated water is sufficiently large and constant ; other species become dominant sooner or later when there is any failure of water supply in these respects. Again, it has to be remembered that water is never supplied except with substances in solution, so that the supply of water in a physically favourable condition for the plant, is likely to be associated with the supply of nutrients under conditions which favour assimilation. It would appear that when such a favourable condition reaches a certain level, spruce is able to develop its greater relative growth potential to such an extent that its position in the forest as a dominant is assured. It will take a subordinate position, or be entirely eliminated, when supplies fall below this level.

3. According to this argument, relative growth potential is of particular importance in determining the survival in mixed forest, of the less shade-tolerant species of which, in the regions worked in, Sitka spruce is one. This may be an obvious point, but it is one of some importance ; this is, perhaps, particularly so where the economic life of the forest covers a relatively short period of the total potential life of the species which form the dominant canopy. It is plain, if one considers the needs of a tree as an organism which continuously develops in size, that a relatively small supply in the soil will be sufficient at first, though a much larger will be needed later. There are thus suggestions on shallow soils, providing the level of soil fertility in terms of unit volume is sufficiently high, that Sitka spruce may be able to compete satisfactorily with more shade-tolerant competitors at first, even though later it may become suppressed. This was suggested by the stands in which Plots 19 and 24 were situated near Port Clements (Page 28, para. 9, Table 8) ; these grew on

shallow gleyed podsols and had a low Site Index value ; Sitka spruce occurred in low proportions and at 90 years of age was tending to become dominated. In Britain many soils planted with this species are probably of no greater fertility than these, and it would appear that, considered purely from the point of view of growth, the value of producing a mixed forest, or perhaps of entirely superseding Sitka spruce by other species, must depend largely on its growth rate relative to the other species during this comparatively youthful period of its potential existence.

4. It may be taken, however, in principle, that the failure of one species relative to others which, together with it, form the dominant canopy, may take place at any age. There are plainly two tendencies expressed in mixed forest with regard to this. In the one case failure may take place early owing to the less vigorous growth of one or more species relative to others. Sitka spruce seems clearly to be suppressed in this way on soils of really low fertility ; e.g., by cedar and hemlock on some of the wetter and shallowly rooted poor soils ; or by pine, or hemlock and silver fir on some of the drier soils. On the other hand it seems clearly able to suppress any of the other species, at least to the extent of reducing them to a subordinate position in the dominant canopy, on soils of rather higher fertility, though still of rather limited supply capacity. The various sub-plots of the transects taken at Tlell illustrate both these cases (Page 35, para. 1). It is of particular importance to understand these aspects of failure whenever the economic rotation is comparatively short, for they concern the earlier part of the life of the tree. The later aspects of failure concern occurrences in a dominant canopy which is mature and fully developed. It may be taken for practical purposes that all soils are of limited supply capacity considering the potential demands of the trees, and that sooner or later failure in vigour will occur because of this. There is a tendency, when the high canopy consists of mature, fully developed trees, for the larger to show signs of decline in vigour. The large emergents in a mixed forest, of which Sitka spruce form a part will often be of this species, and because of this, in fully developed forest, one may often observe a greater proportion of crowns showing debility among the spruce than among any other species. The same will apply to any species which has developed appropriately, relatively to the others with which it grows. There is, for example, a very good case in the western part of the Olympic Peninsula in which the emergents are western red cedar of considerable size and age, and appropriately they show the dead tops which, for them, are the typical signs of the decline in vigour which arises owing to this eventual failure of soil supply.

5. The age, or size, at which this failure of soil supply to the dominants in high canopy becomes critical plainly depends on the nature of the site and the character of the species of tree which grow on it. It occurs when the trees are relatively small on the muskeg, and on the shallowly-rooted gleyed podsols which often occur round about this, near Port Clements and Tlell, though sometimes because of slow growth, the trees affected may be of considerable age. It occurs, however, at a comparatively early age in the same region, for example, between 80 and 100 years, on brown podsolic soils which are of greater intrinsic fertility, though shallow. It appears thus that this type of failure in vigour is something which needs to be understood if economic management is to be efficient, and that this becomes increasingly true the less fertile soils become.

6. The soil characteristics which determine the size to which any species of tree will grow and the volume of timber capable of standing on any area, seem clearly to be found mainly in those physical attributes which determine the space available for root development, the intensity throughout this space with which the development of feeding roots can take place, together with the physical position of the site as determining its characteristics as regards topographical drainage. If old-growth forest is considered, then in the forests seen during this work, stands in which the dominant canopy was closed and was at a great height, and in which the standing volume of timber per acre was high, occurred on well-drained soil which permitted of at least moderately deep rooting, and which was in a water-receiving site topographically ; Plot 4, on Yakoun River alluvium and Plot 13 on lower slope colluvium by Marie Lake, provide examples (Tables 3, 6 and 23). One of the characteristics of such stands is the relatively poor development of the dominated aspects of the canopy in all places except where the high canopy has been broken. The maintenance of dense crown development in trees of great size is responsible for this, and plainly such a condition is possible only where the soil rooting space is adequate in volume and in other necessary qualities.

7. Any reduction in the quality of the rooting space necessarily affects the manner of development of the dominant canopy of the forest. A principal feature is that the high canopy opens out when the dominants are of a smaller size than on better soils and so permits, in terms of size, an earlier development of the dominated aspects. The quality of the rooting space may, plainly, be poorer in many different ways. Plot L9, Lakelse (Tables 19 and 22 and Fig. 21) provides an example of a deeply rooted site, in a water-receiving situation in which the reduction is mainly through extreme stoniness. The deeper roots reach to a permanent water supply, but

the upper roots are in soil which must become water-deficient in any dry summer. The appreciable amount of root die-back exposed on digging the soil pit, and also probably the appreciable incidence of infection with *Trametes* (*Fomes*) *pini* is related to this. The crowns of the dominants were narrow and in many cases becoming thin, but not mainly because of lack of space. The character of this stand as a two-storied forest with a well-developed dominated canopy is to be related directly to the character of the soil on which it stood. Its deep rooting on a water-receiving site made possible the great height growth ; but the excessive stoniness and drainage of most of the rooting profile compelled a comparatively early reduction in crown development and density, with an associated development of root disease. This resulted in there being sufficient light and water for the development of the dominated canopy at a point in development of size of dominant when neither would have been adequately present on a more favourable site. The slow growth of the dominated canopy is also consistent with these conditions ; e.g., western hemlock and red fir of about four inches diameter at breast height varied in age from 60 to 100 years.

8. There is, therefore, a development in size of dominant, and in structure of the complex or complete canopy, which is characteristic for the site. Thus the poor development of the dominated canopy in Plots T2 and T4 (Figs. 14 and 15), in which the emergent spruce were of about the same age as those in Plot L9 (Fig. 21), is natural to the shallowly rooted soil, and will always tend to occur at the stage of development of the forest illustrated in these cases. In the same way the presence of hemlock as an understorey beneath pine, at the age of about 120 years, is characteristic of the dry, stony, though fairly deeply rooted sand on which Plot K6 occurred (Fig. 10). The size and condition of the trees which compose the forest, *both with regard to root and shoot*, is thus, necessarily, a characteristic of the site and, in the main, has to be accepted as the basis on which economic management must be planned, in so far as this is concerned with the growth of trees.

9. Much silvicultural theory, especially in so far as this is concerned with temperate forests dominated by conifers, is based on the assumption that a closed dominant canopy is always possible, and the management of this dominant canopy obviously has played an important part in the care of the forest, both theoretically and practically. It has been possible to hold this conception largely because economic forestry is concerned mainly with the youth and early maturity of the forest. It is, however, characteristic for the dominant canopy to fail, and to become more or less open if a fuller natural development is allowed. The height and size of tree at which this process begins in any particular type of forest, will depend mainly on the soil characteristics of the site, any one climatic zone being under consideration. It may, thus, confidently be expected that the dominant canopy will begin to fail in forest on the very shallowly rooted gleyed podsols, which occur in the north-east of Graham Island (e.g., Plots 19 and 24, Table 8), when the trees which compose it are of a relatively small size considering their inherent capacity for growth : further, no policy with regard to thinning will do a great deal to prevent this. It is a characteristic of the site, and is determined mainly by the nature of the soil supply.

10. The importance in the soil of nutrient status per unit volume cannot adequately be considered here owing to an almost complete lack of information. It seems, however, to be reflected most obviously in the shallowly rooted soils. If it may be taken that a ground vegetation which consists of broadleaved non-ericaceous shrubs, together with ferns and herbs, is indicative of a relatively high nutrient status per unit volume of soil as compared with one in which this consists mainly of ericaceous shrubs, then there seems to be no doubt that, other things being equal, the richer soil gives a mature forest greater both as regards height and density. It may be taken as certain that this would become particularly obvious were growth data available which illustrated the sequence in development of various types of forest. It is quite clear, however, that in a humid climate such as that worked in, shallowness of rooting need not prevent growth to a great height (see Tables 18 to 22). The suggestions seem to be equally clear that, on what are poorer soils as judged by ground vegetation, but still shallowly rooted, total height growth is much smaller (Tables 8 and 10). It should be noted that, as judged by western European or eastern Canadian standards, the height growth achieved on these poor soils is quite considerable and that, given sufficiently low extraction costs, the possibility of their utilisation should be beyond doubt.

11. It would appear that, in reality, there are quite a number of problems to be solved if an adequate comparison is to be made of soils of similar rooting depth, but significantly different fertility as judged by the growth of the forest. It is certainly suggested that hard compressed material at the base of the shallow root system is an appreciable disadvantage : e.g., in Table 8, profiles 19, 20A, 20B and 24 (1) and 24 (2) all possessed a subsoil of this nature. This would place physical factors high as causes of infertility, even if comparison is confined to soils of such limited rooting capacity as are these. The inevitable suggestion is that different water-regimes determined by differing physical conditions in the

various soil horizons are responsible to a considerable extent for the differences in vigour of growth. It is certain that the absence of such a hard, more or less cemented layer beneath the root system may be accompanied by greater height growth, as well as a change in the proportionate composition of the forest. Plot 20 may be compared with the adjacent 20A with regard to this (Table 8). The rooted soil appeared to be very similar in the two areas : the principal difference lay in the presence of the cemented ironpan on the surface of hard compressed material in 20A. This matter of the relative significance of physical and chemical factors in determining the degree of soil fertility is one of considerable importance.

12. One aspect of this matter of the relationship between soil conditions and growth which tends often to be overlooked, is the inter-relationship between crown condition and root condition in any type of forest. If direct injuries to the crown, whether by living or non-living factors, are ignored for the purposes of this discussion, then it may be said that any failure in vigour, or condition, in the crown finds its correlative in a similar failure in the root. All the excavations done during this work point to the general occurrence of root disease which is fundamentally of non-parasitic origin. Much of this root disease, as it affects the trees during the earlier part of their life, is probably slight and easily recovered from ; but when a dominant is reaching the size limit determined by the soil supply capacity of the site, such root disease seems always to have developed more or less seriously. There is a direct and inescapable connection between this type of disease and soil supply capacity ; its fundamentally non-parasitic nature is indicated by its very general occurrence throughout old-growth forest without consequent widespread death of trees. There can be little doubt that the development of heart-rots is influenced greatly by this aspect of the relationship between soil conditions and the growth of the forest. It seems also to be plain that a better understanding of this relationship between the demand made by the forest and the supply available in the soil would largely help to explain the manner in which, on a site of any particular character, the natural thinning of the forest must take place ; or alternatively in forest under economic management, in which thinnings play an important part, the manner in which these should be carried out to be efficient in helping to maximise production on the site in question.

13. One interested in British forestry is inevitably impressed with the possibility of relatively poor soils in the coastal forest, producing utilisable material. It is, however, very difficult to compare poor soils in Britain with poor soils in western Canada and say in any efficient manner where the similarities and differences lie. Much more study in this connection is needed before it can be said with any certainty what determines the course of growth in either country or in any particular situation. Among a number of interesting problems in this connection the function of the organic surface covering appears to be one of considerable importance. In the cool, humid, climate of Graham Island the more shallow is the rootable depth of mineral soil, the more important does the organic soil covering become as a rooting medium for the forest. This is well illustrated by Fig. 2 relating to Plot Tlell II. It is quite plain from this that in some places on this area most of the root system is to be found within the humus, and that forest largely depends on this as a medium for root activity. The data given in Tables 7 and 8 also indicate how large a part the organic surface covering may form of the total soil volume rooted in shallow soils. The humus in this material is usually intensely rooted and it would appear that the very fertility of the site is dependent to a considerable extent on its development. The development of the organic surface covering and its function in the life of the forest, appears thus as one of the matters worthy of further study.

The Position of Sitka Spruce in the Forest, Relative to its Associated Species

1. The place of a species of tree in mixed forest is determined partly by the position it must take in the canopy if it is to survive, and partly by its reaction to changes in fertility of site relative to that which such changes induce in the associated species. Of the four species of conifer considered here, in the main, i.e., Sitka spruce, western hemlock, western red cedar and lodgepole pine, with the exception of the pine, spruce is the least shade-tolerant. Its place, therefore, is necessarily in the upper part of the canopy, if mature closed forest is considered. The forests mainly worked in were more or less of this character. They usually consisted chiefly or entirely of spruce, hemlock and cedar ; and if they were fully-developed mature forest, they contained trees of all ages. If, moreover, the high canopy was more or less closed, Sitka spruce occurred mainly, or entirely, in the upper part of the complex canopy as a co-dominant, or dominant. The dominated aspects of the canopy were made up of the shade-tolerant species, i.e., hemlock and cedar, with hemlock as by far the more numerous species. It may be said, therefore, that in its mature, fully developed stage and on sufficiently fertile sites, the forest consists of a matrix of the more shade-tolerant trees, of which hemlock is the more abundant in most situations ; it may also be said that the less shade-tolerant spruce is set within this as a co-dominant

or emergent. This tendency to become an emergent in the canopy is made possible by the greater growth vigour of spruce relative to the other species, and especially by its greater vigour in height growth. This tendency is shown in even-aged forest as much as in fully developed " all-aged " forest.

Average Height in feet of Dominant and Co-dominant Trees

TABLE 23

Plot No.	H	S	C	P	D	Age in years
1	167	—	—	—	—	All-aged
3	135	153	—	—	—	100
4	192	227	—	—	—	All-aged
5	—	237	—	—	—	All-aged
6	—	—	64	—	—	All-aged
7	149	152	145	—	—	All-aged
8	148	160	132	—	—	All-aged
9	146	157	135	—	—	All-aged
10	94	110	—	—	—	All-aged
11	—	136	135	—	—	All-aged
12	114	132	—	—	—	75
13	203	219	—	—	—	295
14	51	—	88	—	—	All-aged
15	114	—	118	—	—	All-aged
16	169	227	—	—	—	All-aged
17	128	128	—	—	—	87
18	170	205	—	—	—	All-aged
19	74	—	74	74	—	90
20	108	120	—	—	—	90
21	—	105	90	—	—	90
22	151	156	—	—	—	150
23	137	134	—	—	115	97
24	92	82	84	79	—	90

H=*Tsuga heterophylla*, western hemlock.
S=*Picea sitchensis*, Sitka spruce.
C=*Thuja plicata*, western red cedar.
P=*Pinus contorta*, lodgepole pine.
D=*Alnus rubra*, Oregon alder.
Data collected by R. L. Schmidt.

2. Sitka spruce is only able to take up this dominant position in the canopy when the fertility of the site sufficiently favours its growth. The figures given in Table 19, which apply to the region of Lake Lakelse, show that this does not mean that the site necessarily is highly fertile. It means that the site must possess particular qualities, at present not satisfactorily defined, in which the growth of spruce is favoured sufficiently to prevent it being suppressed by its more shade-tolerant associates. Indeed it seems to be quite clear that forest of at least moderately good Site Index value exists in which spruce does not occur, owing to its failure to compete in growth with its more shade-tolerant associates. This is a matter which it is impossible satisfactorily to discuss here, owing to lack of information ; it is for that reason one which invites future research. The position with regard to this matter in Graham Island is illustrated to some extent by the data presented in Table 23, compiled by Mr. R. L. Schmidt. It will be noted that where the average height of spruce, or of hemlock, is greater than 100 feet, the height of spruce is equal to or greater than that of hemlock. Had sub-dominant trees been included in this estimate, the height of spruce relative to that of hemlock would have been greater than is shown ; and more plots would have shown both species as present. Of the poorer plots, No. 10 was at a high elevation (1,900 feet) and is not comparable with the others. The remainder are all plots of low Site Index value, and even if it is not down in the Table, spruce was present, but as a tree in the sub-dominant or dominated canopy. Again, however, it needs to be stressed that it is not the low Site Index value that has determined the dominance of hemlock or cedar on these areas : e.g., Plot K4 (Table 15, Kitsumkalum Lake) has a lower Site Index value than Plot 24, and yet spruce was clearly the chief dominant ; whereas in Plot 24 hemlock was the chief dominant and spruce occurred only sparsely, had rather poor crowns, and was tending to lose position in the dominant canopy.

3. These considerations suggest that great care is needed before it is decided, on any site and under economic management, that one species should be favoured against another. This is particularly true when it is remembered that the length of rotation under such management may easily be no greater than 100 years, and possibly may be shorter than this. Interest in future management will thus tend to become concentrated more on the early developmental period of growth, rather than the later and longer maintenance period when the dominant canopy in the forest consists of mature trees.

4. There are two tendencies in growth on the shallower soils which are worthy of notice. If the soil favours the growth of spruce and this species regenerates in appreciable quantity, it seems to be clear that cedar tends to be eliminated, and hemlock to be relegated to the sub-dominant or dominated canopy in the main. The better parts of the Tlell transects (Table 12) and Plot T2, Table 18 and Fig. 14 seem to provide examples of this. This is to be regarded as a fairly early development in the potential history of the stand. The site limitation in supply determined by the comparative shallowness of soil will, however, affect the stronger growing trees first ; if the spruce are these they will be the first to show signs of debility and overmaturity. Under such circumstances a time will come when the less vigorously developing shade-tolerant species, in this case western hemlock and western red cedar, tend to overtake the spruce and equal it in height growth. This was the stage reached in Plot T4 (Table 18), and probably Plots 7, 8, 9, 17, 22 and 23

(Table 23) were in or approaching this condition. This is a matter which, of course, needs actual investigation through stem analysis. It does, however, bring up a silvicultural and ecological point of some importance, namely that the advantage in competition, of greater vigour in growth, is limited to the period required to reach that size of tree, the demand of which exhausts the supply capacity of the site. It is to be expected, thus, that on many sites the advantage to any species, of greater vigour in growth, may only obtain for a comparatively limited period ; but of course, with the relatively limited period of existence which is likely to be permitted under economic management, this may cover what is, economically, a most important period in the life of the tree.

5. It seems to be clear that some of the more important factors which influence the relative vigour of growth of species in these forests relate to the water regime of the site. The relative growth on shallow soils, referred to above, is probably determined largely by the nature of this. It is certainly suggested that hemlock and cedar, as the more site-tolerant species, endure more satisfactorily than does spruce, greater variations in water supply ; they are thus able satisfactorily to form forest on sites on which spruce tends to fail. It is possible, of course, that the influence of site conditions during the regeneration period may play an important part here in determining the proportionate abundance of species. Little can be said on this aspect of the matter, except that cases have been observed in which there is every reason to believe that seed of a species of relatively rare occurrence was adequately available during a period of regeneration after fire, when nominally, all should have had an equal chance of establishment, seed being present.

6. It is not improbable that nutrient factors are also of considerable importance in determining the distribution of species, and this especially during the early period of growth. There seem thus to be clear indications of the association of Sitka spruce in relative abundance with sites on which nitrification might be expected to occur during periods of open canopy when regeneration is taking place. A relatively high degree of nitrifying activity might also be expected to be associated with good conditions for the supply of water and air, and also of other nutrients than nitrogen. This is entirely consistent with the place of spruce, on the whole, as the least site-tolerant of the species of conifer with which it occurs naturally. If this analysis is right, then sites in which the supply of available water is rather limited, and especially perhaps very variable, and in which nitrification tends naturally to be poor, are suggested as those on which spruce cannot be expected to do well, or at least to assert or maintain dominance in growth for any length of time. The recognition of what is essential in the edaphic character of a site becomes thus a matter of considerable importance, especially as one is concerned here with fertility of site as reflected in the relative satisfaction of the needs of different species, rather than with fertility as reflected in some measure of height growth such as a Site Index value.

7. It may be of interest to point out, in connection with the place of Sitka spruce in its natural forests, that any species in mixed forest, which is less shade-tolerant than its associates, but is found as a constituent of the mature, fully-developed aspect of such forest, necessarily tends to occur as a co-dominant, or an emergent. Eastern white pine (*Pinus strobus*) in the Northern Hardwood-Hemlock-White Pine forest in New England, provides a very good example. It may be observed in old growth forest, in which the dominant canopy is formed mainly by beech, maples and eastern hemlock, as a clear emergent with a crown rising well above the level of this. Douglas fir seems clearly to provide another example, and in forest which is closely related to that in which Sitka spruce occurs, for the associated species maybe similar in both cases. A principal difference between these and Sitka spruce is that they are the more site tolerant, at least on the dry side, and for this reason are able to occupy a much more dominant position as regards area of occurrence. This greater site tolerance enables both Douglas fir and eastern white pine more easily to take a prominent part in the dominated aspect of the canopy than does Sitka spruce ; for they are able to grow more or less satisfactorily on sites on which their shade-tolerant associates are relatively at a disadvantage. It is also of interest to note in this connection that, on a water-losing site of moderate Site Index value, eastern white pine, at the age of 130 years, was observed largely to have prevented the development of the dominated aspects of the canopy. Nothing has been seen which suggests that on an equivalent site in its native area Sitka spruce would be able to exercise similar control, though a pure stand might do so if it occurred densely on good moist soil (e.g., Plot L7, Fig. 20, Tables 19 and 22). Plate 40 shows a pure and fairly well-stocked stand of Sitka spruce growing on wind-blown sand. The Site Index value is low, and it will be seen that the dense well-developed under-canopy of salal necessarily indicates a rather light crown density on the part of the spruce. The age is about 90 years. Evidence such as this suggests that, when grown in pure stands, one result of the relatively limited site tolerance of spruce, as compared with its associates, will be seen in the comparatively early onset of low crown density, and of

the poorer growth with which this is associated. This seems to fit in well with the general pattern of species distribution, especially as this is seen around Terrace, on the eastern limit of the natural range of Sitka spruce. It also points to the need for incremental studies of the associated species on sites of different types.

8. It seems impossible, in giving final consideration to this matter of the relative position of Sitka spruce and its associated species, to avoid the conclusion that, if marginal conditions for successful competitive growth in even-aged canopy are considered, the margin for spruce is ordinarily set at a higher level of fertility than that for hemlock, cedar or pine. Marginality in fertility, in regard to any species, must necessarily be measured in growth rates, and by this standard conditions in mature forest certainly suggest that this advantage of the associated species is not always maintained. The skunk cabbage types round Lake Lakelse (Table 19) provide examples of sites of low fertility in which spruce seems able to hold its own in terms of growth rate, even though it may not be the more abundant species. One is, thus, left with the problem of determining what are the qualities in soil deficiency which determine relative competitive power. On the whole, however, it seems to be clear that in the regions worked in, and on sites which give approximately marginal conditions for economic production, the associated species have the advantage over Sitka spruce.

Pathological Problems

1. The writer, as a pathologist, was inevitably interested in the pathological aspect of site conditions and especially insofar as root development is affected. Reference to this aspect of things has been made from time to time above, but the matter warrants some special reference here. No examples were seen of significant injury to the crown of trees by direct action, either by non-parasitic or parasitic factors, except in special cases which do not affect this discussion, and the effect of this type of injury on the root system is not considered here. There are two aspects to the conditions under which disease of the root system develops under the influence of site conditions. The one is concerned with competitive effects, and is to be regarded as normal to the forest ; it is merely the result of the population being too great for the area colonised. The other relates to the inherent needs of the root system for its full development, and to the capacity of the soil to satisfy these needs. This capacity of the site naturally influences the competitive effects, so that the two aspects quite commonly operate concurrently. This is a complex subject which will be dealt with here only to a limited extent.

2. It seems quite clearly to be necessary, in considering this subject, to take into account the influence, in connection with both the competitive effect and site capacity, of the continually changing size of the trees. It is simplest to think in terms of an even-aged canopy. The resultant effect of competition and site capacity on the forest must be considered to vary, under any particular set of conditions, with the increasing size of the trees which constitute it. It seems to be clear that at first the competitive effect is the more important. A really small tree needs only a small capacity for supply in the soil to satisfy its needs, and under these circumstances the number of trees per unit area is more important than anything else. The site capacity effect always operates, but it may be estimated to begin to show obviously, at least on some types of site, after a high canopy has been formed. The size of tree, for any species, at which this effect will have a serious influence on growth, will plainly depend on the soil characteristics ; i.e., on such things as available space for root development ; and the nature of the water and nutrient supply within this. There will be a biotic aspect, but this will depend largely on these basic physical and chemical characteristics.

3. Competition involves a condition of mutual strain between the competing organisms, and must be regarded as always tending to have a pathological effect ; in the case of the trees which succumb this is obvious and, while the successful trees may not usually be affected, seriously, they must also be influenced. It seems to be plain thus, that during the critical period in competition, it is more easily possible for deficiencies in site capacity to have a general effect in the forest than either before or after ; e.g., after many trees have succumbed and the number of stems per acre has been greatly reduced. It is thus to be expected, purely from the aspect of competition, that periods of strain will be passed through, according as the canopy develops, and that these periods will be normal to the life of the forest whatever its age : also that while they are at their height, at least, some pathogenic tendencies are to be expected, even in the successful competitors.

4. The pathogenic tendencies inherent in competition are most easily observed during the early part of the life of an even-aged stand, and especially when the trees are quite small. During this early period it is characteristic for the dominants to be the successful competitors. This is a well-recognised characteristic, and it persists for some time ; in the West Coast forests worked in, probably for at least the first 100 years as a rule. Complications arise quite early, however, owing to deficiencies in site supply capacity. This matter of deficiency in site

capacity for root development and action is more complex than perhaps might seem at first sight, even when considered from the physical standpoint only. There is, e.g., the simple physical deficiency in rooting space as, for example, when a few inches of soil only occurs over hard compressed material as in profiles 19, 20B and 24 in Table 8, or the only less shallow soils on skunk cabbage sites (Table 20). Ordinarily, however, matters are more complex, and many variations occur according to soil and site characteristics. Another class of soils in which there is obvious physical deficiency is provided by extremely stony, very freely-draining, soils, such as that in Plot L9, near Lakelse, referred to above (Table 22, Page 77, para. 11), or the parts of the ancient fan of Granite Creek, Lakelse, in which the soil consists almost entirely of rounded boulders and which carried poor hemlock-pine forest. The most common site capacity restricting characteristics in the hill region investigated in Graham Island were, on the one hand, the occurrence of hard compact material as the basic root-restricting layer, and on the other, the occurrence of coherence with massiveness of structure in the main rooting zone. Plot 3 (Plates 17 and 26) in the Indian Reservation, Skidegate Mission, among many others, provides an example of both. This was a lower slope site in an even-aged 100-year-old stand of Sitka spruce and western hemlock regenerated after fire. The high canopy was passing through one of the critical periods in competition when a more or less drastic natural thinning is due to take place ; there was practically no understorey. The total rooting depth was 55 inches. The top six inches of this consisted of humus and was intensely rooted ; the remainder of the rooted profile consisted of loam with some large blocks of angular hard stone. The top eight inches of this loam consisted irregularly of either loose, or coherent compact material : the loose material contained frequent live roots, but the compact either no roots or only fine dead roots. The next 39 inches consisted mainly of compact coherent material which was penetrable by roots, but in which the development of fine roots was not favoured. The roots which passed through this were sparsely branched, frequently they showed dead ends and in the lower 20 inches the dead ends of large sinker roots occurred. The remaining two inches of rooted soil were loose and porous ; they contained many live active feeding roots. There occurred below this a hard almost plastic sandy clay which was not rooted. It is, of course, quite impossible to say what proportion of the root system had died in this place ; but the description fits many sites excavated, and may be taken to indicate what is of very general occurrence. It may be taken as certain that much of this dying of roots has little to do with competition ; much would have taken place in any case and is dependent on the soil characteristics.

5. Observation of this type of root disease indicates that it is fundamentally non-parasitic in origin. It was always observed, to a greater or less extent, in the soil profiles dug, and in old-growth stands often plainly had developed to a considerable extent. It may be taken that in many cases the whole forest is more or less affected ; but there is every indication that it does not result in the general death of trees. However, it undoubtedly affects competitive vigour, and the possibility of survival in the general competitive life of the forest. The effect of this type of root disease, on any site, becomes more severe the larger is the tree ; for its dependence on deficiencies in site capacity to supply the needs of the root necessarily means that the greater the tree, the more will the site deficiences tend to be felt. This relationship between site deficiency and the development of root disease has the effect, eventually, of reversing the relationship in competition between the dominants, or emergents, in the high canopy and those trees which hold an inferior position. The larger trees develop crown debility in response to root die-back to a greater extent than the smaller and, because of this, become the less vigorous in competition. This is the phenomenon referred to above in the discussion on crown development (Chapter 8, page 80). It has a very definite pathological basis, and is usually not merely a phenomenon of old age ; that is of the development of inefficiency in the working of the organism because of increasing age, irrespective of the quality of living conditions.

6. It is of interest to note that the larger roots of spruce in old-growth forest very frequently show two phenomena which seem to be directly related to this type of root disease. They are the occurrence of false heart wood and of resin-soaked heart wood. Neither of these phenomena are normal, and large roots occur which are free from both. It would be of interest to know what is the relationship between the occurrence of these and the development of decay ; that is whether they are related to conditions which helped to slow its development, or whether they are merely a sign of its rapid extension. Observation inclines one to think that the former indication may be true.

7. It should be noted that, although it was not observed in the forests worked in, there may be, and often is, a relationship between parasitic action and the development of the type of root disease discussed here. It is indeed plain that this is necessarily intimately connected with the development of butt-rot and of decay in roots. More obviously parasitic phenomena, involving the death of trees in relation to fungus attack, seem to occur mainly at a relatively

early age, and perhaps chiefly when the forest consists of dense young stands of between 30 and 60 or 70 feet in height. It is not proposed to discuss this matter further, since no case was observed during the work under discussion.

8. The consideration of root disease which develops owing to deficiencies in site capacity leads to the conclusion that, within any climatic zone, a reduction in Site Index value tends ordinarily to be associated with a rise in risk to the healthy development of the trees. This means that a change in Site Index value from higher to lower is often not merely the reflection of a balanced reduction in opportunity for feeding, with the consequent necessary reduction in growth rate : commonly, it is the result of conditions which are pathological at least in part. Root die-back, determined largely by the constitution of the soil and the character of the soil supply to the root, is the consequence of this. The risks of raising trees of a particular size are, for this reason apart from others, ordinarily greater on the poorer sites than on the better. All observations made during this work bore evidence to the truth of this, and especially the root examinations.

9. One point that, perhaps, should be referred to, is the occurrence of injuries to the bark on the butt lengths of the main stem, on trees which still bear dead suppressed branches, or the remains of these. These injuries, and sometimes the more or less extensive death of bark, are particularly noticeable in the Terrace region : they were not noticed in Graham Island, but may occur there. They were seen on Sitka spruce, western hemlock and lodgepole pine, but not on western red cedar. The more common type of injury occurs immediately round dead branch butts and, at least on lodgepole pine and Sitka spruce, is usually accompanied by a secretion of resin. Occasionally injuries which resemble target cankers develop, but this is not common. Quite long strips of bark die sometimes : this was noticed particularly on lodgepole pine. No attempt was made to determine the cause of these injuries. It seemed possibly significant that they were much more common round Terrace than in Graham Island, and that their more frequent occurrence there might be connected with the different and more severe climate, especially between the autumn and spring. This sort of injury occurs in Britain on a number of species of conifer. It has been noticed there particularly on Sitka spruce and Japanese larch, and its development seems to be based either in the action of frost or in lack of water. The callus region round a small dead branch snag is one in which cambial activity begins early, relative to other places on the stem and, under suitable conditions, it is, for this reason, susceptible to injury. The more extensive dying of bark is related to this. Fungi, if they occur as parasites, play a secondary role. Interest in this matter lies principally, perhaps, in the possibility of its being evidence of the difference in conditions of climate in the two regions worked in and, in this connection, that the adaptation of a species to climatic change is limited.

10. Finally, mention may be made of the occurrence of splits in the main stems of trees. These were observed, both round Terrace and on Graham Island. They occur not infrequently and were seen in Sitka spruce and western hemlock, but not in other species of tree. They are usually slightly spiral : they may be of very great length, at least thirty or forty feet long, or may be quite short. None of those seen had the raised lips which are usually considered typical of winter frost crack, though around Terrace foresters were quite clear that this occurred and could be heard taking place. There seems to be only two possible causes of these : either they are the result of low winter temperatures ; or they are the result of drought. There were, for example, some particularly large ones in Plot 16 (Table 3), the soil of which is of light texture and freely draining, and they were quite frequent, though small as a rule in Plot 22, Yakoun Bay (Table 23, Plate 22), the soil of which is a porous gravel. These cracks looked very similar to the drought cracks which have been observed in western Europe (Day, 1954) on a number of species of conifer, including both Sitka spruce and western hemlock, and it seemed probable that some of them, at least, were of this nature. The principal interest in such phenomena as these lies in the light they cast on climatic, or soil, conditions and here, perhaps, lies the principal warrant for their investigation.

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Appendix I

List of Plots Examined

Symbols used :

SSp = Sitka spruce.
WH = Western hemlock.
WRC = Western red cedar.
LPP = Lodgepole pine (as an aggregate species).
BIC = Black cottonwood.
RAI = Red alder.
bh = Breast height.

S = Sand, Sm = medium ; Sb = heavy, sand.
L = Loam, La = light ; Lm = medium ; Lb = heavy loam.
Si = Silt.
C = Clay.
P = Peat.
H = Humus.
Gr = Gravel.
f = fine ; co = coarse ; v = very ;
loc = locally ; gr = gravelly ;
s = sandy ; si = silty ; c = clayey ; l = loamy.

† A/B = Depth in hollows/Depth in humps.
* Present as subdominant or in under-storey.
Location of Plots : Nos. 1-24 and Tl. 1-3 in Graham Island, Queen Charlotte Islands, B.C. ; K1-6; L12, 34, 56 and 7-9 ; and T1-4 in the region of Terrace, B.C.

Situation	Plot Ref.	Age	Average Height of Taller Trees according to Species (feet)						Parent Material	Soil			Observed Rooting (of Trees)		Type of Humus	Observed Depth of Water Table (ins.)	Notes mainly on Ground Vegetation
			SSp	WH	WRC	LPP	BIC	RAI		Group	Texture	Drainage	Depth (in.)	Condition			
1. Riverside flats (*a*) Flooded	5	All ages	237	—	—	—	—	—	Alluvium	Immature	lS-sL Gravel	Free	84	Good	Layered alternately with mineral soil	ca90	Situations 1 and 2 are characterised by a field layer having ferns and herbs, often with *Oplopanax horridum* as a shrub ; *Vaccinium spp.* tend to occur on podsolic sites (e.g. 4) but may be absent (e.g. L7).
	18	All ages	205	170	—	—	—	—	Alluvium	Immature	Variable ; lS and S over Gr	Free (?Excessive)	69	Many large dead	Layered alternately with mineral soil	Not reached	
	T3	All ages	193	*	—	—	197	—	Alluvium	Immature	Shallow cL/fSm	Free	57	Many large lower dead	Layered alternately with mineral soil	Not reached	
	T1	Conifers 70-90	80	—	74	—	165	—	Alluvium	Immature	La/large cobbles	Free	48	Good	Layered alternately with mineral soil	Not reached	*Equisetum* may be abundant (e.g. K1). Skunk cabbage may occur in wet hollows (e.g. K1, K3).
	SA1	—	ca200	Not measured-felled *	—	—	—	—	Alluvium	Immature	Lm/Lb/sC	Free (?slow) /Impeded	80	Many large dead	Friable, loose, not layered	80	
(*b*) Not flooded	4	All ages	227	192	—	—	—	—	Alluvium	Podsol	Lm/Lb/sC	Free (?slow) /Impeded	64	Many large lower dead	Friable, loose	Not reached	

Situation	Plot Ref.	Age	Average Height of Taller Trees according to Species (feet)						Parent Material	Soil			Observed Rooting (of Trees)		Type of Humus	Observed Depth of Water Table (in.)	Notes mainly on Ground Vegetation
			SSp	WH	WRC	LPP	BIC	RAl		Group	Texture	Drainage	Depth (in.)	Condition			
2. Alluvial fans. (Not usually flooded)	16	All ages	227	169	—	—	—	—	Alluvium	BFS (degraded; possibly immature)	Variable; La, sL, cL, L with Gr	Free (?Excessive)	41	Many large dead	Friable, loose	Not reached	*See note above.* Very large slightly spiral cracks occurred in the main stems. The dominant spruce characteristically had broken tops.
	K1	All ages	150	—	ca125	—	—	—	Alluvium	Immature (flooded)	fS-Sb	Free to 18.5 in.	32	Many large dead	Layered with mineral soil	32	*A. sinuata* occurred.
	K2	All ages	200	170	155	—	—	—	Alluvium	Podsol	Variable; sL, L, Sb, Gr	Free	96	Many large dead	Friable, loose	108	
	K3	All ages	178	161	126	—	—	—	Alluvium	Podsol	Variable, Sb, Lb, L, S	Free to 15 in.	27	Moderately good	Friable, loose	31	*A. amabilis* was frequent in the under storey. *O. horridum, C. uniflora* and *Cornus canadensis* as ground veg. on higher ground.
3. Flat Alluvial valley sites (not flooded)	L7	125 at br.h.	166	*	*	—	—	—	Alluvium	Podsol	Variable Si, fS, C and P	Free to 40 ins.	41	Moderately good	Friable, loose	41	Field layer—*A. felix-femina—O. horridum.*
	L8	130 at br.h	150	120	114	—	—	—	Alluvium	Grey Meadow	Variable siS, S, P	Free to 10 in.	15	Moderately good	Friable, loose	25	Field layer—*A. felix-femina. L. camschatcensis.*
4. Flat valley or plain swamp sites	14	All ages	*	51	88 (Hollows always swampy)	—	—	—	Glacial gravel and peat	Gley or organic	Loc. Gr, or siL; Loc. Peat	Impeded in Gravel, Swampy in peat	8 (gravel) 2 (peat)	Moderately good in soil surface	Fibrous, porous	14 In peaty hollows variable in gravel humps	Field layer—Peaty hollows—*Sphagnum* with grasses. Gravel humps. *H. splendens, R. loreus, C. canadensis, V. ovalifolium.*
	15	All ages	*	114	118 (Flooded in Spring)	—	—	—	Peat over alluvium	Organic	Peat/Clay	Impeded in clay	4 mainly total 12	Good in top 4 in. then dead	Crumbly friable in top 4 in. then coherent	15	Probably a skunk cabbage site—floor mainly bare.
	6	All ages	*	—	64 (Probably flooded in Spring)	—	—	—	Deep peat	Organic	Peat	Stagnant below 8 in.	8	Good in surface then mainly dead	Fibrous matted	8	*G. shallon, L. groenlandicum; V. viride* and mosses, including *Sphagnum* spp.
	21	90	105	—	90 (Flooded in Spring)	—	—	*	Deep peat *	Organic	Peat	Stagnant below 20-24 in.	18.5	Many dead	Fibrous becoming coherent	14	Worms occured in surface humus.

Situation	Plot Ref.	Age	Average Height of Taller Trees according to Species (feet)						* Parent Material	Soil			Observed Rooting (of Trees)		Type of Humus	Observed Depth of Water Table (in.)	Notes mainly on Ground Vegetation
			SSp	WH	WRC	LPP	BIC	RAI		Group	Texture	Drainage	Depth (in.)	Condition			
4. Flat valley or plain swamp sites—*continued*	L12	All ages	101	(<70)	89	—	—	—	Deep peat	Organic	Peat	Stagnant below 13 in.	13/21†	Many dead	Friable, loose on surface	13-16	Wet hollows; *L. camtschatcenis*. Humps: *Vaccinium-Menziesia—C. canadensis—D. linneana.*
			(Subject to flooding)														
	L34	All aged	114	(77)	94	—	—	—	Shallow peat/lake Silts	Organic	Peat	Impeded	10/26†	Moderately good	Friable, loose	ca.13	Wet hollows: *L. camtschatcensis* with *Rubus-Cornus*. Lady fern: Humps: *Vaccinium-Menziesia-Cornus.*
			(Subject to flooding)														
	L56	All aged	160	(117)	133	—	—	*	Lacustrine clay	Gley	Clay	Impeded	15/11†	Moderately good, prob. many heart roots dead	Hollows: Very matted. Humps soft, porous	Hollows: 15 (perched) Humps: Nil	Hollows: *O. horridum, Rubus* with *L. camschatensis.* Humps: *Vaccinium, C. canadensis, D. linneana*, also *A. amabilis* in understorey.
5. Hill slopes showing hump and hollow relief	1	All ages	—	167	—	—	—	—	Colluvium /Till	Brown Podsol	L/Gr.C (Till)	Free to 50 in.	50	Many large lower dead	Tough raw humus	Nil	Much regeneration almost entirely W.H., but a little S.Sp. occurred.
	3	100	153	135	—	—	—	—	Colluvium /Till	Brown Podsol	L/sC (Till)	Free to 53 ins.	53	Moderately good but frequent ½-1 in. dead	Friable, loose	Nil	A *Polystichum munitum* site on lower slope of a hanging valley.
	7	All aged	152	149	135	—	—	—	Colluvium /Till	Gley	L/Gr. C/ Gr. sC Till	Impeded	Variable in humps; †36-20/2	Moderately good but frequent dead lower	Friable, loose	In hump ca. 24 (perched)	Humps: Mainly moss *Vaccinium, D. linneana*—herb type in open. Hollows: *Mnium, Sphagnum.*
	8	All aged	160	146	132	—	—	—	Colluvium /Till	Brown Podsol	L/Till	In humps free to till	Variable; in humps 40-20	Moderately good some dead locally	Loose, crumbly	Nil	Much as 7, but the hollows were less wet.
	12	75	132	114	—	—	—	—	Colluvium /Till	Brown Podsol	La/Lm	Free to till	Variable †48-20/ 18-12	Good	Friable, loose	Nil	A moss type with much *Rh. loreus.*
	13	295	219	203	—	—	—	—	Colluvium /Till	Brown Podsol	Lm/ Cemented Till	Free to till	Variable; up to ca. 72	Many large dead	Tough coherent, porous	A dribble at 68 in. over the till	A moss type (e.g. *Pl. undulatum* was abundant).

Situation	Plot Ref.	Age	Average Height of Taller Trees according to Species (feet)						Parent Material	Soil			Observed Rooting (of Trees)		Type of Humus	Observed Depth of Water Table (in.)	Notes mainly on Ground Vegetation
			SSp	WH	WRC	LPP	BIC	RAI		Group	Texture	Drainage	Depth (in.)	Condition			
6. Hill slope with no obvious "hump and hollow" relief	17	87	128	128	—	—	—	*	Partly colluvium, partly *in situ*	Brown Podsol	Stoney La/Soft fissured rock	Free (possibly excessive in bed-rock)	Variable, ca. 48-12 in.	Moderately good, locally dead	Friable, loose	Nil	On a short slope up from the sea beach.
	K4	120	82	79 (At the foot of a slope)	*	—	—	—	Probably a lacustrine clay	Gley	Sa.Gr/C	Impeded	21	Many dead in Gley	Friable, loose	Nil	*Rh. triquetrus*, *R. loreus*, etc., with *Pyrola* and *Habernaria*.
	K5	120	—	76	*	89	—	—	Lake beach sand/lacustrine clay	Podsol	Sa/C	Free to 38 in.	38	Moderately good	Hardly any; a matted F layer	Nil	*H. splendens*.
	K6	120	*	50	*	82	—	—	Raised beach gravel	Podsol	coS, Gt; cobbles/S	Free	82†	Moderately good	Hardly any; a matted F layer	Nil	*H. splendens*. Many scrubby, W.H. occurred and one small Sitka spruce.
	T2	All aged	172	136	*	—	—	—	Lacustrine clay	Gley	C	Impeded below 15 in.	15½	Many dead	A trace only occurred	Nil	*O. horridum*; *A. felix femina*; *Clintonia uniflora*.
7. Bottom of Dry Valley	T4	All aged	164	151	151	—	—	—	Partly colluvium, partly Till	Podsol	Lm/GrL/GrL (Till)	Free to Till	19½	Moderately good, but frequently dead	Slightly coherent, or loose	Nil	*Clintonia uniflora*; *Cornus canadensis*, Lady fern (occ.).
8. Side Moraine at foot of mountain slope	L9	All aged	187	169 (Ab. amabilis ca. 150)	133	—	—	—	Side Moraine	Podsol	f.s.L/ang. hard rock †c.S.L over compact sC at Ca. 84 in.	Free	More than 65	Many dead	Friable, loose	Not reached; probably occurs temporarily	Variable hollows. *O. horridum*; *Rubus*—Fern: Higher parts: *V. ovalifolium*; *Clintonia*; *C. canadensis*. *A. amobilis* occurred frequently in understorey.
9. Shelf on Mountain side	9	All aged	157	146 (A "hump and hollow" site)	135	—	—	—	Colluvium, Till, or Peat	Gley, Podsol, Brown Podsol or Peat Podsol	Very variable sL, Gr, si, P, etc.	Very variable	32	Not properly seen	Usually friable, loose	Locally 6-8, often Nil	Very variable, varying from *Vaccinium* — herb type on humps to *Mnium* or *Sphagnum* where wet. This was on a reverse slope.
10. Sites on the N.E. plain of Graham Island	19	90	—	74	74	74	—	—	Till ?	Gley Podsol	Gr. sC/Till of same material	Impeded	12	Many lower dead	Friable, loose	Nil	
	20	90	120	108	*	—	—	—	Drift/layered sC and S	Gley	Variable grL/sC, Gr, si, v.f. S	Imperfect/Impeded	14-20	Moderately good; frequent small, dead	loc. loose; loc. matted	ca. 34 (perched)	Plots 19, 20 and 24 showed mainly a bare floor with mosses. They probably would be invaded by *G. shallon* —*M. ferruginea* bush as the canopy, opened.

Situation	Plot Ref.	Age	Average Height of Taller Trees according to Species (feet)						Parent Material	Soil			Observed Rooting (of Trees)		Type of Humus	Observed Depth of Water Table (in.)	Notes mainly on Ground Vegetation
			SSp	WH	WRC	LPP	BIC	RAI		Group	Texture	Drainage	Depth (in.)	Condition			
10. Sites on the N.E. plain of Graham Island—*continued*	22	150	156	151	—	—	—	—	Raised beach gravel	Brown Podsol	Gr/sGr	Free (Possibly excessive)	Variable often shallow, ca. 10-15	Moderately good as seen	Friable, but slightly coherent	Nil	An understorey of W.H. occurred as a rule. Small slightly spiral cracks occurred frequently on main stems.
			(Slightly a "hump and hollow" site)														
	23	97	134	137	—	—	—	85-90	Till?	§Brown Podsol or Podsol	grL	Free in humps; elsewhere impeded	Variable; up to 60 in. in humps	Usually moderately good. Lower often dead	Coherent	Nil	§Immature on younger humps.
			(A marked "hump and hollow" site)														
	24	90	92	92	84	79	—	—	Till	Gley	cGr	Impeded	10-13	Many lower dead	Friable	Locally 13, perched	See plot above.
	Tl 1 (*drier*)	95-100	111	92	77	—	—	§	Layered sandy gravelly clays	Gley	S grC with thick H	Impeded	Variable very shallow in hollows	Moderately good frequent dead	Friable, loose	Nil	§Alder occurred at first; sparse mosses only.
			(A marked "hump and hollow" site)														
	Tl 2 (*drier*)	95-100	106	80	98	—	—	§	Layered sandy gravelly clays	Gley	S grC with thick H	Impeded	Variable very shallow in hollows	Moderately good frequent dead	Friable, loose	Nil	§Alder occurred at first; sparse mosses only.
			(A marked "hump and hollow" site)														
	Tl 1 (*wetter*)	95-100	65	77	82	78	—	—	Layered sandy gravelly clays	Gley	S grC with thick H	Impeded and water-logged	In the organic surface only	Many dead	Soft, coherent	10-15 (except in humps)	Moss and Liverworts.
			(Some organic humps occurred)														
	Tl 2 (*wetter*)	95-100	73	72	73	—	—	—	Layered sandy gravelly clays	Gley	S grC with thick H	Impeded and water-logged	In the organic surface only	Many dead	Soft, coherent	10-15 (except in humps)	Moss and Liverworts.
			(Some organic humps occurred)														
11. Wind deposited shelly sea sand	Tl 3	80	79	*	—	—	*	—	Shelly sand	Brown§ Podsol	S	Free	34	Many dead especially lower roots	Friable, loose	Not reached	*Gaultheria shallon* with a moss cover beneath. §Rooted sand was acid; lower unrooted sand was alkaline and shelly.

Appendix II

Basal Area and Volume per Acre in Relation to Type of Site

The data presented in the tables below give basal area and volume per acre for the various plots in Graham Island, and basal area only for the plots around Terrace. The data for volume, basal area and height for the Graham Island plots are derived from data collected at the time of this investigation by Mr. R. L. Schmidt ; all other information was collected by the author and Mr. S. P. Lok. The basal area figures can be identified by a text-figure always being quoted in reference to them. It will be seen that a figure for total volume per acre is usually given for the Terrace plots. This is only an approximate value, but it gives some idea of the standing volume of timber at the time of observation. It is calculated from the regression of volume on basal area for the Graham Island plots (Fig. 26). This is highly significant, but it is obviously calculated from a small number (20) of plots. It is not believed that the change in geographical position from Graham Island to Terrace, nor any possible genetic change in constitution of species, is of any very appreciable importance in this matter.

The data are arranged according to type of soil (organic, Table 24 ; mineral, Tables 25-27) ; according to the physical nature of the site (bench sites, Tables 25, 26 and 28 ; slope sites, Table 27) ; and according to depth of rooting (shallowly rooted bench sites, Table 25 ; deeply rooted, Table 26). The order in the tables is in that of increasing basal area per acre, except in Table 28, in which it is in order of increasing wetness of site. It will be seen also that in this table both organic and mineral soils occur.

The interest in these plots lies, not in their representative nature, which is poor, but in their illustration of the standing volumes of timber which may occur, sometimes with extremely shallow rooting. The plots fall into two groups : Root development in Nos. 6, 15 and 21 was entirely in organic material and, whether this was deep or shallow, that which underlay the root systems was in the " fossil " state, with the original natural structure highly preserved ; the long-standing occurrence of anaerobic conditions was thus indicated. The interest here lies in the comparison between No. 6 and Nos. 15 and 21. This, it may be suggested relates to the nutrient status of the rooted materials, e.g., it has been shown above in the main text (Page 29, para. 14), in connection with Plot 21, that beyond the influence of the creek by the side of which this stood, growth became very poor, although there was no very appreciable difference in appearance of the material rooted or in rooting depth. The worst parts of this stand probably would show standing volumes no higher than that for No. 6, and with the species in the same order.

The rooted material in No. 14 was mainly mineral, accumulated in small wind-throw humps set in water-saturated peat swamp. The small size of the humps, and the condition of the organic material, served severely to restrict root development and so growth.

No. 11 was nearest in character to Nos. 19 and 24, Table 25, but they were, by land formation, in water-losing situations, whereas No. 11 was in a water-receiving, but draining, site. Here is to be found the main reason for the co-dominance in height growth of spruce and cedar, and the sub-dominant position of hemlock, though this last-named was the most numerous species present. This plot is included here because at the time of examination the living roots appeared to be entirely in the organic material. The stand had passed through the period of improvement in soil condition which follows regeneration *en masse*, on sites such as this and Nos. 19 and 24, and had passed into the period of root and crown degeneration. As a result of this, the surface of the till was completely water-logged, and all the roots which had shallowly penetrated into it, dead.

The plots collected together here are united by their being situated on benches, or relatively flat places and, taking the average depth, being shallowly rooted. It is obvious from the data that there is no necessary connection between depth of rooting and volume of standing timber, although the three plots with the lower standing volumes (Plot Nos. K4, 19 and 24) are three of the more shallowly rooted. The suggestion is that the order of arrangement, if put in terms of standing volume, reflects water supply and nutrient status. Thus Nos. 19 and 24, in which pine is well represented, both occurred on sites characterised by the strong development of ericaceous bush (salal-false azalea-bilberry) as the high canopy becomes open ; K4 was a moss type, under canopy, usually associated with moderately dry conditions ; but Nos. T2 and T4, having the higher basal areas, were both devil's club-fern-herb types, T4 being the less moist.

Plot 20 represents regeneration after fire and No. 23 similar regeneration after wind-throw : the site fertility in terms of height growth is very moderate in both cases, but conditions, given such pretreatment, favour the early growth of spruce, and

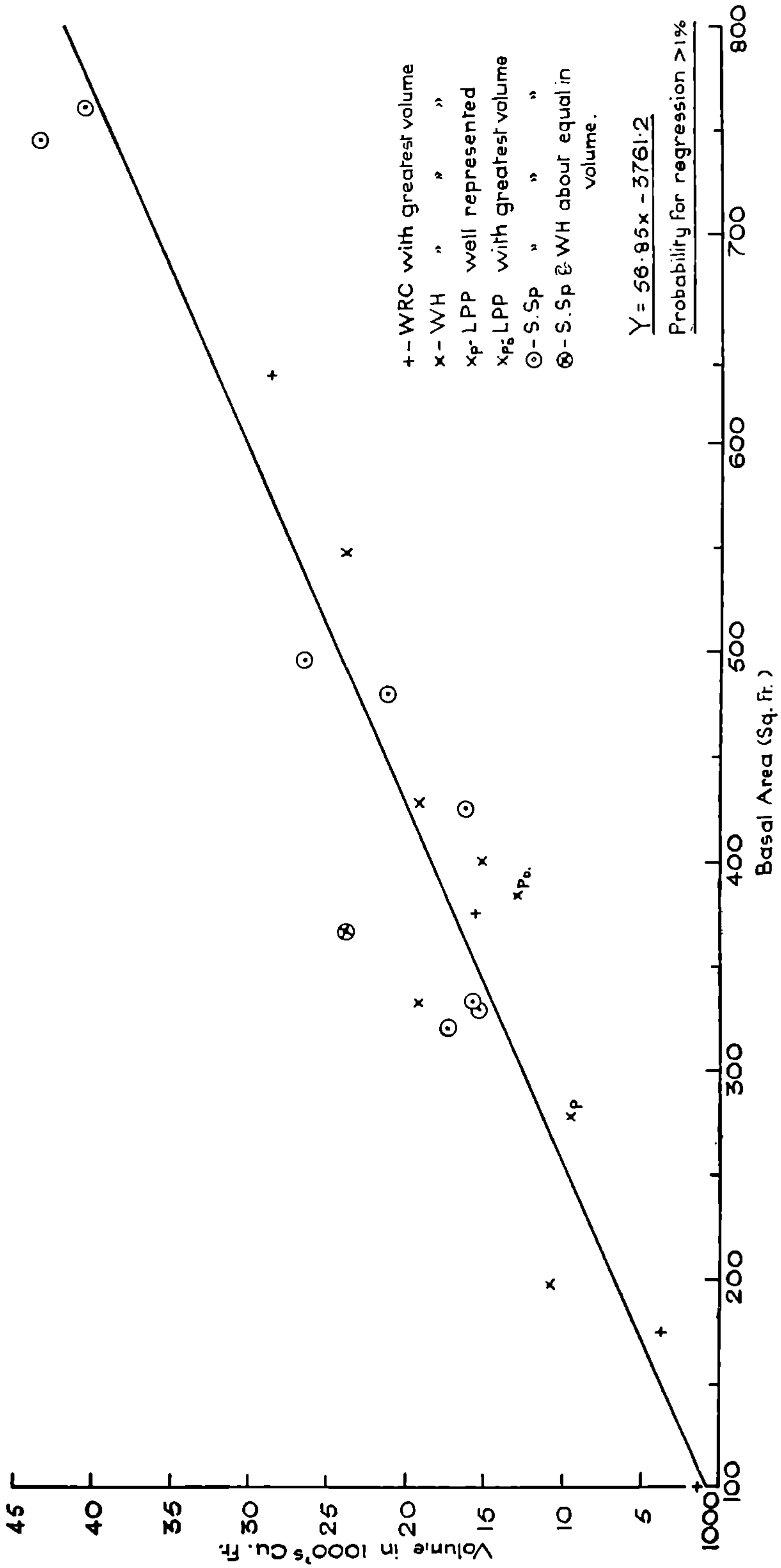

FIG. 26.

Relationship between Basal Area and Volume per Acre for the Graham Island Plots.

TABLE 24

Stands in Graham Island on Organic, or Mainly Organic Soils

Volumes in true measure, over bark

Plot No.	Age	Type of situation	Soil: Group	Soil: General character	Soil: Approx. Depth rooted	Soil: Root distribution	Est. mean height (ft.) of dominants and co-dominants	Basal Area (sq. ft.) per acre: S	Basal Area (sq. ft.) per acre: C	Basal Area (sq. ft.) per acre: W	Total basal area	Volume per acre (cub. ft.) including stump and top : no deductions: S	C	H	Other Spp.	Total volume per acre (cu. ft.)
Sites with organic, or mainly organic soil																
14	All ages	Swampy bench ; (H.W.)	Podsol or Gley and Organic	Small mineral humps separated by peat swamp	In humps only (T)	Root die-back common and often severe in lower wetter soil rooted	C = 88 H = 51 (S = very small)	3	56	41	100	18	1,813	496	—	2,327
6	All ages	Flat ; site of lake	Organic	Deep peat, stagnant below 8 in.	8 (T)		C = 64 H ca = 30 (S = very small)	—	133	42	175	—	3,251	742	—	3,993
11	All ages	Plain, gentle slope to creek	Organic (over Gley)	8 in. of organic over till	11 (TT)		S = 136 C = 135	54	226	95	375	2,824	9,960	3,133	—	15,917
15	All ages	Flat bench by river, site of pool	Organic	Shallow peat (over clay), stagnant below 5-6 in.	5 (T)		C = 118 H = 114 S = Ca 110	9	165	226	400	355	6,335	8,480	—	15,160
21	90	Flat, by small creek : site of lake	Organic	Deep peat, stagnant below 18 ins.	18 (T)		S = 105 C = 90	372	22	30	424	14,179	550	862	715(A)	16.306

Symbols : H = Hump and hollow site; W = Wet hollows; T = Water-table present; TT = Temporary Water-table; S = Sitka spruce; W = Western hemlock; C = Western red cedar; A = Red alder

TABLE 25

Volumes in true measure, over bark

Stands situated on Bench or Plain Sites and with Shallow Rooting in Mineral Soil

Plot No.	Fig. No.	Age in years	Type of situation	Soil		Root		Estimated Mean Height (ft.) of dominants and co-dominants	Basal Area (sq. ft.) per acre				Total Basal Area	Volume per Acre (cub. ft.)				Total Volume per acre
				Group	General character	Approx. Depth (in.)	Distribution		S	C	W	Other Spp.		S	C	H	Other Spp.	
K4	8	120	Bench at foot of slope	Gley	Shallow sandy gravel over varved clay	20	Good for top 10 in.	S = 82 H = 79	86	68†	124†	—	279	—	—	—	—	—
19	—	90	Nearly flat top of a gentle rise	Gley Podsol	Stony loam over till	12.5	—	H = } 74 P = }	1	101	127	70 (P)	279	20	2,805	3,778	2,579 (P)	9,832
20	—	90	Nearly flat top of a gentle rise	Brown Podsol over Gley	Shallow stony loam over varved clays and sand	24	—	S = 120 H = 108	166	8	146	—	320	11,781	206	5,543	—	17,530
23	—	97	Nearly flat top of a low hill	Disturbed (Podsol, Gley or Immature)	Loam over till H	6-48	Good where soil disturbed	S = 134 H = 137 A = 115	183	—	107	42 (A)	332	9,074	—	4,793	1,901 (A)	15,768
24	—	90	Nearly flat top of a gentle rise	Gley Podsol	Stony loam over till, L.T.	10.5	—	S = 82 H = 92 C = 84 P = 79	30	103	100	151	384	1,442	2,823	3,189	5,931 (P)	13,385
9	—	All ages	Bench with reverse slope on mountain side	Podsol or Gley	Loam over till or rock. H. L.T.	Very variable 0-36	Usually good where deepest	S = 157 H = 146 C = 135	78	121	228	—	427	3,218	5,057	10,976	—	19,251
T4	15	Old growth	Bottom of a small dry valley	Podsol	Loam over till	20	—	S = 164 H = } 151 C = }	200 (52)	151 (61)	175 (87)	—	526	—	—	—	—	26,100 (R)
T2	13	Old growth	Sloping bench at foot of steep slope	Gley	Clay over varved clay	16	—	S = 172 H = 136	486 (132)	101 (92)	93 (79)	—	680	—	—	—	—	34,900 (R)

Symbols :

H = Wind-throw hump and hollow relief.
T = Water-table within reach of roots observed.
L = Locally.

S = Sitka spruce.
W = Western hemlock.
A = Red alder.
C = Western Red Cedar.
P = Lodgepole pine.
(R) = Volume estimated from regression with basal area, for Graham Island (Fig. 26).
(52), etc.—Number of trees per acre.
† Includes 48 sq. ft. for occasional old growth trees.

this is reflected strongly in the composition of the stand. It has been shown above (Page 29, para. 13) that in the case of No. 20, a change in soil conditions altered the proportionate specific composition of the stand, spruce tending to be eliminated as the site became less fertile : Nos. 19 and 24, which occurred in the same region, illustrate this.

The site for comparison with No. 23 is the rather older stand No. 22, Table 26. The comparison is between regeneration on a loam well shaken up and cultivated by wind-throw and on a gravel with a leached surface. The data for height growth show that the difference is not between fertility as reflected in the relative growth of spruce and hemlock as mature trees ; it is much more a matter of the degree to which surface conditions affected regeneration. A comparison of the basal area and volume figures suggests that in No. 23 spruce has some advantage in growth, as compared with hemlock ; but that on the gravelly soil of No. 22 it had none : a much closer analysis, with the determination of growth curves, would be needed to prove this.

It should be noted that the accumulation of relatively large volumes of standing timber on these shallow soils has been made possible by the character of the climate for the areas concerned, and that they imply the absence of any frequent occurrence of seasons with severe water shortage. This is reflected in another characteristic of such stands, namely, to show an appreciable amount of root die-back and, as in the case of Plot T2, sometimes a very great amount on the dominants, but yet still to be able to maintain a high canopy in a state of relatively good health. The indications from this are that times of severe stress for supply from the soil occur ; but that they are rarely sufficiently severe to become catastrophic to the trees in the dominant canopy.

The sites illustrated in Table 26 compare with those in Table 25 in the relatively great depth of soil rooted ; but in general topographical class they are similar. On the whole, the order in which they are arranged is of increasing water supply as influenced by soil texture, consistence and porosity, abundance of stones, and the presence of a water-table within reach of the root systems. Thus K5 and K6 were dry moss types, and this was related mainly to the texture and consistency of the soil. The influence of the stoniness of K6 is seen in its lower volume and in the subdominant position of hemlock in relation to pine (see Fig. 10). Plot 4 appears to be out of place ; but although the soil is a deeply rooted heavy loam, the occurrence of a deep, compact B horizon, in which the development of feeding roots was practically absent, caused this to be an inefficient soil ; though, as the height shows, it is a relatively fertile one.

The influence of subsoil water supply on growth is seen in various ways in Nos. 12B, T3, L9 and 12A. 12B was a dry moss type with a very similar soil, in texture and stoniness, to that of K6. The predominants by volume in this part of the transect shown in Fig. 12 were spruce and cedar, with hemlock as the main co-dominant and sub-dominant species. This predominance in position in canopy of spruce and cedar points to the favourable influence of the subsoil water-supply. The absence of pine points in the same direction, for the local indications were that there would have been no absence of pine seed at the time of regeneration.

The mediocre position of T3, as regards basal area, especially as compared with L7 and T2, Table 25, is related to the close compaction of the fine pure sand which formed the main body of the soil rooted (see Plate 13). This is another example of an inefficient soil, from the aspect of feeding root development. The water-table was not reached in this case, but its influence was seen in the dead condition of the lower part of the root system. Nevertheless it is the presence of permanently moist sand within reach of the root-system which has made the relatively good growth possible.

Plot L9 had what was essentially a " rock " soil with a seasonal, but fairly long continued water-table. This is, by natural composition, an exceedingly freely draining, easily drying soil, and the growth achieved illustrates the importance of subsoil irrigation in the presence of a great lack of water-retaining soil colloids. It is particularly important to remember the moist character of the climate in which this area is situated, as also providing favourable conditions for growth. The large spruce in this stand, which were outstandingly emergent from the main canopy, all markedly showed restriction in crown development, and corresponding to this, small diameters for their height, as Fig. 21 shows. This restriction in diameter growth and so in volume production must be related mainly to the freely draining rocky nature of the soil.

12A contrasts with, and is part of the same transect as 12B. It illustrates the influence of change in soil texture on character of stand composition and growth. Nevertheless this mainly sandy soil was inefficient as regards feeding root development, owing to the occurrence in it of close compact masses. The standing volume, although large, is not high for the specific composition and age, and this mediocrity in growth is not entirely to be accounted for by defective stocking.

The relative unimportance of deep rooting for moderately high volume production is shown by a comparison of L7 with 12A, and still more if the latter is compared with T2, Table 25. Both L7 and 12A belong roughly to the same type as regards

TABLE 26

Stands on Bench Sites and with Deep Rooting

Volumes in true measure, over bark

Plot No.	Text Fig.	Age in years	Type of situation	Soil: Group	Soil: General character	Root: Approx. Depth (in.)	Root: Distribution	Estimated Mean Height (ft.) of dominants and co-dominants	Basal Area (sq. ft.) per acre: S	Basal Area: C	Basal Area: H	Basal Area: Other Spp.	Total Basal Area	Volume per Acre (cub. ft.): S	Volume: C	Volume: H	Volume: Other Spp.	Total Volume per acre
K6	10	120	Bench on hill-side (raised beach)	Podsol	36 in. coarse, very stony sand over finer sand with clay bands	> 100	Locally good in top 70 in. then poor	P = 82 (All H in under-storey)	—	5	60	181 (P)	246	—	—	—	—	—
4	—	All ages	Riverside bench; not flooded	Podsol over Gley	Deep heavy loam over clay	64	Mostly poor	S = 227 H = 192	139	—	193	—	332	8,725	—	11,011	—	19,736
K5	9	120	Bench at foot of hill slope (raised beach)	Podsol	37 in. sand over varved clay	40	Irregular, often poor.	P = 89 H = 76	—	17	159	235 (P)	412	—	—	—	—	—
—	12B	Old growth	Lakeside flat not flooded glacial deposit	Podsol	Coarse sand, grit and stone. T (probably)	Not known probably deep	—	Not measured	65	101	224	—	337	—	—	—	—	15,300 (R)
T3	24	All ages	Riverside bench; still flooded	Immature	9 in. loam over compact medium fine sand	57	Good for 9 in. then poor	BC = 197 S = 193	314	—	35	96 (BC)	445	—	—	—	—	21,500 (R)
22	—	150	Raised beach	Podsol	Deep fine gravel	Irregularly deep, mostly shallow	—	S = 156 H = 151	122	—	324	—	446	6,863	—	17,472	—	24,335
L9	21	All ages	Bench at foot of steep mountain slope	Podsol	Shallow loam over broken rock (moraine). TT	> 65	Good (between pieces of rock)	S = 187 H = 169 C = 133	356	95	51	—	502	—	—	—	—	24,750 (R)
—	12A	All ages	Lakeside flat not flooded; old fan of creek	Podsol	Irregularly loamy sand and fine gravel. T at 10 ft.	96	Moderately poor	S = 200 H = 170 C = 155	240	132	160	—	532	—	—	—	—	26,500 (R)
L7	20	125 at BH	Plain; old lake bed	Podsol	Alluvial; loam, clay and peat. T at 41 in.	41	Locally good	S = 166	579	8	11	—	598	—	—	—	—	30,300 (R)
16	—	All ages	Bench at foot of mountain slope; fan of creek	Podsol	Light loam, sand and gravel, irregularly. T at 61 in.	41	Mostly good	S = 227 H = 169	561	—	185	—	746	34,247	—	9,545	—	43,792
5	—	All ages	Riverside bench; covered at high flood	Immature	Deep light loam over gravel. T at 84 in.	84	Mostly good	S = 237	617	—	144	—	761	33,436	—	7,134	—	40,540

Symbols: T = Water-table observed at base of root system. TT = Temporary seasonal water-table. S = Sitka spruce. C = Western Red Cedar. H = Western hemlock. BC = Black cottonwood. P = Lodgepole pine. BH = Breast height. (R) = Volume estimated from regression; see Fig. 26

ground flora (devil's club-fern-herb type), but L7 was the more moist, both as regards general soil retentiveness and owing to the relatively shallow depth at which the water-table lay. The growth difficulties on this site lie much more in excessive wetness in the lower soil layers, with a fairly marked tendency for roots to die owing to water-logging. Thus, while this is a very productive site, it is not one on which long continued freedom from root die-back can be expected.

Plots 5 and 16 are examples of sites with freely draining, rather light textured soil, of adequate nutrient status, in which the soil structure and general condition permitted of a good distribution and development of feeding roots throughout most of the rooting space. This root distribution, together with the occurrence of a subsoil water supply within reach of the root systems, must be accounted as making possible the accumulation of the high standing volumes of timber. The often sandy, gravelly nature of the soil in Plot 16 had resulted in much local dying of roots of the great dominants, but it may again be pointed out that in the cool, moist climate of Graham Island, with its ordinarily short, warm summer season, this periodic occurrence of root die-back may not, even over centuries, have any fatal result.

If Tables 25 and 26 are considered together, the evidence seems to be that, in the two types of climatic position represented, within the moist Pacific Coast forest and between latitudes 53 and 54 degrees north, no very great depth of rootable soil is necessary to enable the development of very high volumes of standing timber. The aspect of the matter which it is impossible to illustrate here, in any way, is the relative efficiency of sites in terms of growth increment. It is possible to show that sites may differ very greatly in this respect. Problems relating to canopy structure and specific composition come in here which only much further work could elucidate. The taller trees recorded all occurred, however, on sites in which there was a subsoil water supply, usually with the presence of a water-table, and which was usually favourable, at least at some period during the life of the tree, for the healthy development of feeding roots within the zone of soil influenced by it. It seems to be probable that this condition, which permits of the development of a lower zone of feeding roots within the reach of a permanent water supply, is necessary for long continued efficient volume increment. The evidence of the slope sites listed in Table 27 is in this direction.

Plots which stood on slope sites in Graham Island are collected together here. It will be seen that four out of the seven showed " hump and hollow " relief, associated with wind-throw, and this is characteristic of the hill-side forests. The rooting depth is often very irregular because of this ; but none of the soils can be said to be critically shallow. There is usually no true water-table on sites such as these ; but the indurated till, which so often forms the restricting base to the rooted soil, is impervious. The result is that, as is shown in the table, water commonly may be found draining downhill over the surface of the till. This is a most important matter, so far as the height of the trees is concerned and, in the rather drier climate of the region round Terrace, often seems to determine the relatively abundant occurrence of spruce. It is thus no accident that the poorest height growth in this table is to be found in Plots 12 and 17, in which the general evidence showed that this downhill drainage of subsoil water was either absent or slight.

It will be seen that there is no real difference between these slope sites and the bench sites illustrated in Tables 25 and 26, so far as volume of standing timber is concerned. They are, however, usually much more important, by area of land covered, in hilly country with narrow mountain valleys. The factors which determine both height growth and standing volume are seen in fact to be those which determine the efficiency of the rooting space in terms of supply of the needs of the trees ; and good sites, or bad sites, may occur both on slopes and on flatter places. It is probably true, however, that in the country from which these plots were taken, relatively poor sites are most common, owing to drainage conditions mainly, where land is relatively flat.

This table includes a number of valley bottom, bench sites examined in the region of Terrace. The sites are arranged in estimated order of increasing wetness. They thus begin with the dry moss type, 12B and end with the skunk cabbage swamp types 16, 17 and 18. A water-table was present at least in part in all the sites examined. It will be seen that at first the basal area per acre increases as the sites become more moist, and that to some extent this is related to increasing nearness to the surface, of the water-table. There is then a fall as the *Lysichiton* swamp types are entered. The greater heights occurred on the deeper rooted soil, and this agrees with the observations in Table 26 : the poorer heights occurred in the swamp types.

The vegetation given indicates that it is unlikely that, considered per unit volume of well-rooted soil, any significant nutrient deficiencies occurred. It was, then, probably the physical conditions of the sites which largely determined the differences in growth. The indications are, thus, that in a forest in this region, it is an advantage, in terms of basal area produced, and with a soil of adequate nutrient status, to have a water-table fairly near to the surface, as in Nos. 19 and 22. These indeed show the

TABLE 27

Stands on Slope Sites in Graham Island

Volumes in true measure, over bark

Plot No.	Age (years)	Type of situation	Soil: Group	Soil: General character	Root: Approx. depth (in.)	Root: Distribution	Established mean Height of Dominants and Co-dominants	Basal area (sq. ft.) per acre: S	C	H	Other spp.	Total Basal area	Volume (cu. ft.) per acre: S	C	H	Total volume per acre
*1	All ages	Moderate mid slope, doubly convex	Podsol	Loam over till D. H in part	Variable 18-48	Locally good, or poor	H = 167	—	—	198	—	198	—	—	11,006	11,006
12	77	Very steep lower slope on mountain side	Dis-turbed	Loam over till H	Very variable 6-36	Good where disturbed	S = 132 H = 114	194	4	130	—	328	9,175	165	5,235	15,575
13	295	Mid moderate slope on small hill	Podsol	Loam over till or, locally, rock H.D.	Usually deep up to 48	Moderately good for 24 in. then poor	S = 219 H = 203	175	—	193	—	368	12,419	2	11,639	24,060
17	77	Moderate lower slope	Podsol	Loam over till or fissured rock	Variable 12-36	—	S = } 128 H = }	418	—	56	8 (A)	482	19,333	—	1,975	21,308
3	90	Concave steep lower slope	Podsol	Loam over till. D	Usually deep up to 50	Locally good, often poor	S = 153 H = 135	374	—	117	—	491	21,109	—	5,722	26,831
8	All ages	Steep slope (above 7) and below a hillside bench	Podsol or Gley	Loam over till, H.D. ; T in hollows	Very variable 2-30	Locally good, often poor	S = 160 H = 148 C = 132	129	36	383	—	548	5,376	1,533	17,422	24,331
7	All ages	Moderate slope above a swampy hillside bench	Podsol or Gley	Loam over till, H.D or T in hollows	Very variable 2-30	Locally good, often poor	S = 152 H = 149 C = 145	97	326	209	—	632	4,867	13,970	9,449	28,726

* Much of plot was occupied by thickets of hemlock regeneration. The high canopy incomplete.

Symbols : D = Water draining over the till. H = Wind-throw humps and hollow relief. T = Water-table.
S = Sitka spruce. H = Western hemlock.
C = Western red cedar. A = Red alder.

Volumes in true measure, over bark

Comparison of Stocking on Ten Valley Bottom Stands round Terrace, all with a Water-table and arranged approximately in Order of increasing Wetness of Site

TABLE 28

Fig. No.	Plot No.	Age (years)	Type of ground vegetation under canopy	Soil			Approx. Rooting Depth, inches	Basal area and Number per acre for :—								Totals per acre		Approx. mean height of larger trees (feet)	Remarks
				Material	Drainage	Type		SSp		WRC		WH		Other species					
								BA	No.	BA	No.	BA	No.	BA	No.	No.	BA and volume		
12	—	Old growth even aged	*Hylocomium splendens, Calliergonella schreberi*	Glacial coarse grit and stone	Free	Podsol	Not known probably deep	65	25	101	58	224	264	—	—	347	390 18,500 (V)	Not known, much lower than in Plot K2	
24	T3	All ages	*Oplopanax*—Fern-herb	Alluvial shallow loam over compact fine sand	Free	Immature	57	314	64	—	—	35	27	96 (BC)	18	109	445 21,400 (V)	195	
12	K2 in part	All ages	*Oplopanax*—Fern-herb	Alluvial fan, sand and fine gravel	Free	Podsol	96*	240	24	132	69	160	80	—	—	172	532 26,600 (V)	*200=SSP 170=WH 155=WRC	*Figures for Plot K2.
20	L7	125 at BH	*Athyrium*—*Oplopanax*—*Rubus*	Alluvial loam, clay and fen peat	Partly impeded	Podsol	41	579	158	8	84	11	74	—	—	316	598 30,300 (V)	166=SSp	
19	L8	130 at BH	*Lysichiton*—Fern-herb	Alluvial loam, clay and fen peat	Impeded	Immature	15	351	76	572	120	64	33	—	—	228	978	150=SSp 120=WRC 114=WH	
22	K1 in part	All ages	*Equisetum*—Fern-herbs—*Cornus* (in hollows, *Lysichiton*)	Alluvial fan, fine sand	Impeded	Immature	32*	†282 §378	96 129	334 447	133 177	72 96	84 113	23 31	24 32	337 452	688 35,300 (V) 952	150=SSp Other species much lower	*For higher part †For total area §For net area with large trees
23	K3	All ages	*Oplopanax*—*Clintonia*—moss (*Lysichiton*—fern-herb in hollows)	Alluvial silty sand/coarser sand	Impeded	Podsol (in higher parts)	19*	†125 §187	8 12	107 166	25 37	159 212	91 118	0.4 — (AF)	8 —	133 167	391 557 28,000 (V)	178=SSp 161=WH 126=WRC	*In higher part †For total area §For net area with large trees
18	L56	All ages	*Rubus*—fern—*Lysichiton*	Lacustrine clay H	Impeded	Gley	20 (drier) 12 (wetter)	190	37	70	19	104	193	46	37	286	410 19,400 (V)	160=SSp 133=WRC 117=WH	Bench swamp forest
17	L34	All ages	*Lysichiton*—fern *Rubus*	Shallow peat over lacustrine clay H	Impeded	Organic	26 (drier) 10 (wetter)	144	44	148	103	91	235	—	—	382	383 18,000 (V)	114=SSp 94=WRC 77=WH	Lakeside swamp forest
16	L12	All ages	*Lysichiton*	Deep peat H	Water sodden except in humps	Organic	21 (drier) Nil (wetter)	44	39	68	79	110	408	3	39	566	225 9,000 (V)	101=SSp 89=WRC <70=WH	Lakeside swamp forest

Symbols : H = Hump and Hollow relief. BA = Basal Area. SSp = Sitka spruce. WH = Western hemlock. WRC = Western red cedar. BC = Black cottonwood. AF = Amabilis fir. (V) = Volume in cubic feet per acre estimated from regression (see Fig. 26) greatest basal area per acre observed in any plot and, in spite of the moderate height growth, had a very great standing volume. This is in accordance with the evidence discussed above that relatively shallow rooting may be accompanied by a very considerable development in standing volume (e.g., T2, Table 25 and 7, Table 27). These very moist sites, with a fertile but rather shallowly rooted soil, tend to carry a considerable volume of cedar ; and they probably illustrate sites on which the larger volumes of this species are often found. It is to be noted, however, that the tallest cedar in this table are recorded for the deeply rooted site, 12A, and it may be taken that the largest individual cedar would grow on well-drained, deeply rooted but moist sites, at least in the latitudes worked in.

Hemlock was most abundant on the dry soil 12B, on which it was the main constituent in the high canopy, and on the swamp sites, 16, 17 and 18 ; most of the hemlock on these wetter sites were understorey trees. Plots K5 and K6, Table 26 (Figures 9 and 10) provide further illustrations of hemlock occurring abundantly on dry soils. These examples illustrate the wide site-tolerance of hemlock. As a timber tree it is, in this region, better than cedar on such drier sites, but much inferior on the wetter.

Spruce shows the greater height growths, and forms the larger proportions of the stand by basal area, on the deeper-rooted soils which for one reason or other must be reckoned moist. This is probably characteristic for the types of site and of stand covered. It will be seen that it is consistently the taller species, and this is probably an indication of a faster early rate of growth ; though it is difficult or impossible to assess the degree to which different times of regeneration and different conditions for growth as determined by position in canopy, are responsible for differences in height growth. On the whole, the poorer the height growth of spruce, the sooner in terms of size does crown deterioration and the related root die-back begin ; and here is certainly to be found one of the reasons why hemlock appears so prominently in the understorey on wet sites such as Nos. 16, 17 and 18.

Nos. 20 and 24 (Plots L7 and T3) plainly represent early successional stages in stand development, which will change in the course of time. It may, however, be difficult to judge with regard to this, at least without close examination. Thus in No. 21 (Plot L9, Table 26), in which by basal area spruce is strongly predominant, the oldest trees observed were hemlock and not the tall emergent spruce.

Conclusion

It should be remembered that the plots discussed were constituted of indigenous species growing in unutilised, unmanaged forest. The evidence seems clearly to be that a deep, moist soil, possessed of a structure which favours a well-distributed development of feeding roots, will carry the larger trees and the higher standing volumes. It may be taken also that trees will remain healthy over longer periods of time, while growing to great size, on such sites than on those which are inferior in terms of soil conditions. Sites which approach this ideal are of very limited area usually, and the common, or average, good site is much less productive, both in terms of individual growth and standing volume : it is nevertheless capable of carrying valuable forest in which very high standing volumes of timber occur. Foresters who use the species referred to as exotics, should remember that the relationships between site character and growth are largely determined by the climatic conditions which prevail, and that similar soils in a different, even though similar climate, may not give the same results in growth or healthy endurance.

One of the matters which no tables such as the above can illustrate is the progress in development of standing volume, with increasing age of stand, whether this is even aged or irregularly aged. Thus the relative low basal area, or standing volume per acre in Plot 1, Table 27, is almost certainly determined by the stage in development of the stand, which included appreciable areas of young thickets of hemlock, rather than by any special deficiency in site relative, for instance, to No. 12, which has the next lowest volume in this table. Then in plots such as are shown in Figs. 19 and 22, with a very high basal area, and especially in the shallowly rooted and relatively young stand No. 19, one must inevitably ask for how long this condition will be maintained ? The severe restriction in root development in depth on this site must, it would seem, inevitably involve a relatively early break-up of the high canopy ; if so, what will be the effect on standing volume, especially of serviceable timber ? One is here largely concerned with problems of canopy development which have been discussed above to some extent (Chapter 8, page 80). There is no doubt, however, that regular evenly stocked stands such as were Nos. 19 and 24 (Table 25), are doomed to a relatively early break-up of the high canopy, with the development of ericaceous scrub as the main more or less continuous stratum of the complex canopy of the forest. Such a development is, of course, inefficient from the standpoint of economic timber production.

The suggestion from these tables is that, judging by size of tree, the more fertile the site, as judged by height of tree, the longer usually can the dominant strata of the complex canopy be kept in the crowns of the tall timber, as compared with lower strata of regenerating timber trees and other undergrowth. In terms of timber production, this illustrates the law of " to him that hath shall be given ". It may be taken also that poverty in growth, and so inefficiency in timber production, is accompanied by an early onset of debility in root and crown ; indeed the early development of such debility is the first result of the action of the pathogenic factors which are responsible for infertility. It may be said thus, that even with the comparatively short rotations which are likely to be adopted in economic working, one of the more important differences between the more and the less fertile sites will be the lesser, or greater, susceptibility to disease based on the relative severity of site deficiencies in supply to the trees. The poorer sites tend thus not merely to be poorer producers in terms of rate of growth ; they are also more subject to disease because of the infertility which is inherent in them.

It needs to be stressed here, that quality of site in terms of production of timber can only efficiently be judged when the growth achieved over an adequate length of time has been considered. Fertility expressed in terms of growth is thus, a complex matter, one of the important aspects of which is the length of time over which steady healthy growth can be maintained. For example, a site may have a high fertility in terms of rate of growth of trees and then fail ; or have a lower fertility as so measured, but be capable of maintaining such growth over a relatively long period. The best sites combine a good rate of growth with long maintenance, and it is this that gives the very high volumes of standing timber, concentrated eventually in a relatively few very large trees, as in Plots 5 and 16, Table 26. The determination of the length of the period of efficient growth which characterises any forest type is thus of great importance in economic management.

Glossary

Names of Herbs, shrubs and trees, based on : *Illustrated Flora of the Pacific States*, by Leroy Abrams, Stanford Univ. Press, California and O.U.P. London, 1940, Vols. I to III.

Herbs and Ferns in Alphabetical order by Latin names :

Actaea arguta Nutt. Western red baneberry.
Aralia nudicaulis L. Wild sarsaparilla.
Aruncus vulgaris Raf. Goat's beard.
Athyrium felix-femina (L.) Roth. Lady fern.
Chimaphila umbellata var. *occidentalis* (Rydb.) Blake. Western Prince's pine.
Circea alpina L. Small enchanter's nightshade.
Clintonia uniflora (Schult.) Kunth. Single-flowered clintonia.
**Coptis aspleniifolia* Salisb. Gold thread.
Dodecatheon L. (probably *D. Jeffreyi* Van Houtte). Shooting star.
Drosera rotundifolia L. Round-leaved sundew.
Dryopteris linnaeana C. Chr. Oak fern.
Equisetum L. (species unidentified). Horse tails.
Linnaea borealis L. var. *americana* (Forbes) Rehd. Twin flower.
Lysichiton camtschatcensis (L) Schott. Yellow skunk cabbage.
Maianthemum dilatatum (Wood) Abrams. Two-leaved Solomon's seal.
Menyanthes trifoliata L. Buckbean.
Moneses uniflora (L) A. Gray. Moneses.
Ophrys convallariodes (Sw.) W. F. Wright. Broad-lipped tway-blade.
Oxalis oregona Nutt. Oregon Wood-Sorrel.
Polystichum munitum (Kaulf.) Presl. Western sword fern.
Pteridium aquilinum pubescens Underw. Western bracken.
Smilacina amplexicaulis Nutt. Western Solomon's seal.
Streptopus amplexifolius (L.) D.C. Clasping twisted stalk.
Streptopus curvipes Vail. Simple-stemmed twisted stalk.
Struthiopteris spicant (L.) Weis. Deer fern.
Tiarella laciniata Hook. Laciniate tiarella.
Tiarella trifoliata L. Laceflower.
Veratrum viride Ait. Green false hellebore.
Viola (Tourn.) L. (Probably *V. palustris*—Marsh violet.)

Names of trees and shrubs based on Abrams (loc. cit.) :

Shrubs :

Arctostaphyllos uva-ursi (L.) Spreng. Kinnikinnick. Red bearberry.
Mahonia nervosa (Pursh.) Nutt. Oregon grape.
Cornus canadensis L. Dwarf cornel ; Bunchberry.
Cornus stolonifera. Michx. American dogwood.
Empetrum nigrum L. Black crowberry.
Gaultheria shallon Pursh. Salal.

* Flora of Alaska and Yukon, by Eric Hulten, page 714, Lunds Univ. Arsskrift N.F. Avd. 2 Bd. 40 No. 1.

Juniperus sibirica Burgsd. (Adams). Dwarf juniper.
Kalmia polifolia Wang. subsp. *occidentalis* (Small) Abrams. Western swamp Kalmia.
Ledum groenlandicum Oeder. Labrador tea.
Menziesia ferruginea Smith. False azalea ; Pacific menziesia.
Oplopanax horridum (J. E. Smith) Miq. Devil's club.
Rubus parviflorus Nutt. Thimble berry.
Rubus spectabilis Pursh. Salmonberry.
**Sambucus racemosa* L. sub. sp. *pubens* (Michx.) Hult. Red-berried, or stinking elder.
Vaccinium parvifolium Smith. Red bilberry ; red huckleberry.
Vaccinium ovalifolium Smith. Oval-leaved bilberry.
Viburnum trilobum Marsh. High bush cranberry ; Guelder rose (very near to *V. opulus* L.).

Trees :

Abies amabilis (Dougl.) Forbes. Red, amabilis or lovely fir.
Abies lasiocarpa (Hook.) Nutt. Alpine fir.
Alnus oregona Nutt. Oregon, or red alder.
Alnus sinuata (Regel.) Dydb. Sitka alder.
Betula papyrifera occidentalis (Hook.) Sarg. Western paper birch.
Chamaecyparis nootkatensis (Lamb.) Spach. Alaska, or yellow cedar.
Picea sitchensis (Bong.) Carr. Sitka spruce.
Pinus contorta Loud. Lodgepole, or tamarack pine (with *P. contorta murrayana* (Balf.) Engelm. as the inland spp.).
Pinus strobus L. Eastern white pine.
Populus tremuloides Michx. American aspen.
Populus trichocarpa Torr. and Gray. Black cottonwood.
Pyrus rivularis Douglas. Crab apple.
Taxus brevifolia Nutt. Western yew.
Thuja plicata D. Don. Giant, or Western red cedar.
Tsuga heterophylla (Raf.) Sarg. Western hemlock.
Tsuga mertensiana (Bong.) Sarg. Mountain hemlock.

Names of Mosses, based on *Moss Flora of North America* by A. J. Grout, Vol. I, Newfane, Vermont, 1936 ; Vol. II, 1940, and Vol. III, 1928, New York City.

Calliergonella schreberi (Willd., B. & S.) Grout.
Eurynchium oreganum (Sulliv.) J. & S.
Hylocomium splendens (Hedw.) B. & S.
Mnium insigne Mitt.
Mnium punctatum (L.) Hedw.
Plagiothecium undulatum (L., Hedw.) B. & S.
Poganatum alpinum (Hedw.) Roehl.
Rhytidiadelphus loreus (L., Hedw.) Warnst.
Rhytidiadelphus squarrosus (L., Hedw.) Warnst.
Rhytidiadelphus triquetrus (L., Hedw.) Warnst.
Rhytidiopsis robusta (Hook.) Broth.

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* Hulten's Flora of Alaska and Yukon, loc. cit. page 1,441.

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