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Water Relations and Forest Distribution in the Douglas-fir Region on Vancouver Island

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Ottawa, Ontario

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CONTENTS

	PAGE
INTRODUCTION.....	5
METHODS	
Climate.....	10
Vegetation.....	11
Microclimate.....	12
Soils	
Profile characteristics.....	12
Moisture regimes.....	13
RESULTS	
Climate.....	15
Vegetation.....	17
Microclimate.....	31
Soils	
Profile characteristics.....	36
Moisture regimes.....	46
DISCUSSION.....	60
SUMMARY.....	65
ACKNOWLEDGMENTS.....	66
REFERENCES.....	67
APPENDICES.....	69

INTRODUCTION

Water relations play an important role in the distribution of vegetation in regions with low summer rainfall because the availability of water is commonly a limiting factor. Pearson (32), for example, concluded that the distribution of certain forest types in the south-western United States was largely determined by the presence or absence of soil drought and differences in its time of occurrence. McMinn (29) reached a similar conclusion for various plant associations in the northern Rocky Mountains. Even when available soil moisture has not been completely exhausted, the productivity of plants is influenced by deficits, that is by the reduction of soil moisture to amounts less than field capacity (35). The present study was undertaken to evaluate the significance of water relations in the differentiation and distribution of forest associations within the Douglas-fir (*Pseudotsuga menziesii*¹) region on Vancouver Island, British Columbia².

The Douglas-fir region of coastal British Columbia may be defined as the region in which Douglas-fir stands can predominate on most sites. This region is approximately coincident with the Southern Pacific Coast and Strait of Georgia Sections of the Coast Forest Region described by Rowe (39). Krajina (20, 21) recognizes within the Douglas-fir region a Coastal Douglas-fir Zone in which Douglas-fir is considered to be the climatic climax dominant. This Zone corresponds to the Strait of Georgia Section of the Coast Forest Region (39). Elsewhere in the Douglas-fir region, and even on some sites within the Coastal Douglas-fir Zone, the prevalence of Douglas-fir stands appears to be related to the periodic occurrence of forest fires, promoted by the hot, dry summers characteristic of the rainshadow climate of this region (40). Without such fires, Douglas-fir forests occurring outside the driest sections of the Douglas-fir region might eventually have been replaced by stands of more shade tolerant species, such as *Thuja plicata* (western red cedar) and *Tsuga heterophylla* (western hemlock). Various forest associations occurring within the Douglas-fir region of coastal British Columbia have been defined by Krajina (20).

The area selected for study was a portion of the Nanaimo River Valley, some eight miles southwest of Nanaimo, British Columbia (Fig. 1). The Nanaimo River is one of a series of easterly flowing streams arising in the central height of land which runs the length of Vancouver Island. The drainage basins of these rivers constitute much of the Douglas-fir region of coastal British Columbia. The study area (Fig. 2) consisted of a section of the valley extending seven miles downstream from Fourth Lake, which lies approximately twelve miles inland from the east coast of Vancouver Island. The Nanaimo River drops gradually from 1,000 ft. above sea level near Fourth Lake to 600 ft. above sea level east of First Lake. West of Second Lake, the valley floor is less than one-half mile wide and its sides rise steeply for more than 2,000 ft. (Fig. 3). Many of the peaks are over 4,000 ft. high. The topography of this western portion of the study area is typical of the terrain of the central mountainous area of Vancouver Island. To the east of Second Lake, the valley widens and its sides rise less steeply. This section is characteristic of the less rugged topography of eastern Vancouver Island.

¹Nomenclature is that of Little (25) for trees, Peek (33) for other vascular plants, Conard (8) for mosses, and Howard (18) or Fink (11) for lichens, except where other authorities are given.

²This report is based on a thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in the Department of Biology and Botany, University of British Columbia.



FIGURE 1—Map of southern Vancouver Island, showing location of study area and various weather stations. The mountainous topography of the west coast and central regions of the Island contrasts with the less rugged terrain of the eastern side. Vertical scale is increased five times.

The dominant tree canopy of most stands in the Nanaimo River Valley originated as a more or less even-aged stand following a forest fire. Within the study area, the age of the oldest trees of the dominant canopy varied from 220 to 320 years (Table I), suggesting their establishment following several different fires. Some stands were evidently also affected by subsequent fires, the most recent of which occurred about 65 years prior to the present study (41). These recent fires had little effect on *Pseudotsuga menziesii*, a relatively fire-resistant tree with a deep root system and a thick bark at maturity. On the other hand, even ground fires may kill *Tsuga heterophylla* and *Thuja plicata*, species which have thin bark and shallow root systems. The *Tsuga heterophylla* and *Thuja plicata* understoreys of many stands in the Nanaimo River Valley were of a younger age class than their *Pseudotsuga menziesii* overstoreys. Such understoreys may have originated following fires which occurred after the establishment of the overstorey. These fires presumably also influenced the composition of subordinate plant layers and the depth of litter layers.

The following associations were studied:

Pseudotsuga menziesii-*Pinus contorta*-*Gaultheria shallon*-*Peltigera membranacea*-*Peltigera aphthosa* association (*Pseudotsuga*-*Gaultheria*-*Peltigera* association³);

³The designation of associations is according to the classification proposed by Krajina (20). The abbreviated names shown in parentheses are used in all subsequent reference to the various associations.

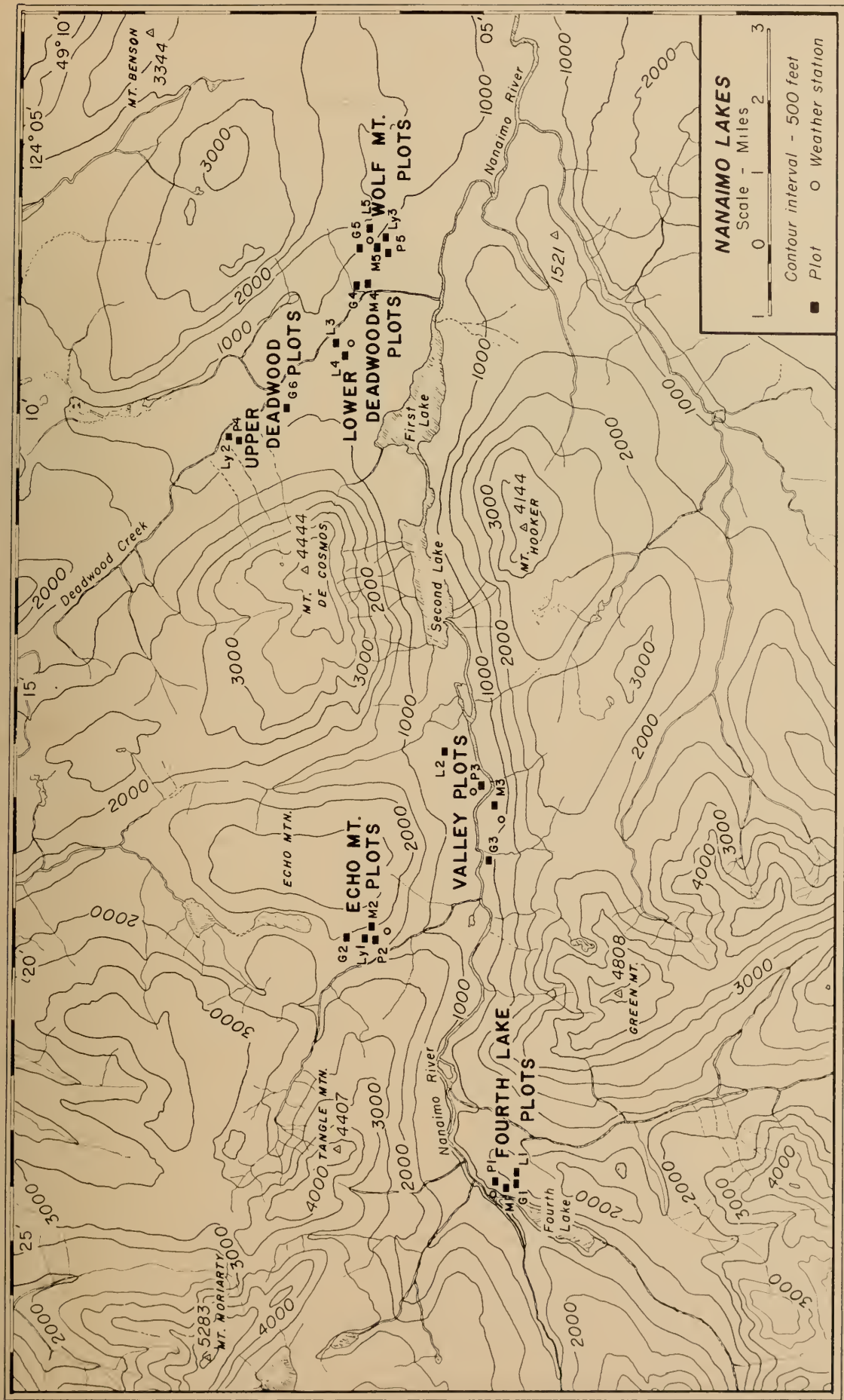


FIGURE 2—Map of study area, showing location of plots and weather stations.



FIGURE 3—A typical hillside in the Nanaimo River Valley, showing the variation in tree heights from upper slopes to valley floor. This change reflected the sequence of forest associations.

Pseudotsuga menziesii-Gaultheria shallon association (*Pseudotsuga-Gaultheria* association);

Pseudotsuga menziesii-Tsuga heterophylla-Gaultheria shallon association (*Pseudotsuga-Gaultheria* association);

Pseudotsuga menziesii-Tsuga heterophylla-Hylocomium splendens-Eurhynchium oreganum association (*Pseudotsuga-Tsuga-Hylocomium* association), which occurs as a subassociation *typicum* and a subassociation *nudum*;

Pseudotsuga menziesii-Thuja plicata-Polystichum munitum association (*Pseudotsuga-Polystichum* association);

Thuja plicata-Lysichitum americanum association (*Thuja-Lysichitum* association).

In the easterly portion of the study area, ridges at the top of hillsides characteristically supported stands of the *Pseudotsuga-Gaultheria-Peltigera* association, with *Pseudotsuga-Gaultheria* stands occurring on upper slopes, *Pseudotsuga-Tsuga-Hylocomium* stands at mid-slope, *Pseudotsuga-Polystichum* stands on lower slopes and the valley floor, and *Thuja-Lysichitum* stands in swampy bottomlands (Fig. 4). Local variation from this catenary distribution of stands was, nevertheless, frequent. In the more mountainous western portions of the valley, *Pseudotsuga-Tsuga-Gaultheria* stands replaced the *Pseudotsuga-Gaultheria* association and still other associations occurred at high elevations. Even at low elevations, associations other than those studied were present. A *Thuja plicata-Abies grandis-Adiantum pedatum* association, for example, was found on occasionally-flooded alluvial benches, an *Arctostaphylos uva-ursi* association occurred on treeless rock outcrops, and *Sphagnum* spp. characterized stagnant swamps (20). Other Douglas-fir types have also been described from Washington and Oregon (2). The associations covered in this study, nevertheless, represent some of the most prevalent site classes and commercial timber types of the Douglas-fir region on Vancouver Island.

TABLE I

LOCATION, TOPOGRAPHY, AND AGE OF PLOTS REPRESENTATIVE OF FOREST ASSOCIATIONS ANALYZED IN A STUDY OF WATER RELATIONS IN THE DOUGLAS-FIR REGION ON VANCOUVER ISLAND, BRITISH COLUMBIA

Association	Plot No.	Lat. N. °	Long. W. °	Altitude (feet)	Topographic position	Exposure	Slope (degrees)	Years since establishment*
FOURTH LAKE <i>Pseudotsuga-Gaultheria-Peltigera</i> <i>Pseudotsuga-Tsuga-Gaultheria</i> <i>Pseudotsuga-Tsuga-Hylocomium</i> <i>Pseudotsuga-Polystichum</i>	L1	49 05	124 24	1570	Ridge	NW	0-5	285
	G1	49 05	124 24	1420	Upper slope	NW	20	245
	M1	49 05	124 24	1080	Mid-slope	NW	25	275
	P1	49 05	124 24	1050	Lower slope	NW	20	270
ECHO MOUNTAIN <i>Pseudotsuga-Tsuga-Gaultheria</i> <i>Pseudotsuga-Tsuga-Hylocomium</i> <i>Pseudotsuga-Polystichum</i> <i>Thuja-Lysichitum</i>	G2	49 07	124 20	1700	Upper slope	WSW	20	285
	M2	49 06	124 20	1600	Mid-slope	SW	20	285
	P2	49 06	124 20	1410	Lower slope	SW	10	285
	Ly1	49 06	124 20	1450	Lower slope	SW	10	285
VALLEY <i>Pseudotsuga-Gaultheria-Peltigera</i> <i>Pseudotsuga-Gaultheria</i> <i>Pseudotsuga-Tsuga-Hylocomium</i> <i>Pseudotsuga-Polystichum</i>	L2	49 05	124 16	750	Ridge	SSW	0-25	285
	G3	49 05	124 18	870	Mid-slope	N	20	275
	M3	49 05	124 17	850	Mid-slope	NE	25	320
	P3	49 05	124 17	640	Valley floor	-	0	220
DEADWOOD CREEK (Upper) <i>Pseudotsuga-Gaultheria</i> <i>Pseudotsuga-Polystichum</i> <i>Thuja-Lysichitum</i>	G6	49 08	124 10	810	Bench	E	5	320
	P4	49 08	124 10	840	Valley floor	NE	2	285
	Ly2	49 08	124 10	830	Depression	NE	2	285
DEADWOOD CREEK (Lower) <i>Pseudotsuga-Gaultheria-Peltigera</i> <i>Pseudotsuga-Gaultheria-Peltigera</i> <i>Pseudotsuga-Gaultheria</i> <i>Pseudotsuga-Tsuga-Hylocomium</i>	L3	49 07	124 09	740	Bench	SE	2	285
	L4	49 07	124 09	750	Bench	E	0-15	285
	G4	49 07	124 08	720	Lower slope	SW	12	320
	M4	49 07	124 08	700	Gully	SW	4	320
WOLF MOUNTAIN <i>Pseudotsuga-Gaultheria-Peltigera</i> <i>Pseudotsuga-Gaultheria</i> <i>Pseudotsuga-Tsuga-Hylocomium</i> <i>Pseudotsuga-Polystichum</i> <i>Thuja-Lysichitum</i>	L5	49 06	124 07	1000	Ridge	SSW	20	220
	G5	49 06	124 07	880	Lower slope	SW	10	220
	M5	49 06	124 07	810	Lower slope	SSW	10	220
	P5	49 06	124 07	760	Lower slope	SW	5	220
	Ly3	49 06	124 07	770	Depression	SW	3	220

* Approximate age of oldest tree measured in the dominant canopy.

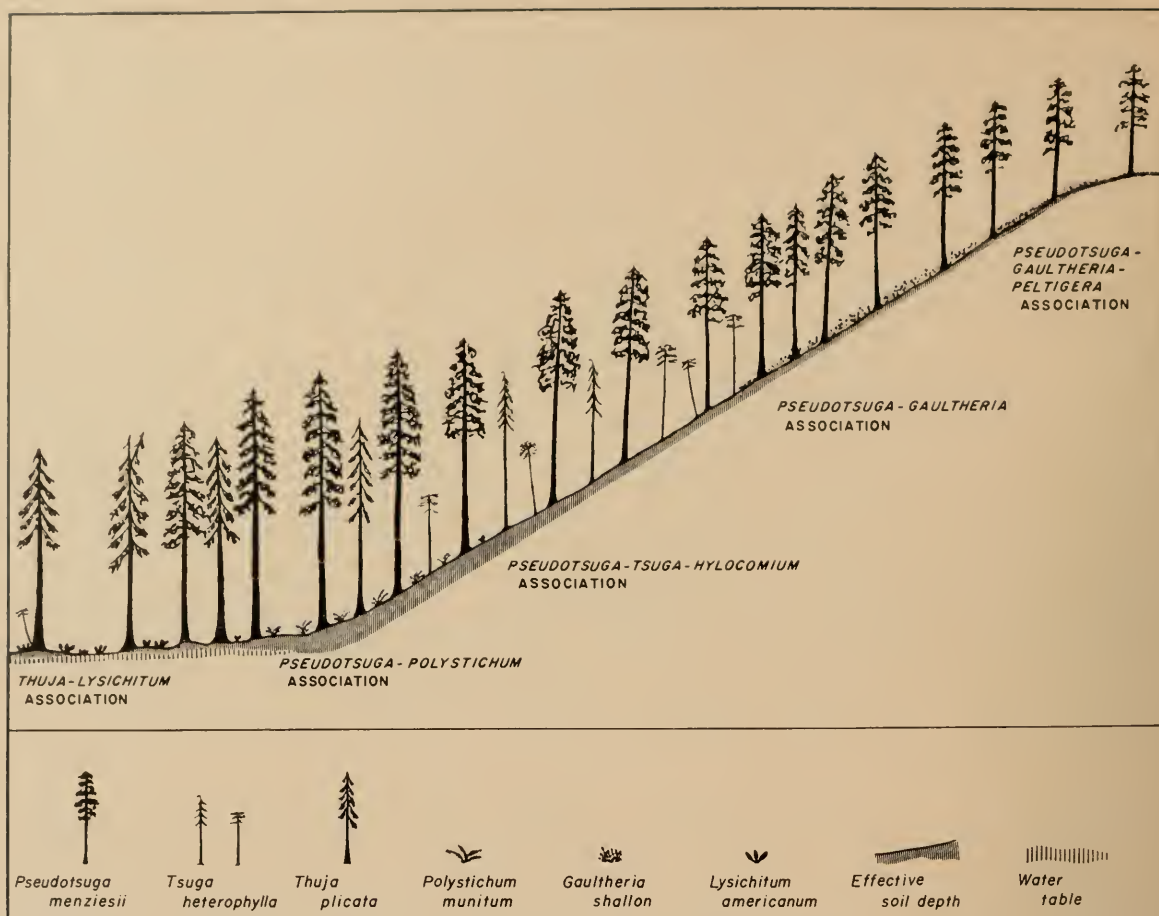


FIGURE 4—Sequence of forest associations in the Douglas-fir region on Vancouver Island.

METHODS

Groups of plots (Fig. 2, Table I) were selected in mature stands at various locations along the valley so that comparisons could be made between both plots representing different associations under similar climatic conditions and plots representing the same association under different climates. Since plots were to be visited at frequent intervals, accessibility was important and restricted the study to areas served by logging roads. This limitation meant that some of the plots chosen were situated in atypical positions in the catenary sequence. All plots, however, were considered to be representative of their association. Twenty-four plots, each of one-quarter acre, were analyzed.

Climate

Precipitation, and maximum and minimum temperatures were recorded at monthly intervals to indicate the climate of the six localities in which plots were situated. Recording stations were located in clear-cut areas at least 50 m. from the standing timber. Measurements were made from June, 1951, through December, 1956. Data for other locations on Vancouver Island were obtained from the published records of the Meteorological Division of the Canada Department of Transport and records taken at the Nitinat Camp of the British Columbia Forest Products Company Limited.

Rain gauges with an orifice of 185 sq. cm. (6 in. in diameter) were used for precipitation measurements, since a large orifice size has been shown to minimize inaccuracies due to wall effect (30). Evaporation of the water collected between

readings was restricted by the addition of paraffin oil to the reservoirs. Inaccuracies resulting from turbulence about the orifice were reduced by placing the rain gauges in small pits with their orifices almost flush with ground line (38). In winter, extra sleeves were added to bring the orifice of the gauges above the anticipated depth of snow. These sleeves prevented snow from drifting into the gauges, although they had the disadvantage of increasing turbulence about the orifice. Any ice or snow accumulated during winter months was melted with a portable gasoline stove before measurements were made.

Initially the Six's type maximum and minimum thermometers used for recording temperatures 1.5 m. above ground level were housed in improvised shelters. During 1955 and 1956, temperatures were also recorded in standard Stevenson screens. Comparison of records for these years showed that maximum values from the improvised shelters were higher than those from the Stevenson screens during warm summer months. Summer values consequently are based only on records from the Stevenson screens. Winter values, on the other hand, are based on the entire 1952-56 record because maximum and minimum values from both types of shelter corresponded closely during this season.

Vegetation

The trees and subordinate plants (shrubs, herbs, mosses, and lichens) in each plot were analyzed by various techniques appropriate to the different layers. Subordinate plant layers were analyzed during July and early August when all plants were fully developed⁴.

The diameter at breast height (4.5 ft.) of all trees over 4 in. in diameter outside the bark was measured, together with the height and age of trees of each species representative of the diameter classes present. Other tree heights were then obtained from the height/diameter curves constructed for each species in each plot. The average height of the dominants and codominants of each species were determined by averaging the height of the tallest 55 per cent of the trees of each species. Site index for Douglas-fir was determined from the curves developed by McArdle, Meyer, and Bruce (28). Volumes per acre were derived from volume tables prepared by the Forest Surveys Division of the British Columbia Forest Service (13).

The density of plants in the shrub layer was determined by line interception (5). Ten lines, each 50 ft. long, were run across the plots at approximately 6-ft. intervals. The length of line covered by a vertical projection of leaf surfaces was recorded and expressed as a percentage of interception. The line interception method as employed in this study involved some inaccuracy, since tall shrubs could not be viewed from directly above. However, any error seemed sufficiently small that the use of a plumb line did not appear warranted.

Plants of the herb layer were evaluated by the frequency method (4). The size of frequency frame used, 2 by 5 dm., was gauged to allow an appropriate number of species to fall within each frame. Since this size was too small to describe accurately the frequency of such large herbs as *Polystichum munitum* and *Lysichitum americanum*, these plants were also evaluated by the line interception method. In the case of ferns, the length of line covered by a circle described around the clump was recorded as the amount intercepted. Frequency frames were set at 5-ft. intervals along the lines used for line interception. Eighty to one hundred frames were tallied on each plot and results were expressed as the percentage of frames in which a species occurred.

⁴The original specimens determined during vegetation analyses were destroyed by fire.

Mosses and lichens growing on the ground were evaluated by the point frequency method (24). A 10-point frame was set at 5-ft. intervals along the line interception tape. Eight hundred to one thousand points were examined on each plot and the frequency with which species were contacted was expressed as a percentage.

The abundance and coverage of mosses and lichens growing on decaying logs and the boles of trees up to a height of 2 m. above the ground were estimated according to the 11-point total estimate scale of Krajina and Domin (19).

Microclimate

Precipitation that penetrated the tree canopy was measured by averaging collections from four rain gauges placed on each plot. Percentages of interception were calculated by comparing the amounts collected within plots with those collected in adjacent open areas. Records were maintained from June, 1951, until October, 1953. Since little or no water ran down tree boles during summer months, the only season when such water might be expected to influence soil moisture content, this component of precipitation was not measured.

During part of the study, nine additional rain gauges were placed on four plots of different associations to test the adequacy of the four-gauge sample. It was concluded that the four-gauge average was a satisfactory measure of the precipitation reaching subordinate plant layers because the smaller sample rarely varied from the larger by more than 1 or 2 mm., a difference which could have no appreciable influence on soil-moisture regimes.

Porous porcelain atmometers (26) were used to compare evaporation rates in plots and at three of the adjacent open stations. Bulbs were placed at 5 cm. and 100 cm. above ground line. Entry of rain water into the reservoirs was restricted by the use of mercury valves (9). Each atmometer was standardized on a rotating table in the customary manner. Readings were taken twice monthly from June through September, 1951 and 1952. For simplicity, results were expressed as relative evaporation by converting each value to a percentage of the highest value recorded.

Maximum and minimum air temperature at 1.5 m. above the ground were recorded on the Wolf Mountain and Fourth Lake plots at monthly intervals June to September, 1953.

Soil-surface temperatures were measured with Six's type maximum and minimum thermometers buried with their bulbs approximately 5 cm. below the soil surface. In most cases this depth placed the bulbs just below the litter layer. Readings were made in all plots, twice monthly during the summer and at one- or two-month intervals during other seasons. Records were maintained from June, 1951, until November, 1953. The temperature of deeper soil horizons was measured whenever soil moisture was sampled. During direct sampling, measurements were made by inserting a thermometer into the side of the sampling pit at various depths. The thermistors incorporated in the fiberglass soil moisture units allowed simultaneous temperature measurements during indirect moisture sampling (7).

Soils

Profile Characteristics

Five or more soil profiles were examined in each plot. Descriptions were made in accordance with the terminology of the United States Department of Agriculture Soil Survey Manual (44), although some additional terms were used

for humus layers and organic soils (17, 45). In addition to field descriptions, ten profiles were treated with vinylite resin to preserve them for laboratory examination (42).

Particle size distribution within the 2-mm. soil fraction was determined by the hydrometer method, according to the procedure prescribed by the American Society for Testing Materials (1). Textural classes were interpreted from the chart included in the Soil Survey Manual (44).

Sieved, air-dried soils were re-wet to a saturated paste for pH determinations (34). Measurements were made with a Beckman N-2 glass electrode meter.

Moisture Regimes

Periodic measurements of soil-moisture contents were made using both direct and indirect sampling methods. Samples for direct determinations were obtained by digging pits because the soils of most plots were too stony for the use of samplers. Samples were taken at 1-dm. intervals to a depth of 1m., or to the hardpan in shallow soils. Sample pits were refilled after use and new sample pits were dug at least 3 m. distant from earlier pits. The moisture content of samples was determined by oven drying the 5-mm. soil fraction at 105° C. and results were expressed as a percentage of dry weight. Direct sampling was used from July, 1951, until September, 1952.

Indirect measurements of soil moisture were continued from October, 1952, until November, 1953. Fiberglas units (7) were inserted into the side of pits at depths of approximately 5, 15, 30, 50, 80, and 120 cm. in deep profiles or down to the hardpan in shallower soils. This method of placement may have resulted in some soil-moisture values being too high because the number of living roots in the soil adjacent to units was doubtless reduced by the severance of some roots when pits were dug. Nevertheless, seasonal changes in moisture values appeared sufficiently marked to suggest that enough roots were left to bring about soil-moisture depletions to characteristic levels. One bank of units was placed in each plot. The rapid measurement of units was facilitated by connecting their leads to a rotary selector switch.

Interpretation of field records was made from calibration curves derived from substitute units because the original soil-moisture units were accidentally destroyed before their calibration had been undertaken. However, tests conducted on ten of the new units in a single test soil showed that variability among such fiberglas units was less than 1 per cent at low soil-moisture contents.

Each soil-moisture unit was calibrated against the 5-mm. fraction of the soil which surrounded the original soil-moisture unit in the field. The 5-mm. fraction was used for calibration because collection of the undisturbed cores recommended by Hendrix and Colman (16) was impractical in the coarse, gravelly soils of the study area. Moreover, sieved samples were thought to be satisfactory because wilting percentage is more dependent on soil texture and organic content than on structure, and the major emphasis in this study is on available soil-moisture content. The moisture contents of sieved samples are also considered to be more truly comparable with one another than contents derived from unsieved samples because in the latter case considerable variability may be introduced through differences in coarse gravel contents.

The cans used for the calibration of soil-moisture units contained approximately 150 gms. of soil. Uniformity of soil-moisture content in these cans was promoted by covering them with a loosely fitting lid during drying cycles. A drying cycle consisted of a series of warm periods at 35° C. to expel moisture, each followed by an equilibration period of one or more days at 15° C. Tests showed that following this procedure moisture contents were essentially uniform

throughout the can. Can weights and the resistance reading of each unit were determined after each equilibration period. Following determination of the oven-dry weight of soil in the can, the moisture percentage corresponding to each resistance was calculated. The calibration curve plotted for each soil was based on at least four drying cycles, each consisting of six or more readings between saturation and wilting range.

Since the results of moisture samplings were to be expressed as percentages of available moisture, a wilting percentage was established for each of the nearly 2,200 samples collected. The 15-atmosphere percentage, as determined by a pressure membrane apparatus (36), appeared to be the most satisfactory value that could be obtained for such a large number of samples, even though some deviation between the two values has been reported (27). The procedure followed was similar to that outlined by Richards (34), except that the 5-mm. soil fraction was used. A standard sample of known moisture constant was included with each sample lot. When the value obtained for this standard differed from the true value by less than 2 per cent a correction factor was applied to the values obtained for the unknown samples in the lot. A new extraction was made when the difference was greater than 2 per cent. A 15-atmosphere percentage was determined on a subsample of the soil surrounding each fiberglass unit and each of the samples dug for direct measurement. Available-moisture percentages were found by subtracting the appropriate 15-atmosphere percentage from the field-moisture percentage.

While no laboratory procedure is entirely satisfactory for the measurement of field capacities, the 1/3-atmosphere percentage appears to be a convenient value to indicate when soils are nearing saturation (37). The procedure followed was similar to that of Richards (34), except that extractions were made on the 5-mm. soil fraction and a Visking membrane was used. It was found that values obtained using this method corresponded closely to field-moisture contents determined after soils had drained to field capacity following heavy rainfall. The 1/3-atmosphere percentage of all very wet samples was determined to confirm whether gravitational water was in fact present. Observation pits on each plot were also inspected at intervals to determine the depth of any water table present.

The volume weight and depth of fine soil present in representative profiles were determined so that soil-moisture contents could be expressed as depths of available water. Sample volume for volume-weight determinations was found by measuring the volume of sand required to fill a plastic bag lining the cavity which remained following the removal of each sample. Volume weights were then calculated by dividing the oven-dry weight of each sample by its volume. Values from the five pits sampled at decimeter intervals on each plot were averaged. The amount of fine soil in each 2 dm. of a representative profile was found by sifting the 5-mm. fraction from samples of known cross-sectional area (2 by 5 dm.) and measuring the volume of water it displaced. The depth of fine soil in each 2 dm. was calculated by dividing the volume displaced by the cross-sectional area of the sample.

The depth of available water present each time soil-moisture contents were sampled was calculated by multiplying the appropriate depth of fine soil in each 2 dm. of the profile by the percentage by volume of available soil moisture present (volume weight \times percentage by weight of available water/100). Assuming that the amount of water held by coarse soil fractions is negligible, the total depth of available water was found by summing the depths present in each 2 dm. of the profile. Values for the 30-month period during which soil-moisture contents were sampled were averaged to show the seasonal variation in depth of available water present in each plot.

RESULTS

Climate

Summer months in the Nanaimo River Valley and other locations in the Douglas-fir region, for which long-term records are available, were characterized by potential water deficiencies during the study period because summer rainfall was light and temperatures were relatively warm (Table II). Such weather seems quite typical, since the 1951-56 averages differed little from the long-term averages (Appendix I).

The low summer rainfall and relatively high summer temperatures characteristic of stations within the Douglas-fir region contrast with the higher rainfall and lower temperatures recorded at stations in the hemlock zone (21). The climate of Pachena Point, for example, on the west coast of Vancouver Island is typically maritime, while that of central mountain and east coast stations in the Douglas-fir region has a continental "tone". Such differences in precipitation occur because most rain-bearing winds come from the Pacific Ocean, placing areas to the lee of the mountainous west coast of Vancouver Island under the influence of a rainshadow effect (6). The width of this zone and the intensity of the rainshadow effect is, nevertheless, quite variable. During periods of high rainfall, such as in autumn and winter months, stations in the central mountain portion of the Douglas-fir region (for instance Nitinat Camp or Fourth Lake) seemed to be outside the rainshadow zone, for they received almost as much precipitation as Pachena Point in the hemlock zone (Table II). In summer months, on the other hand, rainfall at such stations amounted to little more than half that at Pachena Point. Presumably this westward displacement of the rainshadow climate in summer occurs because the relatively small moisture content of clouds passing the coastal mountains is soon depleted, leaving little to fall farther east. During the growing season, therefore, even the westerly plots in the study area were inside the rainshadow zone. That the intensity of the rainshadow effect increases from west to east is exemplified by records from Nitinat Camp, Cowichan Lake, and Duncan. Average rainfall, both in summer and the year round, at the east coast station (Duncan) was only half that measured at the westerly station (Nitinat Camp). A similar trend was demonstrable in the study area. Potential moisture deficiencies are, therefore, likely to be more extreme in the easterly portion of the study area than farther west. Cloudy weather also occurred less frequently in the easterly section of the valley than it did farther west.

Winter temperatures in the study area were usually sufficiently low for much of the December-through-March precipitation to fall as snow. However, the depth and duration of the snow pack in different locations varied considerably. During the period 1952 to 1956, the average maximum depth of snow at the Fourth Lake Station was 38 in., at the Valley Station it was 19 in., and at the Deadwood Creek Station it was only 8 in. Such variation reflected temperature as well as precipitation differences. On several occasions during visits to the study area to collect weather data, snow was falling at Fourth Lake, while only rain was encountered at Deadwood Creek. In the springs of both 1952 and 1954, snow remained at the Fourth Lake and Echo Mountain Stations into April, by which time the ground was only partly covered in the Valley area and the Deadwood Creek area was already clear. Similarly, at the end of March, 1956, the snow pack was still near its maximum depth of 5 to 6 ft. at Fourth Lake and 3 to 4 ft. on Echo Mountain. The Valley Station, on the other hand, had little more than 6 in. and the Deadwood Creek area was largely free from snow.

TABLE II
THE CLIMATE OF STATIONS IN THE NANAIMO RIVER VALLEY COMPARED WITH THE CLIMATE OF OTHER STATIONS IN THE DOUGLAS-FIR REGION AND THE HEMLOCK REGION ON VANCOUVER ISLAND, BRITISH COLUMBIA

STATION	LOCATION			PRECIPITATION (inches)		MONTHLY EXTREME TEMPERATURE (°F.)				WATER BALANCE ¹					
						Summer maxima (mean 1955-56)	Summer range (mean 1955-56)	Winter minima (mean 1952-56)	Winter range (mean 1952-56)	Annual T-E ⁴	Summer T-E ⁴	Summer % T-E ⁴	Surplus (inches)	Deficiency (inches)	
	Lat. N. °	Long. W. °	Altitude (feet)	Annual (mean 1952-56)	Summer ² (mean 1951-56)										
NANAIMO RIVER															
Fourth Lake.....	49 05	124 24	1000	107	5.9	88	48	15	34	—	—	—	87 ⁵	8	
Echo Mountain.....	49 06	124 20	1400	88	4.8	84	40	18	28	—	—	—	72 ⁶	10	
Valley.....	49 05	124 17	650	77	4.7	88	49	15	36	—	—	—	50 ⁷	10	
Deadwood Creek.....	49 07	124 09	750	54	3.2	87	49	16	36	—	—	—	41 ⁸	11	
OTHER STATIONS															
DOUGLAS-FIR REGION															
Nitinat Camp.....	48 55	124 29	560	121	6.0	—	—	—	—	—	—	—	97 ⁵	7	
Cowichan Lake.....	48 49	124 08	580	88	5.2	85	44	18	30	24	12	50	52	9	
Duncan.....	48 47	123 43	28	43	3.2	93	48	20	33	26	14	54	25	13	
HEMLOCK REGION															
Pachena Point.....	48 43	125 06	150	125	10.4	70	28	24	26	24	10	42	89	1	

¹According to Thornthwaite and Mather (43).

²Summer: June, July, August.

³Winter: December, January, February.

⁴T-E: Thermal Efficiency.

⁵Surplus and deficiency calculated using T-E for Cowichan Lake.

⁶Surplus and deficiency calculated using T-E for Cumberland.

⁷Surplus and deficiency calculated using T-E for Alberni.

⁸Surplus and deficiency calculated using T-E for Cassidy.

The growing season in the study area extended from early May until mid-October. At Fourth Lake and on Echo Mountain, however, the growing season appeared to be somewhat shorter than it was farther east, since phenological events in spring, such as the appearance and increase in size of new *Polystichum munitum* fronds, were generally one or two weeks later in occurrence.

Vegetation

Vegetation analyses confirmed that the composition and productivity of tree and subordinate plant layers in the plots studied were typical of their respective associations. Differences evident among plots of the same association seemed attributable to the influence of geographic location, topography, and the soil characteristics of the individual plot.

Pseudotsuga-Gaultheria-Peltigera association

Despite the relatively large number of *Pseudotsuga menziesii* per acre, their small height and diameter in the *Pseudotsuga-Gaultheria-Peltigera* plots resulted in stands with rather open canopies and low volumes per acre (Table III, Fig. 5). At Fourth Lake (Plot L1), volume per acre was further decreased by stand openings occupied by rock outcrops. Tree heights in this plot were also lower than those in the other *Pseudotsuga-Gaultheria-Peltigera* plots. No secondary canopy of intermediate trees occurred in any plot, although occasional suppressed *Pseudotsuga menziesii*, and, in some plots, *Tsuga heterophylla*, *Pinus contorta*, and *P. monticola* were present. The absence of a secondary canopy may have been at least partially attributable to ground fires subsequent to stand establishment. The presence of charred bark on the lower boles of several trees in each plot attested to the occurrence of such fires. Occasional clumps of *Tsuga heterophylla* up to 40 ft. high were present on most plots and individual *Pinus contorta* reached 60 ft. in Plot L4. All understorey trees, however, were less than 100 years old, some 100 to 200 years younger than most trees of the dominant canopy.

Gaultheria shallon, less than 6 dm. high, constituted the principal cover of shrub layers. Other species occurred only as scattered individuals. Clumps of *Tsuga heterophylla*, 4 to 5 ft. tall, were present in some plots, particularly those toward the western end of the study area. A few *Pseudotsuga menziesii* were also included within the shrub layer in the Wolf Mountain Plot (L5). Although a fairly large number of species was represented in the herb layer of most plots, only *Linnaea borealis*, *Chimaphila umbellata*, *Mahonia nervosa*, and *Goodyera oblongifolia* occurred with any considerable frequency. *Camptothecium megaptilum*, *Calliergonella schreberi*, *Polytrichum* spp., and *Rhacomitrium* spp., mosses characteristic of the association, formed extensive patches on some plots. *Hylocomium splendens* and *Eurhynchium oreganum* were common throughout. Various species of *Cladonia*, *Peltigera*, and *Stereocaulon* were also present amongst the ground cover plants, especially on the Fourth Lake Plot. Other lichens, particularly *Alectoria sarmentosa*, *Sphaerophorus globosus*, *Parmelia physodes*, and *Cetraria* spp. were a conspicuous feature on the bark of trees in all plots.

Pseudotsuga-Gaultheria association

The greater height and diameter of *Pseudotsuga menziesii* in the *Pseudotsuga-Gaultheria* plots resulted in larger basal areas and volumes per acre than those of the *Pseudotsuga-Gaultheria-Peltigera* plots (Table III). A secondary canopy of suppressed *Tsuga heterophylla* and *Thuja plicata* was present in Plot G6, but these species occurred only as scattered clumps or individuals in other plots and they contributed little to stand volume. All trees of these species, however, were of a younger age class than the *Pseudotsuga menziesii* overstoreys in the plots analyzed.



FIGURE 5—A stand of the *Pseudotsuga-Gaultheria-Peltigera* association, showing the small diameters of *Pseudotsuga menziesii* and sparseness of *Gaultheria shallon*. The meter stick is marked in decimeters.

FIGURE 6—A stand of the *Pseudotsuga-Gaultheria* association. The increased diameters of *Pseudotsuga menziesii* and height of the *Gaultheria shallon* layer may be judged from the meter stick.

FIGURE 7—A stand of the *Pseudotsuga-Tsuga-Gaultheria* association, showing the small diameters of both *Pseudotsuga menziesii* and *Tsuga heterophylla*.

FIGURE 8—The Fourth Lake Plot of the *Pseudotsuga-Tsuga Hylocomium* association, showing the comparatively large size of *Tsuga heterophylla* (beside meter stick). One of the rain gauges is evident in the right foreground.

The *Gaultheria shallon* of the shrub layer was commonly over 1 m. in height and considerably denser than in the *Pseudotsuga-Gaultheria-Peltigera* plots (Fig. 6). Other shrubs still had little cover value and herb layers were characterized by a poor species representation. The most common plants of herb layers in the *Pseudotsuga-Gaultheria-Peltigera* plots were also common in the *Pseudotsuga-Gaultheria* plots, but their frequencies were lower. *Hylocomium splendens* and *Eurhynchium oreganum* were the prominent mosses of moss-lichen layers, and they covered the ground to the virtual exclusion of other species. Lichens were absent from the ground layer.

TABLE III
VEGETATION ANALYSES OF PLOTS REPRESENTATIVE OF FOREST ASSOCIATIONS
IN THE NANAIMO RIVER VALLEY, BRITISH COLUMBIA
PSEUDOTSUGA-GAULTHERIA-PELTIGERA ASSOCIATION

LOCATION.....	WOLF MT.	DEADWOOD	DEADWOOD	VALLEY	FOURTH LK.
PLOT NUMBER.....	L5	L4	L3	L2	L1
AGE OF OLDEST TREE IN DOMINANT CANOPY (years).....	220	285	285	285	275
SITE INDEX FOR <i>Pseudotsuga</i> (feet at 100 years).....	90	80	80	90	70
TREE LAYER					
<i>Pseudotsuga menziesii</i>					
Av. height, dom. and codom. (ft.).....	106	95	99	116	87
Av. diam., dom. and codom. (in.).....	17	18	16	19	19
Av. age, dom. and codom. (years).....	215	240	250	230	250
Trees per acre.....	140	108	160	152	92
Basal area (sq. ft. per acre).....	250	210	260	360	185
Volume (cu. ft. per acre).....	8,750	5,990	8,060	12,410	4,790
SHRUB LAYER (Line interception)					
<i>Gaultheria shallon</i>	25	35	33	38	24
<i>Tsuga heterophylla</i>	—	1	+*	3	6
<i>Pseudotsuga menziesii</i>	1	1	1	—	+
<i>Mahonia nervosa</i> (Pursh) Nutt.....	2	1	3	1	—
<i>Pinus monticola</i>	—	3	1	+	+
<i>Arctostaphylos columbiana</i>	—	+	+	—	—
<i>Thuja plicata</i>	+	—	—	—	1
<i>Vaccinium membranaceum</i>	—	—	—	—	+
<i>Pinus contorta</i>	—	+	+	—	+
<i>Vaccinium parvifolium</i>	—	+	+	—	+
<i>Rosa gymnocarpa</i>	—	+	+	—	—
HERB LAYER (Frequency)					
<i>Gaultheria shallon</i>	88	97	92	84	74
<i>Linnaea borealis</i>	13	4	40	26	21
<i>Chimaphila umbellata</i>	29	35	40	10	9
<i>Goodyera oblongifolia</i> (Raf.).....	11	17	4	2	1
<i>Boschniakia hookeri</i>	3	3	7	5	1
<i>Mahonia nervosa</i>	11	5	20	21	+
<i>Pseudotsuga menziesii</i>	9	19	9	+	1
<i>Arctostaphylos uva-ursi</i>	—	+	14	—	4
<i>Festuca occidentalis</i>	6	+	+	2	5
<i>Vaccinium parvifolium</i>	—	3	4	—	+
<i>Pyrola picta</i>	+	1	2	—	—
<i>Allotropa virgata</i>	+	2	1	+	+
<i>Hieracium albiflorum</i>	1	1	+	+	+
<i>Chimaphila menziesii</i>	—	2	—	—	+
<i>Apocynum androsaemifolium</i>	+	4	—	—	—
<i>Mahonia aquifolium</i> (Pursh) Nutt.....	1	+	+	—	—
<i>Viola orbiculata</i>	—	1	+	—	—
<i>Pteridium aquilinum</i>	1	1	7	1	+
<i>Trientalis latifolia</i>	13	3	+	1	—
<i>Achlys triphylla</i>	4	+	—	6	—
<i>Malus diversifolia</i>	1	1	—	+	—
<i>Pinus monticola</i>	—	1	1	+	—
<i>Vaccinium membranaceum</i>	—	—	—	—	30
<i>Rosa gymnocarpa</i>	11	—	+	—	—
<i>Symphoricarpos hesperus</i> G. M. Jones..	7	—	—	+	—

TABLE III—Continued

PSEUDOTSUGA-GAULTHERIA-PELTIGERA ASSOCIATION—Concluded

LOCATION.....	WOLF MT.	DEADWOOD	DEADWOOD	VALLEY	FOURTH LK.
PLOT NUMBER.....	L5	L4	L3	L2	L1
HERB LAYER (Frequency)—Concluded					
<i>Campanula scouleri</i>	6	+	+	—	—
<i>Pyrola bracteata</i>	—	—	1	—	—
<i>Vaccinium ovalifolium</i>	—	—	—	—	1
<i>Tsuga heterophylla</i>	—	1	+	—	—
<i>Rubus vitifolius</i>	1	—	+	+	+
<i>Bromus vulgaris</i>	1	—	—	—	—
<i>Monotropa latisquamea</i> (Rydb.) Hulten	+	+	+	—	+
MOSS-LICHEN LAYER (Point frequency)					
<i>Eurynemum oreganum</i>	19	15	23	22	2
<i>Hylocomium splendens</i>	1	3	23	17	9
<i>Rhytidiadelphus triquetrus</i>	2	+	2	+	+
<i>Rhytidiadelphus loreus</i>	—	—	+	+	+
<i>Dieranum scoparium</i>	+	5	2	4	2
<i>Camptothecium megaptilum</i> Sull.....	2	1	1	3	1
<i>Peltigera membranacea</i> Ach.....	1	1	1	1	1
<i>Peltigera aphthosa</i>	+	1	1	+	1
<i>Calliergonella schreberi</i>	+	+	9	3	8
<i>Dieranum fuscescens</i>	1	+	+	1	+
<i>Polytrichum juniperinum</i>	—	1	+	+	+
<i>Cladonia sylvatica</i>	—	—	+	+	3
<i>Cladonia gracilis</i>	—	+	+	+	+
<i>Cladonia squamosa</i>	—	—	+	—	+
<i>Cladonia fureata</i>	+	+	+	+	+
<i>Cladonia bellidiflora</i>	—	—	+	—	1
<i>Cladonia macilenta</i>	—	—	+	—	—
<i>Cladonia fimbriata</i>	+	+	—	—	+
<i>Rhacomitrium lanuginosum</i>	+	+	+	+	—
<i>Rhacomitrium canescens</i>	+	+	+	+	+
<i>Rhacomitrium heterostichum</i>	+	+	+	+	+
<i>Aulaeomnium androgynum</i>	+	+	+	+	—
<i>Bryum pallens</i> Swartz.....	—	+	+	+	—
<i>Stereocaulon tomentosum</i>	—	+	+	—	—
<i>Stereocaulon pasehale</i>	—	+	+	—	+
<i>Pilophoron eereolus</i>	+	+	+	+	—
<i>Pseudotsuga menziesii</i>	+	+	+	+	+
ON DECAYING WOOD (Total estimate)					
<i>Dieranum fuscescens</i>	1	+	1	3	1
<i>Hypnum circinale</i>	—	—	—	3	—
<i>Aulaeomnium androgynum</i>	+	+	+	2	—
<i>Eurhynchium oreganum</i>	+	+	1	3	2
<i>Hylocomium splendens</i>	—	—	+	3	+
<i>Peltigera aphthosa</i>	+	+	—	2	+
<i>Cladonia gracilis</i>	+	+	+	2	1
<i>Cladonia bellidiflora</i>	1	1	—	—	+
<i>Cladonia fimbriata</i>	+	+	—	+	—
<i>Peltigera membranacea</i>	—	+	+	+	+
<i>Dieranum strictum</i>	+	+	+	+	+
<i>Pseudisothecium stoloniferum</i>	1	—	—	1	+
<i>Calliergonella schreberi</i>	—	—	+	—	+
<i>Polytrichum juniperinum</i>	+	+	—	—	—
ON <i>Pseudotsuga</i> BARK (Total estimate)					
<i>Alectoria sarmentosa</i>	3	4	3	1	5
<i>Sphaerophorus globosus</i>	2	1	1	3	3
<i>Parmelia physodes</i>	2	1	2	2	1
<i>Cetraria lacunosa</i>	2	3	2	2	—
<i>Cetraria glauca</i>	—	—	3	—	3
<i>Cetraria scutata</i>	1	1	1	—	—
<i>Nephromopsis ciliaris</i>	2	2	—	2	—
<i>Hypnum circinale</i>	1	+	1	2	2
<i>Cladonia macilenta</i>	—	3	2	2	—
<i>Alectoria oregana</i>	—	—	1	—	2
<i>Alectoria jubata</i>	+	+	—	—	2
<i>Oehrolechia upsaliensis</i>	—	1	1	—	—
<i>Lobaria oregana</i>	—	—	+	+	—
<i>Usnea plicata</i>	—	+	1	—	—
<i>Letharia vulpina</i>	+	—	+	—	—

TABLE III—Continued
PSEUDOTSUGA-GAULTHERIA ASSOCIATION

LOCATION.....	WOLF MT. G5	DEADWOOD G4	DEADWOOD G6	VALLEY G3
PLOT NUMBER.....				
AGE OF OLDEST TREE IN DOMINANT CANOPY (years).....	220	320	320	275
SITE INDEX FOR <i>Pseudotsuga</i> (feet at 100 years).....	130	140	120	140
TREE LAYER				
<i>Pseudotsuga menziesii</i>				
Av. height, dom. and codom. (ft.).....	147	175	148	169
Av. diam., dom. and codom. (in.).....	22	27	26	28
Av. age, dom. and codom. (years).....	215	300	300	250
Tree per acre.....	100	108	104	64
Basal area (sq. ft. per acre).....	300	470	410	280
Volume (cu. ft. per acre).....	13,320	23,650	17,880	12,840
<i>Tsuga heterophylla</i>				
Av. height, dom. and codom. (ft.).....	—	—	66	88
Av. diam., dom. and codom. (in.).....	—	—	10	11
Av. age, dom. and codom. (years).....	—	—	190	130
Trees per acre.....	—	—	40	16
Basal area (sq. ft. per acre).....	—	—	24	12
Volume (cu. ft. per acre).....	—	—	640	130
<i>Thuja plicata</i>				
Av. height, dom. and codom. (ft.).....	—	—	74	60
Av. diam., dom. and codom. (in.).....	—	—	10	11
Av. age, dom. and codom. (years).....	—	—	220	130
Trees per acre.....	—	—	28	12
Basal area (sq. ft. per acre).....	—	—	16	7
Volume (cu. ft. per acre).....	—	—	475	135
SHRUB LAYER (Line interception)				
<i>Gaultheria shallon</i>	59	41	64	31
<i>Mahonia nervosa</i>	4	1	+	+
<i>Polystichum munitum</i>	+	+	+	5
<i>Vaccinium parvifolium</i>	—	+	+	—
<i>Rosa gymnocarpa</i>	+	+	+	+
<i>Thuja plicata</i>	+	+	+	+
<i>Tsuga heterophylla</i>	+	+	+	+
<i>Pseudotsuga menziesii</i>	+	+	—	—
<i>Holodiscus discolor</i>	—	—	—	+
HERB LAYER (Frequency)				
<i>Gaultheria shallon</i>	89	78	83	71
<i>Linnaea borealis</i>	11	1	9	10
<i>Chimaphila umbellata</i>	16	10	1	—
<i>Mahonia nervosa</i>	47	10	14	7
<i>Achlys triphylla</i>	56	31	14	29
<i>Boschniakia hookeri</i>	6	1	1	—
<i>Rubus vitifolius</i>	11	6	1	6
<i>Goodyera oblongifolia</i>	+	—	+	—
<i>Rosa gymnocarpa</i>	1	4	—	1
<i>Chimaphila menziesii</i>	2	1	1	—
<i>Symphoricarpos hesperus</i>	4	1	+	—
<i>Pteridium aquilinum</i>	2	+	+	1
<i>Polystichum munitum</i>	+	+	+	10
<i>Vaccinium parvifolium</i>	+	+	+	+
<i>Pyrola picta</i>	+	+	—	—
<i>Pyrola bracteata</i>	+	+	—	—
MOSS-LICHEN LAYER (Point frequency)				
<i>Hylocomium splendens</i>	1	15	15	16
<i>Eurhynchium oreganum</i>	22	+	13	10
<i>Rhytidiadelphus loreus</i>	—	—	—	2
<i>Rhytidiadelphus triquetrus</i>	—	+	—	+
<i>Camptothecium megaptilum</i>	+	—	—	—
<i>Dicranum scoparium</i>	+	—	—	+
<i>Pseudisothecium stoloniferum</i>	+	—	—	—
<i>Hypnum circinale</i>	2	—	—	+
ON DECAYING WOOD (Total Estimate)				
<i>Hylocomium splendens</i>	2	2	4	3
<i>Eurhynchium oreganum</i>	4	3	3	4

TABLE III—Continued
PSEUDOTSUGA-GAULTHERIA ASSOCIATION—Concluded

LOCATION..... PLOT NUMBER.....	WOLF MT. G5	DEADWOOD G 4	DEADWOOD G6	VALLEY G3
ON DECAYING WOOD—Concluded				
<i>Scapania bolanderi</i>	—	+	1	1
<i>Dicranum fuscescens</i>	—	1	1	—
<i>Dicranum scoparium</i>	2	1	—	+
<i>Hypnum circinale</i>	2	2	2	—
<i>Mnium punctatum</i>	+	—	+	—
<i>Rhytidiadelphus loreus</i>	—	—	+	1
<i>Pseudisothecium stoloniferum</i>	+	1	—	—
<i>Tsuga heterophylla</i>	+	+	1	—
ON <i>Pseudotsuga</i> BARK (Total estimate)				
<i>Dicranum fuscescens</i>	1	3	2	3
<i>Sphaerophorus globosus</i>	+	1	1	1
<i>Hypnum circinale</i>	2	2	3	4
<i>Cladonia macilenta</i>	3	2	4	+
<i>Cetraria lacunosa</i>	3	2	1	—
<i>Nephromopsis ciliaris</i>	3	2	2	—
<i>Parmelia physodes</i>	+	—	+	—
<i>Ochrolechia pallescens</i>	+	1	+	—
<i>Scapania bolanderi</i>	—	—	+	2
<i>Alectoria sarmentosa</i>	1	+	—	—

PSEUDOTSUGA-TSUGA-GAULTHERIA ASSOCIATION

LOCATION..... PLOT NUMBER.....	FOURTH LK. G1	ECHO MT. G2
AGE OF OLDEST TREE IN DOMINANT CANOPY (years).....	245	285
SITE INDEX FOR <i>Pseudotsuga</i> (feet at 100 years).....	90	60
TREE LAYER		
<i>Pseudotsuga menziesii</i>		
Av. height, dom. and codom. (ft.).....	110	77
Av. diam., dom. and codom. (in.).....	17	14
Av. age, dom. and codom. (years).....	235	260
Trees per acre.....	172	104
Basal area (sq. ft. per acre).....	300	130
Volume (cu. ft. per acre).....	10,310	2,950
<i>Tsuga heterophylla</i>		
Av. height, dom. and codom. (ft.).....	71	70
Av. diam., dom. and codom. (in.).....	10	12
Av. age, dom. and codom. (years).....	160	250
Trees per acre.....	32	120
Basal area (sq. ft. per acre).....	17	120
Volume (cu. ft. per acre).....	490	2,540
<i>Thuja plicata</i>		
Av. height, dom. and codom. (ft.).....	74	64
Av. diam., dom. and codom. (in.).....	14	9
Av. age, dom. and codom. (years).....	200	230
Trees per acre.....	36	24
Basal area (sq. ft. per acre).....	44	12
Volume (cu. ft. per acre).....	1,190	325
SHRUB LAYER (Line interception)		
<i>Gaultheria shallon</i>	50	36
<i>Tsuga heterophylla</i>	+	+
<i>Thuja plicata</i>	+	+
<i>Vaccinium parvifolium</i>	—	+
<i>Vaccinium membranaceum</i>	—	+
HERB LAYER (Frequency)		
<i>Gaultheria shallon</i>	76	76
<i>Linnaea borealis</i>	50	5
<i>Vaccinium parvifolium</i>	12	26
<i>Goodyera oblongifolia</i>	6	5

TABLE III—Continued
PSEUDOTSUGA-TSUGA-GAULTHERIA ASSOCIATION—Concluded

LOCATION.....	FOURTH LK.	ECHO MT.
PLOT NUMBER.....	G1	G2
HERB LAYER—Concluded		
<i>Mahonia nervosa</i>	15	+
<i>Chimaphila umbellata</i>	9	6
<i>Achlys triphylla</i>	2	—
<i>Boschniakia hookeri</i>	+	1
<i>Chimaphila menziesii</i>	1	+
<i>Vaccinium membranaceum</i>	+	5
<i>Vaccinium ovalifolium</i>	—	2
<i>Vaccinium alaskaense</i> Howell.....	+	—
<i>Gaultheria ovatifolia</i>	—	2
<i>Tsuga heterophylla</i>	—	1
MOSS-LICHEN LAYER (Point frequency)		
<i>Hylocomium splendens</i>	16	23
<i>Rhytidiadelphus loreus</i>	5	5
<i>Rhytidiopsis robusta</i>	1	12
<i>Eurhynchium oreganum</i>	4	+
<i>Camptothecium megaptilum</i>	1	1
<i>Plagiothecium undulatum</i>	+	—
ON DECAYING WOOD (Total estimate)		
<i>Hylocomium splendens</i>	2	2
<i>Eurhynchium oreganum</i>	2	+
<i>Scapania bolanderi</i>	1	1
<i>Dicranum fuscescens</i>	1	+
<i>Hypnum circinale</i>	1	+
<i>Rhytidiopsis robusta</i>	—	+
ON <i>Pseudotsuga</i> BARK (Total estimate)		
<i>Dicranum fuscescens</i>	+	+
<i>Sphaerophorus globosus</i>	+	1
<i>Cladonia macilenta</i>	+	+
<i>Parmelia physodes</i>	1	1
<i>Hypnum circinale</i>	—	+
<i>Cetraria lacunosa</i>	—	+
<i>Alectoria sarmentosa</i>	+	+

PSEUDOTSUGA-TSUGA-HYLOCOMIUM ASSOCIATION

LOCATION.....	DEAD WOOD	VALLEY	FOURTH LK.	WOLF MT.	ECHO MT.
PLOT NUMBER.....	M4	M3	M1	M5	M2
SUBASSOCIATION.....	<i>typicum</i>	<i>typicum</i>	<i>typicum</i>	<i>nudum</i>	<i>nudum</i>
AGE OF OLDEST TREE IN DOMINANT CANOPY (years).....	320	320	275	220	285
SITE INDEX FOR <i>Pseudotsuga</i> (feet at 100 years).....	130	130	120	170	170
TREE LAYER					
<i>Pseudotsuga menziesii</i>					
Av. height, dom. and codom. (ft.)....	158	157	144	199	209
Av. diam., dom. and codom. (in.)....	26	23	22	33	37
Av. age, dom. and codom. (years)....	290	300	260	210	250
Trees per acre.....	96	84	68	80	72
Basal area (sq. ft. per acre).....	380	270	210	500	550
Volume (cu. ft. per acre).....	17,140	12,870	9,110	27,960	31,400
<i>Tsuga heterophylla</i>					
Av. height, dom. and codom. (ft.)....	85	86	136	65	87
Av. diam., dom. and codom. (in.)....	9	10	18	7	10
Av. age, dom. and codom. (years)....	190	190	220	80	170
Trees per acre.....	176	88	64	96	52
Basal area (sq. ft. per acre).....	92	50	140	26	28
Volume (cu. ft. per acre).....	3,670	1,710	7,330	750	960
<i>Thuja plicata</i>					
Av. height, dom. and codom. (ft.)....	101	78	85	—	107

TABLE III—Continued

PSEUDOTSUGA-TSUGA-HYLOCOMIUM ASSOCIATION—Concluded

LOCATION..... PLOT NUMBER.....	DEAD WOOD M4	VALLEY M3	FOURTH LK. M1	WOLF MT. M5	ECHO MT. M2
<i>Thuja plicata</i> —concluded					
Av. diam., dom. and codom. (in.).....	13	13	14	—	14
Av. age, dom. and codom. (years).....	190	200	220	—	170
Trees per acre.....	12	12	56	—	16
Basal area (sq. ft. per acre).....	13	11	68	—	20
Volume (cu. ft. per acre).....	500	350	2,260	—	800
SHRUB LAYER (Line interception)					
<i>Gaultheria shallon</i>	5	+	3	+	+
<i>Mahonia nervosa</i>	1	—	2	—	—
<i>Polystichum munitum</i>	3	+	+	+	+
<i>Tsuga heterophylla</i>	1	+	+	+	+
<i>Thuja plicata</i>	—	—	+	—	+
HERB LAYER (Frequency)					
<i>Chimaphila menziesii</i>	7	2	2	+	12
<i>Mahonia nervosa</i>	11	+	9	1	1
<i>Linnaea borealis</i>	2	11	49	+	—
<i>Viola orbiculata</i>	1	—	1	1	6
<i>Pyrola picta</i>	1	+	1	+	1
<i>Achlys triphylla</i>	3	3	4	—	3
<i>Gaultheria shallon</i>	13	1	19	+	+
<i>Goodyera oblongifolia</i>	1	+	+	2	1
<i>Vaccinium parvifolium</i>	+	1	21	+	+
<i>Chimaphila umbellata</i>	+	2	12	+	+
<i>Monotropa uniflora</i>	+	+	+	+	—
<i>Monotropa latisquamea</i>	—	+	—	—	+
<i>Listera cordata</i>	—	—	—	+	+
<i>Corallorhiza maculata</i>	—	+	—	+	—
<i>Polystichum munitum</i>	+	+	—	+	+
<i>Trillium ovatum</i>	+	—	+	+	+
MOSS-LICHEN LAYER (Point frequency)					
<i>Eurhynchium oreganum</i>	10	18	17	3	2
<i>Hylocomium splendens</i>	44	35	8	2	+
<i>Rhytidiadelphus loreus</i>	+	8	2	+	+
<i>Rhytidiadelphus triquetrus</i>	+	1	—	+	—
<i>Rhytidiopsis robusta</i>	—	—	2	—	+
<i>Pseudisothecium stoloniferum</i>	—	+	+	1	+
<i>Camptothecium megaptilum</i>	—	+	2	+	—
<i>Dicranum fuscescens</i>	+	—	—	+	+
<i>Mnium spinulosum</i>	—	—	—	+	+
ON DECAYING WOOD (Total estimate)...					
<i>Hypnum circinale</i>	4	4	3	4	4
<i>Cephalozia media</i>	2	1	2	2	2
<i>Scapania bolanderi</i>	2	1	—	2	1
<i>Dicranum fuscescens</i>	2	1	1	2	1
<i>Lepidozia reptans</i>	1	—	—	1	1
<i>Rhytidiadelphus loreus</i>	+	+	+	+	—
<i>Eurhynchium oreganum</i>	2	+	+	1	—
<i>Hylocomium splendens</i>	2	1	1	1	—
<i>Tsuga heterophylla</i>	2	+	1	1	1
ON <i>Pseudotsuga</i> BARK (Total estimate)					
<i>Hypnum circinale</i>	4	3	2	4	2
<i>Dicranum fuscescens</i>	2	3	2	1	2
<i>Cladonia macilenta</i>	3	2	—	4	—
<i>Scapania bolanderi</i>	—	1	—	+	—

TABLE III—Continued
PSEUDOTSUGA-POLYSTICHUM ASSOCIATION

LOCATION.....	DEADWOOD	FOURTH LK	ECHO MT.	WOLF MT.	VALLEY
PLOT NUMBER.....	P4	P1	P2	P5	P3
AGE OF OLDEST TREE IN DOMINANT CANOPY (years).....	285	270	285	220	220
SITE INDEX FOR <i>Pseudotsuga</i> (feet at 100 years).....	200	160	200	180	200
TREE LAYER					
<i>Pseudotsuga menziesii</i>					
Av. height, dom. and codom. (ft.)....	248	199	244	218	233
Av. diam., dom. and codom. (in.)....	48	36	42	39	37
Av. age, dom. and codom. (years)....	270	260	250	200	200
Trees per acre.....	44	40	52	56	64
Basal area (sq. ft. per acre).....	570	280	440	490	500
Volume (cu. ft. per acre).....	37,130	14,150	30,000	28,700	32,500
<i>Thuja plicata</i>					
Av. height, dom. and codom. (ft.)....	140	137	178	148	—
Av. diam., dom. and codom. (in.)....	34	31	25	29	—
Av. age, dom. and codom. (years)....	140	200	240	190	—
Trees per acre.....	12	12	12	12	—
Basal area (sq. ft. per acre).....	78	77	50	56	—
Volume (cu. ft. per acre).....	2,700	3,060	2,710	2,500	—
<i>Tsuga heterophylla</i>					
Av. height, dom. and codom. (ft.)....	76	106	83	111	96
Av. diam., dom. and codom. (in.)....	10	13	10	11	11
Av. age, dom. and codom. (years)....	70	220	160	100	150
Trees per acre.....	52	76	28	44	24
Basal area (sq. ft. per acre).....	31	94	15	35	16
Volume (cu. ft. per acre).....	1,250	4,400	540	1,600	600
<i>Abies grandis</i>					
Av. height, dom. and codom. (ft.)....	—	—	—	118	77
Av. diam., dom. and codom. (in.)....	—	—	—	13	9
Av. age, dom. and codom. (years)....	—	—	—	120	140
Trees per acre.....	—	—	—	28	8
Basal area (sq. ft. per acre).....	—	—	—	35	4
Volume (cu. ft. per acre).....	—	—	—	1,750	60
SHRUB LAYER (Line interception)					
<i>Polystichum munitum</i>	33	40	21	20	18
<i>Tsuga heterophylla</i>	+	1	4	—	2
<i>Mahonia nervosa</i>	—	+	+	1	+
<i>Thuja plicata</i>	—	+	1	+	—
<i>Athyrium filix-femina</i>	1	—	+	+	+
<i>Rosa gymnocarpa</i>	—	—	+	+	+
<i>Rubus spectabilis</i>	—	—	+	—	+
HERB LAYER (Frequency)					
<i>Polystichum munitum</i>	29	41	8	20	10
<i>Tiarella trifoliata</i>	22	12	58	30	91
<i>Achlys triphylla</i>	24	25	48	13	65
<i>Tiarella laciniata</i> Hook.....	1	—	39	8	30
<i>Trillium ovatum</i>	+	—	1	1	5
<i>Athyrium filix-femina</i>	2	—	2	4	+
<i>Melica subulata</i>	+	—	1	3	1
<i>Adenocaulon bicolor</i>	+	—	5	+	37
<i>Dryopteris linnaeana</i>	27	—	+	+	1
<i>Blechnum spicant</i> (L.) J. E. Smith.....	—	—	4	10	—
<i>Viola orbiculata</i>	+	1	25	+	—
<i>Galium triflorum</i>	8	+	17	+	+
<i>Carex hendersonii</i>	1	—	+	+	9
<i>Claytonia sibirica</i> L.....	+	+	+	4	—
<i>Disporum oreganum</i>	+	—	+	—	2
<i>Streptopus amplexifolius</i>	+	—	+	1	+
<i>Mahonia nervosa</i>	—	4	9	17	19
<i>Linnaea borealis</i>	—	34	54	+	+
<i>Vaccinium parvifolium</i>	—	4	2	+	1
<i>Luzula parviflora</i>	1	—	+	1	4
<i>Tridentalis latifolia</i>	—	+	10	+	2
<i>Bromus vulgaris</i>	+	—	—	+	17

TABLE III—Continued
PSEUDOTSUGA-POLYSTICHUM ASSOCIATION—Concluded

LOCATION..... PLOT NUMBER.....	DEADWOOD P4	FOURTH LK. P2	ECHO MT. P2	WOLF MT. P5	VALLEY P3
MOSS-LICHEN LAYER (Point Frequency)					
<i>Eurhynchium oreganum</i>	2	9	3	8	9
<i>Hylocomium splendens</i>	10	+	+	2	1
<i>Rhytidiadelphus loreus</i>	—	+	1	—	+
<i>Mnium insignis</i>	4	—	—	1	3
<i>Mnium menziesii</i>	—	—	+	1	—
<i>Rhytidiopsis robusta</i>	—	+	+	—	—
ON DECAYING WOOD (Total estimate)					
<i>Lepidozia reptans</i>	1	1	2	2	1
<i>Mnium punctatum</i>	+	+	1	2	1
<i>Mnium spinulosum</i>	+	+	+	+	+
<i>Plagiothecium denticulatum</i>	1	—	+	+	—
<i>Eurhynchium oreganum</i>	3	—	2	3	2
<i>Hylocomium splendens</i>	2	2	3	4	3
<i>Rhytidiadelphus loreus</i>	1	+	1	2	1
<i>Pseudisothecium stoloniferum</i>	2	1	1	+	2
<i>Cephalozia media</i>	1	—	2	4	2
<i>Scapania bolanderi</i>	+	+	1	1	1
<i>Dicranum fuscescens</i>	2	1	1	2	1
<i>Icmadophila ericetorum</i>	—	+	—	+	—
<i>Riccardia latifrons</i>	1	—	—	1	—
<i>Hypnum circinale</i>	1	1	—	3	1
<i>Tsuga heterophylla</i>	—	2	3	+	+
ON <i>Pseudotsuga</i> BARK (Total estimate)					
<i>Hypnum circinale</i>	2	3	—	4	4
<i>Dicranum fuscescens</i>	1	3	2	3	3
<i>Scapania bolanderi</i>	—	3	2	2	2
<i>Hylocomium splendens</i>	1	—	2	—	1
<i>Cladonia macilenta</i>	—	3	2	6	3
<i>Sphaerophorus globosus</i>	—	+	—	—	+
ON <i>Tsuga</i> BARK (Total estimate)					
<i>Pseudisothecium stoloniferum</i>	2	2	3	3	4
<i>Porella navicularis</i>	1	1	2	—	2
<i>Neckera douglasii</i>	—	1	1	—	1
<i>Frullania nisquallensis</i>	2	1	—	1	2
<i>Radula complanata</i>	—	1	—	—	1
<i>Hypnum circinale</i>	—	1	1	4	+
<i>Dicranum fuscescens</i>	1	1	2	1	+
<i>Eurhynchium oreganum</i>	1	—	—	1	1
<i>Cladonia macilenta</i>	1	1	—	2	1
<i>Rhytidiadelphus loreus</i>	—	—	+	—	+

THUJA-LYSICHITUM ASSOCIATION

LOCATION..... PLOT NUMBER.....	WOLF MT. Ly3	DEADWOOD Ly2	ECHO MT. Ly1
AGE OF OLDEST TREE IN DOMINANT CANOPY (years).....	220	285	285
TREE LAYER			
<i>Thuja plicata</i>			
Av. height, dom. and codom. (ft.)....	125	196	177
Av. diam., dom. and codom. (in.)....	38	30	25
Av. age, dom. and codom. (years)....	200	270	250
Trees per acre.....	88	68	60
Basal area (sq. ft. per acre).....	797	366	220
Volume (cu. ft. per acre).....	37,000	20,700	12,000
<i>Pseudotsuga menziesii</i>			
Av. height, dom. and codom. (ft.)....	183	230	206
Av. diam., dom. and codom. (in.)....	40	46	36

TABLE III—Continued
 THUJA-LYSICHTUM ASSOCIATION—Continued

LOCATION..... PLOT NUMBER.....	WOLF Mt. Ly3	DEADWOOD Ly2	ECHO Mt. Ly1			
<i>Pseudotsuga menziesii</i> —concluded						
Av. age, dom. and codom. (years)....	260	270	260			
Trees per acre.....	8	16	16			
Basal area (sq. ft. per acre).....	72	190	120			
Volume (cu. ft. per acre).....	3,600	8,250	6,700			
<i>Tsuga heterophylla</i>						
Av. height, dom. and codom. (ft.)....	71	132	186			
Av. diam., dom. and codom. (in.)....	11	14	26			
Av. age, dom. and codom. (years)....	90	150	240			
Trees per acre.....	60	48	12			
Basal area (sq. ft. per acre).....	48	80	56			
Volume (cu. ft. per acre).....	1,400	5,000	3,800			
SHRUB LAYER (Line interception)	SWAMP	BANKS	SWAMP	BANKS	SWAMP	BANKS
<i>Lysichitum americanum</i>	49	10	46	+	73	11
<i>Oplopanax horridus</i>	—	—	54	+	—	—
<i>Athyrium filix-femina</i>	—	—	8	+	—	—
<i>Rubus spectabilis</i>	—	+	+	+	—	+
<i>Blechnum spicant</i>	3	9	5	16	+	32
<i>Polystichum munitum</i>	—	1	1	3	—	—
<i>Adiantum pedatum</i>	—	—	—	—	1	10
<i>Gaultheria shallon</i>	2	12	—	+	—	+
<i>Thuja plicata</i>	—	+	—	—	—	—
<i>Tsuga heterophylla</i>	—	+	—	+	—	+
HERB LAYER (Frequency)						
<i>Lysichitum americanum</i>	76	12	42	+	54	7
<i>Claytonia sibirica</i>	22	—	2	—	11	—
<i>Galium triflorum</i>	13	+	12	5	28	7
<i>Mitella ovalis</i>	3	—	25	+	—	—
<i>Viola orbiculata</i>	—	—	3	+	35	+
<i>Viola glabella</i>	—	—	—	—	28	7
<i>Listera cordata</i>	—	—	—	—	16	—
<i>Athyrium filix-femina</i>	+	—	11	+	+	—
<i>Stachys ciliata</i>	3	—	—	—	—	—
<i>Oenanthe sarmentosa</i>	+	—	3	—	—	—
<i>Dryopteris linnaeana</i>	—	+	3	+	—	—
<i>Epilobium adenocaulon</i> Hook.....	—	—	3	+	—	—
<i>Carex leptopoda</i>	+	—	+	—	3	—
<i>Thuja plicata</i>	—	—	—	—	3	—
<i>Cardamine angulata</i>	+	—	2	—	—	—
<i>Galium boreale</i>	—	—	2	—	—	—
<i>Maianthemum dilatatum</i> (Wood)						
Abrams.....	—	—	2	—	—	—
<i>Circaea pacifica</i>	+	—	+	—	1	—
<i>Veratrum eschscholtzii</i> A. Gray.....	+	2	+	5	16	7
<i>Tiarella trifoliata</i>	3	12	40	+	11	36
<i>Tiarella laciniata</i>	3	5	9	+	3	14
<i>Streptopus amplexifolius</i>	—	7	2	+	5	—
<i>Achlys triphylla</i>	—	2	—	5	—	57
<i>Blechnum spicant</i>	5	14	2	5	5	50
<i>Vaccinium parvifolium</i>	—	5	—	5	—	—
<i>Gaultheria shallon</i>	8	40	—	+	—	+
<i>Adenocaulon bicolor</i>	—	—	—	—	5	14
<i>Rubus vitifolius</i>	3	5	—	—	—	—
<i>Goodyera oblongifolia</i>	—	+	—	—	—	7
<i>Luzula parviflora</i>	+	—	+	+	3	7
MOSS-LICHEN LAYER (Point frequency)						
<i>Mnium punctatum</i>	36	1	19	+	50	—
<i>Eurhynchium stokesii</i>	16	+	12	—	11	1
<i>Brachythecium washingtonianum</i>						
Eaton.....	14	1	2	—	7	—
<i>Conocephalum conicum</i>	1	—	+	—	3	—
<i>Pellia columbiana</i> Krajina and						
Brayshaw.....	1	—	3	—	1	—
<i>Mnium menziesii</i>	3	—	1	—	2	—

TABLE III—*Concluded*
THUJA-LYSICHTUM ASSOCIATION—Concluded

	SWAMP	BANKS	SWAMP	BANKS	SWAMP	BANKS
<i>MOSS-LICHEN LAYER—Concluded</i>						
<i>Mnium insignie</i>	+	—	2	—	+	—
<i>Eurhynchium oreganum</i>	2	10	+	+	—	—
<i>Hylocomium splendens</i>	—	5	+	2	—	+
<i>ON DECAYING WOOD (Total estimate)</i>						
<i>Cephalozia media</i>	3		2		2	
<i>Calypogeia trichomanis</i>	2		+		+	
<i>Mnium punctatum</i>	2		1		2	
<i>Scapania bolanderi</i>	3		1		2	
<i>Hylocomium splendens</i>	4		2		1	
<i>Eurhynchium oreganum</i>	3		2		1	
<i>Dicranum fuscescens</i>	+		1		2	
<i>Lepidozia reptans</i>	2		1		1	
<i>Rhytidiadelphus loreus</i>	1		1		1	
<i>Mnium spinulosum</i>	+		+		+	
<i>ON Thuja BARK (Total estimate)</i>						
<i>Hypnum circinale</i>	1		2		3	
<i>Dicranum fuscescens</i>	+		2		2	
<i>Cladonia macilenta</i>	1		1		3	
<i>Scapania bolanderi</i>	1		+		+	
<i>Frullania nisquallensis</i>	—		+		+	

* Less than one percent.

** According to the total estimate scale of Krajina and Domin (19). Interpretation of the scale values as follows:

- + solitary, with small dominance.
- 1 seldom, with small dominance.
- 2 very scattered, with small dominance
- 3 scattered, with small dominance.
- 4 often, with 1/20 dominance.
- 5 often, with 1/5 dominance.
- 6 any number, with 1/4 to 1/3 dominance.
- 7 any number, with 1/3 to 1/2 dominance.
- 8 any number, with 1/2 to 3/4 dominance.
- 9 any number, with dominance more than 3/4, but less than complete.
- 10 any number, with complete dominance.

Pseudotsuga-Tsuga-Gaultheria association

Site index for *Pseudotsuga menziesii* in the *Pseudotsuga-Tsuga-Gaultheria* plots was as low as in the *Pseudotsuga-Gaultheria-Peltigera* plots (Table III). Unlike the *Pseudotsuga-Gaultheria-Peltigera* and *Pseudotsuga-Gaultheria* plots, *Tsuga heterophylla* constituted nearly half the stand volume of the Echo Mountain *Pseudotsuga-Tsuga-Gaultheria* Plot, although little occurred in the Fourth Lake Plot. *Tsuga heterophylla* heights and diameters were poor, nevertheless (Fig. 7).

The presence of *Chamaecyparis nootkatensis*, *Vaccinium membranaceum*, *V. alaskaense*, and *Gaultheria ovatifolia* showed the affinity of the *Pseudotsuga-Tsuga-Gaultheria* plots with stands characteristic of relatively high altitudes. Other plants of shrub and herb layers occurred in both the *Pseudotsuga-Gaultheria* and *Pseudotsuga-Tsuga-Gaultheria* plots, although many were smaller and less abundant in the *Pseudotsuga-Tsuga-Gaultheria* plots than they were in *Pseudotsuga-Gaultheria* sites at lower elevations. In the moss-lichen layer, *Rhytidiadelphus loreus* and *Rhytidiopsis robusta* were other species common in high altitude stands, although the predominant moss, *Hylocomium splendens*, was equally widespread in lower altitude plots. Both mosses and lichens were common on the bark of trees, with *Lobaria oregana* being particularly conspicuous on both living and dead branches in the Echo Mountain Plot.

Pseudotsuga-Tsuga-Hylocomium association

The average height of 144 to 155 ft. for the dominant and codominant *Pseudotsuga menziesii* in the subassociation *typicum* plots was considerably less than the 199 to 209 ft. averaged in the *nudum* plots (Table III). In most plots *Tsuga heterophylla* formed a secondary canopy 70 to 130 ft. below the dominant *Pseudotsuga menziesii* canopy. Although as numerous as *Pseudotsuga menziesii*, *Tsuga heterophylla* made up only a minor proportion of stand volume because individual trees were smaller. With the exception of the Fourth Lake Plot, however, all *Tsuga heterophylla* were younger than the trees of the dominant canopy. In the Fourth Lake Plot, some *Tsuga heterophylla* were of the same age class as the *Pseudotsuga menziesii* and both species were represented in the codominant canopy (Fig. 8).

The subordinate vegetation of the *Pseudotsuga-Tsuga-Hylocomium* plots was characterized by an almost complete lack of shrubs and herbs. Various inconspicuous plants characteristic of the association were present, but their cover value was small (Table III). Stunted *Gaultheria shallon*, *Polystichum munitum*, and *Achlys triphylla*, species characteristic of other associations, also occurred locally, but their frequency was low.

The forest floor in the subassociation *typicum* plots consisted of an almost continuous green carpet of mosses (Fig. 9), *Hylocomium splendens* and *Eurhynchium oreganum* being the predominant species. The forest floor in the subassociation *nudum* plots was essentially bare (Fig. 10). Epiphytic lichens were absent from the lower boles of trees in all plots, but bryophytes such as *Hypnum circinale*, *Dicranum fuscescens*, and *Scapania bolanderi* were quite common.

Pseudotsuga-Polystichum association

The largest trees and highest volumes per acre of any stand were recorded in the *Pseudotsuga-Polystichum* plots (Table III). Tree heights on the Fourth Lake Plot (P1) were somewhat lower than average for the association because this plot was located toward the upper margin of the stand type. A logging setting lower down the same slope, which had been cut prior to the present study, had large stump diameters and a high site index comparable with those of the other plots of this association (22). With the exception of the Valley Plot (P3), *Thuja plicata* was the tallest tree of the secondary canopy, although its frequency was low. *Tsuga heterophylla* constituted the bulk of a secondary canopy, some 100 to 150 ft. below the crowns of the dominants. *Tsuga heterophylla* volumes were low in most plots because trees were small and considerably younger than the *Pseudotsuga menziesii* of the dominant canopy.

Polystichum munitum clumps, commonly 80 cm. high, dominated subordinate plant layers (Fig. 11). Shrubby plants had little cover value. On some plots other ferns, such as *Blechnum spicant* on Plot P5, *Dryopteris linnaeana* on Plot P4, and *Athyrium felix-femina* on Plot P2, were also common. *Achlys triphylla*, a characteristic herb of the *Pseudotsuga-Polystichum* association, was particularly common in the Valley Plot (P3). This plot represented a subtype in which *Achlys triphylla* is even more abundant than *Polystichum munitum* (20). Other herbs characteristic of moist and fertile soils, such as *Tiarella trifoliata*, *Trillium ovatum*, *Adenocaulon bicolor*, and *Galium triflorum*, were represented on most plots. *Mnium insigne* and *M. menziesii*, mosses characteristic of the *Pseudotsuga-Polystichum* association, were present in the moss-lichen layer and other characteristic bryophytes occurred on decaying wood. Epiphytic mosses were also quite abundant, another feature typical of *Pseudotsuga-Polystichum* stands.



FIGURE 9—A stand of the *Pseudotsuga-Tsuga-Hylocomium* association, showing the mossy carpet present in subassociation *typicum* stands.

FIGURE 10—A stand of the *Pseudotsuga-Tsuga-Hylocomium* association, showing the bare forest floor of subassociation *nudum* stands.

FIGURE 11—A stand of the *Pseudotsuga-Polystichum* association. The large diameters of *Pseudotsuga menziesii* are evident.

FIGURE 12—A stand of the *Thuja-Lysichitum* association. The *Lysichitum americanum* leaves in the foreground cover a swampy portion of the stand. The *Thuja plicata* behind are growing on a marginal hummock.

Thuja-Lysichitum association

Although trees were restricted to the hummocks and banks which bordered swampy areas, volumes per acre in the *Thuja-Lysichitum* plots were quite high because individual *Thuja plicata* trees were large (Table III). The occasional *Pseudotsuga menziesii* included in these plots more properly belonged to adjacent sites bordering the stands analyzed.

Lysichitum americanum dominated swampy areas in the *Thuja-Lysichitum* plots during the growing season (Fig. 12). Other species characteristic of the association which grew among and beneath the *Lysichitum americanum* leaves included *Veratrum eschscholtzii*, *Mitella ovalis*, *Circaea pacifica*, *Mnium punctatum*, and *Conacephalum conicum*. Hummocks and the marginal banks of swamps supported a variety of species which also occurred in other associations.

Microclimate

Precipitation Interception

During the summer, average interception by the tree canopy ranged from 30 to 57 per cent (Table IV). Presumably such high values were recorded because summer rainfall occurred mostly as light showers, and a large proportion of each shower was required to wet the tree canopy before penetration took place. Low humidities and high temperatures might then evaporate much of this foliage moisture before it could drop to the ground (15). Interception by the tree canopy undoubtedly substantially reduced the amount of water that summer rainfall could add to soil-moisture reserves.

TABLE IV
AVERAGE PERCENTAGE OF PRECIPITATION INTERCEPTED BY THE TREE
CANOPIES OF PLOTS REPRESENTATIVE OF FOREST ASSOCIATIONS IN THE
NANAIMO RIVER VALLEY, BRITISH COLUMBIA, 1951-1953

ASSOCIATION	INTERCEPTION (%)	
	Annual	Summer
<i>Pseudotsuga-Tsuga-Gaultheria</i>	20	30
<i>Pseudotsuga-Gaultheria-Peltigera</i>	28	39
<i>Pseudotsuga-Gaultheria</i>	31	49
<i>Pseudotsuga-Tsuga-Hylocomium</i>	34	51
<i>Pseudotsuga-Polystichum</i> *.....	44	57
<i>Thuja-Lysichitum</i>	33	40

*Excluding Plots P1 and P2, which were understocked.

During periods of high rainfall, such as in autumn and winter, interception values were as low as 5 per cent. Mean annual interception values were consequently lower than those of the summer months. High percentages of interception did occur with light snowfalls and even in late winter snow depth beneath the trees was less than it was in adjacent open areas. However, since the snow pack in clear-cut areas usually melted earlier than it did beneath the tree canopy, moisture was supplied by melting snow later into the growing season than would have been the case had no tree canopy been present.

The highest percentages of interception occurred in the *Pseudotsuga-Tsuga-Hylocomium* and *Pseudotsuga-Polystichum* stands. Tree crowns were large and canopies were dense and two-layered in most of these plots. Interception values in Plots P1 and P2 of the *Pseudotsuga-Polystichum* association,

however, were below average for the association, apparently because stocking in these plots was low. Low stand density could also account for the low interception values of the *Thuja-Lysichitum* plots. In the *Pseudotsuga-Tsuga-Gaultheria* and *Pseudotsuga-Gaultheria-Peltigera* plots, the small size of tree crowns and absence of a dense secondary canopy doubtless contributed to the relatively low interception values recorded. However, the influence of such increased penetration was probably largely negated by more rapid evaporation than would have occurred had less insolation penetrated the tree canopy.

Temperature

Air and soil-surface temperatures were highest in the open *Pseudotsuga-Gaultheria-Peltigera* plots (Table V). Soil-surface temperatures reached 124° F. during summer months, even in undisturbed stands. Still higher values (135° F.) were recorded within the blackened soil-surface layer of Plot G4 of the *Pseudotsuga-Gaultheria* association the summer following a ground fire which destroyed the subordinate vegetation. More moderate temperatures were recorded in the denser *Pseudotsuga-Tsuga-Hylocomium* and *Pseudotsuga-Polystichum* stands and in the moist *Thuja-Lysichitum* plots. This trend reflected the moderating influence of stand density and moist soils. The soils of the higher altitude and westerly plots were cooler and warmed up more slowly in spring than their lower altitude and more easterly counterparts. Air and soil-surface temperatures however, were higher than their association averages during summer and autumn

TABLE V
AVERAGE QUARTERLY TEMPERATURES IN PLOTS REPRESENTATIVE OF
FOREST ASSOCIATIONS IN THE NANAIMO RIVER VALLEY,
BRITISH COLUMBIA, 1951-1953

ASSOCIATION	TEMPERATURE (°F.)			
	Spring ¹	Summer ²	Autumn ³	Winter ⁴
<i>PSEUDOTSUGA-GAULThERIA-PELTIGERA</i>				
(easterly plots: L2, L3, L4, L5)				
Air, at 1 m. (max./min.).....	—	88/49	—	—
Soil surface (max./min.).....	93/37	111/48	59/33	54/31
5 cm. below surface ⁵	47	59	45	36
15 cm. below surface.....	45	58	47	36
50 cm. below surface.....	45	55	48	38
(westerly plot: L1)				
Air, at 1 m. (max./min.).....	—	87/45	—	—
Soil surface (max./min.).....	89/37	108/46	54/34	47/29
5 cm. below surface.....	42	57	43	35
15 cm. below surface.....	42	56	44	36
50 cm. below surface.....	42	53	47	38
<i>PSEUDOTSUGA-GAULThERIA</i>				
(easterly plots: G3, G4, G5, G6)				
Air, at 1 m. (max./min.).....	—	85/47	—	—
Soil surface (max./min.).....	76/39	86/49	51/35	47/32
5 cm. below surface.....	45	57	45	35
15 cm. below surface.....	45	56	45	36
50 cm. below surface.....	44	54	49	40
<i>PSEUDOTSUGA-TSUGA-GAULThERIA</i>				
(westerly plots: G1, G2)				
Air, at 1 m. (max./min.).....	—	82/40	—	—
Soil surface (max./min.).....	68/38	83/46	49/33	42/32
5 cm. below surface.....	41	54	45	35
15 cm. below surface.....	41	54	45	36
50 cm. below surface.....	42	52	46	38

TABLE V—*Concluded*

ASSOCIATION	TEMPERATURE (°F.)			
	Spring ¹	Summer ²	Autumn ³	Winter ⁴
<i>PSEUDOTSUGA-TSUGA-HYLOCOMIUM</i>				
(easterly plots: M3, M4, M5)				
Air, at 1 m. (max./min.).....	—	79/48	—	—
Soil surface (max./min.).....	64/38	77/49	50/35	46/32
5 cm. below surface.....	45	56	45	36
15 cm. below surface.....	43	55	46	37
50 cm. below surface.....	44	54	47	39
(westerly plots: M1, M2)				
Air, at 1 m. (max./min.).....	—	83/46	—	—
Soil surface (max./min.).....	63/38	75/47	49/34	43/32
5 cm. below surface.....	42	54	43	35
15 cm. below surface.....	41	53	44	35
50 cm. below surface.....	41	51	44	37
<i>PSEUDOTSUGA-POLYSTICHUM</i>				
(easterly plots: P3, P4, P5)				
Air, at 1 m. (max./min.).....	—	80/47	—	—
Soil surface (max./min.).....	63/38	72/48	50/34	47/32
5 cm. below surface.....	45	57	45	35
15 cm. below surface.....	43	55	46	36
50 cm. below surface.....	43	52	48	39
(westerly plots: P1, P2)				
Air, at 1 m. (max./min.).....	—	84/46	—	—
Soil surface (max./min.).....	60/39	71/48	50/34	42/32
5 cm. below surface.....	42	53	45	35
15 cm. below surface.....	42	53	45	37
50 cm. below surface.....	41	50	48	39
<i>THUJA-LYSICHTUM</i> ⁶				
(easterly plots: Ly2, Ly3)				
Air, at 1 m. (max./min.).....	—	80/45	—	—
Soil surface (max./min.).....	56/40	65/49	48/35	44/32
5 cm. below surface.....	43	53	43	44
15 cm. below surface.....	44	56	43	45
50 cm. below surface.....	44	51	46	45

¹Measurements made early in April, May, and June.

²Measurements made early in July, August, and September.

³Measurements made early in October, November, and December.

⁴Measurements made early in January, February, and March.

⁵Subsurface measurements were made at the same time as soil moisture was sampled.

⁶Plot Ly1 was logged before sufficient temperature data had been recorded.

months in the Fourth Lake *Pseudotsuga-Tsuga-Hylocomium* and *Pseudotsuga-Polystichum* Plots, presumably because both stands were adjacent to cut-over areas.

Soil-surface layers did not remain frozen long enough to impede infiltration appreciably, even though monthly minima at the soil surface fell below 32° F. Upper soil horizons commonly had monthly minima as low as 34° F. in winter, but temperatures rarely dropped below 38° F. at depths of 50 or more centimeters beneath the soil surface. While such temperatures have been shown to impede water uptake by plants (23), some water must always have been available since subsurface soils were not frozen.

AVERAGE EVAPORATION FROM LIVINGSTON ATMOMETERS AT OPEN STATIONS AND STATIONS IN PLOTS REPRESENTATIVE OF
 FOREST ASSOCIATIONS IN THE NANAIMO RIVER VALLEY, BRITISH COLUMBIA, FOR THE PERIOD JUNE THROUGH SEPTEMBER,
 1951 AND 1952

* Actual evaporation expressed as a percentage of the largest value recorded (836 ml., from a standard Livingston atmometer at the Echo Mountain Open Station for the period July 1-15, 1952).

Evaporation

Evaporation rates were lowest in the moist *Thuja-Lysichitum* plots and highest at the Open Stations and in the open-canopied *Pseudotsuga-Gaultheria-Peltigera* plots (Table VI). That the high humidity associated with the swampy soils of the *Thuja-Lysichitum* plots more than counterbalanced the openness of the tree canopy in these plots demonstrated the influence of soil moisture as well as canopy density on evaporation rates. Transpiration loss by the vegetation of subordinate plant layers was presumably similarly influenced, even though evaporation loss from atmometers has been shown to be somewhat disproportionately influenced by wind movement (3).

Plots at higher altitudes commonly had lower evaporation rates than equivalent stands at lower elevations. Evaporation losses at the Fourth Lake *Pseudotsuga-Tsuga-Hylocomium* Plot, for example, were lower than those of the other plots of this association farther east at lower altitudes. Similarly, despite the openness of their tree canopies, evaporation rates in the *Pseudotsuga-Tsuga-Gaultheria* plots were among the lowest recorded. The relative frequency of a low cloud ceiling in the westerly portion of the study area in which these stands were located and the reduced insolation characteristic of north slopes, such as the one on which the Fourth Lake Plot was located, doubtless contributed to such conditions. On the other hand, the relatively high Echo Mountain Open Station had the highest rates of any station, apparently because it was located on a shoulder freely exposed to wind movement. Similarly, evaporation rates in the Fourth Lake *Pseudotsuga-Polystichum* Plot were higher than average for the association. This plot was exposed to abnormal air movement by its proximity to a cut-over area.

The influence of a shrub canopy on evaporation was indicated by the rates from the atmometers 5 cm. above the ground. The *Gaultheria shallon* canopy apparently exerted an appreciable influence in reducing rates near ground line. At 1 m., rates in the *Pseudotsuga-Gaultheria* plots were considerably higher than in the more densely canopied *Pseudotsuga-Tsuga-Hylocomium* stands. At 5 cm. the reverse was true. The absence of subordinate vegetation in *Pseudotsuga-Tsuga-Hylocomium* stands allowed unrestricted wind movement, and no shrub canopy was present to reduce insolation or raise humidities by transpiration.

The highest evaporation rates occurred in July (Table VII). Rates during the first half of both July and August, 1952, were nearly double those of the

TABLE VII
AVERAGE MONTHLY EVAPORATION FROM LIVINGSTON ATMOMETERS AT 100 CM. ABOVE THE GROUND IN PLOTS REPRESENTATIVE OF FOREST ASSOCIATIONS IN THE NANAIMO RIVER VALLEY, BRITISH COLUMBIA, JUNE THROUGH SEPTEMBER, 1951-52

ASSOCIATION	RELATIVE EVAPORATION*			
	June	July	August	September
<i>Pseudotsuga-Gaultheria-Peltigera</i>	52	68	58	45
<i>Pseudotsuga-Gaultheria</i>	46	59	47	33
<i>Pseudotsuga-Tsuga-Hylocomium</i>	38	53	43	33
<i>Pseudotsuga-Tsuga-Gaultheria</i>	34	44	39	30
<i>Pseudotsuga-Polystichum</i>	34	43	36	28
<i>Thuja-Lysichitum</i>	28	39	32	26

*Actual evaporation expressed as a percentage of the largest value recorded (836 ml., from a standard Livingston atmometer at the Echo Mountain Open Station for the period July 1-15, 1952).

second half of each month. During these latter periods, rainfall occurred and cloudy days were more common. Such a difference in rates showed that transpiration usage during the warm, dry summers characteristic of the study area would be considerably higher than in moister, cooler climates outside the rainshadow zone.

Soils

Profile Characteristics

Pseudotsuga-Gaultheria-Peltigera association

Soil profiles in the *Pseudotsuga-Gaultheria-Peltigera* plots were usually shallow, being terminated by bedrock or an ortstein layer less than 50 to 70 cm. below the surface (Table VIII, Fig. 13 A and C). Most profiles were gravelly and angular cobbles and small boulders were numerous. Clinker-like and shotty concretions were also common. In many samples, the 2-mm. fraction made up less than 50 per cent of the 25-mm. fraction and the 2-mm. fraction itself was coarse-textured. Such characteristics resulted in profiles with small moisture storage capacities. The infrequency of mottling in any layer showed the soils of these plots to be little affected by seepage moisture.



FIGURE 13—Typical soil profiles from plots representative of forest associations in the Nanaimo River valley, British Columbia. The scale is marked in decimeters. A. The *Pseudotsuga-Gaultheria-Peltigera* association (Plot L1 at Fourth Lake). B. The *Pseudotsuga-Tsuga-Gaultheria* association (Plot G1 at Fourth Lake). C. The *Pseudotsuga-Gaultheria-Peltigera* association (Plot L3 at Deadwood Creek). D. The *Pseudotsuga-Gaultheria* association (Plot G6 at Deadwood Creek). E. The *Pseudotsuga-Tsuga-Hylocomium* association (Plot M5 at Wolf Mountain). F. The *Pseudotsuga-Polystichum* association (Plot P1 at Fourth Lake). G. The *Pseudotsuga-Polystichum* association (Plot P3 in the Valley area). H. The *Pseudotsuga-Polystichum* association (Plot P2 at Echo Mountain). I. The *Pseudotsuga-Polystichum* association (Plot P5 at Wolf Mountain). J. The *Thuja-Lysichitum* association (Plot Ly3 at Wolf Mountain).

The mor-type humus and quite strongly acidic soil pH values of the *Pseudotsuga-Gaultheria-Peltigera* plots indicated the relative infertility of their soils. The weak definition of A₂ horizons, nevertheless, suggested that leaching was less intense than on some moister sites.

Profiles in the easterly Plots (L2, L3, L4, and L5) resembled the Shawnigan series described by Day, Farstad, and Laird (10). Most profiles in the Fourth Lake Plot (L1), however, corresponded more closely to the Quinsam series (10). In the moister climate of this westerly portion of the study area, soil colors were brighter and A₂ horizons deeper than in the more easterly *Pseudotsuga-Gaultheria-Peltigera* plots. The gravel content of most profiles examined in Plot L1 was also lower than that in the other plots of this association.

Pseudotsuga-Gaultheria association

The greater depth of material above the ortstein layer in the *Pseudotsuga-Gaultheria* plots resulted in somewhat larger soil-moisture storage capacities than those of the *Pseudotsuga-Gaultheria-Peltigera* plots (Table VIII, Fig. 14), even though stones and angular cobbles were equally common and the 2-mm. fraction made up scarcely 50 per cent of the 25-mm. fraction. Moreover, some mottling was usually present in deeper horizons. Such mottling, together with the stronger color of the dappled, reddish-yellow coatings on cobble and gravel particles showed that the soils of the *Pseudotsuga-Gaultheria* plots were somewhat more influenced by seepage moisture than those of the *Pseudotsuga-Gaultheria-Peltigera* plots.

TABLE VIII
TYPICAL SOIL PROFILES IN PLOTS REPRESENTATIVE OF FOREST ASSOCIATIONS
IN THE NANAIMO RIVER VALLEY, BRITISH COLUMBIA

PSEUDOTSUGA-GAULTHERIA-PELTIGERA ASSOCIATION		
LOWER DEADWOOD CREEK (Plot L3)		
A _o F	3-2 cm.	Very dark brown (10YR 2/2)* partially decomposed litter; pH 4.9.
H	2-0 cm.	Black (10YR 2/1) granular to felty mor, up to 4 cm. thick among surface cobbles; pH 5.0; roots common.
A ₂	0-2 cm.	Gray (5Y 6/1) sandy loam; weak fine subangular blocky structure; very friable; pH 4.9.
B	2-10 cm.	Brown (10YR 5/3) gravelly sandy loam, with angular cobbles in places very numerous; weak fine subangular blocky structure; loose; numerous shotty concretions, with yellowish red (5YR 5/8) coatings; light, dappled, strong brown (7.5YR 5/8) coatings on cobbles and gravel; pH 5.7; roots common.
B	10-20 cm.	Light yellowish brown (10YR 6/4) gravelly sandy loam, with angular cobbles; weak fine subangular blocky structure; very friable; shotty concretions; dappled, strong brown (7.5YR 5/8) coatings on cobbles and gravel; pH 5.6; roots common.
B	20-55 cm.	Pale brown (10YR 6/3) gravelly sandy loam, with scattered angular cobbles; weak fine subangular blocky structure; very friable; shotty concretions; dappled, strong brown (7.5YR 5/8) coatings on cobbles and gravel; pH 5.7; roots moderately common.
B	55-70 cm.	Pale olive (5YR 6/3) gravelly sandy loam, with scattered angular cobbles; weak fine subangular blocky structure; very friable, becoming weakly cemented with increasing depth; numerous light olive gray (5Y 6/2) clinker-like concretions, with yellowish red (5YR 5/8) staining; dappled, yellowish red (5YR 5/8) coatings on cobbles and gravel; pH 5.9; roots sparse, although fine roots common above the ortstein layer.
Ortstein	70+cm.	Light olive gray (5Y 6/2) gravelly sandy loam; irregular thick platy structure; cemented; reddish yellow (5YR 6/8) staining, particularly in the upper part; pH 6.2; roots absent.
FOURTH LAKE (Plot L1)		
A _o F	2-1 cm.	Very dark brown (10YR 2/2) partially decomposed litter.
H	1-0 cm.	Black (10YR 2/1) felty mor; pH 4.9; roots common.
A ₂	0-2 cm.	Light gray (5Y 7/1) loam, varying from less than 1 cm. to 5 cm. thick among surface cobbles; weak fine subangular blocky structure; pH 4.5; roots common.
B	2-20 cm.	Red (2.5YR 4/6) gravelly sandy loam, with scattered angular cobbles; weak fine subangular blocky structure; friable; shotty concretions, with yellowish red (5YR 5/8) coatings; dappled, yellowish red (5YR 5/6) coatings on cobbles and gravel; pH 5.1; roots common.

TABLE VIII—*Continued**PSEUDOTSUGA-GAULTHERIA-PELTIGERA ASSOCIATION—Concluded*FOURTH LAKE (Plot L1)—*Concluded*

B	20-35 cm.	Yellowish red (5YR 5/6) gravelly sandy loam, with scattered angular cobbles; weak fine subangular blocky structure; friable; shotty concretions; dappled, yellowish red (5YR 5/8) coatings on cobbles and gravel; pH 5.2; roots moderately common.
B	35-55 cm.	Reddish yellow (5YR 6/8) gravelly sandy loam, weak fine to medium subangular blocky structure; friable; dappled, reddish yellow (5YR 6/8) coatings on cobbles and gravel; scattered, faint blue (7.5BG 7/2) mottling; pH 5.3; roots sparse, although numerous on rock surface, commonly forming a mat; fine dead roots present.
D	55+cm.	Rock, seepage water occasionally present.

PSEUDOTSUGA-GAULTHERIA ASSOCIATION

UPPER DEADWOOD CREEK (Plot G6)

A ₀ F	4-2 cm.	Very dark brown (10YR 2/2) partially decomposed litter.
H	2-0 cm.	Very dark brown (10YR 2/2) felty mor; pH 5.2; roots common.
A ₂	0-1 cm.	Dark gray (10YR 4/1) sandy loam; thicker among surface cobbles; weak fine subangular blocky structure; very friable; pH 4.8; roots common.
B	1-10 cm.	Brown (10YR 5/3) gravelly sandy loam, with scattered angular cobbles; weak fine subangular blocky structure; very friable; numerous shotty concretions, with reddish yellow (7.5YR 6/6) coatings; dappled, reddish yellow (7.5YR 6/6) coatings on cobbles and gravel; pH 5.7; roots common.
B	10-25 cm.	Pale brown (10YR 6/3) gravelly sandy loam, with scattered angular cobbles; weak fine subangular blocky structure; very friable; shotty concretions very numerous; dappled, reddish yellow (7.5 YR 6/6) coatings on cobbles and gravel; pH 5.7; roots common.
B	25-50 cm.	Light yellowish brown (2.5Y 6/4) gravelly loam, with angular cobbles; weak fine subangular blocky structure; very friable; numerous shotty concretions; light yellowish brown (2.5Y 6/4) clinker-like concretions, with reddish yellow (7.5YR 6/8) staining; dappled, strong brown (7.5YR 5/8) coatings on cobbles and gravel; pH 5.9; roots moderately common.
B	50-80 cm.	Pale olive (5Y 6/3) gravelly sandy loam, with scattered angular cobbles; weak fine subangular blocky structure; firm to weakly cemented with increasing depth; clinker-like concretions common, becoming numerous towards the ortstein layer; dappled, reddish yellow (5YR 6/8) coatings on cobbles and gravel; reddish yellow (5YR 6/8) staining common above the ortstein; pH 6.2; roots sparse, but fine roots common just above the ortstein.
Ortstein	80+cm.	Olive gray (5Y 5/2) gravelly sandy loam; irregular thick platy structure; cemented; yellowish red (5YR 5/8) staining, prominent in the upper portion; pH 6.5; roots absent.

PSEUDOTSUGA-TSUGA-GAULTHERIA ASSOCIATION

ECHO MOUNTAIN (Plot G2)

A ₀ F	5-3 cm.	Very dark brown (10YR 2/2) partially decomposed litter.
H	3-0 cm.	Very dark brown (10YR 2/2) to black (10YR 2/1) felty mor; pH 4.6; roots forming dense network.
A ₂	0-4 cm.	Light gray (10YR 7/1) gravelly sandy loam, in places up to 10 cm. thick among surface cobbles; upper parts often including bleached humus; weak fine subangular blocky structure; very friable; shotty concretions; pH 4.6; roots numerous.
B	4-35 cm.	Strong brown (7.5YR 5/8) gravelly sandy loam, with scattered angular cobbles; weak fine subangular blocky structure; very friable; shotty concretions common, sometimes with heavy, red (2.5YR 4/8) coatings; dappled, yellowish red (5YR 5/8) coatings on cobbles and gravel; scattered, faint, yellowish red (5YR 5/8) mottling; pH 5.5; roots common.
B	35-55 cm.	Yellowish brown (10YR 5/6) gravelly sandy loam, with scattered angular cobbles; weak fine subangular blocky structure; very friable; shotty concretions common; dappled, faint, reddish yellow (7.5YR 6/8) coatings on cobbles and gravel; pH 5.7; roots moderately common.

TABLE VIII—*Continued**PSEUDOTSUGA-TSUGA-GAULTHERIA* ASSOCIATION—*Concluded*ECHO MOUNTAIN (Plot G2)—*Concluded*

B	55-75 cm.	Light yellowish brown (10YR 6/4) gravelly sandy loam, with numerous angular cobbles; weak fine to medium subangular blocky structure; friable; dappled, reddish yellow (7.5YR 6/8) coatings on cobbles; pH 5.4; roots sparse, although more numerous on rock surface, commonly forming a mat.
D	75+cm.	Rock; seepage water occasionally present. (In some profiles the B horizon merged into the D horizon; in others the root zone was terminated by an ortstein layer).

PSEUDOTSUGA-TSUGA-HYLOCOMIUM ASSOCIATION

VALLEY (Plot M3)

A ₀ F	3-2 cm.	Very dark brown (10YR 2/2) partially decomposed litter; pH 5.3.
H	2-0 cm.	Very dark brown (10YR 2/2) to black (10YR 2/1) felty mor; pH 5.2; roots moderately common.
A ₂	0-2 cm.	Gray (10YR 2/1) sandy loam, up to 10 cm. thick among surface stones; weak fine subangular blocky structure; very friable; pH 5.0; roots common.
B	2-20 cm.	Brown (10YR 5/3) gravelly sandy loam, with numerous angular cobbles and stones; weak fine subangular blocky structure; very friable; shotty concretions common; faint, strong brown (7.5YR 5/8) coatings on cobbles, gravel and shot; pH 5.5; roots common.
B	20-45 cm.	Yellowish brown (10YR 5/6) gravelly sandy loam, with angular cobbles weak fine subangular blocky structure; very friable; shotty concretions occasional pale olive (5YR 6/3) clinker-like concretions, with yellowish red (5YR 5/6) staining; dappled, strong brown (7.5YR 5/8) coatings on cobbles and gravel; pH 5.3; roots moderately common.
B	45-75 cm.	Yellowish brown (10YR 5/6) gravelly loamy sand, with angular cobbles; weak fine subangular blocky structure; friable; shotty concretions; clinker-like concretions more common; strong brown (7.5YR 5/8) coatings on cobbles and gravel; pH 5.8; roots sparse.
B	75-100 cm.	Yellowish brown (10YR 5/8) gravelly loamy sand, with scattered angular cobbles; weak fine subangular blocky structure; becoming weakly cemented; shotty concretions; clinker-like concretions nearly continuous; strong brown (7.5YR 5/8) coatings and mottling; faint bluish (7.5BG 7/2) mottling; pH 5.4; roots sparse.
Ortstein	100+cm.	Olive gray (5Y 5/2) gravelly sandy loam; irregular thick platy structure; cemented; yellowish red (5YR 4/8) staining; no roots.

FOURTH LAKE (Plot M1)

A ₀ F	7-5 cm.	Very dark brown (10YR 2/2) partially decomposed litter; pH 4.7.
H	5-0 cm.	Very dark brown (10YR 2/2) to black (10YR 2/1) felty mor; pH 4.2; roots numerous. In places the surface horizon consisted of up to 15 cm. of decayed wood.
A ₂	0-6 cm.	Light brownish gray (2.5Y 6/2) sandy loam; up to 15 cm. thick under decayed wood; weak fine subangular blocky structure; very friable; pH 4.3; roots common.
B	6-6.5 cm.	Dark reddish brown (5YR 3/4) loam; discontinuous.
B	6.5-20 cm.	Reddish brown (5YR 5/4) gravelly sandy loam, with angular cobbles and stones; weak fine subangular blocky structure; very friable; shotty concretions with yellowish red (5YR 5/8) coatings; dappled, yellowish red (5YR 5/8) coatings on cobbles and gravel; pH 5.3; roots common.
B	20-40 cm.	Reddish brown (5YR 5/4) gravelly sandy loam, with angular cobbles; weak fine subangular blocky structure; friable; shotty concretions common; occasional light yellowish brown (2.5Y 6/4) clinker-like concretions, with heavy, yellowish red (5YR 4/8) staining; heavy, dappled reddish yellow (5YR 6/8) staining on cobbles and gravel; pH 5.3; roots common.
B	40-65 cm.	Brown (7.5YR 5/4) gravelly sandy loam, with angular cobbles and stones; weak fine subangular blocky structure; friable; shotty concretions; clinker-like concretions more common; heavy dappled, yellowish red (5YR 5/8) staining on cobbles and gravel; faint bluish (7.5BG 7/2) mottling; pH 5.3; roots moderately common.

TABLE VIII—Continued

PSEUDOTSUGA-TSUGA-HYLOCOMIUM ASSOCIATION—Concluded

FOURTH LAKE (Plot M1)—Concluded

B	65-90 cm.	Yellowish brown (10YR 5/6) gravelly sandy loam, with angular cobbles and stones; weak fine to medium subangular blocky structure; friable; shotty concretions; clinker-like concretions numerous; heavy, dappled yellowish red (5YR 5/8) coatings on cobbles and gravel; scattered bluish (7.5BG 7/2) mottling; pH 5.7; roots sparse, although fine roots common above ortstein layer.
Ortstein	90+ cm.	Olive gray (5Y 5/2) gravelly sandy loam; irregular thick platy structure; cemented; yellowish red (5YR 4/8) staining; no roots.

LOWER DEADWOOD (Plot M4)

A ₀ F	3-2 cm.	Very dark brown (10YR 2/2) partially decomposed litter; pH 5.3.
H	2-0 cm.	Black (10YR 2/1) felty mor; pH 5.5; roots common.
A ₂	0-1 cm.	Gray (10YR 5/1) sandy loam, often thin but well defined; weak fine subangular blocky structure; very friable; pH 5.6.
B	1-10 cm.	Brown (7.5YR 5/4) gravelly loamy sand, with angular cobbles; weak subangular blocky structure; very friable; numerous shotty concretions; faint, strong brown (7.5YR 5/8) coatings on cobbles, gravel, and shot; pH 6.0; roots common.
B	10-20 cm.	Yellowish brown (10YR 5/4) gravelly loamy sand, with scattered cobbles; weak fine subangular blocky structure; very friable; numerous shotty concretions; faint, strong brown (7.5YR 5/8) coatings on cobbles, gravel, and shot; pH 6.0; roots common.
B	20-40 cm.	Yellowish brown (10YR 5/6) gravelly sandy loam, with scattered cobbles and stones; weak fine subangular blocky structure; very friable; shotty concretions common; light yellowish brown (2.5Y 6/4) clinker-like concretions, with faint, strong brown (7.5YR 5/8) staining; faint, strong brown (7.5YR 5/8) coatings on cobbles, gravel, and shot; very slight bluish (7.5BG 7/2) mottling; pH 6.0; roots moderately common.
B	40-70 cm.	Yellowish brown (10YR 5/8) gravelly loamy sand, with scattered cobbles; weak fine subangular blocky structure; very friable; shotty and clinker-like concretions common; faint, strong brown (7.5YR 5/8) coatings on cobbles, gravel, and shot; pH 6.7; roots sparse.
B	70-100 cm.	Light yellowish brown (2.5Y 6/4) gravelly loamy sand, with cobbles; very weak granular structure; loose; cobbles and gravel largely unstained pH 6.2; roots sparse.

ECHO MOUNTAIN (Plot M2)

A ₀ F	2-1 cm.	Very dark brown (10YR 2/2) partially decomposed litter; pH 5.2.
H	1-0 cm.	Very dark brown (10YR 2/2) felty mor; roots moderately common.
A ₂	0-1 cm.	Dark gray (10YR 4/1) sandy loam, in places poorly defined; weak fine subangular blocky structure; very friable; pH 5.7.
B	1-20 cm.	Yellowish red (5YR 5/8) gravelly sandy loam, with angular cobbles; weak fine subangular blocky structure; friable; shotty concretions common; dappled, strong brown (7.5YR 5/8) coatings on cobbles, gravel, and shot; pH 5.6; roots common.
B	20-40 cm.	Yellowish red (5YR 5/8) gravelly sandy loam, with scattered angular cobbles; weak fine subangular blocky structure; friable; shotty concretions; strong brown (7.5YR 5/8) coatings on cobbles, gravel, and shot; pH 5.9; roots common.
B	40-75 cm.	Strong brown (7.5YR 5/6) gravelly sandy loam, with scattered angular cobbles; weak fine subangular blocky structure; friable; shotty concretions; strong brown (7.5YR 5/8) coatings on cobbles, gravel, and shot; pH 5.9; roots sparse.
B (G)	75-100 cm.	Yellowish brown (10YR 5/6) gravelly sandy clay loam, with stones and angular cobbles; medium subangular blocky structure; firm; strong brown (7.5YR 5/8) coatings on cobbles and gravel; faint bluish (7.5BG 7/2) mottling; pH 5.7; roots sparse.

WOLF MOUNTAIN (Plot M5)

A ₀ F	2-1 cm.	Very dark brown (10YR 2/2) partially decomposed litter; pH 5.5.
H	1-0 cm.	Black (10YR 2/1) duff mull; pH 5.5; roots moderately common.
A ₂	0-1 cm.	Very dark brown (10YR 2/2) loam; weak crumb structure; friable; pH 5.7; roots moderately common.
B	1-10 cm.	Red (2.5YR 4/6) loam; weak medium subangular blocky structure; friable; shotty concretions, with yellowish red (5YR 5/6) coatings; diffuse, yellowish red coatings on gravel; pH 6.4; roots common.

TABLE VIII—Continued

*PSEUDOTSUGA-TSUGA-HYLOCOMIUM ASSOCIATION—Concluded*WOLF MOUNTAIN (Plot M5)—*Concluded*

B	10-20 cm.	Yellowish red (5YR 4/6) sandy loam; weak fine subangular blocky structure; friable; numerous shotty concretions; yellowish red (5YR 5/6) coatings on gravel and shot; pH 6.5; roots common.
B	20-45 cm.	Yellowish red (5YR 5/6) sandy loam; weak fine subangular blocky structure; friable; numerous shotty concretions; yellowish red (5YR 5/6) coatings on gravel and shot; pH 6.4; roots moderately common.
B	45-70 cm.	Yellowish brown (10YR 5/8) sandy loam; weak fine subangular blocky structure; friable; shotty concretions; scattered, red (2.5YR 5/8) coatings on gravel; pH 6.1; roots moderately common.
B	70-100 cm.	Light olive brown (2.5Y 5/4) sandy loam; weak fine subangular blocky structure; friable to firm; red (2.5YR 5/7) coatings on gravel and scattered red staining above compact horizon below; faint, bluish (7.5BG 7/2) cast and weak, red mottling; pH 6.3; roots sparse, although some fine roots present just above the compact horizon.
D	100-130 cm.	Pale olive (5Y 6/4) sandy loam; weak medium subangular blocky structure; firm to weakly cemented; compact; diffuse, red (2.5YR 5/8) coatings on gravel; red staining and mottling; pH 6.1; roots absent.

PSEUDOTSUGA-POLYSTICHUM ASSOCIATION

UPPER DEADWOOD CREEK (Plot P4)

A ₀ F	3-2 cm.	Very dark brown (10YR 2/2) partially decomposed litter; pH 5.5.
H	2-0 cm.	Black (10YR 2/1) duff mull to granular mor; pH 5.2; roots common.
A ₁	0-1 cm.	Black (10YR 2/1) sandy loam, somewhat discontinuous; crumb structure; friable; roots numerous.
B	1-10 cm.	Dark reddish brown (5YR 3/3) gravelly sandy loam, with occasional rounded cobbles; weak fine subangular blocky structure; friable; scattered shotty concretions; scattered, faint, strong brown (7.5YR 5/8) coatings on cobbles; pH 6.3; roots common.
B	10-20 cm.	Yellowish brown (10YR 5/6) sandy loam, with occasional rounded gravel and cobbles; weak fine subangular blocky structure; friable; scattered shotty concretions; scattered, faint, strong brown (7.5YR 5/8) coatings on cobbles; pH 6.3; roots common.
B	20-40 cm.	Yellowish brown (10YR 5/8) sandy loam, with occasional rounded gravel and cobbles; very weak fine subangular blocky structure; very friable; scattered shotty concretions; scattered, faint, strong brown (7.5YR 5/8) coatings on cobbles and gravel; pH 6.1; roots common.
B	40-50 cm.	Gray and brown sand, rounded gravel and cobbles; single grain structure; loose; scattered, faint, strong brown (7.5YR 5/8) coatings on cobbles and gravel; roots sparse.
B	50-75 cm.	Strong brown (7.5YR 5/6) gravelly sandy loam, with scattered rounded coarse gravel and cobbles; weak fine subangular blocky structure; very friable; scattered, faint, strong brown (7.5YR 5/8) coatings on cobbles and gravel; pH 6.4; roots moderately common.
B	75-100 cm.	Yellowish brown (10YR 5/7) gravelly loamy sand, with scattered rounded coarse gravel and cobbles; very weak fine subangular blocky structure; scattered, faint, strong brown (7.5YR 5/8) coatings on cobbles and gravel; pH 6.3; roots sparse.
B	100-130 cm.	Light yellowish brown (2.5Y 6/4) gravelly loamy sand, with scattered rounded coarse gravel and cobbles; very weak fine subangular blocky structure; very friable; scattered, faint, strong brown (7.5YR 5/8) coatings on cobbles and gravel; pH 6.2; roots very sparse.

FOURTH LAKE (Plot P1)

A ₀ F	4-3 cm.	Very dark brown (10YR 2/2) partially decomposed litter; pH 5.0.
H	3-0 cm.	Very dark brown (10YR 2/2) felty mor; pH 4.5; roots common.
A ₂	0-1 cm.	Reddish brown (5YR 5/3) sandy loam; weak fine subangular blocky structure; friable; shotty concretions; roots common; this horizon merges into the next.
B	1-4 cm.	Yellowish red (5YR 5/6) gravelly sandy loam, often discontinuous; weak fine subangular blocky structure; friable; numerous shotty concretions, with heavy, yellowish red (5YR 5/8) coatings; roots common.
B	4-20 cm.	Yellowish red (5YR 4/6) gravelly sandy loam, with scattered angular cobbles; weak fine to medium subangular blocky structure; friable; numerous shotty concretions; scattered, reddish yellow (5YR 6/8) coatings on gravel and shot; pH 5.3; roots common.

TABLE VIII—Continued

PSEUDOTSUGA-POLYSTICHUM ASSOCIATION—Continued

FOURTH LAKE (Plot P1)—Concluded

B	20-45 cm.	Strong brown (7.5YR 5/6) gravelly loam, with scattered angular cobbles; weak medium subangular blocky structure; friable; shotty concretions; scattered, reddish yellow (5YR 6/8) coatings on gravel and shot; pH 5.6; roots moderately common.
B	45-75 cm.	Yellowish brown (10YR 5/6) gravelly loam, with scattered angular cobbles; weak medium subangular blocky structure; friable; diffuse, reddish yellow (5YR 6/8) coatings on cobbles and gravel; pH 5.8; roots common.
B	75-100 cm.	Yellowish brown (10YR 5/8) gravelly loam, with scattered stones and angular cobbles; weak medium to coarse subangular blocky structure; firm; faint, dappled, yellowish red (5YR 5/8) coatings on gravel and cobbles; pH 5.9; roots sparse.
B	100-120 cm.	Light yellowish brown (2.5Y 6/4) gravelly loam, with stones and angular cobbles; weak coarse subangular blocky structure; slightly plastic when moist; very firm when dry; dappled, yellowish red (5YR 5/8) coatings on cobbles and gravel; pH 5.6; roots sparse.

ECHO MOUNTAIN (Plot P2)

A ₀ F	8-6 cm.	Very dark brown (10YR 2/2) partially decomposed litter; pH 5.4.
H	6-0 cm.	Very dark brown (10YR 2/2) duff mull to felty mor; often includes dark reddish brown (2.5YR 3/4) woody peat from decayed wood; where peat absent humus about 2 cm. deep; pH 5.4; roots common.
A ₂	0-1 cm.	Dark reddish gray (5YR 4/2) loam; under peaty decayed wood, this horizon may be up to 10 cm. thick; weak fine subangular blocky structure; friable; roots common.
B	1-3 cm.	Dark red (2.5YR 3/6) sandy loam; weak fine subangular blocky structure; friable; shotty concretions with heavy, red (2.5YR 5/8) coatings; dappled, yellowish red (5YR 5/8) coatings on gravel; pH 5.6; roots numerous.
B	3-10 cm.	Red (2.5YR 4/8) sandy loam; weak fine to medium subangular blocky structure; numerous shotty concretions; yellowish red (5YR 5/8) coatings on gravel and shot; pH 5.9; roots common.
B	10-20 cm.	Yellowish red (5YR 4/8) sandy loam; weak fine to medium subangular blocky structure; friable; numerous shotty concretions; yellowish red (5YR 5/8) coatings on gravel and shot; pH 6.1; roots common.
B	20-50 cm.	Yellowish red (5YR 4/8) sandy loam; weak fine to medium subangular blocky structure; friable; shotty concretions; yellowish red (5YR 5/8) coatings on gravel and shot; pH 6.0; roots moderately common.
B	50-75 cm.	Red (2.5YR 4/6) sandy loam; weak fine to medium subangular blocky structure; friable; shotty concretions; diffuse, yellowish red (5YR 5/8) coatings on gravel; roots sparse. This horizon is commonly below the water table; pH 6.1.
Ortstein	75 + cm.	Olive gray (5Y 5/2) sandy loam; irregular thick platy structure; cemented; prominently mottled with yellowish red (5YR 5/8) on exposure to air; roots absent.

WOLF MOUNTAIN (Plot P5)

A ₀ F	3-2 cm.	Very dark brown (10YR 2/2) partially decomposed litter.
H ₁	2-1 cm.	Very dark brown (10YR 2/2) felty mor; roots common.
H ₂	1-0 cm.	Black (10YR 2/1) granular duff mull; roots common.
A ₂	0-1 cm.	Dark gray brown (10YR 4/2) loam, often discontinuous and poorly defined; weak fine subangular blocky structure; friable; roots common.
B	1-2 cm.	Dark reddish brown (5YR 3/2) loam, often discontinuous; weak fine subangular blocky structure; friable; roots common.
B	2-10 cm.	Dark red (2.5YR 3/6) sandy loam; weak fine to medium subangular blocky structure; friable; numerous shotty concretions with yellowish red (5YR 5/8) coatings; pH 6.0; roots numerous.
B	10-25 cm.	Red (2.5YR 4/8) sandy loam; weak fine to medium subangular blocky structure; friable; numerous shotty concretions, with yellowish red coatings; pH 6.2; roots common.
B	25-40 cm.	Yellowish red (5YR 5/6) sandy loam; weak fine subangular blocky structure; friable; shotty concretions common; pH 6.1; roots common.
B	40-70 cm.	Yellowish brown (10YR 5/7) gravelly sandy loam; weak fine subangular blocky structure; friable; occasional shotty concretions with bright, yellowish red (5YR 5/8) coatings; scattered, faint, yellowish red (5YR 5/8) coatings on gravel; scattered, distinct, yellowish red (5YR 5/8) mottling; pH 6.1; roots sparse.

TABLE VIII—*Concluded**PSEUDOTSUGA-POLYSTICHUM ASSOCIATION—Concluded*WOLF MOUNTAIN (Plot P5)—*Concluded*

G	70-100 cm.	Light olive gray (5Y 6/2) gravelly sandy loam, with occasional rounded cobbles; fine to medium subangular blocky structure; firm; compact; gleyed; scattered, faint, yellowish red (5YR 5/8) coatings on gravel; occasional yellowish red (5YR 5/8) mottling; pH 6.5; roots very sparse.
VALLEY (Plot P3)		
A ₀ F	1.5-0.5 cm.	Very dark brown (10YR 2/2) partially decomposed litter.
H	0.5-0 cm.	Very dark brown (10YR 2/2) duff mull; pH 5.1; roots common.
A ₁	0-2 cm.	Black (10YR 2/1) loam; weak fine to medium crumb structure; friable; pH 5.2; roots common.
B	2-3 cm.	Very dark brown (10YR 2/2) loam; fine subangular blocky structure; friable; occasional shotty concretions; roots common.
B	3-8 cm.	Dark brown (10YR 3/3) loam; weak fine subangular blocky structure; friable; occasional shotty concretions; pH 5.6; roots common.
B	8-20 cm.	Dark yellowish brown (10YR 4/4) sandy loam; very weak fine subangular blocky structure; very friable; pH 5.4; roots common.
B	20-50 cm.	Yellowish brown (10YR 5/6) sandy loam; very weak fine subangular blocky structure; very friable, with bands of loose sand; pH 6.2; roots moderately common.
B	50-70 cm.	Dark yellowish brown (10YR 4/4) loam; weak fine subangular blocky structure; very friable; pH 6.0; roots common. This horizon may be the upper part of a buried profile.
B	70-100 cm.	Light gray and brown, raw, river gravel and sand; single grain structure; loose; occasional, light, dappled, strong brown (7.5YR 5/8) coatings on gravel; pH 6.2; roots very sparse.

THUJA-LYSICHITUM ASSOCIATION

WOLF MOUNTAIN (Plot Ly3)

A: SWAMP

0-1 cm.	Moss and debris (needles, twigs, wood fragments).
1-20 cm.	Black muck; water level varying from 0 to 10 cm. below the moss layer; pH 5.6.
20-23 cm.	Olive gray (5Y 4/2) mucky sandy loam; firm; compact; roots sparse (mostly <i>Lysichitum</i>).
23-35 cm.	Olive gray (5Y 5/2) gleyed sandy loam; plastic; slightly sticky when wet; firm; compact; hard when dry; brown and yellowish red mottling (faint before exposure to air); pH 6.8; roots absent.

B: BANKS AND HUMMOCKS

0-1 cm.	Partially decomposed litter.
1-2 cm.	Very dark brown (10YR 2/2) felty mor; pH 4.7.
2-20 cm.	Dark red (2.5YR 3/6) fibrous peat; contains twig and wood fragments; roots forming a dense network.
20-40 cm.	Very dark brown (10YR 2/2) to black muck; pH 4.2; roots sparse.
40 + cm.	Olive gray (5Y 5/2) gleyed gravelly sandy loam; upper portion heavily infiltrated with muck; slightly plastic; slightly sticky; firm; compact; hard when dry; water commonly running over the surface; pH 6.8; roots absent.

*Color descriptions are according to the Munsell Soil Color Chart (Munsell Color Company, Inc., Baltimore, Maryland, U.S.A.) and refer to soils in the moist state.

The greater depth of litter layers in the *Pseudotsuga-Gaultheria* plots seemed partly attributable to the forest floor being cooler and moister than in the *Pseudotsuga-Gaultheria-Peltigera* plots. Although somewhat more productive than *Pseudotsuga-Gaultheria-Peltigera* sites, the mor-type humus and acidic soil pH values of the *Pseudotsuga-Gaultheria* plots suggested that their soils were not particularly fertile. The deeper A₂ horizons of the *Pseudotsuga-Gaultheria* plots indicated that leaching was more intense than in the *Pseudotsuga-Gaultheria-Peltigera* plots.

Soil profiles in the Wolf Mountain and Deadwood Creek Plots (G4, G5, and G6) were comparable with the Shawnigan series (10). On the other hand, most profiles in the Valley Plot (G3) resembled the Sproat series (10), because their colors were brighter and their A₂ horizons more distinct than those of the more easterly plots.

Pseudotsuga-Tsuga-Gaultheria association

Soil depth in most of the profiles examined in the *Pseudotsuga-Tsuga-Gaultheria* plots was limited by bedrock less than 80 cm. below the surface. Soil-moisture storage capacity was further limited by the frequency of small boulders, angular cobbles, and shotty and clinker-like concretions (Table VIII, Fig. 13 B). The occurrence of mottling nevertheless showed that the soils of these plots were affected by seepage moisture.

The deep litter layers characteristic of the *Pseudotsuga-Tsuga-Gaultheria* plots were indicative of the cool and moist condition of the forest floor during much of the year. The mor character of these litter layers, the deep A₂ horizons, and strongly acidic soil pH values of these plots indicated the intensity of leaching and relative infertility of their soils.

Soil profiles in the *Pseudotsuga-Tsuga-Gaultheria* plots corresponded to the Quisam series of Day, Farstad, and Laird (10).

Pseudotsuga-Tsuga-Hylocomium association

Soil profiles in the *typicum* plots were characterized by their coarse texture and the clear differentiation of A₂ horizons. In the Fourth Lake and Valley Plots (M1 and M3) up to 40 per cent of soil volume was occupied by small boulders, angular cobbles, and clinker-like concretions over 25 mm. in diameter. The last were particularly common toward the base of profiles. Mottling, indicative of the periodic occurrence of seepage moisture, was present in the lower profile of all soil pits examined on Plots M1 and M3 (Table VIII). However, seepage moisture in such coarse-textured profiles was probably less influential than in finer-textured soil because surface layers remained essentially unaffected and rapid internal drainage limited the duration of supplements to soil-moisture reserves. The deep A₂ horizon and bright color of profiles in the Fourth Lake Plot (M1) were characteristics that these profiles had in common with the Stamp series of Day, Farstad, and Laird (10). Such characteristics are typical of profile development in a wet climate. Soil profiles in Plot M3 were similar to the Sproat series (10), another soil developed under quite wet climatic conditions. The soils of Plot M4, being derived from coarse outwash material, resembled the Qualicum series (10). The shallow A₂ horizon of such profiles is typical of soil development under relatively dry climatic conditions.

In contrast to the *typicum* plots, soil profiles in the *nudum* plots were characterized by relatively fine soil textures and little or no development of A₂ horizons. In the Wolf Mountain Plot (M5), the upper 90 to 100 cm. of the profile consisted of fine outwash material, nearly 90 per cent of which was included within the 5-mm. soil fraction (Fig. 13 E). While the soils of the Echo Mountain Plot (M2) contained angular cobbles and small boulders, clay contents were higher than those of soils in the *typicum* plots. Both plots consequently had quite high soil-moisture storage capacities. Downward percolation of water was restricted by a compact layer in the lower profile of both plots. The mottling present above this layer indicated the occurrence of high moisture contents during part of the year. Wilde (46) designates such profiles as gamma-gley soils.

The occurrence of an A₁ horizon with a crumb structure on Plot M5 was indicative of a relatively fertile soil. Even in Plot M2, litter layers were shallow

and the A₂ horizon weakly defined. Both characteristics suggest that seepage moisture was relatively effective in ameliorating the leaching influence of the wet climate in this section of the study area (20).

Most of the profiles examined on Plot M2 were comparable with the Alberni series, although those developed from relatively coarse material resembled the Stamp series more closely (10). Profiles in Plot M5 were similar to the Royston series (10).

Pseudotsuga-Polystichum association

While the soil parent-material and topographic position of the *Pseudotsuga-Polystichum* plots were diverse, profile development was such that the soils of all plots supported a similar vegetation type. Salient profile characteristics were the duff-mull character of litter layers, the weak differentiation of A₂ horizons, and the moderate acidity of pH values, all features denoting relatively fertile soils. Furthermore, the fairly high proportion of fine material included in all profiles resulted in quite high soil-moisture storage capacities. The mottling evident in most profiles indicated that moisture reserves were also supplemented by seepage moisture.

Soil profiles in Plot P1 seemed typical of *Pseudotsuga-Polystichum* sites developed under fairly wet climatic conditions. Despite the relatively high rainfall of this section of the valley, A₂ horizons consisted of merely one or two centimeters of reddish-brown sandy loam (Table VIII, Fig. 13 F). The occurrence of mottling in all horizons indicated that seepage moisture was influential even in surface layers, a characteristic of beta-gley soils (46). In addition to augmenting soil-moisture supply, this seepage presumably ameliorated the leaching action of the regional climate and limited the development of an A₂ horizon. The clay-loam layer at the base of profiles limited the downward percolation of seepage moisture. Profiles in this plot were comparable to the Stamp series of Day, Farstad, and Laird (10).

The Deadwood Creek Plot (P4), on stratified outwash material in the bottom of a wide U-shaped valley, represented *Pseudotsuga-Polystichum* stands growing on fertile soils under fairly dry climatic conditions. The presence of a black, loamy, A₁ horizon with a crumb structure, indicated the relatively high fertility of the soil in this plot. Although some bleaching was present beneath piles of decayed wood, no A₂ horizon had developed. Profiles in this plot were similar to the Qualicum series, although their predominantly yellowish-brown coloration showed that they also had an affinity with the Somas series (10).

Soil profiles in Plots P2 and P5 were characteristic of soil development under the influence of a high water table. Profiles in Plot P5 (Table VIII, Fig. 13 I) resembled the Puntledge series of Day, Farstad, and Laird (10) in being comprised of a shallow loamy deposit overlaying an impervious gleyed layer which caused a high water table. In Plot P2 (Table VIII, Fig. 13 H), the presence of fine gravel and shotty concretions seemed to render the profile above the ortstein quite porous. No evidence of the gray coloration usually associated with gleization was apparent. This lack of gray color was attributed to the ease with which ground water moved through the profile, a feature these soils had in common with the Bowser series (10).

Soil profiles in Plot P3 (Table VIII, Fig. 13 G) were typical of soil development on fertile alluvial benches. Most profiles included an A₁ horizon, and A₂ horizons occurred only beneath piles of decayed wood. The B horizon, which intergraded from a very dark-brown loam to a yellowish-brown sandy loam, contained almost no material larger than 2 mm. in diameter. The soils of this plot corresponded to the Chemainus series (10).

Thuja-Lysichitum association

The *Thuja-Lysichitum* plots occurred where seepage water came to the surface and the resulting streamlets spread out to form swamps. That such swamps were not stagnant and infertile was shown by their circumneutral pH values (Table VIII) and the slowly moving water which trickled through them. Profiles within the swampy areas consisted of varying depth of black muck, underlain by an olive gray, gleyed, sandy-loam layer (Fig. 13 J). Before exposure to the air, bluish mottling was predominant, indicating that this layer was continuously submerged. Tree roots were not encountered in the swampy parts of these plots.

Swampy areas were bordered by hummocks and banks of partially decomposed litter and wood, underlain by layers of very dark-brown, felty mor and reddish-brown, fibrous peat. These layers were densely interwoven by *Thuja plicata* roots. Tree roots, however, rarely extended into the gleyed, gravelly material below the peaty layers.

Moisture Regimes

Weather patterns during the soil-moisture sampling period were generally in accord with average values, although some variation did occur (Appendix II). In 1951, for example, below-average rainfall from April until the end of August accentuated the normal summer drought. At Cassidy, 12 miles to the east of Deadwood Creek, rainfall during this period was only 2.88 in. compared with an average of 10.75 in. Even Nitinat Camp in the central mountainous region recorded only 6.60 in., compared with the 16.44 in. normally received. In 1952, the summer drought period extended into autumn longer than usual. Rainfall at Deadwood Creek during September and October was only 1.3 in. as compared with the 7.5 in. average, and only 5.0 in. were recorded at Fourth Lake, considerably less than the average of 16.4 in. for this period.

During the winter of 1952-53 temperatures were more moderate than usual and most precipitation fell as rain. Precipitation during December and January was unusually heavy. Deadwood Creek received 31.9 in. during this period compared with an average of 20.6 in. and the Echo Mountain value of 47.8 in. was 18 in. more than usual. Precipitation was also somewhat greater than normal during June and July, 1953, and temperatures were below average.

Pseudotsuga-Gaultheria-Peltigera association

Depletion of soil-moisture reserves in the *Pseudotsuga-Gaultheria-Peltigera* plots began in May and continued throughout the growing season (Table IX, Fig. 14). In 1951 and 1952, available soil moisture in the Wolf Mountain, Deadwood Creek, and Valley Plots was reduced to very small amounts at all depths by early July. Although the summer of 1953 was somewhat wetter than usual, low percentages were still recorded by August.

Soil-moisture deficits in the Fourth Lake Plot (L1) were less marked than they were in the easterly plots, even during the dry summers of 1951 and 1952. Appreciable reduction in soil-moisture content had not occurred below the surface layers of the relatively fine-textured profile sampled in Plot L1 during early September, 1952, although values were quite low in the coarse-textured profile sampled during August. Even litter layers in the westerly plots had shorter periods of desiccation than in the stands farther east. It was noted, for example, that early September rainfall in 1951 was sufficient to re-wet litter layers in the Fourth Lake and Valley Plots, although these layers in the Deadwood Creek and Wolf Mountain Plots remained below wilting percentage until the end of the month.

Pseudotsuga-Gaultheria association

Available soil moisture was not depleted as early in the growing season in the *Pseudotsuga-Gaultheria* plots as it was in the *Pseudotsuga-Gaultheria-Peltigera* stands. Marked reductions were nevertheless evident by July and amounts of available moisture remained small until replenished by the autumnal rains. As in the *Pseudotsuga-Gaultheria-Peltigera* association, litter layers remained below wilting percentage during much of the growing season. Such desiccation presumably decreased the effectiveness of summer rainfall, since litter layers might absorb nearly 1 cm. of water before horizons containing appreciable numbers of plant roots were re-wet.

The importance of vegetation in moisture depletion was evident from the data for Plots G4 and G6 (Table IX). During the autumn of 1952 these plots were swept by ground fires which removed all the subordinate vegetation and, on Plot G6, killed some trees. In 1953, moisture deficits in these disturbed plots were small, even though soil-moisture depletion had been as great as it was in other plots of the *Pseudotsuga-Gaultheria* association (Plots G3 and G5) during the previous growing season.

After periods of heavy rainfall in late autumn, temporary water tables were common above hardpan layers and high moisture percentages were recorded at all depths. When Plot G6 was sampled in early December, 1951, this perched water table above the ortstein layer was 10 cm. deep. On resampling in early January, 1952, some two weeks after a heavy snowfall had covered the ground, there was no gravitational water above the hardpan and the moisture percentage of all layers was lower. Presumably, such a reduction in moisture content occurred because internal drainage in these gravelly, shotty soils was rapid, and excess moisture quickly drained away once further addition of water was prevented by the snow blanket. During the winter of 1952-53, perched water tables were present more or less continuously since there was little snow or frozen soil to restrict infiltration of the abnormally heavy rainfall of December and January.

Pseudotsuga-Tsuga-Gaultheria association

Soil-moisture values in the *Pseudotsuga-Tsuga-Gaultheria* plots were high in the available range during the early part of the growing season. Even litter layers contained available moisture at most samplings. Low values, particularly in the upper 20 cm., were recorded in July, 1951, and August, 1952, although periods with small amounts of available soil moisture were of shorter duration than in the droughty *Pseudotsuga-Gaultheria* plots.

Pseudotsuga-Tsuga-Hylocomium association

Available soil moisture was virtually exhausted from the surface layers of the easterly subassociation *typicum* plots of the *Pseudotsuga-Tsuga-Hylocomium* association during the late summer of 1951 and 1952. The moisture content of deeper layers was also reduced to small amounts by the latter part of these growing seasons. This depletion was particularly marked in Plot M4 (Table IX). On the other hand, deficiencies were of shorter duration in Plot M1 at Fourth Lake, where even litter layers contained available moisture at most samplings. Litter layers in the easterly plots remained below wilting percentage much of the growing season. Soil-moisture deficits were smaller in all plots during the wet summer of 1953 than they were during 1951 and 1952.

Soil-moisture deficits in the subassociation *nudum* plots of the *Pseudotsuga-Tsuga-Hylocomium* association were smaller than in the *typicum* plots. Low values were nevertheless recorded in surface layers by the end of the unusually

TABLE IX

MONTHLY VALUES OF AVAILABLE SOIL MOISTURE IN PLOTS REPRESENTATIVE OF FOREST ASSOCIATIONS IN THE NANAIMO RIVER VALLEY, BRITISH COLUMBIA, 1951 TO 1953

DEPTH (cm.)	AVAILABLE SOIL MOISTURE (per cent)*																	
	1951						1952						1953					
	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	
PSEUDOTSUGA-GAULTHERIA-PELTIGERA ASSOCIATION																		
WOLF MOUNTAIN (Plot L5)																		
A ₀	0	0	0	—	—	90	—	—	—	—	—	—	—	—	—	—	—	—
0-10	+	+	+	13	—	12	—	—	—	—	—	—	—	—	—	—	—	—
10-20	1	1	+	17	—	13	—	—	—	—	—	—	—	—	—	—	—	—
20-30	+	1	+	12	—	9	—	—	—	—	—	—	—	—	—	—	—	—
30-40	2	+	1	10	—	8	—	—	—	—	—	—	—	—	—	—	—	—
40-50	3	+	1	9	—	8	—	—	—	—	—	—	—	—	—	—	—	—
50-60	1	+	+	11	—	9	—	—	—	—	—	—	—	—	—	—	—	—
60-70	2	1	1	9	—	9	—	—	—	—	—	—	—	—	—	—	—	—
70-80	2	5	2	8	—	9	—	—	—	—	—	—	—	—	—	—	—	—
80-90	1	—	—	—	—	10	—	—	—	—	—	—	—	—	—	—	—	—
90-100	2	—	—	—	—	11	—	—	—	—	—	—	—	—	—	—	—	—
LOWER DEADWOOD CREEK (Plot L4)																		
A ₀	0	—	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
0-10	3	—	+	18	—	9	—	—	—	—	—	—	—	—	—	—	—	—
10-20	1	—	1	15	—	13	—	—	—	—	—	—	—	—	—	—	—	—
20-30	1	—	2	15	—	12	—	—	—	—	—	—	—	—	—	—	—	—
30-40	2	—	+	15	—	13	—	—	—	—	—	—	—	—	—	—	—	—
40-50	2	—	1	17	—	3	—	—	—	—	—	—	—	—	—	—	—	—
50-60	3	—	1	13	—	4	—	—	—	—	—	—	—	—	—	—	—	—
60-70	3	—	1	14	—	6	—	—	—	—	—	—	—	—	—	—	—	—
70-80	—	—	+	15	—	6	—	—	—	—	—	—	—	—	—	—	—	—
80-90	—	—	1	13	—	5	—	—	—	—	—	—	—	—	—	—	—	—
90-100	—	—	—	14	—	7	—	—	—	—	—	—	—	—	—	—	—	—

[illegible]

TABLE IX—Continued

DEPTH (cm.)	AVAILABLE SOIL MOISTURE (per cent)*																							
	1951								1952								1953							
	Jul. Aug. Sep. Oct. Nov. Dec.	Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.	Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.	Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.	Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.	Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.	Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.	Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.																
PSEUDOTSUGA-GAULTHERIA ASSOCIATION																								
WOLF MOUNTAIN (Plot G5)																								
A _o	0	0	0	—	—	165	—	—	—	—	—	—	—	—	—	—	—							
0-10	3	6	4	21	—	17	—	—	—	—	—	—	—	—	—	—	—							
10-20	3	3	2	15	—	14	—	—	—	—	—	—	—	—	—	—	—							
20-30	4	2	1	13	—	10	—	—	—	—	—	—	—	—	—	—	—							
30-40	4	2	1	11	—	9	—	—	—	—	—	—	—	—	—	—	—							
40-50	5	3	1	10	—	9	—	—	—	—	—	—	—	—	—	—	—							
50-60	4	3	1	9	—	6	—	—	—	—	—	—	—	—	—	—	—							
60-70	3	3	3	7	—	5	—	—	—	—	—	—	—	—	—	—	—							
70-80	4	3	2	9	—	5	—	—	—	—	—	—	—	—	—	—	—							
80-90	4	2	1	5	—	—	—	—	—	—	—	—	—	—	—	—	—							
90-100	5	2	2	6	—	—	—	—	—	—	—	—	—	—	—	—	—							
LOWER DEADWOOD CREEK (Plot G4)																								
A _o	0	0	0	125	—	200	—	—	—	150	50	0	0	35	ground fire	—	—							
0-10	2	1	1	18	—	14	—	—	—	18	19	1	2	4	—	—	—							
10-20	2	2	1	15	—	15	—	—	—	14	9	3	+	+	—	—	—							
20-30	2	3	+	14	—	14	—	—	—	10	7	2	+	+	—	—	—							
30-40	3	1	1	15	—	14	—	—	—	10	8	3	+	+	—	—	—							
40-50	2	+	+	13	—	16	—	—	—	9	8	2	1	+	—	—	—							
50-60	1	1	+	11	—	21†	—	—	—	11	12	3	1	+	—	—	—							
60-70	2	0	3	12	—	18†	—	—	—	16†	14	2	1	+	—	—	—							
70-80	1	2	0	19†	—	21†	—	—	—	13†	8	1	1	+	—	—	—							
80-90	—	2	3	6	—	15†	—	—	—	—	23	1	—	+	—	—	—							
90-100	—	1	—	9	—	—	—	—	—	—	—	2	—	—	—	—	—							
UPPER DEADWOOD CREEK (Plot G6)																								
A _o	+	—	0	—	—	400	—	—	—	210	190	55	0	0	ground fire	—	—							
0-10	3	—	1	23	—	24†	17	—	—	15	15	8	2	+	7	7	19							

10-20	4	—	3	17	—	20†	17	—	—	—	18	12	5	3	+	6	6	16	22†	18†	16	16	15	16	13	15	21†	17†
20-30	5	—	3	19	—	18†	17	—	—	—	11	12	5	3	+	—	—	—	—	—	—	—	—	—	—	—	—	—
30-40	7	—	2	17	—	19†	17	—	—	—	11	9	6	2	1	5	5	15†	21†	17†	12	13	13	11	11	10	13	14†
40-50	9	—	3	11	—	19†	16	—	—	—	11	10	7	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—
50-60	7	—	1	11	—	13	15†	—	—	—	11	12	7	2	2	3	4	11	13†	11	10	11	10	10	10	12†	11	—
60-70	5	—	2	15	—	19†	15†	—	—	—	12	13	5	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—
70-80	6	—	2	17†	—	—	16†	—	—	—	11	9	6	1	+	—	—	—	—	—	—	—	—	—	—	—	—	—
80-90	—	—	2	20†	—	—	15	—	—	—	12	—	8	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
90-100	—	—	2	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

VALLEY (Plot G3)

A _o	0	—	25	210	—	180	—	—	—	155	145	100	—	50	—	—	—	—	—	—	—	—	—	—	—	—
0-10	+	—	13	22	—	29†	—	—	—	18	18	11	3	4	8	12	34†	30†	24†	19	21†	20	17	13	8	9
10-20	3	—	+	21	—	25†	—	—	—	15	17	7	3	4	2	6	53†	45†	33†	25	26†	25	21	13	1	27†
20-30	5	—	1	21	—	17†	—	—	—	14	16	7	3	7	—	—	—	—	—	—	—	—	—	—	1	33†
30-40	4	—	2	22	—	17†	—	—	—	7	10	8	2	6	3	12	25†	24†	19†	16	19†	17†	16	11	2	22†
40-50	7	—	4	18	—	18†	—	—	—	8	13	7	1	7	3	24†	22†	24†	24†	20	23†	21	13	16	2	22†
50-60	6	—	8	10	—	13†	—	—	—	—	—	—	2	10	—	—	—	—	—	—	—	—	—	—	—	25†
60-70	—	—	5	—	—	—	—	—	—	—	—	—	4	7	—	—	—	—	—	—	—	—	—	—	—	—
70-80	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—
80-90	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—
90-100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

PSEUDOTSUGA-TSUGA-GAULTHERIA ASSOCIATION

FOURTH LAKE (Plot G1)

A _o	25	—	—	—	—	—	—	—	—	260	180	135	0	25	—	—	—	—	—	—	—	—	—	—	—	—
0-10	4	—	40	16	—	245	—	—	—	25†	8	19	4	13	6	29†	24†	24†	20	23	23	24†	18	8	6	17
10-20	6	—	22	50†	—	31	—	—	—	20†	42†	20	7	17	9	32†	30†	31†	22	25	21	25	20	14	11	30†
20-30	12	—	5	31†	—	25	—	—	—	23†	16†	28	3	22	—	—	—	—	—	—	—	—	—	—	18	5
30-40	11	—	4	71†	—	22	—	—	—	38†	—	29†	3	14	9	8	15†	13†	11	11	11	12†	12†	10	10	12†
40-50	14	—	5	—	—	18	—	—	—	44†	—	37†	4	15	—	—	—	—	—	—	—	—	—	—	10	1
50-60	20†	—	6	—	—	19	—	—	—	—	—	—	4	19	8	11	17†	13†	12	12	13†	13†	12	10	15†	11
60-70	18†	—	4	—	—	20†	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	10	13†
70-80	29†	—	—	—	—	25†	—	—	—	—	—	—	6	—	9	20†	17†	17†	15	16†	16†	16†	16†	13	13	17†
80-90	29†	—	—	—	—	36†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18†
90-100	—	—	—	—	—	39†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE IX—Continued

DEPTH (cm.)	AVAILABLE SOIL MOISTURE (per cent)*																							
	1951								1952								1953							
	Jul	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.							
PSEUDOTSUGA-TSUGA-GAULTHERIA ASSOCIATION--Concluded																								
ECHO MOUNTAIN (Plot G2)																								
A _o	1	-	70	240	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
0-10	2	-	4	9	-	350	-	-	-	-	-	-	-	-	-	-	-	-						
10-20	5	-	3	15	-	20†	-	-	-	-	-	-	-	-	-	-	-	-						
20-30	6	-	3	14	-	17	-	-	-	-	-	-	-	-	-	-	-	-						
30-40	7	-	1	15	-	15	-	-	-	-	-	-	-	-	-	-	-	-						
40-50	7	-	2	13	-	18†	-	-	-	-	-	-	-	-	-	-	-	-						
50-60	8	-	2	14	-	21†	-	-	-	-	-	-	-	-	-	-	-	-						
60-70	7	-	4	14†	-	24†	-	-	-	-	-	-	-	-	-	-	-	-						
70-80	8	-	5	11†	-	—	-	-	-	-	-	-	-	-	-	-	-	-						
80-90	8	-	6	13†	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
90-100	—	-	7	20†	-	-	-	-	-	-	-	-	-	-	-	-	-	-						
PSEUDOTSUGA-TSUGA-HYLOCOMIUM ASSOCIATION																								
SUBASSOCIATION TYPICUM																								
LOWER DEADWOOD CREEK (Plot M4)																								
A _o	+	0	0	-	-	250	-	-	-	-	-	-	-	-	-	-	-	-						
0-10	2	3	+	16	-	28†	-	-	-	-	-	-	-	-	-	-	-	-						
10-20	4	3	3	15	-	12	-	-	-	-	-	-	-	-	-	-	-	-						
20-30	5	2	3	15	-	10	-	-	-	-	-	-	-	-	-	-	-	-						
30-40	3	3	2	15	-	11	-	-	-	-	-	-	-	-	-	-	-	-						
40-50	4	3	3	14	-	7	-	-	-	-	-	-	-	-	-	-	-	-						
50-60	5	3	3	12	-	9	-	-	-	-	-	-	-	-	-	-	-	-						
60-70	4	3	2	7	-	8	-	-	-	-	-	-	-	-	-	-	-	-						
70-80	3	4	3	7	-	8	-	-	-	-	-	-	-	-	-	-	-	-						
80-90	1	4	2	7	-	6†	-	-	-	-	-	-	-	-	-	-	-	-						
90-100	6	1	1	10	-	5†	-	-	-	-	-	-	-	-	-	-	-	-						

VALLEY (Plot M3)																					
A _o		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0-10	130	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10-20	19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
20-30	20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30-40	19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
40-50	21	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
50-60	11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
60-70	11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
70-80	12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
80-90	13†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
90-100	13†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
FOURTH LAKE (Plot M1)																					
A _o		37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
0-10	185	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10-20	27	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
20-30	25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30-40	25†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
40-50	21	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
50-60	26†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
60-70	22†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
70-80	21†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
80-90	20†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
90-100	≡	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
SUBASSOCIATION NUDUM																					
A _o		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
0-10	65	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10-20	17	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
20-30	16	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30-40	19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
40-50	18	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
50-60	19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
60-70	23	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
70-80	16	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
80-90	7†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
90-100	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
120	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE IX—Continued

DEPTH (cm.)	AVAILABLE SOIL MOISTURE (per cent) *																	
	1951						1952						1953					
	Jul. Aug. Sep. Oct. Nov. Dec.	Jan. Feb. Mar. Apr. May Jun.	Jul. Aug. Sep. Oct. Nov. Dec.	Jan. Feb. Mar. Apr. May Jun.	Jul. Aug. Sep. Oct. Nov.	1953												
PSEUDOTSUGA-TSUGA-HYLOCOMIUM ASSOCIATION—Concluded																		
SUBASSOCIATION NUDUM																		
ECHO MOUNTAIN (Plot M2)																		
A _o	35	—	0	270	—	270	—	—	—	—	—	—	—	—	—	—	—	
0-10	9	—	4	12	—	20†	16	—	—	2	12†	7	9†	9†	7	8	7	
10-20	9	—	3	14	—	20†	14	—	—	2	3	9	12†	11	9	10	9	
20-30	7	—	3	13	—	20†	15	—	—	2	2	9†	10†	9†	8	8	7	
30-40	9	—	4	12	—	20†	14	—	—	2	2	9	10†	9†	8	8	7	
40-50	9	—	3	14	—	19†	15	—	—	5	6	10†	10†	10†	9	9	8	
50-60	6	—	3	15	—	16†	15	—	—	5	6	10†	10†	10†	9	9	8	
60-70	9	—	5	15	—	16†	16	—	—	13	9	7	7	15	7	7	6	
70-80	8	—	5	16	—	15†	15	—	—	14	11	7	10	19	17	17	16	
80-90	10	—	2	14†	—	16†	16†	—	—	15†	13	6	11	17	17	18†	16	
90-100	9	—	3	10	—	20†	19†	—	—	17†	15	6	11	17	17†	16	16	
										6	14	19†	19†	20†	17†	18†	14	
										12	—	—	—	—	—	—	18†	
										21†	—	—	—	—	—	—	20†	
PSEUDOTSUGA-POLYSTICHUM ASSOCIATION																		
UPPER DEADWOOD CREEK (Plot P4)																		
A _o	50	—	0	92	—	120	—	—	—	ground	—	—	—	—	—	—	—	
0-10	32	—	9	44	—	65†	44	—	—	fire	—	—	—	—	—	—	—	
10-20	12	—	12	10	—	65†	50	—	—	0	35†	—	38†	33†	23	28	29	
20-30	7	—	6	24	—	51†	52†	—	—	0	+	16	23	29	27	37	30	
30-40	15	—	5	12	—	46†	37	—	—	4	3	16	37†	36	33	35	29	
40-50	32	—	8	50	—	21	51†	—	—	3	—	—	36	36	36	35	29	
50-60	—	—	14	36	—	27†	21	—	—	+	+	8	12†	15†	11	12†	11	
60-70	33	—	9	30	—	44†	16	—	—	3	—	—	11	10	11	10	6	
70-80	24	—	8	37	—	51†	17	—	—	3	—	—	26†	26†	26†	22	19	
80-90	18	—	12	36	—	—	19†	—	—	3	4	—	24	27†	25	26†	19	
90-100	21	—	9	35	—	—	21†	—	—	3	4	—	19†	23†	17	22†	13	
120	—	—	—	—	—	—	—	—	—	28	4	4	10	19†	22†	16	5	

[illegible]

TABLE IX--Concluded

DEPTH (cm.)	AVAILABLE SOIL MOISTURE (per cent) *																	
	1951				1952				1953									
	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	
PSEUDOTSUGA-POLYSTICHUM ASSOCIATION—Concluded																		
VALLEY (Plot P3)																		
A.	36	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
0-10	11	—	5	22	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10-20	30	—	4	13	—	—	—	—	—	—	—	—	—	—	—	—	—	—
20-30	27	—	5	19	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30-40	17	—	3	17	—	—	—	—	—	—	—	—	—	—	—	—	—	—
40-50	13	—	2	19	—	—	—	—	—	—	—	—	—	—	—	—	—	—
50-60	11	—	4	20	—	—	—	—	—	—	—	—	—	—	—	—	—	—
60-70	21	—	1	13	—	—	—	—	—	—	—	—	—	—	—	—	—	—
70-80	20	—	2	12	—	—	—	—	—	—	—	—	—	—	—	—	—	—
80-90	12	—	3	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—
90-100	6	—	2	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
125	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1951																		
1952																		
THUJA-LYSICHITUM ASSOCIATION																		
WOLF MOUNTAIN (Plot Ly3)																		
A (SWAMP)																		
0-10	670†	150†	490†	565†	—	680†	—	—	—	—	540†	640†	550†	640†	205†	156†	32†	
10-20	—	330†	510†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
20-30	—	590†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
B (BANK)																		
Litter	10	0	—	190	—	—	—	—	—	—	140	—	—	—	0	—	—	
2-10	270	291†	0	110	—	210†	—	—	—	—	200†	175†	0	110	160†	—	—	
10-20	405†	42†	250†	370†	—	520†	—	—	—	—	345†	410†	460†	375†	220†	—	—	
20-30	—	—	220†	380†	—	32†	—	—	—	—	355†	41†	254†	485†	245†	—	—	
30-40	—	—	32†	110†	—	—	—	—	—	—	78†	30	58†	190†	620†	—	—	
40-50	—	—	—	—	—	—	—	—	—	—	—	—	—	14	290†	—	—	
50-60	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9†	—	—	

UPPER DEADWOOD CREEK (Plot Ly2)														
A (SWAMP)														
0-10	640†	—	620†	700†	—	—	—	—	—	810†	—	—	—	500†
10-20	—	—	500†	—	—	—	—	—	—	—	—	—	—	370†
A (SWAMP MARGIN)														
Litter	—	—	330	485†	—	—	—	—	—	450†	—	—	—	150
2-10	360†	—	157	530†	—	—	—	—	—	540†	—	—	35	380†
10-20	250†	—	175	352†	—	—	—	—	—	400†	—	—	305†	140†
20-30	195†	—	84	116†	—	—	—	—	—	370†	—	—	180†	69†
30-40	—	—	61†	60†	—	—	—	—	—	78†	—	—	87†	60†
40-50	—	—	—	69†	—	—	—	—	—	20†	—	—	60†	—
50-60	—	—	—	68†	—	—	—	—	—	—	—	—	—	—
60-70	—	—	—	70†	—	—	—	—	—	—	—	—	—	—
70-80	—	—	—	88†	—	—	—	—	—	—	—	—	—	—
B (BANK)														
Litter	0	—	0	150	—	—	—	—	—	220	—	—	0	0
2-10	60	—	150	155	—	—	—	—	—	70	160	—	45	5
10-20	85	—	350†	110	—	—	—	—	—	90	150	20	45	65
20-30	81	—	490†	330†	—	—	—	—	—	210†	200	145	45	—
30-40	—	—	—	520†	—	—	—	—	—	120†	295†	160†	155†	—
40-50	—	—	—	—	—	—	—	—	—	—	375†	150†	183†	—
											—	—	—	290†
ECHO MOUNTAIN (Plot Ly1)														
A (SWAMP)														
0-10	—	—	305†	245†	—	—	—	—	—	110†	—	—	217†	181†
10-20	—	—	710†	—	—	—	—	—	—	—	—	—	—	—
20-30	—	—	430†	—	—	—	—	—	—	—	—	—	—	—
B (BANK)														
Litter	—	—	—	—	—	—	—	—	—	—	—	—	3	90
2-10	22	—	30	140	—	—	—	—	—	300	180	200	5	250†
10-20	200†	—	40	130	—	—	—	—	—	80	170	216†	165	246†
20-30	315†	—	120	290†	—	—	—	—	—	270†	281†	184†	492†	33†
30-40	—	—	370†	90†	—	—	—	—	—	—	143†	—	490†	26†
40-50	—	—	41†	—	—	—	—	—	—	—	—	—	415†	36†

* Percentage, by weight, of the 5-mm. soil fraction. Samples taken from July, 1951, through September, 1952, were determined gravimetrically; those taken in October and December, 1951, were sampled during the last ten days of the month, while the remainder were sampled within the first ten days. Determinations from October, 1952, through November, 1953, were made electrometrically on the first day of each month.

† Gravimational water present (greater than field capacity).
 — Bedrock.
 — Ortstein.
 ----- Water table.

0 Less than wilting percentage.

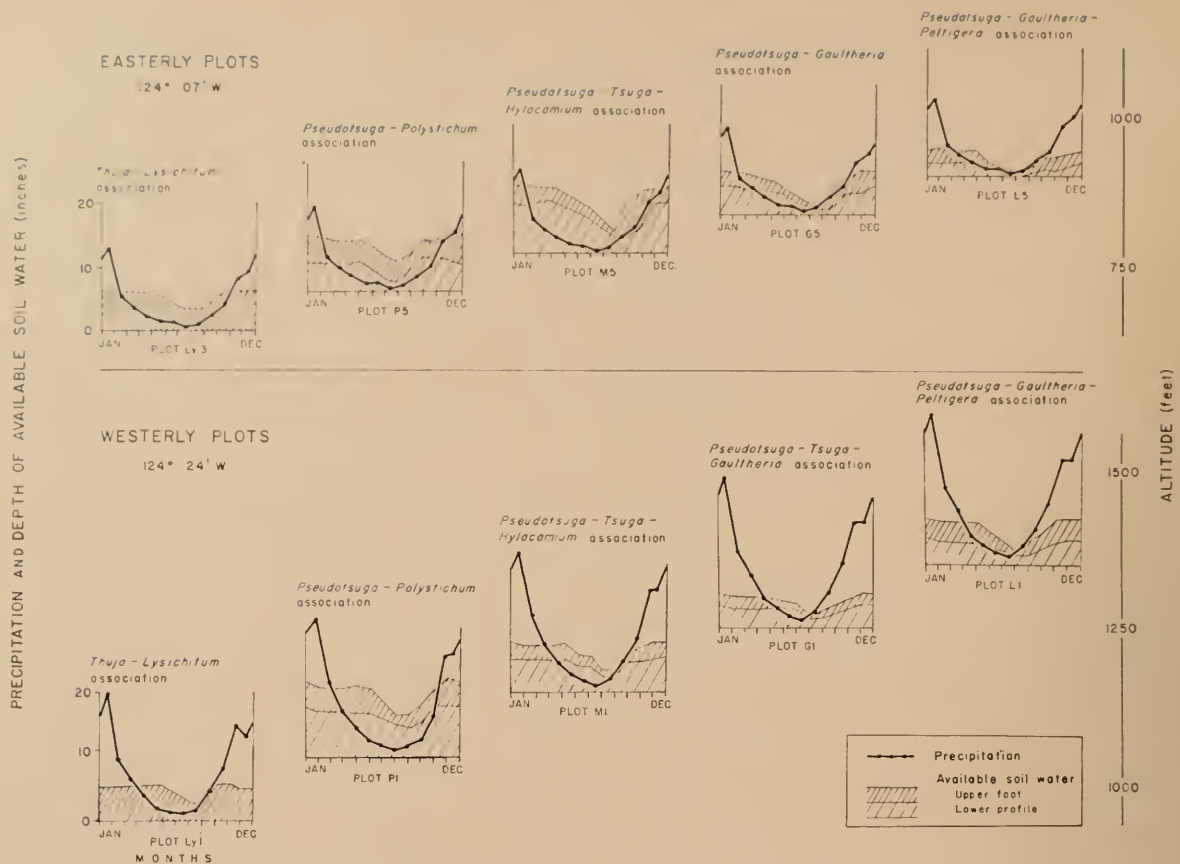


FIGURE 14—Average monthly precipitation and average depth of available soil water in plots representative of forest associations in the Nanaimo River Valley, British Columbia, 1951-1953. The moisture storage capacities of profiles may be judged by comparing the depths of available water present when soils are close to field capacity during winter months

prolonged summer drought of 1952. In the Echo Mountain Plot, gravitational water was present above the clay-loam layer during spring and autumn, although none occurred during the summer. Similarly, when this plot was sampled in early January, 1952, two weeks after heavy snowfalls had restricted further infiltration, no gravitational water was found above the clay-loam layer. Accumulations of water did occur in an open observation pit on Plot M5 after the prolonged autumnal rains of 1951, but normally the soil of this plot was well drained to a depth of 1 m. or more.

Pseudotsuga-Polystichum association

Considerable depths of available moisture were present in most of the *Pseudotsuga-Polystichum* plots at all seasons and low moisture percentages were infrequent (Table IX). Seepage promoted such moist conditions in several plots.

In the Echo Mountain Plot (P2), a high water table was sustained by moisture seeping into the concave portion of the slope on which the plot was located. During spring and early summer, this seepage originated from the melting snow on a slope which reached nearly 3,000 ft. above sea level. The water table in an observation pit showed only moderate fluctuations in level. During much of the year, this level remained within 40 cm. of the soil surface, although in the late summer of 1952 it dropped to 50 cm. and during the winter it sometimes rose to within 20 cm. of the ground line. While such levels represented conditions in a moist part of the stand, since the observation pit was near

the margin of a slight depression, soil-moisture samples taken from other locations showed that values remained high in the available range throughout the growing season. Even litter layers were above wilting percentage at most samplings.

Fluctuations in the height of the water table in the observation pit on the Wolf Mountain Plot (P5) were greater than in the Echo Mountain Plot. The dry summer climate of the easterly portion of the valley in which Plot P5 was located and the short duration of the snow pack on the adjacent 1,600-ft. slope may account for this difference. During the latter part of the summer the water level in the observation pit was commonly 100 cm. below the soil surface. Although available moisture in upper soil horizons was not exhausted at such times, percentages were usually lower than in the Echo Mountain Plot. At other seasons the water table remained about 40 cm. below ground line. During a prolonged rainy spell in December, 1952, the level in the pit rose to within 10 cm. of the soil surface.

Except in late summer and early autumn, some water was present in an observation pit in the Fourth Lake Plot (P1) the year round. Normally this seepage moisture flowed over the compact soil layer toward the base of the profile, some 80 cm. beneath the surface. In late spring and early summer, water from melted snow usually raised the water level and during prolonged wet spells, such as that of December, 1952, water even overflowed from the pit, despite this plot being on a 20° slope. Moisture values in mineral soil layers remained well within the available range throughout the growing season.

Ground water was encountered within the upper 100 cm. of the profile in the Deadwood Creek Plot (P4) only once, in early December, 1951, following the heavy rainfall of November. On this occasion, water flowed into the sampling pit 60 cm. below the soil surface. When the same pit was resampled in early January, about two weeks after snowfall prevented further infiltration, no water was encountered within 100 cm. of the soil surface. The high soil-moisture unit readings of early February, April, and May, 1953, however, indicate that seepage moisture may have been present in the lower profile on these occasions as well. The absence of high values later in the season shows that no further supplements to soil-moisture reserves occurred within the upper 100 cm. Nevertheless, since this stand was adjacent to the Deadwood Creek *Thuja-Lysichitum* Plot, it is possible that seepage moisture, which came to the surface in the latter stand, also affected deeper layers than those sampled in the *Pseudotsuga-Polystichum* Plot. The upper profile, however, appeared little affected by seepage moisture at any time of the year. Although moisture values were high in the available range at most samplings, reserves were reduced to quite low levels during the prolonged drought of 1952, and some deficits occurred in the latter part of each season.

During the early months of each growing season, soil-moisture contents were found to be high in the available range in the deep, stone-free profile of the Valley Plot (P3). In dry years, nevertheless, marked deficits were evident later in the season. Values above field capacity were recorded at 125 cm. during October and November, 1953, and each winter, temporary sloughs were present in hollows adjacent to the plot. However, the location of this stand on an old river terrace precluded additions to soil-moisture reserves by ground water during the growing season. This plot was less influenced by seepage moisture than any of the other *Pseudotsuga-Polystichum* stands sampled and it had the driest soil-moisture regime.

Thuja-Lysichitum association

Water remained close to the surface of the swampy areas in the *Thuja-Lysichitum* plots at all times. This water table was perched above the gley layer beneath the muck. Late in summer water levels dropped 10 or 15 cm., but the muck layer remained close to saturation at all times (Table IX).

Litter layers on the marginal hummocks of the Deadwood Creek and Wolf Mountain *Thuja-Lysichitum* Plots (Ly2 and Ly3) dried out by the latter part of each summer. Farther west in the Echo Mountain Plot, however, even this layer contained available moisture throughout the growing season. The upper portion of the peaty layers beneath the litter layer showed some moisture deficits during summer months, but values did not drop below wilting percentage. Lower layers remained moist even by late summer and they were saturated during winter months.

DISCUSSION

Water Relations and the Differentiation of Associations

The considerable differences in moisture regime between plots representing different associations indicate the importance of water relations in site differentiation. Thus, the small size and low volume per acre of *Pseudotsuga menziesii* in the *Pseudotsuga-Gaultheria-Peltigera* plots were correlated with a dearth of available soil moisture during much of the growing season. Moisture deficits were likewise sufficient to account for the low height and density of *Gaultheria shallon*. The high soil-surface temperatures and rapid evaporation rates which resulted from this openness in tree and shrub canopies doubtless accentuated the droughtiness of superficial soil horizons. Such droughtiness could well be a limiting factor in the survival of ground cover species characteristic of more humid locations. The greater height and volume of *Pseudotsuga menziesii* and increased density of *Gaultheria shallon* in the *Pseudotsuga-Gaultheria* plots were associated with a somewhat less droughty soil-moisture regime. However, this greater density of the tree and shrub layers appeared to limit the abundance of the lichens and mosses characteristic of the ground cover and lower boles of trees in *Pseudotsuga-Gaultheria-Peltigera* stands. The large volume per acre of *Pseudotsuga menziesii* in the *Pseudotsuga-Polystichum* plots was correlated with soils having relatively small moisture deficits during the growing season. On the other hand, infrequency of *Pseudotsuga menziesii* in the *Thuja-Lysichitum* plots was coincident with the occurrence of a very high water table at all seasons. Such swampy areas supported an herbaceous flora characteristically restricted to wet locations with a cool, humid atmosphere.

While differences in the floristic composition and productivity of the sites studied were found to be correlated with different soil-moisture regimes, significant differences in soil-nutrient regimes were also evident. The duff-mull character of litter layers, the limited development of A₂ horizons, and the moderate acidity of soil pH values in the *Pseudotsuga-Polystichum* plots indicate that soil-fertility levels were relatively high. On the other hand, the mor-type humus, clear differentiation of A₂ horizons, and acid soil pH values in the *Pseudotsuga-Gaultheria* plots, for example, suggest that their soils were relatively infertile. The lower site index for *Pseudotsuga menziesii* of *Pseudotsuga-Gaultheria* sites seems consequently to result from soil-fertility levels lower than those of *Pseudotsuga-Polystichum* sites, as well as less favorable soil-moisture regimes. The seepage moisture which augments soil-moisture supplies in *Pseudotsuga-Polystichum* sites may also ameliorate the leaching action of the regional climate evident in *Pseudotsuga-Gaultheria* sites (20).

Likewise, the composition of subordinate plant layers seemed to be influenced by soil-fertility levels. The absence of *Gaultheria shallon*, for example, from the mineral soil of the *Pseudotsuga-Polystichum* plots indicates that other factors than adequate moisture supply limited its distribution. Its presence on decaying wood, but scarcity in stand openings and on clear-cut *Pseudotsuga-Polystichum* sites suggest that intolerance to the shade conditions prevailing in the dense, two-storied stands characteristic of these sites is not the main obstacle to the spread of this species to *Pseudotsuga-Polystichum* sites. Evidently such species as *Gaultheria shallon*, *Hylocomium splendens*, and *Eurhynchium oreganum* are sufficiently obligate oxylophytes that their distribution is restricted to less fertile soils than those characteristic of *Pseudotsuga-Polystichum* sites. Such plants as *Polystichum munitum*, *Achlys triphylla*, *Tiarella trifoliata*, and *Mnium insigne*, on the other hand, being confined to moist, relatively fertile soils, characterize the *Pseudotsuga-Polystichum* association. However, their abundance also appears to be somewhat dependent on the humid, shady conditions of the forest floor of *Pseudotsuga-Polystichum* stands, since most of these species are less numerous in clear-cut areas than they are beneath standing timber (31).

As in the *Pseudotsuga-Polystichum* plots, the large size of the *Pseudotsuga menziesii* in the subassociation *nudum* plots of the *Pseudotsuga-Tsuga-Hylocomium* association was correlated with relatively favorable soil-moisture conditions. The lack of well-defined A₂ horizons and the low frequency of *Gaultheria shallon*, *Hylocomium splendens*, and other oxylophytes on the forest floor of these stands suggest that their soils were also quite fertile. However, the paucity of ground-cover plants characteristic of the *Pseudotsuga-Polystichum* association and the somewhat lower site index for *Pseudotsuga menziesii* of these plots seem to reflect the occurrence of both slightly larger soil-moisture deficits during the growing season and somewhat less favorable soil-fertility levels than those typical of *Pseudotsuga-Polystichum* sites.

Site index for *Pseudotsuga menziesii* in the subassociation *typicum* plots of the *Pseudotsuga-Tsuga-Hylocomium* association was no higher than it was in the *Pseudotsuga-Gaultheria* plots. In the easterly *typicum* plots, this poor growth would appear at least partially attributable to soil drought, since soil-moisture deficits were comparable with those of *Pseudotsuga-Gaultheria* sites. However, the absence of *Gaultheria shallon* would imply that other factors were different. Such differences might be related to soil fertility and the fairly dense tree canopy characteristic of *Pseudotsuga-Tsuga-Hylocomium* stands.

On the other hand, the low site index for *Pseudotsuga menziesii* in the Fourth Lake *Pseudotsuga-Tsuga-Hylocomium* Plot (M1) was probably more closely related to poor soil fertility than soil drought, since soil-moisture deficits in this plot were less pronounced than those of the more easterly Deadwood Creek Plot (M4). Despite its relatively droughty soil-moisture regime, the Deadwood Creek Plot had a higher site index for *Pseudotsuga menziesii* than the Fourth Lake Plot. The deeper A₂ horizon and lower pH values of the westerly plot (M1) indicate that its soils were more strongly leached than those of the easterly plot (M4). Apparently the more favorable soil-moisture regimes of the Fourth Lake Plot did not offset a less favorable soil-fertility regime.

The similarity of site index for *Pseudotsuga menziesii* in Plots M1 and M4 of the *Pseudotsuga-Tsuga-Hylocomium* association, despite dissimilarities in soil-moisture regime, illustrates the compensatory roles played by soil-nutrient and soil moisture regimes under different climatic conditions. The more favorable soil-moisture regimes of the westerly plots were evidently counterbalanced by more highly leached soils than those of similar vegetation types farther east.

The improved soil-moisture regimes of the westerly plots probably resulted from both rainfall being higher and the snow pack lasting longer than farther east. Although summer rainfall at Fourth Lake was light, it was, nonetheless, nearly double that at Deadwood Creek to the east. Presumably evaporation rates and transpiration usage were also influenced by the greater prevalence of cloudy conditions in the westerly portion of the valley. The long duration of the snow pack on the upper slopes of this mountainous area was probably even more influential than summer rainfall, because melting snow supplied seepage moisture well into the growing season, long after such additions to soil-moisture supply had ceased in the more easterly plots.

Soil-moisture deficits in the *Pseudotsuga-Tsuga-Gaultheria* Plots at Fourth Lake and on Echo Mountain were somewhat greater than those of the Fourth Lake *Pseudotsuga-Tsuga-Hylocomium* Plot, and their soils appeared to be even more strongly leached. On Echo Mountain (Plot G2), such conditions resulted in the lowest site index for *Pseudotsuga menziesii* of any plot. The better growth of *Pseudotsuga menziesii* in the Fourth Lake *Pseudotsuga-Tsuga-Gaultheria* Plot (G1) may have been the result of subsurface soils in this plot being more influenced by seepage moisture than those of the Echo Mountain Plot (G2). Such seepage presumably brought about the somewhat more favorable soil-moisture regime and it may also have ameliorated to some extent the leaching influence of the wet climate of this portion of the study area. Soil-surface temperatures and evaporation rates within subordinate plant layers show that conditions in the *Pseudotsuga-Tsuga-Gaultheria* plots were normally cooler and moister than in the more easterly *Pseudotsuga-Gaultheria* plots. The presence of *Chamaecyparis nootkatensis*, *Gaultheria ovatifolia*, *Rhytidiopsis robusta*, and other species common in relatively high altitude stands, was doubtless related to this difference.

As in the *Pseudotsuga-Tsuga-Gaultheria* and *Pseudotsuga-Tsuga-Hylocomium* plots at Fourth Lake, it is likely that the low site index for *Pseudotsuga menziesii* in Plot L1 of the *Pseudotsuga-Gaultheria-Peltigera* association resulted as much from the highly leached character of its soils as it did from drought, since moisture deficits were neither so extreme nor prolonged as they were in the easterly plots of this association. However, temperatures and evaporation rates in this open-canopied stand were relatively high, and lichens and drought-tolerant mosses had a frequency of occurrence characteristic of the association. Occasional severe or prolonged droughts might also play a part in reducing the abundance of mesophytes. Most of the shrubby *Tsuga heterophylla*, which occurred as thickets in this plot, had died by 1959, following the very dry summers of 1952 and 1958. Greater mortality among *Tsuga heterophylla* regeneration than in that of *Pseudotsuga menziesii* has been observed in other stands on similar sites following the very dry summer of 1958 (12). The relatively deep root system of *Pseudotsuga menziesii* may increase its drought resistance under such conditions.

Some of the *Tsuga heterophylla* on the Fourth Lake *Pseudotsuga-Polystichum* Plot were in the same age class as the *Pseudotsuga menziesii* of the dominant canopy, even though many were younger, since *Tsuga heterophylla* is quite shade-tolerant. *Pseudotsuga menziesii*, nevertheless, overtopped by 25 ft. or more the 175 ft. reached by the tallest *Tsuga heterophylla*. While the height of all tree species in strongly leached soils was less than in the relatively fertile soil characteristic of *Pseudotsuga-Polystichum* sites, the impairment of *Tsuga heterophylla* in the strongly-leached and periodically moisture-deficient soils of the Echo Mountain *Pseudotsuga-Tsuga-Gaultheria* Plot seemed comparably less than that of *Pseudotsuga menziesii*. In this latter plot, *Pseudotsuga menziesii* averaged only 7 ft. taller than the 70 ft. averaged by *Tsuga heterophylla* of the same age class. On the more fertile and moister *Pseudotsuga-Polystichum* site at

Fourth Lake the difference was 25 ft. in favor of *Pseudotsuga menziesii*, as previously noted. In more strongly leached soils, such as those of the adjacent *Pseudotsuga-Tsuga-Hylocomium* Plot (M1), *Pseudotsuga menziesii* still remained less clearly dominant than it was in more fertile soils, even though soil-moisture deficits were small.

The relative productivity of *Pseudotsuga menziesii* and *Tsuga heterophylla* in the easterly plots of the study area was not directly comparable because all the *Tsuga heterophylla* were in a younger age class than the *Pseudotsuga menziesii* of the dominant canopy. The ground fires which swept many stands subsequent to their initial establishment might have destroyed any older *Tsuga heterophylla* formerly present. The abundance of this species might also have been limited by unfavorable conditions for the survival of *Tsuga heterophylla* seedlings during the initial period of stand establishment (14). Data from stands analyzed by Schmidt (41) in various parts of Vancouver Island, nevertheless, suggest that the volume produced by *Pseudotsuga menziesii* on high-quality sites, such as those supporting stands of the *Pseudotsuga-Polystichum* association, is greater than that of *Tsuga heterophylla*. In the study area, *Pseudotsuga menziesii* productivity on dry sites seems to have been greater than that of *Tsuga heterophylla*. However, since the *Tsuga heterophylla* in the easterly plots were few in number and limited to the secondary canopy, the productivity of this species relative to that of *Pseudotsuga menziesii* on dry sites can only be surmised. It might be anticipated, nevertheless, that growth rates for *Pseudotsuga menziesii* would be better than those of *Tsuga heterophylla* of the same age class because the latter species is shallow-rooted. Presumably shallow-rooted trees growing on dry sites would have access to a smaller volume of available soil moisture than deep-rooted species.

Growth rates for *Thuja plicata*, another shallow-rooted species, likewise seemed impaired by a droughty soil-moisture regime. This species, moreover, seems to be more adversely affected by highly-leached soils than *Tsuga heterophylla*. The greatest productivity of *Thuja plicata* in the Douglas-fir region is reported to be in the quite fertile and occasionally flooded soils of *Pseudotsuga-Thuja-Adiantum* sites (20). The continuously high water table of *Thuja-Lysichitum* sites appears to be somewhat less than optimum even for *Thuja plicata*.

Water Relations and Forest Distribution

Since water relations evidently exert a considerable influence in the differentiation of the associations studied, factors which regulate water relations would seem of importance in forest distribution. In a region where the climate is characterized by potential moisture deficiencies during the growing season, topography and the depth and texture of the soil profile seem to be the most influential regulators of soil-moisture regimes. The catenary distribution of forest associations occurring in the Douglas-fir region on Vancouver Island is evidently a consequence of these factors. Thus, ridges support stands of the *Pseudotsuga-Gaultheria-Peltigera* association partly because ground water does not supplement soil-moisture reserves in such topographic positions and partly because moisture reserves are commonly limited by shallow soil depth and coarse texture. Where greater soil depth results in a slightly larger soil-moisture storage capacity, *Pseudotsuga-Gaultheria* sites occur, even though soil texture may be equally coarse. Furthermore, on slopes, seepage-moisture flow, even if of short duration, may contribute to the improvement in water relations which allows the development of *Pseudotsuga-Gaultheria* stands. Lower slopes evidently support *Pseudotsuga-Polystichum* stands because seepage moisture from upper slopes, supplementing moisture reserves, results in favorable soil-moisture

regimes. Such supplements are especially effective when relatively fine soil texture promotes the influence of seepage moisture even in the superficial layers of soil profiles. On the other hand, it seems likely that *Pseudotsuga-Tsuga-Hylocomium* sites occur at mid-slope because seepage moisture there is insufficiently sustained to maintain such favorable soil-moisture or fertility levels. In locations where seepage water is so abundant that it comes to the surface, swampy *Thuja-Lysichitum* sites are formed, as long as this water remains moving and does not become stagnant. Such sites are essentially independent of rainfall for the recharge of their moisture reserves.

The influence of soil texture on stand distribution is well illustrated by the occurrence of either *typicum* or *nudum* stands of the *Pseudotsuga-Tsuga-Hylocomium* association at mid-slope according to soil-parent material. Where soils are derived from coarse-textured materials, seepage has relatively little influence on the upper soil profile and *typicum* sites occur. Such sites have quite strongly leached and droughty upper-soil horizons, despite the occurrence of seepage moisture in the lower profile. On the other hand, finer-textured soils normally support *nudum* stands, apparently because moisture reserves are then greater and seepage has more influence, both through supplementing soil-moisture supplies and ameliorating the leaching influence of the climate.

Even greater site differences can occur when the secondary relief of hillsides diverts the flow of seepage moisture. The Echo Mountain *Pseudotsuga-Tsuga-Hylocomium* Plot (M2), for example, was located on a concave portion of the main slope, which was influenced by seepage moisture at least into early summer. On the other hand, the coarse-textured soil of the adjacent *Pseudotsuga-Tsuga-Gaultheria* Plot (G2), which was on a convex shoulder of the same slope less than one-half mile away and only 100 ft. higher in elevation, was much less influenced by seepage. The soils of this latter plot consequently were drier in summer and more strongly leached than those of Plot M2. The difference of 110 ft. in site index for *Pseudotsuga menziesii* would seem largely a consequence of this diversion of seepage moisture.

Minor variations in relief and differences in soil-parent material and soil depth may also modify moisture regime and stand distribution on the relatively level terrain of valley floors. The *Pseudotsuga-Polystichum* Plot (P4) on the valley floor of Deadwood Creek, for example, was situated on fairly deep outwash material which remained moist during much of the growing season. On the other hand, the coarse-textured, glacial-till soil of a nearby moraine was droughty because it was uninfluenced by ground water during the growing season and moisture reserves were small. This slight ridge supported a stand of the *Pseudotsuga-Gaultheria* association (Plot G6). An adjacent *Pseudotsuga-Gaultheria-Peltigera* site (Plot L3) was still more droughty because there the ortstein layer was even closer to the surface. Conversely, even though Plot P3 of the *Pseudotsuga-Polystichum* association, which was situated on an old river terrace in the main valley of the Nanaimo River, was likewise uninfluenced by ground water during the growing season, its relatively deep, fine-textured profile had enough moisture-storage capacity to provide available moisture for a considerable proportion of the growing season. The recent alluvium which formed the parent material of this plot seemed to be fertile as well. However, lack of seepage moisture resulted in this plot having a drier soil-moisture regime than the other *Pseudotsuga-Polystichum* sites analyzed and this difference presumably accounts for the relatively high frequency of *Achyls triphylla*. As on the valley floor of Deadwood Creek, nearby glacial-till soils supported stands of the *Pseudotsuga-Gaultheria* or *Pseudotsuga-Gaultheria-Peltigera* associations.

While the ortstein layer present in many profiles merely restricts the depth of the root zone and limits soil-moisture storage capacity, such impervious

layers also play an important role in seepage-water movement. Without impervious bedrock, ortstein, clay, or gleyed layers, gravitational water could penetrate to considerable depths, as occurs, for example, in deep gravel soils or soils derived from shales having their cleavage planes normal to the soil surface; much drier sites than those characteristic of lower slopes in the study area might then occur. The gross distribution of associations is accordingly a catenary sequence of stands largely because seepage water remains within the root zone. There, such water can effectively influence water relations through its influence on soil-moisture regimes, a manifestly important factor in forest distribution because the climate of the Douglas-fir region is potentially moisture deficient during the growing season. Nevertheless, it is evident that secondary topography, soil-parent material, and soil depth can modify this catenary sequence because these factors also play an important role in the determination of soil-moisture and nutrient regimes.

SUMMARY

The climate, vegetation, microclimate, soil profiles, and soil-moisture regimes of 24 plots were analyzed to evaluate the influence of water relations on forest distribution in the Douglas-fir region on Vancouver Island, British Columbia. Plots were located in mature stands representative of six forest associations in the Nanaimo River Valley.

Species representation and the abundance and vigor of plants were found to be correlated with differences in soil-moisture regime and atmospheric humidity. The low site index for *Pseudotsuga menziesii* and stunted growth of *Gaultheria shallon* in *Pseudotsuga-Gaultheria-Peltigera* plots were associated with a reduction of soil-moisture content to the wilting range for extended periods during the growing season and with relatively arid atmospheric conditions. The somewhat higher site index for *Pseudotsuga menziesii* and taller *Gaultheria shallon* of *Pseudotsuga-Gaultheria* plots were correlated with less extreme soil-moisture deficiencies. In *Pseudotsuga-Polystichum* plots, soil-moisture contents remained high in the available range during much of the growing season. Such moist and relatively fertile sites had a high site index for *Pseudotsuga menziesii* and characteristic mesophytes were frequent in subordinate plant layers. *Thuja plicata*, rather than *Pseudotsuga menziesii*, was the most abundant tree in *Thuja-Lysichitum* plots and other characteristic species were typical of the non-stagnant, swampy parts of these stands. A consistently high water table and humid atmosphere were characteristics of such sites.

The low site index for *Pseudotsuga menziesii* in *Pseudotsuga-Tsuga-Gaultheria* plots seemed to result as much from the highly leached character of their soils as it did from lack of available water, since the soils of these plots were moister during much of the growing season than those of *Pseudotsuga-Gaultheria* sites. Similarly, the relatively moist, but quite highly leached, soil of a subassociation *typicum* plot of the *Pseudotsuga-Tsuga-Hylocomium* association had a lower site index for *Pseudotsuga menziesii* than plots with droughtier but less highly leached soils.

Since rainfall supplies little moisture during the growing season in this rainshadow region, two influential factors regulating soil-moisture regimes are the moisture-storage capacity of soil profiles and the extent of influence of seepage. The catenary distribution of stands typical of hillsides seems to reflect the sequence of soil-moisture regimes controlled by these factors. It was concluded that ridges are droughty partly because their topographic position precludes ground water from supplementing moisture stored in their profiles and partly because such reserves are usually limited by shallow soil depth and

coarse texture. Farther downslope, both seepage from upper slopes and deeper soils normally result in moister soils and a higher site index for *Pseudotsuga menziesii*. Variation in the extent of coverage by the different stands in the typical sequence of associations occurs, nevertheless, since differences in local topography and soil characteristics influence soil-moisture regimes.

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APPENDIX I

1951-56 MEANS COMPARED WITH LONG-TERM MEANS FOR PRECIPITATION AND TEMPERATURE AT VARIOUS WEATHER STATIONS ON VANCOUVER ISLAND

	PACHENA POINT		NITINAT CAMP		COWICHAN LAKE		DUNCAN	
	31 year mean	1951-56 mean	9 year mean	1951-56 mean	40 year mean	1951-56 mean	30 year mean	1951-56 mean
PRECIPITATION (inches)								
Annual mean.....	111	125	113	121	72	88	39	43
Summer ¹ mean.....	9.5	10.4	5.8	6.0	3.8	5.2	3.2	3.2
TEMPERATURE (°F.) ²								
Summer mean monthly maxima...	72	70	—	—	87 ³	85	91	93
Summer mean monthly ranges....	30	28	—	—	47	44	49	44
Winter ⁴ mean monthly minima....	25	24	—	—	17	18	17	20
Winter mean monthly ranges.....	27	26	—	—	31	30	37	33

¹Summer: June, July, and August.

²Mean temperatures for the years 1942-55 only.

³Mean temperatures for the years 1950-56 only.

⁴Winter: December, January, and February.

APPENDIX II

MONTHLY PRECIPITATION DURING 1951, 1952 AND 1953, AT STATIONS ADJACENT TO PLOTS SAMPLED FOR SOIL MOISTURE
IN THE NANAIMO RIVER VALLEY, BRITISH COLUMBIA, COMPARED WITH 1951-1956 AVERAGES

RECORDING STATIONS AND ADJACENT PLOTS	PRECIPITATION (inches)											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1951												
WOLF MOUNTAIN Plots L5, G5, M5, P5, Ly3.....	—	—	—	—	—	0.4	0.2	0.7	3.5	7.5	8.6	7.0
LOWER DEADWOOD CREEK Plots L3, L4, G4, M4.....	—	—	—	—	—	0.4	0.2	0.5	3.7	6.8	8.3	7.0
UPPER DEADWOOD CREEK Plots G6, P4, Ly2.....	—	—	—	—	—	0.4	0.2	0.9	3.8	6.8	8.1	6.7
VALLEY Plots L2, P3.....	—	—	—	—	—	0.4	0.2	0.2	4.8	9.3	13.0 ¹	6.7
Plots G3, M3.....	—	—	—	—	—	0.4	0.2	0.2	5.1	10.3	15.0 ¹	8.6
ECHO MOUNTAIN Plots M2, P2, Ly1.....	—	—	—	—	—	0.3	0.2	0.1	5.6	11.1	15.3 ¹	7.6
Plot G2.....	—	—	—	—	—	0.4	0.3	0.2	5.9	11.5	15.7 ¹	8.3
FOURTH LAKE Plots M1, P1.....	—	—	—	—	—	0.3	0.1	0.4	6.0	11.0	16.5 ¹	10.5
Plots L1, G1.....	—	—	—	—	—	0.4	0.2	0.4	6.9	11.8	17.7 ¹	10.6
1952												
WOLF MOUNTAIN Plots L5, G5, M5, P5, Ly3.....	10.2 ²	6.3 ²	2.7 ²	3.1 ²	1.0	1.0	0.3	0.9	0.4	0.9	4.2	13.3
LOWER DEADWOOD CREEK Plots L3, L4, G4, M4.....	10.2 ²	6.3 ²	2.7 ²	3.1 ²	0.9	0.9	0.3	0.9	0.4	0.9	4.4	13.0
UPPER DEADWOOD CREEK Plots G6, P4, Ly2.....	10.3 ²	6.3 ²	2.2 ²	2.6 ²	1.2	1.3	0.3	1.2	0.4	1.3	3.2	11.8
VALLEY Plots L2, P3.....	13.0 ^{1,2}	8.7 ^{1,2}	4.3 ²	5.1 ²	1.3	1.6	0.4	1.7	0.8	1.8	8.2	16.9
Plots G3, M3.....	13.8 ^{1,2}	9.0 ^{1,2}	5.5 ²	6.3 ²	1.3	1.8	0.4	1.8	1.1	2.1	8.3	20.5 ¹
ECHO MOUNTAIN Plots M2, P2, Ly1.....	14.2 ^{1,2}	11.0 ^{1,2}	5.5 ²	6.3 ²	1.8	2.3	0.3	1.8	1.2	2.4	9.0	18.5
Plot G2.....	16.1 ^{1,2}	12.6 ^{1,2}	6.3 ²	7.1 ²	1.5	2.4	0.4	1.9	1.5	2.7	—	—
FOURTH LAKE Plots M1, P1.....	18.1 ^{1,2}	13.4 ^{1,2}	6.7 ²	8.3 ²	1.8	3.1	0.4	2.7	1.7	3.3	9.0	23.6 ¹
Plots L1, G1.....	20.0 ^{1,2}	14.2 ^{1,2}	7.1 ²	8.7 ²	1.9	2.4	0.5	2.9	1.8	3.3	9.5	23.6 ¹

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