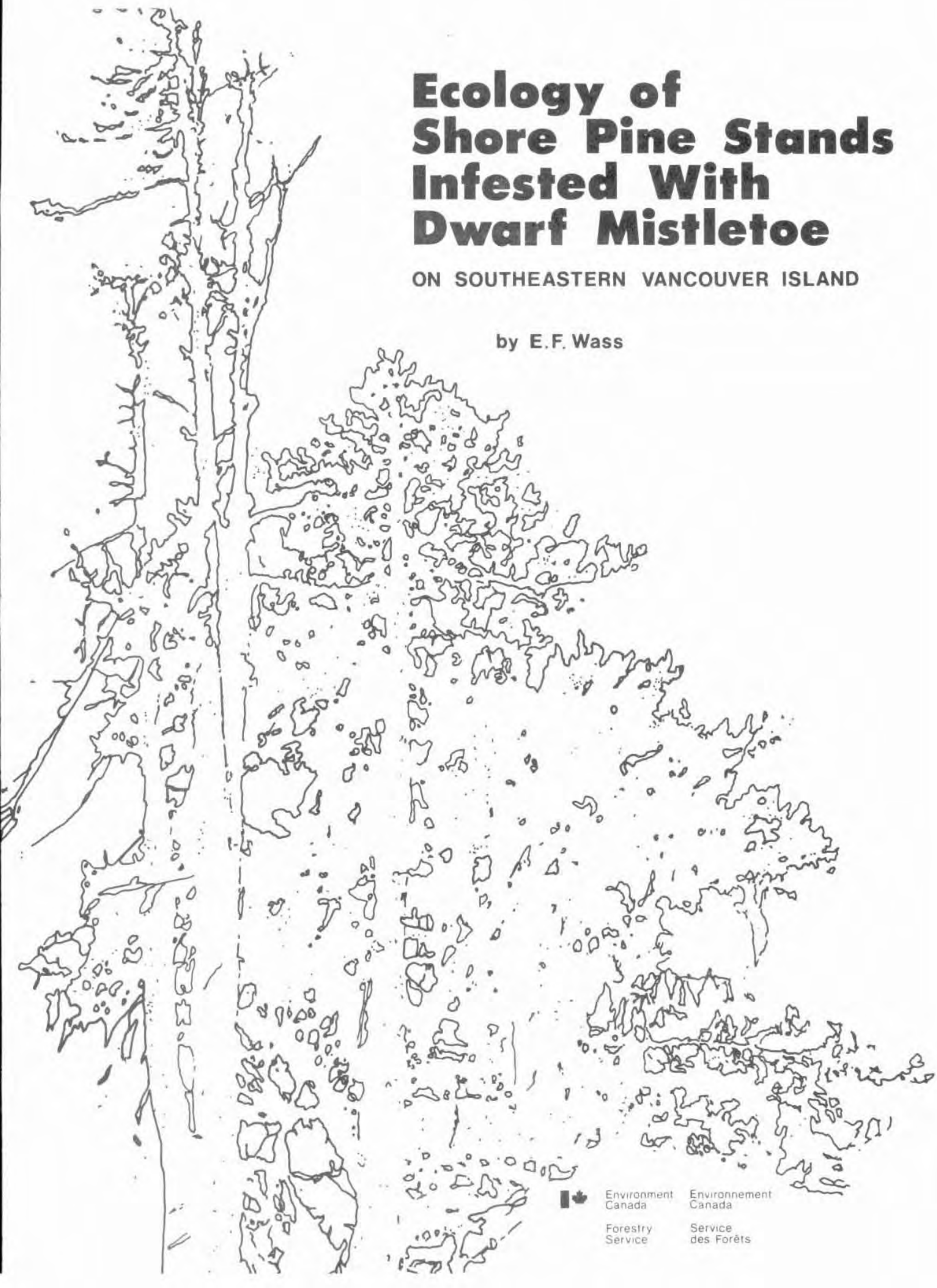

Ecology of Shore Pine Stands Infested With Dwarf Mistletoe

ON SOUTHEASTERN VANCOUVER ISLAND

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CONTENTS

ABSTRACT

The dwarf mistletoe occurring on shore pine (Pinus contorta var. contorta) in Coastal British Columbia is classified as Arceuthobium tsugense, a mistletoe that principally parasitizes western hemlock (Tsuga heterophylla). Shore pine is considered its secondary host.

A detailed study of infestations on S.E. Vancouver Island indicated that dwarf mistletoe intensity on the shore pine was extremely high. An average of 85% of trees over 1.4 m were infected and the average stand infection intensity ranged from 0.7 to 5.l on a 6-class system.

Most infection centers were located in the Coastal Douglas-fir Zone on mountain tops consisting of a mosaic of plant communities of forest on lithosols and rocky knolls. Vegetation was dominated by Pinus contorta var. contorta, Pseudotsuga menziesii, Arbutus menziesii, Salix scouleriana, Gaultheria shallon, Arctostaphylos columbiana, Holodiscus discolor and Arctostaphylos uva-ursi.

The study showed that A. tsugense on shore pine flourishes on habitats separated from A. tsugense on hemlock. Separation of the two would favor maintenance of the physiological differentiation indicated by earlier cross-inoculation experiments.

RÉSUMÉ

L'auteur identifie le Faux-gui habitant le Pin tordu (P. contorta var. contorta) le long de la côte de la Colombie-Britannique comme étant Arceuthobium tsugense, parasite principal de la Pruche occidentale (Tsuga heterophylla) mais secondaire du Pin tordu.

Selon des relevés détaillés dans le sud-est de l'île de Vancouver, ce Faux-gui se révèle extrêmement fréquent sur le Pin tordu. En moyenne, 85% des arbres mesurant plus de 1.4 m étaient infectés et l'intensité moyenne d'infection dans les peuplements variait de 0.7 à 5.1 selon le système de la classe 6.

La plupart des centres d'infection se situaient dans la zone des Douglas latifoliés côtiers au sommet des montagnes et consistant en une mosaique d'associations de plantes en forêt sur lithosols et sommets rocheux. La végétation était dominée par Pinus contorta var. contorta, Pseudotsuga menziesii, Arbutus menziesii, Salix scouleriana, Gaultheria shallon, Arctostaphylos columbiana, Holodiscus discolor et Arctostaphylos uva-ursi.

A. tsugense sur le Pin tordu se trouve dans des habitats différents de ceux de A. tsugense sur la Pruche. La séparation des deux favoriserait le maintien de la différentiation physiologique indiquée par des expériences anterieures d'inoculation croisée.

FIG. 1. Cross-hatched area indicates distribution of Arceuthobium tsugense on western hemlock. Numbers refer to areas where A. tsugense has been found on shore pine: 1. - Victoria-Sooke area; 2- Parksville-Horne Lake area; 3- Sprout Lake; 4- Courtenay; 5- Texada Island; 6- Sechelt; 7- Malcolm Island; 8- Terrace; 9- Port Clements; 10- Lund area; 11- Savory Island; 12- Maurelle Island 13- Cortes Island; 14- Orcas Island. Box indicates study area.

INTRODUCTION

Hemlock dwarf mistletoe, Arceuthobium tsugense, a parasite of considerable importance (2), ranges from near Haines, Alaska to central California and is found throughout the coastal hemlock forests of British Columbia (Fig. 1). The principal host in British Columbia is western hemlock (Tsuga heterophylla) but several other tree species are attacked when they grow in association with infected hemlock; namely, shore pine (Pinus contorta var. contorta), amabilis fir (Abies amabilis), alpine fir (Abies lasiocarpa), grand fir (Abies grandis), Engelmann spruce (Picea engelmannii), Sitka spruce (Picea sitchensis) and white pine (Pinus monticola) (2).

In their classification of Arceuthobium, Hawksworth and Wiens (18) premised that a species must remain morphologically distinct when occurring on any of its hosts. They recognized that the dwarf mistletoe on shore pine occurred in mixture with non-infected or very lightly infected western hemlock, but they did not have sufficient reason to classify this species other than as A. tsugense.

In the Parksville area (Fig. 1, No. 2), Kuijt (23) found several mixed stands where either western hemlock or shore pine were heavily infected, but infections were not found on the other host. Smith and Wass (40) quantitatively studied the disease intensity on both hosts, confirming Kuijt's earlier observations.

Smith (39) showed that inoculation of A. tsugense from shore pine on western hemlock produced only one definite swelling and no shoots (abortive type of infection). In contrast, 22.5% of seed of A. tsugense from western hemlock resulted in infections on western hemlock and all swellings produced aerial shoots. On other hosts, A. tsugense from shore pine generally produced more globose swellings than A. tsugense from western hemlock. Field inoculation experiments, presently underway (38), have produced the same results as the plantation inoculations.

Dwarf mistletoe on shore pine was first reported in 1906 by Rosendahl and Butters on Vancouver Island. It was reported by Kuijt (23) on the eastern side of Vancouver Island, as far north as Comox, and near Sechelt on the mainland and by Hawksworth and Wiens (18) on Orcas Island, Washington. A. tsugense occurs on shore pine in less than half of the latitudinal range of A. tsugense, being absent south of the San Juan Islands and in Alaska (15, 18).

Most of the infested stands occur in elevations of up to 500-m a.s.l. in the Coastal Douglas-fir Biogeoclimatic Zone (22). Infestations in the Coastal Douglas-fir Zone consist of extensive pine stands with no, or only lightly, infected western hemlock present. In contrast, within the Coastal Western Hemlock Zone (Fig. 1, Nos. 7, 8 and 9), stands consist mainly of western hemlock, western red cedar and stunted shore pine (Fig. 2). The western hemlock trees are heavily infected. The few shore pine infected have a very high infection intensity rating and are characterized by well-defined fusiform (spindle-shaped) swellings.

FIG. 2. Brooms and branch swellings caused by A. tsugense on shore pine at Malcolm Island.

On the southern tip of Vancouver Island, heavily infected stands of shore pine are found on rocky knolls and mountain tops even though the major host, western hemlock, is either not present or not infected. Is A. tsugense on shore pine an ecotype physiologically adapted to a localized habitat? To aid in answering this question, a survey was designed to determine the distribution of A. tsugense on shore pine and to define the ecological characteristics of the dwarf mistletoe infested stands and their habitats.

FIG. 5. Logging of Douglas-fir on rocky terrain near Sooke.

METHODS

Mountains, located on topographical maps and aerial photographs, were visited to observe whether infection of dwarf mistletoe occurred on shore pine. As infection foci were identified, the search radiated outward to new areas. Shore pine and western hemlock along the route to the mountain tops were checked for A. tsugense. Shore pine stands in bogs were also examined for the presence of A. tsugense. The boundaries of infestation centers were transferred to aerial photographs (1:15,840) and areas were calculated using a planimeter.

Once a shore pine stand was located, the following data were collected: location, elevation, age of stand, whether infected with dwarf mistletoe, and the extent of infestation. Eleven infestation centers and one non-infested area in shore pine, and one infested area in western hemlock were selected for more intensive study (locations 1-13, Appendix I). A representative 0.04 ha plot was established in each of these stands.

Soils were described from one or more pits, dug at each plot. Profile descriptions follow the Canadian Soil Classification System (6). Soil texture was obtained using the Bouyoucos hydrometer method (4). A field pH meter (Corning Glass Works, Model 7) was used to determine the pH of soil horizons using H_2O and $CaCl_2$ (27). Munsell color charts were used for soil color (29).

Species cover and abundance was an estimate using the scale of Braun-Blanquet (Appendix III) (5). Rocky knolls within the plot were examined as part of the plot, and by themselves as a separate sub-plot.

Air temperature was measured in standard Stevenson screens with two max-min thermometers in Plots 6 and 7. Max -min thermometers were also placed below the litter layer and on an open grassy slope between these plots. Records were taken once a week from July 23 to Nov. 5, 1973. Relative humidity was recorded in the two plots for a 12- hour period (6 a.m. to 6 p.m.) on July 31, 1973.

Each host tree taller than 1.4 m was rated for infection intensity by visually dividing the crown into thirds and scale rating each third (17). Trees less than 1.4 m were excluded because of the slight chance of infection of such a small target. The

TABLE 1 - Climatic data for stations in surveyed areas.

Station	Elevation a.s.l. (m)	Mean precipitation (mm) Mean annual	Driest month July	Wettest month Dec.	Mean temperature (°C) Mean annual	Warmest month July	Coolest month January	Frost free days	Water deficiency during vegetative period (cm) [a]	Mean snowfall year (cm)	Climatic zones (Koppen)
Victoria-Gonzales (1) [b]	70	658	13	114	10.1	15.7	4.1	282	26.9	32.8	Cool Mediterranean
William Head (2)	12	907	13	152	9.7	15.7	3.8	-	-	24.6	Cool Mediterranean
Becher Bay (3)	12	1006	15	168	9.6	15.6	3.7	189	21.3	24.4	Transitional
Shawnigan Lake (4)	122	1179	23	211	9.3	17.2	1.6	168	23.6	88.1	Transitional
Sooke Lake (5)	229	-	25	379	-	-	-	-	-	-	Transitional
Jack Lake (6)	405	-	18	-	-	14.9	-	-	-	-	Transitional
River Jordan (7)	3	1990	36	325	9.0	14.5	3.4	215	9.4	21.8	Maritime
Bear Creek (8)	351	3320	51	551	6.8	14.3	-0.5	-	-	238.0	Maritime

[a] 7.5 cm storage, Day et al. (8)

[b] Location of climatic stations (Fig. 11)

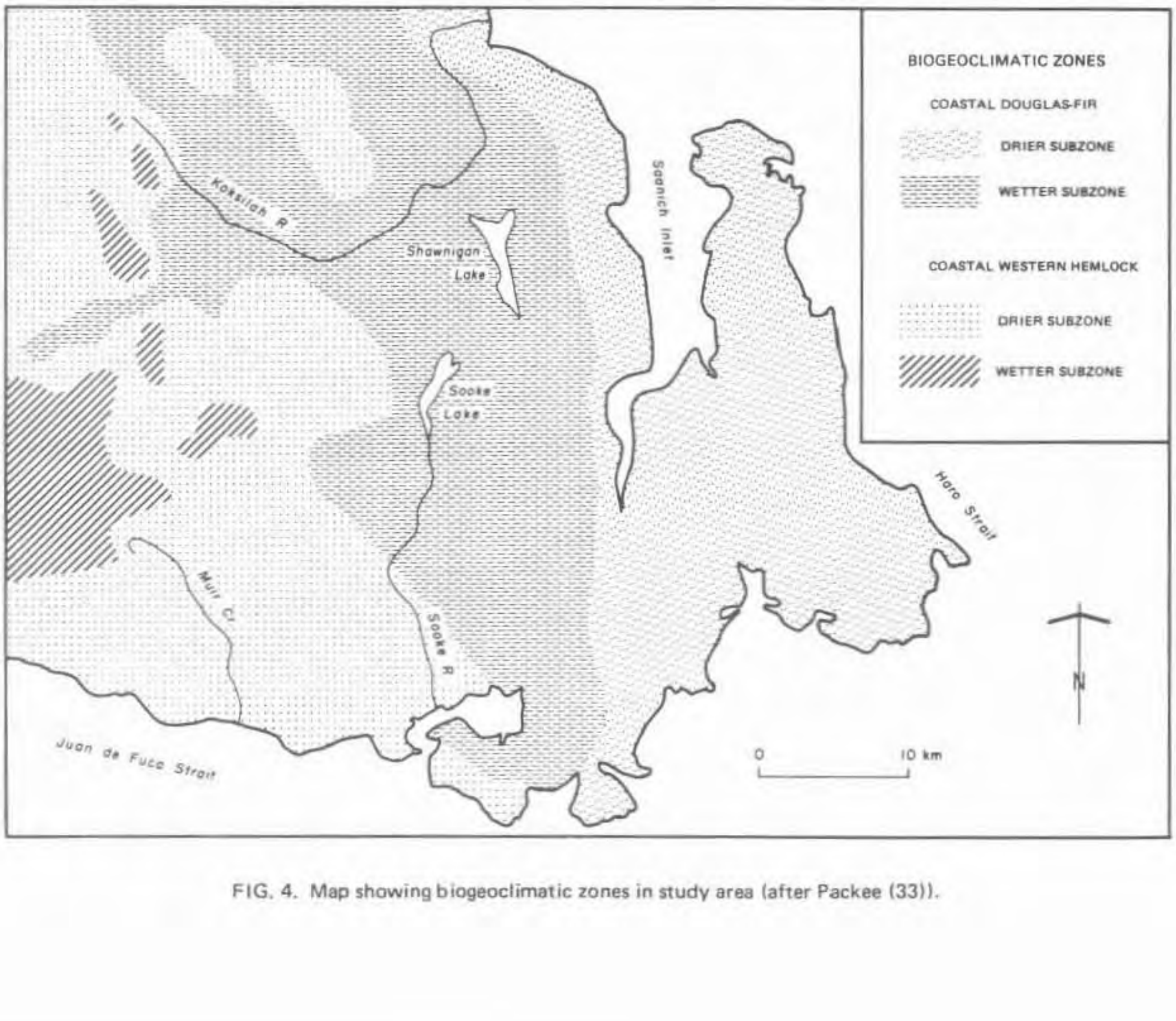

FIG. 4. Map showing biogeoclimatic zones in study area (after Packee (33)).

FIG. 5. Logging of Douglas-fir on rocky terrain near Sooke.

METHODS

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Each host tree taller than 1.4 m was rated for infection intensity by visually dividing the crown into thirds and scale rating each third (17). Trees less than 1.4 m were excluded because of the slight chance of infection of such a small target. The bare bole was included in the bottom third of the crown. Each third was rated as follows:

0 = No mistletoe signs or symptoms present
1 = 1%-50% of the crown third infected
2 = 51% or more of the crown third infected.

An infected bole was counted as one infected branch. Brooms were rated on the basis of the crown area, with a "2" rating given if more than 50% of the crown third was involved.

The rating for each third was summed and infection classes were determined for each tree, as follows:

Summation	Class
0	healthy
1-2	light
3-4	moderate
5-6	severe

FIG. 6. Xeric habit favorable for shore pine succession. Kirky Hill, Plot 13.

A stand infection index for each 0.04 ha plot was then calculated by summing individual tree ratings and dividing by the total number of host trees.

Stand Infection Index	Class
0	healthy
0.1 - 2.0	light
2.1 - 4.0	moderate
4.1 - 6.0	severe

Where residuals occurred in the plot, they were excluded from the stand infection index. The incidence of infection was based on the number of living, infected trees as a percentage of the total number of live trees over 1.4 m high.

A simple linear regression analysis using the least squares method was employed to test various relationships between average plot mistletoe rating, average age of stand and percent of trees infected. The regressions presented (Figs. 15, 16, 17) were the best among those tested.

RESULTS

Soils

Shore pine stands studied in detail were located in top or upper slope positions, with the exception that Plot 4 (Appendix I) occurred on a mid slope. The land type was mainly rock outcrop with a few plots on colluvial slopes. Slope ranged from 1 to 34% in the shore pine plots and 40% in the western hemlock plot. Hygrotope class ranged from mesic to very dry for the shore pine stands studied in detail (Appendix I). The western hemlock plot had a hygrotope class of wet.

A thin mantle of glacial till, colluvium or a mixture of both covered most plots (Table II). Aeolian deposits were found on Ragged Mtn. In the western hemlock plot on Glinz Ck., the parent material was colluvium over coarse alluvium.

Two soil great groups were encountered - Sombric Brunisols and Dystric Brunisols (Table II). Subgroups of the great groups found in the study were Orthic, Degraded and Lithic.

All the soils examined were medium to coarse textured, ranging from gravelly sandy clay loam to very gravelly loamy sand. The soils were strongly to very strongly acid, the acidity usually increasing with depth.

Soil profile 10b, classified as a Lithic Sombric Brunisol, lacked a Bm layer, the C horizon directly

TABLE II. Classification of soil profiles for each plot.

Plot no.	Profile no.	Soil classification	Dominant vegetation	Soil depth from mineral surface (cm)	Texture of parent material	Litter depth (cm)	F-H depth (cm)	pH parent material $CaCl_2$	Origin of landforms [3]
1		Degraded Dystric Brunisol	Pl -Salal [1]	85.0	gravelly sandy clay loam	1.0	1.0	4.7	GT/R
2		Orthic Dystric Brunisol	Pl -Arbutus -Salal	64.0	very gravelly sandy loam	1.5	7.0	4.8	C/GT/R
3	a	Lithic Sombric Brunisol	Pl -Rhytidiadelphus triquetrus	18.0	very gravelly sandy loam	1.0	1.0	5.0	C/GT/R
	b	Orthic Dystric Brunisol	Pl -Salal	70.0	gravelly sandy loam	3.0	3.5	5.2	C/GT/R
4	a	Lithic Sombric Brunisol	Pl -Eurhynchium oreganum	15.0	gravelly loam	2.0	2.0	4.6	C/R
	b	Orthic Dystric Brunisol	Pl -Salal	52.0	very gravelly loam-sandy loam	2.0	3.0	5.1	C/R
5	a	Degraded Dystric Brunisol	Pl -Rhytidiadelphus triquetrus	46.0+ [2]	gravelly clay loam	5.0	8.0	4.4	E/GT/R
	b	Orthic Dystric Brunisol	Pl -Salal	54.0	gravelly sandy loam	10.0		4.7	E/GT/R
6		Orthic Sombric Brunisol	W. hemlock-Polystichum munitum	103.0+	gravelly loamy sand	2.0	1.0	5.8	C/A
7	a	Lithic Dystric Brunisol	Pl -Eurhynchium oreganum	46.0	very gravelly sandy loam	2.0	2.0	5.0	C/R
	b	Orthic Dystric Brunisol	Pl -Salal	56.0	very gravelly loam to sandy loam	2.0	2.0	5.1	C/GT/R
8		Orthic Dystric Brunisol	Pl -Eurhynchium oreganum	69.0	very gravelly sandy loam-loamy sand	3.0	4.0	4.7	C/G/R
9		Orthic Sombric Brunisol	Pl -Salal	40.0+	very gravelly sandy loam	2.0	2.0	5.6	C/GT/R
10	a	Orthic Dystric Brunisol	Pl -Arbutus-Eurhynchium oreganum	85.0+	very gravelly loam	2.0	6.0	5.1	C/G/GT/R
	b	Lithic Sombric Brunisol	Elymus-Arctostaphylos uva-ursi	39.0	very gravelly sandy loam	1.0	2.0	5.2	C/GT/R
11		Lithic Dystric Brunisol	Pl -Salal	23.0	gravelly silt loam	3.0	4.0	5.3	C/GT/R
12		Orthic Dystric Brunisol	Pl -Salal-Vaccinium ovatum	89.0+	very gravelly silt loam	2.0	4.0	5.3	C/G/GT/R
13		Lithic Dystric Brunisol	Pl -Salal-Vaccinium ovatum	43.0	gravelly sandy loam	3.0	2.0	4.7	C/GT/R

1/ Pl = shore pine

2/ + = bedrock not reached

3/ C = colluvium
A = alluvium
G = glacial fluvial
GT = glacial till
R = bedrock
E = aeolian (windblown)

underlaying the Ah. Because of the lack of a Bm layer, this soil might be classified as a Lithic Regosol. It was developed under a grass cover. Representative soil profile descriptions are included in Appendix II. Including Lithic soils (bedrock within 50 cm), bedrock was located close to (within 1 m) the surface of 13 out of 18 of the profiles studied.

Vegetation

Shore pine on mountain tops occurred in a mosaic of forest communities on lithosols intermingled with rocky knolls. Two plots (Nos. 12 and 13) were in the Cladonia-Douglas-fir association of the Western Hemlock Biogeoclimatic Zone. The western hemlock plot (No. 6) was located in the Swordfern association and the remaining 10 plots were in the Salal-lichen association of the Coastal Douglas-fir Biogeoclimatic Zone (9).

Lithosols were characterized by a tree cover, heavy shrub layer and moderate herb-moss layer (Fig. 7). The lichen layer increased in abundance with decrease in density of stand and increase in exposure. In contrast, the rocky knolls were characterized by a lack of tree cover, a scant shrub layer and ground vegetation dominated by moss, grasses and lichens (Fig. 8).

Structure of the forest communities depended on the stand history which is dominated by fire. The tree stratum was three structured. The upper layer, overmature Douglas-fir (over 200 years old), occurred scattered throughout the area. Below this was a layer of mature shore pine and Douglas-fir, varying from an equal mixture to the complete absence of Douglas-fir. The immature tree layer was dominated by shore pine with Douglas-fir, Arbutus menziesii, and Salix scouleriana. The stands differed greatly in their stage of succession.

The shrub layer in the forest on lithosols ranged from 10-80% cover and was characterized by Gaultheria shallon, Arctostaphylos columbiana, Berberis nervosa, Arctostaphylos uva-ursi, Rosa

FIG. 7. Forest on lithosol with salal ground cover. Ragged Mtn. (Plot 5). >

FIG. 8. Rocky Knoll dominated by mosses and lichens, Bluff Mtn. (Plot 9). V

FIG. 9. Heavy growth of lichens on infected shore pine. Aerial shoots of A. tsugense (arrow).

gymnocarpa, Pachystima myrsinites and Holodiscus discolor (Appendix III). Salal growth was poor (30-60 cm tall) in all plots except 12 and 13, which were in the Western Hemlock Biogeoclimatic Zone. In these, salal was 90 to 120 cm high and Arctostaphylos columbiana was replaced by vigorous Vaccinium ovatum. Herbs included Goodyera oblongifolia, Trientalis latifolia, Erythronium oreganum, Hieracium albiflorum, Dodecatheon hendersonii, Habenaria unalascensis, Listera cordata and Circaea alpina. Mosses in the forested area were abundant, but less diverse than on the knolls. Eurhynchium oreganum, Rhytidiadelphus triquetris and Dicranum howellii were most common. A lichen characterizing these shore pine stands was Peltigera aphthosa. Shore pine were heavily covered with lichens (Appendix IV) (Fig. 9), predominantly Alectoria sarmentosa.

Rocky knolls, which occupied from 2 to 70% of the plots, were characterized in the shrub layer by Gaultheria shallon, Holodiscus discolor and Arctostaphylos uva-ursi (Appendix II). The herb layer included an abundance of grasses, mainly Elymus glaucus, Festuca rubra and Aira praecox, with Achillea millifolium, Cryptogramma crispa and Selaginella wallacei. Mosses included Rhacomitrium canescens, Dicranum fuscescens, Polytrichum juniperinum and Rhacomitrium lanuginosum. In comparison to the forest on lithosols, there was a greater variety and abundance of lichens; namely, Sterocaulon tomentosum, Cladonia furcata, Cladonia bellidiflora, Parmelia saxatilis, Parmelia sulcata and Umbilicaria hirsuta.

The western hemlock infected plot was represented in the tree layer by Tsuga heterophylla, Thuja plicata and Taxus brevifolia. Gaultheria shallon, Rubus spectabilis and Vaccinium parvifolium were the most prevalent shrubs. Herbs included Polystichum munitum, Pteridium aquilinum, Tiarella trifoliata, Achlys triphylla, Lactuca biennis and Mitella pentandra. Moss layer was represented by Rhizomnium glabrescens.

Shore pine was examined in lowland bogs developed on deep material deposited during the retreat of glaciers. They were in the Pinus-Gaultheria-Ledum association (34, 35) dominated, in the understory, by Ledum groenlandicum, Gaultheria shallon, Sphagnum capillaceum, Vaccinium oxycoccus and Empetrum nigrum.

Temperature and Relative Humidity

Maximum temperature averaged 2.2°C higher in the shore pine stand than in the western hemlock stand. The average minimum was 1°C higher in the shore pine stand. Maximum litter temperatures averaged 6°C higher in the shore pine stand than in the hemlock stand. Maximum temperatures averaged 17°C higher for litter on open rocky slopes than on forested slopes. The average minimum temperature was 0.6°C higher.

Absolute maximum and minimum temperatures reached at Glinz Ck. and Hill 22, between July 23 and October 26, are shown in Table III.

TABLE III. Temperature data from shore pine forest, western hemlock forest and open slope sites.

	Glinz Ck. western hemlock	Hill 22 shore pine	Hill 22 open slope
	°C		
Stevenson screen			
maximum	27	30	-
minimum	1	4	-
Below litter			
maximum	24	40	54+
minimum	4	4	6

Figure 10 shows air temperature and relative humidity in relation to time during a 12- hour period on July 31, 1973. Maximum temperature was reached at 1600 hr for both sites, with a difference of 2°C. Relative humidity was 96% for both sites in the morning. The minimum relative humidity was reached at 1500 hr in the shore pine stand, an hour earlier and 10% lower than in the western hemlock stand.

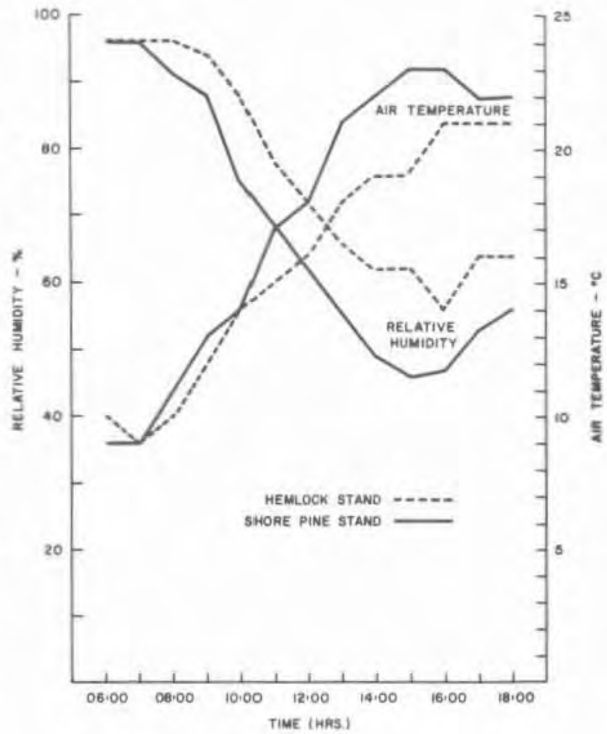

FIG. 10. Relative humidity and temperature for western hemlock and shore pine sites on July 31, 1973.

TABLE IV - Distance between infested shore pine stand and nearest infested western hemlock stand.

W. hemlock infestation centers	Nearest shore pine infestation center	Horizontal distance difference (km)	Vertical elevation difference (m)
Glinz Ck. (No. 6) [a]	Hill 22 (No. 7)	0.3	91
Bamberton Provincial Park (No. 26)	Jocelyn Hill (No. 24)	7.7	335
Iron Mine Hill (No. 27)	Mt. Matheson (No. 8)	7.6	213
West side of Sooke Lk. (No. 29)	Mt. Healy (No. 28)	2.3	536
Mile 6 Boneyard Lk. Rd. (No. 37)	½ mile N.W. of Boneyard Lk.	1.6	243
2 miles north of Sooke River Rd. and Boneyard Lake Rd. crossing (No. 38)	Hill 25 (No. 36)	0.8	213
Junction of Phillips Rd. and Sooke Rd. (No. 50)	Mt. Manual Quimper (No. 4)	5.5	512
3 miles north on Phillips Rd. (No. 51)	Mt. Manual Quimper (No. 4)	4.5	490

[a] Location numbers from Figure 11.

Dwarf Mistletoe Distribution

Main study area

Fifty-one localities were examined within the 789 km^2 study area (Appendix V and Fig. 11).

Twenty-seven infestation centers on shore pine were found in the study area, 24 on mountain tops, 1 on an island (Fig. 11, No. 19) in the center of Shawnigan Lake, 1 in a bog (Fig. 11, No. 47) and 1 on a rocky knoll on the edge of Matheson Lake (Fig. 11, No. 45). Eight infestation centers on western hemlock were located, all in valley bottoms (Fig. 11). Seven stands of shore pine on mountain tops, 3 in bogs and 1 on a gravelly outwash plain (Fig. 11, No. 33) were examined and found to be non-infected. Area of infested stands ranged from a small area (few individual shore pine) to 165 ha (Appendix V).

Infested shore pine stands located on mountain tops ranged from 722 m a.s.l. (Mt. Healy) to a low of 274 m a.s.l. at Mt. Matheson. The three infested areas not found on a mountain top had elevations of 116 m (Memory Island), 351 m (Charter's bog) and 24 m (Matheson Lake). Western hemlock stands that were infested ranged from 24 m a.s.l. at Sooke Rd. and Phillips Rd. Junction to 244 m a.s.l. at Glinz Ck.

Of all these areas examined not once did A. tsugense on western hemlock grow in association with or close to infected shore pine. Except for two collections (Memory Island and Matheson Lake) there was no elevational overlap between the two host/species combinations. The distance and elevation differences between the two host/species combinations are shown in Table IV.

Five bogs were examined for A. tsugense on shore pine (Appendix V). They ranged in elevation from 30 m to 488 m and tree ages ranged from 55 to 127 years. Dwarf mistletoe was found in only one bog, on two trees only. These were heavily infected and stunted (Fig. 12). The age of shore pine averaged 81 and 127 years for infected and non-infected trees, respectively. All four western hemlock trees present (153 years old) were found to be non-infected. All trees had fire scars and burned bark.

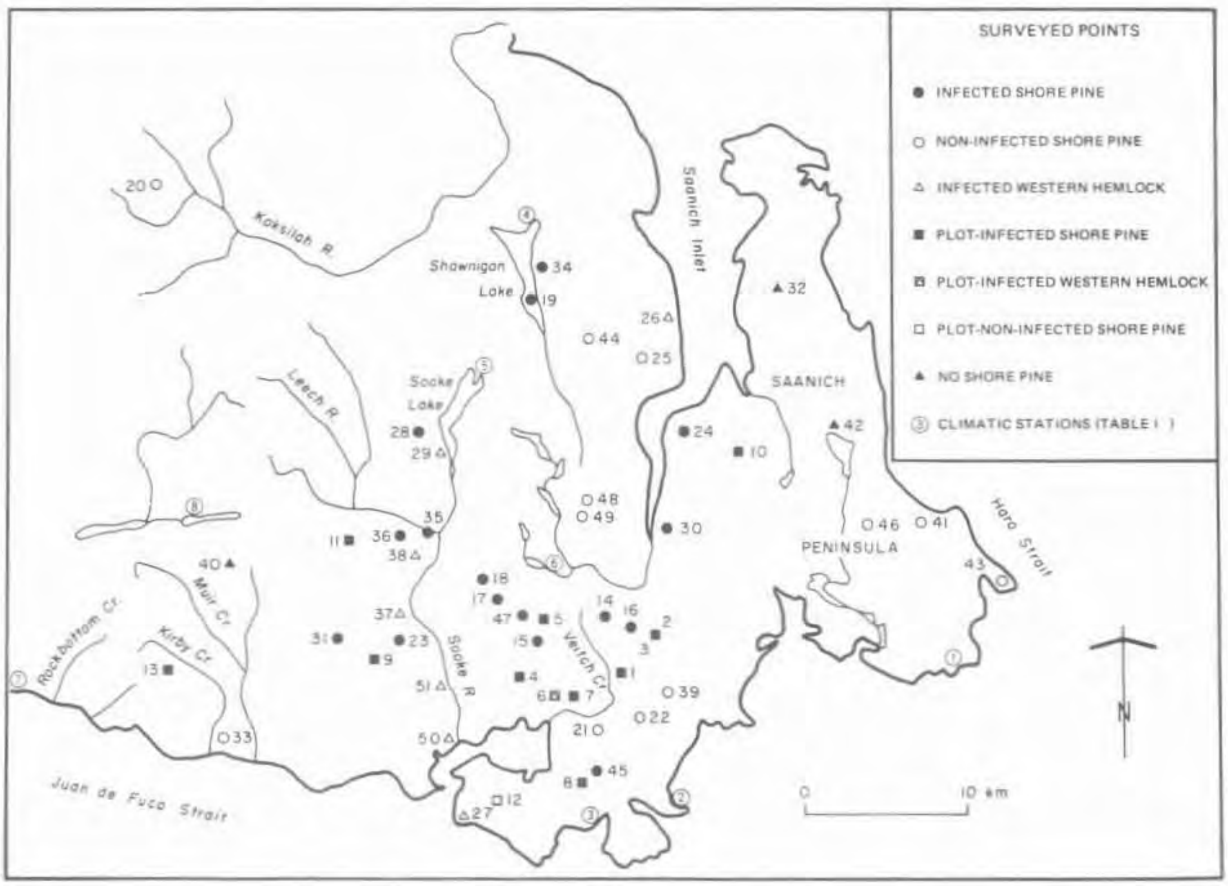

FIG. 11. Survey points checked for dwarf mistletoe. Locations, elevations and size of infested area for individual survey points are given in Appendix V.

FIG. 12. Infected shore pine (arrow) in Charter's bog.

FIG. 13. Stunted infected shore pine on summit of Mt. Constitution, Orcas Island.

Orcas Island

The only recorded parasitism of shore pine by A. tsugense in the U.S.A. occurs on Mt. Constitution, Orcas Island. Mt. Constitution consists of Triassic-Jurassic sandstones and siltstones (26) and has been altered by glaciation, both by contouring and deposition of glacial drift.

Because of the rain shadow effect of the Olympic mountains, the summers are dry and relatively cool, the winters wet and mild; the frost-free period is long. Mean annual precipitation is 46 cm. The coolest month has a mean min temperature of 0°C (January) and the warmest month (July) a mean max temperature of 22.5°C. Elevation has a primary effect on the local climate (11).

Franklin and Dyrness (11) state that plant communities found on the east coast of Vancouver Island are similar and that the Coastal Douglas-fir Zone is related to the Puget Sound Area. Shore pine and western hemlock stands are located on Mt. Constitution, where the higher elevation results in a greater supply of moisture. The shore pine are found in the xeric sites on shallow gravelly soils of glacial and colluvial origin.

A. tsugense was found on the upper slopes of Mt. Constitution from 671 m to 734 m (the summit). The stand consisted of mainly shore pine, 70-80 years old, with scattered secondary growth Douglas-fir. Shore pine on the summit were stunted (3 m to 5 m tall) due to heavy mistletoe infestation, shallow soils and exposure to high winds (Fig. 13). The stand consisted of a mosaic community similar to the main study area, although knolls were less exposed. Vegetation was similar, except for a higher cover of Chimaphila umbellata.

FIG. 14. Infected western hemlock among heavily infected shore pine. Mt. Constitution, Orcas Island.

One young western hemlock was found in the infested shore pine stand. Although surrounded by heavily infected shore pine, it had only a single branch swelling (Fig. 14). A small patch of moderately infected, 68-year-old western hemlock was found bordering the pine stand in a hollow at mid-slope.

Other areas

Some mountains located north of the study area have similar vegetation communities. Mt. Benson (1019 m) and Mesachie Mtn. (396 m), containing shore pine to the summit, were examined. Kojima (21) found an Arbutus menziesii community similar to the study area, containing shore pine on the extremely dry sites in the Coastal Western Hemlock Zone, on the east side of Buttle Lake. Shore pine were checked in the above locations but were found to be non-infected.

Dwarf Mistletoe Infection Intensity

Thirteen stands were studied in detail, 11 of infested shore pine, 1 of infested western hemlock and 1 of healthy shore pine. The composition of shore pine in the plots ranged from 40% to 96% (Table V).

TABLE V. Stand composition and percent of trees infected (0.04 hectare plots).

Plot no.	Location	Shore pine	Douglas fir	Arbutus	WRC[a]	Western hemlock	Alder	Yew	Shore pine %	Shore pine infected %	Western hemlock %	Western hemlock infected %	Total trees
1	Mt. Helmcken	285	5	6	-	-	-	-	96.3	77.5	-	-	296
2	Mt. Wells	51	14	54	-	-	-	-	42.9	43.8	-	-	119
3	Mt. Wells	30	11	3	-	-	-	-	68.2	83.3	-	-	44
4	Mt. Manuel Quimper	26	15	-	-	-	-	-	63.4	96.2	-	-	41
5	Ragged Mtn.	55	30	-	-	-	-	-	64.7	100.0	-	-	85
6	Glinz Ck.	-	-	-	1	47	-	1	-	-	95.9	61.7	49
7	Hill 22	42	17	3	-	-	-	-	67.7	97.6	-	-	62
8	Mt. Matheson	42	62	1	-	-	-	-	40.0	100.0	-	-	105
9	Bluff Mtn.	59	13	-	-	-	-	-	81.9	100.0	-	-	72
10	Mt. Work	71	10	64	-	-	-	-	49.0	88.6	-	-	145
11	Mt. Jack	100	52	-	1	-	-	-	65.4	100.0	-	-	153
12	Mt. Maguire	352	34	-	1	7	1	-	89.1	0.0	-	-	395
13	Kirby Hill	130	3	1	5	-	-	-	93.5	49.2	-	-	139

a/ WRC = Western red cedar

TABLE VI. Infection intensity rating and age data for each plot.

Plot no.	Avg. infection rating by crown class				Avg. total rating	Infection class	Avg. age of immature stand	Avg. age of residuals
	D	Co	I	S				
1	2.7	2.5	2.7	1.3	2.1	Moderate	40.2	96.0
2	1.8	1.5	0.3	0.2	0.7	Light	23.0	98.3
3	3.4	5.1	3.3	0.0	4.0	Moderate	79.6	79.6
4	3.6	5.1	5.9	3.5	5.0	Severe	61.0	61.0
5	5.2	5.3	4.6	5.4	5.1	Severe	62.7	62.7
6	4.0*	3.0	1.4	1.1	1.3	Light	39.0	113.0
7	5.4	4.7	3.7	3.2	4.4	Severe	62.0	62.0
8	6.0*	3.5	3.6	4.5	3.6	Moderate	41.7	66 + rot
9	4.9	5.0	4.1	4.3	4.6	Severe	57.3	99.0
10	2.7	2.2	2.2	2.6	2.4	Moderate	27.8	68.0
11	4.8	4.6	4.7	5.0	4.7	Severe	78.5	78.5
12	-	-	-	-	0.0	Healthy	64.6	64.6
13	1.0	1.0	0.9	0.2	0.9	Light	41.0	41.0

*Contains residuals only; therefore, no dominant trees included in the avg. total rating.

Average age of stands ranged from 23 to 80 years (Table VI). The stands were even-aged (age range less than 5 years) though, in most cases, residuals were scattered throughout the immature stand.

The average age of stand correlated significantly with the percentage of trees infected ($P<0.001$), with 84% of the variation accounted for by the regression (Fig. 15). Based on the regression obtained, 69% of the stand would be infected at age 30, 86% at 50 years and 100% at age 76.

Since residual infected shore pine were present at the formation of new stands, the duration of infection is considered the same as the stand age. A significant correlation ($P< 0.001$) occurred between average age of stand and average plot mistletoe rating, with 79% of the variation accounted for by the regression (Fig. 16). Stands at 35 years would have an average rating of 2.2 and at 70 years, a rating of 4.8 (Fig. 16). The time for the plot mistletoe rating to increase by one class averaged 15 years.

There was a rapid increase in the percentage of trees infected with increasing average plot mistletoe rating - 46% of the trees were infected in plots having an average mistletoe rating of 1.0, and 100% infected for those with a rating of 5.5 (Fig. 17). Correlation between percentage of trees infected and average mistletoe rating was highly significant ($P<0.001$), with 95% of the variation accounted for by the regression.

The western hemlock infected stand had an average stand infection index of 1.3 with 61.7% of the trees infected.

Plots having a light stand infection index showed a trend of infection rating increasing with tree crown class (Table VI). Once stands reached a moderate or severe index, infection rating for suppressed and intermediate was as high as the dominant and co-dominant trees.

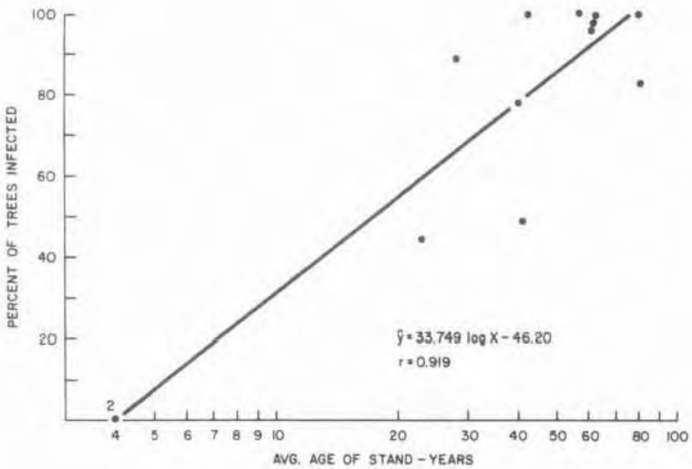

FIG. 15. Relationship between percent of trees infected and average age of stand.

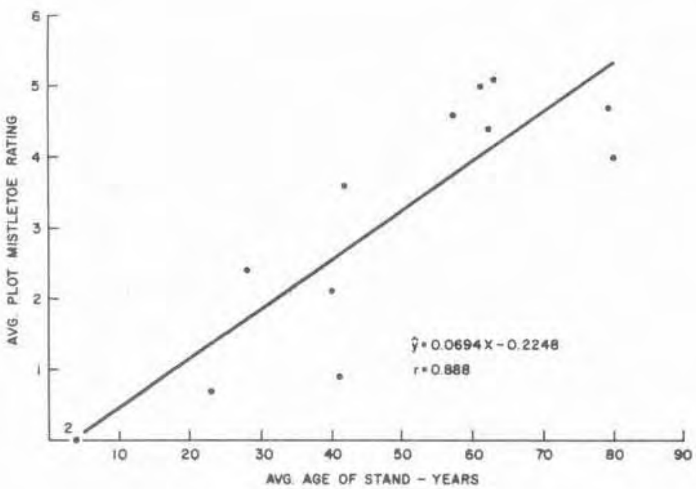

FIG. 16. Relationship between average plot mistletoe rating and average age of stand.

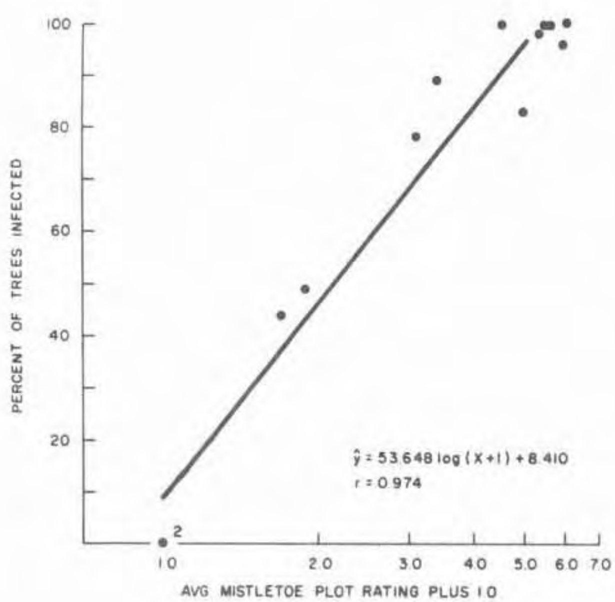

FIG. 17. Relationship between percent of trees infected and average mistletoe plot rating.

Site Index and Stand Condition

Site index (height in meters at 100 years) for Douglas-fir ranged from 15 to 30, with an average of 20 (poor growing site) (9). The average site index for shore pine was less than 18 (poor growing site).

Because of the poor sites and the damage inflicted by mistletoe, the shore pine stands were very "ragged" in appearance (Fig. 18). Dead trees ranged from 1.5% to 29.2% of all trees within the plot. The highest mortality occurred in Plots 5 (Ragged Mtn.), 9 (Bluff Mtn.) and 11 (Mt. Jack). Blowdown and broken tops occurred extensively in the infested areas studied.

FIG. 18. Smallest tree found infected in the study area was 51 cm tall (from root collar (arrow)), growing on a rock outcrop with its roots embedded in the rock crevices. It was 38 years of age.

Damaging Agents on Dwarf Mistletoe

Of the 27 infested areas studied, hyperparasites were found in two areas.

A fungus, Cylindrocarpon gillii (28), was found in Plot 7. Aerial shoots of dwarf mistletoe were heavily infected, many being girdled and killed. This host/hyperparasite combination on shore pine has been previously reported by Kuijt (24).

A fungus, Nectria macrospora, was found on A. tsugense swellings on western hemlock on the west side of Sooke Lake (Fig. 11, No. 29) and is widespread throughout the range of western hemlock dwarf mistletoe in British Columbia (12). Symptoms are resinosis, cankering and girdling of infected host branches.

Shore pine dwarf mistletoe swellings were gnawed by red squirrels (Tamiasciurus hudsonicus lanuginosus). Feeding was restricted to the bark in the vicinity of the infection. Squirrel feeding has been previously reported by Baranyay (1) on lodgepole pine attacked by A. americanum in Central British Columbia and in the Rockies of Alberta, but not on infections of A. tsugense on shore pine. Infections on western hemlock showed no signs of squirrel feeding.

DISCUSSION AND CONCLUSIONS

A. tsugense on shore pine is more extensive than previously realized but is restricted to certain habitats where shore pine is essentially the climax species. Infected shore pine occur in a lithosol -rocky knoll mosaic and in xeric habitats, both in the Coastal-Douglas-fir Biogeoclimatic Zone and the dry subzone of the Coastal Western Hemlock Biogeoclimatic Zone. The heavy concentration of A. tsugense on shore pine in the study area reflects the abundant climatically and edaphically xeric habitats which, with the help of fires and logging, are favorable to continuity of shore pine.

Geographic distribution and habitat are different for A. tsugense on shore pine than those for the parasite on western hemlock. Microclimate, mainly temperature, is different between hemlock and shore pine infested stands. In the Coastal Douglas-fir Zone and the dry subzone of the Coastal Western Hemlock Zone, western hemlock develops only as an edaphic species on subhygric habitats and does not occur on xeric habitats (22).

The size of the infested area reflects the stand history and topography of the area. Where fire was severe and the terrain less of a mosaic (forested and rock outcrops), very few residual infected shore pine were found that could re-infect the secondary growth. Where the mountains were broken up with many subpeaks and where a patchy burn occurred, more infection centers were found, and a larger area was infested.

The older and more extensively infested forest stands were found on mountain tops having a mosaic community of rocky knolls and forest on lithosols on glacial till, colluvium or a mixture of the two. Shore pine could have been more extensive in this area during the early post glacial period, as it is able to thrive on recently disturbed terrain. Thus, A. tsugense on shore pine may have been more extensive, and only in later years largely restricted to mountain tops.

Current spread of A. tsugense on shore pine has been from the mountain top to lower elevation areas adjacent to the stand. This spread probably has accelerated with man's intervention by logging and with increased fires. Infection in isolated locations such as Memory Island, Charter's bog and the edge of Matheson Lake could indicate a long distance dispersal, beyond the normal dispersal distance of the dwarf mistletoe, for which birds could have been responsible.

An average of 15 years is required for the stand infection index to increase by one class. This is very close to the 14 years determined by Hawksworth and Hinds (16). The percentage of stems infected at the younger ages is much higher than that found by Hawksworth (14) on lodgepole pine infected with A. americanum. Intensification of dwarf mistletoe in shore pine stands is very rapid. A survey carried out by the Canadian Forestry Service gives an average infection rating for infected western hemlock of 2.95 for stands having an average age of 62 years. In the present study, shore pine infected with A. tsugense had an average infection rating of 4.08 at the same age.

Dwarf mistletoe causes volume loss and mortality in moderately and severely infected forest stands (2), and control measures may be considered worthwhile for those shore pine stands on deep, relatively productive soils in the study area and for other infected shore pine stands in the Coastal Douglas-fir Zone with a potential for commercial wood production (e.g., Parksville-Horne Lake area). The rapid intensification of mistletoe in the shore pine stands studied means that sanitation measures (removal of infected trees) can not be applied successfully to stands over 20 years of age. Over this age, insufficient healthy trees are available to form the stand after sanitation. For heavily infected older stands on productive soils, early salvage, with removal of all infected understory, is recommended to return the land to full production.

In most cases, the sites supporting infected shore pine in the study area are on rocky hilltops and are more suited to recreation (hiking, nature study) than to commercial forestry. Even for recreational purposes, however, dwarf mistletoe will have to be considered an important factor affecting the appearance and general health of the stands.

The particular habitat requirements of shore pine has isolated a unique gene pool of A. tsugense from the common western hemlock host. Inoculation experiments by Smith (38) indicate some degree of genetic differentiation, although the seed source, unlike the study area, was from an area where infected shore pine and infected western hemlock forest stand habitats were adjacent.

Before a decision can be made on its taxonomic position, a wider spectrum of host/parasite relationships, morphological and physiological characteristics of the dwarf mistletoe and its historical development has to be studied. Field inoculations of dwarf mistletoe seed collected from shore pine from the mountain tops onto western hemlock and from hemlock to shore pine, and measurements of quantitative characters for morphological differentiation of the two races would be helpful in clarifying the taxonomic status of A. tsugense on shore pine.

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REFERENCES

1. Baranyay, J.A. (1968). Squirrel feeding on dwarf mistletoe infections. Bi-Mon. Res. Notes 24(5): 41-42.

2. Baranyay, J.A. and R.B. Smith (1972). Dwarf mistletoes in British Columbia and recommendations for their control. Can. For. Serv., Pac. For. Res. Centre, BC-X-72. 18 pp.

3. Bird, C.D. and R.D. Bird (1973). Lichens of Saltspring Island, British Columbia. Syesis 6: 57-80.

4. Black, C.A. (1965). Methods of soil analysis. Part I. Agronomy No. 9. Madison, Wisconsin. 770 pp.

5. Braun-Blanquet, J. (1965). Plant sociology, the study of plant communities (Transl. rev. and ed. by G.D. Fuller and H.S. Conard). Hafner, London. 439 pp.

6. Canadian Soil Survey Committee (1974). The system of soil classification for Canada. Can. Dept. Agric., Publ. 1455. Queen's Printer, Ottawa. 255 pp.

7. Clapp, C.H. (1917). Sooke and Duncan Map areas, Vancouver Island. Geol. Surv., Canada, Mem. 96. 445 pp.

8. Day, J.H., L. Farstad and D.G. Laird (1959). Soil survey of southeast Vancouver Island and Gulf Islands, British Columbia. Report No. 6 of the British Columbia Soil Survey. Can. Dept. Agric., Research Branch. 104 pp.

9. Forest Club (1971). Forestry handbook for British Columbia. University of British Columbia, Vancouver, B.C. 815 pp.

10. Forward, Charles N (1969). Land use of the Victoria area. B.C. Geographical Paper No. 43, Geological Branch, Dept. of Energy, Mines and Resources, Ottawa. 25 pp.

11. Franklin, Jerry F. and C.T. Dyrness (1973). Natural vegetation of Oregon and Washington. USDA Forest Service, General Technical Report PNW-8. 417 pp.

12. Funk, A., R.B. Smith and J.A. Baranyay (1973). Canker of dwarf mistletoe swellings on western hemlock caused by Nectria fuckeliana var. macrospora. Can. J. For. Res. 3(1): 71-74.

13. Hale, M. and W. Culberson (1970). A fourth checklist of the lichens of the continental United States and Canada. Bryologist 73: 499-543.

14. Hawksworth, Frank G. (1958). Rate of spread and intensification of dwarf mistletoe in young lodgepole pine stands. J. For. 56(6): 404-407.

15. Hawskworth, Frank G. (1975). Personal communication.

16. Hawksworth, Frank G. and Thomas E. Hinds (1964). Effects of dwarfmistletoe on immature lodgepole pine stands in Colorado. J. For. 62(1): 27-32.

17. Hawksworth, Frank G. and Arthur A. Lusher (1956). Dwarfmistletoe survey and control on the Mescalero-Apache Reservation, New Mexico. J. For. 54(6): 384-390.

18. Hawksworth, Frank G. and Delbert Wiens (1972). Biology and classification of dwarf mistletoes (Arceuthobium). USDA, Agric. Handbook 401, 234 pp.

19. Hitchcock, C.L., A. Cronquist, M. Ownbey, and J.W. Thompson (1955-1969). Vascular plants of the Pacific Northwest. Univ. Washington Press. Seattle. 5 Vol.

20. Holland, S.S. (1964). Landforms of British Columbia. A physiographic outline. British Columbia Dept. Mines and Petroleum Resources, Bull. No. 48. Queen's Printer, Victoria, B.C. 138 pp.

21. Kojima, Satoru (1971). Phytogeocoenoses of the coastal western hemlock zone in Strathcona Provincial Park, British Columbia, Canada. Ph.D. Thesis, Univ. British Columbia. 322 pp.

22. Krajina, V.J. (1969). Ecology of forest trees in British Columbia. Ecol. of Western N. Am. 2(1): 1-147.

23. Kuijt, Job (1956). A new record of dwarf mistletoe on lodgepole and western white pine. Madrono 13(5): 170-172.

24. Kuijt, Job (1963). Distribution of dwarf mistletoes and their fungus hyperparasites in western Canada. Nat. Mus. Can. Bull. 186: 134-148.

25. Lawton, Elva (1971). Moss flora of the Pacific Northwest. Nichinan, Miyazaki, Japan. Hattori Bot. Lab. 362 pp.

26. McKee, Bates (1972). Cascadia - the geologic evolution of the Pacific Northwest. McGraw-Hill Inc. U.S.A. 394 pp.

27. McMullan, E.E. (1971). Methods of analysis, soils-biochemistry laboratory service. Can. Dept. Fish. For. Inform. Rept. BC-X-50. 49 pp.

28. Muir, John A. (1973). Cylindrocarpon gillii, a new combination for Septogloeum gillii on dwarf mistletoe. Can. J. Bot. 51(10): 1997-1998.

29. Munsell Soil Color Charts (1954). Munsell Color Company Inc., Baltimore, Maryland.

30. Orloci, Laszlo (1964). Vegetational and environmental variations in the ecosystems of the Coastal Western Hemlock Zone. Ph.D. Thesis. Univ. British Columbia. 204 pp.

31. Otto, G.F. (1968). Lichens of British Columbia. I. Species not previously recorded from the province. Bryologist 71: 368-369.

32. Otto, G.F. and T. Ahti (1967). Lichens of British Columbia: Preliminary checklist. Dept. Botany, Univ. British Columbia. 40 pp.

33. Packee, Edmond C. (1972). The biogeoclimatic subzones of Vancouver Island and the adjacent mainland and islands. MacMillan Bloedel Limited, Forestry Division, For. Res. Note 1. 6 pp.

34. Peden, D.G. (1967). Vegetation and ecology of Rithet's Bog, Royal Oak, British Columbia. B. Sc. (Honours) Thesis, Univ. Victoria, unpublished.

35. Rigg, George B. (1922). A bog forest. Ecology 3(2): 207-213.

36. Roemer, Hans L. (1972). Forest vegetation and environments on the Saanich Peninsula, Vancouver Island. Ph.D. Thesis. Univ. Victoria. 405 pp.

37. Schofield, W.B. (1968). A selectively annotated checklist of British Columbia mosses. Syesis 1: 163-175.

38. Smith, R.B. (1974). Personal communication.

39. Smith, R.B. (1974). Infection and development of dwarf mistletoes on plantation-grown trees in British Columbia. Can. For. Serv., Pacif. For. Res. Centre, Inform. Rep. BC-X-97. 21 pp.

40. Smith, R.B. and E.F. Wass (1976). Field evaluation of ecological differentiation of dwarf mistletoes on shore pine and western hemlock. Can. J. For. Res. (in press).

41. Taylor, T.M.C. (1966). Vascular flora of British Columbia. Preliminary checklist. Dept. Botany, Univ. British Columbia. 31 pp.

APPENDICES

APPENDIX I. Basic plot data

Location	Plot no.	Aspect (o)	Slope (%)	Position on slope	Land type	Hygrotope class b/	A (Trees)	B (Shrubs)	C (Herbs)	D (Bryophytes)	E (Lichens)	F (Bare Rock)	Relief
Mt. Helmcken	1	316	7	Top	R.O.C. a/	0	75	65	25	85	8	1	Straight
Mt. Wells	2	336	17	Upper	Colluvial slope	0	95	30	5	100	1	0	Concave
Mt. Wells	3	40	14	Top	Colluvial slope	-1	90	30	5	100	1	0	Straight
Mt. Manuel Quimper	4	312	34	Middle	Colluvial slope	-1	70	40	35	80	1	0	Straight to concave
Ragged Mtn.	5	270	1	Top	R.O.C.	-1	85	80	10	45	1	0	Slightly concave
Glinz Creek	6	90	40	Lower	Terrace	+2	65	75	30	5	0	0	Concave
Hill 22	7	135	10	Top	R.O.C.	-3	65	50	10	80	15	2	Straight and rock knolls
Mt. Matheson	8	10	13	Upper	R.O.C.	-2	98	10	12	95	5	0	Straight
Bluff Mtn.	9	249	15	Upper	R.O.C.	-2	75	55	5	95	5	1	Concave and convex (rock knolls)
Mt. Work	10	204	15	Top	R.O.C.	-2	45	25	30	90	5	5	Straight and convex (rock)
Mt. Jack	11	280	10	Top	R.O.C.	-2	75	30	4	85	5	2	Straight
Mt. Maguire	12	325	15	Upper	R.O.C.	-1	95	75	2	95	1	1	Concave in depression, convex on rock
Kirby Hill	13	42	20	Top	R.O.C.	-1	50	25	1	70	4	2	Straight (salal) and convex (rock)

a/ R.O.C. - Rock outcrop

b/ Hygrotope class from Orloci (30).

-3 (Very dry), knolls and peaks of rock outcrops
-2 (Dry), Lithic soils
-1 (Moderately dry), shallow coarse stoney glacial tills
0 (Mesic), medium textured deep soils, without seepage
+1 (Moist), deep soils, temporary seepage
+2 (Wet), permanent seepage close to the soil surface
+3 (Swampy), spring-water swamps, muskegs and stream-edge habitats

APPENDIX II. Representative soil profile descriptions

Plot 1 - Degraded Dystric Brunisol

Horizon	Depth (cm)	Description
L	2-1	Undecomposed conifer needles and salal leaves
F-H	1-0	Friable duff mull like
Ae1/	0-1	Trace
$Bmcc_1$	1-10	Reddish brown (5.0 $YR^4/4$) moist, dark brown (7.5 $YR^4/4$) dry, gravelly loam, pH 5.2, large roots (>10 mm) abundant
$Bmcc_2$	10-42	Reddish brown (5.0 $YR^4/4$) moist, dark brown (7.5 $YR^4/4$) dry, gravelly sandy loam, pH 5.1
BC	42-61	Brown (10 $YR^4/3$) moist, pale brown (10 $YR^6/3$) dry, gravelly sandy loam, pH 4.7
BCg	61-85	Mottled brownish yellow (10 $YR^6/8$) and pale red (2.5 $Y^6/2$) moist, gravelly sandy clay loam, pH 4.7
Bedrock	85+	

1/ Ae was 7 cm thick in soil 5a

Plot 8 - Orthic Dystric Brunisol

Horizon	Depth (cm)	Description
L	7-4	Undecomposed conifer needles
F-H	4-0	Very friable, duff mull like, containing high charcoal content
Bm_1	0-7	Dark yellowish brown (10 $YR^3/4$) moist, brown to dark brown (7.5 $YR^3/4$) dry, gravelly loam to sandy loam, pH 5.5
Bm_2	7-17	Brown to dark brown (7.5 $YR^4/4$) moist, brown (7.5 $YR^5/4$) dry, gravelly loam, pH 5.4
Bm_3	17-28	Dark yellowish brown (10 $YR^4/4$) moist, yellowish brown (10 $YR^5/4$) dry, gravelly sandy loam, pH 5.5
BC	28-50	Olive brown (2.5 $Y^4/4$) moist, light yellowish brown (2.5 $Y^6/4$) dry, very gravelly sandy loam, pH 5.0
IIC	50-67	Olive brown (2.5 $Y^4/4$) moist, light yellowish brown (2.5 $Y^6/4$) dry, very gravelly sandy loam-loamy sand, pH 4.7
	67-69	Root layer contact with bedrock
Bedrock	69+	

Plot 7 - Lithic Dystric Brunisol

Horizon	Depth (cm)	Description
L	4-2	Undecomposed moss material
F-H	2-0	Very friable mull
Ah	0-1	Trace
Bm_1	1-7	Dark yellowish brown (10 $YR^3/4$) moist, brown to dark brown (7.5 $YR^4/4$) dry, gravelly loam, pH 5.3
Bm_2	7-19	Dark reddish brown (5 $YR^3/4$) moist, brown to dark brown (7.5 $YR^4/4$) dry, gravelly loam, pH 5.3
Bm_3	19-32	Dark reddish brown (5 $YR^3/4$) moist, dark yellowish brown (10 $YR^4/4$) dry, very gravelly sandy loam, pH 5.0
BC	32-43	Dark yellowish brown (10 $YR^4/4$) moist, yellowish brown (10 $YR^5/4$) dry, very gravelly sandy loam pH 5.0
Bedrock	43+	

Plot 6 - Orthic Sombric Brunisols

Horizon	Depth (cm)	Description
L	3-1	Undecomposed needles and sword fern fronds
F-H	1-0	Friable mull
Ah	0-9	Dark brown (7.5 $YR^3/2$) moist, dark yellowish brown (10 $YR^4/4$) dry, gravelly sandy loam, pH 5.4, charcoal present, earthworms
Bm_1	9-32	Dark yellowish brown (10 $YR^3/4$) moist, dark yellowish brown (10 $YR^4/4$) dry, very gravelly sandy loam, pH 5.5
BC	32-49	Dark yellowish brown (10 $YR^4/4$) moist, light yellowish brown (2.5 $YR^6/4$) dry, very gravelly sandy loam, pH 5.7
Bmb	49-66	Dark yellowish brown (10 $YR^4/4$) moist, yellow brown (10 $YR^5/4$) dry, gravelly sandy loam, pH 5.7
C_1	66-81	Olive brown (2.5 $Y^4/4$) moist, light yellow brown (2.5 $Y^6/4$) dry, some mottling, gravelly sandy loam to loamy sand, pH 5.8
C_2	81-103+	Olive brown (2.5 $Y^4/4$) moist, light yellow brown (2.5 $Y^6/4$) dry, gravelly loamy sand, pH 5.8

Plot 4a - **Lithic Sombric Brunisol**

Horizon	Depth (cm)	Description
L	4-2	Undecomposed dead moss and pine needles
F-H	2-0	Fibrous mor
Ah	0-6	Dark reddish brown (5 $YR^{2}/2$) moist, dark brown (10 $YR^{3}/3$) dry, very gravelly loamy sand, pH 4.9
Bm	6-15	Dark brown (10 $YR^{3}/3$) moist, brown to dark brown (10 $YR^{4}/3$) dry, gravelly loam, pH 4.6
Bedrock	15+	

APPENDIX III. Species and coverage for intensive plots.

Species by stratum	Plot no. 1	2	3	4	5	7	8	9	10	11	12	13	Rocky knoll only 9a	10a	11a	12a	13a
TREE STRATUM																	
T_1 (>18 m)																	
Pseudotsuga menziesii	2	2	+	3					2								
Pinus contorta var. contorta	+																
T_2 (9 m-18 m)																	
Pinus contorta var. contorta		1	4	2	4	3	3	3	1	4	2	2					
Pseudotsuga menziesii	1	2	2	2	2	1	3				1						
T_3 (4.5 m-9 m)																	
Pinus contorta var. contorta		3	1	1	1	2	1	2	+	1	4	3					
Pseudotsuga menziesii		1	+		+	1	1	+	+	1	2						
Arbutus menziesii		+	+			1											
T_4 (<4.5 m)																	
Pinus contorta var. contorta	4	2	+	+		1	1	1	2	+	4	2			+	1	
Pseudotsuga menziesii	+	+	+	+	+	1	+	1	1	1	1	+				1	
Arbutus menziesii	1	3	+						1								
Salix scouleriana	+	1	+	+		+	+	+	1	+							
Thuja plicata											r	+					
Tsuga heterophylla											+						
Alnus rubra											r						
SHRUB STRATUM																	
Gaultheria shallon	3	1	1	1	3	2	1	3		4	5	3	+			1	+
Berberis nervosa	1	1	1	+	1	+	1			1	+	1	+				
Arctostaphylos columbiana	1	3	2		+	3	+	1	1	+			+				
Arctostaphylos uva-ursi	1	+	+		+	+		+	1	2		1		+	+		
Rosa gymnocarpa	1	+	+	1	+	+	1		+		+	+			r	+	
Holodiscus discolor	+	1		+		2		+	+	+				+	+		

APPENDIX III. Species and coverage for intensive plots. (Continued)

Species by stratum	Plot no. 1	2	3	4	5	7	8	9	10	11	12	13	Rocky knoll only 9a	10a	11a	12a	13a
Pachystima myrsinites	+		+			+		+	+		+						
Rubus ursinus						+	+		+	+	+			+			
Amelanchier alnifolia		+					+		+								
Satureja douglasii	+	+	+														
Symphoricarpos albus		+	+														
Cytisus scoparius		+						3					1				
Vaccinium ovatum											1	1				+	
Vaccinium parvifolium										+		+					
Juniperus communis										r					r		
Linnaea borealis											1						
HERB STRATUM																	
Goodyera oblongifolia		+	+	+	+	1	+	+		1	+	+	+				
Trientalis latifolia	+	1	+	+	+	1	+		+								
Selaginella wallacei		+	+	+	+	2							1	1			1
Erythronium oreganum	+	+	+	+	r		+		+								
Hieracium albiflorum	+	+	+	+			+		+	+				+			
Habenaria unalascensis	r	1	1			+	+										
Listera cordata	+			+	1		+					+				+	
Circaea alpina	+	+	+	+			r										
Elymus glaucus		+		2		3	+		2					+			
Dodecatheon hendersonii	+	1	1				1		1								
Montia perfoliata	+	+		1					+								
Fragaria sp.		+	+				+		+								
Festuca rubra	2		+	3	+		1			+							
Aira praecox	2		+	+		4	1						+	+		1	
Collinsia parviflora	+		+						+					+			
Sanicula crassicaulis	+	1	+				+		+								
Heuchera micrantha	+	+		+			+		+								
Camassia quamash			+	1					1								
Achillea millefolium				+		+			+				+	+			+

APPENDIX III. Species and coverage for intensive plots. (Continued)

	Plot no.											Rocky knoll only				
Species by stratum	1	2	3	4	5	7	8	9	10	11	12	13	9a	10a	11a	12a	13a
Polystichum lonchitis	+			+					+			r					
Festuca occidentalis			+	1		1							+	+		1	r
Calypso bulbosa		+	+														
Habenaria orbiculata		+	+														
Corallorhiza maculata		+					+										
Plectritis congesta	+								+								
Sedum stenopetalum	+		+	+													
Rumex acetosella				+					+					+			
Polystichum munitum		+									+						
Anthoxanthum odoratum	+	1	3														
Lomatium utriculatum			+														
Madia madioides			+														
Hypochaeris radicata			+														
Allium cernuum				+													
Zygadenus venosus				+													
Lilium columbianum					r												
Fragaria vesca													+				
Fragaria chiloensis				+						+							
Sedum spathulifolium													+				
Eriophyllum lanatum									1								
Osmorhiza purpurea									+								
Boschniakia hookeri											r						
Polypodium hesperium	+					+	+						r				
Cryptogramma crispa									+				r		+		
Aira caryophylla					+												
Luzula multiflora	+			+													
Festuca subuliflora				+													
Agrostis sp.				+													
Carex inops							+										
Festuca bromoides			+														
Antennaria sp.				+													
Viola glabella						+											
Lactuca biennis						+											
Carex rosii																	1

APPENDIX III. Species and coverage for intensive plots. (Continued)

Species by stratum	Plot no. 1	2	3	4	5	7	8	9	10	11	12	13	Rocky knoll only 9a	10a	11a	12a	13a
Carex pensylvanica														+			
Apocynum androsaemifolium										+							
Pyrola dentata										r							
BRYOPHYTE & LICHEN STRATUM																	
Eurhynchium oreganum	4	3	1	3	4	4	5	2	+	+	3	1					
Rhytidiadelphus triquetrus	2	2	4	3	1	1	+		+		+						
Peltigera aphthosa	1	+	+	1		1	2	+			+	+					
Dicranum howellii	2	+	+	+	1	+			+								
Polytrichum juniperinum		1	+	+		+	+		+				3	2	3	3	2
Hylocomium splendens		1	1	3	1	1	+			+							
Polytrichum piliferum	1		+	+	+	2	+		+						+		
Isothecium cristatum	+	+		1		+											
Rhacomitrium canescens	2	2	+	+			+						1	3	+		1
Dicranium scoparium		2		+		2	2										
Scapania bolanderi	+	+			+		+										
Isothecium stoloniferum				1	1	+	+										
Peltigera canina	1	+		+			+									+	
Cladonia furcata		+		+		+									+		1
Sphaerophorus globosus				+	+		+									+	
Rhytidiadelphus loreus				+		+											
Dicranum fuscescens					+		+			+			3	2	2	2	+
Antitrichia curtipendula		+			+												
Grimmia trichophylla		+				+											
Homalothecium pinnatifidum			+	+													
Rhacomitrium lanuginosum					+	2									+	2	2
Cladonia bellidiflora					+	+									+	+	
Homalothecium megaptilum		+		1													
Leucolepis menziesii			+														
Bryum capillare					+												
Polytrichum commune				1													
Porella navicularis						+											
Pohlia nutans						+											
Rhacomitrium heterostichum													1				
Mnium spinulosum					+												

APPENDIX III. Species and coverage for intensive plots. (Continued)

Species by stratum	Plot no. 1	2	3	4	5	7	8	9	10	11	12	13	Rocky knoll only 9a	10a	11a	12a	13a
Hypnum circinale									+								
Hypnum subimponens									+								
Rhytidiopsis robusta										2							
Parmelia saxatilis			+												+		1
Parmelia sulcata														+		+	
Parmelia omphalodes					+												
Parmelia taractica														+			
Cornicularia aculeata					+									+			
Thamnolia vermicularis														+			
Cladonia pyxidata	1		+											+			
Sterocaulon tomentosum	+			+		2								+		+	+
Umbilicaria hirsuta[a]															+		+
Cladonia uncialis																	+
Cladonia coccifera				+													+
Cladonia norrlini?										+							
Cladonia sp.						+											
Cladonia cornuta			+		+												
Plagiothecium undulatum				+													
Cladonia rangiferina										+							
Umbilicaria vellea												+					
Hypogymnia physodes			+														
Cladonia chlorophaea		+		+													
Cladonia gracilis var. dilatata						+											

a/ Lichen previously found only once in British Columbia by Bird and Bird (3) on Saltspring Island.

1) Cover - abundance scale - 5 (76-100%), 4(51-75%), 3(26-50%), 2(6-25%), 1(1-5%), + (less than 1%), r (solitary individual with small cover).

2) Nomenclature and authorities for the vascular plants follow Hitchcock et al. (19), Lawton (25) for mosses and Hale and Culbertson (13) for lichens. A number of checklists were used to determine whether plant specimens were new to the province (3, 31, 32, 37, 41).

APPENDIX IV. Some lichens found on shore pine

Alectoria sarmentosa

Cladonia pityrea

Cladonia theiophila

Hypogymnia enteromorpha

Hypogymnia physodes

Lecidea sp.

Mycoblastus sanguinarius

Ochrolechia oregonensis

Ochrolechia upsaliensis

Pertusaria sp.

Platismatia glauca

Sphaerophorus globosus

Usnea dasypoga

APPENDIX V. Location, elevation and size of infested area for individual points surveyed (numbers match survey points on Fig. 11).

No.	Location	Elevation (m)	Size of Infested Area (ha)
1	Mt. Helmcken	305	13
2 & 3	Mt. Wells	335	2
4	Mt. Manuel Quimper	536	2
5	Ragged Mtn.	579	12
6	Glinz Creek	244	< 0.5
7	Hill 22	335	3
8	Mt. Matheson	274	1
9	Bluff Mtn.	549	165
10	Mt. Work	427	32
11	Mt. Jack	646	9
12	Mt. Maguire	244	Healthy
13	Kirby Hill	457	13
14	Mt. Braden	467	2
15	Hill 26	518	6
16	Mt. McDonald	429	1
17	Hill 36	610	23
18	Empress Mtn.	673	< 0.5
19	Memory Island	116	< 0.5
20	Waterloo Mtn.	1055	Healthy
21	Redflag Mtn.	305	Healthy
22	Mt. Blinkhorn	244	Healthy
23	½ mile N.W. of Boneyard Lake	427	0.5
24	Jocelyn Hill	396	15
25	Mt. Jeffrey	579	Healthy
26	Bamberton Prov. Park	15	0.5
27	Iron Mine Hill	31	35
28	Mt. Healy	722	24
29	West side of Sooke Lake	186	9
30	Mt. Finlayson	409	0.5
31	Trap Mtn.	711	17
32	Mt. Newton	244	Healthy
33	Area "B" Muir Ck.	76	Healthy