

PHAEOCRYPTOPUS GAEUMANNII ON PSEUDOTSUGA MENZIESII IN SOUTHERN BRITISH COLUMBIA

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ABSTRACT

Infection by *Phaeocryptopus gaeumannii* (Rohde) Petrak was evaluated in second-growth Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) in southern British Columbia, using the percentage of ascocarp-bearing needles as a measure of infection intensity. Infection was appreciable at many locations west of the Coast Range and in the interior mountain ranges in the east (71% of location means 5–100%), but was negligible on the interior intermountain plateau (93% of means 0–4%). Infection was particularly high (74% of means 80–100%) along the west coast of Vancouver Island. Significant positive correlation was found between mean infection and May–July mean rainfall in southern British Columbia. At Cowichan Lake on Vancouver Island provenances and clones from origins west of the Coast-Cascade divide in British Columbia, Washington, and Oregon were significantly less infected (means 0–13%) than those from between the Coast Range and the eastern mountains in British Columbia (29–90%). The relatively high mean rainfall (250–350 mm) during November–January may be a contributing factor towards the heavy infection (80–100%) observed in younger stands in the central North Island of New Zealand.

INTRODUCTION

The needle-inhabiting ascomycete, *Phaeocryptopus gaeumannii*, is associated with a decline in growth of Douglas fir in the central North Island of New Zealand (Beekhuis 1978; McGreevy 1978; Wooff 1978). Infection of foliage collected within younger stands in this area is high (exceeding 80%) and retention of older foliage is low (less than 45% after 4 years) (Hood & Sandberg 1979; Hood & van der Pas 1979) compared with retention levels reported for natural stands in British Columbia (Silver 1962; Brix 1981). *Phaeocryptopus gaeumannii* occurs widely in native Douglas fir, and has been recorded in British Columbia, Washington, Oregon, California, Arizona, and New Mexico, where it mostly causes little or no injury (Liese 1938; Peace 1939; Boyce 1940; Hahn 1941; Molnar 1954). Recently, *P. gaeumannii*-associated needle cast was reported in Douglas fir Christmas tree plantations in Washington and Oregon (Michaels & Chastagner 1982). Despite these various records, there is no detailed information available on infection levels in this region. A quantitative survey was therefore undertaken in order to evaluate the incidence of natural infection within part of the native Douglas fir range in southern British Columbia. To supplement this survey, counts of

infected needles were made in a provenance trial and a thinning trial on Vancouver Island, so that comparisons could be made with results from similar trials in New Zealand.

INFECTION SURVEY

Regional Distribution

Method

Foliage was collected mainly from second-growth Douglas fir in southern British Columbia and north-west Washington. At each site one shoot was detached from each of several trees and taken to the laboratory for counting. Sampling varied, but usually secondary shoots were sampled 1–2 m from ground level on three 4- to 10-m-tall trees at each locality. Sheltered shoots from among grouped trees were taken where possible, particularly in drier areas, since infection may vary with level of foliage exposure (Lyr 1955). Foliage was stored in polythene bags at 4°C and usually examined within 1 week of sampling. In the laboratory approximately 50 needles of each of four age-classes (2–3 to 5–6 years) were counted under a stereomicroscope to determine the percentage with mature or immature ascocarps of *P. gaemannii*. Data from different foliage age-classes on all trees at each locality were averaged to give a single site mean. The relationship was tested between mean infection at each site and the mean 3-monthly May–July rainfall at the nearest meteorological station within 15 km (coast) or 27 km (interior), if one existed, using climate data published by the British Columbia Department of Agriculture (Atmospheric Environment Service 1971). In addition, the percentage of foliage retained was estimated to the nearest 10% for each of four age-classes (3–4 to 6–7 years) on all shoots. To check the reliability of these assessments, percentage needle retention was also determined on a random sample of the shoots by counting. Counts were made on one or more spiral sets of needles and scars along the full length of each of 365 internodes. More than 40 needles or scars were counted per internode.

Results

Phaeocryptopus gaemannii was widespread in southern British Columbia and north-west Washington. The mean incidence of needles with ascocarps varied regionally. Visible infection was greatest west of the Coast Range and in the mountain ranges in the eastern part of the province (Fig. 1), and was negligible in the interior intermountain plateau region between. On the coast a gradation was noticeable, with a very high incidence on the west side of Vancouver Island and the Olympic Peninsula, and reduced but appreciable infection to the east. There was significant ($p < 0.001$) positive correlation between infection and May–July rainfall on the coast (Fig. 1 Coastal; Kendall's non-parametric rank correlation coefficient, $\text{Tau} = 0.47$; $n = 71$) and in the interior (Fig. 1 Interior; $\text{Tau} = 0.53$; $n = 53$). Assessed (y) and counted (x) needle retention levels were linked by the linear regression $y = 0.825x + 13.2$ ($r = 0.93$; $p < 0.001$). This equation was used to derive values of mean percentage needle retention from assessed means of all samples, as follows: 79% (3–4 years; number of internodes, $n = 600$); 68% (4–5 years; $n = 560$); 56% (5–6 years; $n = 460$); 50% (6–7 years; $n = 360$).

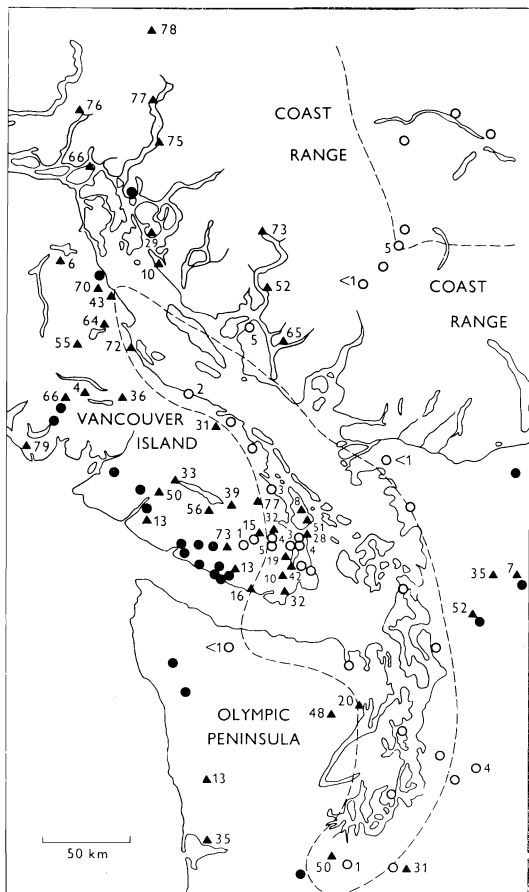
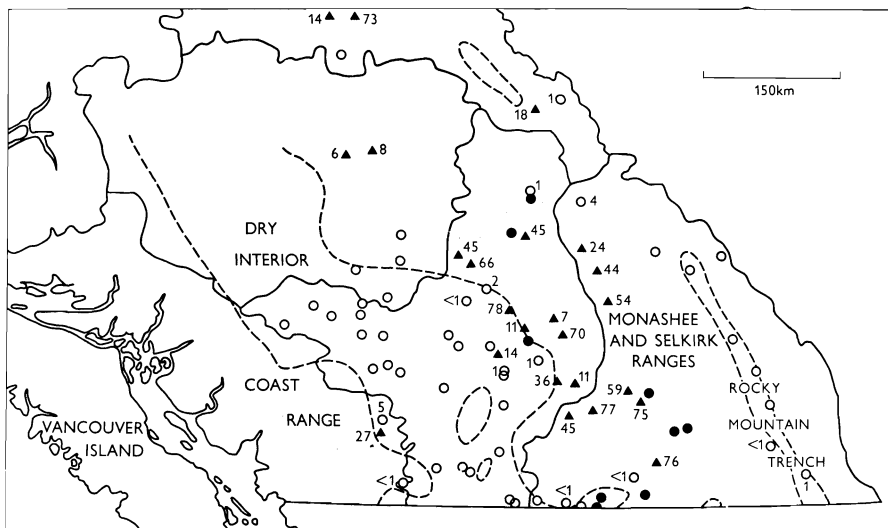


FIG. 1.—Distribution of *Phaeocryptopus gaeumannii* in British Columbia: Coastal (left), Interior (below). Each point denotes the mean percentage of needles infected from counts on four age-classes (2-3 to 5-6 years) on (1-) 3 (-5) trees: ○ = 0-5% (with value if > 0%); ▲ = 6-79% (with value); ● = 80-100%. The broken line delineates the 110-m, 3-monthly (May-July) isohyetal.



Other needle fungi were seen, including two identified as species of *Clypeolum* and *Stomiopeltis* (collections housed at DAVFP); both resembled similar microepiphytes collected on Douglas fir in New Zealand; a species of *Clypeolinopsis* frequently seen in New Zealand was not observed in the British Columbian samples, however. Occasionally species of *Rhizosphaera*, *Rhabdocline*, and *Melampsora* were present in samples.

Provenance Variation in Infection

Method

In August 1981, foliage samples were collected from among the British Columbia Ministry of Forests provenances near Cowichan Lake, Vancouver Island (for details see Orr-Ewing 1973; mean May–July rainfall at Cowichan Lake, 135 mm). Twenty provenances (one plot per provenance) originating from elevations 60–1150 m on the western side of North America, and which had been planted in 1961–72, were used. Seven open-grown trees were selected from the central row within each plot. One secondary shoot with six internodes was cut from the base of a primary seventh-whorl branch on each tree. Infection was counted on two needle age-classes (3–4 and 4–5 years) in the manner described in the previous section. Because the Cowichan Lake trial does not include provenances from coastal British Columbia, additional samples were taken from adjacent, open-grown, Douglas fir clones collected from the coast, together with one clone from Lac le Jeune in the interior.

Results

There were pronounced differences in mean visible infection among provenances and clones (Tables 1 and 2; Fig. 2). Provenances and clones from west of the Coast-Cascade divide from British Columbia to northern California were lightly infected (means 1–15%). Those from interior British Columbia and Washington and from eastern California were heavily infected (means 40–94%), except for two provenances from the interior mountain belt of British Columbia (Revelstoke and Clearwater) which were only moderately infected (means 12–30%). *Rhabdocline* sp., very heavy on some adjacent provenances from the interior United States, was not found on any of these samples.

Infection in a Thinning Trial

Foliage samples were collected from the Douglas fir thinning and fertiliser trial in a 35-year-old stand at Shawnigan Lake, Vancouver Island (Canadian Forestry Service 1978; Brix 1981; mean May–July rainfall at Shawnigan Lake, 94 mm). Two non-fertiliser treatments were chosen: unthinned (4250 stems/ha at age 25–26 years) and thinned to 914 stems/ha at age 25–26 years. Six trees were sampled in each of four plots per treatment, those in unthinned plots being dominants or codominants. Foliage was sampled on each tree at the seventh, tenth, and thirteenth whorls. One secondary shoot was cut from the fifth node of a primary branch at each whorl. Infection and needle retention were evaluated by counting three foliage age-classes (2–3 to 4–5 years) on all shoots, as described previously.

Only trace amounts of infection were present. The 95% confidence limits of treatment means (estimated assuming a binomial distribution) did not exceed 2.6% for

TABLE 1—Mean percentage infection by *P. gaeumannii* visible on provenances at Cowichan Lake

Region	Provenance*	Elevation (m)	Year planted	Foliage age-class (years)	
				3-4	4-5
Interior British Columbia	Isadore Canyon	914	1961	94 ^{a†}	93 ^a
	Monte Lake	640	1970	88 ^a	90 ^a
	Powers Creek	1143	1961	83 ^{ab}	88 ^a
	Merritt	869	1970	74 ^{abc}	66 ^b
	Golden	869	1970	63 ^{bc}	65 ^b
	Nelson	823	1970	60 ^{bc}	66 ^b
	Revelstoke	610	1970	23 ^d	30 ^{de}
	Clearwater	457	1970	12 ^d	16 ^{ef}
Sierra Nevada/ Central Valley, California	Burney	1021	1972	77 ^{abc}	52 ^{bcd}
	Placerville	853	1966	72 ^{abc}	55 ^{bc}
Interior Washington	Spokane	610	1970	49 ^c	58 ^b
Coastal California	Calistoga	716	1972	51 ^c	31 ^{ede}
	Fort Bragg	61	1966	12 ^d	15 ^{ef}
	Arcata	884	1972	5 ^d	5 ^f
Coastal Oregon‡	Detroit	305	1969	4 ^d	13 ^{ef}
	Brookings	305	1969	3 ^d	7 ^{ef}
Coastal Washington‡	Lake Keechelus	793	1970	9 ^d	12 ^{ef}
	Sequim	457	1970	2 ^d	3 ^f
	Cougar	457	1970	1 ^d	6 ^f
	Matlock	122	1970	1 ^d	1 ^f

* For details see Orr-Ewing (1973)

† Means not linked by a common subscript are significantly different; Duncan's test, 0.05 level

‡ Including Cascade Range

TABLE 2—Percentage infection by *P. gaeumannii* visible on clones at Cowichan Lake (95% confidence limits of mean, estimated assuming a binomial distribution)

Region (British Columbia)	Origin*	No. clones†	Elevation (m)	Foliage age-class (years)	
				3-4	4-5
Interior	Lac le Jeune	1	1158	29-51	35-46
Coast Range	Foley Creek	7	610-793	0-1.0	0-3.6
Vancouver Is.	Muchalat (west coast)	7	213-488	0-1.3	0-6.1
	Meade Creek (Cowichan Lake)	7	686-869	0-0.4	0-0.8
	Victoria	2	15	0-1.4	0-1.0

* Locations shown in Fig. 2.

† Maximum available number of clones from each origin was used. Seven trees were sampled per origin irrespective of number of clones.

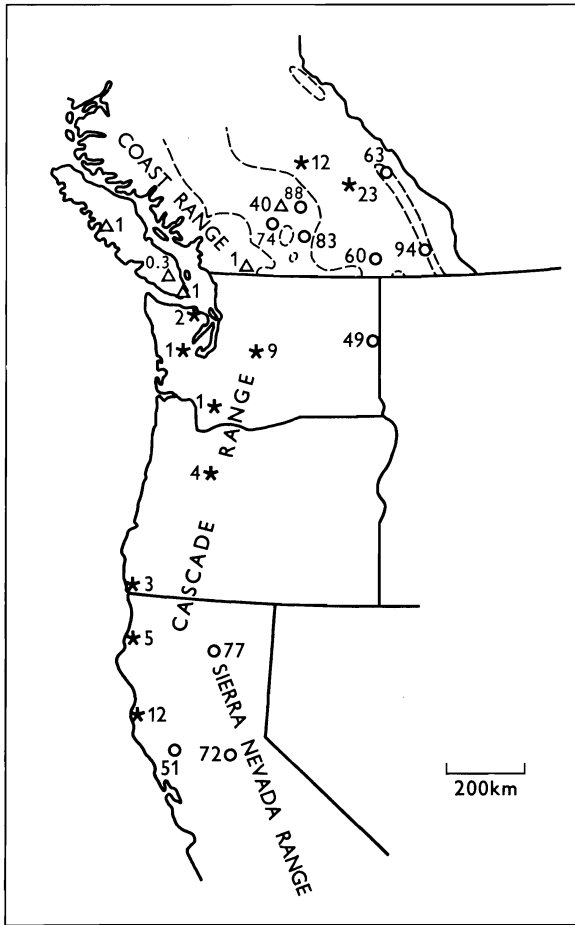


FIG. 2—Origins of provenances and clones at Cowichan Lake Vancouver Island, with values of mean percentage of 3- to 4-year-old needles infected. The mean of any provenance identified by ★ differs from that of any identified by ○ (Duncan's test, 0.05 level); △ identifies origins of clones in Table 2. The 110-mm (May-July) isohyetal in interior British Columbia is shown by a broken line.

any whorl or foliage age-class. There was no significant difference in needle retention (Table 3) between thinned and unthinned treatments (except that one thinned plot had slightly less 3- to 4-year-old foliage at the tenth whorl than all other plots – Duncan's test, 5% level).

TABLE 3—Mean percentage needle retention in thinning trial at Shawnigan Lake* (95% confidence limits, estimated assuming a binomial distribution)

	Whorl								
	7			10			13		
	Foliage age-class (years)								
	2-3	3-4	4-5	2-3	3-4	4-5	2-3	3-4	4-5
Unthinned	93-97	80-90	46-72	93-97	82-92	50-76	90-96	79-92	47-83
Thinned	92-97	75-89	48-75	93-97	73-89	47-78	87-97	84-96	66-88

* Determined by counting samples from six trees in each of four plots per treatment.

RELATIONSHIP BETWEEN PRESENCE OF ASCOCARPS AND INFECTION

Since presence of ascocarps was used as the indicator of needle infection, any infected needles which had not produced fruiting bodies would not have been counted during infection evaluations. Isolations of *P. gaeumannii* were therefore made to investigate the reliability of needle counting as a measure of infection. In the provenance trial, 3- to 4-year needles were freshly collected from fifth-whorl secondary shoots on seven trees in each of two provenances. Needles (2- to 5-year-old) sampled from two plots (thinned and unthinned) during the thinning trial survey were also used (within 8 days of collection, stored at 4°C). Detached needles in each of these four groups were sorted into those with or without ascocarps. After wetting in 70% ethanol, needles were surface-sterilised in 10% hydrogen peroxide. A sharp sterile scalpel was used to peel back the epidermis and hypodermis from the adaxial (non-stomatal) surface of each needle, exposing the mesophyll. Needles were then plated, adaxial surface down, on 1.25% malt agar and incubated at 21°C. Emerging *P. gaeumannii* colonies were subcultured to avoid occasional contamination by more rapidly growing colonies of other fungi.

Colonies of *P. gaeumannii* appeared along margins of infected needles from 10 days after plating out. Results after 28 days (minimum) are shown in Table 4. Forty out of 42 needles bearing ascocarps yielded cultures of *P. gaeumannii*. Results from needles without ascocarps varied according to incidence of mean infection counted under the microscope. In the provenance with 88% visible infection, a further 10 out of 25 apparently uninfected needles yielded *P. gaeumannii* (equivalent to real infection 93%). Among the provenances or treatments with 4%, or less, visible infection, only three out of 45 apparently uninfected needles yielded *P. gaeumannii*. Results therefore indicate that needle counts gave slightly reduced values of real infection.

TABLE 4—Isolations of *P. gaeumannii* from four collections of needles on Vancouver Island

Visible infection (mean %)	Needles without ascocarps		Needles with ascocarps	
	Total	Yielding <i>P. gaeumannii</i> *	Total	Yielding <i>P. gaeumannii</i>
88	25	10	24	22
1	25	0	—	—
4	10	1	13	13
1	10	2	5	5

* No significant differences between sources with $\leq 4\%$ visible infection, in proportions of needles without ascocarps yielding *P. gaeumannii* (χ^2 tests).

DISCUSSION

Results of needle infection evaluated during the survey in southern British Columbia are presented as means in order to smooth out variation caused by factors such as year-to-year climate differences, or differences between local micro-climates in crowns of trees at each site. Mean infection varied regionally and fitted a distribution pattern related to recognised climatic and geographic regions within British Columbia. Possible factors influencing distribution include rainfall, temperature, and humidity. Strittmatter

(1974) demonstrated experimentally a dependence of infection development upon needle wetness and humidity during May–July, when sporulation occurs in the Northern Hemisphere (Rohde 1937; Ford & Morton 1971). Ford & Morton (1971) also found a relationship between 48-hour rainfall and spore release during May–July. In British Columbia significant regional correlation was found between mean infection and approximate mean rainfall during the May–July period. Infection was greater in the coastal and interior rainbelts and negligible in the drier intermountain region east of the Coast Range (delineated in Fig. 1 Interior by the 110 mm isohyetal). These facts suggest that rainfall may be implicated as one of the factors controlling distribution of *P. gaeumannii* in British Columbia. In Europe the existence of a relationship between rainfall or humidity and level of infection appears to be generally accepted (Merkle 1951; Durrieu 1957; Bonifacio *et al.* 1970; cf. Peace 1962). It may therefore be significant that the mean November–January 3-monthly rainfall is relatively high (250–350 mm; Department of Statistics 1980, p. 14) during the infection period (Hood & Kershaw 1975) in the central North Island of New Zealand compared to the mean May–July rainfall in much of British Columbia. In the central North Island, high infection (80–100%) was observed in stands less than 25 years old (Hood & Sandberg 1979; Hood & van der Pas 1979). Such high infection was also commonly found at sites along part of the very wet west coast of Vancouver Island where mean rainfalls around 200–300 mm occur during May–July. Foliage retention was comparatively high on samples collected during the survey, in agreement with other reports for British Columbia (Silver 1962). Needle retention was also relatively high in all plots in the thinning trial at Shawnigan Lake (cf. Brix 1981).

The Cowichan Lake provenance trial is unreplicated (one plot per provenance) and is limited by being only semi-randomised. Trees sampled were open crowned and growing on a site of moderate topography with no pronounced changes in relief. This implies that the large variation in infection by an air-dispersed fungus over short distances was due to variation in provenance resistance, as might be expected, rather than to any effect of local environment. Provenances from the region between the Coast Range and the eastern mountains in British Columbia, where negligible infection was found, were heavily infected at Cowichan Lake on the coast. On the other hand, infection was only light on most provenances and clones from the area west of the Coast-Cascade divide in British Columbia and Washington where natural infection was appreciable. Others (e.g., Schober 1963) have also observed provenance variation in resistance, although in a number of reports it is not always clear whether infection or needle retention levels are meant. The Cowichan Lake results contrast sharply with those of an 11-year-old trial at Rotorua in the central North Island of New Zealand, where between-provenance differences in infection were not observed (unpublished survey data; provenances did differ in mean needle retention). In the Rotorua trial all provenances were heavily infected, including five from widely scattered origins in the zone west of the Cascade Range in Washington and Oregon (No. 1, 3, 5, 8, 11 in the report by Sweet (1965)). Provenances from this zone were only lightly infected at Cowichan Lake (Fig. 2).

Earlier thinning has been recommended for the control of the growth decline of Douglas fir associated with *P. gaeumannii* in the central North Island of New Zealand

(Cameron *et al.* 1978). In a trial in Kaingaroa Forest, thinning to 220 or 740 stems/ha at age 17 years did not reduce infection which 5 years later remained greater than 80% (Hood & Sandberg 1979). Similarly, no effect of thinning was noticeable at Shawnigan Lake, Vancouver Island, where mean infection did not exceed 3%. It is still a possibility that at places where mean infection lies between these extremes thinning might be effective in reducing stand infection. It remains to be seen whether such localities occur in New Zealand.

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