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Blister Rust Testing in British Columbia: Choosing Inoculum Sources and a Screening Site

Abstract

In order to test for possible geographic variants in white pine blister rust (*Cronartium ribicola* J.C. Fisch.), four rust sources from British Columbia (BC), Canada were cultivated on *Ribes* spp. and used to inoculate sets of 2-year-old seedling progeny of 24 parents of western white pine (*Pinus monticola* D. Don). The six parents from Coastal United States possessed known rust defenses; six parents from Interior Washington, and Idaho, were considered somewhat resistant to rust, whereas 12 parents from BC (six from the Coastal zone and six from the Interior zone) were untested previously. All seedlings were inspected annually in transplant beds, where rust symptoms and stages were recorded.

A pooled source, composed of aeciospores from six lower-Coastal BC locations, was the most virulent, judged by infection percentage, highest mean spots per seedling, lowest spots-only response, shortest latency, greatest aecial production, and greatest mortality of infected seedlings. Combined data from the two Coastal rust sources, (pooled and Cowichan) demonstrated more virulence than both Interior sources (Nakusp and Valemount). No evidence was found to suggest that a unique race exists in the Cowichan source that overcomes spots-only resistance. Screening Interior western white pine for resistance to blister rust with pooled Coastal rust sources would be superior to using single or pooled Interior rust sources; therefore, only one Coastal inoculation facility is necessary to screen seedlings for both Coastal and Interior zones.

Introduction

The introduction of white pine blister rust (*Cronartium ribicola* J.C. Fisch.) to western North America produced a devastating epidemic in highly susceptible hosts, especially western white pine (*Pinus monticola* D. Don) (Bingham 1983). Within western white pine's range the gene pool of the rust is limited (White et al. 1996), probably because the introduction is known to have occurred only once from one nursery in France (Boyce 1948). This would suggest that differences in infection success would reflect mainly differences in host susceptibility. Exceptions are known, for virulence variation due to the rust has been demonstrated in a few locations (Kinloch and Comstock 1981, Kinloch and Dupper 1987, McDonald et al. 1984). Blister-rust-resistant selections from Idaho are highly susceptible near Cowichan, British Columbia (BC), but not elsewhere in BC, possibly because the gene pool of the rust is unique in this area (Hunt and Meagher 1989).

Such reports, and experience in plantations in BC (Hunt and Meagher 1989; Meagher 1988) indicated that rust screening for a white pine improvement program in BC (Meagher et al. 1990) might require use of different rust sources, perhaps different sources for each of two seed zones (Meagher and Hunt 1999). A trial to test for differences among rust sources in ability to infect seedlings and develop later stages, using aeciospores from four rust sources from BC, was initiated in 1987. Analyses of rust-spot (foliar lesion by rust) number per seedling and spot color at the first inspection were reported by Meagher (1991). Data of further infection success, rust development and seedling survival are analyzed here, to determine if separate rust sources and screening facilities are recommended for these two zones.

Material and Methods

Aeciospores from two Interior sources, Nakusp and Valemount, and two Coastal sources, Cowichan and " pooled" (Figure 1), were inoculated onto isolated wild groves of *Ribes bracteosum* Dougl. or cultivated *Ribes* spp. in spring, 1987. The pooled source was composed of leaves from groves infected separately by aeciospores from six Coastal rust sources, excluding Cowichan. A pooled Coastal source was chosen because it would be practical to collect aeciospores annually from

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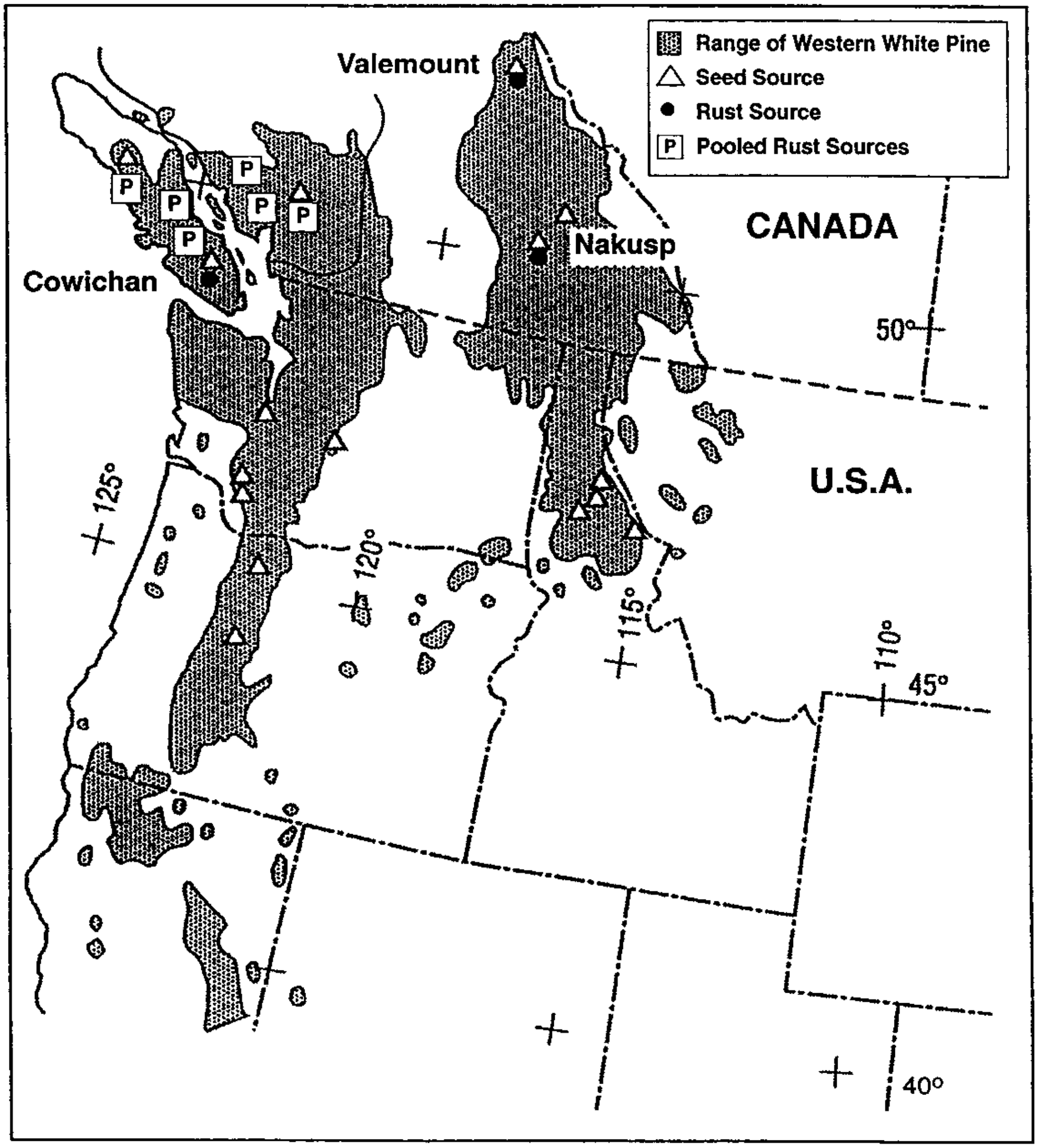

Figure 1. Northern range of *Pinus monticola* (stippled) showing sources of seed and rust sources

several Coastal sources, while it would be very difficult to make such collections from Interior sources, for annual screening trials. At each location (Figure 1) aeciospores were collected from a minimum of six blister rust cankers. Inoculation (Hunt 1988) of 2–year old seedlings occurred in a Coastal facility in September. Seed parents were located in each of two seed zones, Coastal and Interior, with six parents chosen from each of four regions [BC Coast, United States (US) Coast, BC Interior, and US Interior]. Parents from BC had not been tested vs. blister rust, whereas US parents had been tested, and selected. Each parent was represented by up to 10 seedlings in a row of movable Ray Leach "fir" cells® (Canby OR) per replicate. Sets, representing each parent, were randomized in 10 replicates per rust source.

Following spot counting, and classifying spots by color the next spring, all seedlings were transplanted in prepared ground near Victoria, BC. Seedlings were planted in replicate plots per seedlot within rust source with seedling identity in each replicate maintained to permit full concordance with earlier data per seedling. Seedlot and plot (replicate) number were marked on a stake at the start of each plot.

Inspection of each seedling was conducted annually, beginning in spring, 1989, and continuing to1993. In general, we followed the protocol of Hoff and McDonald (1980) with progressive rust stages recorded per seedling, as follows:

0 No rust signs or symptoms

1 Stem orange colored (sign), or rust spots (symptom) on 2-year leaves

2 Needle bases gouty (symptom)

3 Stem swollen (symptom) and orange colored (sign)

4 Pycnia produced (sign)

5 Aecia produced (sign)

6 Slow-canker-growth resistance (see Hunt 1997). This trait was recorded through to 1995.

Due to a change in property management, an entire bed of stock, including all of three seedlots, and part of another seedlot in the Nakusp rust source and most of one seedlot in the Valemount rust source, was removed after the 1990 inspection. Furthermore, inadequate soil drainage reduced survival sporadically throughout the transplant beds. Seedlings in such areas were omitted from the calculation of survival among seedlots and rusts.

Data analyses

Following examination of residuals, ARCSIN transformation of proportion data was used to attain normality.

Analyses of variance were conducted using SAS for Student-Neuman-Keuls (SNK) multiple-range testing at $P \leq 0.05$. Parameters tested were:

1. Infection success: proportion of seedlings infected with rust (showing any sign or symptom of rust, including spotted leaves in 1988).
2. Spots only (including needle shed): proportion of seedlings that shed spotted leaves, by spring 1989, or which exhibited no further rust symptoms, though spotted in 1988 [see McDonald and Hoff (1970) and Bingham (1983) for a description of this resistance].
3. Latency: mean years to first signs of stem rust (orange discoloration in the bark), by inspection year.
4. Aecial stage: proportion of infected seedlings exhibiting aecial stage, by year.
5. Slow-canker growth: proportion of infected seedlings exhibiting slow-canker growth.
6. Mortality: proportion of infected seedlings dead to date, by year.

All effects but replicate in rust were considered fixed. "Error" mean square was the testing term for all effects in the analytical model:

$$\text{Effect} = \text{mean} + \sigma^2_{\text{Rust source}} + \sigma^2_{\text{Rep (Rust source)}} + \sigma^2_{\text{Country}} + \sigma^2_{\text{Rust source (Zone)}} + \sigma^2_{\text{Region}} + \sigma^2_{\text{Parent (Region)}} + \sigma^2_{\text{Rust source*Region}} + \sigma^2_{\text{Parent(Region) * Rust source}} + \sigma^2_{\text{Error}}$$

Least-squares regression correlations of the later stages of development with rust spots were conducted on family mean spots per seedling, averaged among replicates within rust source. When results were combined across rusts, intra-rust spot means by family still were used, resulting in increased degrees of freedom.

Results

Infection success

Infection, here and elsewhere in the manuscript, is defined as seedlings with spots or other advanced symptoms or signs of rust. Results from 1990, 33 months after inoculation, are discussed here (Table 1a) because they are based on material prior to the removal of any stock and losses due to inadequate soil drainage. Infection by rust source varied from 59% (pooled) to 30% (Cowichan). However, Coastal rust sources, pooled and Cowichan, produced similar infection rates (44%) to both Interior rust sources, Nakusp and Valemount, (38%).

Infection differed by country (33% for US vs. 49% for Canada) ($P<0.0001$), by country in seed

TABLE 1a. Rust-infection percentage[1] of inoculated *Pinus monticola* in 1990, by seed source and rust source.

Seed Source		Rust Source[2]						
		Coastal			Interior			Mean
Country	Region	Pooled	Cow	Zonal mean	Nak	Vale	Zonal mean	all sources
Canada	BC Coast	69.5	32.2	50.8	32.4	49.8	41.1	46.0
	BC Interior	74.9	36.7	55.8	41.5	57.1	49.3	52.5
	Mean	72.3	34.4	53.3	36.9	53.5	45.2	49.2 A[3]
U.S.A.	US Coast	49.9	26.3	38.1	33.6	29.3	31.5	34.7
	US Interior	39.9	23.2	31.6	29.3	35.2	32.2	31.9
	Mean	44.9	24.8	34.8	31.5	32.2	31.8	33.3 B
	Mean all	58.5 A	29.6 C	44.1 A	34.2 BC	42.8 B	38.5 A	41.3

[1] Mean of percentage of infected seedlings by seed parent.

[2] Source of aeciospores. Pooled = a mix of Coastal sources; Cow = Cowichan; Nak = Nakusp; Vale = Valemount.

[3] Corresponding means followed by the same letter do not differ at $P \leq 0.05$ per the Student-Neuman-Keuls (SNK) test.

TABLE 1b. Analysis of variance of rust-infection percentage in 1990.

Source	df	Mean Square	F	Prob.
Rust source	3	3.616	88.1	0.0001
Rep (Rust source)	36	0.157	3.8	0.0001
Seed country ["Country"]	1	6.348	154.6	0.0001
Seed zone	1	0.587	14.3	0.0002
Country X Zone ["Region"]	1	0.859	20.9	0.0001
Parent (Region)	20	0.406	9.9	0.0001
Rust source X Country	3	0.342	8.3	0.0001
Rust source X Zone	3	0.041	1.01	0.3872
Rust source X Region	3	0.033	0.80	0.4914
Rust X Parent (Region)	60	0.124	3.02	0.0001
Error	798	0.041		

zone (35% vs. 46%, US vs. Canada, respectively, for Coastal zone and 32% vs. 53% for Interior zone) ($P<0.0001$) (Table 1), and by seed parent in country ($P<0.049$). The most susceptible stock came from the BC Interior region (52.5%), followed by the BC Coast (Table 1a). BC Interior stock consistently showed the highest infection by all rust sources, whereas either US Interior or US Coastal stock exhibited the lowest infection, depending on the rust source. The rust source X country term ($P<0.0001$) reflects mainly the higher susceptibility of seedlings from unscreened Canadian trees, especially to the pooled rust source.

However, the rust source X parent in region ($P<0.0001$) term indicates that the pattern of results is complex. Infection among seedlots ranged between 89.9%, by the pooled source, and 8.0% (US Coastal Seedlot 2444 by the Cowichan source). Positive correlations were found between family mean of rust spots per seedling and percentage of seedlings exhibiting stem signs or symptoms for the Valemount source ($R^2=0.22$, $P<0.012$) for Coastal rusts ($R^2=0.22$, $P<0.0004$) and for all rusts combined ($R^2=0.12$, $P<0.0004$).

Unspotted seedlings

Rust signs developed in 463 of 1424 (32.5%) unspotted seedlings by 1993. The percentage of such seedlings exhibiting rust differed among rust sources (Table 2), being highest from the pooled source and lowest from the Nakusp source. Coastal sources, both pooled and Cowichan, produced a

TABLE 2. Rust-infection percentage[1] to 1993 of unspotted *Pinus monticola* seedlings by seed source and rust source.

Seed Source		Rust Source[2]						
		Coastal			Interior			Mean
Country	Region	Pooled	Cow	Zonal mean	Nak	Vale	Zonal mean	all sources
Canada	BC Coast	61.4	19.9	40.6	12.6	36.7	24.6	32.6
	BC Interior	49.5	47.1	48.3	24.8	48.8	36.8	42.6
	Mean	55.4	33.5	44.4	18.7	42.7	30.7	37.5 A
U.S.A.	US Coast	44.0	32.4	38.2	23.8	39.4	31.6	34.9
	US Interior	40.7	32.8	36.7	11.5	33.7	22.6	29.6
	Mean	42.3	32.6	37.4	17.6	36.5	27.1	32.2 A
	Mean all	48.9	33.0	40.9	18.1	39.6	28.9	34.8
		A[3]	B		C	AB		
				A			B	

[1] Mean of percentage of infected seedlings by seed parent.

[2] Source of aeciospores. Pooled = a mix of Coastal sources; Cow = Cowichan; Nak = Nakusp; Vale = Valemount.

[3] Corresponding means followed by the same letter do not differ at $P \leq 0.05$ per the Student-Neuman-Keuls (SNK) test.

higher infection level than did both Interior sources (Nakusp and Valemount) (Table 2).

Spot Color

Only 1069 seedlings were found displaying one spot. This low frequency and scatter among sources precluded statistical analyses. However, when combined across sources, and grouped by color, "orange" spots were most efficacious (41.3% of 46 seedlings infected), followed by "Reddish" spots (red, red-brown and red-green combined, 61 seedlings) and "Yellowish" spots (yellow, yellow-brown and yellow-green combined, 792 seedlings) both at 36.9%, then by "Brownish" spots (brown and brown-green combined, 170 seedlings) at 26.5%. No obvious pattern between spot color and rust source was apparent.

Spots only

This rust symptom differed by rust source ($P<0.0001$), but also by country of seed origin ($P<0.0001$) and seed parent ($P<0.0001$). The interaction terms rust source X seed zone ($P<0.0177$), rust source X seed region ($P<0.0327$) and rust source X parent in region ($P<0.0005$) also were significant. The highest spots-only (SO) incidence was produced by the Nakusp source (51.3%), whereas the lowest was produced by the pooled source (30.7%) (Table 3).

Canadian seed parents averaged 30.8% showing SO, while US seed parents averaged 50.3%. The rust source X seed zone interaction seems due to the increased incidence of SO by Coastal families vs. Interior rust sources. Family mean rust spots per seedling was correlated negatively with increasing SO for the Valemount source ($R^2=0.60$, $P<0.0011$), for both Coastal ($R^2=0.40$, $P=0.0060$) and Interior sources ($R^2=0.37$, $P<0.0067$) and for all sources combined ($R^2=0.40$, $P<0.0001$).

Latency

Latency was affected by rust source ($P<0.0001$), country of seed origin ($P<0.0001$) and seed parent ($P<0.0001$), but also by the interaction of rust source X seed zone and interaction of rust source X seed parent in zone ($P<0.001$) (Table 4). The pooled source progressed to stem symptoms the quickest (mean time 1.4 years), while the Nakusp source was the slowest (mean time 2.0 years). Canadian seed sources exhibited stem rust significantly earlier than US seed sources: 1.6 vs. 1.9 years. The shortest mean time to exhibit stem rust (0.9 years) was found in a BC Coastal family inoculated with the Cowichan source, whereas the slowest-developing rust (3.1 years) was found in a US Coastal family inoculated with the same source. The rust source X seed zone interaction seems due to the slow development of the Valemount source vs. the pooled source in US

TABLE 3. Percentage[1] of rust-spotted *Pinus monticola* seedlings displaying Spots Only response, by seed source and rust source.

Seed Source		Rust Source[2]						
		Coastal			Interior			Mean
Country	Region	Pooled	Cow	Zonal mean	Nak	Vale	Zonal mean	all sources
Canada	BC Coast	24.5	31.1	27.1	50.2	32.7	41.4	34.9
	BC Interior	18.8	34.0	23.9	31.8	25.4	27.9	26.0
	Mean	21.6	32.3	25.6	42.8	29.0	35.3	30.8 B[3]
U.S.A.	US Coast	40.5	50.4	46.5	55.3	52.8	54.1	49.8
	US Interior	42.9	58.4	51.5	61.3	39.5	50.4	50.9
	Mean	41.5	54.4	48.0	58.3	46.2	52.3	50.3 A
	Mean all	30.7	45.6	37.4	51.3	37.6	44.1	41.0
		C	AB		A	BC		
				A			A	

[1] Mean of seed parents.
[2] Source of aeciospores. Pooled = a mix of Coastal sources; Cow = Cowichan; Nak = Nakusp; Vale = Valemount.
[3] Corresponding means followed by the same letter do not differ at $P \leq 0.05$ per the SNK test.

TABLE 4. Years to first stem symptom of rust (latency) on rust-spotted *Pinus monticola* seedlings[1], by seed source and rust source.

Seed Source		Rust Source[2]						
		Coastal			Interior			Mean
Country	Region	Pooled	Cow	Zonal mean	Nak	Vale	Zonal mean	all sources
Canada	BC Coast	1.38	1.66	1.49	1.79	1.39	1.59	1.55
	BC Interior	1.24	1.62	1.37	1.89	1.61	1.72	1.55
	Mean	1.31	1.64	1.43	1.83	1.50	1.65	1.55 B[3]
U.S.A.	US Coast	1.58	2.18	1.88	1.99	1.62	1.80	1.84
	US Interior	1.40	1.94	1.70	2.43	2.02	2.23	2.00
	Mean	1.51	2.07	1.81	2.21	1.82	2.02	1.92 A
	Mean all	1.40	1.90	1.63	2.04	1.66	1.84	1.71
		C	AB		A	BC		
				B			A	

[1] Mean of seed parents.
[2] Source of aeciospores. Pooled = a mix of Coastal sources: Cow = Cowichan: Nak = Nakusp; Vale = Valemount.
[3] Corresponding means followed by the same letter do not differ at $P \leq 0.05$ per the SNK test.

Interior stock. A positive correlation between latency and reduced family mean rust spots per seedling was found for only both Coastal sources combined (R^2=0.12, P<0.018) and for all sources combined (R^2=0.10, P<0.0015).

Aecial stage

The percentage of infected seedlings developing aecia increased throughout the study. This stage was affected by rust source (P<0.0001) for all years but 1991 (P<0.02) and 1992 (P<0.47). Incidence among sources in 1993 ranged from 57.5% to 39.2% (Table 5), when seedlings inoculated by the pooled source produced significantly (P<0.0001) more aecia than did seedlings inoculated by all other sources. (Table 5). Country of seed origin was always statistically significant for each inspection (P<0.0001 to 0.0235), and seed parent was significant in all years but 1990. Rust source X country of seed parent was statistically

TABLE 5. Percentage[1] of rust-infected *Pinus monticola* seedlings that developed aecia to 1993, by seed source and rust source.

Seed Source		Rust Source[2]						
		Coastal			Interior			Mean
Country	Region	Pooled	Cow	Zonal mean	Nak	Vale	Zonal mean	all sources
Canada	BC Coast	68.7	44.6	59.0	43.9	54.1	49.0	53.6
	BC Interior	62.7	57.9	61.1	32.3	45.2	40.1	50.0
	Mean	65.7	50.3	60.0 A[3]	39.3	49.6	44.9 B	51.9 A
U.S.A.	US Coast	49.4	30.4	39.9	46.4	38.4	42.0	40.9
	US Interior	45.1	36.9	41.0	32.9	34.4	33.6	36.6
	Mean	47.7	33.0	40.4 B	39.0	36.4	37.6 B	38.9 B
	Mean all	57.5	40.1	49.9	39.2	43.0	41.2	45.2
		A	B		B	B		
				A			B	

[1] Mean of seed parents.
[2] Source of aeciospores. Pooled = a mix of Coastal sources; Cow = Cowichan; Nak = Nakusp; Vale = Valemount.
[3] Corresponding means followed by the same letter do not differ at $P \leq 0.05$ per the SNK test.

significant in all years, apparently due to reduced aecial production by the Cowichan and Valemount source on US seedlings. The significant rust source X seed zone term ($P<0.015$) seems due to the high value of the pooled source on Coastal stock vs. the low value of the Nakusp source on Interior stock. A significant, positive, correlation with increasing family mean rust spots was found for all sources combined ($R^2=0.09$, $P<0.0029$) and for both Coastal sources combined ($R^2=0.22$, $P<0.0015$).

Slow-canker growth

The incidence of slow-canker growth resistance (SCG) in infected seedlings was low, ranging from 0.3 to 8.3% (Table 6). The previously selected US seed sources had significantly more SCG individuals than the untested BC sources. The

TABLE 6. Percentage[1] of seedlings demonstrating slow-canker growth to 1995, by seed source and rust source.

Seed Source		Rust Source[2]						
		Coastal			Interior			Mean
Country	Region	Pooled	Cow	Zonal mean	Nak	Vale	Zonal mean	all sources
Canada	BC Coast	2.6	0.6	1.6	2.4	2.3	2.4	2.0
	BC Interior	0.5	0.4	0.5	0.3	0.3	0.3	0.4
	Mean	1.6	0.5	1.0	1.5	1.5	1.5	1.2 A[3]
U.S.A.	US Coast	3.1	1.6	2.4	5.0	2.9	4.0	3.2
	US Interior	3.3	4.7	4.2	8.3	4.8	6.4	5.3
	Mean	3.2	3.2	3.2	6.4	3.9	5.1	4.2 B
	Mean all	2.3	1.9	2.1	4.6	2.8	3.6	2.8
		AB	B		A	AB		
	A	A						

[1] Mean of seed parents.
[2] Source of aeciospores. Pooled = a mix of Coastal sources; Cow = Cowichan; Nak = Nakusp; Vale = Valemount.
[3] Corresponding means followed by the same letter do not differ at $P \leq 0.05$ per the SNK test.

TABLE 7. Percentage[1] mortality of rust-infected seedlings through 1993, by seed source and rust source.

Seed Source		Rust Source[2]						
		Coastal			Interior			Mean
Country	Region	Pooled	Cow	Zonal mean	Nak	Vale	Zonal mean	all sources
Canada	BC Coast	86.5	84.3	85.6	88.0	79.2	83.6	84.5
	BC Interior	95.7	82.3	91.2	79.0	81.6	80.5	85.6
	Mean	91.1	83.5	88.3	84.4	80.4	82.2	85.0 A[3]
U.S.A.	US Coast	87.9	62.5	75.2	68.2	62.3	65.0	70.3
	US Interior	84.4	75.2	79.3	63.5	58.9	61.2	68.9
	Mean	86.5	68.8	77.0	65.6	60.6	63.0	69.7 B
	Mean all	88.6	74.6	82.4	76.0	70.5	72.4	77.4
		A	B		B	B		
				A			B	

[1] Mean of seed parents.

[2] Source of aeciospores. Pooled = a mix of Coastal sources; Cow = Cowichan; Nak = Nakusp; Vale = Valemount.

[3] Corresponding means followed by the same letter do not differ at $P \leq 0.05$ per the SNK test.

Cowichan rust source appeared to lower the incidence of SCG significantly compared to the Nakusp source; however, this did not hold for US seed lots inoculated by the Cowichan rust source (Table 6). The incidence of slow-canker growth was not correlated with family mean spotting ($P<0.45$).

Mortality of Infected Seedlings

This parameter was affected significantly by rust source ($P<0.0001$), country of seed parent ($P<0.0001$), seed parent ($P<0.0010$), the interaction of rust source X country ($P<0.0074$), and the interaction of seed parent X rust source ($P<0.0019$). Mortality averaged 77.4%, but varied among rusts from 88.6% (pooled) to 70.5% (Valemount) (Table 7). Coastal-zone rusts caused greater mortality (82.4%) than did Interior-zone sources (72.4%). Infected US seedlings survived better (69.7% mortality) than did BC seedlings (85.0% mortality). The rust source X country significance seems due to the high impact of the pooled rust source on US stocks vs. the other sources. Nakusp was the only rust source to produce a significant correlation ($R^2=0.25$, $P<0.0124$) between mean spots and mortality. However, there was a significant correlation of mortality with increasing family mean rust spots for all rusts combined ($R^2=0.13$, $P<0.0007$) and for Coastal ($R^2=0.08$, $P<0.0441$) and Interior ($R^2=0.08$, $P<0.0313$) zone rust sources.

Discussion

Differences among the rust sources were found at each stage of this trial, due mainly to the pooled source. It produced the highest average number of spots per seedling and the most 1-spot trees (Meagher 1991), the lowest incidence of SO seedlings, but the highest level of rust development on "unspotted" seedlings, the shortest latency, the highest percentage of seedlings producing aecia, and the highest mortality of infected seedlings. The other rusts showed less distinction. However, the Cowichan source ranked second to the pooled source in low incidence of SO, latency, and aecia percentage. Both Coastal sources (pooled and Cowichan combined) produced more infection, including of "unspotted" seedlings, less SO response, shorter latency, higher aecia percentage and greater mortality of infected seedlings than did Interior sources. These results parallel the pooled source results fairly strongly. Both Coastal sources had a low incidence of SCG compared to the Interior sources, but the difference was significant for only the Cowichan and Nakusp sources. On no-spot and 1-spot seedlings, the pooled source was most successful at progressing to stem infection. Thus, the greater virulence of the pooled source may reflect more genetic breath than was obtained from the point samples of the remaining sources.

Racial variation in the rust, based on spot color (McDonald and Hoff 1975), was summarized by Hoff (1988). Similar spot colors were found in this study and none were associated with specific rust sources.

Because insects disperse pycniospores from one canker to another (Hunt 1985), thus conveying DNA from one infection to another, the resulting aeciospores from a single canker are genetically heterogeneous. Analysis of ribosomal DNA from 24 BC locations, including all of the sources tested here, revealed much intra-site variation, but no consistent geographic pattern (White et al. 1996). Further studies, employing isoenzymes, random-amplified DNA and restriction enzyme polymorphism markers in the rust, found no geographic pattern of variation (Kinloch et al. 1998). Those data are compatible with the results obtained here with the point sources of the rust.

Comparing results from only untested BC parent trees, SO resistance was more frequent against Interior rust sources, especially Nakusp, than against Coastal sources (Table 3). This trend was apparent in US parent trees (Table 3), which were selected for known infectability and putative resistance mechanisms, including SO (Meagher 1991). Previously, Hunt and Meagher (1985) suggested that a new strain may be responsible for failure of plantations possessing needle-shed resistance (a type of SO resistance) at Cowichan. In this study, SO resistance is significantly less with Coastal rust sources compared to Interior sources (Table 3), suggesting that gene-frequency differences may cause greater virulence in Coastal sources, including Cowichan. However, this did not result in increased mortality, since mortality was similar with the Cowichan rust source and the pooled or Interior sources in all stocks (Table 7). Similar mortality with all sources suggests that Coastal environmental factors are more important in reducing the effectiveness of needle-shed resistance than are the rust sources. Plantations of stocks possessing needle-shed resistance exhibit good field resistance in the Interior of BC and on a high-elevation Coastal site (Hunt 1994), perhaps because the growing season for the rust is short compared to on low-elevation Coastal sites.

Latency of our most-virulent source (pooled) was the shortest; in contrast, McDonald et al. (1984) found that the more-virulent Champion Mine source displayed increased latency, as well as reduced needle shed.

Analyses of variance show that rust source always was a factor in a significant interaction term, and that seed parent generally was included in the same interaction, indicating that the parents responded differently to the sources employed. Therefore, variation in host response to blister rust can be attributed to variability in the host or pathogen, or both. Similarly complex interaction was found in analyses of rust-spot frequency in this same test (Meagher 1991), so persistence of this interaction is not unexpected.

Correlations with increasing mean spots per parent were found for factors associated with increased infection, i.e., stem signs and symptoms, and greater mortality, while correlations with fewer mean spots per parent were found with increasing latency and increasing SO. Perhaps selecting families for reduced spotting is not only a selection for less infection, but also for these other resistant traits. This needs further investigation. SCG seems to be independent of needle spotting frequency.

All families screened in our programs for selection of seed-orchard material in BC have been subjected to inoculation by a pooled mixture of Coastal rust sources at one Coastal facility. The use of a pooled mixture satisfies logistics when obtaining aeciospores for *Ribes* inoculations and results in a stern test of our selected materials.

Acknowledgements

The assistance of the following is acknowledged with gratitude: Dr. P. Theisen, Portland, OR, Dr. R.J. Steinhoff, Dorena, OR and G.C. Franc, Moscow, ID, all of the US. Forest Service, for supplying seeds from US. parents; Silviculture Branch, BC. Forest Service, for supplying inoculation and transplant facilities and funding for seedling inspections and maintenance; H. Craig, D. Craigdallie, J. Dronzek, G. Jensen and G. Lait, Canadian Forest Service, for technical support. The diligence and helpful suggestions of E. Allen, G. Jensen and E. White of the Pacific Forestry Centre are gratefully acknowledged.

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Received 2 February 1999
Accepted for Publication 29 June 1999