The spread of white pine blister rust in young white pine plantaions

André Lavallée

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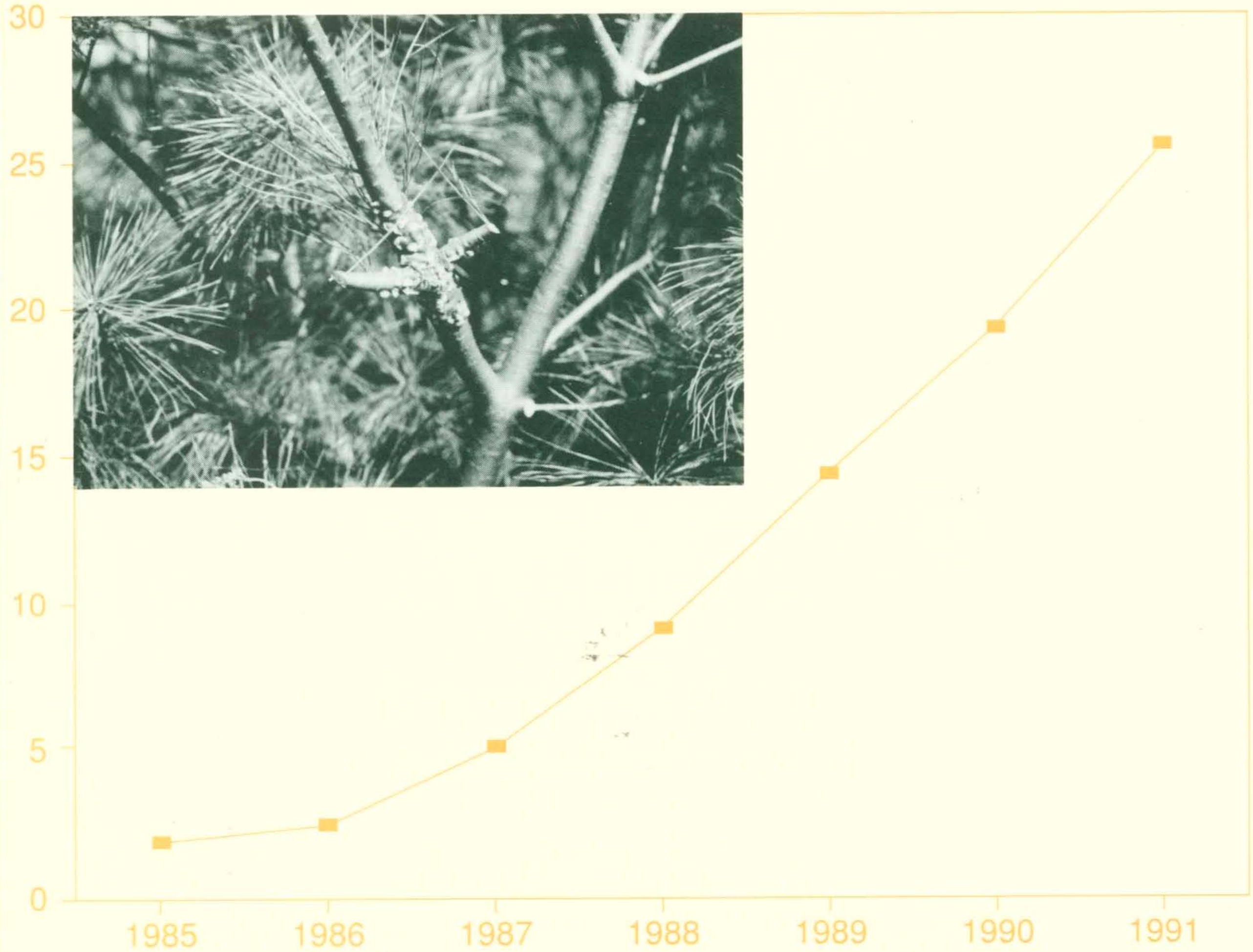

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André Lavallée, Ph. D.

Mr. Lavallée's work focuses primarily on the selection of plantation sites, white pine in particular, with a view to heading off the major problems that effect these plantations. Past work centred on many other problems that beset plantations and natural forests. Since 1960, André Lavallée has been part of the LFC team; he obtained his Ph.D. in forest pathology from Université Laval in 1969.

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INTRODUCTION

White pine blister rust (*Cronartium ribicola* Fischer) has long been recognized as the principal disease affecting white pine (*Pinus strobus* L.) both in Quebec (Pomerleau 1932) and in the rest of North America (Spaulding 1922). In Quebec, surveys demonstrating the gravity of this disease were first carried out in natural forests and then in plantations 15 or more years old (Pomerleau and Bard 1969; Plourde et al. 1991). Even at this early age, some disastrous situations were reported, but we had no survey information available on younger plantations that would have enabled us to determine when action should be taken in various parts of these plantations.

Since 1985, 16 plantations located in southern and central Quebec have been examined yearly in order to document the rate of progress of blister rust from its earliest occurrence. The specific environment of each of the stations was examined in order to characterize areas where rust progressed rapidly before the forest cover was completely closed. Observations were also made of the location of cankers on these young trees to determine whether control measures might benefit young plantations. Some control action in these young plantations might seem premature, but excessive losses due to mortality must be avoided if we want a closed cover and less effort in controlling the disease after the fact. If such measures do become necessary, they will be all the easier to apply since most of the existing white pine plantations are fairly small, with only a few thousand stems.

MATERIAL AND METHODS

The location of plantations studied is shown in Figure 1. The total number and age of trees in the plantation and the number of trees examined in corresponding study sites (s.s.) are listed in Table 1. In all these plantations, spacing between stems was 2.0 or 2.5 m and the sample plot was rectangular (approximately 10 rows of 50 trees) which represents approximately 0.2 ha per study site. When possible, this rectangle was situated near the centre of the plantation to reduce the border effect when taking measurements.

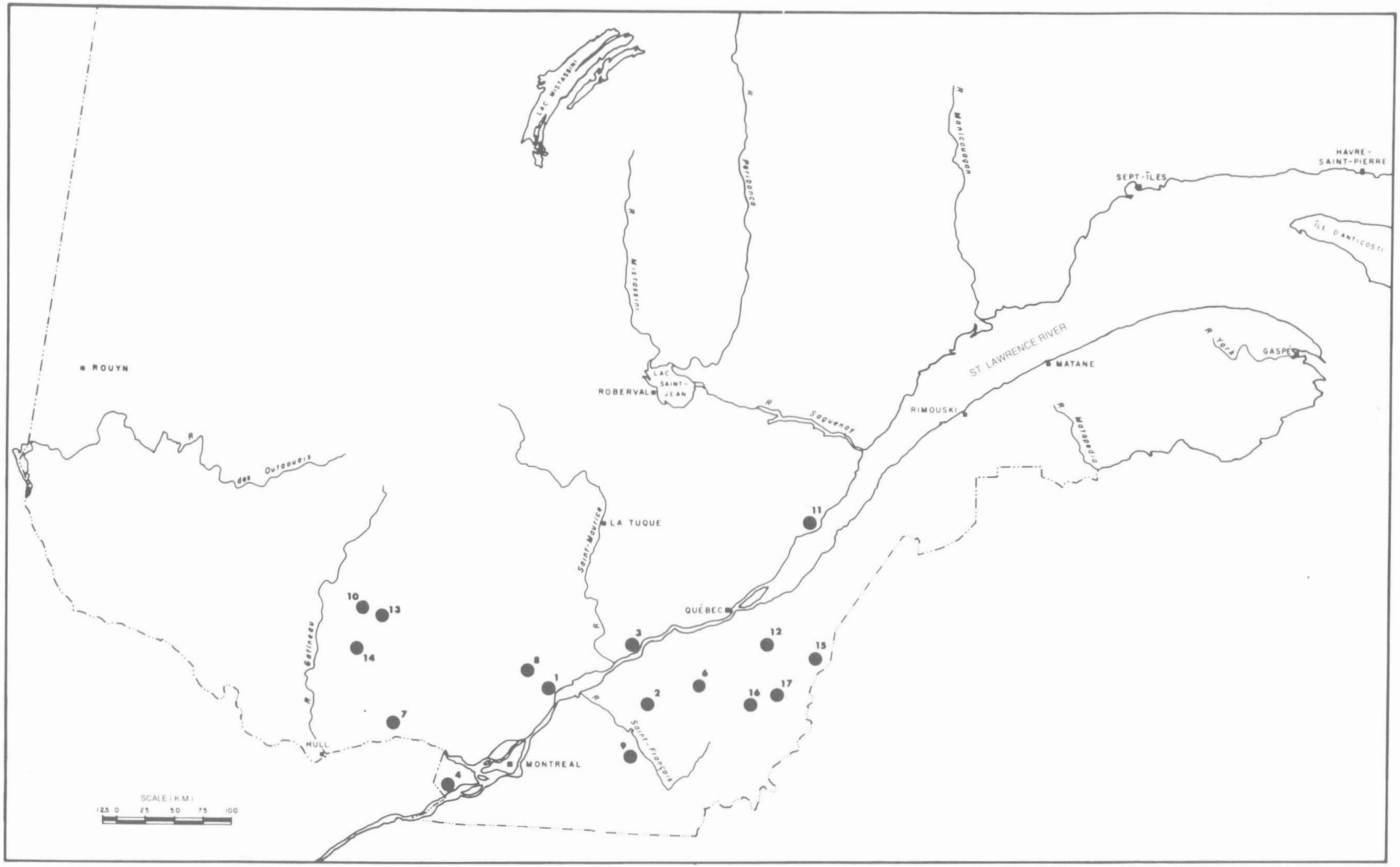

Figure 1. Geographical location of plantation sites used for study of the spread of white pine blister rust.

Table 1. Location of plantations and description of sites for study of the progress of white pine blister rust

No., location, census div. s.s.	Number of trees examined	Total number of white pine	Age in 1986	Start of observations
01 Saint-Cuthbert, Berthier	504	3,000	6	1985
02 Sainte-Clothilde, Arthabaska	509	10,000	6	1986
03 Saint-Luc, Champlain	542	5,000	6	1986
04 Riv.-Beaudette, Soulanges	512	3,500	6	1985
06 Plessisville, Mégantic	842	5,000	6	1988
07 Saint-André-Avellin, Papineau	514	20,000	5	1985
08 Sainte-Béatrix, Joliette	522	2,000	6	1985
09 South Durham, Drummond	516	2,000	6	1985
10 Ferme-Neuve, Labelle	497	3,000	8	1985
11 Saint-Hilarion, Charlevoix	537	20,000	5	1985
12 Saint-Malachie, Dorchester	503	3,000	6	1985
13 Chute-Saint-Philippe, Labelle	516	1,000	8	1985
14 Lac-des-Iles, Labelle	507	1,500	8	1985
15 Saint-Magloire, Bellechasse	514	2,000	6	1985
16 Cap-Poulin, Beauce	500	1,500	6	1986
17 Saint-Alfred, Beauce	500	2,500	7	1986

Within this rectangle, all white pines were examined annually to count affected stems beginning in either 1985, 1986 (for s.s. 02, 03, 16, and 17) or 1988 (s.s. 06). In general, observations continued until 1990 inclusive except at sites 01, 09 and 13 where readings ended in 1989 due to circumstances beyond our control; sites 02, 03, 10, 11, 15, and 17 were examined again in 1991. At least five years of follow-up was thus carried out for almost all study sites.

To characterize the spread of blister rust in these young plantations, the following observations and measurements were made: total height and annual growth of affected and healthy trees, position of canker (distance between base of canker and ground) and length of canker, diameter of affected branch or trunk (measured at base of canker), proportion of circumference affected, and distance between the base of the canker on the branch and the trunk. In addition to enabling us to establish the annual percentage of trees affected on branches and on the trunk, these measures were intended to determine how quickly the rust canker could move from the branches to the trunk and thus assess the benefit of certain prescriptions for pruning of affected branches. From the position of the canker on the tree, we can determine how quickly the disease can kill a branch or young trunk.

To characterize study sites, a soil pit was dug near the centre of each sample plot to identify soil type, texture of various horizons, and other soil characteristics. Descriptions and measurements for physical and chemical analyses were made with the methods used by Lethiecq and Régnière (1988). Since they bore little relation to the epidemiology of blister rust, detailed results of soil analyses will not be presented in this document. However, interested readers may consult them in Lavallée (1992).

RESULTS AND DISCUSSION

Number of trees affected or killed by white pine blister rust between 1985 and 1990

When observations began, trees affected on branches were fewer than those with cankers on the trunk. At the end of observations (1989 or 1990) the proportion of trees affected on branches was greater than that of trees affected on the trunk in most of the plantations examined (Table 2). Infections on trees less than 5 years old were located on or very close to the trunk and constituted lethal attacks for the tree. It is even possible that some seedlings were killed before the age of 5; if this could have been observed, this number would have been added to the first survey data. With time, the point of penetration of rust (on needles) gets farther away from the trunk and the cankers stay longer on the branches before moving to the trunk. This phenomenon gives an idea as to the benefit of pruning between the ages of 5, 10, or 12 years in locations where the proportion of cankers on branches increases rapidly.

Factors related to progression of the disease

Initial level of infection and zones of sensitivity

In 1985 or 1986, all plantations showed less than 2% of trees affected on the trunk except at South Durham (09) where even at 5 years, over 9% of trees were affected or dead; the site located at Plessisville (06) showed approximately 5% of 8-year old trees affected by rust in 1988 (Table 2). Blister rust spread very rapidly during the observation period in these two plantations, as at Saint-Malachie (12) and Saint-Magloire (15). The level of trees attacked or killed during this period exceeded 20% in each of these plantations and the average annual rate of new attacks exceeded 3% in every case (Table 3). In 1991, two of these study sites were measured (06 and 15) and the rate of new attacks was again much higher than 3%.

Table 2. Number and percentage (%) of trees affected on the trunk or branches at the beginning and end of the observation period

No. and location	Total no. of trees examined	No. and (%) of trees affected*			
		Start(1985)		End(1990)	
		Trunk	Branches	Trunk	Branches
01-Saint-Cuthbert[b]	505	1(0.2)	1(0.2)	9(1.8)	17(3.4)
02-Sainte-Clothilde[a]	510	2(0.4)	1(0.2)	9(1.8)	7(1.4)
03-Saint-Luc[a]	542	1(0.2)	0	3(0.6)	3(0.6)
04-Rivière-Beaudette	512	9(1.8)	15(2.9)	30(5.8)	42(8.2)
06-Plessisville[c] [1]	418	14(3.3)	20(4.8)	33(7.9)	73(17.5)
[2]	424	29(6.8)	26(6.1)	65(15.3)	99(23.2)
07-Saint-André-Avellin	513	0	0	6(1.2)	19(3.7)
08-Sainte-Béatrix	522	1(0.2)	0	6(1.1)	8(1.6)
09-South Durham	515	47(9.1)	53(10.3)	127(24.7)	86(16.7)
10-Ferme-Neuve	497	5(1.0)	1(0.2)	21(4.2)	36(7.2)
11-Saint-Hilarion	537	0	0	9(1.7)	27(5.0)
12-Saint-Malachie	513	4(0.8)	6(1.2)	20(3.9)	134(26.1)
13-Chute-Saint-Philippe[b]	516	4(0.8)	3(0.6)	7(1.4)	19(3.7)
14-Lac-des-Iles	507	6(1.2)	3(0.6)	17(3.3)	14(2.8)
15-Saint-Magloire	516	8(1.5)	2(0.4)	28(5.4)	84(16.3)
16-Cap-Poulin[a]	500	2(0.4)	2(0.4)	22(4.4)	36(7.2)
17-Saint-Alfred[a]	500	3(0.6)	3(0.6)	17(3.4)	22(4.4)

* Including trees killed by rust
[a] Started in 1986; [b] Ended in 1989; [c] Started in 1988
[1] Blocks 1 and 4 farthest from *Ribes*
[2] Blocks 2 and 3 closest to *Ribes*

A very low level of infection at the beginning of the observation period resulted in slow spread of the disease during the following five years. The only sites where fewer than 2% of trees killed or affected on the trunk were noted after 5 or 6 years (Table 2) were those with close to or fewer than 1% of trees affected when observations began (Table 3); often the average annual rate of new attacks was less than 1% for the study period. Plantations with low levels of infection and slow spread of rust accounted for 35% of the total of 17 study sites located in 16 plantations; these were s.s. 01, 02, 03, 07, 08, 11, and 16 (the last being the exception to the rule). The locations where rust progressed slightly represent 75% of the s.s. of Zone 1 and 50% of those in Zone 2 (Lavallée 1986).

Table 3. Percentage of newly attacked trees and rate of progress of white pine blister rust during the study period

No. and location	% of trees affected* Start(1985)	End(1990)	Average annual rate (%) of new infection
01-Saint-Cuthbert[b]	0.4	7.4	1.8
02-Sainte-Clothilde[a]	0.6	3.1	0.6
03-Saint-Luc[a]	0.2	1.1	0.2
04-Rivière-Beaudette	4.7	12.3	1.5
06-Plessisville[c] [1]	8.1	25.4	8.6
[2]	12.9	38.5	17.8
07-Saint-André-Avellin	0.0	5.7	1.2
08-Sainte-Béatrix	0.2	3.7	0.7
09-South Durham[b]	15.5	28.3	3.2
10-Ferme-Neuve	1.2	11.5	2.1
11-Saint-Hylarion	0.0	6.7	1.3
12-Saint-Malachie	2.0	36.1	6.8
13-Chute-Saint-Philippe[b]	1.3	5.2	1.0
14-Lac-des-Iles	1.6	5.3	0.7
15-Saint-Magloire	1.9	21.7	4.0
16-Cap-Poulin[a]	0.8	11.8	2.7
17-Saint-Alfred[a]	1.2	7.8	1.6

* Including trees killed by rust
[a] Started in 1986; [b] Ended in 1989; [c] Started in 1988
[1] Blocks 1 and 4 farthest from *Ribes*
[2] Blocks 2 and 3 closest to *Ribes*

In the majority of other study sites (04, 10, 13, 14, and 17), between 5 and 12.3% of trees were found to be affected or dead in 1989 or 1990 and the average annual rate of new infections was between 0.8 and 2.1% for trees with an initial level of infection between 1 and 4.7%. In 1991, two of these study sites (10 and 17) were measured, and both again showed an average rate of new infections of less than 2.1%. In this latter group, study sites 13, 14, and 17 were in Zone 3 while s.s. 04 and 10 were in zones 1 and 2 respectively.

Although the zones of sensitivity to blister rust may serve as a general guide for choosing white pine plantation sites, we observed that each local site displayed specific environmental conditions. As we will see further on, these factors are hard to narrow down.

Moreover, when a high initial level of infection by white pine blister rust was observed in a 4 to 6 year old plantation, the losses occurring five years later seem to be consistently high, although the opposite is not necessarily true (Figure 2). If a low level of infection is observed toward the age of 5 or 6 years, this is not enough to conclude that there is no risk of heavy damage. The plantation should thus initially be examined at the age of 5 years to detect areas of high concentration of the disease and to begin combatting it. However, it would also be wise to plan a second survey 3 to 5 years later even in plantations with a low attack level. For example, at Saint-Magloire (s.s. 15), a low level of infection was observed in 1985 (Figure 3) but in 1991, the percentage of trees affected was close to 30%. A 1989 examination would have detected this trend.

We also noted that the spread of blister rust reflected sensitivity zones fairly closely (Figure 3). S.s. 02 and 03 in Zone 1 showed low levels of infection (Figure 3), while s.s. 10 and 11 with a moderate level of infection were in Zone 2, and s.s. 15 and 17, which were more severely affected, were in Zone 3 of sensitivity of white pine to rust (Lavallée 1986).

Age of plantation

If we refer to the age of plantations in 1986 (Table 1), at the beginning of this study, we see that the most severely affected plantations at both the beginning and the end (09, 06, 12, and 15) of the observation period were no older than the others and thus had not been exposed any longer to the disease. Moreover, plantations that were 8 years old in 1986 showed low levels of infection (between 1.2 and 1.6%) (Table 3) even though they were older.

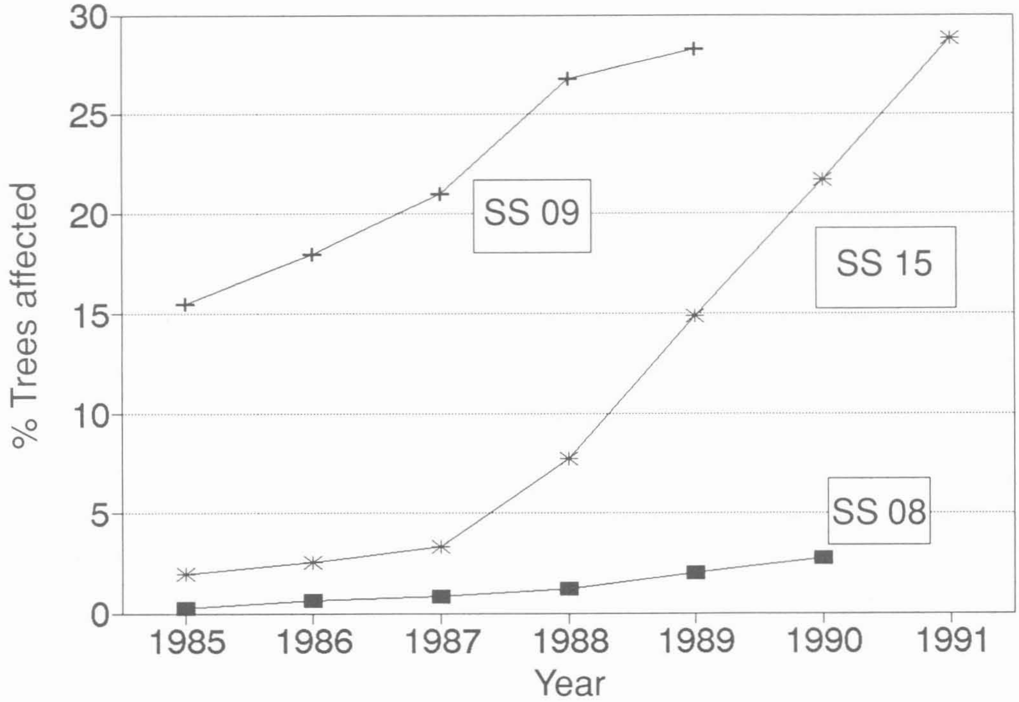

Figure 2. Annual progress of blister rust based on various levels of infection (s.s. 08 = Sainte-Béatrix; 09 = South Durham; 15 = Saint-Magloire).

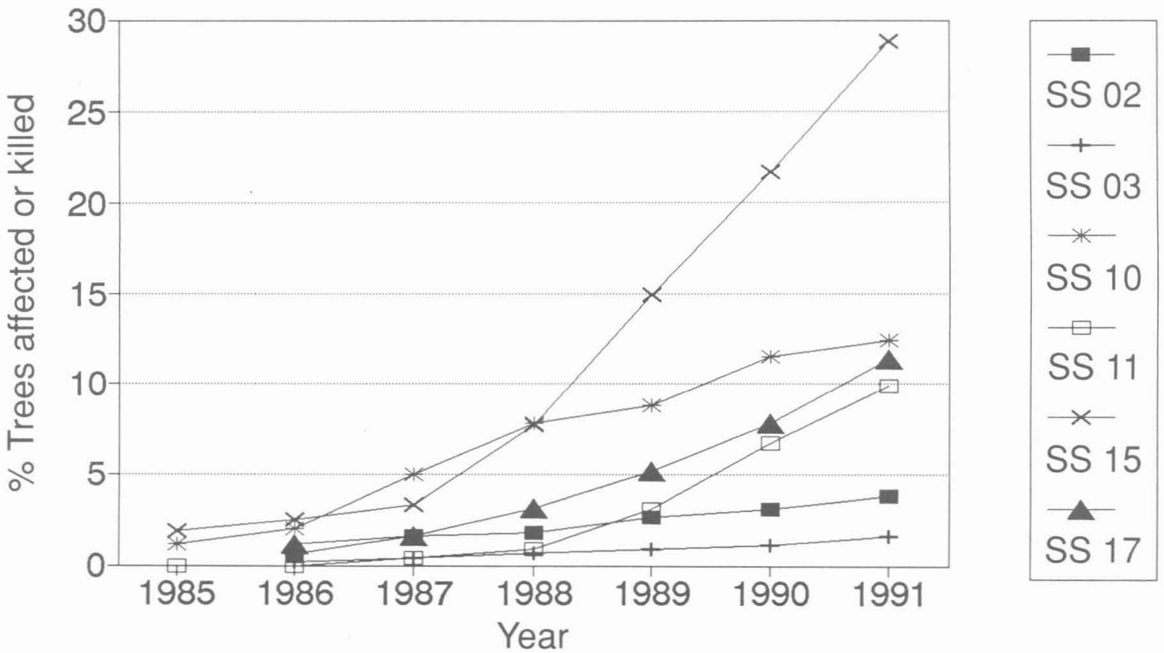

Figure 3. Cumulative spread of white pine blister rust in study sites examined up until 1991 (s.s. 02 = Sainte-Clothilde; 03 = Saint-Luc; 10 = Ferme-Neuve; 11 = Saint-Hilarion; 15 = Saint-Magloire; 17 = Saint-Alfred).

Therefore, the absolute age of the plantation does not seem to explain the levels of infection observed in the young study plantations. It is, however, recognized that the sensitivity of Eastern white pine to blister rust infection decreases with age (Patton 1961). Thus, plantations with a low level of infection at the ages of 10 or 12 years have a better chance of avoiding disaster.

Height and growth of trees

As white pine blister rust is caused by an obligate parasite, it is possible that the pathogen prefers to attack healthy, fast-growing trees (Hiratsuka and Powell 1976). Annual measurements of total height and annual growth of attacked and healthy white pines were thus compared for locations and years in which the data allowed us to obtain a mean based on more than 10 affected trees. This condition occured 18 times during the study period (Table 4).

Averages for small independent samples were compared (T test). At the 0.05 probability threshold, we noted no significant difference in the average total height of affected trees (average height for the year before attack) and healthy trees in the same plantation. The average rate of annual growth of these affected trees (average height for the year before attack) proved to be significantly greater than that of healthy trees in only 3 of the 18 cases examined, i.e. 16.7% of cases. At the probability threshold of 0.10, the total height and annual growth of affected trees was found to be significantly greater than those of healthy trees in only 1 and 6 cases out of 18.

Thus, in plantations between 5 and 10 years of age, this phenomenon of preference of healthy trees is hard to check within a given plantation. The phenomenon is no clearer when comparing these parameters between plantations, although the situation may differ in a natural forest.

For Haddow (1956), the rate of infection in natural stands is generally higher in the taller trees. However, analysis of our data on the total height and annual growth of affected and healthy trees in study plantations tends to indicate the contrary. Cafley (1958) obtained similar data to ours in Ontario. It is likely that when attacked trees grow larger, they withstand infection longer than small trees before being completely girdled; they are thus more numerous, but not necessarily preferred, by blister rust.

Table 4. Total height and annual growth of healthy trees and trees affected for the first time by white pine blister rust (average of 10 or more trees affected)

Study site No. Location	Year	Healthy trees Average			Affected trees Average			T test (significant)			
								Prob. 0.05		Prob. 0.10	
		N	Ht (m)	Gr. (cm)	N	Ht (m)	Gr. (cm)	Ht	Gr.	Ht	Gr.
04-Riv.-Beaudette	89	17	2.0	28.3	11	2.1	15.0	-	2.049	-	1.702
	85	42	0.9	20.9	10	1.1	24.6	-	-	1.676	-
09-South Durham	89	53	4.2	77.8	13	4.1	68.5	-	-	-	1.669
	88	61	3.4	68.3	23	3.3	63.7	-	-	-	-
	87	88	2.7	53.6	13	2.9	56.9	-	-	-	-
	86	109	2.2	60.4	13	2.3	61.8	-	-	-	-
	85	107	1.6	42.8	68	1.5	38.3	-	-	-	1.653
10-Ferme-Neuve	89	6	2.4	31.8	10	2.2	36.7	-	-	-	-
	88	19	2.0	33.6	14	2.2	40.7	-	-	-	1.690
	87	86	1.8	23.7	15	1.9	27.7	-	-	-	-
11-Saint-Hilarion	89	56	1.4	32.9	12	1.5	33.1	-	-	-	-
12-Saint-Malachie	89	54	3.0	67.6	24	2.9	72.0	-	-	-	-
	88	62	2.3	43.3	30	2.2	41.1	-	-	-	-
	87	82	1.8	26.3	12	1.8	27.3	-	-	-	-
	86	81	1.6	32.6	18	1.6	39.7	-	1.984	-	1.661
15-Saint-Magloire								-	-	-	-
	89	34	2.4	60.7	44	2.3	58.6	-	-	-	-
	88	74	1.7	36.7	21	1.8	39.6	-	-	-	-
17-Saint-Alfred	89	35	2.9	63.6	10	3.0	73.8	-	2.015	-	1.680

Physical characteristics of plantations

The site index, drainage category, soil texture, and exposition of plantations gave no valid correlation to explain differences in the rates of attack by blister rust from one location to another (Table 5), nor did the results of physical and chemical analyses of the various reference horizons in the soil profiles of plantations show any relation between soil fertility and the rates of attack by white pine blister rust.

Analysis did, however, reveal that the soil of all the study plantations was very deficient in both phosphorus (P) (1 to 43 ppm vs 150 required) and magnesium (Mg) (0.01 to 0.16 meq/ 100g vs 0.62 required). Apart from one or two exceptions, these soils are also low in potassium (K) (0.01 to 0.12 meq/ 100g vs 0.19 required) (Lavallée 1992).

Proximity of alternate host, *Ribes* spp

During the study period, between 2 and 7 hours were spent looking for *Ribes* (currants, gooseberries) in and around each of the plantations. Between 20 and 50 m of land around the plantations were carefully screened.

In four of the six plantations most affected by blister rust, *Ribes* was found on areas of over 4 m^2 very close to, or even on, the study sites (Table 5). In and around the five moderately affected plantations, *Ribes* was detected at only 20 m from the plantation, as was the case at Cap-Poulin (16). In the group least affected by rust, *Ribes* plants were found in the vicinity of three plantations, but over smaller areas (Table 5) and occasionally at 50 m from the plantation.

Although we do not overestimate the significance of this non-exhaustive and certainly non-systematic survey, it does seem probable that the proximity and abundance of *Ribes* around plantations contributed to the premature onset and spread of the disease in the plantations currently most affected.

One of the best examples of this phenomenon is given by the analysis of sample sites in Plessisville (06) which could be divided into four blocks that coincidentally lay on either side of a concentration of *Ribes hirtellum* Michx. The group of trees (424) beside this source of infection had 12.9 and 38.5% of trees affected in 1988 and 1990 respectively. Moreover, the group of 418 trees around this block, and thus further from the source of infection, had 8.1 and 25.4% of trees affected at the same dates (Table 3). In 1991, the closest blocks contained 50% of affected trees compared to 29.4% for the farthest.

Table 5. Site characteristics of plantations affected by white pine blister rust

Location and severity	Drainage*	Site Index+	Texture	Exposure	*Ribes*#
High					
09 South Durham	3	12	Sandy loam	Level	-
06 Plessisville	1	8	Loam	Southwest	3
12 Saint-Malachie	4	9	Loam	North	3
15 Saint-Magloire	2	9	Sandy loam	Southeast	2
04 Riv.-Beaudette	1	8	Loamy sand	Level	2
10 Ferme-Neuve	1	7	Sand	Level	-
Moderate					
01 Saint-Cuthbert	3-4	10	Sand	Southeast	-
16 Cap-Poulin	4	8	Gravelly loam	Northeast	3
13 Chute-Saint-Philippe	1	7	Loamy sand	East	-
17 Saint-Alfred	3	10	Loam	North	-
14 Lac-des-Iles	1	7	Sandy loam	Level	-
Low					
02 Sainte-Clothilde	4	10	Clayey loam	Level	2
11 Saint-Hilarion	2	6	Sandy loam	Northwest	2
07 Saint-André-Avellin	2	8	Loamy sand	Level	1
08 Sainte-Béatrix	2-3	8	Sandy silt	East	-
03 Saint-Luc	4	8	Fine sand (loamy)	Level	-

* Categories from Cauboue (1988)
+ Values from Bolghari and Bertrand (1984)
# Observed on: 1=less than 4 m^2 ; 2= 4.1 to 10 m^2 ; 3= over 10.1 m^2 ; - = not observed

As to the proximity of *Ribes*, we must conclude with Cafley (1958) that young plantations might be seriously threatened by blister rust, particularly if they are close to the alternative host. Hirt (1939) states that eradication of *Ribes* over a 300 m strip of the plantation might provide effective protection (0.1% of new infections per year over a period of 5 years). In Michigan, *Ribes* eradication measures during the 1950s and 60s seem to have been partially responsible for the low rates of rust observed in 1985 (Robbins et al. 1988).

Years favoring infection

Another factor that may explain variations in the spread of the disease from one area to another might be local climate, as it favors new infections. A period of at least two weeks during which the temperature stays below 20^{0}C, followed by at least 48 hours of saturated humidity, is required to produce new infections on pine (between July and late September) (van Arsdel et al. 1961). This specific condition was studied using meteorological data issued by stations closest to our study sites (Table 6). Even though it is not as accurate as if it had been collected on the exact site of the plantation, this information may indicate possible climate variations from one location to another for each of the five years of the study.

In 1986, conditions favoring new infections were slightly higher for seven of the study sites (01, 03, 04, 07, 10, 11, and 13) while in 1987, five locations were recorded more favorable (06, 08, 09, 10, and 13) (Table 6). At each of these locations, at least three periods favoring new infections were noted in one year. In 1984, at Sainte-Béatrix (08), four periods favoring infection were identified between July and late September. Three periods favoring infection for sites 07 and 13 should also be mentioned for 1985. In other locations and years, only one or two occasions favoring infection were noted.

All in all, the particularities of years favoring new infections probably explain the spread of the disease from one year to another in a given location. However, differences from one location to another are not sufficient and cannot be used to explain why the rate of infection by rust is higher at certain locations. For example, s.s. 13 had three periods favoring infection: 1985, 1986, and 1987; at this location, the average annual rate of new infections was 1% per year and was exceeded by that observed in a number of other plantations (Table 3). The absence or rarity of *Ribes* at this location probably explains this low rate despite seasons favoring new infections. However, s.s. 12 and 15 showed a higher rate of progress of infection even though fewer occasions favoring infection were observed, when *Ribes* was close by.

Risk of infection by blister rust on a plantation site

Van Arsdel et al. (1961) developed a numerical system to predict the presence and probable intensity of white pine blister rust on a specific site in Wisconsin. Under our climatic conditions, the interpretation, and numerical value of infection risk factors, although different, may be nevertheless considered indicative.

Blister rust is generally found in the northern part of the white pine's range and the higher elevations. Within a plantation, the lower part of slopes, narrow valleys, and small forest openings are areas of high risk (van Arsdel 1965). However, the presence and abundance of *Ribes* on and around the site remains a determining factor and favors severe attacks. On our study sites, few of these characteristics could be related to locations heavily attacked by blister rust. The difficulty to correlate individual plantation site characteristics (exposure, slope, drainage, etc.) to various levels of attack by blister rust is not confined to our study area since in northern Michigan, Robbins et al. (1988) encountered this difficulty even in natural forests. Nevertheless, five of the six plantations most affected in 1990 were bordered on one or two sides by hardwood stands, creating conditions similar to the presence of small forest openings (condition favoring cankers), as well as being next to colonies of *Ribes*.

Characteristics of cankers

The height of rust cankers on all living trees was measured each year. Height was measured from the base of the canker on the trunk down to the ground. The distance (proximal) of cankers on branches from the trunk was measured from the base of the canker (closest to the trunk). Whether canker height increases over the years depends on new cankers, since the base of old cankers progresses closer to the ground.

Data on the characteristics of cankers are reported for all stations combined since it was impossible to establish significant differences from one location to another, contrary to the findings of Anderson (1973), who suggested that low-level infections dominated in low-risk zones.

Table 6. Number of climatic occasions favoring the production of new infections by white pine blister rust in study plantations

S.s.	Location	Weather station	Years/occasions *												Total	
			1984		1985		1986		1987		1988		1989			
			P	G	P	G	P	G	P	G	P	G	P	G	P	G
01	Saint-Cuthbert	Berthierville	1	3	0	2	0	3	0	1	0	1	0	2	1	12
02	Sainte-Clothilde	Sainte-Clothilde	0	2	2	0	0	2	1	1	0	1	0	1	3	7
03	Saint-Luc	Champlain	0	2	0	2	1	2	1	1	0	1	0	2	2	10
04	Riv.-Beaudette	Côteau-du-Lac	0	1	0	1	1	2	0	2	1	2	1	1	3	9
	Sub-total, Zone 1:		1	8	2	5	2	9	2	5	1	5	1	6	9	38
06	Plessisville	Laurierville	1	1	0	2	0	2	1	2	1	1	0	1	3	9
07	Saint-A.-Avellin	Montebello	1	1	1	2	1	2	1	1	1	1	1	2	6	9
08	Sainte-Béatrix	Sainte-Béatrix	1	3	0	1	0	2	0	3	0	2	0	2	1	13
09	South Durham	South Durham	0	2	0	2	1	1	1	2	0	1	0	2	2	10
10	Ferme-Neuve	Chute-St-Philippe	0	2	1	2	0	3	0	3	1	1	0	1	2	12
11	Saint-Hilarion	Saint-Hilarion	0	2	1	1	1	2	1	1	0	1	1	0	4	7
12	Saint-Malachie	Saint-Malachie	0	1	0	2	0	1	0	1	0	1	1	1	1	7
	Sub-total, Zone 2:		3	12	3	12	3	13	4	13	3	8	3	9	19	67
13	Ch.-St-Philippe	Ch.-St-Philippe	0	2	1	2	0	3	0	3	1	1	0	1	2	12
14	Lac-des-Iles	Mont-Laurier	0	1	0	2	1	1	1	1	1	1	1	1	4	7
15	Saint-Magloire	Saint-Camill	1	1	1	1	0	2	0	2	0	1	1	1	3	8
16	Cap-Poulin	Saint-Benoît-Labre	0	2	0	2	1	1	0	2	1	1	1	1	3	9
17	Saint-Alfred	Saint-Benoît-Labre	0	2	0	2	1	1	0	2	1	1	1	1	3	9
	Sub-total, Zone 3:		1	8	2	9	3	8	1	10	4	5	4	5	15	45

* P: probable G: good # From Lavallée (1986)

Height of cankers on trunks

At the beginning of the observation period (1986), trees in the plantations were between 4 and 7 years old depending on location. It therefore stood to reason that cankers on trunks were be located between 13 and 18 cm above the ground. Until 1989, most of the cankers on trunks were less than 30 cm from the ground (Figure 4). In 1990, the average height of cankers on affected trunks lay between 28 and 39 cm depending on location. The trees measured were between 2 and 3 m tall at the time. These observations bear out those of Hunt (1982) on silver pine (*Pinus monticola* Douglas ex D. Don). Hunt recommended certain pruning procedures given that the majority of cankers were less than 2 m from the ground.

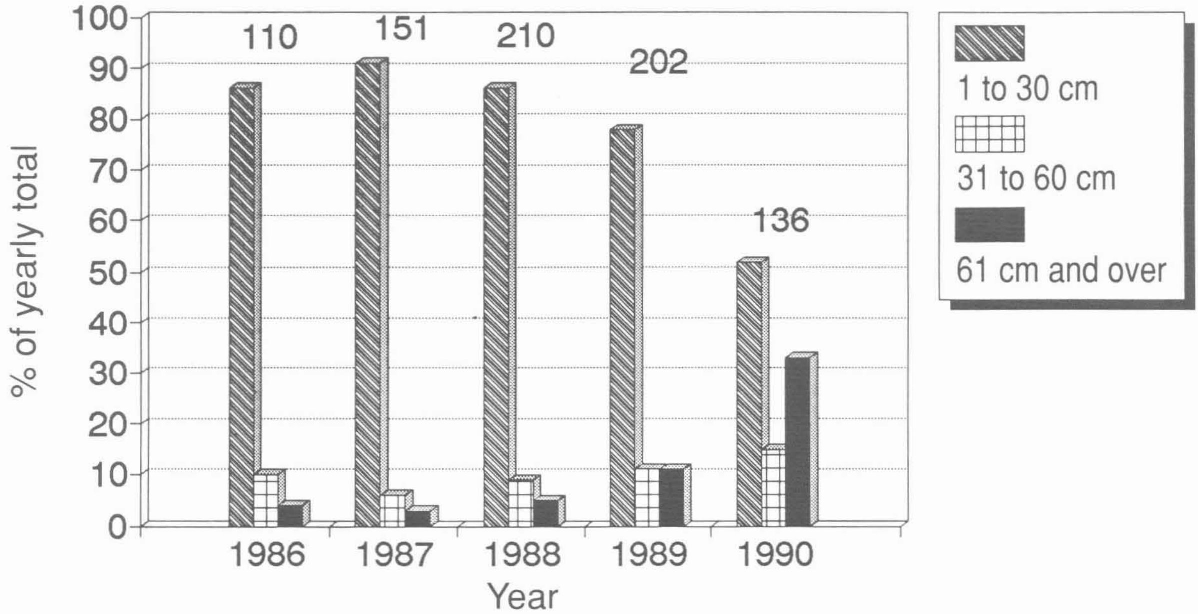

Figure 4. Distribution of height of cankers of blister rust on the trunk of white pine over a five-year period at all study sites. The total number of observations for each year is shown above the histograms.

Height of affected branches

During the five-year period, the proportion of affected branches less than 30 cm from ground level dropped from 73 to 18%, while the proportion of those over 61 cm from the ground rose from 2 to 49% (Figure 5). In 1990, it was noted in several locations (s.s. 12, 06) that a fair proportion (25 to 60%) of new infections occurred at over 1 m from the ground. This change in the level of attack on branches is a good indicator for deciding when and how to treat. For example, in plantations 5, 6, or 7 years old with over 10% of trees affected, pruning lower branches may significantly reduce the number of lethal attacks (Lavallée 1991). In plantations 10 to 12 years old, in heavily attacked areas and where tree height permits, pruning to 1 m from the ground and elimination of other affected branches might prevent many lethal attacks on trunks and thus maintain better density in the plantation so as to delay damage by both this disease and by weevil (*Pissodes strobi* Pk.).

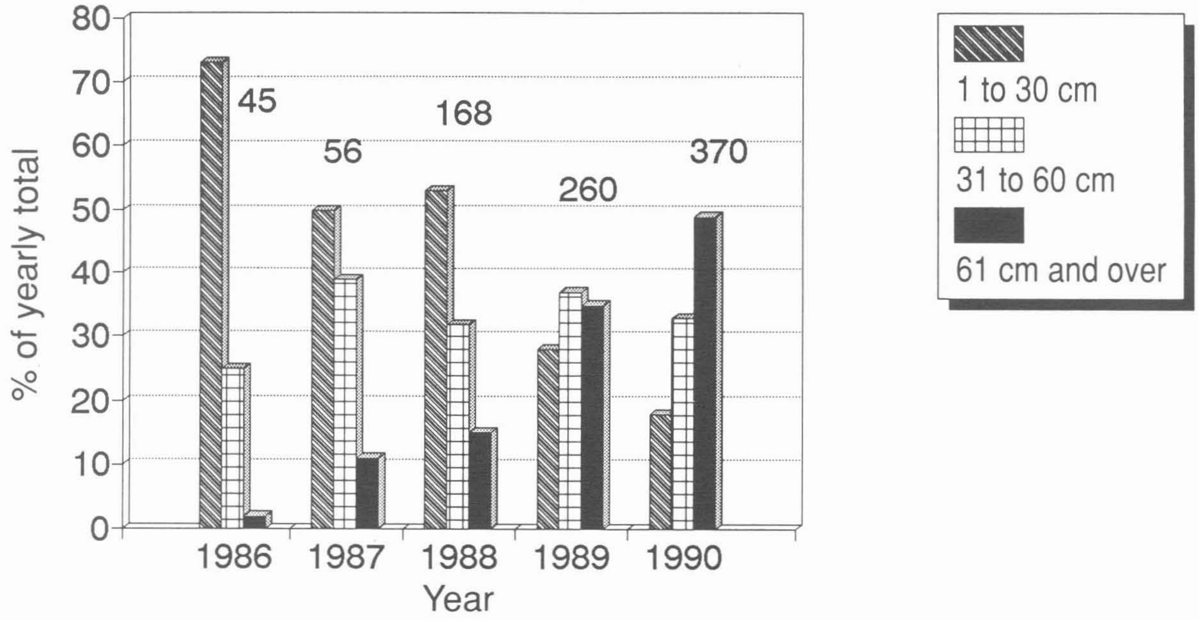

Figure 5. Distribution of height of branches of white pine affected by white pine blister rust over a five-year period in all study sites. The total number of observations is shown above the histograms for the year in question.

Distance from trunk of cankers on branches

The distance of branch cankers from the trunk increases from year to year (Figure 6). In 1986, over 50% of branch cankers were less than 5 cm from the trunk, with the average distance varying from 1 to 10 cm depending on the study locations. In 1989 and 1990, between 55 and 61% of branch cankers were over 16 cm from the trunk. This average distance varied from 13 to 48 cm depending on location. Live needles into which blister rust can penetrate were located farther and farther from the trunk, at least on the lowest branches; the position of cankers on these branches reflects this phenomenon.

Progression towards trunk

In study sites where no intervention had occurred, the average annual advance (in cm) of cankers on branches towards the trunk was slightly greater in Zone 3 than in zones 1 and 2, but these differences are difficult to compare because of the varying numbers of cankers measured (Table 7). In these study sites, it was also observed that the number of cankers on branches increased from Zone 1 to Zone 3. Moreover, as noted by Harvey (1967) on

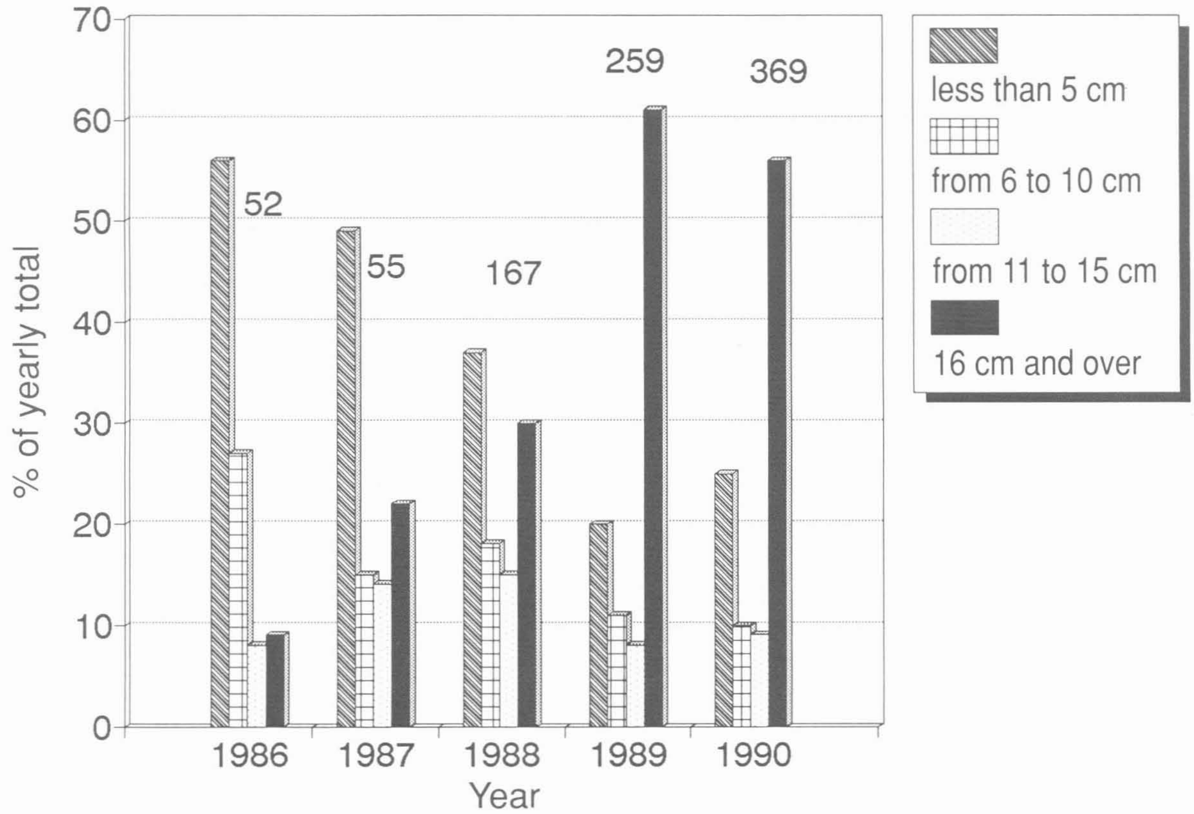

Figure 6. Proximal distance of cankers on branches from trunk. The number of observations made each year at all study sites is shown above the histograms.

Table 7. Average annual advance of cankers living on branches towards trunk

Zone* and Study site		No. of cankers on branches	Annual average advance (cm)
Zone 1	02	1	2
	03	4	6
Zone 2	10	31	6.8
	11	10	3.8
Zone 3	15	52	6.5
	17	12	7.3

* From Lavallée (1986).

Western pines, the average annual advance of these cankers increased with the diameter of the branch (based on non-presented measurements of 128 cankers on branches 1 to 4 cm in diameter). The majority of these branches were 2 cm or less in diameter and progression toward the trunk was 5.5 to 6.6 cm per year.

For the 5-year observation period (1986 - 1990), 15.6% of the 128 cankers measured reached the trunk, 7% died and 77.4% were still spreading towards the trunk. Since the latter cankers were fairly far away (between 10 and 70 cm), we might expect that half of them would die before reaching the trunk. Of the 30 cankers observed and measured in 1986 and 1987, the majority (22/30) were then less than 10 cm from the trunk; of this number, 18/22 had spread to the trunk and 4/22 had died before reaching the trunk.

Lethal attacks on trunk

For the 1986 to 1990 period inclusively, cankers on the trunk caused the death of the tree more or less rapidly, depending on its diameter. Trees with an average trunk diameter of 2.5 to 3.0 cm were dead two years or less after the first symptoms appeared (Table 8); those 4.4 to 7.1 cm were girdled during a period of 1 to 5 years. The 11 cankers that lasted more than 5 years on trunks attacked in South Durham (s.s. 09) were on trunks of 9.5 cm average diameter in 1990. Cankers over 4 years old may in fact become inactive (Kimmey 1969) and consequently not kill the tree. In 1991, at South Durham, cankers that had lasted over 6 years were still all active; 5 of the 11 trees affected were still alive and their average diameter was 10.4 cm while the other 6 trees died during the sixth year. If possible, these cankers should be monitored to determine the diameter beyond which rust does not necessarily cause death. The proportion of inactive cankers, increasing with the age of the canker (Hungerford 1977), is a positive sign that the epidemic will slow down after 15 or 20 years.

Table 8. Characteristics of trunks lethally attacked by blister rust during the 1986-1990 period

Zone* and Study site		No. of trunks affected	Mean diameter# (minimum-maximum)	Mortality after
Zone 1	02	5	2.9 (1.5-3.8)	1 or 2 years
	03	1	4.5	3 years
	04	17	4.6 (3.1-6.1)	1 to 5 years
Zone 2	06	44	5.4 (4.8-10.0)	2 to 3 years
	09	41	7.1 (4.7-8.4)	1 to 5 years
		11	9.5	+ 5 years
	10	5	4.9 (3.0-7.0)	1 to 5 years
	11	3	3.0	1 or 2 years
	12	8	4.3 (3.5-4.6)	2 to 4 years
Zone 3	13	5	4.7 (4.0-5.2)	1 to 4 years
	14	6	5.3 (2.0-3.0)	2 to 4 years
	15	6	2.5 (2.0-3.0)	1 or 2 years
	17	5	4.4 (3.0-5.5)	1 to 3 years

* From Lavallée (1986)
# Average diameter (cm) of stem at the end of lethal attack by blister rust.

CONCLUSION

In plantations 5 to 9 years old, attacks of blister rust on white pine are usually lethal and the trees die in less than 5 years. The point of penetration of new attacks is located farther and farther from the trunk and cankers remain longer on branches before moving to the trunk, causing the death of the tree. In approximately 25% of these plantations, to maintain good density of trees, action may have to be taken before trees are 10 years old .

Zones of sensitivity to blister rust enable us to explain the overall damage observed on white pine, although each plantation may also have particular conditions that favor infection to a varying extent. Examination of the 5-year-old plantation is thus necessary to detect areas with high concentrations of the disease and to consider whether control measures should be taken. If this examination shows that less than 5% of trees are affected by blister rust, a second survey should be made between 3 and 5 years later. A high intensity of the disease at the age of 5 years inevitably results in major losses once the trees reach 10 years of age. Conversely, a low intensity at 5 years may take on greater proportions or remain low for several years.

It was not demonstrated that the age of the plantation, total height and annual growth of trees or the fertility of the site have a direct influence on levels of attack observed in various plantations. However, the proximity and quantity of *Ribes* in and around the plantation remain the principal factors related to the progress of blister rust, particularly if the plantation is protected from air circulation and growing near hardwood stands.

Study of the characteristics of cankers strongly indicates that lower branches should be pruned. For the majority (14/16) of 10-year old plantations, systematic pruning of branches up to 1 m above the ground would leave less than 6% and often only 2 or 3% of trunks affected, including those that were already dead. If necessary, pruning of affected branches above this level would help further delay attacks on the trunk and plantation density would be maintained. A second pruning might be done when the first thinning is done some 10 or 15 years later.

For more heavily attacked plantations such as those at Plessisville and South Durham, the initial examination showed that over 10% of stems had been affected. Earlier action must be taken; otherwise, 12 to 25% of trunks will be attacked within five years and the density of the plantation will be affected before the plantation reaches maturity.

Hygiene measures, involving removal of affected branches and trunks only, were carried out in some of the study sites. The effect of these interventions was limited to reducing the cumulative level of infection (including dead trees) for 1 or 2 years, but this level continued to increase since almost as many branches remained available for new infections. We nevertheless learned that when cankers on branches were more than 10 cm from the trunk, pruning these branches prevented a lethal attack on the trunk.

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