Observations on the evolution of damage by *Pissodes strobi* Peck and characterization of young white pine plantations affected by this weevil

André Lavallée

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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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ABSTRACT

Annual examination of 15 white pine plantations between the ages of 5 and 10 as well as the monitoring of white pine weevil damages in these plantations indicate that one-third of these plantations show virtually no trace of the insect. Most of these plantations had a northern to northwestern exposure at an altitude of over 300 m and were on sites having good nutrients. In six of the 15 study stations, 55 to 92% of the trees had been attacked at least once at the age of 10 or 11. These trees often had an eastern to southeastern exposure on sites with rapid or imperfect drainage that were generally poorer than those of the first group of plantations. A third group was subjected to disturbances during the course of the study and so was more difficult to characterize. Study results helped to confirm the validity of a model for predicting the number of intact trees five years after the first weevils were observed. Observations on the growth of affected trees in these plantations seem different from those previously reported for natural forests.

RÉSUMÉ

L'examen annuel de 15 plantations de pins blancs entre l'âge de 5 et 10 ans, ainsi que l'étude de l'évolution des dégâts occasionnés par différents niveaux de population du charançon du pin blanc nous apprennent que le tiers de ces plantations ne présentaient pratiquement pas de trace de l'insecte. La plupart d'entre elles étaient exposées au nord, nord-ouest à une altitude de plus de 300 m et situées sur de bons sites nutritifs. Six des 15 stations d'étude présentaient une proportion de 55 à 92 % d'arbres ayant été attaqués au moins une fois à l'âge de 10 ou 11 ans. Ces dernières étaient souvent exposées à l'est, sud-est sur des sites à drainage rapide ou imparfait et généralement plus pauvres que le premier groupe de plantations. Un certain nombre de plantations ont été l'objet de perturbations au cours de la période d'étude et deviennent plus difficile à caractériser. Un modèle de prédiction du nombre d'arbres intacts cinq ans après un relevé du charançon a été validé à l'aide des résultats. Les observations relatives à la croissance des arbres attaqués dans ces plantations semblent différentes de celles déjà signalées en forêt naturelle.

INTRODUCTION

The white pine weevil (*Pissodes strobi* Peck) is the greatest obstacle to production of quality stems in white pine plantations (*Pinus strobus* L.) in Quebec (Lavallée and Benoit 1989). By repeatedly attacking the terminal shoot, the insect reduces the merchantable volume of the tree by reducing its height and diameter, by deforming it, and by decreasing the quality of its wood due to the presence of knots, cross grain, and wanes. In some cases, rot sets in after a few years (Brace 1971).

The white pine weevil's first attack on the terminal shoot occurs when the host reaches the age of five years or a height of one metre (Sullivan 1961). Attacks at this early age can deform the stem at a level that renders the butt log unusable. Some white pine plantations may be severely affected while, in others of the same age, the trees show little effect. Predictions on the number of trees that will escape the weevils' attacks during the subsequent five years, based on an initial examination of these young plantations, thus become a tool for helping to choose the protective measures to be taken (Marty and Mott 1964).

To choose an appropriate site for planting white pine, what is needed is a better characterization of the environment favoring early development of the weevil, the white pine's principal enemy. Certain observations or suggestions drawn from North American articles could probably be applied to conditions in Quebec, but they must first be confirmed or at least considered before their pertinence can be evaluated.

In addition to this accumulated knowledge, information obtained and monitored since the initial attacks in young Quebec plantations will be very useful in the selection of future reforestation sites.

Observations on the evolution of the damage caused by this insect since the first year of attack were documented in the surveys carried out in 15 plantations located in the southern and central parts of Quebec. The measurements allowed us to confirm the relevance of the published data and to better define the principal criteria of vulnerability to weevil attacks in white pine plantations.

MATERIALS AND METHODS

The locations of the study plantations are illustrated in Figure 1. The total number of trees in the plantation, as well as the number of trees examined at the corresponding study sites, are described in Table 1. The plantations were numbered from 1 to 17 but plantations 05 and 06 were not used for this study. In all of these plantations, the spacing between the stems was from 2.0 to 2.5 m, and the shape of the sample was rectangular (approximately 10 rows of 50 trees). Wherever possible, this rectangle was situated near the centre of the plantation to lessen any possible margin effects.

All the white pines at this site were examined every year, and the affected stems were counted starting in 1985 (or 1986 for study sites 02, 03, 15, and 16) and continuing until 1989, inclusively. The attacks of earlier years were recorded during the first examination of each study site. In 1986, the age of the plantations varied between 5 and 8 years (Table 1). The medium height of trees varied between 1.1. and 1.6 m depending on age (with two exceptions: 0.7 and 2.1 m).

Every year, a minimum of 25 intact trees were measured for annual increment and total height for the preceding year. Whenever possible, measurements were taken of the same healthy trees every year, but when they had been attacked, observations were continued on nearby healthy trees of equivalent size. The number of affected trees that were measured varied with the severity of the weevils' attack; on several sites with low populations, this number was often less than 25. Moreover, after an initial attack, height measurements could no longer be used to compare.

The fertility index, or site index at 25 years, was calculated, in metres, based on Bolghari-Bertrand curves (1984) for white pine plantations. The number of degree-days as a function of the accumulated heat in a season was obtained from Canadian Climate Program data (1982).

In 1989, a pedon was dug near the center of each study site in order to identify the soil type, the texture of various horizons, root depth, the water table, and other pedological

Figure 1. Geographic location of the 15 plantations involved in the study on the evolution of attacks by the *Pissodes strobi* weevil on the white pine.

Table 1. Identification and size of study sites

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

and ecological characteristics of each site studied. This work was performed with the assistance and advice of Mr. J.L. Lethiecq, who also performed surveys of vegetation on three of the sites (03, 12, 14). The physico-chemical analysis of soil samples was performed according to the methods used in Lethiecq and Régnière (1988) and recommended by the Canadian Society of Soil Science (1978).

Drainage classes were determined according to the scale used by Cauboue (1988). Soil profile data were obtained by using the method of the Canada Soil Survey Committee (1978) and by consulting the Field Manual for Describing Soils (Ontario Institute of Pedology 1982).

RESULTS

Evolution of weevil damage

The damages observed in plantations between 9 and 12 years old in 1989 were classified according to three severity levels: a high level (55 to 92% in 1989), a low level (0.2 to 5% in 1989), and an intermediate level (21 to 31% in 1989). The sites displaying certain anomalies (frozen buds, leaders trimmed by the owner, etc.) during the study period are identified in Tables 2 and 3.

Between 1983 and 1989, the greatest annual or cumulative progression was observed in study sites 01, 03, 08, 10, 13, and 14 (Tables 2 and 3). Within this group, the severity of attacks continued to increase on sites 03 and 10. On site 01, a decline in the annual population was noted in 1989 (Table 2), at which time 92% of the trees had been attacked at least once (Table 3). Two study sites showed a drop in population in 1987 following bud freezing (site 14) or the trimming of infected shoots (site 13). Mechanical control measures were also conducted on sites 01 and 08 between 1985 and 1987, but weevil damage remained high each year. Figure 2 illustrates the cumulative evolution of the damage observed in three of the six severely affected plantations that did not experience major disturbances (03, 10, and 14).

In these plantations, between 55 and 92% of the stems were attacked at least once during the study (Table 3). Moreover, between 16 and 31% of the stems suffered two attacks in four of the six plantations of this category, and between 9 and 20% of these stems had been attacked for three years. Some specimens had been attacked in each of the five years leading up to 1989.

In the intermediate damage group (sites 04, 07, and 16), site 07 was subject to control measures after 1986, after which time annual damage declined and remained low. In 1989, site 07 did, nevertheless, show an increase in the number of attacks. Trimmed leaders were noted in 1989 on site 04 and in 1988 on site 16. It is impossible

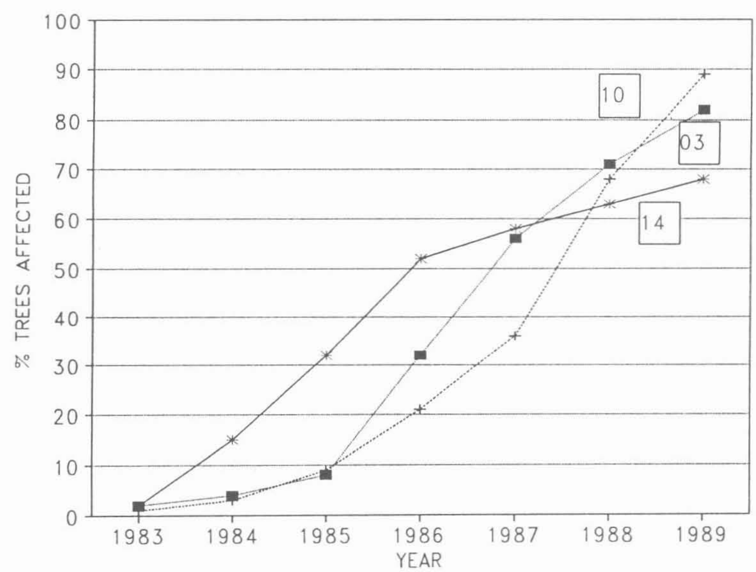

Figure 2. Cumulative evolution of white pine weevil damage in three of the six least-disturbed plantations on high-risk sites.

Table 2. Annual evolution of white pine weevil attacks in study plantations

Severity of attack and study site	% of trees affected						
	1983	1984	1985	1986	1987	1988	1989
Low							
02	0.2	1.0	3.0	1.0*	0.2	0.0	0.0
09	0.2	1.0	0.2	0.6	0.2	0.2	0.0
11	0.0	0.0	0.0	0.0	0.0	0.2	0.0
12	1.0	1.0	0.0	1.0	0.2	0.0	2.0
15	0.0	0.2	0.2	1.0	0.2	0.0	0.2
17	0.2	0.4	0.2	0.2	0.0	0.0	0.0
Intermediate							
04	1.0	10.0	2.0*	2.0	6.0	20.0	0.2*
07	1.0	2.0	2.0	6.0	2.0*	1.0*	13.6
16	0.2	0.2	1.0	5.0	6.0	5.0*	8.0
High							
01	1.0	14.0	10.0*	18.0*	36.0*	69.0	53.0
03	1.0	2.0	8.0	25.0	35.0	42.0	60.0
08	1.0	9.0	5.0*	8.0*	11.0*	25.0	21.0
10	1.0	3.0	6.0	12.0	20.0	41.0	62.0
13	1.0	9.0	15.0	23.0	7.2*	21.7	39.3
14	2.0	13.0	24.0	30.0	14.0+	27.0	40.0

* Mechanical control in the sampling plot. + Buds frozen.

Table 3. Cumulative evolution of white pine weevil attacks in study plantations

Severity of attacks and study site	% of trees affected						
	1983	1984	1985	1986	1987	1988	1989
Low							
02	-	2.0	5.0	5.0*	5.0	5.0	5.0
09	0.2	1.0	1.0	2.0	2.0	2.0	2.0
11	0.0	0.0	0.0	0.0	0.0	0.2	0.2
12	1.0	2.0	2.0	2.0	3.0	3.0	5.0
15	0.0	0.2	0.4	1.4	1.6	1.6	1.8
17	0.2	0.4	0.4	0.6	0.8	0.8	0.8
Intermediate							
04	1.0	10.0	12.0*	13.0	18.0	31.0	31.2*
07	1.0	3.0	5.0	12.0	13.0*	13.0*	27.0
16	0.2	0.4	2.0	6.0	12.0	15.0*	21.0
High							
01	1.0	15.0	23.0*	36.0*	60.0*	87.0	92.0
03	2.0	4.0	8.0	32.0	56.0	71.0	82.0
08	1.0	10.0	13.0*	21.0*	27.0*	44.0	55.0
10	1.0	3.0	9.0	21.0	36.0	68.0	89.0
13	1.0	9.0	24.0	40.0	45.0*	53.0	66.0
14	2.0	15.0	32.0	52.0	58.0+	63.0	68.0

* Mechanical control in the sampling plot. + Buds frozen.

to precisely express the actual weevil level at these locations, but it can be considered average, judging from comparisons of cumulative damage (Table 3).

The plantations characterized by low weevil populations (according to the damage observed up to 1989) were 02, 09, 11, 12, 15, and 17. In all of these plantations, the percentage of stems affected annually was generally 0.2% and never surpassed 3% (Table 2). During the five sampling years a maximum of 5% of the terminal shoots were attacked in two of these plantations, and fewer than 2% of the trees were infected in the others (Table 3).

Predicting the proportion of intact trees

To determine the level of deterioration when no action is taken to combat the white pine weevil, Marty and Mott (1964) designed tables to predict the percentage of pines not attacked five years after an initial survey, regardless of when the first attacks occur.

Using abundant data obtained over a period of seven years in plantations in the northeastern United States, they first determined the proportion of annual attacks on trees not already affected by the weevil. A relationship was then established between the percentage of trees attacked in the current year and the percentage of never-weevilled trees, which led the authors to develop a table of average rates of deterioration for a plantation. Two additional prediction tables are available for high or low risk sites, depending on whether the proportion of trees examined and unaffected by the weevil is greater or less than the general average. An extract from these five-year prediction tables is shown in Table 4. The confidence level of these figures is in the order of 75% or more.

Since these values rely on observations made in the northeastern United States, and since we had seven years of data available, we felt it would be interesting to verify and, if possible, confirm these predictions for locations in Quebec.

The level of agreement between weevil behavior on our most representives study sites and that calculated by Marty and Mott (1964) is illustrated in Figures 3, 4, and 5. Since they

Table 4. Extracts from prediction tables of the proportion of unweevilled white pines if no controls are undertaken (based on Marty and Mott 1964)

% of intact trees at time of initial examination	% of trees predicted to be unaffected by weevils after				
	1 yr	2 yrs	3 yrs	4 yrs	5 yrs
Moderate risk					
99	98	97	95	93	89
90	85	79	72	66	59
80	72	65	57	50	45
Low risk					
99*	98	96	93	89	83
90	85	78	70	62	53
80	72	64	55	46	39
High risk					
99	90	78	73	57	43
90	77	60	50	30	13
80	64	46	35	14	0

* The original publication provides date for each percentage (at 1% levels between 100 and 0) observed at the initial examination. However, examination for a second year makes a better determination of the plantation's risk level possible.

were undisturbed, sites 03 and 10 were used to illustrate the 97% level of unweevilled trees in 1984 (Figure 3a) for a comparison of sites with high risk or above-average risk (Figure 3). For a comparison of sites with high risk or above-average risk (Figure 3), sites 03 and 10 since they were undisturbed were used to illustrate the 97% level of unweevilled trees in 1984 (Figure 3a). Sites 01 and 14 were used to illustrate the 85% level of never-attacked trees in 1984 (Figure 3b). For the intermediate-risk category, the available sites were used from the 98% level (Figure 4a) or from the 90% level of intact stems in 1984 (Figure 4b). Given the small variation in severity of attacks for the low-risk category (Figure 5), sites 09 and 12 were used to illustrate this level of agreement.

The levels of attack recorded in 1984 made it possible to better define low-risk and high-risk locations, while those of 1983 were all very low since the plantations were only 3 to 5 years old at that time.

Using conformity tests (χ^2), all curves, whether illustrated or not, were compared with those of Marty and Mott (1964). In the majority of cases (11 out of 15 stations), the damage observed in Quebec displayed the same tendencies as in the northeastern states of the U.S.

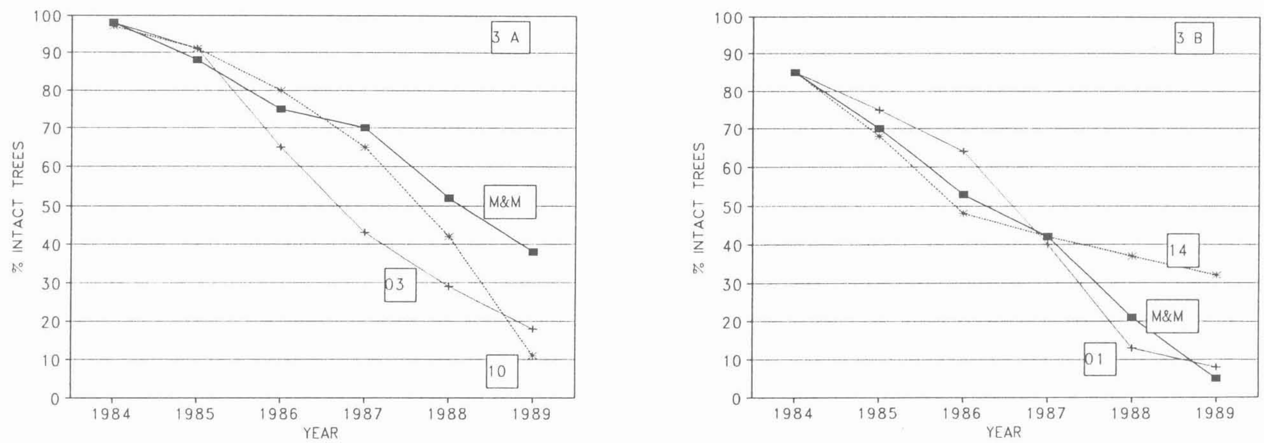

Figure 3. Illustration of the level of agreement observed between the Marty and Mott (1964) (M&M) prediction curve developed from two severity levels (3a and 3b) and the percentage of unweevilled stems in high-risk plantations.

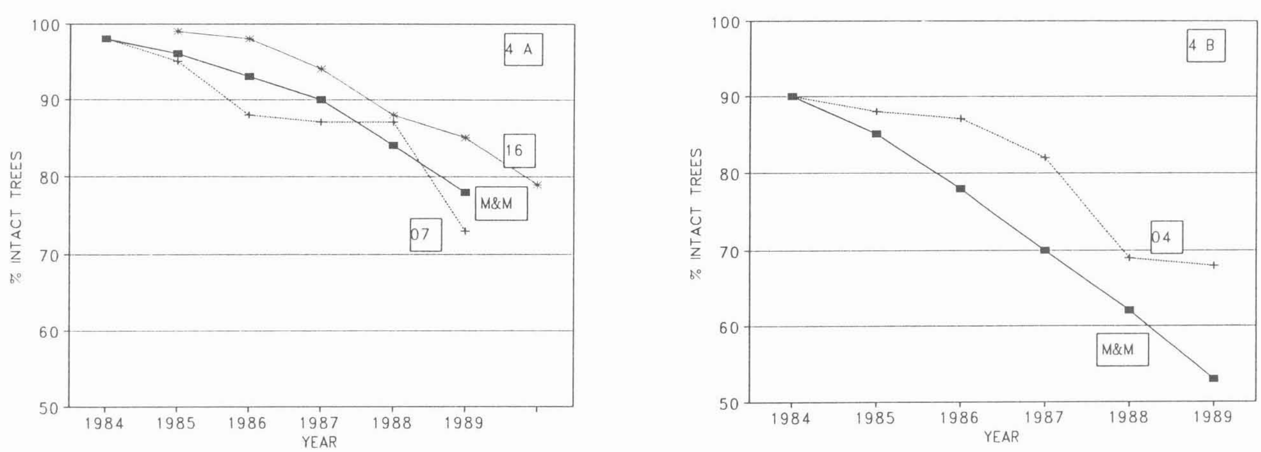

Figure 4. Illustration of the level of agreement observed between the Marty and Mott (1964) (M&M) prediction curve developed from two severity levels (4a and 4b) and the percentage of unweevilled stems in intermediate-risk plantations.

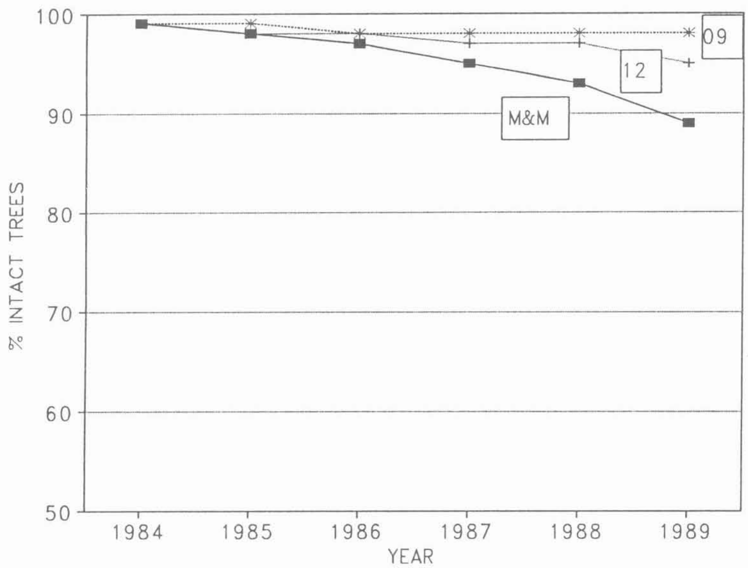

Figure 5. Illustration of the level of agreement observed between the Marty and Mott (1964) (M&M) prediction curve and the percentage of unweevilled stems in two low-risk plantations.

($\chi^2_{0.05}$ < than the critical value). At the four other test stations, the damage observed in recent years was higher than that found by Marty and Mott (1964) in two plantations (03 and 10). Damage was less at two other plantations (13 and 14), probably due to freezing and to the trimming of affected shoots toward 1986.

It thus seems that the prediction curves (Marty and Mott 1964) can be used, without risk of major deviation, for the majority of white pine plantations in Quebec.

Height and increment of affected trees

The measurement of height and increment of affected and healthy trees in these plantations also made it possible to verify other information found in the documents consulted. For example, when there are few attacks in a pine plantation, the majority of these attacks occur on the largest trees (Marty and Mott 1964), or the weevil may prefer developing in shoots with a larger diameter and, often, greater length (Wallace and Sullivan 1985).

For the sites and years where at least ten measurements were taken to establish an average, the average height of trees affected for the first time was significantly greater (t-test, probability level = 0.05) than that of healthy trees in only 4 of the 15 cases where comparison was possible over the course of the study. On the other hand, the diameter of the affected terminal shoots was not measured, but the average length of the shoots that were attacked the following year turned out to be significantly greater than that of shoots on intact trees of the same year in 6 of the 15 comparisons over the course of the study. At a probability level of 0.10, the two proportions mentioned above (4 and 6 of 15) would represent an increase of 1 in each case.

Therefore, in the plantations under study, counter to what had been reported elsewhere, the larger specimens or the longest terminal shoots did not constitute an evident factor of preference for the white pine weevil.

Accumulated heat

With a view to predicting and identifying probable areas with high populations of weevils, we can, like certain other authors (McMullen et al. 1987), consider cumulative degree-days above a certain threshold for a given host. For the Sitka spruce in western Canada, if the cumulative number of degree-days above 7.2°C is below 888 for the May to September period, emergence will be virtually nil (McMullen 1976); at 1167 degree-days for this period, emergence will be at 100%. For the eastern white pine, an emergence of 85% is observed when the number of cumulative degree-days above 4.4°C (40°F) surpasses 1400 between May and September (Godwin and Bean 1956), while at 730 degree-days there is only 50% emergence.

This factor was considered for the study area in attempting to possibly explain certain variations in weevil population growth rates from one place to another. However, at all of the study sites, more than 1400 degree-days between May and September, on average, have been recorded for the past thirty years (Canadian Climate Program 1982).

It thus appears that the area around and within the study sites was favorable for complete development of the white pine weevil. Thus, at least for the study area, major risk zones could not be defined on the basis of the degree-days required for development of the insect.

Characteristics of the stations

The plantations where weevil-caused damage was high between 1985 and 1990 were, in many cases, exposed to the east, southeast or are level, while those displaying low damage for the same period were primarily exposed to the north-northwest, were level, or, in exceptional cases, were exposed to the southeast (Table 5). The average height of healthy 8-year-old trees in the most severely affected group of plantations was generally lower than that of the plantations that were little affected. Finally, two thirds of the plantations minimally affected at the age of 10 or 11 (in 1989) were at an altitude of 300 m or above.

Generally speaking, the soils of the most severely affected plantations often displayed rapid (1 in Caboue, 1988) or imperfect (4) drainage, a sandy or sandy-loam texture, deep mottling, and a slightly lower site index as compared to the other plantation sites examined (Table 5). Those plantations that were only slightly affected by the weevil were primarily on loam or sandy loam with good to moderate drainage, with mottling that is less common and not as deep, and with a site index slightly greater than at other sites.

Table 5. Site characteristics of young white pine plantations affected by the white pine weevil

Location and population level	Drainage	Avg ht at 8 yrs (m)	Site index (m/25yrs)	Texture	Mottling depth (cm)	Exposure	Elevation (m)
Low							
02-Sainte-Clotilde	4	2.6	10	Loamy sand	--	Level	90
09-Durham-Sud	3	4.2	12	Sandy loam	--	Level	180
11-Saint-Hilarion	2	1.4	6	Sandy silt	--	Northwest	425
12-Saint-Malachie	4	3.0	9	Loam	45	North	300
15-Saint-Magloire	2	2.4	9	Sandy loam	--	Southeast	465
17-Saint-Alfred	3	2.3	10	Loam	40	North	305
Intermediate							
04-Riv. Beaudette	1	2.0	8	Sand (loamy)	--	Level	30
07-Saint-André-Avel.	2	3.0	8	Loamy sand	--	Level	150
16-Cap-Poulin	4	2.4	8	Gravelly loam	35	Northeast	335
High							
01-Saint-Cuthbert	3-4	2.9	10	Sand	75	Southeast	60
03-Saint-Luc	4	1.9	8	Fine sand (loamy)	--	Level	30
08-Sainte-Beatrix	2-3	2.8	8	Sandy silt	80	East	245
10-Ferme-Neuve	1	1.8	7	Sand	90	Level	275
13-Ch. Saint-Phil.	1	1.7	7	Sand (loamy)	--	East	275
14-Lac-des-Îles	1	1.5	7	Sandy loam	--	Level	215

Physico-chemical analyses for the 15 test-plantations, when compared with the standards currently used by the Quebec Dept. of Forestry or found in Wilde (1966), show that all of the soils of the plantations analyzed (Appendices 1, 2, and 3) have enormous deficits in both phosphorus (from 1 to 43 ppm vs the required 150, except site 04) and magnesium content (0.01 to 0.16 meq/100 g vs the required 0.62, except site 02). With only one or two exceptions, potassium (K) was likewise deficient (0.01 to 0.12 meq/100 g vs the 0.19 required). On the other hand, excess Ca characterized sites 02, 08, 12, 15, and 17, which could decrease the availability of other nutrients.

Among the 15 samples analyzed in the laboratory in 1989, those that displayed only light weevil damage had Ah (Ap) horizons that were among the richest (15, 17, 12) or were average in richness (11) (see Appendix 3). Analysis of B horizons also showed sites 15 and 17 to be richer than sites 12 and 11, but, in general, stations with low weevil damage were located on sites with good nutrient levels.

The same laboratory analyses identified four of the six sites of high weevil damage as the poorest of the 15 sites analyzed (01, 10, 13, and 14), while the fifth was average (03), and the sixth (08) was among the best nutrient sites (Appendix 1). The same data are presented (Appendix 2) for the intermediate sites.

The plant species identified at three study sites (03, 12, 14) revealed a dominance of species common to abandoned fields. For the moment, the brushwood stratum is generally not very significant. In the herbaceous stratum, species of the genera *Hieracium* and *Lycopodium,* along with several types of moss, were noted only at Lac-des-Îles (site 14). At this stage of the study, the herbaceous plants provide no distinctive criteria for characterizing the plantations most affected by the weevil.

To summarize, if one compares the characteristics of the sites least attacked by the weevil with those most attacked, the latter are often exposed to the east-southeast, have a lower site index and lower fertility, and the rather sandy texture of their soils results in rapid or imperfect drainage. In contrast, the plantations with little damage are exposed to the north-northwest, have better fertility and a better site index; their rather loamy soil texture permits adequate drainage, and they are often at an elevation of 300 m or more.

DISCUSSION AND CONCLUSION

In general, weevil damage at the high-risk stations increased during each of the six or seven years of annual monitoring. Peaking only occurred when more than 90% of the stems had been affected. Subsequent surveys may tell us whether the percentage of trees affected annually will decrease only when such a level has been reached in all plantations. The level of annual attacks observed on our sites is comparable to that of West Jr. (1947) in New Brunswick but exceeds those observed by Marty and Mott (1964), who noted an increase of 2 to 7% in the overall average annual rate in trees of similar size measured in large numbers in eight northeastern U.S. states. Without successive control actions it seems useless to hope for a sizeable reduction in the annual rate of attacks in these high-risk stations.

In 5-year-old white pine plantations, different levels of weevil attack are observed. This may be due to the more or less important presence of local populations at the time seedlings were planted on these plantation sites. The evolution of the weevil during the subsequent five years is often a determining factor, which aids in deciding whether controls are required. Following an initial survey in these plantations, the model for predicting the number of trees that will remain intact over the next five years (Marty and Mott 1964) seems applicable to Quebec. To determine whether a location is at high or low risk, these authors suggest noting the number of injuries visible over the length of a sawlog (5.2 m from stump height) when examining a neighboring stand or plantation. Based on the follow-up carried out at our observation sites, if no such stands or plantations are available in the vicinity and if repeated attacks are observed on more than 25% of the stems of a plantation between 8 and 11 years of age, it is probably a high-risk site. If this examination reveals a level of 2 to 10% in repeated attacks, the risk should be moderate. Where no repeated attack is observed, the risk of attack by the insect should be low for several years.

Our data, based on the height of affected trees and the length of their terminal shoots, did not confirm the weevil's preference for the most vigorous trees (Wallace and Sullivan 1985; West Jr. 1947). This phenomenon may be more evident in natural regeneration than in plantations where environmental conditions are less diverse.

Measurements of healthy trees on our study sites indicate that, in general, young white pines establish themselves more readily on well to moderately drained sandy loam than on sandy sites with imperfect or rapid drainage. The annual or cumulative damage inflicted by the white pine weevil was less rapid on sites where the white pine established itself more rapidly. On the other hand, the damage caused by the weevil increased more rapidly on sites with deficient drainage where the white pine displays slower growth. These results generally corroborate those of Connola and Wixson (1963), who suggest avoiding sites where the soil shows mottling and hardpan. For this reason, a pedological survey seems warranted before proceeding with a plantation.

Many white pine plantations in Quebec are of limited size (fewer than 10 000 trees) and are located on former agricultural soils. Soil analysis clearly indicates a deficiency in phosphorus, magnesium, and potassium on these lands reforested in white pine. The white pine weevil exploits this nutritive stress, at least in plantations that are not yet fully established. Once the insect is well established in these small plantations, the damage grows precipitously unless early intervention is undertaken. As soon as 5 to 10% of the stems are observed to be affected, intervention is imperative if a sufficient number of good quality stems are to be maintained for harvesting.

The highest rates observed on our study sites are most probably related to the station since, during the same period, other plantations of the same age were subject to virtually no attacks. In establishing a plantation, preference should be given to sites whose soil texture permits good drainage, are exposed to the north, and possess sufficient fertility for the white pine. Otherwise, young plantations must be monitored closely, and action must be taken as soon as the insect appears.

Not all of the numerous factors regulating variation in the behavior of the white pine weevil have been considered in the results presented here. For example, certain host provenances probably show greater physical or nutritional resistance to the insect than others provenances. Unfortunately, no reliable data is available concerning the provenances of the plantations studied. Our results focus on the damage observed in young plantations and primarily consider the physical nature of the stations. However, the environment or location of the plantation certainly influences the development of the weevil in these plantations. Factors directly regulating the insect's population (e.g. conditions favorable to oviposition, emergence, and migration of adults, etc.) were not included in our study but could modify some of our conclusions.

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APPENDICES

Appendix 1. Physico-chemical analysis of reference soil horizons for sites subject to high levels of weevil attacks

Study site and horizon		Thickness cm	pH	Total N %	C/N ratio	P ppm	K (meq/100g)	Ca (meq/100g)	Mg (meq/100g)	CO (%)	Fe (%)	Al (%)	>2mm %	Particle size <2mm sand	silt	clay
01	Ah(p)	10	4.7	0.16	19.1	5	0.09	1.40	0.08	3.06	0.44	0.59	26	60.7	28.6	10.7
	BC	65	4.7	0.03	14.3	21	0.02	0.09	0.01	0.43	0.14	0.23	1	91.2	3.8	5.0
03	Ah(p)	27	4.8	0.27	17.0	2	0.03	0.92	0.03	4.58	0.69	0.77	0	59.3	34.8	5.9
	Bf	17	5.2	0.24	16.0	3	0.02	2.48	0.11	3.83	0.60	0.92	0	62.5	30.2	7.3
	Bfg	-	4.9	0.09	21.0	2	0.02	0.84	0.03	1.89	0.65	0.90	0	74.7	20.3	5.0
	Bfjg									0.55	0.25	0.26	0	87.0	10.6	2.4
	Cg												0	95.2	4.8	0
08	Ah(p)	14	5.4	0.20	13.6	9	0.05	3.54	0.12	2.72	0.69	0.65	<1	48.8	46.7	4.5
	Bf	12	5.4	0.16	14.2	3	0.03	2.99	0.02	2.27	0.49	0.81	1	45.9	49.4	4.7
10	Ah(p)	21	4.5	0.11	17.1	20	0.06	0.46	0.05	1.88	0.27	0.35	14	84.7	9.2	6:1
	Bf	46	4.9	0.04	16.3	17	0.01	0.21	0.01	0.65	0.11	0.35	25	92.4	4.0	3.6
13	Ah(p)	14	4.5	0.15	15.7	43	0.05	0.28	0.03	2.35	0.31	0.44	<1	79.5	15.4	5.1
	Bf	30	4.7	0.10	16.7	14	0.08	0.31	0.02	1.67	0.40	0.71		84.5	10.4	5.1
14	Ah(p)	15	4.7	0.13	21.2	7	0.04	0.64	0.05	2.75	0.31	0.49	7	70.3	22.5	7.2
	Bfj	10	4.9	0.03	17.3	13	0.01	0.17	0.01	0.53	0.11	0.26	7	72.6	21.7	5.7
	Bf	55	5.1	0.05	22.0	11	0.02	0.44	0.01	1.10	0.18	0.49	6	71.8	21.3	6.9
	C												3	97.5	0.6	1.9
White pine Plantation Minimum *			4.8-6.0	0.12	16-25	150	0.19	1.25	0.62	2-3.0						25

* Standards based on Wilde (1966).

Appendix 2. Physico-chemical analysis of reference soil horizons for sites displaying intermediate levels of weevil damage

Study site and horizon		Thickness cm	pH	Total N %	C/N ratio	P ppm	K	Ca	Mg	CO	Fe	Al	Particle size			
							meq/100g			%			>2mm %	< 2mm		
														sand	silt	clay
04	Ah(p)	21	4.6	0.03	28.2	135	0.05	0.50	0.05	0.92	0.07	0.20	0.1	90.7	6.5	2.8
	Bf1	12	4.8	0.02	16.7	50	0.03	0.18	0.01	0.31	0.06	0.15	0.5	92.0	6.4	1.6
	Bf2		5.0	0.01	13.3	85	0.03	0.17	0.01	0.13	0.02	0.11	0.3	95.7	3.7	0.6
	C		5.0	0.00	15.6	57	0.01	0.08	0.01	0.03	0.01	0.07	0.2	98.9	0.0	1.1
07	Ah(p)	24	4.5	0.10	22.5	28	0.08	0.68	0.05	2.26	0.27	0.46	0.8	72.2	19.8	8.0
	Bf1	32	4.7	0.02	21.2	33	0.07	0.23	0.01	0.39	0.05	0.23	0.9	84.9	7.8	7.3
	Bf2	22	4.9	0.01	24.7	36	0.05	0.18	0.01	0.16	0.03	0.14	4.3	92.5	6.3	1.2
	C		5.0	0.01	11.1	34	0.03	0.27	0.02	0.09	0.05	0.11	0.1	94.6	1.5	3.9
16	Ah(p)	17	4.8	0.17	14.0	3	0.07	0.44	0.07	2.38	0.53	0.58	17	38.6	46.3	15.1
	Bf1	9	4.8	0.16	13.9	5	0.06	0.47	0.08	2.23	0.44	0.52	37	41.4	44.9	13.7
	Bf2									1.58	0.65	0.74	24	37.2	42.1	20.7
White pine Plantation Minimum *			4.8-6.0	0.12	16-25	150	0.19	1.25	0.62	2-3.0						25

* Standards based on Wilde (1966).

Appendix 3. Physico-chemical analysis of reference soil horizons for sites subject to low levels of weevil attack

Study site	and horizon	Thickness cm	pH	Total N %	C/N ratio	P ppm	K (meq/100g)	Ca (meq/100g)	Mg (meq/100g)	CO (%)	Fe (%)	Al (%)	Particle size >2mm %	< 2mm sand	< 2mm silt	< 2mm clay
02	Ah(p)	26	5.6	0.11	28.7	17	0.05	10.68	0.48	3.02	0.10	0.30	0.3	77.2	18.5	4.3
	Ae		5.4	0.03	26.6	10	0.01	2.25	0.10	0.71	0.02	0.07	0	86.1	10.3	3.6
	Bf1	15	4.9	0.04	49.5	4	0.01	3.40	0.14	2.07	0.07	0.91	0	85.2	6.6	8.2
	Bf2	66	5.1	0.02	33.0	10	0.01	1.12	0.06	0.56	0.12	0.34	0	77.1	17.0	5.9
	C		4.5	0.00	14.8	24	0.06	1.24	0.43	0.07	0.04	0.06	0.1	44.4	44.7	10.9
09	Ah(p)	23	4.7	0.10	25.1	8	0.03	1.63	0.05	2.53	0.29	0.61	0	76.4	17.3	6.3
	Bf1	12	4.7	0.05	35.0	3	0.01	0.73	0.02	1.68	0.17	0.69	0.2	81.7	13.2	5.1
	Bf2	13	4.7	0.03	26.2	13	0.01	0.38	0.01	0.84	0.17	0.35	0.2	89.5	5.2	5.3
	C		4.9	0.01	16.8	35	0.01	0.13	0.01	0.17	0.05	0.13	0	88.8	6.1	5.1
11	Ah(p)	20	5.1	0.20	14.9	5	0.05	0.36	0.03	2.98	0.39	0.62	2	58.4	39.4	2.2
	BC	31	5.5	0.05	16.2	4	0.01	0.24	0.01	0.81	0.08	0.32	0	63.9	36.1	0.0
12	Ah(p)	20	4.8	0.26	13.5	11	0.12	2.72	0.16	3.52	0.59	0.29	28	51.4	37.9	10.7
	Bfg	20	4.8	0.06	12.8	6	0.03	0.95	0.04	0.77	0.40	0.22	28	66.5	23.8	9.7
	Cg												19	51.3	36.8	11.9
15	Ah(p)	20	5.2	0.27	15.4	3	0.12	4.03	0.08	4.16	0.82	0.50	20	39.0	46.7	14.3
	Bf	13	4.9	0.14	14.7	1	0.04	0.89	0.02	2.06	0.90	0.96	24	40.0	40.6	19.4
	C										0.15	0.29	55	55.8	32.4	11.8
17	Ah(p)	20	4.8	0.32	14.2	4	0.11	2.07	0.14	4.54	0.66	0.52	19	39.5	50.2	10.3
	Bf	14	5.0	0.14	21.1	2	0.04	1.25	0.07	2.96	0.57	0.89	24	41.2	45.9	12.9
White pine Plantation Minimum *			4.8-6.0	0.12	16-25	150	0.19	1.25	0.62	2-3.0						25

* Standards based on Wilde (1966).