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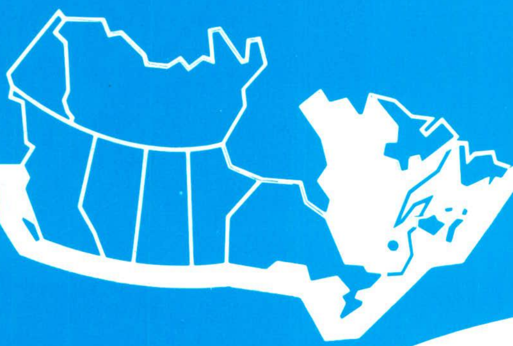
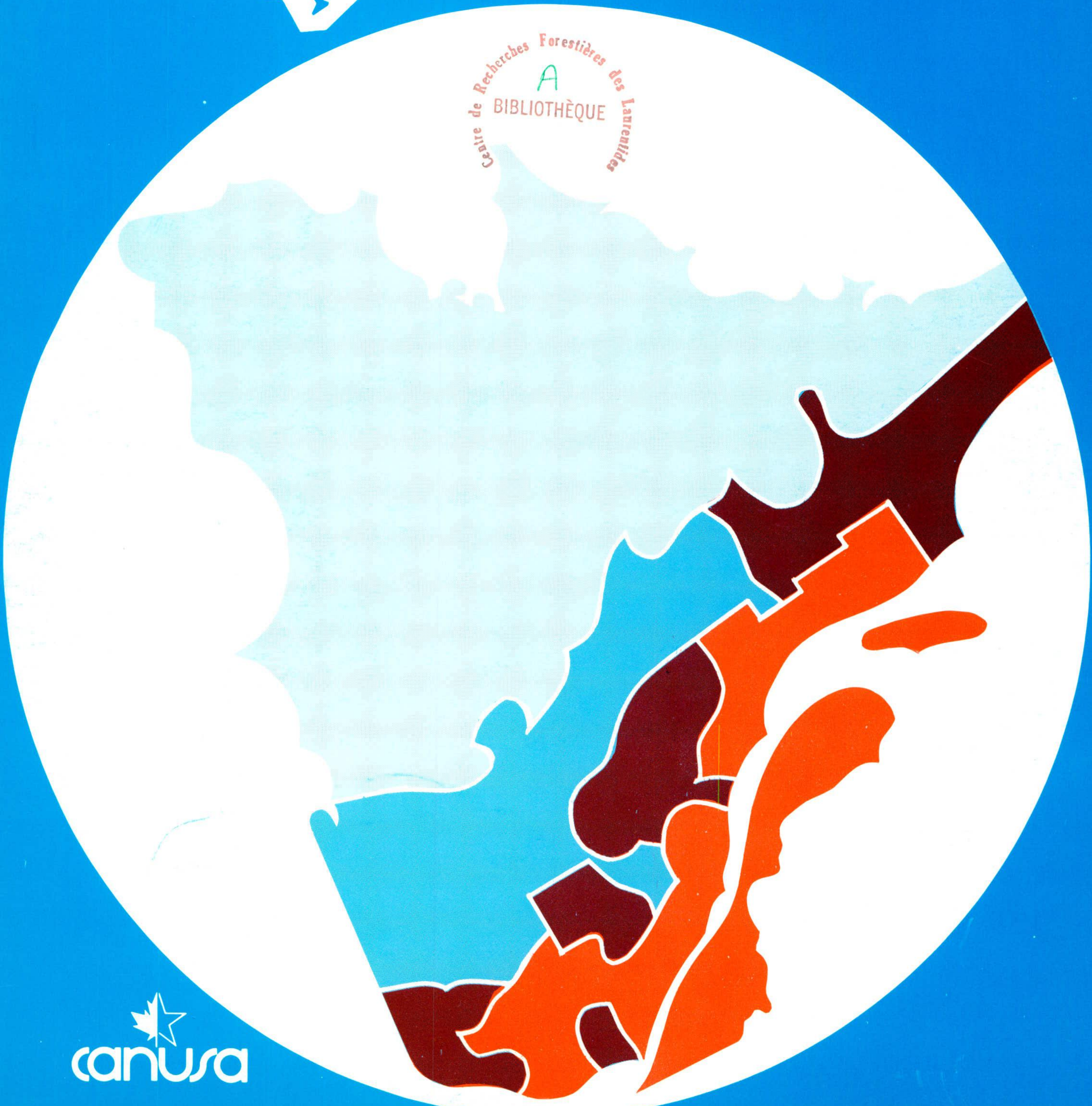
J. R. BLAIS and L. ARCHAMBAULT

LAURENTIAN FOREST RESEARCH CENTRE

LAU-X-51







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*Vulnérabilité du sapin baumier aux attaques de la tordeuse des bourgeons de l'épinette au Québec*

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**ABSTRACT**

A working Group of Canadian Forestry Service scientists from Ontario, Quebec, the Maritimes, and Newfoundland developed a classification of forests with respect to their vulnerability to spruce budworm (*Choristoneura fumiferana* (Clem.)) attack. Forest inventory and current budworm damage data for Quebec were particularly suitable to the elaboration and the testing of a vulnerability rating system. The vulnerability index was calculated on a forest management unit basis and was based on the volume of balsam fir (*Abies balsamea* (L.) Mill.) and white spruce (*Picea glauca* (Moench) Voss), the maturity of fir, the volume of black spruce (*P. mariana* (Mill.) B.S.P.) and red spruce (*P. rubens* Sarg.), and a climate rating based on temperature and precipitation. Calculation of the vulnerability index for each of 75 forest management units showed good accord between the results and actual damage. The application of the system for providing advance warning of future outbreaks and for assisting in the preparation and the implementation of short- and long-term forest management practices is discussed.

Blais, J.R.; Archambault, L. 1982. Rating vulnerability of balsam fir to spruce budworm attack in Quebec. Can. For. Serv. Laurentian For. Res. Centre. LAU-X-51.

**RÉSUMÉ**

Un groupe de travail constitué de scientifiques du Service canadien des Forêts de l'Ontario, du Québec, des Maritimes et de Terre-Neuve a developé un système de classification des forêts quant a leur vulnérabilité aux attaques par la tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* (Clem.)). Les données des inventaires forestiers pour le Québec ainsi que celles sur les dégats occasionnés par l'insecte se prêtaient particulièrement bien à l'élaboration et à l'application d'un tel système. L'indice de vulnérabilité fut calculé par unité d'aménagement. Le calcul de l'indice fut basé sur le volume du sapin baumier (*Abies balsamea* (L.) Mill.) et d'épinette blanche (*Picea glauca* (Moench) Voss), la maturité du sapin, le volume d'épinette noire (*P. mariana* (Mill.) B.S.P.) et d'épinette rouge (*P. rubens* Sarg.), ainsi que sur un bilan climatique en fonction de la température et de la précipitation. Le calcul de l'indice de vulnérabilité pour 75 unités d'aménagement a montré que les résultats correspondaient aux dégats observés. L'application de cette classification pourrait servir à la prédiction d'invasions de la tordeuse, ainsi qu'à l'élaboration et l'application de plans d'aménagement à court et à long terme.

Blais, J.R.; Archambault, L. 1982. Vulnérabilité du sapin baumier aux attaques de la tordeuse des bourgeons de l'épinette au Québec. Serv. Can. For. Centre Rech. For. Laurentides. LAU-X-51F.

# INTRODUCTION

Spruce budworm (*Choristoneura fumiferana* (Clem.)) outbreaks recur in eastern North America where balsam fir (*Abies balsamea* (L.) Mill.) and white spruce (*Picea glauca* (Moench) Voss) are important components of the forest. These tree species are common and occur over widespread areas in Quebec. In this province the greatest concentrations of fir and white spruce occur in the central and southern portions of the Boreal Forest Region and in the northern portion of the Great Lakes-St. Lawrence Forest Region (Rowe 1972). Fir, the most important host of the budworm comprises 22% and white spruce 5% by volume of all species (Ministère des Terres et Forêts Québec 1975). Therefore, it is not surprising that forests in Quebec are prone to budworm attack. In the twentieth century, three budworm outbreaks occurred in Quebec, each starting about 1910, 1940, and 1967. These outbreaks extended to most fir-spruce stands in the province and lasted for several years, the first two came to an end only after much of the fir of merchantable size had been destroyed. Swaine and Craighead (1924) estimated the timber killed in the province by the 1910 outbreak amounted to 150 million cords (544 million $m^3$), equivalent to more than the actual annual world production of pulpwood. Estimates by these authors are probably high, but are indicative of the magnitude of the damage. Losses calculated for regions such as the Gatineau River watershed (McLintock1955), the Gaspé Peninsula (Blais and Martineau 1960), and the Laurentian Park (Blais 1964) indicate that total amount of wood destroyed in Quebec during the 1940 outbreak was also considerable. The most recent outbreak is still in progress, but already important amounts of wood have been destroyed in many regions from the Ontario border to Anticosti Island and the North Shore (Ministère de l'Energie et des Ressources du Québec 1981). Annual aerial surveys conducted by the conservation branch of the *ministère de l'Énergie et des Ressources du Québec* indicate that tree mortality has been progressing from year to year (Table 1). In the Ottawa River watershed where the current outbreak began, about 90% of the fir and 50% of the white spruce of merchantable size was destroyed by 1979 (Blais 1981). Trees will continue to die

Table 1. Yearly total area where varying amounts of tree mortality occurred resulting from the current budworm outbreak in Quebec[a]

| Year | Total area in millions of ha |
|---|---|
| 1974 | 1.0 |
| 1975 | 3.0 |
| 1976 | 3.81 |
| 1977 | 5.67 |
| 1978 | 6.30 |
| 1979 | 8.30 |
| 1980 | 9.25 |
| 1981 | 10.20 |

[a] Based on data obtained by the ministère de l'Énergie et des Ressources du Québec.

for a number of years in many regions, and wood loss in the course of this outbreak will again be very high.

The periodic destruction of large amounts of wood poses a real problem to forest managers and to those responsible for forest protection. The problem will become more acute with time, as the demand for forest products increases while wood reserves are being depleted. The socio-economic consequences of future budworm outbreaks will be even more crucial than formely.

In the past 30 years, several attempts were made to relate budworm-induced mortality of fir to stand characteristics such as age and composition. In his review of the litterature, MacLean (1980) concludes that these attempts have not been particularily successful. Stand characteristics for predicting damage by budworm may be more reliable close to the periphery of infested areas where insect populations are generally lower. However, within large infested areas, populations can be maintained at very high levels for several years; wind dispersal of moths and small larvae results in a redistribution of populations. Stands offering conditions less favorable to the insect may suffer severe damage through repeated invasions from surrounding stands, and any differentiation in stand vulnerability may be lost. Therefore fir vulnerability is easier to predict on a regional than on a stand basis. The term vulnerability refers to the probability of tree mortality resulting from attack, as opposed to the term susceptibility which refers to the probability that a forest would be attacked by budworm (Mott 1963).

During the 1940 and 1967 outbreaks, restricted sections of the infested area were treated with insecticides with moderate to good success (Blais 1977), and some salvage operations were carried out. However, an overall plan of action to reduce damage was not implemented. Regional variations would have to be considered when implementating such a plan since the degree of vulnerability of fir, accessibility of the forest, and dependance on wood supplies vary. Any management program aimed at reducing losses due to budworm would require a hazard-rating of forest to budworm attack.

## CRITERIA FOR DETERMINING THE VULNERABILITY INDEX

A good opportunity to test the validity of a hazard-rating of balsam fir stands to budworm attack on a regional basis in Quebec was provided by recent data from two sources: forest inventories, and tree mortality resulting from budworm attack. In 1970, the Forest Inventory Branch of the Quebec Department of Lands and Forests began a forest inventory of the 77 forest management units in the province (Figure 1) on a ten-year basis. The first phase was completed in 1977. For practically all management units the inventory was made prior to the killing of trees by budworm; the units where tree mortality first occurred (in western Quebec) were those for which the inventory was first completed. For the past several years, members of the conservation branch of the *ministère de l'Énergie et des Ressources du Québec* conducted ground and aerial surveys to determine losses due to budworm. These surveys provide data for the preparation of maps showing the degree and extent of tree mortality for all regions in the province. Maps completed in 1981 served as a reference for assessing current budworm damage for each management unit in Quebec. Because the mid- and lower-North Shore regions, are remote they were covered less critically than other regions. Special ground and aerial surveys were conducted by the authors in 1981 to

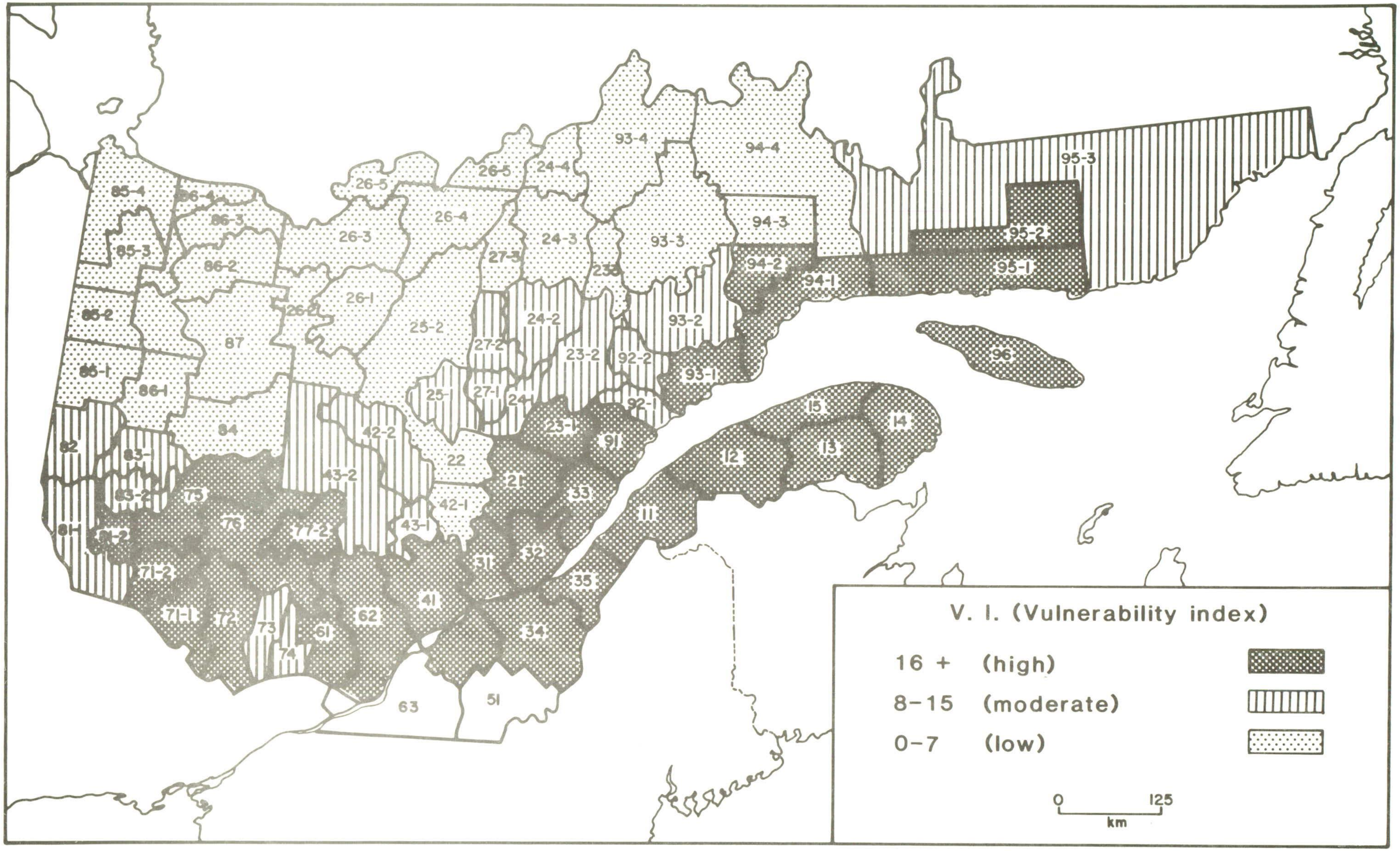


Figure 1. Vulnerability index by forest management unit in Quebec based on forest inventory data and on fir mortality to budworm.

obtain a better appraisal of budworm impact in that sector (Blais 1983). Defoliation continues in certain areas, in Quebec especially in the eastern part of the province, any further damage can be predicted with considerable confidence at this advanced stage of the outbreak. A hazard rating based on pre-damage forest inventory was compared with the ensuing mortality of fir for each of the management units; this provided a means for assessing the validity of the ratings.

Spruce budworm usually feeds on new shoots, and repeated destruction of the current year's foliage results in tree mortality. Merchantable size balsam fir succumbs after about five years of repeated severe (75% +) defoliation. The degree of defoliation depends on insect numbers which can fluctuate from year to year. Insect populations are affected by several factors some of which are predictable while others are not. The unpredictable factors can change over short periods; they are comprised of weather, natural control factors, including parasites and predators, and the influx of populations through massive moth flights (Greenbank et al. 1980). The predictable factors include forest composition, age of fir-spruce stands, and prevailing climate. Composition and age of the forest change gradually, while climate is more or less stable. Only predictable factors can be considered for rating the relative vulnerability of fir for specific areas.

Density and maturity of fir are the most important factors influencing vulnerability of the forest to budworm. Swaine and Craighead (1924) were the first to note that budworm outbreaks were associated with extensive stands of mature and overmature fir. Since then, this observation has been made by many entomologists and foresters working in several regions of eastern North America. White spruce is scarcer and more resistant to budworm attack than fir, nevertheless, because of the greater number of buds per unit length of branch, it can sustain even higher populations than fir on a branch-length basis. White spruce, proportionately contributes at least as much to maintain budworm populations at outbreak levels as fir, and should be given as much consideration in any hazard-rating scheme. Budworm feed on red spruce (*Picea rubens* Sarg.) and black spruce (*Picea mariana* (Mill.) B.S.P.) and these tree species also contribute to maintaining budworm populations, however, they offer less favorable conditions than fir or white spruce; pure black spruce stands are seldom killed by the insect. By furnishing part of the food consumed within areas where fir is fairly abundant, red spruce and black spruce contribute to the maintenance of high populations, and this, in turn, affects the vulnerability of fir.

A warm-dry climate favors the budworm while a cool-wet climate is unfavorable (Wellington et al. 1950; Greenbank 1957; Blais and Martineau 1960; Pilon and Blais 1961; Ives 1974). Although weather conditions vary from year to year, the prevailing climate for a given region is predictable. For instance, climate in the Ottawa River watershed is relatively warm and dry compared with that of the Gaspé Peninsula or the Laurentian Park where it is cool and humid.

Forest management units in Quebec were established on the basis of socio-economic criteria. Units based on ecological criteria would have been preferable for rating vulnerability of fir to budworm, however, there was no alternative but to use existing data. Two of the 77 units (51 and 63) were excluded from the exercise (Figure 1) because farmland occupies most of the area, and what forests exist are mainly hardwoods. The inventory data apply to forests on public lands and to a few large private holdings. In Quebec 90% of the forests are publicly-owned, and it is likely that most characteristics of privately-owned forests resemble the publicly-owned ones within a given unit.

## DERIVATION OF THE VULNERABILITY INDEX

The vulnerability index (V.I.) described in this section was developed and tested by a working group of Canadian Forestry Service scientists from Newfoundland, the Maritimes, Quebec, and Ontario. Four main factors were retained as a basis for calculating the V.I.:

1) combined merchantable volume of fir and white spruce;
2) percentage of mature fir;
3) merchantable volume of black spruce and red spruce when warranted by a sufficient volume of fir and white spruce;
4) climate.

Various ratings were applied for different values within each factor, and various formulas incorporating the ratings were tried to obtain an acceptable V.I. This was done by comparing the various V.I. values obtained for a given unit with the observed effect of the budworm on fir within that unit. Through this approach, a formula was arrived at which gave the best fit between V.I. values and observed mortality of fir for the greatest number of units.

The final rating for values of each factor being considered, and the method for calculating the V.I. are:

1) Volume of fir and white spruce, and maturity of fir are combined to obtain a volume-maturity rating by:

a) determining a rating for merchantable volume of fir and white spruce

| Merchantable volume of fir and white spruce combined ($m^3$/ha) | Rating |
|---|---|
| 1-6 | 1 |
| 7-13 | 2 |
| 14-20 | 3 |
| 21-27 | 4 |
| 28-34 | 5 |
| 35-41 | 6 |
| 42-48 | 7 |
| 49-55 | 8 |
| 56-62 | 9 |
| 63+ | 10 |

b) determining the rating for maturity of fir only

| Percentage of mature fir (over 60 years) | Rating |
|---|---|
| 1-20 | 1 |
| 21-40 | 2 |
| 41+ | 3 |

c) multiplying volume rating by maturity rating. Thus, a unit with a volume of fir and white spruce of 30 $m^3$/ha (rating = 5) and 45% mature fir (rating = 3) has a volume-maturity rating of 5 x 3 = 15.

2) Because black spruce and red spruce contribute to the impetus of an outbreak, it was considered that a value should be given to this factor, but only where fir and white spruce are fairly abundant. Areas with a high content of black spruce and low content of fir and white spruce, generally do not sustain high budworm populations over extended periods. The allotted ratings for volume of black spruce and red spruce are the same as that for fir-white spruce shown above. However, this rating is not multiplied by the maturity rating of fir, and is included in calculations for the V.I. only when the volume rating for fir-white spruce is greater than 4 (over 27 $m^3$/ha).

3) Climate[1] the last factor considered, was given the following ratings:

| Climate | Rating |
|---|---|
| cool-wet | 0 |
| cool-dry | 4 |
| warm-wet | 4 |
| warm-dry | 8 |

warm = mean annual temperature of 2.5°C or more

cool = below 2.5°C

dry = 900 mm/year or less of precipitation

wet = more than 900 mm/year

---

1 Data for climate were obtained from maps supplied by the Quebec Department of Natural Resources showing distribution of mean annual temperatures and mean annual precipitation.

When part of a unit (1/3 to 1/2) falls in a particular rating for climate, while the remainder is in another rating, the rating for the unit is adjusted accordingly, i.e., if half of a unit has a climate rating of four while the remainder has a rating of zero, climate rating for the unit is two.

The formula for calculating the vulnerability index of fir reads:

V.I.= (Vr x Mr) + Vr2* + Cr

Where Vr = volume rating for fir and white spruce

Vr2 = volume rating for black spruce and red spruce

Mr = maturity rating for fir

Cr = climate rating

---

* This volume is added only when Vr > 4

Following are three examples to illustrate the calculation of V.I. based on the above formula:

1) Unit A: fir and white spruce = 30 $m^3$/ha (rating 5); fir = 56% mature (rating 3); black spruce = 39 $m^3$/ha (rating 6); climate is cool and wet (rating 0)
   V.I. = (5 x 3) + 6 + 0 = 21

2) Unit B: fir and white spruce = 18 $m^3$/ha (rating 3); fir = 52% mature (rating 3); black spruce = 46 $m^3$/ha (rating 7); climate cool - dry (rating 4).
   V.I. = (3 x 3) + 0 + 4 = 13

3) Unit C: fir and white spruce = 59 $m^3$/ha (rating 9); fir = 37% mature (rating 2); black spruce = 16 $m^3$/ha (rating 3); climate ½ of unit warm - dry and ½ cool - dry.
   $$V.I. = (9 \times 2) + 3 + \frac{(8 + 4)}{2} = 27$$

Using the rating system just described a range of 3-33 was obtained for the V.I. for the 75 management units being considered (Table 2). For a more workable classification of management units, three vulnerability classes based on the V.I. ratings were established:

A. (high vulnerability) when V.I. > 15

B. (moderate vulnerability) when V.I. is between 8 and 15

C. (low vulnerability) when V.I. is < 8.

On this basis, 28, 23, and 24 units were in the high, moderate, and low vulnerability class (Table 2 and Figure 1). When the ratings were compared with the degree of fir mortality sustained during the current outbreak it became apparent that for 66 of the 75 units (88% of the cases), the actual or imminent mortality was in general accord with that expected. Although the V.I. ratings were high in the management units in the Gaspé Peninsula (13, 14, 15) and in the Lower St. Lawrence region (11, 12, 35), little mortality has occurred because various parts of these two sectors have been treated with insecticides every year for the past seven years; had no treatment been applied, fir mortality would now be extensive throughout these regions. Fir stands in the Gaspé Peninsula and in the Lower St. Lawrence must be considered as highly vulnerable to budworm attack (Table 2 and Figure 1). Areas in certain other regions in Quebec were treated with insecticides, but treatment was not maintained in any one region for more than two or three years; the treatments delayed but did not prevent tree mortality.

The calculated V.I. for nine management units was not in accord with observed damage. The V.I. for units 21, 42-2, 77-2, and 83-1 was lower than expected on the basis of actual mortality of fir in these units, because, although fir stands within these units are relatively scarce, they are affected by the influx of budworm populations from surrounding units where conditions are more favorable to the insect. The vulnerability class for these units was increased (Table 2 and Figure 1). Four units, 23-3, 93-3, 94-3, and 94-4, had V.I. ratings higher than expected on the basis of observed fir mortality. All these units are far north (Figure 1) and it is likely that the prevailing climate is marginal for budworm and that populations cannot maintain themselves at outbreak levels for many years at these latitudes even though some fir stands occur here. Consequently, the vulnerability class for each of these four units was reduced (Table 1 and Figure

1). Finally, the V.I. class for one unit (41) in the St. Maurice River watershed was high, while no trees have yet been killed in this sector. This anomaly cannot be explained. Budworm populations were very high in this unit in 1974 and 1975 and collapsed in 1976, (Lavallée et al. 1976) possibly due to the high incidence of parasitism in 1975 (Paquet and Desaulniers 1975). Fir in this unit suffered high mortality at the time of the two previous outbreaks that affected this part of Quebec, the first about 1910 (Swaine and Craighead 1924) and the second in the late 1940s (Royer 1958). The high rating for this unit was retained (Table 2 and Figure 1).

Table 2. Vulnerability index [a] (V.I.) of fir for each of 75 management units in Quebec based on combined merchantable volume of fir and white spruce, maturity of fir, merchantable volume of black spruce and red spruce, and climate

| Unit | Productive forest (ha) | Vol. bF and wS [b] ($m^3$/ha) | Rating | % of mature bF (60 years) | Rating | Vol. rat. x mat. rat. | Vol. bS and rS [b] ($m^3$ha) | Rating | Climate (temp./prec.) | Rating | V.I. | Vulner. class | Adjusted vulner. class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 349 290 | 53.1 | 8 | 32 | 2 | 16 | 7.8 | 2 | c/h [c] | 4 | 22 | A [d] | - [e] |
| 12 | 570 750 | 63.2 | 10 | 27 | 2 | 20 | 5.5 | 1 | ½/h | 2 | 23 | A | - |
| 13 | 697 650 | 79.2 | 10 | 56 | 3 | 30 | 12.6 | 2 | f/h | 0 | 32 | A | - |
| 14 | 599 880 | 53.4 | 8 | 53 | 3 | 24 | 13.1 | 2 | f/h | 0 | 26 | A | - |
| 15 | 464 820 | 72.0 | 10 | 60 | 3 | 30 | 10.5 | 2 | f/h | 0 | 32 | A | - |
| 21 | 610 140 | 23.7 | 4 | 26 | 2 | 8 | 19.3 | 3 [h] | f/h | 0 | 8 | B | A [f] |
| 22 | 467 350 | 9.5 | 2 | 44 | 3 | 6 | 19.0 | 3 [h] | f/h | 0 | 6 | C | - |
| 23-1 | 393 700 | 47.3 | 7 | 71 | 3 | 21 | 24.5 | 4 | f/h | 0 | 25 | A | - |
| 23-2 | 599 960 | 19.4 | 3 | 87 | 3 | 9 | 66.1 | 10 [h] | f/h | 0 | 9 | B | - |
| 23-3 | 348 050 | 18.0 | 3 | 100 | 3 | 9 | 61.8 | 9 [h] | f/h | 0 | 9 | B | C [g] |
| 24-1 | 228 260 | 19.9 | 3 | 66 | 3 | 3 | 19.9 | 3 [h] | f/h | 0 | 9 | B | - |
| 24-2 | 754 270 | 21.3 | 4 | 91 | 3 | 12 | 66.9 | 10 [h] | f/h | 0 | 12 | B | - |
| 24-3 | 863 190 | 7.5 | 2 | 99 | 3 | 6 | 40.9 | 6 [h] | f/h | 0 | 6 | C | - |
| 24-4 | 368 390 | 2.0 | 1 | 97 | 3 | 3 | 25.5 | 4 [h] | f/h | 0 | 3 | C | - |
| 25-1 | 433 640 | 7.0 | 2 | 78 | 3 | 6 | 30.8 | 5 [h] | f/h | 4 | 10 | B | - |
| 25-2 | 1 643 660 | 10.5 | 2 | 91 | 3 | 6 | 57.3 | 9 [h] | f/h | 0 | 6 | C | - |
| 26-1 | 609 080 | 5.0 | 1 | 95 | 3 | 3 | 50.2 | 8 [h] | f/h | 0 | 3 | C | - |
| 26-2 | 685 230 | 5.9 | 1 | 75 | 3 | 3 | 45.2 | 7 [h] | f/h | 0 | 3 | C | - |
| 26-3 | 911 970 | 2.1 | 1 | 92 | 3 | 3 | 29.4 | 5 [h] | f/s | 4 | 7 | C | - |
| 26-4 | 575 200 | 5.3 | 1 | 100 | 3 | 3 | 53.2 | 8 [h] | f/s | 4 | 7 | C | - |
| 26-5 | 772 080 | 2.1 | 1 | 88 | 3 | 3 | 28.0 | 5 [h] | f/s | 4 | 7 | C | - |

Table 2 (Cont'd)

| Unit | Productive forest (ha) | Vol. bF and wS [b] ($m^3$/ha) | Rating | % of mature bF (60 years) | Rating | Vol. rat. x mat. rat. | Vol. bS and rS [b] ($m^3$ha) | Rating | Climate (temp./ prec.) | Rating | V.I. | Vulner. class | Adjusted vulner. class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27-1 | 196 730 | 13.0 | 2 | 65 | 3 | 6 | 18.0 | 3 [h] | f/s | 4 | 10 | B | - |
| 27-2 | 484 420 | 26.6 | 4 | 76 | 3 | 12 | 48.6 | 8 [h] | f/h | 0 | 12 | B | - |
| 27-3 | 413 390 | 7.4 | 2 | 95 | 3 | 6 | 61.7 | 9 [h] | f/h | 0 | 6 | C | - |
| 31 | 305 790 | 39.3 | 6 | 46 | 3 | 18 | 9.2 | 2 | ½/h | 2 | 22 | A | - |
| 32 | 232 760 | 45.4 | 7 | 27 | 2 | 14 | 16.9 | 3 | f/h | 0 | 17 | A | - |
| 33 | 392 220 | 34.7 | 6 | 56 | 3 | 18 | 22.9 | 4 | f/½ | 2 | 24 | A | - |
| 34 | 60 070 | 48.1 | 7 | 70 | 3 | 21 | 19.5 | 3 | c/h | 4 | 28 | A | - |
| 35 | 88 530 | 60.8 | 9 | 31 | 2 | 18 | 14.1 | 3 | c/h | 4 | 25 | A | - |
| 41 | 469 540 | 24.3 | 4 | 66 | 3 | 12 | 13.6 | 3 [h] | c/½ | 6 | 18 | A | - |
| 42-1 | 389 270 | 19.2 | 3 | 34 | 2 | 6 | 16.9 | 3 [h] | f/h | 0 | 6 | C | - |
| 42-2 | 703 850 | 12.7 | 2 | 57 | 3 | 6 | 36.6 | 6 [h] | f/h | 0 | 6 | C | B [f] |
| 43-1 | 255 850 | 18.4 | 3 | 35 | 2 | 6 | 16.3 | 3 [h] | ½/h | 2 | 8 | B | - |
| 43-2 | 220 220 | 14.3 | 3 | 43 | 3 | 9 | 22.3 | 4 [h] | f/h | 0 | 9 | B | - |
| 61 | 296 780 | 27.3 | 4 | 80 | 3 | 12 | 9.8 | 2 [h] | c/h | 4 | 16 | A | - |
| 62 | 524 470 | 25.9 | 4 | 47 | 3 | 12 | 11.2 | 2 [h] | c/h | 4 | 16 | A | - |
| 71-1 | 285 840 | 16.1 | 3 | 49 | 3 | 9 | 4.2 | 1 [h] | c/s | 8 | 17 | A | - |
| 71-2 | 477 450 | 23.8 | 4 | 66 | 3 | 12 | 9.8 | 2 [h] | c/h | 4 | 16 | A | - |
| 72 | 415 170 | 20.0 | 3 | 87 | 3 | 9 | 3.5 | 1 [h] | c/s | 8 | 17 | A | - |
| 73 | 184 390 | 12.3 | 2 | 74 | 3 | 6 | 2.7 | 1 [h] | c/h | 4 | 10 | B | - |
| 74 | 106 070 | 15.4 | 3 | 65 | 3 | 9 | 2.8 | 1 [h] | c/h | 4 | 13 | B | - |
| 75 | 888 150 | 27.9 | 5 | 81 | 3 | 15 | 16.6 | 3 | f/h | 0 | 18 | A | - |
| 76 | 811 420 | 28.3 | 5 | 78 | 3 | 15 | 11.1 | 2 | f/h | 0 | 17 | | - |
| 77-1 | 280 620 | 23.4 | 4 | 91 | 3 | 12 | 2.3 | 1 [h] | c/h | 4 | 16 | A | - |
| 77-2 | 451 550 | 23.5 | 4 | 60 | 3 | 12 | 17.0 | 3 [h] | f/h | 10 | 12 | B | A [f] |
| 81-1 | 752 600 | 18.9 | 3 | 68 | 3 | 9 | 7.0 | 2 [h] | ½/½ | 4 | 13 | B | - |

Table 2 (Cont'd)

| Unit | Productive forest (ha) | Vol. bF [b] and wS ($m^3$/ha) | Rating | % of mature bF (60 years) | Rating | Vol. rat. x mat. rat. | Vol. bS and rS [b] ($m^3$ha) | Rating | Climate (temp./ prec.) | Rating | V.I. | Vulner. class | Adjusted vulner. class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 81-2 | 216 830 | 35.7 | 6 | 83 | 3 | 18 | 15.4 | 3 | f/h | 0 | 21 | A | – |
| 82 | 435 185 | 18.5 | 3 | 34 | 2 | 6 | 9.2 | 2 [h] | f/s | 4 | 10 | B | – |
| 83-2 | 332 760 | 20.7 | 4 | 70 | 3 | 12 | 16.0 | 3 [h] | f/½ | 2 | 14 | B | – |
| 83-1 | 407 900 | 12.2 | 2 | 36 | 2 | 4 | 13.6 | 3 [h] | f/h | 0 | 4 | C | B [f] |
| 84 | 839 430 | 8.2 | 2 | 73 | 3 | 6 | 33.7 | 5 [h] | f/h | 0 | 6 | C | – |
| 85-1 | 387 020 | 6.1 | 1 | 43 | 3 | 3 | 21.1 | 4 [h] | f/½ | 2 | 5 | C | – |
| 85-2 | 412 060 | 3.4 | 1 | 94 | 3 | 3 | 51.2 | 8 [h] | f/s | 4 | 7 | C | – |
| 85-3 | 385 210 | 2.6 | 1 | 84 | 3 | 3 | 40.6 | 6 [h] | f/s | 4 | 7 | C | – |
| 85-4 | 340 990 | 2.2 | 1 | 78 | 3 | 3 | 33.9 | 5 [h] | f/s | 4 | 7 | C | – |
| 86-1 | 482 690 | 4.2 | 1 | 64 | 3 | 3 | 29.4 | 5 [h] | f/h | 0 | 3 | C | – |
| 86-2 | 889 700 | 2.1 | 1 | 83 | 3 | 3 | 56.6 | 9 [h] | f/½ | 2 | 5 | C | – |
| 86-3 | 371 490 | 1.4 | 1 | 78 | 3 | 3 | 51.7 | 8 [h] | f/s | 4 | 7 | C | – |
| 86-4 | 213 230 | 1.4 | 1 | 77 | 3 | 3 | 44.7 | 7 [h] | f/s | 4 | 7 | C | – |
| 87 | 1 309 530 | 6.4 | 1 | 74 | 3 | 3 | 60.1 | 9 [h] | f/h | 0 | 3 | C | – |
| 91 | 497 100 | 50.2 | 8 | 64 | 3 | 24 | 29.3 | 5 | f/h | 0 | 29 | A | – |
| 92-1 | 290 310 | 13.3 | 2 | 49 | 3 | 6 | 22.9 | 4 [h] | f/s | 4 | 10 | B | – |
| 92-2 | 462 850 | 23.9 | 4 | 86 | 3 | 12 | 62.9 | 10 [h] | f/½ | 2 | 14 | B | – |
| 93-1 | 495 460 | 32.2 | 5 | 77 | 3 | 15 | 40.6 | 6 | f/½ | 2 | 23 | A | – |
| 93-2 | 984 740 | 27.3 | 4 | 89 | 3 | 12 | 73.4 | 10 [h] | f/h | 0 | 12 | B | – |
| 93-3 | 1 405 960 | 19.6 | 3 | 95 | 3 | 9 | 62.9 | 10 [h] | f/h | 0 | 9 | B | C [g] |
| 93-4 | 1 444 790 | 3.8 | 1 | 94 | 3 | 3 | 20.3 | 3 [h] | f/h | 0 | 3 | C | – |
| 94-1 | 712 850 | 44.4 | 7 | 71 | 3 | 21 | 32.1 | 5 | f/h | 0 | 26 | A | – |
| 94-2 | 497 670 | 30.6 | 5 | 84 | 3 | 15 | 41.6 | 7 | f/h | 0 | 22 | A | – |
| 94-3 | 626 970 | 16.0 | 3 | 92 | 3 | 9 | 46.6 | 7 [h] | f/h | 0 | 9 | B | C [g] |
| 94-4 | 792 420 | 19.5 | 3 | 92 | 3 | 9 | 63.7 | 10 [h] | f/h | 0 | 9 | B | C [g] |
| 95-1 | 842 390 | 45.1 | 7 | 86 | 3 | 21 | 33.4 | 5 | f/h | 0 | 26 | A | – |

Table 2 (Cont'd)

| Unit | Productive forest (ha) | Vol. bF [b] and wS ($m^3$/ha) | Rating | % of mature bF (60 years) | Rating | Vol. rat. x mat. rat. | Vol. bS and rS [b] ($m^3$ha) | Rating | Climate (temp./prec.) | Rating | V.I. | Vulner. class | Adjusted vulner. class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95-2 | 754 930 | 37.9 | 6 | 94 | 3 | 18 | 46.5 | 7 | f/h | 0 | 25 | A | - |
| 95-3 | 4 563 970 | 16.6 | 3 | 95 | 3 | 9 | 27.4 | 4 [h] | f/h | 0 | 9 | B | - |
| 96 | 591 350 | 57.4 | 9 | 79 | 3 | 27 | 12.1 | 2 [h] | f/s | 4 | 33 | A | - |

[a] V.I. = volume rating of Fb and wS x maturity rating of Fb + volume rating bS (when volume rating of Fb and wS  4) + climate rating.

[b] Fb = balsam fir, wS = white spruce, bS = black spruce, rSred spruce.

[c] c/h = cold-humid, w/h = warm-humid, c/d = cold-dry, w/d = warm-dry, ½/h = approx. ½ of unit warm-humid and ½ cold-humid.

[d] A = bF high vulnerability, B = bF moderate vulnerability, C = bF low vulnerability.

[e] No adjustment required in vulnerability class.

[f] Vulnerability class increased because unit is greatly exposed to budworm invasion from surrounding areas.

[g] Vulnerability class decreased because climate precludes sustained budworm outbreaks.

[h] Rating of volume of bS and rS not considered in calculation of V.I. because volume rating of Fb and wS is less than 28 $m^3$/ha.

## DISCUSSION

Most management units with a high vulnerability rating are in accessible regions where forest operations in Quebec are concentrated (Figure 1). This increases the importance of losses resulting from depredations by budworm, and provides additional reasons why long-term planning for an integrated forest management program aimed at reducing the effect of future budworm outbreaks should be implemented.

The foregoing vulnerability-rating of forests to budworm attack in Quebec is based on a method that could certainly be improved as more accurate data on various aspects of the forest and climate become available. For instance, average temperature and precipitation for the summer months (at present not available for all units) would reflect more clearly the influence of climate on the insect. More important, forest units based on ecological, rather than socio-political criteria, would improve the accuracy of the ratings. Nevertheless, the method of classification as it stands appears to have considerable merit, since, to a large extent, actual damage is in accord with that predicted. Furthermore, this classification has been applied (with slight modifications) by MacLean (1982) to forests in New Brunswick and Nova Scotia, and there also, predicted damage was in accord with that observed. It is utopic to expect that an absolutely accurate forecasting of the effect of budworm on a forest management unit basis can be made. Unknown and unforeseeable factors, as mentioned earlier, can influence the trend of budworm infestations. However, a hazard-rating of the forest even though it may have shortcomings, could prove very useful in the future.

The recurrence of budworm outbreaks is related to the dynamics of the forest. The probability of a budworm attack increases with an increasing presence of mature fir-spruce stands, since these are a prerequisite to outbreaks by this insect. The reduction in volume of fir resulting from an outbreak is the main reason why budworm populations eventually return to endemic levels. It is only when fir-spruce stands of merchantable size once again occupy extensive areas that another outbreak will develop. A hazard-rating of the various forest management units in Quebec based on data obtained at the time of each 10-year inventory, could provide a valuable tool for predicting the occurrence of budworm outbreaks. A map depicting the relative vulnerability of fir based on data obtained when the current forest inventory is completed (about 1987) would present a mosaic quite different from the one based on the preceding inventory shown in Figure 1. Several management units would show a lower vulnerability because of recent reductions in volume of fir and white spruce due to budworm. With each succesive decade, volume and age of fir-spruce stands will increase, and eventually approach the level which gave rise to the present outbreak. The relative vulnerability of various management units at of the next outbreak may differ to some extent from that of the 1970s. The volume of fir and white spruce in units having suffered heavy losses during the current infestation, such as in the Ottawa River watershed (Blais 1981) may take longer to reach a condition favorable to budworm than in units where losses were less pronounced, as in areas protected through application of insecticides.

A periodic rating of the vulnerability of forests to budworm attack could provide a warning of an impending outbreak and indicate the units where damage is likely to be severe. Such information would enable the elaboration and eventual implementation of long- and short-term measures that could reduce losses. These measures could include systematic cutting of mature fir-spruce stands, the selection of areas requiring treatment with insecticides and the elaboration of eventual salvage operations. It is imperative that future forest management programs take into account the periodic losses resulting from recurring spruce budworm outbreaks. Such programs should be based on regional differences, not only in socio-economic needs but also in the vulnerability of the forests to attack. In the years to come, a haphazard approach at reducing losses due to budworm will be unacceptable.

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