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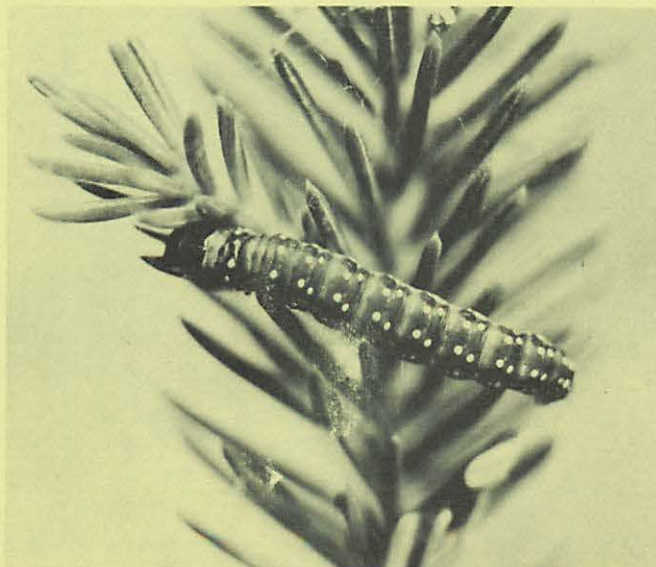
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THE SPRUCE BUDWORM IN NEWFOUNDLAND: HISTORY, STATUS AND CONTROL

by Imre S. Otvos and B. H. Moody



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ABSTRACT

Spruce budworm infestations on the Island have been recorded since 1942. Infestations prior to the present outbreak were small, lasted only a few years, and collapsed without causing significant damage. The collapse of these infestations was caused by natural factors such as weather, parasites, disease and starvation.

The present outbreak started in 1971, and is unprecedented in size and intensity; in 1977 it covered about 90% of the productive forests of the Island and caused an estimated 5 100 000 m³ of tree mortality. The impact of the budworm on the forest cannot be fully assessed at this time as the outbreak is in progress and trees will continue to die for at least 3 years after the outbreak has collapsed.

The biology and habits of the budworm in Newfoundland are similar to those in other areas of eastern North America except development in Newfoundland throughout the life cycle is delayed by 2-3 weeks and a much lower proportion of larvae mines the older needles. Among the natural control factors of the spruce budworm in Newfoundland probably weather is the most important. Other control factors such as parasites and predators alone have not been capable of terminating budworm outbreaks.

At the present time, the only effective way to reduce budworm defoliation and tree mortality over large areas is the aerial application of chemical insecticides. These do not eradicate the budworm but they reduce populations and keep the trees alive. However, chemical insecticides affect non-target organisms and they may also prolong the duration of outbreaks.

There are several promising alternative methods to chemical control, but none is available for operational use over large areas. The microbial insecticide Bacillus thuringiensis is the closest to being operationally feasible although additional work is needed to improve its effectiveness.

The spruce budworm is an integral part of our spruce-fir forest ecosystem and in the long run an integrated control approach appears the most promising. This may include the application of chemical insecticides to highly valuable stands, the salvage of damaged stands, the reduction of stands susceptibility to budworm by silvicultural methods and the application of other control methods as they become operationally feasible.

Résumé

Sur l'Ile de Terre-Neuve des infestations de tordeuses des bourgeons d'épinettes ont été enregistrées depuis 1942. Les infestations antérieures à l'épidémie actuelle étaient petites, ne duraient que quelques années et disparaissaient sans causer de dommages significatifs. La fin de ces infestations étaient dues à des facteurs naturels: température, parasites, maladie et inanition.

L'épidémie courante a commencé en 1972 et a atteint une étendue et une intensité sans précédent; en 1977 elle couvrait 90% des forêts productives de l'Ile et a causé une mortalité d'arbres estimée à 5,100,000 m³. On ne peut pas évaluer encore vraiment l'impact de la tordeuse sur nos forêts, étant donné que l'épidémie est encore en progrès et que les arbres vont continuer à mourir pendant encore au moins 3 ans une fois que l'épidémie aura cessé.

La biologie et les habitudes de la tordeuse de Terre-Neuve sont semblables à ce qu'on retrouve dans les autres régions de l'est de l'Amérique du Nord; sauf qu'ici, le développement pendant le cycle biologique est retardé de 2 à 3 semaines et une proportion beaucoup plus faible de larves attaquent les vieilles aiguilles. Parmi les facteurs naturels qui aident à contrôler la tordeuse des bourgeons d'épinettes à Terre-Neuve, la température est probablement le plus important. Les autres facteurs de contrôle, tels que les parasites et les prédateurs, n'ont pu à eux seuls enrayer les épidémies.

Pour le moment, l'application aérienne d'insecticides chimiques est le seul moyen efficace de réduire sur de grandes étendues, la défoliation et la mortalité des arbres dues à la tordeuse. Ces applications n'enrayent pas complètement la tordeuse mais elles en réduisent les populations et empêchent les arbres de mourir. Cependant, les insecticides chimiques affectent d'autres organismes et ils peuvent aussi prolonger la durée des épidémies.

Il existe plusieurs méthodes de rechange pour le contrôle chimique. Cependant, aucune d'elles n'est encore prête à être utilisée à grande échelle. L'insecticide microbien, Bacillus thuringiensis est le moyen le plus à point; cependant, plus de recherche doit y être consacrée pour en améliorer l'efficacité.

La tordeuse des bourgeons d'épinettes fait partie intégrante de l'écosystème forestier et à long terme, l'approche d'un contrôle intégré semble la plus prometteuse. Ceci peut comprendre l'application d'insecticides chimiques sur les peuplements de grande valeur, la récupération des peuplements endommagés, la réduction de la prédisposition des peuplements à la tordeuse par des méthodes sylvicoles et l'application d'autres méthodes de contrôle à mesure qu'elles deviendront praticables.

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THE SPRUCE BUDWORM IN NEWFOUNDLAND:

HISTORY, STATUS AND CONTROL

by

Imre S. Otvos and B.H. Moody

I. INTRODUCTION

The spruce budworm, Choristoneura fumiferana (Clem.), is the most widely distributed and most destructive forest insect in North America. It is a native pest and periodically causes extensive defoliation and tree mortality to a wide variety of coniferous tree species. In eastern North America it is a major pest of balsam fir, Abies balsamea (L.) Mill., white spruce, Picea glauca (Moench) Voss., red spruce, Picea rubens Sarg., and black spruce, Picea mariana (Mill.) B.S.P. Outbreaks of the spruce budworm are known to have occurred in Canada since the early 1700's (Blais 1965). Only scant records are available of the early outbreaks but those of this century have been well documented. In some of these latter outbreaks timber losses have been estimated "from 1.5 to 10 billion cubic feet" (42 000 to 283 000 m³) (Prebble 1975).

In Newfoundland, small scattered outbreaks have occurred periodically which seldom lasted more than 3 years and caused no appreciable damage or tree mortality. The present outbreak began on the west coast of the Island in 1971 and is now the largest and most severe ever recorded in Newfoundland. The spruce budworm was also recorded in Labrador as early as 1949, but the only extensive defoliation in this region since that time occurred between 1975 and 1977.

This report summarizes the current knowledge of the biology of the budworm in Newfoundland, the history of previous outbreaks, and the progress, status and potential of the present outbreak. It also discusses the role of natural control agents and control measures available at present and those which show promise for future use.

II. BIOLOGY AND POPULATION TRENDS

Details of the life history of the spruce budworm were not studied in Newfoundland until it became evident that it had become an important pest in the Province (Crummey 1976). The generalized life cycle is illustrated in Table 1.

Table 1. Generalized life cycle of the spruce budworm in Newfoundland.

Stage	Month of Year											
	M	J	J	A	S	O	N	D	J	F	M	A
Egg			X	X								
Larva	X	X	X	X	X	X	X	X	X	X	X	X
Pupa			X	X								
Adult			X	X								

The eggs are laid in clusters or masses on the needles in July and August; the peak oviposition usually occurring in late July (Crummey and Otvos, in prep.). There are six larval instars. The first instar larvae hatch approximately 10 days after eggs are oviposited, beginning around early August. These larvae do not feed but are very active and they can be observed hanging on silken threads from where they are easily dispersed by wind, sometimes for considerable distances. This first dispersal is also a period of mortality of larvae. During this initial period the larvae move to protected sites such as under bark scales, flower scars and lichens to spin over-wintering shelters called hibernacula. In these hibernacula they molt into second instar larvae in the fall and hibernate.

The second instar larvae become active in the spring and move towards the tips of the branches to feed. This usually occurs around the latter part of May or early June, depending on the temperature. As larvae search for food they may be blown off the branches and dispersed by wind. This is the second major dispersal period of the budworm and it is also a period of some mortality. The second instar larvae usually mine the previous year's needles, unopened vegetative buds or feed on staminate flowers. Mining of old needles by second instar larvae is much more common elsewhere than in Newfoundland; observations indicate that about 5% of the population mines old needles. Buds, particularly on balsam fir, can be completely consumed leaving only bud scales. As the buds swell and shoot elongation begins, larvae will feed on the new needles until larval development is completed or until the new needles, called current growth, are consumed. The larvae usually web two or three shoots together which form a feeding tunnel and the larvae feed on the foliage inside this tunnel. If the new foliage is consumed before completion of larval development, the late instar larvae will feed on

the old foliage. Feeding on old foliage is commonly referred to as "backfeeding". Only fifth and sixth instar larvae can complete their development on old foliage. If populations are so high that all buds are destroyed while the larvae are in the second or third instar, then these larvae will die. Larval development is usually completed by the latter part of July. The time required is variable and is affected by numerous factors including temperature, humidity, and food quality. Cold, wet weather delays development, while feeding on staminate flowers enhances development. After a short prepupal period the mature larvae transform into pupae.

Pupation usually takes place in or near the feeding shelter constructed by the larvae. Male pupae are generally smaller than female pupae. The pupal stage lasts from 10 to 14 days after which the adults emerge.

The adults appear in the field in late July or early August. Male moths emerge first and females several days later. Mating occurs shortly after emergence and oviposition begins within a few days. Female moths deposit their eggs on the needles of the host trees in clusters of 2, 3 or 4 rows each. The eggs are laid in an overlapping, shingle-like pattern. The number of eggs per mass averages about 25 in stands with a history of light defoliation (Otvos 1977). A female may lay up to 200 eggs of which about one-half is oviposited before females can fly actively. Then, if conditions are suitable, the moths may be caught in rising air currents and transported considerable distances and deposit the remainder of the eggs after their dispersal. Moths of both sexes may be dispersed by wind. Such "moth flights" usually occur in the evening when temperatures are above 15°C (Greenbank 1973). This is the third and perhaps the most important dispersal in the life cycle of the spruce budworm. If temperature and other weather conditions are unsuitable then adult dispersal does not occur and the full complement of eggs are deposited by females in or close to the stands where they emerged.

The spruce budworm in eastern North America is noted for its particular behavior, and population dynamics (Morris 1963). At low population levels with good food supply, a female lays about 200 eggs only two of which would need to survive to the adult stage the following year to maintain the population at a constant level. In general, survival in the egg stage is high, 80-85%. There are high losses (64% (Miller 1958)) as the first instar larvae hatch and are dispersed by the wind, and survival tends to be a function of availability of host species. Overwintering loss is negligible for larvae which are protected in their hibernacula. With the emergence of the second instar larvae in the spring there is a second noticeable reduction in number (about 40% (Miller 1958)) due to dispersal losses as the larvae migrate to feeding

sites in buds, flowers and needles. From the third instar larvae to the late instar larvae and pupae the loss is about 80-90% and is caused by a complex of parasites, predators, diseases and weather. Survival of pupae is high and losses are associated with the above bio-control agents. Survival during the adult stage is highly variable and depends on predation, weather conditions and dispersal.

To date there is little evidence to show that the survival rates of the budworm in Newfoundland differ markedly from the Maritimes. Total mortality within a generation, i.e. egg to adult, under normal conditions is about 99%, so in each generation only one male and one female reach maturity from about 200 eggs (Miller 1975). Therefore, a generation survival rate of .01 (2/200) gives a constant population. However, small reduction in mortality levels have resulted in explosive increases in budworm population levels to outbreak conditions.

Successive life stages of the spruce budworm have been measured through three generations in five regions (two areas per region) in insular Newfoundland. This has been carried out since 1974 as a means of systematically recording population change within a generation and some of the factors causing this change. Population counts were obtained for five life stages: eggs, overwintering larval stage, third instar larvae, late instar larvae and pupae. Survival of the late instar larvae for the 1975-1976 generation was 0.104 which was higher than for the 1974-1975 generation (0.051). This indicated a five-fold increase from one generation to the next. However, much variation existed between regions (0.029 to 0.206)¹. It is also known that survival of large larvae determines to a large extent the survival within the generation and, therefore, the rate of budworm population growth. This survival rate does not always determine generation to generation trend in budworm abundance because invasion or dispersal of moths may also occur.

III. HISTORY OF OUTBREAKS

1. 1942-1954

The earliest reported outbreak in Newfoundland occurred on Bell Island, near St. John's, in 1942 (Brown 1943). This outbreak persisted for a number of years in the slow growing spruce and fir stands, then it spread to the adjacent Avalon Peninsula (Reeks, Forbes and Cuming 1947) (Fig. 1, A). The outbreak peaked in 1948 and collapsed in 1954 (Parrott 1956). Light to severe defoliation but no tree mortality was observed in the infested stands. Some of this defoliation may have been caused by the blackheaded budworm, Acleris variana (Fern.), another defoliator which also occurred in the same general area from 1947 to 1950.

¹Bryant, D.G. & A.G. Raske. 1977. Spruce budworm population studies in Newfoundland. In: Annual review of spruce budworm in eastern North America. Feb. 1977.

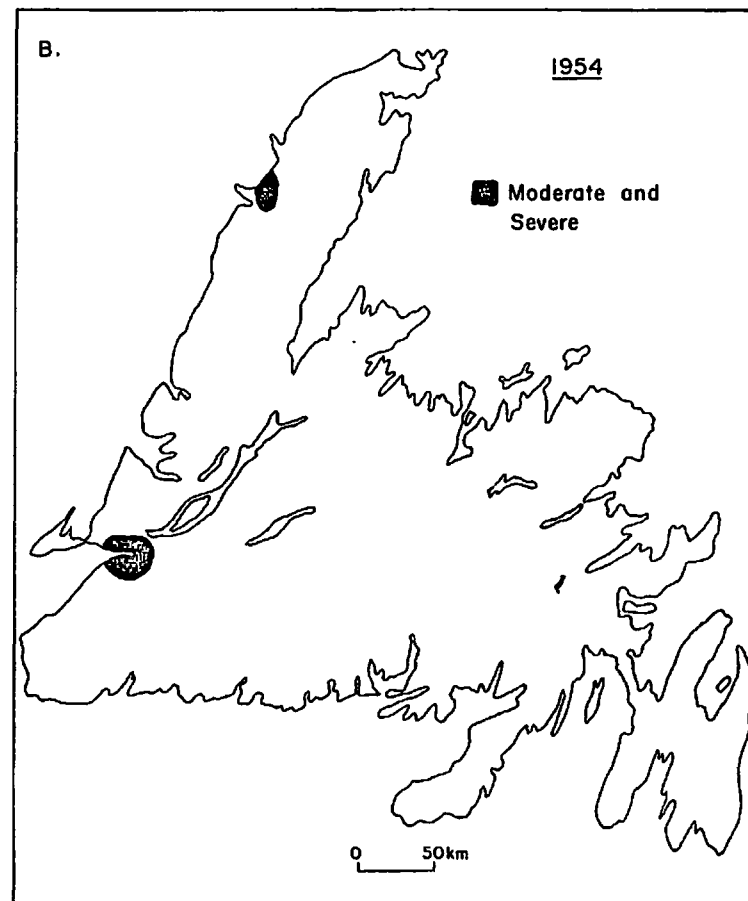
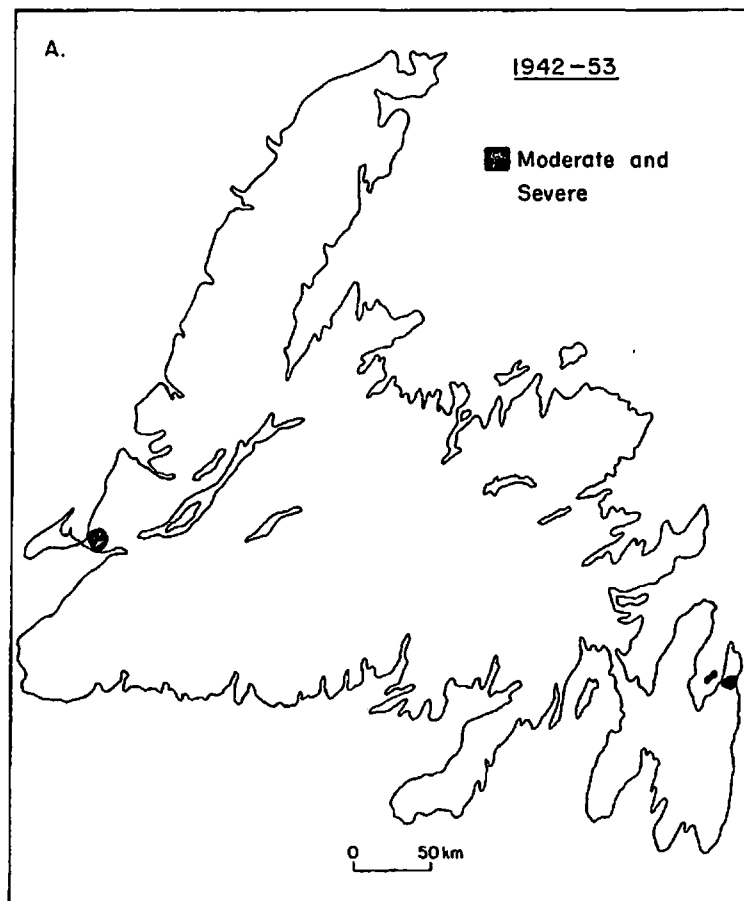


Figure 1. Spruce budworm infestations in Newfoundland:
 A - - - - 1942-53 B - - - - 1954

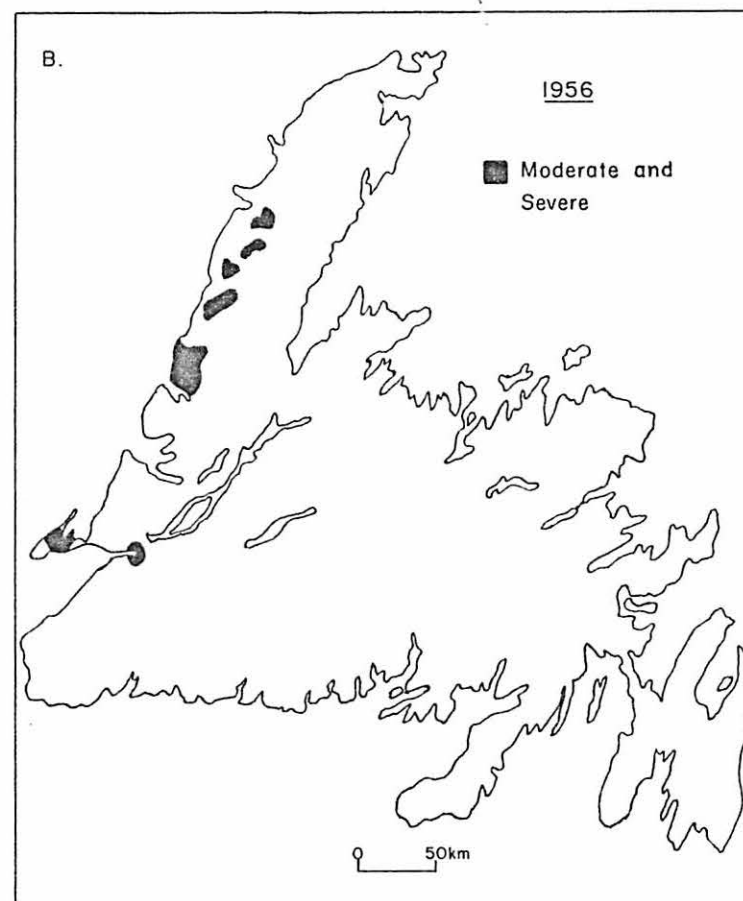
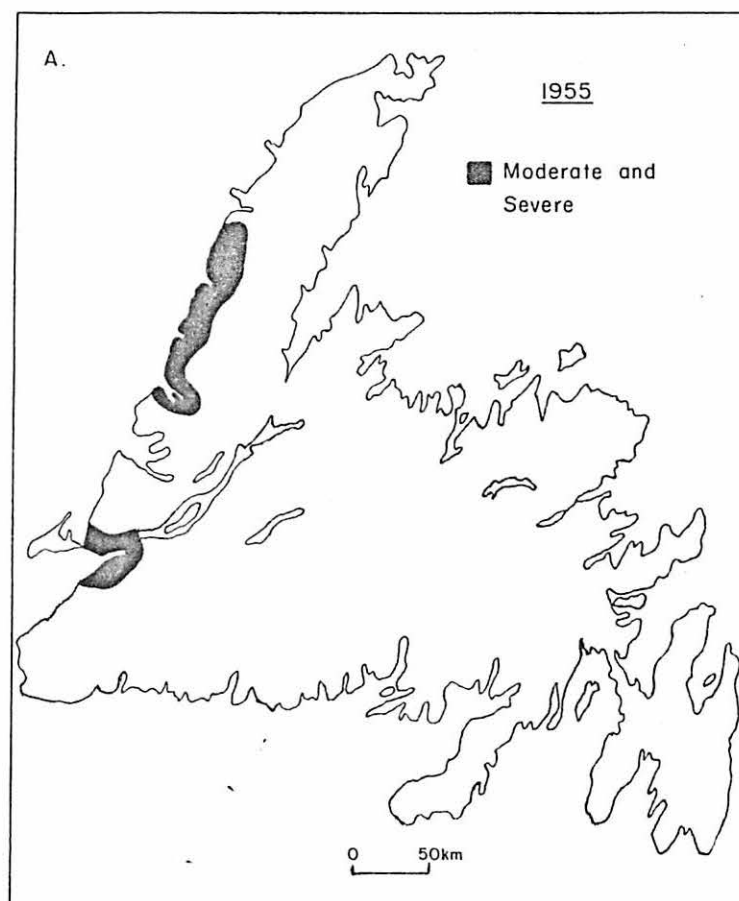


Figure 2. Spruce budworm infestations in Newfoundland:
 A - - - - 1955 B - - - - 1956

2. 1952-1956

A small number of spruce budworm larvae were collected at six locations outside the Avalon Peninsula in 1948 (Carroll 1948). In 1949 larvae were collected at four additional locations on the Island and from one location in Labrador (Reeks, Carroll, Sheppard 1949). In 1952 an increase in budworm numbers was recorded in the St. George's District followed by a further increase in 1953 in several other areas in western Newfoundland. The highest larval numbers were recorded near Stephenville Crossing and St. George's areas where defoliation on white spruce ranged from a trace to 20%¹ (Carroll and Parrott 1952, 1953).

In 1954 population levels increased throughout the Island, especially in a narrow strip along the coast of western Newfoundland (Fig. 1B, 2A). These infestations peaked in 1955 and extended over about 10 400 hectares (ha) (25,600 acres) between Stephenville Crossing and Port au Port and approximately 38 900 ha (96,000 acres) in the St. Barbe District from Trout River to Hawkes Bay. Defoliation ranged from 60% to 90% on balsam fir and from 10% to 60% on white spruce at the centre and up to 25% on both spruce and fir at the periphery. No tree mortality was observed (Carroll 1956).

Egg mass numbers were high in the fall of 1955, 477/10 m² (443/100 sq. ft.) on balsam fir and 473/10 m² (440/100 sq. ft.) on white spruce, respectively, in the northern portion of St. Barbe District and severe defoliation was forecast for 1956. For other areas in western Newfoundland egg mass sampling indicated light to moderate defoliation (Carroll 1956).

In 1956 population levels were low with the exception of St. Barbe District. Here, the previously continuous infestation broke into 4 smaller isolated areas ranging in size from about 800 ha (1,900 acres) to 2 600 ha (6,400 acres) along the west coast at Rocky Harbour, Parsons Pond, River of Ponds and Angle Pond respectively (Fig. 2B). Loss of current foliage ranged from 10% to 95% on balsam fir and 5% to 40% on white spruce. The size of the outbreak in St. George's District also decreased considerably and defoliation of balsam fir ranged from 5% to 10% and on white spruce up to 5%. Many dead larvae were found in 1956 but the cause of death was not determined. A high incidence of parasitism in the late larval and pupal stages also contributed to the decline of the outbreak. Few egg masses, 2/10 m² to 4/10 m² (1 to 4/100 sq. ft.) were found during the fall egg mass survey in 1956 (Parrott and Clarke 1957).

¹Unless otherwise stated all percent defoliation figures refer to new growth consumed and not the total amount of foliage of the tree.

3. 1960-1971

No infestation of the spruce budworm was recorded until 1960 when defoliation was estimated at about 15% of the current year's growth near Stephenville (Parrott, Clarke and Shea 1960, 1961). In 1961 the infestation increased and extended over 3 900 ha (9,600 acres) near the Port au Port Peninsula. Larval numbers were high (100 larvae and pupae per sample tree) and defoliation ranged from 40% to 90%. Larvae were also common throughout the coastal area near Bonne Bay and from Trout River to Hawkes Bay (Fig. 3A) and defoliation ranged from 5% to 20%. In July these areas were re-sampled and between 30% and 40% of the larvae in the samples were dead or dying. Dead and dying larvae were also found near Stephenville. Although the cause of larval mortality was not determined it was suspected that it was caused by disease (Parrott and Clarke 1962).

In 1962 budworm population levels were low in all locations except in a 500 ha (1,300 acre) area east of Stephenville (Fig. 3B) adjacent to the 1961 infestation that collapsed. This new infestation was primarily in pole-size, immature balsam fir and white spruce stands. Defoliation of the current year's growth was 90% to 95% on balsam fir and 40% to 60% on white spruce. Larval development was delayed by a late cold spring in 1962 and few dead larvae were found in the field in comparison to 1961. However, about 20% of the laboratory reared larvae died from parasitism and about 30% died from unknown causes (Parrott, Clarke and Haines 1963). The infestations near Stephenville terminated in 1962 (Parrott, Clarke and Haines 1964).

Spruce budworm population levels remained low until 1968 when about 45 300 ha (112,000 acres) were infested in the coastal stands of balsam fir and white spruce from Heatherton to St. Andrews in western Newfoundland (Fig. 4A). Only light defoliation, 5% to 10%, was recorded (Clarke *et al.* 1969). There was no evidence of spruce budworm in this area in 1969 and reasons for the collapse of the infestation are not known. In 1968, other areas of western Newfoundland were treated with fenitrothion to control an outbreak of the eastern hemlock looper (Otvos, Clark and Clarke 1971). The area infested by the spruce budworm was not sprayed and there is no evidence to suggest that the spray program had any effect on the spruce budworm.

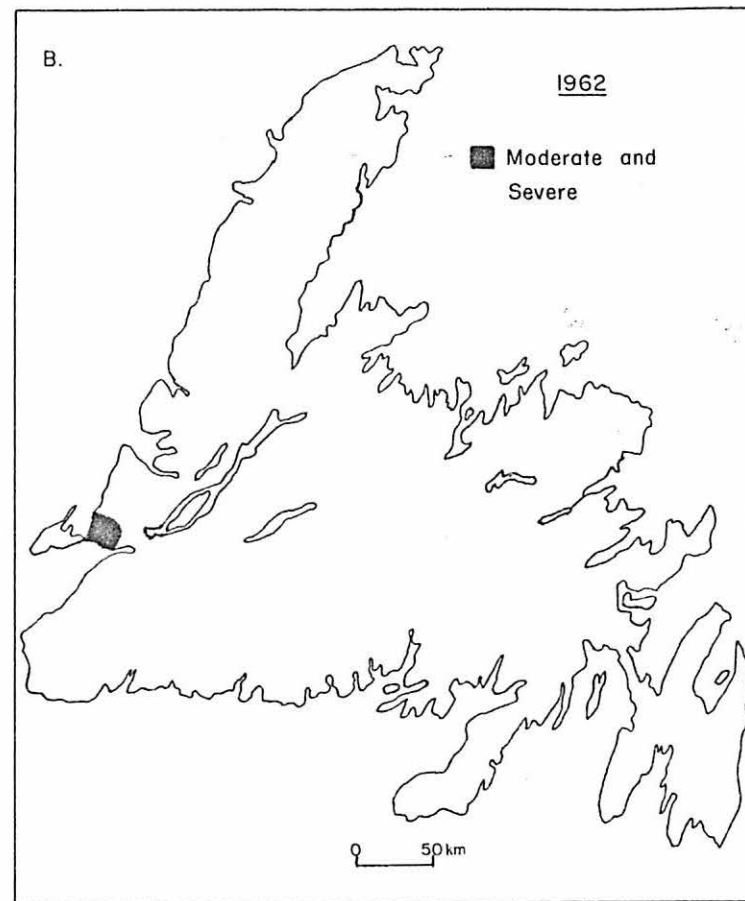
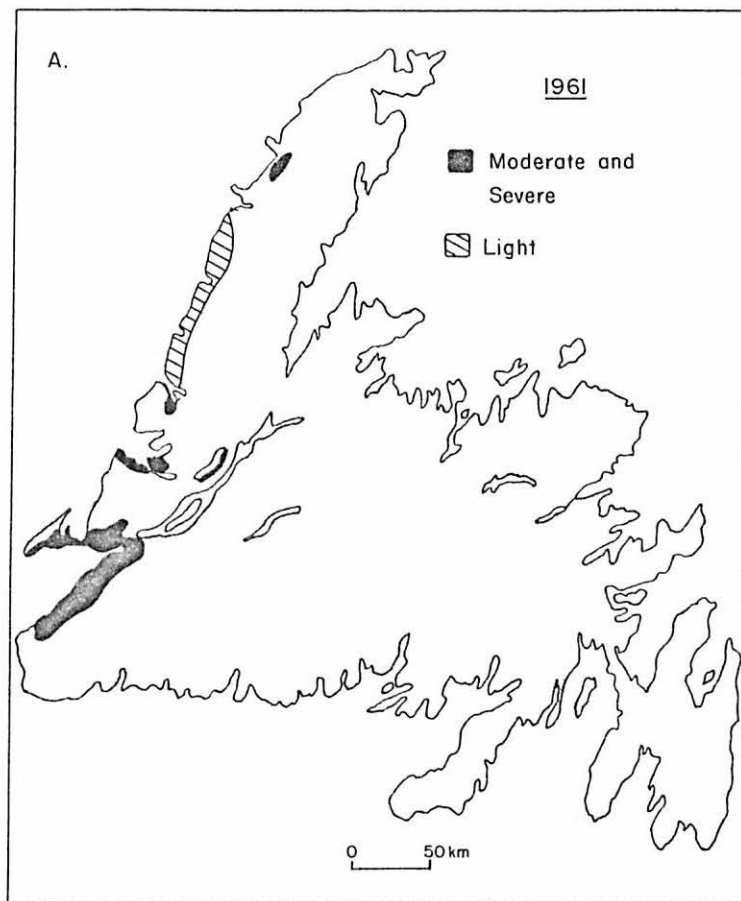


Figure 3. Spruce budworm infestations in Newfoundland:
 A - - - - 1961 B - - - - 1962

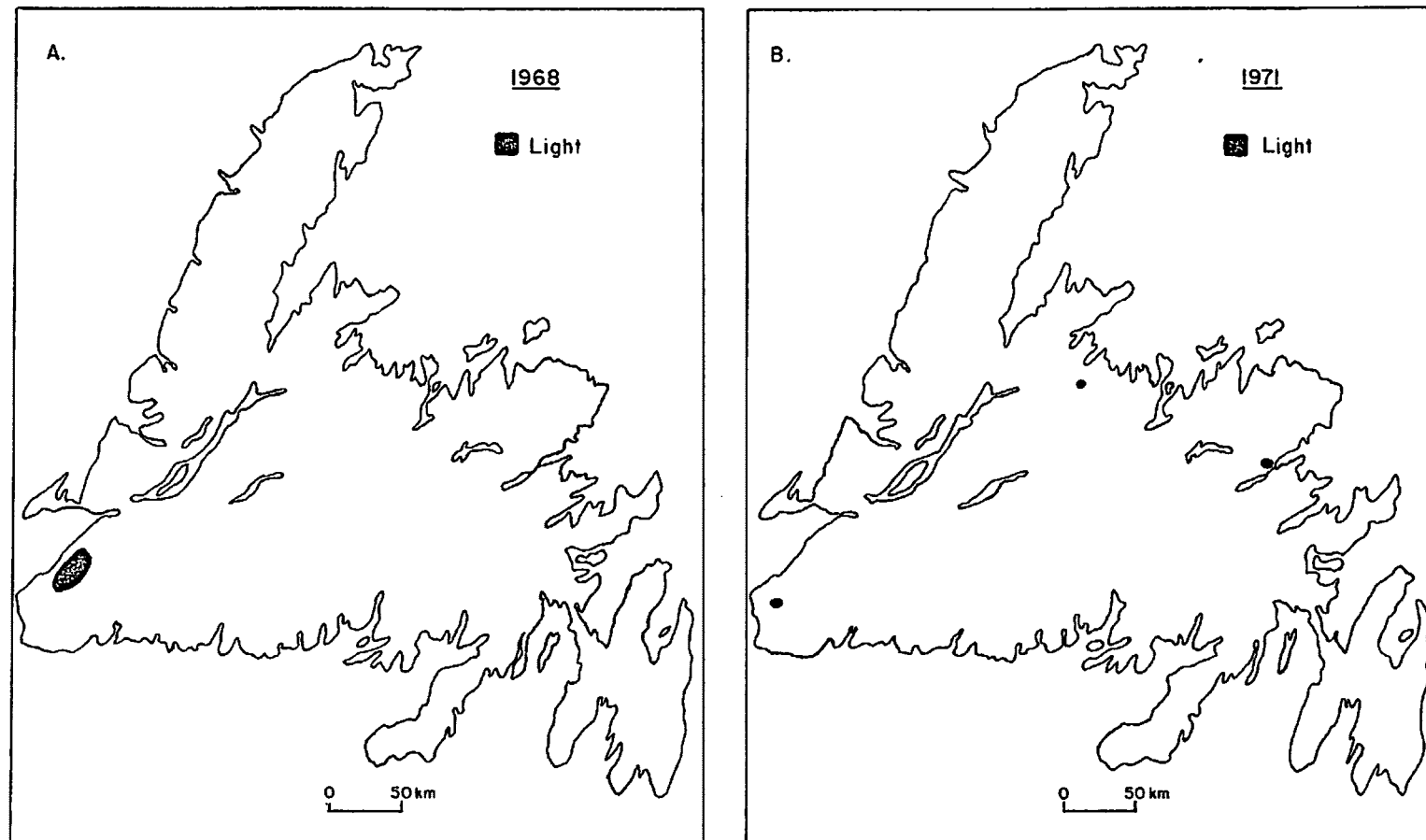


Figure 4. Spruce budworm infestations in Newfoundland:
 A - - - - 1968 B - - - - 1971

4. 1971-1977

In 1971 spruce budworm larval numbers increased at three widely separated locations. Defoliation of about 10% of the current year's foliage was recorded in a 4 ha area of balsam fir in the Codroy Valley in western Newfoundland; an 8 ha area of balsam fir and black spruce at Twin Lakes near Badger in central Newfoundland; and in an 8 ha area of balsam fir near Gambo in eastern Newfoundland (Clarke et al. 1972) (Table 2; Fig. 4B).

In 1972, all three of these infestations subsided. However, other infested areas were recorded over an estimated 647 200 ha (1,600,000 acres), from Codroy Pond north to Hawkes Bay in western Newfoundland and east to Gull Pond near Badger in central Newfoundland (Table 2); of this area about 364 200 ha (900,000 acres) were in the moderate to severe defoliation category (Fig. 5A) (Clarke et al. 1973). The reasons for this sudden increase in the size and intensity of the infestations are not known but the most probable factors are the abnormally warm and favourable weather conditions in the spring and early summer, and possibly a "moth flight" from the Maritime Provinces in the fall of 1971.

An egg mass survey, based on the method of Morris (1954) and Webb et al. (1956), was conducted at 70 locations across the Island in 1972. This survey showed that although egg mass distribution was extensive, population levels were low¹ at 36 of the 70 points examined, moderate at 16 locations and high at the remaining three locations. It was, therefore, forecast that the outbreak would not increase significantly in size and intensity in 1973, but some top killing might be expected in severely defoliated areas (Clark and Richardson 1972).

In 1973, the size of the outbreak increased to cover an estimated 1 414 000 ha (3,500,000 acres) (Table 2; Fig. 5B). The optimistic forecast based on egg samples collected the previous fall was evidently incorrect; it was based only on 70 sample locations, too few to adequately cover the extensive geographic area involved. Also, in 1973 the black-headed budworm, which has been gradually increasing over the past two years, caused defoliation in several areas, and accurate determination of the extent of damage by each of the insects was virtually impossible (Clarke et al. 1974). However, the areas of moderate and severe defoliation decreased from 364 200 ha (900,000 acres) in 1972 to 118 900 ha (293,700 acres) in 1973 (Clark and Singh 1973). The most severe defoliation occurred in balsam fir stands from Flat Bay Brook to Corner Brook and from Birchy Lake to Springdale. In some areas up to 400 larvae per tree sample was recorded in late June and early July and 100% of the current year's foliage was defoliated. However, when these areas were

¹Egg mass density classes are low: 0-107/m² (0-99/100 sq. ft.); moderate: 108-258.10 m² (100-239/100 sq. ft.); high: 259+/10 m² (240+/100 sq. ft.).

Table 2.- The area and intensity of spruce budworm infestation in Newfoundland, 1971-1977.¹ Determined by aerial surveys.

Year	Region	Light		Moderate		Severe		S + O ²		Total	
		ha	acres	ha	acres	ha	acres	ha	acres	ha	acres
1971	Western	4	10	-	-	-	-	-	-	4	10
	Central	8	20	-	-	-	-	-	-	8	20
	Eastern	8	20	-	-	-	-	-	-	8	20
	Total	20	50	-	-	-	-	-	-	20	50
1972	Western	265 790	656,780	58 350	144,170	233 380	576,700	-	-	557 520	1,377,650
	Central	17 240	42,590	21 460	53,020	51 030	126,110	-	-	89 730	221,720
	Eastern	-	-	-	-	-	-	-	-	-	-
	Total	283 030	699,370	79 810	197,190	284 410	702,810	-	-	647 250	1,599,370
1973	Western	670 130	1,655,930	70 970	175,370	29 490	72,860	-	-	770 590	1,904,160
	Central	539 080	1,332,100	2 020	5,000	16 380	40,460	-	-	557 480	1,377,560
	Eastern	86 370	213,420	-	-	-	-	-	-	86 370	213,420
	Total	1 295 580	3,201,450	72 990	180,370	45 870	113,320	-	-	1 414 430	3,495,140
1974	Western	763 740	1,887,240	131 970	326,110	419 040	1,035,460	-	-	1 314 750	3,248,810
	Central	660 520	1,632,430	133 200	329,140	31 140	76,950	-	-	824 960	2,038,520
	Eastern	88 410	218,470	-	-	-	-	-	-	88 410	218,470
	Total	1 512 770	3,738,140	265 170	655,250	450 180	1,112,410	-	-	2 228 120	5,505,800

(Cont'd ...)

Table 2 - Concluded

Year	Region	Light		Moderate		Severe		S + O ²		Total	
		ha	acres	ha	acres	ha	acres	ha	acres	ha	acres
1975	Western	454 100	1,122,090	109 500	270,590	392 030	968,730	-	-	955 630	2,361,410
	Central	855 600	2,114,240	78 920	195,010	87 080	215,170	-	-	1 021 600	2,524,420
	Eastern	40 530	100,160	-	-	-	-	-	-	40 530	100,160
	Total	1 350 230	3,336,490	188 420	465,600	479 110	1,183,900	-	-	2 017 760	4,985,990
1976	Western	463 920	1,146,360	71 390	176,400	422 910	1,045,020	121 570	300,400	1 079 790	2,668,170
	Central	617 480	1,525,820	158 290	391,140	300 880	743,490	15 420	38,110	1 092 070	2,698,560
	Eastern	268 030	662,320	49 300	121,830	55 010	135,930	5 800	14,330	378 140	934,410
	Total	1 349 430	3,334,500	278 980	689,370	778 800	1,924,440	142 790	352,840	2 550 000	6,301,140
	Labrador	81 970	202,540	29 690	73,370	39 100	96,630	-	-	150 760	372,540
	Grand total	1 431 400	3,537,040	308 670	762,740	817 900	2,021,070	142 790	352,840	2 700 760	6,673,680
1977	Western	639 220	1,579,530	55 010	135,940	335 030	827,880	-	-	1 029 250	2,543,350
	Central	578 840	1,430,340	52 320	129,290	637 650	1,575,670	-	-	1 268 810	3,135,300
	Eastern	223 700	552,780	17 230	42,580	191 530	473,270	-	-	432 460	1,068,630
	Total	1 441 760	3,562,650	124 560	307,810	1 164 210	876,820	-	-	2 730 520	6,747,280
	Labrador	20 880	51,600	13 600	33,600	18 200	44,970	-	-	52 680	130,170
	Grand total	1 462 640	3,614,250	138 160	341,410	1 182 410	2,921,790	-	-	2 783 210	6,877,450

¹Both hectares and acres rounded off to nearest 10²Severe damage to new and old foliage

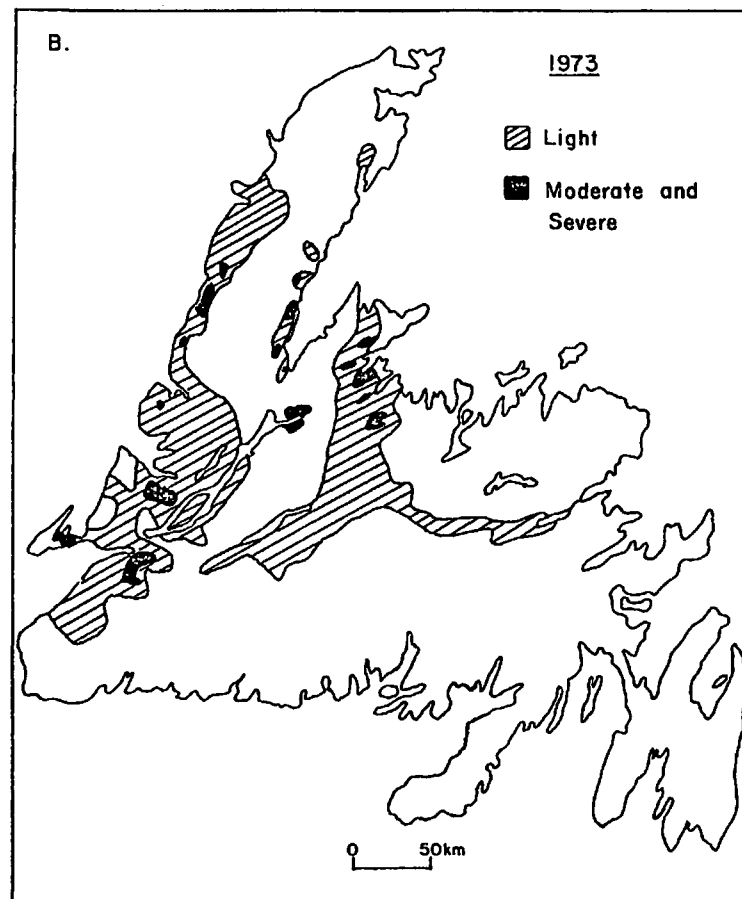
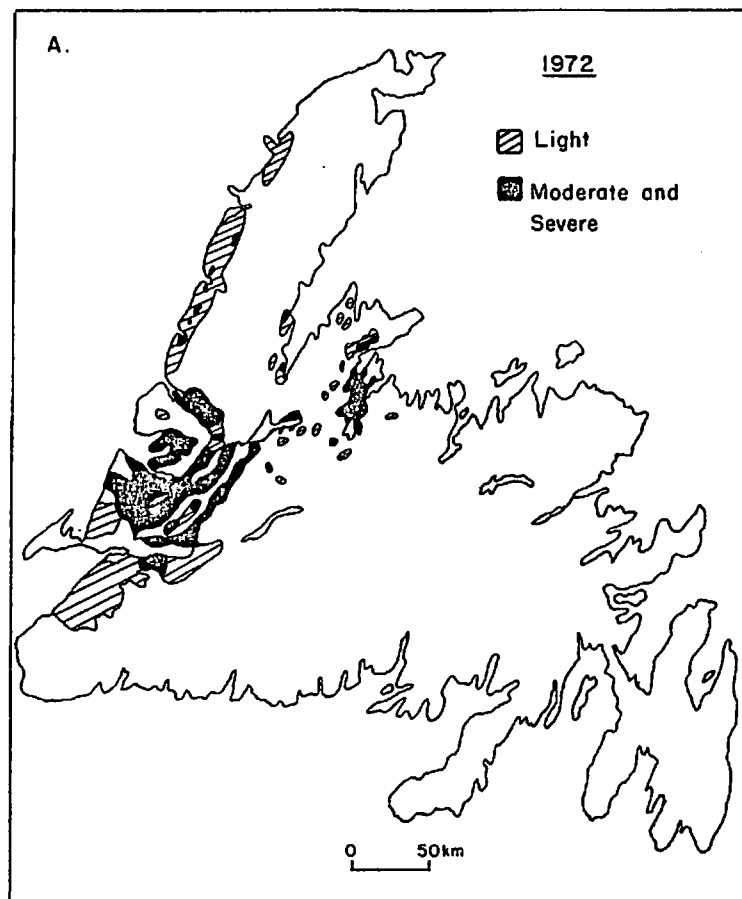


Figure 5. Spruce budworm infestations in Newfoundland:
A - - - - 1972 B - - - - 1973

re-sampled in late July and early August, both larvae and pupae were scarce, and none of the old foliage had been consumed. A high incidence of a fungal disease was recorded at some locations in western Newfoundland and this disease may have caused or contributed to the decline at the other locations as well.

The intensity of egg mass surveys was increased in 1973 to 128 sample locations of which 58 showed low egg mass numbers, 15 moderate, four showed severe egg mass density, and the remaining locations had none.

In 1974, the size of the outbreak increased to 2 228 100 ha (5,510,000 acres) distributed from Cape Ray north to Main Brook and east to Gander, and a separate infestation occurred at Random Island (Table 2; Fig. 6A). Larval populations increased from an Island-wide average of 9 per tree sample in 1973 to 22 per tree sample in 1974 (Clarke et al. 1975).

In 1974, the number of egg-mass samples was increased to 745 locations. Egg-masses ranged from zero to a high of 2 700 per 10 m² per location. Based on the results of this survey it was forecast that in 1975 the overall size of the outbreak would increase to about 2 024 300 ha (5,000,000 acres) and that areas of moderate and severe defoliation would increase to 1 821 900 ha (4,500,000 acres). Some tree mortality was also forecast in about 174 100 ha (430,000 acres), primarily in stands severely defoliated by the budworm for two or more years and weakened in the past by other forest pests, such as the balsam woolly aphid, the eastern hemlock looper and the balsam fir sawfly.

In 1975, the outbreak area was 2 017 800 ha (4,986,000 acres) and of this about 667 530 ha (1,650,000 acres) was in the moderate and severe defoliation category (Table 2, Fig. 6B). This represents a decrease in the net area of approximately 47 800 ha (118,200 acres) from 1974 in the moderate and severe defoliation category. The most noticeable decrease occurred in the Codroy Valley in western Newfoundland and between Bishops Falls and Bay d'Espoir in central Newfoundland. Spruce budworm defoliation was generally light east of Gander except for two locations, one near Soulis Pond and the other on Random Island, where moderate to severe defoliation was recorded. Larval numbers for the Island increased from an average of 22 per tree in 1974 to 29 per tree in 1975 (Clarke et al. 1976).

The egg-mass survey was conducted in September when a total of 619 locations were sampled across the Island; of these 359 showed high egg-mass densities, 60 moderate densities, 93 locations had low egg-mass numbers and the remaining 107 locations had no egg-masses. Based on the results of this survey, it was forecast that the total area of moderate

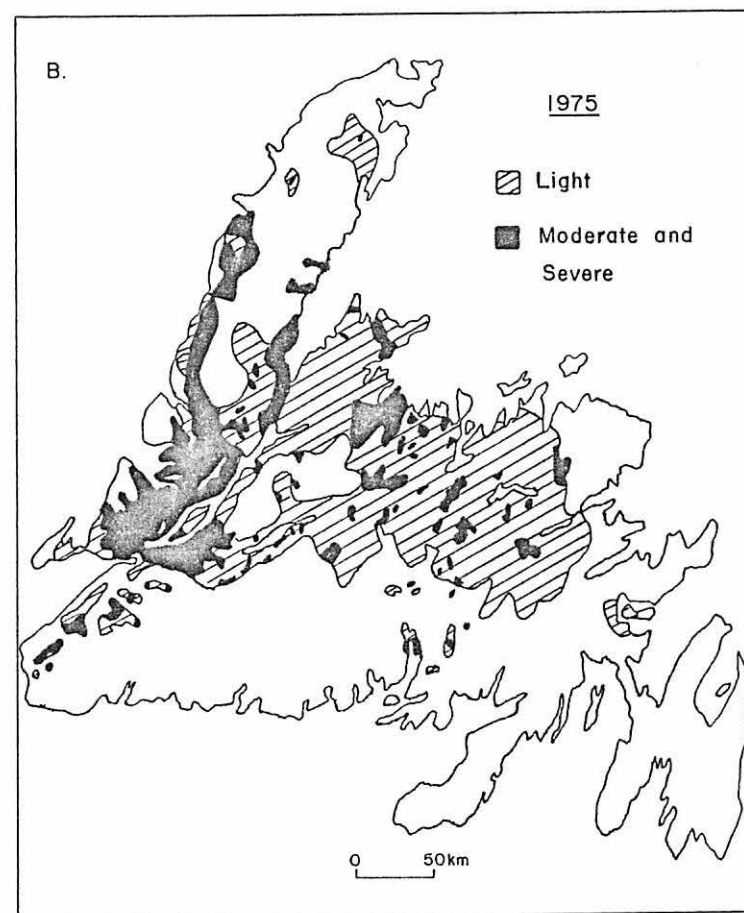
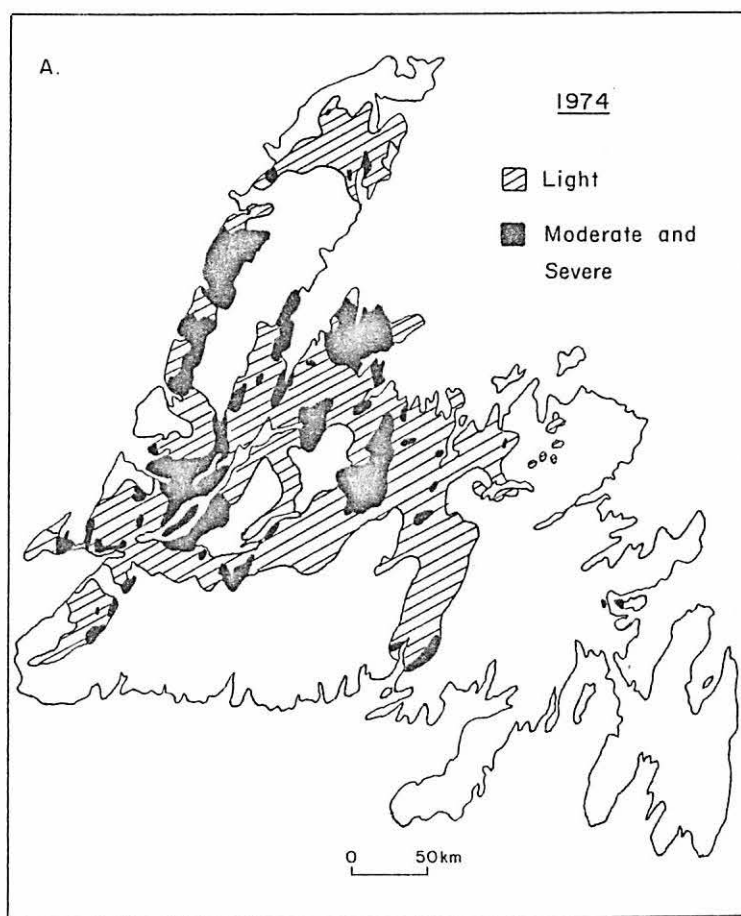


Figure 6. Spruce budworm infestations in Newfoundland:
 A - - - - 1974 B - - - - 1975

and severe defoliation would increase by an estimated 404 900 ha (1,000,000 acres) primarily in central and parts of eastern Newfoundland. It was also forecast that within the areas of moderate and severe defoliation, some tree mortality, mainly in western Newfoundland, would occur in about 264 800 ha (654,000 acres) especially in stands severely defoliated by the budworm for two or more years and damaged in the past by other forest pests. It was estimated that tree mortality in 1976 would be about 2 900 000 m³ (800,000 cords) (Clarke and Singh 1975).

In 1976, the outbreak extended over an area of 2 550 200 ha (6,301,000 acres). Of this about 1 200 570 ha (2,966,650 acres) were in the moderate and severe category (Table 2, Fig. 7A). In addition, in Labrador the outbreak covered approximately 150 760 ha (373,000 acres) including about 68 800 ha (170,000 acres) in the moderate and severe defoliation category (Table 2; Fig. 7B). Most of the areas infested by spruce budworm in Labrador in 1976 were also infested by the blackheaded budworm and/or the balsam fir sawfly, but the spruce budworm caused most of the damage (Clarke et al. 1977).

In September 1976 the budworm egg-mass survey included 777 locations on the Island and 20 in Labrador. This was the first time that an egg-mass survey was conducted in Labrador.

On the basis of the results of this survey it was forecast that the outbreak would increase to 3 522 000 ha (8,700,000 acres) representing about 90% of the productive fir-spruce forest areas of the Island.

The areas of moderate and severe defoliation were forecast to expand very little in 1977 in western Newfoundland, however a major increase was expected for central and eastern regions for a total of about 1 538 000 ha (3,800,000 acres). The total area of moderate and severe defoliation included 257 500 ha (636,000 acres) where tree mortality was forecast to occur in 1977. The amount of tree mortality would vary considerably with stand age and history of damage, and would average about 20% in stands of regeneration, 10% in semi-mature and mature stands but may reach as high as 50% or even higher in some of the stands previously damaged by other insects.

Egg-mass samples from the 20 locations in Labrador showed that despite the relatively high larval numbers and the intensity of the 1976 defoliation, only two sample points had high egg counts; two others had low counts and the remainder none. Based on these results, only two areas, one near Goose River and the other at Mud Lake, were forecast to have a potential for high larval numbers and severe defoliation in 1977.

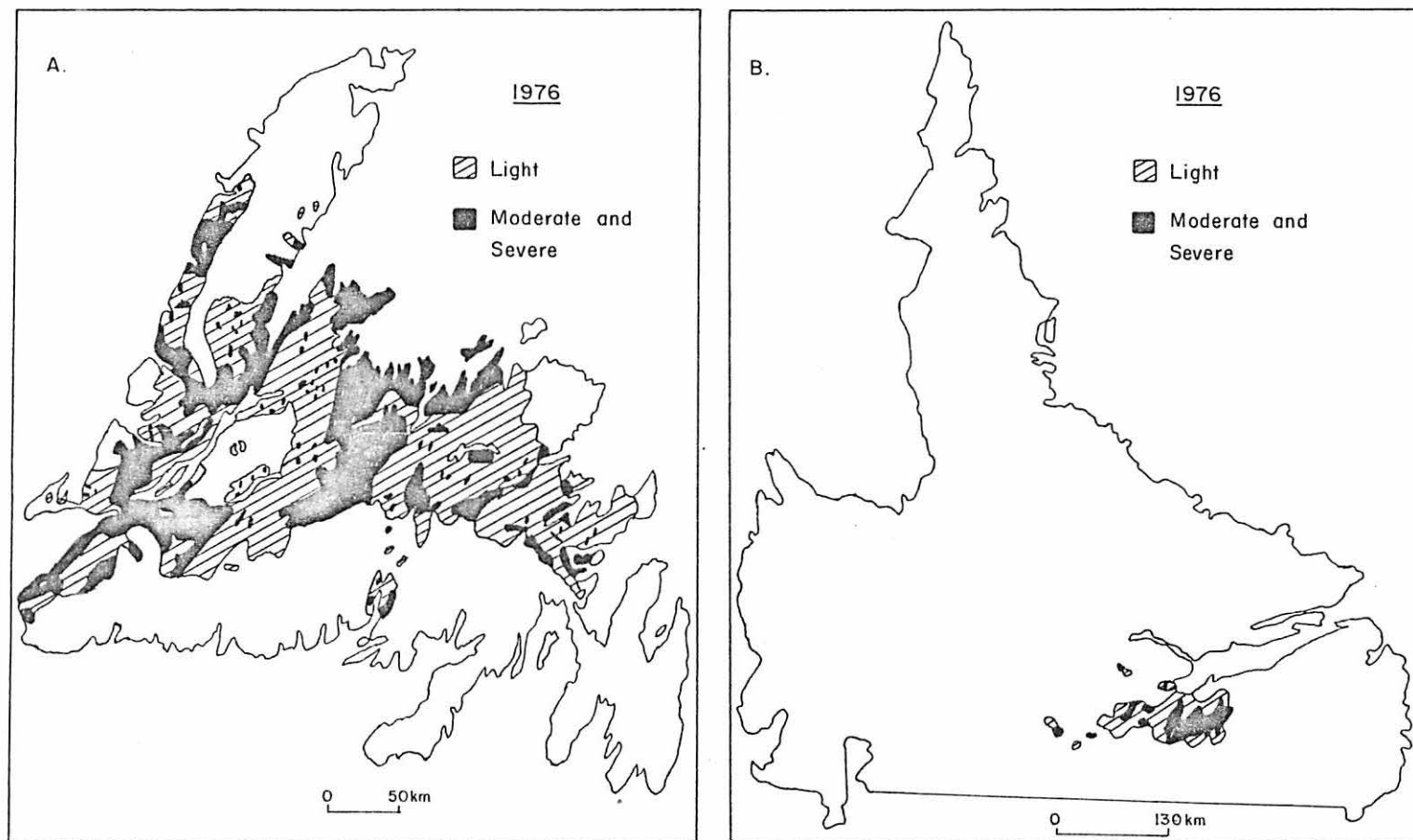


Figure 7. Spruce budworm infestations in Newfoundland and Labrador:
 A - - - - Insular Newfoundland, B - - - - Labrador

In 1977 spruce budworm larval activity commenced 1 to 2 weeks later than usual and noticeable defoliation was not observed until late June. On the west coast, from Port aux Basques to Robinsons River, budworm population levels were high (up to 500 larvae per tree sample) and defoliation of current foliage was severe. From Robinsons north to Bonne Bay and east to Badger, larval populations were considerably lower (maximum 85 larvae per tree sample). Although defoliation was widespread and severe in these areas, it was not as extreme as in 1976. The probable reasons for the lower larval numbers in these areas were starvation of early instar larvae and unfavourably cool and wet weather conditions. On the Northern Peninsula, budworm defoliation was severe for the second consecutive year throughout the Roddickton and Ten Mile Lake area.

From Badger east to St. John's, throughout the Bonavista Peninsula and on the Avalon Peninsula, the infestation was widespread and defoliation of current foliage was severe on balsam fir, white spruce and black spruce. There was considerable defoliation of larch in many areas in central and eastern Newfoundland, particularly on Random Island, and throughout the Terra Nova National Park. However, by late August virtually all of the larch in these areas had refoliated.

In 1977 the aerial defoliation survey was cancelled because heavy rains had removed most of the damaged and red foliage. This made it impossible to classify defoliated areas from the air. A special aerial assessment survey augmented by ground checks was conducted in late August to determine the area(s) and merchantable volume of dead and damaged timber. Damage assessments were also made in semi-mature and regeneration stands. The results of this assessment are discussed in the section on "Impact of the Spruce Budworm".

In 1977 spruce budworm infestation in Labrador covered an estimated 52 700 ha (130,000 acres) of balsam fir-black spruce forest of which about 31 800 ha (79,000 acres) were in the moderate to severe defoliation class and the remaining 20 900 ha (52,000 acres) were lightly defoliated.

The 1977 spruce budworm egg-mass survey included 919 locations on the Island and 31 in Labrador. The results of the survey indicate that the overall size of the outbreak in 1978 will decrease on the Island and budworm population levels will be lower than in 1977. The areas of moderate to severe defoliation in 1978 will be about 1 012 100 ha (2,500,000 acres) from the Codroy Valley to the south end of Grand Lake; from Ten Mile Lake to Roddickton in western Newfoundland; from White Bay along the northeast coast to the Avalon Peninsula; and in isolated areas near Bay d'Espoir and Red Indian Lake (Fig. 8B).

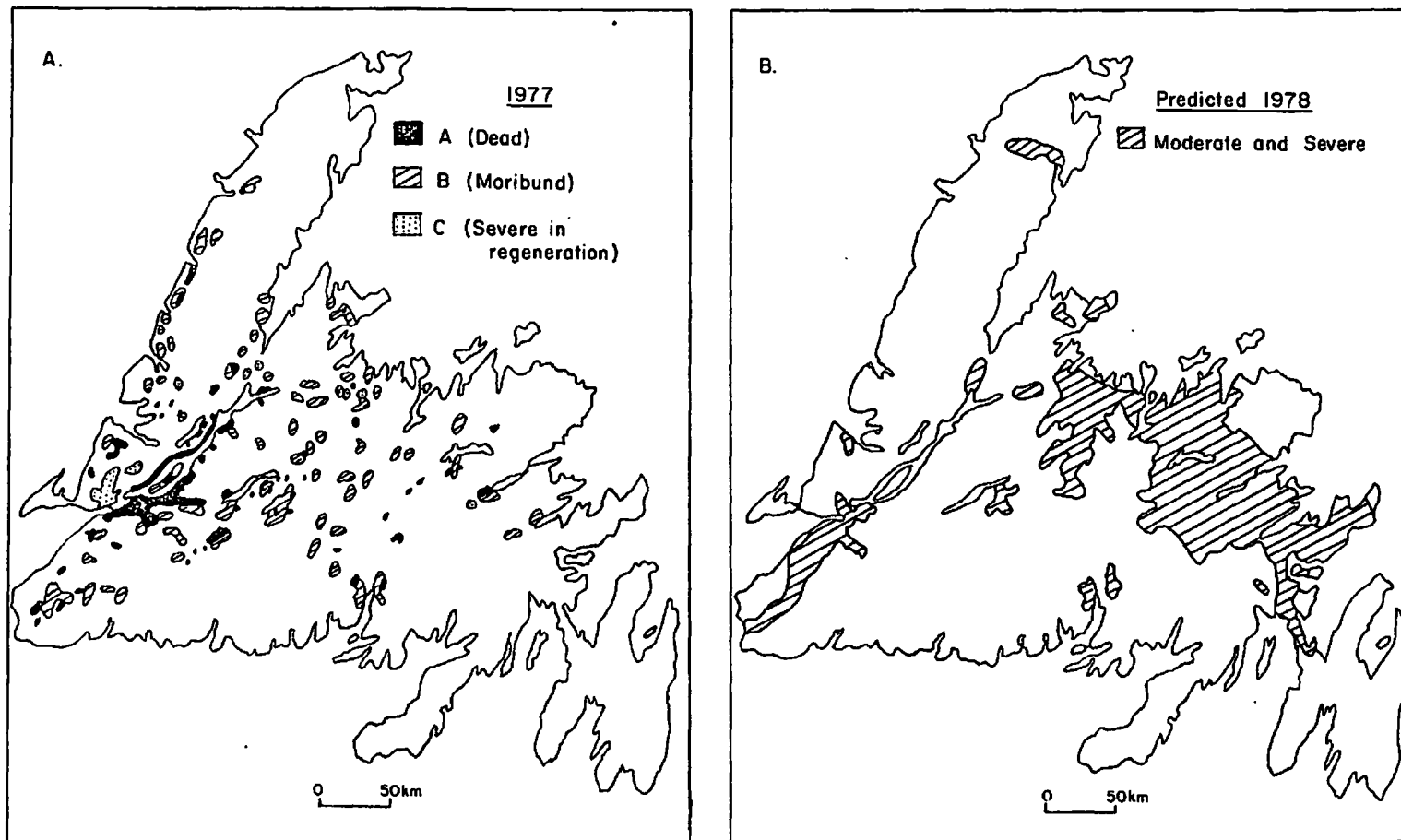


Figure 8. Spruce budworm infestations in Newfoundland and Labrador:
 A - - - - Areas of dead and moribund stands in 1977.
 B - - - - Predicted moderate and severe defoliation
 in 1978.

Although population levels are forecast to be lower in 1978, tree mortality will continue in mature stands classified as moribund and these areas may increase by about 10%, particularly where severe defoliation is predicted for 1978.

In regeneration and semi-mature stands examined in 1977 in western Newfoundland, it is forecast that tree mortality will range from 12% to 100%. This is based on 100% loss of current foliage and with 90% or more whole tree defoliation and on the general vigor of the tree in 1977.

Based on the results of general observations and on a limited egg-mass survey (31 sample points), the 1978 outbreak in Labrador is forecast to remain about the same as in 1977.

IV. CHARACTERISTICS OF OUTBREAKS

The history of spruce budworm outbreaks in eastern North America shows that they occur periodically but not necessarily in predictable cycles. Two major factors, namely, forest composition and weather are believed to be responsible for their development. The initial escape appears to be triggered by a combination of climate and forest conditions with the result that local outbreaks tend to occur over large regions almost simultaneously. However, local phenological constraints may impart considerable variability to the outbreak pattern.

Climatic "release" appears to be essential before outbreak populations develop even in areas where susceptible stands are available. Large areas of mature fir/spruce forest, high in fir content, are the areas that are most susceptible to budworm attack. Factors required for climatic "release" are warm, dry summers in or near susceptible stands for a period of 3-4 years (Wellington et al. 1950, Pilon and Blais 1961, Ives 1974). Infestations may occur in widely separated areas in various regions and thus permit a gradual development of outbreaks. Under these conditions biological control factors such as parasites, predators and diseases are unable to restrict budworm population levels which may increase from less than five larvae per tree to more than 16,000 larvae per sample tree in six years. Defoliation usually becomes noticeable in the third or fourth year of the population increase.

The recorded outbreaks in Newfoundland from 1942-1954, 1952-1956 and 1960-1971 were small in size and of short duration but the current outbreak continued to increase during 1971-1977 reaching an unprecedented size and intensity. Past outbreaks occurred over small areas, rose to peak intensity and collapsed in a short time, the entire cycle being 3 to 4 years. Defoliation was light to severe but no tree mortality occurred. These early outbreaks probably collapsed from the combination of high insect mortality due to cool wet weather during larval development, starvation, and the effect of parasites, predators and disease following the decrease in budworm population levels.

Optimum forest conditions for budworm outbreaks, i.e. an abundance of mature balsam fir occur in western Newfoundland. While, optimum weather conditions i.e. dry summers usually occur in the central region, but forest conditions with a large portion of black spruce stands in the central and eastern regions are a more limiting factor than climate is in the west. However, Ives (1974) pointed out that the wide range of weather conditions under which outbreaks develop also implies that different races (geographic variations) of the spruce budworm have evolved, each capable of withstanding local weather conditions. Successive years of warm and dry weather in spring and early summer is partly responsible for the current outbreak in Newfoundland. The role of weather in the development of outbreaks is discussed later in this report.

Table 3 shows the distribution of egg-mass sample points by predicted defoliation classes for three geographical regions in Newfoundland and for Labrador from 1972-1977. These data indicate that once outbreak levels were reached in western Newfoundland in 1972, the infestation spread eastward until the predicted severe defoliation for 1977 was highest in the eastern region. This implies a tendency for regional infestation to spread along prevailing wind gradients, i.e. from west to east as moths are carried downwind from intensely defoliated stands with high budworm population. However, the pattern of the outbreak is not uniform, either in terms of insect population level or of its geographic distribution. Factors affecting the decline in the intensity of the infestation in certain areas included cool wet weather, starvation, exposure to the sun, reduced fecundity, high dispersal losses, and lack of suitable oviposition sites. This decline was assisted at lower population levels by disease and parasites.

In Newfoundland, under the present outbreak conditions all ages of balsam fir, white spruce, black spruce and larch have been attacked but mortality attributable to the budworm has occurred only in balsam fir. Although mature fir stands are known to be more vulnerable to budworm infestation, damage occurred in large stands of regeneration as well. It is not yet known how long the budworm population will remain high or what is the capability of these young trees to recover, but to date only low levels of mortality, less than 10%, have occurred.

V. IMPACT OF THE SPRUCE BUDWORM

The general impact on a tree will be discussed first, then on the forest, and lastly the impact of this insect on the forests in Newfoundland to date.

Table 3.- Distribution of sample points by predicted defoliation classes and geographical regions, 1972-1977.

Year sampled	Region ¹	No. points sampled	Distribution of sample locations in the predicted defoliation classes ²			
			0	light	moderate	severe
1972	W	43	13(18.6) ³	23(32.8)	5(7.2)	2(2.8)
	C	27	2(2.8)	13(18.6)	11(15.7)	1(1.4)
	E	0	0	0	0	0
	Total	70	15(21.4)	36(51.4)	16(22.9)	3(4.3)
1973	W	86	32(25.0)	51(39.8)	11(8.6)	2(1.6)
	C	32	19(14.8)	7(5.5)	4(3.1)	2(1.6)
	E	0	0	0	0	0
	Total	128	51(39.8)	58(45.3)	15(11.7)	4(3.2)
1974	W	428	43(5.8)	74(9.9)	58(7.8)	253(34.0)
	C	241	47(6.3)	85(11.4)	26(3.5)	83(11.1)
	E	76	37(5.0)	34(4.6)	4(0.5)	1(0.2)
	Total	745	127(17.1)	193(25.9)	88(11.8)	337(45.3)
1975	W	313	50(8.1)	44(7.1)	38(6.1)	181(29.2)
	C	212	19(3.1)	24(3.9)	17(2.7)	152(24.6)
	E	94	38(6.1)	25(4.0)	5(0.8)	26(4.2)
	Total	619	107(17.3)	93(15.0)	60(9.6)	359(58.0)
1976	W	372	59(7.4)	67(8.4)	40(5.0)	206(25.8)
	C	281	21(2.6)	39(4.9)	22(2.8)	199(25.0)
	E	124	23(2.9)	22(2.8)	5(0.6)	74(9.3)
	Labr.	20	15(1.9)	1(0.1)	2(0.3)	2(0.3)
	Grand total	797	118(14.8)	129(16.2)	69(8.7)	481(60.3)
1977	W	432	165(17.4)	157(16.5)	52(5.5)	58(6.1)
	C	315	68(7.2)	108(11.4)	42(4.4)	97(10.2)
	E	172	47(5.0)	38(4.0)	11(1.2)	76(8.0)
	Labr.	31	19(2.0)	8(1.0)	2(0.2)	2(0.2)
	Grand total	950	299(31.6)	311(32.7)	107(11.3)	233(24.5)

¹W = west C = central E = east

²Defoliation classes are predicted as light: 0-107 egg masses/10 m²,
moderate: 108-258 egg masses/10m², severe: 259+/10 m².

³Percentages in brackets are based on total number of sample points.

1. Damage to trees

Defoliation of balsam fir by the spruce budworm has been studied for many years by various authors. This defoliation can cause rootlet mortality, losses in height and diameter growth and ultimately tree mortality.

Mortality of a balsam fir generally begins in the fourth or fifth year of severe defoliation (Belyea 1952, Blais 1958a, Baskerville 1960, Batzer 1973), if only the current growth is destroyed each year. Tree mortality can occur after two years of severe defoliation if the majority of the old foliage is eaten as well (Blais 1958a). Individual trees differ in their ability to survive defoliation, and some trees die during the outbreak, while other trees do not succumb until up to three years after the outbreak has collapsed (Batzer 1973). The smaller-than-average diameter trees tend to die after three to four years of severe defoliation, and the larger-than-average diameter trees after five or more years of severe defoliation (MacDonald 1962). Co-dominant trees, near the average size diameter classes are most likely to survive a spruce budworm outbreak (Baskerville 1960).

Loss of diameter growth is a certain consequence of severe defoliation. Loss of increment occurs first in the stem at mid-crown, and if defoliation continues reduction appears at breast height two to three years after the first year of severe defoliation (Craighead 1925, McLintock 1955, Williams 1967, Blais 1958a). Increment remains below normal during the outbreak and for two years after defoliation has ended (McLintock 1955), and may even remain lower than average for four to five years (Sheppard *et al.* 1977). Increment loss in any one year may be greater than 90%, but usually averages between 50% to 75% during an outbreak lasting for several years (Kuhlman 1971). Increment loss in any given year does not begin until the first of July (Belyea 1952) and will not occur at all unless at least 65% of the new foliage has been consumed (Duff and Nolan 1953).

Height growth is also affected by severe defoliation; growth may be reduced or prevented through top killing. Mortality of the leader, or top kill, commonly occurs because the spruce budworm concentrates its feeding in the tops of trees. Smiege (1961) reported that 60 cm or more of the tops were dead on up to 80% of the trees after three years of complete defoliation of the current growth. Top kill may also result in infection of the main stem by heart rot fungi (Stillwell 1956).

Another important impact of the spruce budworm is rootlet mortality. One year of 70% to 100% defoliation of current growth caused 30% to 75% rootlet mortality of balsam fir. Rootlet mortality increased

with each succeeding year of defoliation. When defoliation was reduced in subsequent years, young trees produced new rootlets, but mature and overmature trees could not, even though these trees would partially refoliate before death (Redmond 1959).

Defoliation also affects the trees in several other ways of varying importance. Fewer vegetative buds, flowers and cones are produced, abnormal budding occurs, and epicormic branches may develop (Johnson and Denton 1975, Ghent 1958). In Newfoundland the spruce budworm has caused a pronounced decrease in cone and seed production by balsam fir and black spruce. Severe defoliation reduced the size and number of shoots upon which cones are usually produced. Also the budworm has been observed to feed on flowers and young cones of fir and spruce.

2. Damage to stands

Damage to forest stands is more complex than to trees, and also less predictable. The degree of damage depends upon many factors and their interactions which are difficult to measure.

The most pronounced effect of the spruce budworm on forests is the break-up and deterioration of mature and overmature stands with high fir content (Baskerville 1975). This break-up of the fir-spruce stand is caused by extensive mortality of mature trees, which creates openings in the stand for new trees initiating a new stand (Vincent 1962). In unsprayed stands in Minnesota and New Brunswick about 60% of the stand, by basal area, was killed by the budworm (Batzer 1973, Baskerville 1960, MacDonald 1962), and 75% in Maine and Ontario (McLintock 1955, Turner 1952). There is no agreement in the literature on the relationship between site quality and the amount of mortality in stands (Turner 1952, McIntock 1955, Blais 1958b, Batzer 1969). However, percent mortality of fir increased with increasing basal area of fir per acre (Turner 1952, McIntock 1955).

The break-up of the stand canopy through tree mortality generally leads to abundance of dead standing trees and tends to dry the ground cover. This condition constitutes a serious fire hazard to the damaged forests (Johnson and Denton 1975).

Spruce budworm attack can affect stand composition; the density of fir declines and that of the spruces, pines, and hardwoods increases. This change in stand composition lasts only for one or two rotations before fir regains its former status (Baskerville 1975).

Outbreak population levels of this insect invariably kills the understory trees, including advanced regeneration. Therefore, the stand must start from seed again, which adds an additional 10 to 15 years to the rotation (Johnson and Denton 1975). Seed production is usually drastically reduced by defoliation because severely attacked trees produce very few cones (Ghent 1958). The effect of reduced seed production on natural regeneration in Newfoundland is not known.

3. Impact of the present outbreak on forests of Newfoundland

The impact of the spruce budworm on the forests of Newfoundland cannot be fully assessed at this time. The outbreak is still in progress and total effect has not yet occurred. Furthermore trees will continue to die for at least three years after the outbreak has terminated. Nevertheless the outbreak has persisted long enough that measurable damage has occurred. Assessing the damage caused by the spruce budworm in Newfoundland is more difficult than elsewhere, because, here, the damage assessment is complicated by outbreaks of other important insects on fir and spruce in the recent past. The eastern hemlock looper had damaged stands in large areas of the Island from the late 1960's until the early 1970's. The balsam woolly aphid caused severe damage in several locations scattered across the Island. Also, the blackheaded budworm, and to a lesser extent the balsam fir sawfly, were causing defoliation at the same time as the spruce budworm, or a year or two previous to the budworm outbreak.

Generally tree mortality can be expected to occur after four to five consecutive years of severe defoliation of the current growth. Five areas have been severely defoliated at least for four years (Fig. 9): Southwest Brook Valley, near Corner Brook, near Pasadena and St. Paul's Inlet in western Newfoundland; and near Baie Verte in central Newfoundland. An area, too small to show on a map, on the shores of Birchy Lake has been severely defoliated for five years. Extensive mortality can be expected in all these areas. However, considerable mortality has occurred and can be expected in areas of only three or even two years of severe defoliation because of continued moderate defoliation or extensive back-feeding by the budworm or previous damage caused by other insects such as the hemlock looper, balsam woolly aphid and the balsam fir sawfly (Fig. 8A).

Estimates of mortality in semi-mature stands where the budworm was the only damaging insect has been negligible except in a few small areas (Table 4 and Appendix I). Increment reduction caused by defoliation in these stands was not yet evident at breast height in 1976. However, increment was reduced by up to 20% at mid-crown in several plots in western Newfoundland. Increment loss is expected to increase even if budworm populations collapse completely in 1978.

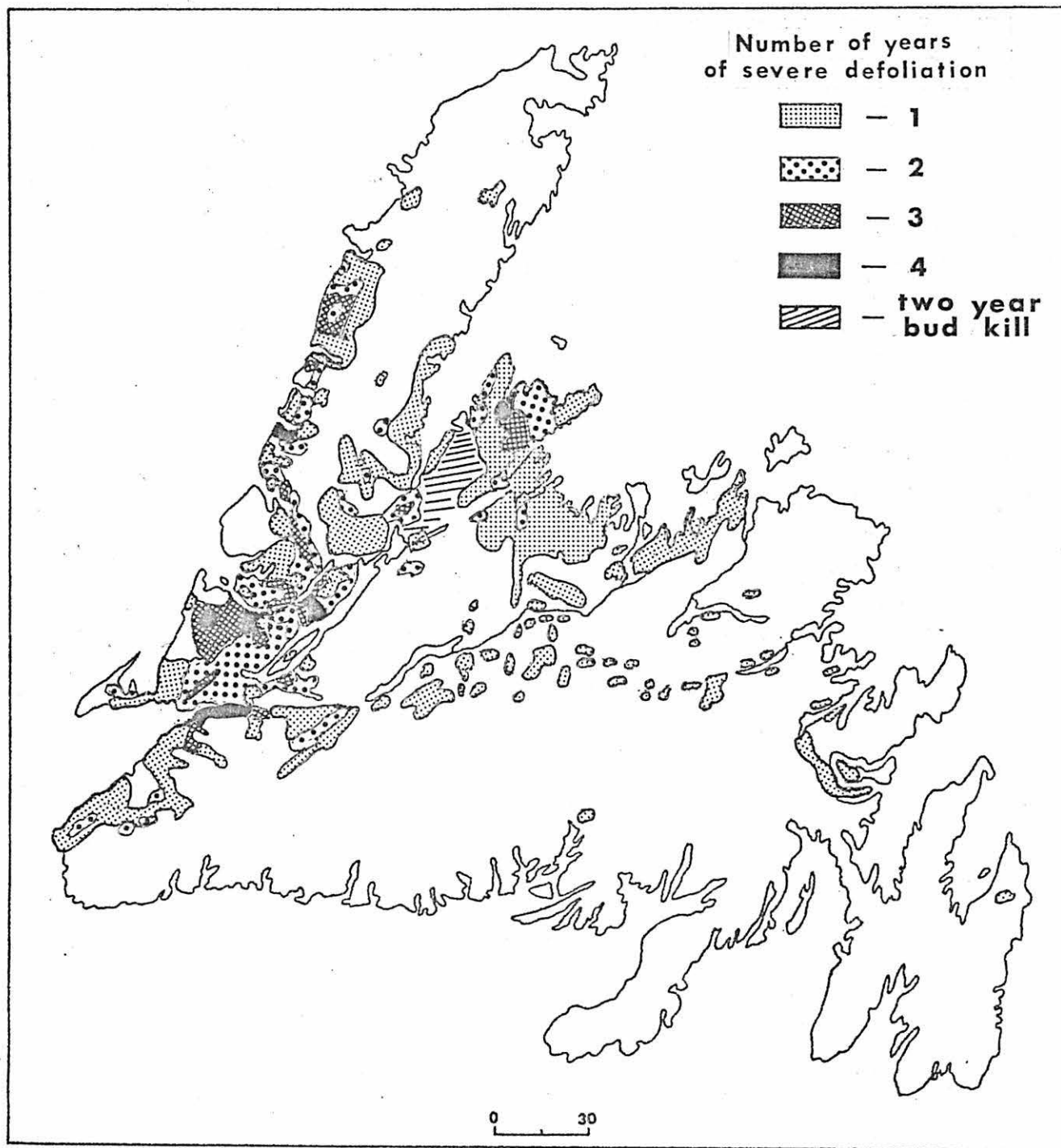


Figure 9. The distribution of areas with consecutive years of severe spruce budworm defoliation between 1971 and 1976.

Table 4.- Spruce budworm defoliation and tree mortality in spruce budworm impact plots - Summary by region and tree species (Raske unpublished data).

Region	Tree species	No. of plots	Avg. % plot defoliation			% mortality (by stems)		
			1975	1976	1977	1976	1977	Predicted
Western	Fir	31	89	90	80	0.6	1.5	21.6
Central	Fir	18	50	100	100	1.1	1.0	1.4
Eastern	Fir	4	81	82	100	0.2	2.8	2.8
Total	Fir	53	76	93	88	0.7	1.4	13.3
Central	Spruce	14	33	84	95	0.5	0.6	0.6
Eastern	Spruce	2	5	100	67	2.0	2.0	2.0
Total	Spruce	16	29	86	91	0.7	1.5	1.5
Central	Larch	2	(100)	(100)	66	0	0	0

A damage assessment survey conducted in 1977 classified the merchantable coniferous forests of the Island and Labrador into four categories: A - dead standing, B - moribund and not likely to recover, C - severely damaged but expected to recover, and D - very light or no damage. The location and size of dead and moribund stands (stands classified as A or B) determined from aerial surveys (Fig. 8A), have been superimposed upon inventory maps and the areas and stand volumes computed (Table 5). These data do not imply that every single tree in the stand is dead or moribund, but from a silvicultural viewpoint the stand as a whole was classified as such. Therefore, volumes in Table 5 represent estimates of total stand volumes, though some trees in the stand may not be dead nor moribund. The total area of stands killed was about 64 000 ha (158,200 acres) containing an estimated 5 138 000 m³ (2,100,000 cords) of wood. The area of moribund stands totalled about 110 600 ha (273,000 acres) with approximately 8 507 000 m³ (3,500,000 cords) of wood. Mature stands severely damaged but likely to recover totalled 774 000 ha (2,000,000 acres). These losses are directly attributable to the spruce budworm, but it must be emphasized that most stands killed or in a moribund state had been previously damaged by other insects.

In Labrador the area of moderate to severely damage stands totalled about 32 000 ha (79,000 acres). The volume of dead trees scattered within these stands was approximately 236 000 m³ (98,100 cords), and an additional 532 000 m³ (220,700 cords) were classed as moribund which are also expected to die.

The spruce budworm outbreak in Newfoundland was unusual in that severe infestations also occurred in large areas of regeneration, however stands of regeneration are more tolerant to spruce budworm damage, because they have greater ability to recover from severe damage than older trees (Redmond 1959). Damage to regeneration was assessed in 1977 in a total of 147 plots established in 22 stands, most of which were balsam fir in western Newfoundland (Table 6). Most of the plots had no tree mortality to date, a few had 1% and 2% mortality, seven plots south of Gallants averaged 8% mortality, and one plot, in the Trout Brook valley, had 28% mortality. However, severe defoliation, including extensive backfeeding, had occurred in many of the plots and additional mortality is likely to occur in the next few years.

Top-kill had occurred in most stands of regeneration examined, and often affected up to 50% of the trees. However, 15% to 30% of the trees with top-kill was most common. Up to 1977 from one to six years of height growth has been lost in those trees. This not only retards development, but also puts these trees at a disadvantage with undesirable plant species in the competition for light and space. Loss of height is not the only form of damage. These trees are likely to have deformed stems or bushy crowns, making them unfit for several uses, such as lumber and fence posts. Percent of trees with top-kill is also expected to increase in the future in many of these stands.

Table 5.- Spruce budworm damage assessment survey of merchantable timber, 1977.
Volume based on 85 cu.ft./cd. (2.41 m³)¹

Area by 1:250,000 map sheet	Area and volume affected			
	Dead		Moribund	
	Area (ha)	Volume (m ³)	Area (ha)	Volume (m ³)
Port aux Basques	1 100	90 800	8 600	716 000
Stephenville	24 500	1 974 400	9 000	690 400
Red Indian Lake	18 400	1 538 500	16 400	1 208 900
Sandy Lake	11 200	932 900	37 900	2 980 200
Port Saunders	3 200	151 800	16 300	1 316 000
Gander Lake	4 200	346 500	7 400	525 200
Bonavista	0	0	100	9 100
Botwood	1 500	102 400	8 000	577 000
Belleoram	(8)	600	6 900	484 500
Total	64 100	5 137 900	110 600	8 507 300
Ownership				
Bowaters	47 200	3 954 000	67 200	5 529 700
Price (Nfld.)	7 800	614 400	17 500	1 176 000
Crown (Prov.)	7 000	431 700	18 900	1 292 700
Terra Nova Nat'l Park	0	0	600	47 700
Gros Morne Nat'l. Park	2 100	137 800	6 400	461 200
Total	64 100	5 137 900	110 600	8 507 300

¹Both area and volume figures have been rounded off to nearest 100.

Table 6. Summary of spruce budworm damage assessment to fir and spruce regeneration - 1977¹

No.	Stand	Hectares	No. of plots	Avg. ht. (m)	No. yrs. severe defoliat. (+77)	Total no. trees	No. live trees	% trees with various levels of damage			% mortality		
	Location							Top kill	% defoliation curr.	% defoliation total	Lateral takeover	1977 predicted	
1	Logging School Rd.	276	3	1.6	1	98	98	0	0	5		0	0
2	Stag Lake (spray)	152	5	2.4	1	168	167	0	5	10		1	0
3	Pinchgut Lk. Road (spray block)	259	8	1.8	2	150	150	18	21	18		0	0
4	" " "	184	10	2.3	2	214	214	17	43	14	7	0	0
5	North Gallants (Long Pond)	100	11	2.4	3	131	131	46	98	33		0	1
6	Grand Lake Brook (Camp 33 Rd.)	38	4	2.9	3	66	66	12	98	18		0	0
7	Grand Lake Brook	92	12	3.1	4	221	216	22	99	63		2	12
8	Bottle Pond	527	8	2.4	3	83	83	10	98	28		0	0
9	South of Gallants - White's Rd. (10% bS)	121	11	1.7	3	131	131	17	38	28		0	18
10	" "	52	7	1.7	4	173	160	24	96	93		8	57
11	" "	50	5	1.6	4	139	139	52	97	76		0	55
12	" "	55	3	1.8	4	121	121	45	96	96	3	0	91
13	Furries Brook - Harry's River	61	6	2.4	4	157	157	8	99	68		0	57
14	" "	54	6	4.4	4	119	119	56	98	80		0	50
15	Trout Brook	48	5	4.3	4	97	97	16	100	86		0	80
16	Trout Brook	369	7	2.6	4	147	147					0	44

Cont'd...

Table 6 - Concluded

No.	Stand		No. of plots	Avg. ht. (m)	No. yrs. severe defoliat. (+77)	Total no. trees	No. live trees	% trees with various levels of damage			% mortality	
	Location	Hectares						Top kill	% defoliation curr.	% defoliation total	Lateral takeover	1977 predicted
17	Trout Brook	40	1	4.9	4	25	18	0	100	99		28 100
18	Bottom Brook	90	10	2.1	2	155	155	10	85	18		0 0
19	Middle Brook - Barry Brook	133	5	2.4	1	77	77	0	58	13		0 0
20	" "	311	3	1.6	1	98	98	0	5	5		0 0
21	Taylor's Brook (spray block #6)		13	3.6	2	145	143	46	10	35	39	1 0
22	Sops Arm turn-off (control block)		4	1.9	2	57	57	70	80	23	4	0 12

¹Moody unpublished data.

VI. NATURAL CONTROL FACTORS

Natural control factors can be classed into two groups, biotic (living) and abiotic (non-living). Biotic factors are usually subdivided into predators, parasites and pathogens while the abiotic group include such factors as weather, competition and food quantity and quality. These rarely, if ever, act alone on the population. One of these factors may be more important than the others, and at times largely responsible for determining the population level in a given situation. However, they interact with each other in a complex manner.

The effect of natural control factors on population fluctuation of the spruce budworm will be discussed based on published literature reported from other regions, where the budworm had been a pest much longer, and compared with preliminary and unpublished data from Newfoundland. More detailed treatment of the role of these factors on budworm populations will be forthcoming as the recently initiated studies are brought to completion.

1. Weather

The influence of weather on budworm abundance has been examined by numerous authors including Wellington and Henson (1947), Wellington *et al.* (1950), Wellington (1952), Greenbank (1956, 1963b) and others. Dry, sunny weather favours the development and survival of budworm and the relationship between such favourable weather and development of an outbreak has been demonstrated in several regions (Wellington 1952, Greenbank 1956, Pilon and Blais 1961, Ives 1974).

Unseasonably cold temperatures during the winter appear to have little effect on hibernating larvae (Terrell 1960). However, the emergence of second instar larvae from the hibernacula is closely related to temperatures in April and May (Rose and Blais 1954). In fact the sum of the accumulated degree days (the number of heat units accumulated above a certain temperature, usually 6°C) in April and May can be used to predict the approximate date of larval emergence in the field.

Several days of continuous late frost in the spring can reduce spruce budworm populations. The frost can kill the young larvae directly or indirectly by freezing the new, tender shoots of the host trees, thus causing starvation. Young larvae require new shoots for survival, and only the later instars can feed successfully on older needles.

Weather can also be responsible for asynchrony between emergence of the second instar larvae and development of the host. The larvae emerge before the buds have begun to swell. Therefore, there is a lack of suitable food. This can be crucial in stands severely defoliated at

least for one year. This condition occurred on the Baie Verte Peninsula in 1975 where the presence of pack ice caused early summer weather to be cold. Defoliation had been severe in the area in 1974, and egg mass counts in the fall indicated high larval populations for 1975. When second instar larvae emerged from the hibernacula in 1975, bud development was not well advanced. The emerged larvae mined the buds before the shoots could elongate leaving the older needles as the only available food supply. However, most of the larvae were too young to feed on older foliage and many died of starvation resulting in a much lower population level than predicted.

In late larval instars weather continues to affect budworm behaviour and activity. During continuous rainy periods the air in the feeding tunnels become saturated and budworm larvae remain inactive and do not feed readily (Wellington and Henson 1947, Greenbank 1956). Feeding is more continuous under dry and sunny conditions which accelerates larval development. Cool, wet weather will prolong larval and pupal development and increase the period that the insect is exposed to attack by pathogens, parasites and predators. In the adult stage rain, overcast conditions, and strong winds adversely affect mating and flight activity, and reduces the chances of moth dispersal (Greenbank 1973).

Weather data just before and during the current outbreak in Newfoundland showed that highly favourable weather occurred during budworm development (Fig. 10). Mean daily temperatures in June, July and August were higher than normal for two years prior to the beginning of the outbreak in 1971, and remained above normal for six of the seven following years. Precipitation was less than normal for four of the 10 summers between 1968 and 1977. There were three consecutive dry summers starting with 1974. This weather provided favourable conditions for larval development in June and July, and a drier than normal August was favourable for budworm mating and egg laying. The lower than normal summer temperatures of 1974 were probably responsible for the reduction in the infestation in 1975. In 1977, June was warmer and drier than the normal, while July and August only slightly warmer and considerably wetter than the normal, especially in western Newfoundland. This unfavourable weather in July and August for budworm development and survival simultaneously favoured the incidence of fungal disease and reduced budworm populations in most areas.

2. Predators

Predators may be classified as vertebrates (birds, small mammals) and invertebrates (ants, other insects, spiders and mites). Among the vertebrates, birds are undoubtedly the most important group of predators.

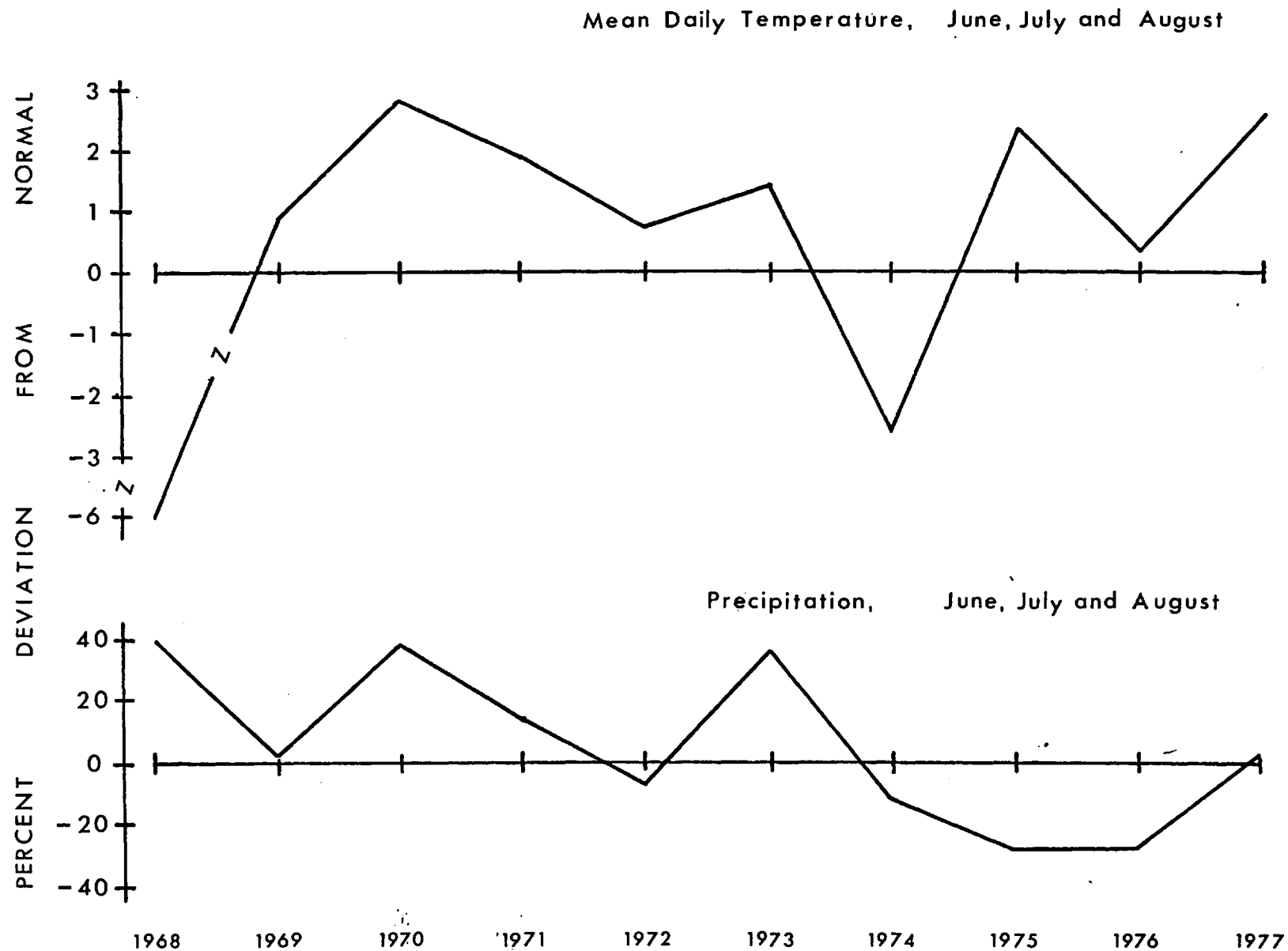


Figure 10. Mean daily temperature deviation from the normals (1941-1970) of June + July + August, and precipitation deviations from the normals of June + July + August. Based on the following meteorological stations: Port aux Basques, Stephenville Airport, Corner Brook, Daniel's Harbour, Deer Lake Airport, Buchans, Exploits Dam, Grand Falls, Glenwood, Gander, Bonavista, Colinet, St. John's Airport.

a. Vertebrates - The value of birds in budworm control has been investigated by Tothill (1923), Kendeigh (1947), George and Mitchell (1948), Mitchell (1952), Dowden, Jaynes and Carolin (1953), Mook (1963) and others. These authors determined from stomach analyses that budworm contributed from 3% to 40% of the diet of the birds examined, depending on budworm population levels. The general consensus in the literature is that birds have the greatest control value at low or endemic budworm population levels, and that they do not have an appreciable influence at high densities even though some species of birds were reported to show numerical (Mook 1963) as well as functional response (Zach and Falls 1975) to budworm numbers.

Stomach analysis of 28 species of birds collected in Newfoundland between 1973 and 1977 revealed that 13 species fed on spruce budworm larvae and pupae. Spruce budworm composed 4%, 31%, 21%, 14%, and 24% of the diet of the birds examined respectively in the years from 1973 to 1977. The decreased proportion of the budworm taken as food in 1976 was probably caused by the presence of other food sources in the area. In 1976 a major portion of the birds examined were collected in an area that was also infested by the blackheaded budworm and the eastern hemlock looper, which were also used as food while in the other years birds were mainly collected in stands infested primarily by spruce budworm. The more important bird predators of the budworm were: boreal chickadee (Parus hudsonicus (Forster)), several warbler species (Dendroica spp.), American robin (Turdus migratorius Linnaeus), white-throated sparrow (Zonotrichia albicollis (Gmelin)) and blue jay (Cyanocitta cristata (Linnaeus)). Although, in some cases the entire stomach content was composed of budworm, it appears that birds have had only a limited control value during the present outbreak (Otvos, in prep.).

b. Invertebrates - Although invertebrate predators of the spruce budworm include an extensive list of arthropods their role in budworm control is limited. Warren (1954) and Thomson (1957) found that the spruce coneworm, Dioryctria reniculella Grt. can, under certain conditions, prey on spruce budworm pupae. Up to 18.2% of the pupae found in the 400 pupal sites examined had been attacked by predators; the coneworm caused 5.8% mortality, various other insects were responsible for 5.2% mortality and the remaining 7.2% was undetermined.

Loughton, Derry and West (1963) used serological technique to assess spider and mite predation on the spruce budworm. Both they and Renault and Miller (1972) considered spiders as important predators of budworm larvae at low population levels. Although spiders are abundant in the forest, their role in budworm control however, even at endemic population level, is limited.

No special effort has been made to date to investigate the role of invertebrate predators in budworm control during the present outbreak in Newfoundland. The spruce coneworm was never observed to feed directly on budworm pupae. However, coneworms were present in many of the samples collected from spruce, and these samples also contained several spruce budworm pupae that showed evidence of predation. It is estimated that less than 5% of the pupae in these samples were attacked.

3. Parasites

A large number of parasite species have been reared from the spruce budworm, and most of these attack the host in the larval stage. Several lists of parasites known to attack the spruce budworm have been compiled (Wilkes, Coppel and Matters 1948, Jaynes and Drooz 1952, McGugan and Blais 1959). Over 70 species parasitize the budworm and 30 of these are common throughout the geographic range of the budworm.

The species complex varies with time and space but the most important parasites are usually the same 9 to 15 species (Table 7). Of this group an egg parasite, two larval parasites attacking first and second instars, and about five or six species which attack the late larval and pupal stages are generally important.

Trichogramma minutum Riley is the only common parasite of budworm eggs. It has been recorded both in Canada and in the United States. However, authorities cannot agree on its control value. Hewitt (1912) found parasitism by T. minutum to vary from 1% to over 70%. Miller (1963b) reported 48% egg parasitism in 1950; parasitism decreased in the same area in 1951 and fluctuated between 0% and 10% irrespective of host density. Similarly, Thomas (1966) found no trend in T. minutum activity during budworm outbreaks in Maine and he concluded that this egg parasite has only a small influence on spruce budworm numbers. In Newfoundland egg parasitism was less than 1% in 1975, 1976 and 1977, and therefore of no control value. Perhaps the effectiveness of this parasite in Newfoundland is limited by the density of alternate hosts, a similar observation was also made by Miller (1963b) in New Brunswick.

Apanteles fumiferanae Vier. and Glypta fumiferanae (Vier.) are the two most common species attacking first and second instar budworm larvae in which they overwinter. Both species can attack the same larva (multiple parasitism), and both parasites can lay more than one egg into a single host (super-parasitism). However, only one parasite will emerge from a single host larva (Lewis 1960). Generally, in Canada Glypta appears to be more important (Miller 1963b) while in the eastern United States Apanteles is considered to be more important (Jaynes and Drooz 1952). The combined apparent parasitism by these two species have been reported to vary between 20% to 30% (Jaynes and Drooz 1952, Miller 1963b).

Table 7.- Common parasites of the spruce budworm and the host stage they attack.

Parasite species	Present in Newfoundland	Stage attacked
HYMENOPTERA		
Braconidae		
<u>Apanteles fumiferanae</u> Vier.	X	Instar I and II
<u>Meteorus trachynotus</u> Vier.	X	Large larvae
Ichneumonidae		
<u>Apechthis ontario</u> (Cress.)	X	Pupae
<u>Glypta fumiferanae</u> (Vier.)	X	Instar I and II
<u>Horogenes cacoeciae</u> (Vier.)	?	Instar I and II
<u>Itoplectis conquisitor</u> (Say)	?	Pupae
<u>Phaeogenes hariolus</u> (Cress.)	X	Pupae
Pteromalidae		
<u>Amblymerus</u> (=Mesopolobus) <u>verditer</u> (Nort.)	X	Pupae
<u>Psychophagus tortricis</u> (Brues)	X	Pupae
Trichogrammatidae		
<u>Trichogramma minutum</u> Riley	X	Eggs
DIPTERA		
Tachinidae		
<u>Actia interrupta</u> (Curr.)	X	Large larvae
<u>Eumea caesar</u> (Ald.)	X	Large larvae
<u>Lypha setifacies</u> (West.)	?	Large larvae
<u>Madremyia saundersii</u> (Will.)	X	Large larvae
<u>Omotoma fumiferanae</u> (Tot.)	?	Large larvae
<u>Phryxe pecocensis</u> (Tns.)	X	Large larvae
Sarcophagidae		
<u>Pseudosarcophaga</u> (=Agria) <u>affinis</u> (Fall.)	X	Large larvae or pupae
<u>Sarcophaga aldrichi</u> Park.	?	Pupae

X - species reared in Newfoundland
 ? - not recovered in Newfoundland

Both A. fumiferanae and G. fumiferanae have been common in Newfoundland during the present outbreak, and combined apparent parasitism¹ by them varied between 10% and 25% over the years, reaching the high of 25% in 1975, then it slowly declined. In general, G. fumiferanae was about four times as numerous as A. fumiferanae.

About 12 to 15 species of parasites may attack late instar budworm larvae or pupae. Of these 5 to 10 species are parasitic flies (Diptera) (McGugan and Blais 1959, Miller 1963b) which in most cases did not occur with sufficient regularity to be considered important; the remainder are parasitic wasps (Hymenoptera). Meteorus trachynotus Vier. is the most noteworthy of this latter group, and it attacks late instar larvae. This parasite has been credited with varying degrees of importance depending on the location and age of the budworm outbreak. Parasitism by this species is known to increase gradually over the outbreak period, and a marked increase is apparent in the years of outbreak decline. This pattern of increase prompted some investigators to consider M. trachynotus as an indicator of the decline of a budworm outbreak. This increase by M. trachynotus has not been observed in Newfoundland; its numbers have been consistently low during the current outbreak.

At least five species of parasites are known to attack the spruce budworm in the pupal stage. Three of these: Apechthis ontario (Cress.), Itoplectis conquisitor (Say), Phaeogenes hariolus (Cress.) are ichneumonid wasps, and the other two, Amblymerus verditer (Nort.) and Psychophagus tortricis (Brues), are chalcids. Of these only two, P. hariolus and A. ontario are generally considered of major importance (McGugan and Blais 1959, Jaynes and Drooz 1952, Miller 1963b, Blais 1965). Both P. hariolus and A. ontario were reported to be the most important hymenopterous parasites of budworm pupae in Maine (Jaynes and Drooz 1952). This agrees with the records in Newfoundland. On the mainland the effectiveness of the two parasites varied with host numbers and the age of budworm outbreaks. P. hariolus is another species which becomes abundant during the latter years of an outbreak (Miller 1963b). According to Blais (1960) I. conquisitor may also show spectacular increase in numbers as an outbreak declines.

It is difficult for parasites or predators to provide effective control of the spruce budworm because of the unusual population behaviour of the pest. Normally budworm numbers reach extremely high levels relatively quickly during epidemics; this is followed by very low population levels for extended periods (30-50 years) between outbreaks. Parasites and predators, to be effective, must be able to respond extremely quickly to sudden population increases and must be able to maintain

¹ Apparent parasitism refers to the proportion of hosts (budworm) attacked by a parasite and is determined from a sample drawn from the host population.

their numbers at high levels during periods when budworm numbers are low. Only few of the known parasites have both of these characteristics. Maintenance of a parasite population at a low host density is aided by having alternate hosts during periods when budworm is not available. Some parasites also require alternate hosts for the completion of their life cycle, even in the presence of budworm, and this further reduces their efficiency.

Parasitism of the budworm by all species combined in eastern Canada generally fluctuated between 20% and 40% during peak years of budworm outbreak (Blais 1965). However, during the declining years of outbreak, it can be much higher. Parasites have not been effective control agents during build-up, and at peak years of outbreaks but may be important in hastening the decline of an outbreak when budworm numbers have been reduced by other factors such as weather or starvation (McGugan and Blais 1959, Blais 1960, Miller 1963b). In some parts of the eastern United States, however, parasites are considered to be most important in budworm control (Dowden and Carolin 1950, Jaynes and Drooz 1952) than in Canada. In the eastern United States, unlike in Canada, balsam fir occurs in mixed and discontinuous stands where the alternate hosts for parasites may be more abundant. Also some species of parasites may even complete two generations in one generation of the budworm in the warmer climate of parts of the United States.

During the current outbreak in Newfoundland apparent parasitism gradually increased over the years from about 3% in 1972 and 1973, to 10% in 1974, 15% in 1975, 30% in 1976 and to 35% in 1977. Over 30 species of primary parasites have been reared from the spruce budworm, 11 of which have alternate hosts (Table 8). The most important parasites

Table 8.- Spruce budworm parasites with known alternate hosts.

Parasite species	Reared from	
	eastern hemlock looper	blackheaded budworm
HYMENOPTERA		
<u>Apanteles fumiferanae</u>	X	
<u>Apechthis ontario</u>	X	
<u>Glypta fumiferanae</u>		X
<u>Itoplectis quadricingulata</u>		X
<u>Meteorus argyrotaeniae</u>		X
<u>Phaeogenes hariolus</u>		X
<u>Tranosema arenicola</u>	X	
DIPTERA		
<u>Actia interrupta</u>		X
<u>Eumea caesar</u>	X	
<u>Madremyia saundersii</u>	X	
<u>Phryxe pecosensis</u>	X	

attacking the spruce budworm in Newfoundland were two larval parasites A. fumiferanae and G. fumiferanae, and two pupal parasites, A. ontario and P. hariolus. The latter two species showed the greatest increase in numbers during the last two years, and this may indicate that the current budworm outbreak is declining. The parasite P. hariolus continued to be the more numerous than A. ontario in 1977. A rapid increase in the numbers of P. hariolus and Meteorus trachynotus (a larval parasite) has been associated elsewhere with the decline of spruce budworm outbreaks. Although M. trachynotus was present in Newfoundland it did not show a similar increase to that of P. hariolus. It is of interest that A. ontario was introduced into Newfoundland in 1947 and 1948 against the spruce budworm, and it now also attacks the eastern hemlock looper and blackheaded budworm. The other three species A. fumiferanae, G. fumiferanae and P. hariolus, also attack the black-headed budworm as an alternate host.

Parasite introductions - In eastern North America a number of attempts were made to introduce exotic parasites to increase the control complex of the spruce budworm. Four species from British Columbia were relocated in the late 1940's to other parts of Canada (excluding Newfoundland) and 12 species were introduced from Europe into Canada (a number of these were from Choristoneura muriana (Hbn.), a close relative of the spruce budworm) between 1948 and 1956. These attempts apparently failed and no explanation is known for their failure (McGugan and Coppel 1962). Eight species were introduced into Newfoundland between 1947 and 1951, however, only two have been recovered from the spruce budworm (Clark, Otvos and Pardy 1973). In the early 1970's two species were introduced from the todo-fir budworm, Choristoneura diversana Hbn., from Japan into New Brunswick. This introduction was later abandoned because of host parasite incompatibility (Varty 1976). Attempts to relocate a chalcid parasite of the gypsy moth, Lymantria dispar L., for budworm control in Maine is still in progress (Minot and Leonard 1976).

4. Pathogens

The spruce budworm is infected by four groups of microorganisms: viruses, bacteria, protozoa and fungi. The role of these groups of organisms in the natural control of the budworm will be treated first, and in a later section a discussion will follow regarding their potential use in an integrated control program directed towards reduction of budworm damage.

a. Protozoa - Of all the diseases of the budworm those caused by Microsporidia (Protozoa) are probably the most common. The first protozoan parasites of the spruce budworm, Nosema fumiferanae (Thom.) was described by Thomson (1955). Infection by this microsporidian retards both larval and pupal development and may cause some larval mortality. But, its greatest effect is the reduction of pupal weight, fecundity, and adult longevity. These changes probably result from interference with the ability of the budworm to assimilate food (Thomson 1958).

The incidence of microsporidial infection in natural populations can be high. Neilson (1956) reported 43% infection in New Brunswick and Thomson (1960) as high as 81%, in the fifth year of his investigation of an infestation in Ontario. However, only a relatively small portion of the infected larvae die, usually before the fifth instar; the others complete their development to the adult stage. Neilson (1956) noted that some of the adults were so heavily infected that he considered it highly unlikely that they could have mated and produced viable eggs.

The microsporidia, N. fumiferanae were present in most of budworm larval samples across the island of Newfoundland, but the incidence was lower than that reported from mainland Canada (Neilson 1956, Thomson 1960).

b. Viruses - Four types of viruses infect the spruce budworm in North America: nuclear polyhedrosis virus (NPV), entomopoxvirus (EPV), cytoplasmic polyhedrosis virus (CPV) and granulosis virus (GV). One of the most desirable attributes of viruses is that they normally have a high year-to-year carryover infection, i.e. once they have been introduced into a population they persist for a long time. A good example of this carryover effect is the highly successful virus disease of the European spruce sawfly, Gilpinia (Diprion) hercyniae (Htg.) (Balch and Bird 1944). This virus has persisted since its introduction in the 1940's and it is considered to be a major control factor of the sawfly.

Extensive work has been done on viruses to control spruce budworm (Bergold 1950; Bird 1959, 1963, 1964; Stairs 1964, 1965; Cunningham et al. 1974). Of the viruses tested the nuclear polyhedrosis virus (NPV) has had the most carryover infection. Initial levels of infection with NPV were high (42%) in the year of application but it decreased with each successive year to less than 5% in the fourth year (Cunningham et al. 1975).

Under field conditions the incidence of naturally infected larvae in the budworm population is low, the incubation period is long and most of the naturally occurring viruses of the budworm are not particularly virulent.

The presence of a virus in the spruce budworm in Newfoundland has been tentatively identified, however, the low incidence of infection suggest that viruses are not important in budworm control in this Province.

c. Fungi - Four genera of fungi: Hirsutella sp., Beauveria sp., Isaria sp. and Empusa sp. have been reported from the spruce budworm in Ontario (MacLeod 1949). For a long time fungi, along with bacteria, were considered insignificant in budworm control. Neilson (1963) voiced a general opinion of the time on the role of fungi in forest insect control when he said "There is no evidence in the literature that either the Fungi or Bacteria have caused sufficient mortality to be classified as even mildly epizootic" (an outbreak of disease). However, in Newfoundland, fungi may be important control agents. Budworm larvae and pupae infected by fungi in Newfoundland were first reported in 1972. The fungi were identified as Entomophthora egressa MacLeod and Tyrrell and Entomophthora sphaerosperma Fresenius; the same two species that contributed to the collapse of hemlock looper outbreak in 1971 (Otvos, MacLeod and Tyrrell 1973). These two fungi were previously not known to occur on the spruce budworm. The fungal disease was widespread in western Newfoundland in 1973 and was later reported from the central part of the Island. It was found in eastern Newfoundland in 1974 and by 1975 it was widespread all across the Island, and has remained so since. The combined Islandwide infection by the two species varied from 10% to about 40% over the years depending on weather conditions. It reached as high as 90% infection in one localized area in 1975. In 1977 the fungal disease caused about 30% mortality in the late larval and pupal stages and as high as 60% in some locations in western Newfoundland where precipitation was higher than the rest of the Island (Otvos, unpublished).

These fungi are extremely sensitive to weather. They require warm moist conditions for optimal infection, growth and spread of the disease. Usually this type of weather does not prevail in Newfoundland until mid- to late July and August by which time most of the budworm development is complete. Dry, hot sunny weather arrests the development of the fungi and prevents sporulation and subsequent infection (spread of the disease). This limits the effectiveness of these organisms as control agents.

In recent years fungal infection of the spruce budworm has been reported from central Canada and the New England States. Harvey and Burke (1974) found E. sphaerosperma infecting the spruce budworm in Ontario and Vanderberg and Soper (1975) reported both E. egressa and E. sphaerosperma from the spruce budworm in Maine. The presence of fungal epizootics in these widely separated locations suggest that fungi, under certain conditions, can be important in the control of the spruce budworm.

d. Bacteria - Numerous varieties of crystalliferous, spore-forming bacteria of the genus Bacillus are associated with lepidopterous larvae, including the spruce budworm (Angus 1965). One of the most common of these is Bacillus thuringiensis Berliner which is commercially available and is registered for insect control in agriculture and forestry. B. thuringiensis or B.t. has been used experimentally in forest insect control since the early 1960's. In the early days commercial preparations of B.t. (Thuricide) caused considerable mortality of the spruce budworm in laboratory tests and aerial spray trials but it was not sufficient, however, to justify its substitution for the chemical insecticides (Mott et al. 1961, Klein and Lewis 1966). Since then a number of other commercially available or laboratory strains have been tested in forest insect control either alone, or with chitinase, or with chemicals added (Angus et al. 1970, Smirnoff, Fettes and Desaulniers 1973, Morris and Hildebrand 1974, Morris, Armstrong and Hildebrand 1975). Results to date have been inconclusive, or contradictory, and seldom reproducible. This has led to a diversity of opinions and conclusions as to the value of B.t. The inconclusive results have been caused by factors such as difference in the potency of the bacterial strain, differences in the spore to crystal ratio, the concentrations of the active "ingredient", formulation, timing, weather and the amount of active ingredient reaching the target insect and others. Several reports discussing in detail the present knowledge of B. thuringiensis and its role in forest pest control have been published recently (Harper 1974, Fettes 1974, Forsberg 1976, Abbott's B.t. symposium 1976). These will be discussed in the Applied Control section.

5. Food quality and food quantity

Food quality and quantity are important extrinsic factors affecting directly or indirectly the fecundity of the spruce budworm (Blais 1953, 1957; Miller 1957, 1963a). Food quality is largely determined by the age of needles. Food quantity is a function of larval population density and the current foliage production, i.e. amount of available current foliage.

Changes in the quantity and quality of food available affects the developmental time of the larvae, susceptibility to disease (insects under stress are more susceptible to disease), fecundity of female adults, and dispersal.

Second and third instar larvae normally mine vegetative buds or needles but if staminate flowers are present a large proportion of the larvae will feed on this food source (Greenbank 1963c). Larval development is faster when they feed on staminate flowers but the mean pupal weights and fecundity are not significantly different from those feeding on current foliage (Jaynes and Speers 1949, Blais 1952). The faster development of insects in the staminate flowers on white spruce may be caused by temperatures in the flowers that are 5°C to 8°C above

the temperatures in the vegetative buds in sunlight and may be 10°C to 14°C higher than air temperature (Wellington 1950). Blais (1953) and Miller (1957) reported that females from larvae reared on current foliage had higher fecundity than those reared on old foliage. The development of the larvae reared on old foliage was also retarded.

Differences in larval development can be readily observed in the field. Mean fecundities of females obtained from field populations where defoliation of the current growth was 100% in successive years were 111, 99, and 94 instead of the usual 200 eggs per female (Miller 1963a). This reduction in fecundity was also observed in several areas in Newfoundland during the present outbreak. Pupae collected from stands severely defoliated for several years were small, the average pupal weight was 0.0511, 0.0377, 0.0397 gr compared to 0.0657 gr for pupae collected from light to moderately defoliated stands. Egg mass numbers were usually low and contained fewer eggs in stands severely defoliated for a number of years, provided there was no influx or invasion of spruce budworm adults into these stands.

VII. APPLIED CONTROL MEASURES PRESENTLY USED AND ALTERNATIVE METHODS

Recently efforts have been intensified to develop alternatives to the use of chemical insecticides for budworm control. Some of these control strategies have been reviewed by Blais (1973) and more recently by a committee chaired by Baskerville for the New Brunswick Cabinet Committee on Economic Development (1976). This Committee has also evaluated the control potentials of the alternative methods. We too are presenting a brief evaluation of the control methods with special reference to Newfoundland conditions. It is difficult to rank the methods still being developed, but the control alternatives are discussed in a descending order of their probable efficacy. It should be noted, however, that two or more of the neighbouring methods listed may have, in our opinion, similar chances of succeeding to the operational stage.

1. Aerial spraying with chemical insecticides

a. Aerial spraying of larvae - The history of the aerial application of chemical insecticide to control the spruce budworm and other forest insect pests in Canada has been documented by Prebble (1975). The first attempts were made between 1927 and 1929 using calcium arsenate, in dust formulations, applied from hopper-equipped aircraft flying at heights of 15 to 30 m above the trees. These control measures were considered to be unsatisfactory for the spruce budworm as only about 50% larval mortality was achieved. However, a more satisfactory control was achieved when the insecticide was applied to the

hemlock looper. Published reports at the times made no mention of injurious side effects of these treatments on wildlife but correspondence files of the day made reference to the finding of a small number of dead rabbits and birds in the treated plots and the acceptance of the probability that some small animals and birds would be killed by the treatments.

The use of calcium arsenate in aerial application against the spruce budworm was discontinued after 1929 and no further aerial applications of any insecticides to control forest insects were made in Canada until the mid-1940's when DDT was developed, and more modern and larger aircrafts became available. From 1945 to 1968, the chlorinated hydrocarbon, DDT, was the most commonly used insecticide for operational purposes. Large scale application of this insecticide started in the early 1950's with the objective of eliminating the spruce budworm. Obviously this was impossible and the objective changed to that of foliage protection and to keeping the trees alive. The side-effects of DDT in wildlife and other non-target organisms, and the long-term build-up of residual toxicity in the soil culminated in the complete restriction of the use of DDT for the aerial control of forest insect pests in 1969 and virtually all other insect control in Canada and the United States.

Laboratory experiments and field trials conducted by the Chemical Control Research Institute of Canada and its equivalent in the United States, have resulted in the acceptance of several organo-phosphate and carbamate insecticides as alternate chemicals for spruce budworm control. The chemicals most widely used in recent years on an operational basis against the spruce budworm have been fenitrothion, phosphamidon, Carbarol and Orthene of the organophosphate group and Matacil^R and Zectran^R of the carbamate group. These have been used singly, or in various combinations and dosages. Although not as effective as DDT, these chemicals have satisfactory efficacy against the spruce budworm and other forest defoliators. They are far less toxic to wildlife and other non-target organisms and have little long-term residual effects on the environment. The effects of a single treatment of DDT were evident for two years and these areas usually did not require treatment for 3 or 4 years (Blais 1977).

At the present time, the use of chemical insecticides is the only control method available to forest managers that can be used with any degree of effectiveness against epidemic spruce budworm populations. However, the prolonged use of insecticides to keep trees alive can extend the duration of outbreaks (Blais 1973), and may also hasten the recurrence of outbreaks (Blais 1974). In Newfoundland, only two aerial spray programs have been conducted against forest insect pests. The first was in 1968 and 1969 when fenitrothion and phosphamidon were used against the eastern hemlock looper (Otvos, Clark and Clarke 1971).

The second was conducted in 1977 when the Newfoundland Forest Service treated approximately 76 900 ha (190,000 acres) of spruce budworm infested forest at various locations across the Island (Carter 1977). This operation was primarily a pilot project designed to develop operational techniques and logistics, in the event that a large-scale operation became necessary in the future, and also to protect a number of Forest Improvement areas in which the Province has long term and expensive work in progress.

b. Aerial spraying of adults - The objective of spraying budworm adults is to kill moths, thus minimize egg laying. There are two major methods: (1) air-to-ground spraying against local and invading moths, and (2) air-to-air spraying against moth swarms in flight. Only the air-to-ground method has been field tested to date. Testing was done in New Brunswick in 1972 and 1973, and the best result was a 40% to 50% reduction in egg mass density in the treated blocks. Treatment consisted of phosphamidon applied twice at the rate of 0.14 kg/ha (2 oz/ acre) (Kettela 1976). Similar results were obtained by using Matacil (Miller et al. 1977).

Spraying adult moths shows some promise as a control measure. However, like larval spraying, timing of application is critical (a 2-3 week period) and because of the rapid breakdown of the chemicals used at least two applications are necessary. In addition a moth invasion may reduce the control results.

2. Bacillus thuringiensis

Of the alternatives to chemical insecticides, the microbial insecticide, B. thuringiensis (B.t.) is probably the most promising. B.t. acts like a stomach poison; the budworm larvae ingest the bacterial spores which germinate in the digestive tract and invade the gut wall. Considerable work has been done on the use of B.t. (Mott et al. 1961, Klein and Lewis 1966, Angus et al. 1970). It was tested operationally in Quebec in 1972, 1974 and 1975 (Smirnoff 1971, 1974a, Smirnoff et al. 1973) with and without the enzyme chitinase, and also with sublethal doses of chemical insecticides (Morris and Armstrong 1974). Chitinase hastens the invasion and stimulates pathogenicity. The results of these various experimental and operational spray tests were variable, both in terms of larval kill and foliage protection, and most experts working with B.t. agree that it is not recommended at the present for large scale operations, except in certain ecologically sensitive areas, until foliage protection can be expected with reasonable consistency. To accomplish this, more information is needed on such questions as dosage, concentration of active ingredient, formulation, droplet size, persistence, etc.

The advantages of B.t for budworm control are that it is a safe microbial insecticide with no known side effects. It has a narrow range of activity as it infects mainly lepidopterous larvae. In the many tests conducted there was no evidence that B.t., either alone or with chitinase, affected birds, mammals, aquatic fauna (fish or insects), parasites of the spruce budworm, honey bees or any other non-target organisms in a significant way (Buckner et al. 1974). Spruce budworm larvae weakened by starvation, microsporidial infection or other stresses, such as induced by sublethal doses of insecticides, are more likely to be killed by B.t. than healthy larvae (Smirnoff 1974a, Diamond 1974, Morris and Armstrong 1974).

The use of B.t. has three disadvantages: (1) It would have to be applied every year, like an insecticide, because it does not remain on the foliage from year to year. (2) When budworm larval population levels are very high, more than 25 early stage larvae per 45 cm branch tip (this is during outbreak conditions), the application of B.t. cannot kill enough larvae to provide adequate foliage protection (Smirnoff 1974b). (3) B.t. is expensive, about four times as expensive as chemical insecticides (Blais 1976).

Until the cost of application can be drastically reduced and the treatment consistently provides significant foliage protection B.t. is not likely to be used consistently in large-scale control operations. In the meantime, the use of B.t. is a viable alternative to most chemical insecticides under certain circumstances. These include high value or publicity sensitive areas such as parks, plantations, campground and recreation areas, and perhaps in certain watersheds or near reservoirs.

3. Pathogens combined with sublethal doses of chemical insecticide

Generally, insects are more susceptible to infection by disease causing organisms when under stress. In combining pathogens with chemical insecticides the sublethal dose of insecticide acts as a stressor on the insect thus making it more susceptible to the pathogen. Conversely, insects suffering from sublethal infection by pathogens should also be more susceptible to low doses of insecticides. The two can be applied simultaneously or sequentially.

Laboratory and field tests with virus + fenitrothion (Morris et al. 1974), B.t. + fenitrothion, and B.t. + Orthene (Morris 1972) have been encouraging. Both total mortality and incidence of pathogens were higher among budworm treated with the "combination" than among budworm treated with either the insecticide or pathogen alone. This control concept has promise, however its full potential will not be known until the problems associated with the use of B.t. and the viruses can be solved.

The concept of using an insect pathogen with sublethal doses of chemical insecticide is relatively new and have been tried mainly with B.t. However, all forms of insect pathogens, such as fungi, can be used in this control method as long as the pathogen is compatible with the chemical.

4. Fungi

Members of the genus Entomophthora are probably the most important fungi known to infect the spruce budworm. Under certain climatic conditions they can cause appreciable budworm mortality, at least in Newfoundland.

The control concept using fungi is to initiate an epizootic before it would occur naturally, or to increase its rate of spread once initiated by providing additional amount of inoculum in the field during weather conditions favourable for fungal growth.

The strategy for the use of fungi depends on the method of dissemination. One method is to introduce laboratory-reared and infected larvae into natural insect population to initiate an epizootic (Otvos, MacLeod and Tyrrell 1973). It is currently possible to use this method, however it is expensive and not practical to employ over extensive areas. To treat large areas, the fungus must be in a form capable of dissemination with regular spray equipment and the fungus retains its viability, and ability to cause infection and the material should be produced inexpensively. The resting spore stage of Entomophthora appears to offer the greatest potential for introduction into insect populations, because this spore is long lived, resistant to a wide variety of weather conditions, and being thick-walled it is probably able to withstand the rigors of spray application.

At present resting spores of E. egressa and E. sphaerosperma can be produced in the laboratory on coagulated egg yolk media. This method is cumbersome, expensive and impractical for commercial production. Work is presently in progress to develop a liquid fermentation technique for the mass production of the resting spores of E. egressa in Canada (Dunphy, Nolan and Otvos 1977) and for E. sphaerosperma in the United States (Soper, pers. comm.)¹. Mass production appears to be a difficult problem for both species and it may take a few years to produce a sufficient quantity of spores by fermentation technique for field testing. Following the production of spores the technology for dissemination, using regular spray equipment, will have to be developed. One limiting factor in using this method will be weather because the fungal spore will have to be applied when warm, moist conditions exist, to ensure establishment and favour the spread of the disease.

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5. Forest management

The control of spruce budworm by forest management is not a new concept; it was recommended as early as the 1920's (Tothill 1923; Swaine and Craighead 1924). However, management practices are long term control measures to minimize damage and unfortunately none of the suggested management practices have been applied over sufficiently large areas to determine whether the suggested management principles still apply 50 years later. Many management practices suggested probably cannot be applied to the conditions in Newfoundland.

Forest types most susceptible to budworm outbreaks have been described many times and recently was summarized by van Raalte (1972).

- (a) When 50% or more of a spruce-fir stand is balsam fir it is highly susceptible; susceptibility decreases if fir is associated with black spruce.
- (b) Susceptibility increases with age; 50 year or older stands are highly susceptible but stands are generally considered less susceptible if the conifers are less than 40 years old.
- (c) Large continuous areas of susceptible forest and mature open stands also increase the susceptibility to budworm attack.

Much of the forests of Newfoundland are susceptible to budworm attack. In western Newfoundland about 87% of the productive forest is mature and overmature and 65% of the gross merchantable volume is balsam fir (Anon. 1974). In central and in eastern Newfoundland 73% and 23% of the stands, respectively, are mature and overmature and 35% and 55% of the gross merchantable volume is balsam fir (Anon. 1974). Extensive budworm damage also occurred, not only in these mature stands, but also in young, pole-size stands and in regeneration. It is believed, however, that the damage in the younger stands was a result of "spill-over" affect of epidemic budworm populations in mature stands.

The principle behind using forest management or silvicultural practices to control the spruce budworm is to alter the forest environment by manipulation of the host stand to reduce budworm numbers and subsequent damage. This manipulation can bring about a change in the available food quantity or quality, making the stand less favourable for budworm development.

It has been suggested by numerous authors that forest managers can minimize the frequency or severity of outbreaks by:

- (a) shortening the rotation age to less than 50 years.
- (b) breaking up large areas of susceptible stands into small areas separated by non-susceptible stands and preventing stands from reaching maturity simultaneously over large areas.
- (c) altering the forest composition to favour non-host species or to reduce the proportion of balsam fir.

The use of forest management as a tool to reduce budworm damage requires a good road system and a certain amount of flexibility that permits adjusting harvesting schedules.

All these management practices have certain applicability in reducing damage or the need for protection but none by itself will likely provide consistent protection from the budworm. However, before these forest management methods can be used successfully certain changes are needed in regional, national and international cooperation. The spruce budworm does not recognize provincial or international borders, and perhaps control efforts should be coordinated accordingly. This problem is being recognized as indicated by the formation of various regional and international committees to coordinate efforts both at the research and control operational level. However, only time will tell whether it is feasible to attempt to manage the forest, more or less uniformly, over the geographical distribution of the budworm to minimize damage.

6. Viruses

In theory, insect viruses have probably the greatest potential for the control of pest populations, and dramatic successes have been achieved with some insect pests (Balch and Bird 1944). Viruses are part of the natural environment, are usually highly specific and once established they normally persist from year to year, and spread from the point of application. However, laboratory propagation of viruses for operational programs can be expensive but the method is economically attractive if long-term control can be achieved.

Several kinds of viruses occur naturally in spruce budworm populations. Unfortunately, none causes a high rate of mortality in the field and the incubation period is relatively long during which the infected larvae normally feed and can cause considerable defoliation. Viruses are susceptible to inactivation by ultraviolet rays of the sun and have to be protected if they are to be artificially added to the environment. The Insect Pathology Research Institute has been working for years to find highly virulent virus strains with good persistence. To date this search has not been successful and insect viruses are not likely to be used for budworm control unless a highly virulent strain is discovered.

7. Sex pheromone

Sex pheromones or sex attractants are chemical substances produced and secreted by unmated females (in Lepidoptera) to attract males for mating. Such an attractant has been isolated, identified and synthesized from the spruce budworm (Weatherston et al. 1971) and it can be produced commercially.

Sex pheromone has two main potential uses in budworm control: (1) to monitor population changes at endemic densities or to detect the invasion of moths into new areas providing lead time for initiation of control measures, and (2) direct control by disrupting mating behaviour. The latter would be achieved by luring males to baited traps where they can be captured, or by saturating the forest environment with artificially produced sex pheromones to confuse and prevent males from locating and fertilizing females. Trapping is not a practical method for population reduction of the spruce budworm. In a small field test Sanders (1975, 1976) reported that males located fewer virgin females in sex-pheromone saturated areas than in the untreated areas; there was no significant difference in egg-mass numbers between the treated and untreated area. This was attributed to moth invasion. These results suggest that sex pheromones may only have a limited use in budworm control.

Two compounds closely related to the sex pheromone have recently been shown to inhibit the reception of sex attractant by males (Sanders et al. 1972); releasing these inhibitors in the forest may also reduce mating.

Although environmentally this method of control is desirable, it is considered unlikely that sex pheromone or the inhibitors can be used successfully at epidemic population levels over extensive areas. Not all females will be prevented from mating and the mated females will probably produce sufficiently high residual population to cause defoliation - even if one ignores the possibility of moth invasion.

8. Parasites and predators

Biological control by introducing parasites has the greatest potential for success if used against an introduced pest. Introduced pest populations usually increase to high population levels in a new environment in the absence of their native biological control agents. The spruce budworm, however, is native to North America and it already has a complex of about 70 parasite species attacking it; approximately 30 of these also occur in Newfoundland. This parasite complex has not prevented outbreaks from reaching epidemic levels and introductions in

the past have not increased appreciably the effectiveness of the parasites in preventing budworm outbreaks. The introduction of one or more exotic parasite species might further strengthen the existing complex, but it is not likely to prevent the development of outbreaks. The introduction of additional foreign parasites would likely be effective only if the parasite came from a similar climatic region, and if they would complete two or more generations within the span of one budworm generation.

The manipulation of native species of parasites and predators to increase their effectiveness present, perhaps, an even more difficult problem, and at this time offers little hope of success. The technique involves rearing and releasing large number of native parasites or predators, or modifying the environment to increase their numbers.

For all practical purposes, none of the known predators of the spruce budworm lend themselves to feasible manipulation to significantly increase their role in budworm control. Birds are probably the most important predators of the spruce budworm. Bird populations have been increased successfully in the less extensive forests in Europe by providing birds with nesting boxes (Gillmeister 1963). In these forests birds have kept population levels of some of the defoliating insects in control or at endemic densities longer than it was the case prior to placing the nest boxes. However, due to the size and composition of the forest in North America, or even those of Newfoundland, it is impractical to attempt to increase bird populations sufficiently to provide effective budworm control.

9. Microsporidia

Microsporidian parasites are probably the most prevalent of the disease causing organisms of the spruce budworm both in laboratory and in natural populations. Microsporidia may occasionally reach high levels of infection but they normally act as a "stress" causing rather than a mortality agent. The relatively high incidence of microsporidia in field populations of the budworm and the associated low mortality suggest that the prospects for the use of microsporidia in budworm control is low.

There is some evidence, however, that budworm populations infected with microsporidia are more susceptible to chemical insecticides and to B.t. This suggests their possible use in budworm control. However, the spores are difficult to propagate on a large scale at the present. Experiments are in progress to determine whether the microsporidia (N. fumiferanae) can be introduced artificially into spruce budworm populations in the field, and whether the disease will persist to provide control in succeeding years (Wilson and Kaupp 1975).

10. Insect growth regulators

Growth and development in insects are regulated by three natural hormones of which the juvenile hormone is the best known (Wyatt 1972). The concentrations of the three hormones are in a delicate balance with respect to one another, and if this balance is disturbed abnormal growth and development occurs during metamorphosis which normally results in death. The strategy for using hormones as growth regulators for the budworm is to apply either a naturally occurring juvenile hormone, or one of its synthetic analogs, juvenoid hormones to produce abnormal development. Generally, the last larval instar is the most sensitive to juvenile hormone treatment. Juvenoid hormones are slow-acting and must be either ingested or come into contact with the insect to be effective. Initial laboratory and small-scale field tests using juvenile hormone analogs appeared promising and gave mortality in the egg stage (Retnakaran 1970) or induced abnormalities and death in the larval, pupal or adult stage (Retnakaran, Howse and Kaupp 1977). However, in field trials conducted later the effects of growth regulators were discouraging; only one compound which inhibits chitin synthesis, showed any promise. At this time there is no candidate hormone ready for operational field testing (Retnakaran, Howse and Kaupp 1977).

There are disadvantages in using juvenile hormone analogs for budworm control: (1) they would normally be applied to the last larval instar and this would result in little foliage protection in the year of application, (2) they are not species specific, and may also affect other insect species including budworm larval parasites (Outram 1974). Juvenile hormones, or any other growth regulating hormone, are not likely to gain wide acceptance for operational use unless the side effects on non-target organisms can be minimized.

11. Genetic control

Control of insect pests by genetic manipulation is a relatively new concept but it has been used successfully to suppress populations of several agricultural insects (Knipling 1968, Proverbs 1969). The most common method of genetic control is the "sterile male technique". The principle is to rear and release large numbers of male insects which have been exposed to radiation, or to chemicals, to induce complete sterility without affecting male mating behaviour or competitiveness for females. Females which mate with sterile males will lay sterile eggs and thus the population is reduced.

This method of control is best suited for insects that mate only once, occur at low densities in geographically isolated areas, and do not migrate over long distances. Unfortunately none of these criteria

fit the budworm. The spruce budworm which is the most widely distributed forest pest in North America, both males and females mate more than once (Campbell 1961, Outram 1968) and wind can carry budworm over large distances (Greenbank 1963a). Therefore, the sterile male technique for budworm control over large areas would probably not be successful.

Conclusions on Applied Control Methods

The aerial spraying of chemical insecticides against the larval stage is the only available method to control the budworm at outbreak levels; spraying gives immediate protection and keeps the trees alive. However, the application of chemicals has undesirable side effects. Three other methods appear to have the potential for successful control of epidemic budworm populations - aerial spraying of adults, B.t., and insect pathogens combined with chemical insecticide. Six of the remaining control possibilities, i.e. fungi, viruses, sex pheromones, microsporidia, parasites and predators and forest management technique have a potential use either in preventing the development of or hastening the collapse of outbreaks, but not for the control of the budworm at the peak of outbreaks. As none of the available, or potentially available, alternative budworm control methods are entirely satisfactory an integrated approach is recommended. Integrated control is an ecological approach to pest management in which some or all available control techniques are combined into a program to manage pest population levels to reduce economic damage and minimize adverse side effects of the treatments. Also, Newfoundland may be in an advantageous position in that the climate is probably marginal for the development of budworm outbreaks and direct control measures, to minimize damage, may not be required with the same frequency as elsewhere.

Minimizing wood losses through the application integrated control of the spruce budworm may include salvage operations, aerial spraying of chemical larval insecticides, B.t. or other disease causing organisms in combination with insecticides and the selected use of forest management techniques to decrease stand susceptibility to budworm damage. It is highly desirable to minimize the area sprayed with insecticides because of the undesirable side effects of chemical insecticides on non-target organisms and because of the possible prolongation of the outbreak. Only high value stands should be treated, and inaccessible areas or stands that will be harvested within the next 3-5 years should not need protection.

Harvesting methods and forest management practices should be modified to reduce rotation age and favour regeneration of non-susceptible host trees. This would tend to delay the development of budworm epidemics and would make outbreaks less extensive and less severe.

A vigorous outbreak detection system followed by an earlier suppression type of control (while most of the trees still have good foliage complement and have a better chance for survival) method may be more meaningful in the long-run than trying to keep severely defoliated stands alive. In addition, work should be accelerated on the more promising alternative control methods to develop them from the conceptual stage to the operational phase.

VIII. COMPARISON OF THE PREVIOUS AND PRESENT OUTBREAKS

Large areas of a favourable food supply (mature and overmature balsam fir and spruce) and several consecutive years of warm and dry spring and summer weather are the two major conditions essential for the development of the spruce budworm to outbreaks. These two conditions occurred simultaneously together at least six times in eastern Canada between 1760 and 1960 (Blais 1965). In each case budworm outbreaks developed and caused severe damage and tree mortality over extensive areas.

The earliest spruce budworm outbreak recorded in Newfoundland in 1942 was on Bell Island, on the east coast. This outbreak covered an estimated 1 280 ha (3,200 acres). It is possible that budworm outbreaks occurred prior to this in Newfoundland but they were not reported. The Bell Island outbreak spread to the adjacent Avalon Peninsula where it persisted until 1953 and then collapsed, probably from natural causes. Several smaller infestations were also recorded on the Island, mainly in western Newfoundland, between 1953 and 1956 and 1961 and 1962. However, with the exception of the one on the Avalon Peninsula, none of these persisted for more than four years and did not cause significant damage or tree mortality although some top killing occurred in stands defoliated for more than two years.

The present outbreak started in the western part of the Island in 1971. It increased annually to 1977 when it covered about 90% of the productive balsam fir-spruce forests - 3 521 000 ha (8,700,000 acres). By 1977 about 5 137 700 m³ (2,131,800 cords) of dead trees were scattered within the severely damaged stands. The behavior of the present spruce budworm outbreak in Newfoundland is completely different from that of the previous outbreaks, and resembles the outbreak patterns recorded elsewhere in eastern North America.

It is interesting to theorize about the possible causes for these vastly different types of outbreaks. Although it is not possible to explain the reasons for the differences with certainty, the following explanations, however, are probably a close representation of what has happened and why.

We have to restrict our comparison mainly to the spruce budworm outbreaks that were recorded in this century, and we have to assume that outbreaks that probably occurred before the turn of the century were relatively small and caused insignificant damage. According to early records eastern white pine, Pinus strobus L., formed extensive stands on the Island (Murray and Howley 1881). Stands of this non-host tree "broke" up the continuous stands of food source making the spruce-fir part of the forest less susceptible to the development of budworm outbreaks. The elimination of white pine has probably increased the susceptibility of the forest to budworm attack.

The biological control agents of the budworm are believed to be essentially the same both before and after 1971. Eight species of parasites were introduced against the budworm between 1947 and 1951 and of these only two became established. These two species, if anything, should have improved the effectiveness of the parasite complex.

Perhaps weather in combination with competition from the eastern hemlock looper may be the most important reason for the extent of the present spruce budworm outbreak. The hemlock looper, another defoliating insect, competes with the spruce budworm for the spruce/fir forest. Hemlock looper outbreaks also usually develop in mature and overmature stands with high balsam fir content, and damage is most severe in these stands. Warm, dry summers are also favourable for the hemlock looper but this insect has a lower temperature threshold than spruce budworm. Six outbreaks of the hemlock looper have been recorded in Newfoundland since the turn of the century. It is postulated that the hemlock looper reduced stand susceptibility to budworm attack by killing mature and overmature stands of balsam fir during the first five outbreaks in this century. In the sixth and most recent outbreak a considerable portion of the mature and overmature stands was saved by a chemical spray operation. With the presence of this ideal food source, one of the two conditions prerequisite for a budworm outbreak was present. Favourable weather, the second condition necessary for budworm population increase in Newfoundland began in 1969. It is probable that in addition to the build-up of the local population in Newfoundland, a considerable increase was caused by moth flights from mainland Canada where spruce budworm infestations increased annually from about the mid-1960's. By 1975 the area of moderate and severe defoliation in Ontario, Quebec and the Maritimes¹ was more than double the area (25 000 000 ha or 61,800,000 acres) of any previous outbreak in this century (Brown 1970).

¹The areas infested by the spruce budworm in these Provinces were taken from the appropriate sections submitted by the regions for the Annual Reports, Forest Insect and Disease Survey, Fisheries and Environment Canada.

There are two indirect evidences to support the theory of moth invasion into Newfoundland. In 1976 spruce budworm males were caught in traps baited with synthetic sex pheromone in western Newfoundland before any local adults had emerged. These moths probably were carried by wind to the Island rather than by any other means of transport. Such long-distance dispersal is supported by evidence from radar studies of moth dispersal conducted in New Brunswick in 1975 when a radar equipped aircraft followed a spruce budworm moth flight about half way across the gulf between Nova Scotia and Newfoundland (Greenbank, pers. comm.).

It is suggested that all the above reasons contributed to the unprecedented size and severity of the present spruce budworm outbreak in Newfoundland.

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Appendix IA. Spruce budworm defoliation and tree mortality in spruce budworm impact plots in western Newfoundland (Raske unpublished data).

Plot No.	Location	Avg. % plot defoliation ¹			% Mortality (by stems)		
		1975	1976	1977	1976	1977	Predicted
<u>Fir</u>							
1	Barry Bk.	14	49	100	0	0	0
2	Barry Bk.	2	50	100	0	0	0
3	Barachois R.	100	100	100	0	0	73
4	Barachois R.	100	97	100	0	0	27
5	Southwest Bk.	96	100	100	5	5	5
6	Southwest Bk.	99	100	100	0	0	0
7	Trout Bk.	99	100	100	0	0	58
8	Trout Bk.	91	100	100	0	0	44
9	Trout Bk.	88	100	100	0	0	100
10	Gallants	94	100	2	0	0	100
11	Gallants	97	100	2	0	0	100
12	Georges Lake	100	96	75	0	0	27
13	Georges Lake	100	96	100	0	0	4
14	Cooks Bk.	100	100	100	0	0	0
15	Cooks Bk.	100	100	100	0	0	0
16	Serpentine	90	99	100	0	0	16
17	Serpentine	100	99	100	0	0	42
18	Goose Arm	100	100	100	0	0	0
19	Goose Arm	100	100	100	0	0	0
20	Goose Arm	100	100	89	0	0	0
21	Goose Arm	99	100	44	0	0	0
22	Hughes Bk.	100	100	88	0	0	11
23	Hughes Bk.	100	100	77	0	0	4
28	Pasadena	74	26	75	0	3	3
29	Pasadena	90	13	43	0	0	0
30	Pasadena	98	88	59	4	11	18
31	Pasadena	93	87	73	7	17	17
32	Pasadena	85	90	26	0	0	0
33	Pasadena	66	90	15	0	4	4
64	Bonne Bay	-	(100)	23	-	6	6
65	Bonne Bay	-	(100)	5	-	0	10
Grand Average (No. of Plots = 31)		89	90	80	0.6	1.5	21.6

¹Refers to current year's growth.

²No needles on branches and no 1977 growth in plot.

Appendix IB. Spruce budworm defoliation and tree mortality in spruce budworm impact plots in central Newfoundland (Raske unpublished data).

Plot No.	Location	Avg. % plot defoliation ¹			% Mortality (by stems)		
		1975	1976	1977	1976	1977	Predicted
<u>Fir</u>							
24	Sandy Lake	8	100	100	0	0	0
25	Sandy Lake	94	100	100	0	0	0
36	Lake Ambrose	91	100	100	0	0	0
37	Lake Ambrose	93	100	100	0	0	0
38	Lake Ambrose	90	100	100	0	0	0
39	Lake Ambrose	98	100	100	2	2	2
40	Mings Bight	24	100	100	0	0	0
41	Mings Bight	38	100	100	0	0	0
42	Rambler	20	100	100	0	0	0
43	Rambler	15	100	100	0	0	0
44	Baie Verte	55	100	100	0	0	0
45	Baie Verte	37	100	100	0	0	0
46	Baie Verte	20	100	100	0	0	0
47	Baie Verte	21	100	100	0	0	0
48	Badger	46	100	100	10	10	17
49	Badger	51	100	100	6	6	6
68	Northwest Gander R.	-	100	100	-	0	0
69	Northwest Gander R.	-	100	100	-	0	0
Average (No. of Plots = 18)		50	100	100	1.1	1.0	1.4
<u>Spruce</u>							
26	Sandy Lake	17	96	100	0	0	0
27	Sandy Lake	43	78	86	3	3	3
34	Lake Ambrose	1	37	100	0	0	0
35	Lake Ambrose	0	19	100	0	0	0
50	Crooked Bog	33	100	96	2	4	4
51	Crooked Bog	36	100	97	2	2	2
52	Gull Pond	16	100	91	0	0	0
53	Gull Pond	16	100	96	0	0	0
54	Grand Falls	13	100	100	0	0	0
55	Grand Falls	15	100	100	0	0	0
56	Loon Bay	100	75	76	0	0	0
57	Loon Bay	100	76	91	0	0	0
66	Southwest Gander R.	-	100	100	-	0	0
67	Southwest Gander R.	-	100	100	-	0	0
Average (No. of Plots = 14)		33	84	95	0.5	0.6	0.6
<u>Larch</u>							
70	Buchans Jct.	(100)	(100)	67	-	0	0
71	Buchans Jct.	(100)	(100)	65	-	0	0
Average (No. of Plots = 2)		(100)	(100)	66	0	0	0
Grand Average (No. of Plots = 34)		43	93	96	0.8	0.8	1.0

¹Refers to current year's growth.

Appendix IC. Spruce budworm defoliation and tree mortality in spruce budworm impact plots in eastern Newfoundland (Raske unpublished data).

Plot No.	Location	Avg. % plot defoliation ¹			% Mortality (by stems)		
		1975	1976	1977	1976	1977	Predicted
<u>Fir</u>							
60	Bunyan's Cove	82	100	100	0	0	0
61	Bunyan's Cove	54	100	100	4	11	11
62	Milton	100	28	100	0	0	0
63	Random Island	88	100	100	0	0	0
<hr/>							
Average (No. of Plots = 4)		81	82	100	2	2.8	2.8
<hr/>							
<u>Spruce</u>							
58	Port Blandford	4	100	55	0	0	0
59	Port Blandford	5	100	78	4	4	4
<hr/>							
Average (No. of Plots = 2)		5	100	67	2	2	2
<hr/>							
Grand Average (No. of Plots = 6)		56	88	89	1.0	2.5	2.5

¹Refers to current year's growth.