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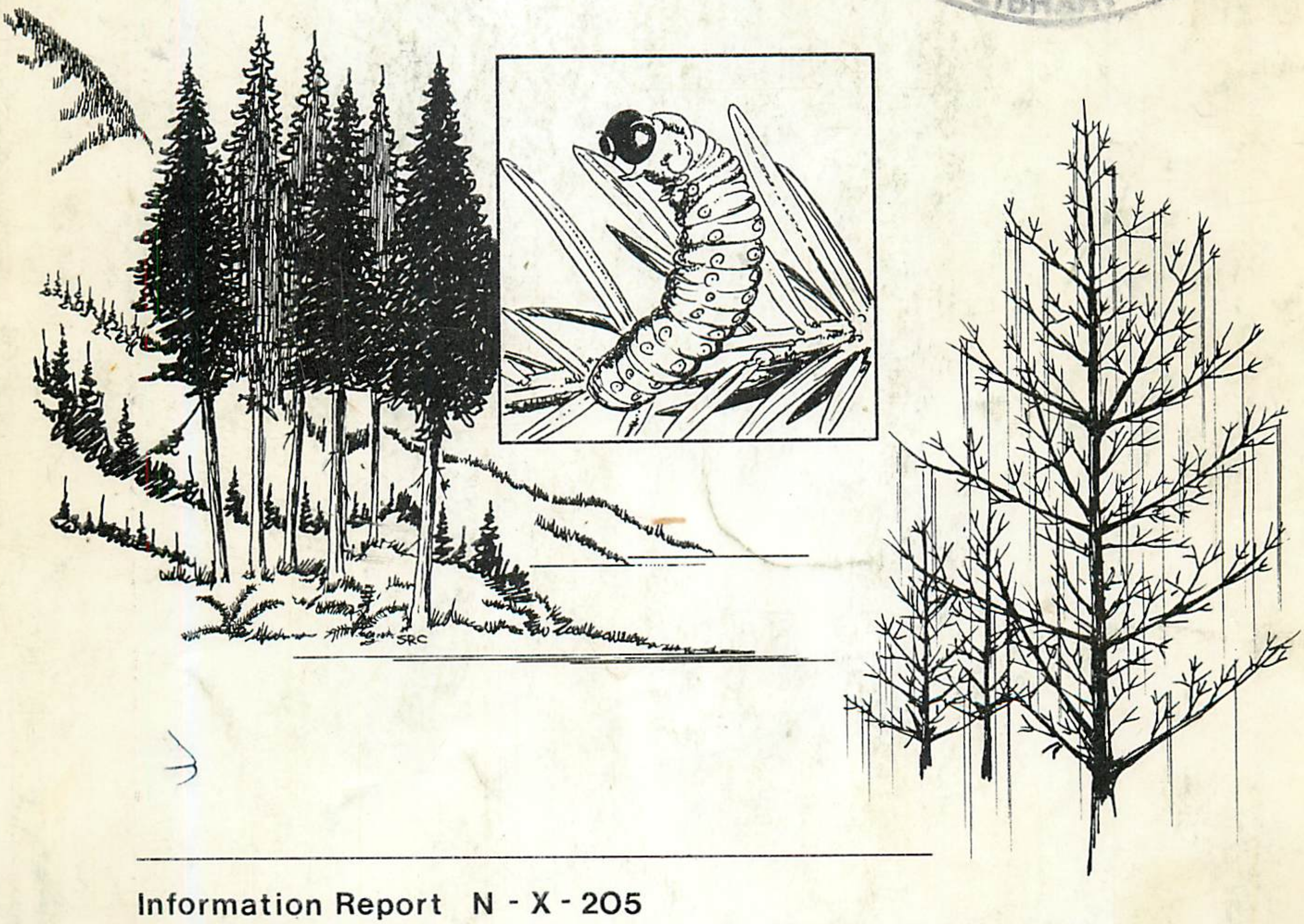
# Review of the Spruce Budworm Outbreak in Newfoundland - Its Control and Forest Management Implications

## Canadian Forestry Service Submission to the Newfoundland and Labrador Royal Commission on Forest Protection and Management



J. Hudak and A.G. Raske, Editors

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# REVIEW OF THE SPRUCE BUDWORM OUTBREAK IN NEWFOUNDLAND - ITS CONTROL AND FOREST MANAGEMENT IMPLICATIONS

based on the
CANADIAN FORESTRY SERVICE SUBMISSION
TO THE NEWFOUNDLAND AND LABRADOR
ROYAL COMMISSION ON FOREST PROTECTION
AND MANAGEMENT

J. Hudak and A.G. Raske, Editors



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# REVIEW OF THE SPRUCE BUDWORM OUTBREAK IN NEWFOUNDLAND – ITS CONTROL AND FOREST MANAGEMENT IMPLICATIONS

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CANADIAN FORESTRY SERVICE SUBMISSION TO THE NEWFOUNDLAND AND LABRADOR ROYAL COMMISSION ON FOREST PROTECTION AND MANAGEMENT

## SUMMARY

### I. Introduction

Populations of the eastern spruce budworm (*Choristoneura fumiferana* (Clem.)) have erupted in the 1970's into the largest outbreak ever recorded in the forests of Newfoundland. The application of available chemical protection measures became highly controversial. Therefore, the Government of Newfoundland and Labrador established a Royal Commission to examine all aspects of forest protection and management in the Province. The Royal Commission has requested the Canadian Forestry Service to provide background information addressing its terms of reference. This report is a synopsis of information covering the various aspects of the spruce budworm fir-spruce forest complex, with special emphasis on Newfoundland.

### II. The Forests of Newfoundland and their Major Pests and Fire History

Newfoundland's boreal forests occupy 3 786 000 ha of productive land on the Island. Softwoods comprise 83% of the commercial volume, being dominated by balsam fir (49%) and black spruce (34%). Birch, the major hardwood (12%), occurs in mixed and occasionally in pure stands. Stands dominated by balsam fir tend to occupy the better sites. The better black spruce stands, which usually originate after a fire, occur in central Newfoundland. Balsam fir and black spruce stands may produce 175 $m^3$/ha over a rotation.

The Island's maritime climate is characterized by relatively cool summers, and moderately cold winters. Precipitation is evenly distributed throughout the year and may vary between 760 mm and 1 525 mm/year. Bedrock geology varies greatly. Podzols of low to moderate fertility predominate on the well-drained sites. Gleyed soils are common.

The productive forests of Labrador cover about 2 756 000 ha, and most of them are concentrated in the large river valleys located in the central and southeastern portions. About 95% of the forests are softwoods, of which 70% is black spruce and 25% is balsam fir. Merchantable volumes of mature stands are comparable to those on the Island. The climate generally is continental, with short, warm summers and cold winters. Precipitation ranges from 500 mm to 1015 mm/year. Bedrock is mostly infertile granite and gneiss.

Several pests have caused major depletion of the forests of Newfoundland. The balsam woolly aphid, an accidentally introduced sucking insect, has spread in the 1950's and early 1960's to most of the forests of the Island. It reduced the volume of growth by about 5% and caused additional damage through reducing wood quality. It also predisposed trees to early mortality if subsequently damaged by other pests. The two principal, native defoliating insects are the eastern hemlock looper and the eastern spruce budworm. Looper populations reached outbreak levels in the late 1960's and the volume of mature and overmature stands with tree mortality totalled 12 000 000 $m^3$ at the end of the outbreak. The present outbreak of the budworm started in 1971 and by 1979 the budworm has very severely damaged or killed 38 400 000 $m^3$; more than three times the damage caused by the latest looper outbreak. Heart rots of living trees caused by a number of wood destroying fungi affect about 10% of the gross pulpwood inventory volume. They may cause higher losses in the sawlog inventory. Heart rots do not kill trees but reduce the net merchantable volume. Sap rots caused by decay fungi destroy the wood in dead trees killed by insects or other causes and in time make them unsuitable for commercial use. Armillaria root rot, a disease of world-wide distribution, affects all tree species. In Newfoundland the most important losses occurred in plantations where tree mortality reached 35%. The disease also contributed to the mortality of trees damaged by other pests.

## III. History of Spruce Budworm Outbreaks in Eastern North America with Special Reference to Newfoundland

Spruce budworm outbreaks are a natural phenomenon associated with the biota of the boreal forest. Two main conditions are required for the development of outbreaks: favourable weather and extensive stands of mature balsam fir. Past outbreaks in eastern Canada occurred more frequently in the Atlantic region than in Ontario, and they appear to have become more frequent and more severe in recent times. This situation may be attributed in part to cutting practices, forest fire control, and chemical treatment of infested stands. Between 1940 and 1970, only sporadic and local infestations were observed in Newfoundland. The current outbreak began in 1971 and rapidly spread to nearly all productive forests on the Island. An infestation in Labrador began in 1975 and terminated in 1979 through natural factors. Causes of the outbreak are probably attributable to presence of extensive fir stands and to favourable weather. Influx of moths from the mainland may have contributed to increasing local populations on the Island although these can attain epidemic levels independently.

## IV. Biology, Habits, Population Trends of the Spruce Budworm, Characteristics of Outbreaks and Associated Pests

The life history of the spruce budworm spans two calendar years. Eggs are laid in early August of one year, and emerging larvae spin hibernacula for overwintering. These larvae emerge the following spring and feed on buds, flowers and needles. Mature larvae pupate in mid-July and adults emerge in late July. Major within-generation mortality occurs before hibernation in fall, small larval stage in spring, and in the mature larval stage. The extent of mortality of mature larvae determines the population trend. Population dispersal occurs when larvae hatch in August, when larvae emerge from hibernacula in spring and particularly when adults emigrate.

Spruce budworm outbreaks originate in small areas, spread rapidly to cover very extensive regions. Uncontrolled outbreaks usually last 8 to 10 years and terminate when the food supply becomes scarce and tree mortality widespread. Balsam fir is the most vulnerable host tree and dies after 4 to 5 years of severe damage to the current year's foliage. White and red spruce may withstand up to 6 years of severe defoliation before dying. Black spruce trees, especially in pure stands, usually survive. However, some black spruce stands have been killed in central Newfoundland. Fir stands tend to replace stands killed by the budworm in the Maritimes, but in Newfoundland regeneration may be lacking and succession to shrub species may occur.

In Newfoundland, preceeding, concurrent or successive damage by other defoliators, such as the hemlock looper, black-headed budworm, spruce coneworm, balsam fir sawfly, or damage by the balsam woolly aphid may result in increased mortality rates of the host trees. Armillaria root rot may also hasten the death of trees damaged by the budworm.

## V. Damage Caused by the Spruce Budworm

Consecutive severe defoliation of trees causes a reduction in stored food, loss of growth hormones and seed crops, reduction in radial and height growth, rootlet mortality and eventual death. Most mature trees do not survive when more than 75% of their total foliage had been destroyed. In past budworm outbreaks in mainland Canada height growth losses averaged 2 m to 4 m and reduction of increment ranged between 30% to 90%. Volume loss through reduced radial and height growth in an outbreak in Quebec was estimated at one-third of the loss caused by tree mortality.

In uncontrolled outbreaks in the mainland, mortality of balsam fir ranged between 70% to 100% in mature stands, and 30% to 70% in immature stands. Mortality of white spruce was 10% to 40%, and that of black spruce even less. Volume loss through reduced increment and stocking in surviving stands is substantial and most stands never regain their pre-defoliation volume.

The present spruce budworm outbreak in Newfoundland is unprecedented in size and severity. Tree mortality in merchantable stands in 1979 was about 10 280 000 $m^3$, the volume of dying trees increased to 11 661 000 $m^3$ and the total volume of stands containing some tree mortality has reached 38 412 000 $m^3$. Radial growth in damaged stands has been reduced by an average of 80%. Damaged fir trees have not increased in height during the outbreak and an estimated 15% of the surviving trees have had 1 m or more of their top killed. In addition about 46 600 ha of immature stands of fir have also been very severely damaged of which 23 300 ha had tree mortality ranging from 50% to 100%.

Loss of seed, both in balsam fir and black spruce, is detrimental to the establishment of future stands both natural and artificial. Where the advanced fir regeneration or stands younger than seed-bearing age have been killed by the budworm, the site may be taken over by competing hardwood species. In damaged black spruce stands, the trend is toward Kalmia-heath vegetation.

The effect of budworm outbreak on fish and wildlife habitat is of minor importance and may be somewhat beneficial to ungulates. Though the consequences of outbreak on emenity forest values are not quantified, they are considered important. The aesthetic value of forests is greatly reduced, especially in parks and suburban areas. Damage to young fir stands made them unsuitable for the harvesting of Christmas trees.

There is a lack of agreement as to whether budworm-killed stands pose a serious fire hazard. Hazard may be higher in central than in western Newfoundland. Also spring fires may be more severe than normal and summer fires less severe because of the proliferation of green understory vegetation in the summer.

Salvaging of damaged stands for pulpwood will increase the cost of harvesting, manufacturing and ultimately the price of pulp and paper. Killed stands may be utilized for pulpwood for 4 to 5 years but losses through breakage or windthrow may make the harvesting uneconomical and very dangerous.

Accelerated harvesting of damaged stands and storage of wood to circumvent the detrimental effect of possible windthrow entails increased expenses through additional capital and labour costs and interest. Also cellulose-destroying deterioration is more common in stored wood than in standing trees. Accelerated harvesting and log storage is uneconomical.

The total area of moderate and severe defoliation in the productive forests of the Island was about 926 000 ha and about 428 000 ha of merchantable stands contained dead trees. Dead volume within this area was estimated at 17 000 000 $m^3$; an increase of almost 7 000 000 $m^3$ since 1979. The volume of dying trees was estimated at almost 5 000 000 $m^3$ and the total living and dead volume within these damaged stands was about 40 000 000 $m^3$ in 1980, or about 23% of the total softwood volume on the Island. A total of 65% of the dead trees have died within the last two years. The total area of submerchantable stands with tree mortality was about 63 000 ha in 1980. A slight decrease in area of moderate and severe defoliation, to 800 000 ha, is forecast for 1981, and the area with some tree mortality is expected to increase to about 780 000 ha.

## VI. Economic Impact of the Present Outbreak of the Spruce Budworm in Newfoundland

The forest resource and dependent industries are important to the Newfoundland economy. Harvesting and wood-using industries provide a major source of employment and income, especially in central and western regions. The forest resource provides sawlogs and fuelwood for the many thousands of people who live in rural communities. Significant recreation benefits are also provided. An adequate wood supply at competitive cost is of crucial importance to all forest based industries. Reduction in wood supply would have serious social and economic implications for the provincial economy in the future.

The spruce budworm outbreak has already incurred a serious impact on the forest resource and future wood supplies are threatened. A large proportion of the balsam fir on the Island may be killed by 1984 if the outbreak continues and protection is not provided. Total volume in dead, dying and severely damaged stands could reach 68 000 000 to 98 000 000 $m^3$ by 1984, representing 39% to 55% of the total softwood volume on the Island. If these losses occur there will be a drastic impact on provincial forest industry with wood shortages leading to reduced output and possibly to mill closures.

The costs of providing protection to 1980 by chemical spraying ($18 000 000) are modest compared to the possible value losses through failure to protect. Major cost estimates associated with not spraying include lost timber values ($29 000 000), and possible cost of forest rehabilitation measures ($105 000 000). Another possible cost would be lost value added to the provincial economy. In an example, a 20% reduction in industrial activity for the period 1990 to 2000 was estimated to result in a loss of $318 000 000 value added.

Future wood shortages will not only affect large newsprint mills but also small sawmills and fuelwood supplies as well. Wood shortages will coincide with increased industrial and domestic demand for fuelwood.

## VII. Natural Factors Affecting Budworm Populations

Numerous biotic and abiotic factors such as predators, parasites, diseases and weather affect spruce budworm populations. These factors may be more important at endemic population levels but cannot prevent epidemics if conditions favour budworm development and survival. The collapse of a budworm epidemic is associated with many factors, such as the increased activity of parasites, predators, pathogens, and increased competition for food. The most important of these is the competition for food which leaves the forest dead, dying or in a severely stressed condition. Differences among trees in the severity of defoliation in the early stages of outbreak suggests differences in susceptibility based on food quality. However, such differences largely disappear when insect numbers increase and manipulation of foliage quality will not likely prevent or control epidemics.

## VIII. Applied Control Measures Registered for Commercial Use and Potential Control Methods

Six chemical insecticides and one biological insecticide are registered for forestry application against the spruce budworm in large forest areas. Fenitrothion and aminocarb have been used successfully over millions of hectares in recent years. Acephate was used extensively and effectively in Ontario; its relatively low toxicity to fish makes it a good choice for use near streams. Carbaryl, just recently registered, has not been used in Canada because higher volume applications are required relative to aminocarb and fenitrothion. Phosphamidon and trichlorfon have very limited use.

*Bacillus thuringiensis* (= *B.t.*), the only registered biological insecticide, has been effective when its limitations are acknowledged. It is most effective when used at 4.6 ℓ/ha at the registered dose of 20 BIU/ha and when applied by small aircraft. *B.t.* sprays cost 3 to 5 times more than chemical insecticide sprays. A new oil formulation may prove to be effective and economical.

Intensive research is in progress to develop new methods and techniques to reduce dependence on chemical insecticides. Insect growth regulators when ingested prevent maturation to the adult stage by inhibiting moulting in larvae and show potential for control. Some insect growth regulators are being field tested and may be registered in a few years. They probably will be cheaper to produce than microbials and less hazardous to the environment than chemical insecticides. Sex pheromones are substances emitted by female moths to attract male moths for mating. When synthetic attractants are diffused into the atmosphere, male moths become adapted to the odours and do not respond to the females. Theoretically the number of fertile egg masses laid and the incidence of moth dispersal will also be reduced. Sex pheromones appear promising but several technological problems need to be solved, which may take years of research. Control of epidemic populations by either microsporidia, fungi, viruses, parasites or predators, all natural agents, does not as yet appear promising. Probably fungi and viruses show the most potential but each requires continued research as major obstacles have to be overcome. Control through the mass release of sterile or genetically altered insects to reduce reproduction and survival awaits at least 5 to 10 years of development and testing. The potential of genetic control is in its being incorporated into an integrated control program of endemic populations. The strategy of using pathogens together with sublethal doses of chemical insecticides has considerable potential for spruce budworm control, but laboratory and field testing are needed to better assess this potential. Antifeedants are chemicals which inhibit pest feeding. They may be produced in minute quantities by the host plant. These and chemicals of non-plant origin are being tested for their anti-feeding affect on the spruce budworm. Trees posses various complex chemical, physiological and morphological properties in their gene pool to resist and survive insect attack. Breeding and using insect resistant trees is a desirable long-range pest-management strategy. However, breeding trees for resistance takes a long time, and much longer still to establish resistant trees in the natural forest.

Budworm control by forest management is a very long term strategy that could potentially ameliorate impacts; not eliminate them. Management practices could alter species composition, change the age-class distribution and the spatial structures of forest stands. These practices would take 50 to 100 years, and would need to be applied over large regions to be effective. Also each management strategy has substantial drawbacks. However, forest management techniques will play a role in the integrated control of the balsam fir-budworm problem.

Integrated control or pest management is the intelligent use of all practical methods of control applied in harmony with the environment to minimize economic damage. Present budworm control practices are in agreement with this concept of integrated control. The only effective methods to control epidemic populations are chemical and biological insecticides and they are used sparingly, and only when and where necessary. Research seeks the development of other methods to reduce the dependence on chemicals and as they become operational they may be incorporated into the control program.

## IX. Environmental Effects of Forest Pest Management Options

There is no evidence of persistent environmental damage from presently used insecticides on fish, fish food organisms, birds or mammals. The effect of sprays on the community of terrestrial arthropods, including parasites and predators of the budworm, pollinators are either minimal or temporary. Influx of populations from surrounding areas and reproduction rapidly replace any short term reduction caused by the spray.

The possibility of budworm populations developing resistance to insecticide is very remote. Seven years of spraying fenithrothion has produced no evidence of resistance.

Over 80% of the sprayed material usually sediments to the ground rapidly under gravity. The remainder of the spray is in very minute droplets and form clouds that may drift more than 300 m from the swath line. Gentle updrafts cause greater drift than light winds. Chemicals suspended as aerosals or vapors appear to degrade rapidly in the air without conversion into toxic substances. Drift has not caused recognizable ecological side effects.

The aerial application of chemical insecticides in current use have caused no known adverse effects from repeated short-term exposure. Spray chemicals have no mutagenic activity in humans, and chronic effects, including carcinogenetic activity, are not known to occur from long-term exposure. Also Reye's syndrome has not been linked to forest spray programs. The claimed viral enhancing effects of chemical insecticide formulations have not been substantiated.

Current formulations of *B.t.* are considered environmentally safe, as are other potential natural control methods, such as viruses, fungi, sex pheromones and insect growth regulators. However, insect growth regulators must meet very strict safety standards before use is permitted.

The no-control option during epidemics normally leads to the death of the mature forest stands. The environmental impacts of considerable tree mortality is unlikely to have detrimental effects on aquatic or terrestrial fauna. The greatest impact of a no-control option is the socio-economic impact caused by increased unemployment through the loss of the forest. This impact has been identified as a major threat to the health of the Newfoundland population dependent on the forests.

## X. Review of the Status of Forest Insect Control and the CFS Stand on Pest Management

Canadian forests are susceptible to severe insect damage because one cover type may occupy vast areas. The spruce budworm and the fir-spruce forest form a complex cyclic system in which budworm outbreaks rejuvenate mature fir stands periodically. Natural factors, other than a limited food supply, play only a minor role in regulating epidemic budworm populations.

Only aerial treatments with chemical pesticides or with *B.t.* have been effective in limiting tree mortality. Chemicals have provided consistently better protection than *B.t.* and current spray operations are not known to be detrimental to the environment. The aim of operational control programs is to maintain a live forest inventory rather than to control budworm numbers. There is no documented evidence that such spraying has been detrimental to human health. Alternate means of protection against budworm damage are still in the research stage and are not yet available for operational use.

Forests will be more intensively managed in the future, and will need even greater protection from economically important forest pests to assure benefits from silvicultural treatments. Therefore, the need for chemical spraying will likely increase until alternative protection methods become available. In the meantime the wise use of chemical pesticides on current forest crops allows management options to be kept open.

It is the policy of the Canadian Forestry Service to provide support to Provincial agencies and forest industries by researching in all areas of the spruce budworm and other forest pest problems; from the screening of new insecticides to monitoring the environmental effects of spray operations and to the development of effective alternative control methods. The Canadian Forestry Service also provides advice and services; such as budworm population forecasts, damage surveys and developing silvicultural management techniques. The Canadian Forestry Service has played a lead role in developing ecologically sound principles and methods of pest management, has transferred pertinent information to outside agencies, and provided needed services to forest users and managers.

## XI. Forest Management Practices in Newfoundland

Over the past 80 years, forest management in Newfoundland has developed gradually from early policies of resource allocation to encourage industrial development, to extensive forest management, techniques in the 1970's, and now to the initiation of some intensive forest management practices.

Withdrawals of productive land from forestry use and site damage caused by logging operations represent significant losses in growth capacity. Practices which rehabilitate sites lost from production, such as reforesting bulldozed landings, and those which improve utilization, such as cable yarding, should be encouraged.

Clearcutting is the traditional and most economic method of harvesting in Newfoundland. This practice will likely continue, although it tends to increase the proportion of budworm-susceptible fir forest over the years. Alternative harvesting techniques are more costly and would not make forests less susceptible to the spruce budworm.

Stand improvements such as pre-commercial thinning and forest fertilization increase forest productivity and improve yields but treated stands may be more susceptible to insect pests than untreated stands.

Herbicide treatment eliminates competing vegetation in young softwood stands giving improved growth, but the released trees are probably more susceptible to insect attack. Prescribed burning is an efficient site preparation tool which can eliminate fir regeneration permitting stand conversion to species less susceptible to pests. Scarification is an essential preparation for planting or seeding on many sites. Direct seeding is an efficient and effective reforestation practice in Newfoundland.

Planting bareroot or container-grown seedlings is the traditional method of reforestation. Despite recent increases in areas reforested, it is questionable if the present scale of reforestation in Newfoundland is adequate.

It is theoretically possible to breed trees resistant to attack by certain insect pests, but the time-scale required to achieve practical results makes this method unrealistic.

## XII. Forest Policy and Implementation

Federal forest policy recognizes the national importance of forestry to the economy and the growth potential in forest-based industries. Serious problems exist, such as inadequate stocking, wood supply, and competitive position of Canadian industry that have to be corrected if forest industries are to remain competitive in the long run. After a period of neglect there now appears to be a renewed awareness of the importance of forestry in the federal bureaucracy. In Newfoundland the federal government provides forestry research and advisory services through the Canadian Forestry Service and special funding assistance for provincial forestry programs through the Department of Regional Economic Expansion.

Considerable progress was made in the early 1970's in forest policy development by the Province and significant improvements were made in the intensity of forest management. Some improved forests have been killed and others are threatened because of inadequate protection policies and programs. A protection policy must be developed and implemented before further progress can be made.

There is ongoing cooperation between federal and provincial forestry agencies in the Province through committees established for this purpose. Communications appear to have weakened in recent years and these committees should be strengthened.

Essential elements in an intensive forest management plan are inventory, protection, regulation and administration. Short-term utilization measures and longer-term forest improvement practices that ensure maximum recovery of wood fibre from forest stands are suggested for Newfoundland. Important questions of funding and tenure, remain to be resolved.

Research and development play a vital role in long-term forest management. Existing capabilities in Newfoundland should be strengthened if research is to keep ahead of the needs of resource managers.

Forest agencies and resource managers in Newfoundland have failed to maintain healthy two-way communications with the public and politicians. This has led to a credibility gap and lack of support for vital protection programs. Strenuous efforts are needed to establish communications and promote mutual understanding between managers and the public.

# REVUE DE L'INFESTATION DE TORDEUSES D'EPINETTE A TERRE NEUVE — SON CONTROLE ET SES IMPLICATIONS POUR L'AMENAGEMENT DES FORETS

d'après la

PRÉSENTATION DU SERVICE CANADIEN DES FORÊTS À LA COMMISSION ROYALE DE TERRE-NEUVE ET DU LABRADOR SUR LA PROTECTION ET L'AMÉNAGEMENT DES FORÊTS

## RESUME

### I. Introduction

Au cours des années 70, les forêts de Terre-Neuve ont connu la plus grande infestation jamais observée de la tordeuse des bourgeons de l'épinette. Les pulvérisations chimiques suscitèrent de fortes controverses. Le gouvernement de Terre-Neuve a donc créé une commission royale pour examiner tous les aspects de l'aménagement et de la protection des forêts de la province. La commission a demandé au Service Canadien des Forêts de la documentation de base dont elle avait besoin pour remplir son mandat. Le présent document résume l'information remise sur les différents aspects des relations entre les forêts d'épinette et de sapin et la tordeuse.

### II. Les Forêts de Terre-Neuve: Principaux Ravageurs et Historique des Incendies

La forêt boréale de l'île Terre-Neuve occupe 3 786 000 ha de terres productives. Les résineux, qui représentent 83% du volume commercial, sont dominés par le sapin baumier (49%) et l'épinette noire (34%). Le bouleau, principal feuillu (12%), pousse dans les peuplements mixtes et parfois dans les purs. Les peuplements où domine le sapin baumier ont tendance à occuper les meilleures stations. Les peuplements d'épinette noire les plus intéressants, qui s'implantent habituellement à la suite d'un incendie, se trouvent dans le centre de l'île. Au cours d'une rotation, les peuplements de ces deux résineux peuvent produire 175 $m^3$/ha.

Le climat maritime de l'île se caractérise par des étés relativement frais et des hivers pas trop froids. Les précipitations, réparties uniformément durant l'année, peuvent varier entre 760 et 1525 mm/an. La géologie de la roche mère varie considérablement. Les podzols, de fertilité faible à moyenne, prédominent aux endroits bien drainés. Les gleysols abondent.

La forêt productive du Labrador occupe environ 2 756 000 ha; elle est concentrée en majeure partie dans les grandes vallées du centre et du sud-est. Composée à 95% environ de résineux, elle compte 70% d'épinette noire et 25% de sapin baumier. Le cubage commercialisable des peuplements mûrs se compare à ceux de l'île. Le climat, généralement continental, donne un été court et chaud et hiver froid. Les précipitations vont de 500 à 1015 mm/an. La roche mère se compose principalement de granite et de gneiss infertiles.

Plusieurs ravageurs ont dégarni les forêts de Terre-Neuve. Le puceron lanigère du sapin, insecte suçeur introduit accidentellement, s'est répandu au cours des années 50 et au début des années 60 dans la plupart des forêts de l'île. Il a réduit leur croissance d'environ 5%, sans compter que la qualité du bois en a souffert. Les arbres ont aussi eu tendance à mourir précocement s'ils étaient ensuite endommagés par d'autres ravageurs. Les deux principaux défoliateurs indigènes sont l'arpenteuse de la pruche et la tordeuse des bourgeons de l'épinette. La pullulation d'arpenteuses a eu lieu vers la fin des années 60; à la fin de cette infestation, le nombre d'arbres morts dans les peuplements arrivés à maturité ou à surmaturité représentaient 12 millions de $m^3$ de bois. La présente infestation de tordeuse a débuté en 1971. En 1979, l'insecte avait endommagé très gravement ou détruit 38 400 000 $m^3$ de bois, soit trois fois plus que l'arpenteuse au cours de sa dernière pullulation. La pourriture du coeur des arbres, provoquée par certains champignons qui s'attaquent au bois, atteint environ 10% des réserves brutes de bois de pâte. Les pertes peuvent encore être plus élevées dans le cas des réserves de bois de sciage. L'arbre n'en meurt pas, mais le cubage net commercialisable s'en trouve réduit. La pourriture de l'aubier, due à des champignons, détruit le bois des arbres tués par des insectes ou autrement, ce qui le rend impropre à la commercialisation. Le pourridié-agaric, maladie répandue à la grandeur du globe, s'attaque à toutes les essences. A Terre-Neuve, les pertes les plus lourdes sont observées dans les plantations où la mortalité des arbres atteint 35%. La maladie contribue aussi à tuer des arbres endommagés par d'autres ravageurs.

Périodiquement, des incendies rasent de vastes superficies de la province. Dans l'île, c'est surtout l'homme qui en est la cause, et au Labrador, la foudre. Au cours des deux dernières décennies, les pertes dues aux incendies ont été considérablement réduites grâce au programme de détection et d'extinction de la province, qui a été grandement amélioré.

## III. Rappel des Infestations de Tordeuses dans l'est de l'Amérique du Nord et Plus Particulièrement à Terre-Neuve

L'infestation de tordeuses est un phénomène naturel dans la forêt boréale. Deux conditions principales sont nécessaires pour qu'elle se produise: la température doit être favorable et il faut de vastes peuplements mûrs de sapin baumier. Dans l'est du Canada, les infestations passées se sont produites plus souvent dans la région de l'Atlantique qu'en Ontario. De plus, elles semblent avoir été plus fréquentes et plus éprouvantes ces derniers temps. Cette situation peut être attribuée en partie au méthodes de coupe, à la lutte contre les incendies de forêt et au traitement chimique des peuplements infestés. Entre 1940 et 1970, on n'a observé, à Terre-Neuve, que des infestations locales et sporadiques. L'infestation actuelle, commencée en 1970, s'est rapidement étendue à presque toute la forêt productive de l'île. Une infestation a débuté en 1975 au Labrador et s'est terminée en 1979 de façon naturelle. Elle aurait été favorisée par la présence de vastes peuplements de sapin et des conditions météorologiques propices. L'arrivée de papillons du continent a pu contribuer à l'augmentation des effectifs locaux de l'île, bien que ceux-ci puissent atteindre le stade épidémique sans apport extérieur.

## IV. Biologie, Habitudes de la Tordeuse et Tendance de ses Effectifs, Caractéristiques des Infestations et des Ravageurs qui y sont Associés

Le cycle vital de la tordeuse s'étend sur deux ans. L'insecte pond au début d'août, puis les larves qui éclosent s'enveloppent d'un cocon pour hiverner. Ces larves réapparaissent le printemps suivant et se nourrissent de bourgeons, de fleurs et d'aiguilles. Arrivées à maturité, elles se transforment en chrysalides à la mi-juillet et arrivent au stade adulte à la fin de juillet. Au cours d'une génération, les mortalités s'observent surtout à l'automne précédant l'hivernation, puis au printemps chez les petites larves et enfin au dernier stade larvaire. Le taux de mortalité des larves arrivées à maturité détermine l'importance des effectifs. Leur dispersion se produit lorsque les larves éclosent en août, lorsqu'elles sortent de leur cocon au printemps et surtout lors de la migration des adultes.

L'infestation, d'abord localisée, s'étend rapidement à de très vastes régions. La pullulation naturelle dure habituellement de huit à dix ans et se termine avec la raréfaction de la nourriture et la mort généralisée des arbres. Le sapin baumier est l'hôte le plus vulnérable: il meurt après que le feuillage de l'année a été fortement détruit quatre à cinq années de suite. Les épinettes blanches et rouges peuvent résister jusqu'à six ans à ce genre de défoliation avant de mourir. Les épinettes noires, en particulier dans les peuplements purs, y survivent habituellement. Il n'empêche que certains peuplements de cette essence ont été détruits dans le centre de Terre-Neuve. Dans les Maritimes, des sapinières tendent à remplacer les peuplements détruits par la tordeuse, mais, à Terre-Neuve, cette régénération peut faire défaut et seuls des arbrisseaux s'implantent alors.

À Terre-Neuve, les dommages antérieurs, simultanés ou successifs causés par d'autres défoliateurs comme l'arpenteuse de la pruche, la tordeuse à tête noire, la spirale des cones de l'épinette, le diprion du sapin ou ceux qu'inflige le puceron lanigère du sapin peuvent aggraver les taux de mortalité. Le pourridié-agaric peut aussi accélérer la mort des arbres infestés par la tordeuse.

## V. Dommages causés par la Tordeuse

La défoliation ininterrompue et importante des arbres entraîne une réduction de leurs réserves alimentaires, une perte d'hormone de croissance et de semences, une réduction de leur croissance en hauteur et en diamètre, la mort des radicelles et finalement celle de l'arbre. La plupart des arbres arrivés à maturité ne survivent pas à la destruction de plus de 75% de leur feuillage. Dans le passé, les infestations des forêts continentales du Canada ont réduit la croissance en hauteur de 2 à 4 m en moyenne, et la croissance en diamètre de 30 à 90%. Le déficit en volume ainsi occasionné au Québec par une infestation a été, estime-t-on, l'équivalent du tiers des pertes causées par la mort d'arbres.

Au cours des infestations laissées à elles-mêmes sur le continent, de 70 à 100% des sapins baumiers ont été détruits dans les peuplements mûrs, et de 30 à 70%, dans les jeunes. De 10 à 40% des épinettes blanches ont été détruites et moins dans le cas de l'épinette noire. La perte de volume due aux réductions de l'accroissement des arbres et de la densité relative, dans les peuplements ayant survécu, est considérable, et la plupart de ces peuplements ne retrouveront jamais leur volume antérieur à la défoliation.

À Terre-Neuve, nous assistons actuellement à une infestation record par son étendue et son intensité. Dans les peuplements commercialisables, 10 280 000 $m^3$ de bois ont été perdus en 1979: le nombre d'arbres condamnés représente 11 661 000 $m^3$ de bois et le volume total de peuplements où des arbres sont détruits a atteint 38 412 000 $m^3$. Dans les peuplements atteints, la croissance en diamètre a été réduite en moyenne de 80%. Les sapins endommagés n'ont pas poussé durant l'infestation et l'on évalue à 15% le nombre d'arbres vivants dont 1 m ou plus de la cime a été détruit. En outre, de jeunes sapins ont aussi été endommagés sur environ 46 600 ha, et leur taux de mortalité y a été de 50 à 100% sur 23 300 ha.

La perte de semences de sapin baumier et d'épinette noire sape l'implantation naturelle et artificielle des futurs peuplements. Quand des sapins en bonne voie de regénération ou trop jeunes pour porter des graines sont détruits par la tordeuse, des feuillus peuvent envahir le territoire dévasté. Dans les peuplements endommagés d'épinette noire, les éricacées et les kalmias ont tendance à s'implanter.

L'infestation de tordeuses a peu d'effet sur l'habitat du poisson et de la faune, et peut même présenter certains avantages pour les ongulés. Bien que ses conséquences pour la forêt d'agrément ne soient pas mesurées, on les considère comme importantes. Les forêts perdent beaucoup de leur valeur esthétique, en particular dans les parcs et les banlieues. Les dommages qu'ont subis les jeunes sapins les ont rendus inutilisables comme sapins de Noël.

Les vues sont partagées quand il s'agit de savoir si les peuplements détruits par la tordeuse constituent un risque sérieux d'incendie. Les risques pourraient être plus élevés dans le centre que dans l'ouest de Terre-Neuve. En outre, les incendies du printemps peuvent être plus dévastateurs qu'à la normale et ceux d'été moins en raison de la prolifération de la végétation pastorale de sous-étage à cette période.

Sauver des peuplements endommagés pour en tirer du bois de pâte augmentera les coûts d'exploitation, de fabrication et, en définitive, le prix de la pâte et du papier. On peut exploiter les peuplements morts pour en extraire du bois de pâte pendant quatre à cinq ans, mais les pertes que représentent les arbres cassés ou déracinés par le vent peuvent rendre la récolte du bois trop chère et très dangereuse.

L'exploitation accélérée des peuplements endommagés et le stockage du bois pour ne pas avoir à subir les inconvénients du déracinement par le vent entraîne plus de dépenses en raison des coûts et des intérêts supplémentaires d'investissement et de main-d'oeuvre. De plus, la cellulose du bois se décompose plus vite dans le bois stocké que dans les arbres sur pied. L'exploitation accélérée et l'entreposage du bois ne constituent donc pas une solution économique.

La superficie totale où il y avait défoliation modérée et grave dans les forêts productives de l'île était d'environ 926 000 ha. Environ 428 000 ha de peuplements commercialisables comportaient des arbres morts. On a estimé a 17 000 $m^3$ le volume de bois mort dans cette région, soit une augmentation de près de 7 000 000 $m^3$ depuis 1979. On a evalué à pres de 5 000 000 $m^3$ le volume d'arbres mourants, et à environ 40 000 000 $m^3$, en 1980, le volume de bois mort et vivant de ces peuplements endommagés, soit environ 23% du volume total de bois mou de l'île. Au total, 65% des arbres morts le sont devenus au cours des deux dernières années. En 1980, la superficie totale des peuplements de bois non encore marchand comportant du bois mort était d'environ 63 000 ha. On prévoit pour 1981 que la superficie totale où il y aura défoliation moderée et grave diminuera jusqu'a 800 000 ha et que la surface forestière comportant du bois mort augmentera jusqu'a environ 780 000 ha.

## VI. Répercussions Économiques de la Présente Infestation de la Tordeuse à Terre-Neuve

La forêt et les industries qui dépendent de cette ressource comptent pour beaucoup dans l'économie terre-neuvienne. Les entreprises d'exploitation et de transformation du bois constituent la principale source d'emplois et de revenus, en particulier dans le centre et l'ouest. La forêt fournit du bois de sciage et de chauffage à des milliers de ruraux. Elle offre aussi des avantages non négligeables pour les loisirs. Un bon approvisionnement en bois à un prix concurrentiel est capital pour l'industrie forestière. Une réduction de l'approvisionnement pourrait avoir de graves conséquences socio-économiques dans cette province.

L'infestation de tordeuses a déjà effectivement atteint la forêt en tant que ressource, et l'approvisionnement en bois s'en trouve menacé. D'ici à 1984, une part importante des sapins baumiers de l'île pourra être détruite en l'absence de mesures de protection. Le volume total de bois des peuplements morts, condamnés et fortement endommagés pourrait, à cette échéance, se situer entre 68 000 et 98 000 $m^3$, ce qui représente 39 à 55% du volume total de résineux de l'île. Si ces pertes surviennent, leurs répercussions sur l'industrie forestière de la province seront considérables, la pénurie de bois entraînant des ralentissements et peut-être la fermeture d'usines.

Les coûts des mesures de protection en 1980 par l'arrosage chimique (18 000 000 $) sont modestes comparativement au coût possible des pertes en l'absence d'intervention. Les principales estimations financières, en l'absence d'arrosage, comprennent la valeur du bois d'oeuvre perdu (29 000 000 $) et le coût éventuel des mesures de restauration de la forêt (105 000 000 $). Il faudrait peut-être aussi ajouter les pertes que subirait l'économie de la province. Selon un exemple, une réduction de 20% de l'activité industrielle entre 1990 et l'an 2000 entraînerait, selon les estimations, une perte de 318 000 000 $ de la valeur ajoutée.

La pénurie de bois ne touchera pas seulement les grandes usines de papier journal, mais aussi bien les petites scieries que les fournisseurs de bois de chauffage. Elle coincidera avec l'augmentation de la demande industrielle et domestique de bois de chauffage.

## VII. Facteurs Naturels Influant sur les Effectifs de la Tordeuse

Prédateurs, parasites, maladies et température sont autant de facteurs qui influent sur les effectifs de l'insecte. Ils peuvent être plus importants au stade endémique, mais ne peuvent empêcher les épidémies si les conditions sont favorables à la croissance et à la survie de la tordeuse. De nombreux facteurs concourent à la fin d'une épidémie. Citons, par exemple, l'augmentation du nombre de parasites, de prédateurs et d'agents pathogènes ainsi que de la lutte pour la nourriture. C'est ce dernier facteur qui est le plus important et qui entre en jeu lorsque la forêt est détruite, mourante ou très durement éprouvée. Des différences de degré de défoliation au tout début de l'infestation portent à croire qu'il existe des différences de susceptibilité fondées sur la qualité de la nourriture. De pareilles différences disparaissent cependant dans une large mesure avec l'accroissement du nombre d'insectes, et la modification de la qualité du feuillage ne sera guère capable d'empêcher ou de réduire l'épidémie.

## VIII. Insecticides Homologués d'usage Commercial et Mesures Possibles de Lutte

Six insecticides chimiques et un biologique ont été homologués pour lutter contre la tordeuse dans de vastes régions forestières. Ces dernières années, on a arrosé avec succès des millions d'hectares avec du fénitrothion et de l'aminocarbe. L'acéphate a été largement employé en Ontario et a donné de bons résultats; sa toxicité relativement faible pour le poisson en fait un bon choix pour les épandages près des cours d'eau. Le carbaryl, qui vient d'être homologué, n'a pas été employé au Canada parce que les quantités à appliquer sont supérieures à ce qu'il faut d'aminocarbe et de fénitrothion. L'emploi de phosphamidon et de trichlorfon est très limité.

Le *Bacillus thuringiensis* (*B.t.*), seule technique biologique homologuée, s'est révélé efficace lorsqu'on en connaît les limitations. Son efficacité est maximale lorsqu'on en épand 4.6 ℓ/ha à la dose homologuée de 20 x $10^9$ UI/ha à partir d'un petit avion. L'épandage de *B.t.* revient de trois à cinq fois plus cher que l'utilisation d'insecticides chimiques. Une nouvelle formulation à l'huile pourrait se révéler efficace et économique.

Des recherches intensives sont en cours pour mettre au point de nouvelles méthodes et techniques visant à réduire l'emploi d'insecticides chimiques. Les régulateurs de la croissance de l'insecte, quand ils sont ingérés, l'empêchent de parvenir à l'état adulte en bloquant la métamorphose des larves, ce qui pourrait permettre de lutter contre lui. Certains de ces régulateurs sont actuellement mis à l'essai sur le terrain et pourraient être homologués dans quelques années. Ils coûteront sans doute moins chers à produire que les agents pathogènes et seront moins dangereux pour l'environnement que les insecticides chimiques. Les phéromones sexuelles sont des substances émises par les papillons femelles pour attirer les mâles en vue de l'accouplement. Des substances attractives de synthèse étant diffusées dans l'atmosphère, les mâles d'adaptent à ces odeurs et ne réagissent plus à celles des femelles. Théoriquement, le nombre de masses d'oeufs fertiles pondus et la dispersion des papillons seront aussi réduits du même coup. Ces phéromones semblent prometteuses mais plusieurs difficultés d'ordre technique devront être résolues, ce qui nécessitera des années de recherche. La répression des pullulations par les microsporidies, les champignons, les virus, les parasites ou à les prédateurs, qui sont tous des agents naturels, ne soulèvent pas encore d'espoirs. Les plus prometteurs sont sans doute les champignons et les virus, mais, dans chaque cas, il faut poursuivre les recherches étant donné que d'importants obstacles restent encore à surmonter. La lutte contre l'insecte par la libération massive d'insectes stériles ou génétiquement modifiés, pour réduire les taux de reproduction et de survie, nécessitera au moins cinq à dix ans de mise au point et d'essais. Les possibilités d'intervention génétique sont actuellement combinées au programme de lutte intégrée contre les effectifs endémiques. La stratégie fondée sur l'emploi d'agents pathogènes combineé à des doses sublétales d'insecticide chimique a de fortes chances de réduire le nombre de tordeuses, mais il faudra mener des tests en laboratoire et sur le terrain pour mieux évaluer les chances de succès. Les inhibiteurs de l'appétit, qui sont des produits chimiques, pourraient être produits en quantité minime par la plante hôte. Ces produits naturels et d'autres de synthèse sont actuellement mis à l'essai pour vérifier leurs effets sur la tordeuse.

Les arbres ont dans leur bagage génétique differentes propriétés chimiques, physiologiques et morphologiques complexes qui leur permettent de résister et de survivre aux attaques des insectes. Une stratégie de lutte antiparasitaire souhaitable à long terme consiste à faire des croisements pour obtenir des arbres qui résistent aux insectes. Cependant, il faut beaucoup de temps pour réussir des croisements et encore d'avantage pour en intégrer le produit aux forêts naturelles.

La lutte contre la tordeuse par l'aménagement des forêts constitue une stratégie à très long terme qui pourrait réduire les effets des infestations mais non les éliminer. Cet aménagement pourrait consister à remplacer certaines essences par d'autres, à charger la distribution des classes d'âge et la répartition spatiale des peuplements. Pour se réaliser, ces changements pourraient prendre de 50 à 100 ans, et devraient être faits sur de vastes régions pour être efficaces. De plus, chaque stratégie d'aménagement comporte de sérieux inconvénients. Il n'empêche que ces techniques d'aménagement seront utilisées dans la lutte intégrée pour protéger le sapin baumier contre la tordeuse.

La lutte intégrée contre les ravageurs consiste à recourir avec intelligence et en harmonie avec l'environnement, à toutes les méthodes pratiques de lutte pour réduire au minimum les dommages d'ordre économique. Les techniques de lutte actuelles vont dans le sens de cette idée de lutte intégrée. Les seules façons efficaces d'enrayer les épidémies sont fondées sur l'emploi d'insecticides chimiques et de techniques biologiques qu'on utilise avec mesure seulement quand et où c'est nécessaire. La recherche vise à trouver d'autres méthodes pour réduire l'emploi des produits chimiques qui, lorsqu'elles auront été éprouvées, seront intégrées au programme de lutte.

## IX. Effets sur l'Environnement des Méthodes de Lutte Contre les Ravageurs Forestiers

Rien n'indique que l'emploi d'insecticides cause des dommages permanents aux poissons, aux organismes dont ils se nourrissent, aux oiseaux ou aux mammifères. L'effet des épandages sur les arthropodes terrestres, parasites et prédateurs de la tordeuse compris, et les insectes favorisant la pollinisation, sont minimes ou temporaires. L'arrivée d'organismes des régions environnantes et la reproduction comblent rapidement les vides.

La possibilité que la tordeuse développe une résistance aux insecticides n'est pas pour demain. Après sept ans d'épandage de fénitrothion, aucun indice de cette résistance n'a été decelé.

Plus de 80% de la substance pulvérisée se dépose habituellement rapidement sur le sol sous l'effet de la pesanteur. Le reste forme d'infimes gouttelettes en nuage qui peuvent dériver à plus de 300 m du tracé à pulvériser. Des légers courants ascendants font plus dériver l'insecticide en suspension que les vents légers. Les produits chimiques sous la forme d'aérosol ou de vapeur semblent se décomposer rapidement dans l'air sans devenir toxiques. Leur dérive ne semble pas avoir eu d'effets secondaires décelables sur le plan écologique.

La pulvérisation aérienne des insecticides chimiques habituels, n'a eu aucun effet défavorable après des expositions répétées à court terme. Les aérosols chimiques n'ont aucun effet mutagène sur l'homme et aucun effet cancérogène ou autre, de nature chronique, n'a été décelé à la suite d'une exposition à long terme. Aucun lien n'a en outre été établi entre le syndrome de Reye et les campagnes d'épandage. La prétendue facilitation envers les virus qu'auraient les formulations d'insecticides chimiques reste encore à démontrer.

Les préparations actuelles de *B.t.* sont jugées sans danger pour l'environnement, comme le sont d'autres méthodes possibles de lutte naturelle fondées sur des virus, des champignons, des phéromones sexuelles et des régulateurs de la croissance des insectes. Ces derniers doivent cependant obéir à des normes de sécurité très strictes avant qu'il soit permis de les employer.

Sans intervention durant les pullulations, on aboutit normalement à la mort des peuplements mûrs. La destruction d'arbres sera sans doute peu nuisible à la faune aquatique ou terrestre. La plus grande répercussion sera d'ordre socio-économique: augmentation du nombre de sans-emplois par la destruction des forêts. Il s'agit de la principale menace à laquelle devront faire face les Terre-Neuviens vivant de la forêt.

## X. Examen des Mesures de Lutte Contre les Ravageurs Forestiers et Position du SCF à cet Égard

Les forêts canadiennes sont susceptibles d'être fortement ravagées par les insectes du fait de l'uniformité du couvert forestier sur de vastes parties du territoire. La tordeuse et la forêt d'épinette et de sapin participent à un cycle complexe, dans lequel les infestations rajeunissent périodiquement les peuplements mûrs de sapin. Les facteurs naturels autres que la limitation de l'approvisionnement en nourriture ne jouent qu'un rôle secondaire dans la régulation des pullulations de tordeuses.

Seule la pulvérisation aérienne d'insecticides chimiques ou de *B.t.* a réussi à limiter la destruction d'arbres. Les produits chimiques ont fourni une protection de façon plus consistante et les campagnes actuelles d'épandage ne sont pas néfastes pour l'environnement. L'objectif des programmes de lutte consiste à maintenir les forêts en vie plutôt que de limiter le nombre de tordeuses. Rien n'indique jusqu'à présent que les pulvérisations ont nui à la santé. Pour ce qui est des autres façons de protéger la forêt contre la tordeuse, on en est qu'au stade des recherches, dont les résultats ne sont pas encore applicables.

Les forêts feront l'objet d'un aménagement plus intensif dans l'avenir et devront même être protégées davantage contre les ravageurs pour que l'on puisse tirer avantage des techniques sylvicoles. En conséquence, la pulvérisation de produits chimiques augmentera probablement tant que l'on ne disposera pas d'autres méthodes de protection. Entretemps, l'emploi mesuré de ces pesticides pour l'exploitation actuelle des forêts permet d'envisager diverses possibilités d'aménagement.

Le Service Canadien des Forêts a comme principe de fournir aux organismes provinciaux et à l'industrie forestière l'aide dont ils ont besoin en menant des recherches sur toutes les questions relatives à la tordeuse et à d'autres ravageurs forestiers, depuis la mise à l'essai de nouveaux insecticides jusqu'au contrôle des effets sur l'environnement des campagnes d'épandage et à la mise au point de nouvelles méthodes efficaces de lutte conre les insectes. Le Service donne aussi des conseils et des services qui consistent notamment à prévoir les effectifs de la tordeuse, à faire le relevé des dommages et à élaborer des techniques d'aménagement sylvicole. Le Service Canadien des Forêts a tenu un rôle de premier plan dans l'élaboration de méthodes et de principes respectueux de l'environnement pour lutter contre les ravageurs, a communiqué l'information dont il disposait aux organismes extérieurs et fourni aux aménageurs et aux exploitants forestiers les services dont ils avaient besoin.

## XI. Aménagement des Forêts à Terre-Neuve

Au cours des 80 dernières années, l'aménagement des forêts de Terre-Neuve est passé graduellement de l'affectation de ressources pour favoriser l'essor industriel à la mise en place, dans les années 70, de techniques d'aménagement intensif après que différentes commissions d'enquête eurent déposé leurs rapports.

Pour la foresterie, la diminution des superficies productives et les dommages causés par la coupe diminuent substantiellement la capacité de croissance. Les pratiques visant à restaurer les endroits exploités, comme le reboisement des depôts forestiers sillonnés par les bouteurs, et celles qui améliorent l'exploitation des forêts, comme le débusquage par câble, devraient être encouragées.

À Terre-Neuve, la coupe à blanc est la méthode traditionnelle d'exploitation et la plus économique aussi. Cette pratique continuera sans doute, même si elle a fait augmenter progressivement, au cours des ans, la proportion des sapinières susceptibles d'être infestées par la tordeuse. Les autres techniques d'exploitation coûtent plus cher et ne protègeraient pas davantage la forêt contre l'insecte.

L'amélioration des peuplements, notamment par les coupes d'éclaircie et l'ensemencement des forêts, augmente la productivité sylvicole et améliore le rendement, mais les peuplements aménagés sont plus susceptibles d'être ravagés que les autres. Les essais actuels d'aménagement du sapin et du bouleau pour protéger les sapinières des insectes ne sont guère prometteurs et l'on ne peut envisager que des mesures de protection à court terme.

L'emploi d'herbicides élimine la végétation qui nuit aux jeunes résineux pour favoriser leur croissance, mais les arbres ainsi dégagés sont probablement plus susceptibles d'être infestés. Le brûlage dirigé sert à aménager une station où l'on veut éliminer la régénération des sapins pour implanter des essences moins susceptibles aux ravageurs. Dans la plupart des endroits, la scarification est essentielle avant de procéder à la plantation ou à l'ensemencement. Comme technique de reboisement à Terre-Neuve, l'ensemencement direct est efficace et rentable. Il faudrait l'encourager davantage.

Traditionnellement, le reboisement se fait par plantage de semis à racines nues ou en récipients. En dépit de l'augmentation récente du reboisement, il faut se demander si, à Terre-Neuve, le rythme actuel de reboisement est suffisant. Il faudrait favoriser les contrôles de reboisement et la fixation de normes pour le matériel de régénération.

Bien que, théoriquement il soit possible d'apporter des améliorations génétiques pour rendre les arbres plus résistants à certains ravageurs, il n'est pas réaliste de l'envisager étant donné le temps qu'il faut pour arriver à des résultats pratiques.

## XII. La Politique Forestière et son Application

Dans sa politique forestière, le gouvernement fédéral reconnaît l'importante contribution, sur le plan national, de la foresterie à l'économie et au potentiel de croissance de l'industrie forestière. Le manque de matériel sur pied pour l'approvisionnement en bois pose cependant des problèmes réels et la position concurrentielle de l'industrie canadienne doit être améliorée si on veut qu'elle le demeure à longue échéance. Après avoir été négligée, la foresterie semble maintenant trouver un regain d'intérêt auprès de la bureaucratie fédérale. À Terre-Neuve, le gouvernement fédéral participe à la recherche forestière et fournit des services consultatifs par l'entremise du Service Canadien des Forêts, ainsi qu'une aide financière spéciale pour des programmes provinciaux de foresterie, par le biais du Ministère de l'Expansion Economique Régionale.

Depuis le début des années 70, la province a accompli des progrès considérables en vue d'asseoir sa politique forestière et l'on a véritablement intensifié l'aménagement forestier. Certaines forêts améliorées ont été détruites et d'autres sont menacées du fait de l'insuffisance des programmes et des mesures de protection. Pour progresser davantage, il faudra d'abord établir et mettre en application une politique de protection.

Dans la province, il existe actuellement, grâce aux comités créés à cette fin, une collaboration entre les organismes fédéraux et provinciaux de foresterie. Les relations entre ces parties semblaient s'être relâchées ces dernières années, mais avec ces comités, elles devraient se resserrer.

Les éléments essentiels d'un plan d'aménagement intensif passent par l'inventaire, la protection, la réglementation et l'administration des forêts. Pour les forêts de Terre-Neuve, on propose des mesures d'exploitation à court terme et des pratiques d'amélioration à long terme qui garantiront une récupération maximale de fibre. Il reste à résoudre d'importantes questions de financement et de tenure.

Dans l'aménagement à long terme des forêts, la recherche et le développement jouent un rôle vital. Les capacités actuelles de Terre-Neuve devraient être augmentées si la recherche doit continuer d'aller au-devant des besoins des aménageurs forestiers.

À Terre-Neuve, les organismes forestiers et les aménageurs n'ont pas réussi à maintenir, dans les deux sens, de saines relations entre le public et les politiciens. Il s'en est suivi un manque de crédibilité et d'appui aux programmes de protection, qui sont essentiels. Des efforts considérables devront être déployés pour renforcer ces relations et favoriser, de part et d'autre, une meilleure compréhension entre les aménageurs et le public.

# REVIEW OF THE SPRUCE BUDWORM OUTBREAK IN NEWFOUNDLAND - ITS CONTROL AND FOREST MANAGEMENT IMPLICATIONS

## 1. INTRODUCTION

J. Hudak

The eastern spruce budworm, *Choristoneura fumiferana* (Clem.), is one of the most widely distributed and the most destructive forest insect in North America. It is a native species and a principal 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. (Greenbank 1963b). The budworm also attacks eastern larch, *Larix laricina* (Du Roi) K. Koch, and eastern hemlock, *Tsuga canadensis* (L.) Carr. Periodic outbreaks of the budworm in eastern Canada are known to have occurred since the early 1700's (Blais 1965). Widespread outbreaks usually have resulted in tree mortality over extensive areas. Timber losses in some of the recent outbreaks have been estimated in millions of $m^3$ and usually exceeded 50% of the volume of the infested fir-spruce forests (Blais 1973).

In Newfoundland only three small infestations have been recorded before 1970. They lasted only a few years and caused no appreciable tree mortality (Otvos and Moody 1978). The present outbreak started in 1971 in western Newfoundland, spread rapidly to almost all of the productive forests and by 1979 the total volume of stands with tree mortality exceeded 38 000 000 $m^3$ (Moody 1980). The size of the infested area and the intensity of damage are unprecedented in Newfoundland history.

The Provincial Government conducted a trial spray program in 1977, an operational control program in 1978, and used *Bacillus thuringiensis* to treat forest improvement areas in 1979 and 1980. Public concern over the safety of aerial control programs has increased and the Government appointed a Royal Commission in 1980 to investigate all aspects of forest protection and management in Newfoundland and Labrador.

The Royal Commission requested the Canadian Forestry Service through the Newfoundland Forest Research Centre to provide information on the spruce budworm fir-spruce forest complex. A report was prepared in response to that request which briefly described: the forest resource of Newfoundland and Labrador prior to the budworm outbreak; the influencing climatic and edaphic conditions; the biology of the budworm; the history and characteristics of the outbreaks; the natural control factors affecting populations; the damage caused by the present outbreak; the economic impact of this damage; the presently available and potential control measures and their effect on the environment; the past and present forest management practices in Newfoundland; and finally, the development of federal and provincial forest policy and the possible components of an intensive forest management plan for Newfoundland.

The Brief prepared by members of the Canadian Forestry Service and presented to the Newfoundland Royal Commission on Forest Protection and Management was a state of the art report on all major aspects of the spruce budworm outbreak in Newfoundland - its control and forest management implications. Although the climate, soils, forests and human activities within the environment may not be entirely applicable in all spruce budworm problem areas, we feel that the report serves as an example of an attempt to discuss a major forest insect pest in a comprehensive way. We hope that the publication of this report will be of benefit to others with an interest in insects, forests and man's interaction with them.

# II. THE FORESTS OF NEWFOUNDLAND, THEIR MAJOR PESTS AND FIRE HISTORY

R.S. van Nostrand, B.H. Moody and D.B. Bradshaw

## 1. THE FORESTS

### a) THE FORESTS OF THE ISLAND

All of the Island lies within the Boreal Forest Region (Rowe 1972). Approximately 34% or 3 786 000 ha of the total area is classed as productive forest land (land capable of producing a stand of more than 35 $m^3$/ha). This productive forest area is concentrated in the central and western parts with lesser amounts on the Avalon, Bonavista, and Great Northern peninsulas (Fig. II-I). The forests are dominated by balsam fir and black spruce which comprise 83% of the commercial volume. Black spruce (34%) is the most common species in the eastern and east-central areas. Balsam fir (49%) predominates in western, west-central, and northern areas. White birches, *Betula papyrifera* Marsh, and *B. cordifolia* (Reg.) Fern (12%) are the major hardwood species. Birch occurs mainly in central and western parts mixed with spruce and fir or at times in pure stands. Other species occurring scattered in many stands are white spruce, eastern larch, white pine, *Pinus strobus* L., yellow birch, *Betula alleghenienis* Britton, and trembling aspen, *Populus tremuloides* Michx (Anon. 1974a).

Stands classed as softwoods (75% to 100% softwood) occupy 74% of the productive forest area, and make up 76% of the merchantable volume (Anon. 1974a).

Softwood stands dominated by black spruce are the climax vegetation on many wet or very dry sites. Spruce stands also occur commonly on more productive sites as a result of past fires. These stands attain heights of 9 to 15 m and produce a volume of 70 to 175 $m^3$/ha at maturity (Anon. 1972).

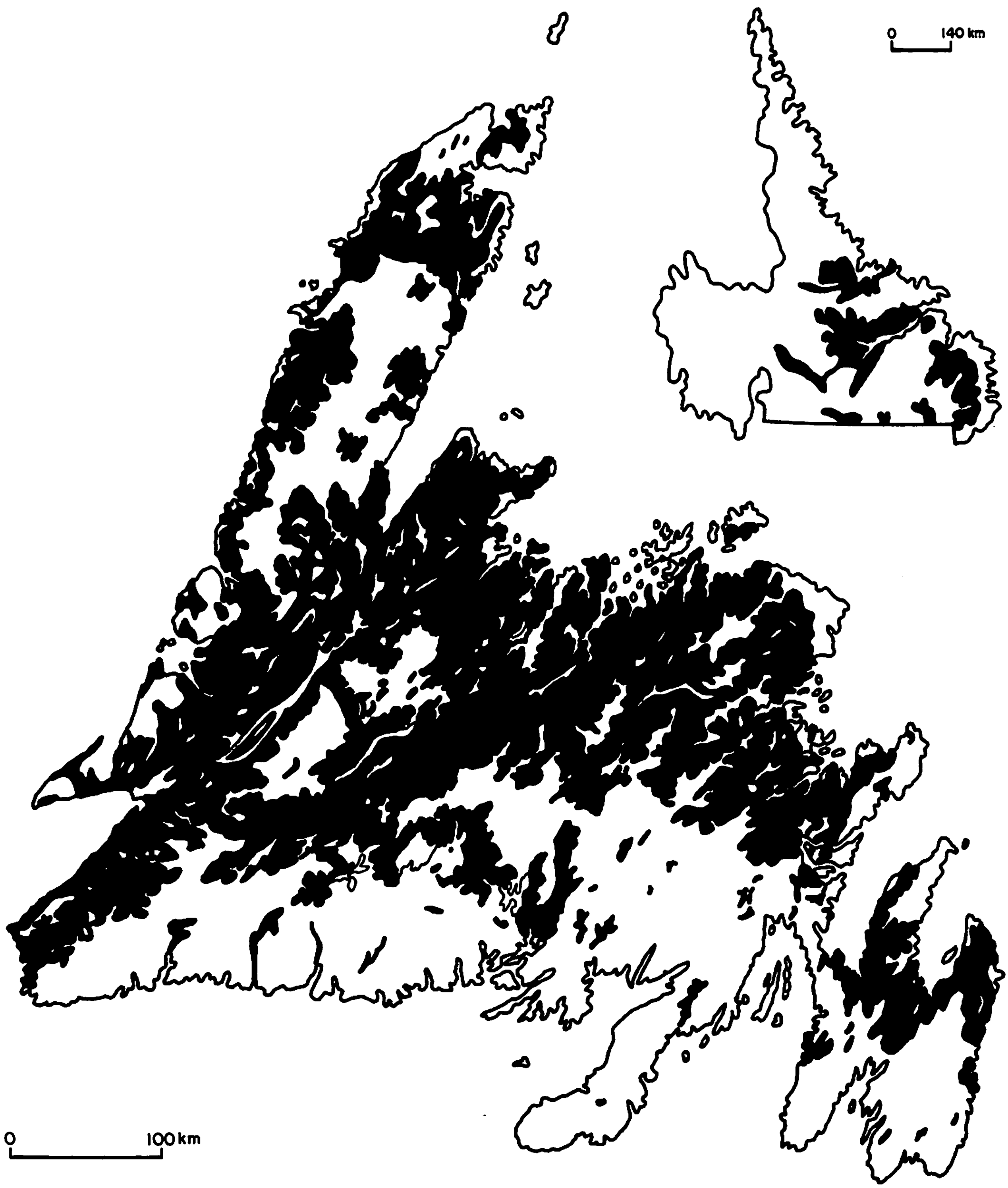


Figure II-1. Productive forest area of Newfoundland and Labrador.

Softwood stands dominated by balsam fir are the climax vegetation on moderate to good sites. Heights of average mature stands range from 9 to 15 m, and volume from 70 to 175 $m^3$/ha. However, some stands may attain heights of 21 m and volume of 350 $m^3$/ha (Anon. 1972).

Mixed softwood-hardwood stands occur on moderate to good sites. The major components are usually fir and birch with scattered black spruce, white spruce and aspen. Productivity is similar to pure softwood stands (Anon. 1972).

Hardwood stands (75% to 100% hardwood) occur on moderate to good sites and consist mainly of white birches. Yellow birch and trembling aspen stands are much smaller components. The productivity of birch stands is similar to that of mixed-wood stands. Aspen is more productive than any other native species on similar sites (Anon. 1972).

The most recent published data of commercial wood volumes for the Island (Anon. 1974a) are now obsolete. Annual cutting and severe losses caused by insect infestations have changed these statistics for most areas. The Department of Forest Resources and Lands has up-dated the forest inventory statistics (Anon. 1980b).

## b) THE FORESTS OF LABRADOR

About 2 756 000 ha or 10% of the total land area of Labrador contain most of the productive forests (Fig. II-1). These forests are concentrated in the valleys of the western tributaries of Lake Melville, and the major rivers of southeastern Labrador. About 45% of this area supports merchantable stands with volumes ranging from 40 to 250 $m^3$/ha. Approximately 95% of the productive forests are comprised of softwoods of which 70% is black spruce and 25% is balsam fir. White spruce, eastern larch and white birch form the remaining 5% (Anon. 1972).

## c) CLIMATE

The maritime climate of the Island is characterized by relatively cool summers with July mean temperature of $10^{\circ}$ to $16^{\circ}C$, and moderately cold winters with January mean temperatures of $-9^{\circ}$ to $-4^{\circ}C$. Precipitation, which generally is well distributed throughout the year, ranges from 1270 to 1525 mm/year in the southern half of the Island, and 760 to 1140 mm/year in central and northern parts. Marked temperature extremes are more common in central areas than on coastal regions. Average wind speeds are high, 20 to 25 km/hr., in all areas with the higher occurring along western, southern and eastern shorelines (Hare 1952).

The bulk of Labrador has a continental climate. Mean temperatures in the forested areas range from 10° to 16°C in July, and from -20° to -9°C in January. Precipitation ranges from 500 to 1015 mm/year. Wind speeds are generally lower than on the Island (Anon. 1972).

## d) GEOLOGY AND SOILS

The bedrock of Newfoundland and Labrador is varied but generally of low base status. Thus, only in western and northern portions of the island of Newfoundland, where fertile limestones occur, does the bedrock have a direct influence on forest productivity.

Topography, because of its strong influence on drainage, is by far the most important factor controlling soil drainage and site fertility. Typically, slope summits have shallow well-drained till with orthic podzols, midslope positions are influenced by seepage characterized by gleyed podzols, and lower slopes and basins are characterized by surplus moisture and the development of gleysols and organic soils such as fibrisols, mesisols and humisols.

The poorest forest sites occur on coarse textured till, such as outwash sands and gravels. On these deposits, extremely rapid drainage results in rapid leaching of essential nutrients. The soil structure is frequently degraded by iron pan formations.

The richest sites are restricted to bottoms of long seepage slopes, or to river floodplains, where a constant supply of nutrients exists and the proper balance of soil texture and organic matter ensures their retention. These are the only sites where brunisolic soils cover appreciable areas.

# 2. MAJOR FOREST PESTS

The major insect problems of the Province are associated with balsam fir, but all other native and exotic tree species are periodically damaged. Two native insects, the spruce budworm and the hemlock looper, *Lambdina fiscellaria fiscellaria* (Guen.) and the accidentally introduced balsam woolly aphid, *Adelges piceae* (Ratz.), are the most important pests attacking balsam fir. Other insects of lesser importance but which may contribute to the mortality of native fir and spruce include the spruce coneworm, *Dioryctria reniculelloides* (Mut. & Mon.), the blackheaded budworm, *Acleris variana* (Fern.), and the balsam fir sawfly, *Neodiprion abietis* complex.

The principal disease problems of the forests of Newfoundland are Armillaria root rot caused by the fungus *Armillaria mellea* (Vahl. ex Fr.) Kummer, heart rot of living trees and sap rot of dead or dying trees. A number of common foliage diseases of both softwood and hardwood species are of lesser economic importance. The recently, accidentally introduced European race of Scleroderris canker, caused by *Gremmeniella abietina* (Lagerb.) Morelet, has the potential of causing widespread, severe damage in conifers.

The following are brief accounts of the impact of a few of the major forest pests of Newfoundland and Labrador.

The spruce budworm - No serious outbreak of the spruce budworm had been recorded in Newfoundland until 1972 when an infestation developed in about 650 000 ha of fir-spruce forests. This outbreak is now causing extensive tree mortality and growth reduction in mature and immature stands in Newfoundland. By 1979, tree mortality was occurring in 517 800 ha of softwood stands containing a total volume of 38 412 000 $m^3$ of wood. A more detailed account of damage by this pest is in Chapter V.

The hemlock looper - Before the present spruce budworm outbreak, the hemlock looper was considered to be Newfoundland's major forest pest. Six outbreaks have been reported in Newfoundland and they usually originated from mature or overmature balsam fir stands (Otvos *et al.* 1979). The most recent outbreak began in 1966 and continued until 1972. In 1968 and 1969 about 1 000 000 ha of infested forests were sprayed with chemical insecticides, and stands containing a total volume of about 24 100 000 $m^3$ of wood were saved. However, about 721 000 ha of fir forest were defoliated and stands containing about 12 000 000 $m^3$ of wood were killed. The amount of wood salvaged was less than 17% of the total volume of wood killed by the looper. Looper numbers started to increase again since 1977, mainly in western and central Newfoundland where budworm numbers had decreased.

The balsam woolly aphid - This insect was accidentally introduced to Newfoundland in the 1930's and has since spread to over 1 600 000 ha of balsam fir forest (Schooley and Bryant 1978). The aphid attacks balsam fir trees of all ages causing deformity, and branch and twig mortality. Trees usually die after four to six years of attack, but severe infestation on the stems may kill trees in two or three years. Damage is most severe in stands growing on fresh and dry sites at less than 200 m above sea level (Schooley and Bryant 1978). Perhaps the greatest problem caused by aphid attack is a physiological weakening of the trees which are then easily killed by defoliating insects, such as the hemlock looper. Weather is the principal factor regulating population levels of the aphid. Temperatures below -36°C are fatal to overwintering life stages of the aphid, and early and late frosts will kill exposed feeding aphids (Greenbank 1970).

Armillaria root rot - In Newfoundland, this disease has been recorded on all commercial forest tree species of all age classes. The disease occurs in trees of all vigor classes, but is common on trees damaged by insects or other fungi and more prevalent in plantations than in natural stands. Exotic tree species are more susceptible to the disease than are native species and tree mortality has reached 34% in localized areas (Singh 1980). Infection is accompanied by a loss in vigor, reduction in growth and the ultimate death of trees. The disease kills the inner bark and cambium of trees and causes sapwood and heartwood decay of the roots and root collar. No direct control measures are available but losses can be minimized by cultural practices, such as maintaining vigorous stands, seeding in preference to planting, and the use of native instead of exotic species.

Heartrots in living trees - The rots are caused by a number of fungi which attack the heartwood of all commercial tree species. They do not kill trees but reduce the net merchantable volume. The average merchantable volume loss from cull for the Island was about 10% for all tree species (Hudak *et al.* 1971). Losses from heartrots may be minimized by harvesting stands before they become overmature.

Saprots of dead trees - Several decay fungi deteriorate the sapwood of trees killed by insects and other causes. Degradation of wood properties over a period of time make the trees unsuitable for commercial use. A more detailed account of this damage is in Chapter V.

# 3. FIRE HISTORY

Fire has played a dominant role in determining the extent and composition of forests in eastern and central Newfoundland and in Labrador. The extensive heathlands of the Avalon and Burin peninsulas bear mute testimony to three centuries of wanton burning by man. During the latter portion of this period, railroad fires of the coal-burning era proved to be beneficial by providing thrifty stands of black spruce along the railway right-of-way, especially across the drier interior of the Island.

Fire has had a much lesser part in determining the forest composition in western Newfoundland. The moisture-laden prevailing westerly winds provide a fairly evenly distributed annual precipitation of about 112 cm, which results in a relatively fire-proof balsam fir forest being the predominant landscape feature (Wilton and Evans 1974). Lightning has not been a major cause of forest fires on insular Newfoundland, but it is of prime importance in Labrador. Black spruce stands of fire origin are a major constituent of the forested zone in Labrador (Wilton 1965). In the non-forested zone, lightning-caused fires burn unimpeded during many fire seasons, and the landscape bears witness to this devastation.

Particularly destructive fires on insular Newfoundland in 1904 resulted in the formation of a fire suppression organization to which the present Department of Forest Resources and Lands traces its origin (Wilton and Evans 1974). Periodic severe losses to fires continued until 1961, when, in that year alone, over 400 000 ha burned (Anon. 1961). The acquisition of the Province's water bomber fleet was part of a determined effort to prevent a repeat of the 1961 fire season. In Labrador, organized fire suppression dates from 1959, when extensive fires occurred. During the past decade, fires have burned about 50 000 ha annually in the Province of which about 10% is merchantable timber and a further 4% is young growth. The remaining 86% is waste land, cutover, and recent burn (Anon. 1979c).

## SUMMARY

Newfoundland's boreal forests occupy 3 786 000 ha of productive land on the Island. Softwoods comprise 83% of the commercial volume, being dominated by balsam fir (49%) and black spruce (34%). Birch, the major hardwood (12%), occurs in mixed and occasionally in pure stands. Stands dominated by balsam fir tend to occupy the better sites. The better black spruce stands, which usually originate after a fire, occur in central Newfoundland. Balsam fir and black spruce stands may produce 175 $m^3$/ha over a rotation.

The Island's maritime climate is characterized by relatively cool summers, and moderately cold winters. Precipitation is evenly distributed throughout the year and may vary between 760 mm and 1525 mm/year. Bedrock geology varies greatly. Podzols of low to moderate fertility predominate on the well-drained sites. Gleyed soils are common.

The productive forests of Labrador cover about 2 756 000 ha, and most of them are concentrated in the large river valleys located in the central and southeastern portions. About 95% of the forests are softwoods, of which 70% is black spruce and 25% is balsam fir. Merchantable volumes of mature stands are comparable to those on the Island. The climate generally is continental, with short, warm summers and cold winters. Precipitation ranges from 500 mm to 1015 mm/year. Bedrock is mostly infertile granite and gneiss.

Several pests have caused major depletion of the forests of Newfoundland. The balsam woolly aphid, an accidentally introduced sucking insect, spread in the 1950's and early 1960's to most of the forests of the Island. It reduced the volume of growth by about 5% and caused additional damage through reducing wood quality. It also predisposed trees to early mortality if subsequently damaged by other pests. The two principal, native defoliating insects are the eastern hemlock looper and the eastern spruce budworm. Looper populations reached outbreak levels in the late 1960's and the volume of mature and overmature stands with tree mortality totalled 12 000 000 $m^3$ at the end of the outbreak. The present outbreak of the budworm started in 1971 and by 1979 the budworm has very severely damaged or killed 38 400 000 $m^3$; more than three times the damaged caused by the latest looper outbreak. Heart rots of living trees caused by a number of wood destroying fungi affect about 10% of the gross pulpwood inventory volume. They may cause higher losses in the sawlog inventory. Heart rots do not kill trees but reduce the net merchantable volume. Sap rots caused by decay fungi destroy the wood in dead trees killed by insects or other causes and in time make them unsuitable for commercial use. Armillaria root rot, a disease of

world-wide distribution, affects all tree species. In Newfoundland the most important losses occurred in plantations where tree mortality reached 35%. The disease also contributed to the mortality of trees damaged by other pests.

Periodically, fires swept large areas of the Province. Man-caused fires predominated on insular Newfoundland, and lightning-caused fires in Labrador. During the past two decades a much improved provincial detection and suppression program has substantially reduced fire losses.

# III. HISTORY OF SPRUCE BUDWORM OUTBREAKS IN EASTERN NORTH AMERICA WITH SPECIAL REFERENCE TO NEWFOUNDLAND

J.R. Blais, E.G. Kettela and B.H. Moody

The spruce budworm is a native insect and outbreaks of this insect are a natural phenomenon associated with the biota of the boreal forest. Budworm outbreaks probably occurred on this continent long before the arrival of the first Europeans. Recurring natural phenomena often have a *raison d'être*, and by killing extensive stands of mature and overmature spruce and fir, they prevent the perpetuation of decadent forests and bring about their rejuvenation. In recent times, the forest has become an important source of raw material for the needs of modern man, and any situation seriously affecting wood and fibre supplies can have far-reaching socio-economic consequences.

Reconstruction of the history of past outbreaks for various regions for periods of 200 to 300 years has been possible through ring-growth studies of old white spruce trees (Blais 1968). In the past 200 years, outbreaks recurred more frequently in Quebec and the Atlantic sector of mainland Canada than in Ontario. During this time, spruce-fir stands within some regions in the Atlantic sector had five outbreaks, while stands within regions in Ontario generally suffered only two or three attacks (Blais 1979).

During the twentieth century, outbreaks have recurred at intervals approaching 30 years in some regions, but intervals were generally greater during the eighteenth and nineteenth century. Also, the degree and duration of the radial-growth suppression in the host trees caused by the outbreaks would indicate that outbreaks in the twentieth century were more severe and of longer duration than earlier ones; furthermore, they appear to be more widespread. Brown (1970) compiled the extent of spruce budworm defoliation from 1909 to 1966 which is reproduced here and updated to 1979 (Fig. III-1). The trend to more severe outbreaks in recent years is evident, but the reason for this is not clear. The maximum areas of defoliation were 10 000 000 ha in the 1910's and 25 000 000 ha in the late 1940's. The largest extent of the most recent outbreak (Table III-1) was about 55 000 000 ha in Canada, about twice as large as the previous outbreak in the 1940's (Appendix III).

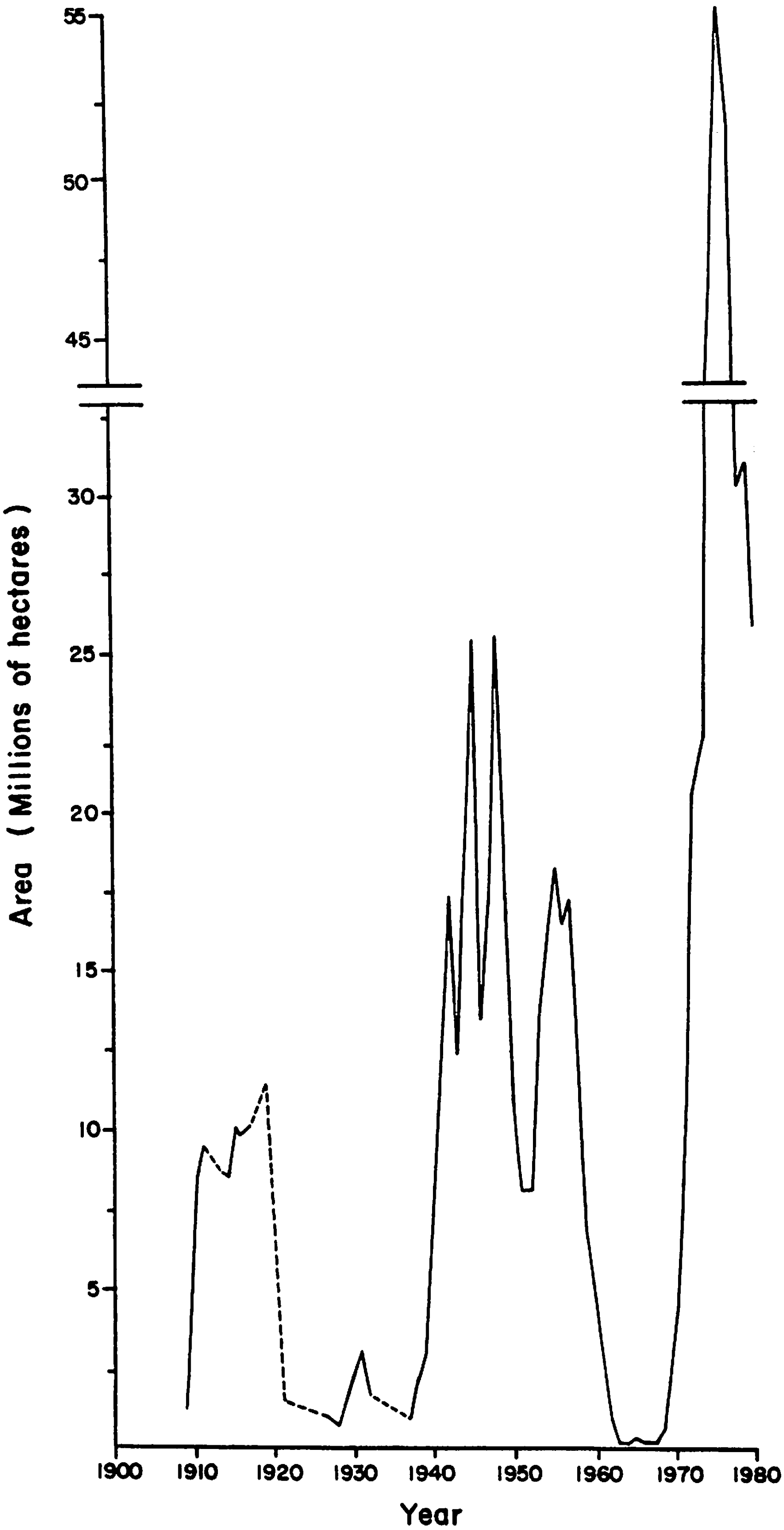


Figure III-1. Area of moderate and severe infestation by the eastern spruce budworm in eastern North America 1909 to 1979.

Table III-1. Area of moderate to severe spruce budworm defoliation in eastern Canada and United States from 1967 to 1979 in ha (x 1000).

| | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Newfoundland | - | + | - | - | + | 360 | 120 | 720 | 670 | 1 270 | 1 320 | 810 | 970 |
| Prince Edward Island | ++ | + | + | + | +++ | +++ | 70 | 20 | 240 | 170 | 70 | 110 | 30 |
| Nova Scotia | ++ | 20 | 10 | 80* | 180 | 140 | 90 | 190 | 890 | 850 | 820 | 510 | 810 |
| New Brunswick | 110 | 390 | 980 | 580 | 1 420 | 1 740 | 3 160 | 3 360 | 3 520 | 690 | 470 | 670 | 1 340 |
| Quebec | + | 150 | 230 | 1 360 | 3 440 | 10 400 | 11 410 | 32 210 | 35 250 | 33 150 | 21 650 | 13 560 | 4 740 |
| Ontario | 80 | 320 | 980 | 2 000 | 5 350 | 7 800 | 7 490 | 7 490 | 13 460 | 14 750 | 15 700 | 15 160 | 18 410 |
| Total Canada | 190 | 880 | 2 200 | 4 020 | 10 390 | 20 440 | 22 340 | 43 990 | 54 030 | 50 880 | 40 030 | 30 820 | 26 300 |
| Maine | 110 | 130 | 120 | 270 | 210 | 310 | 460 | 1 930 | 3 120 | 530 | 2 270 | 2 630 | 1 820 |
| Minnesota | 10 | 40 | 90 | 150 | 110 | 80 | 40 | 90 | 60 | 60 | 10* | 20 | 100 |
| Other States | | | | | | | +++ | 60 | +++ | 40 | 40 | 200 | |
| Total U.S. | 120 | 170 | 210 | 420 | 320 | 390 | 500 | 2 080 | 3 180 | 630 | 2 320 | 2 850 | 1 920 |
| Grand Total | 310 | 1 050 | 2 410 | 4 440 | 10 710 | 20 830 | 22 840 | 46 070 | 57 210 | 51 510 | 42 350 | 33 670 | 28 220 |

- No budworm inféstation
+ Trace
++ Area of defoliation < 1000 ha
+++ Area of defoliation > 1000 ha but unknown
* Estimated value.

Two conditions thought to be required for the development of endemic populations of the outbreaks are: 1) favourable weather consisting of three to four consecutive years of early summer drought (Wellington *et al.* 1950, Greenbank 1956, Pilon and Blais 1961), and 2) extensive stands of mature fir. Exploitation of softwood stands for pulpwood began at the turn of the century. Clearcutting of these stands favoured fir at the expense of spruce, thus increasing their vulnerability to budworm attack (Westveld 1931, Hatcher 1960, MacLean 1960). Also, the more effective methods of combating forest fires in recent years is resulting in a decrease of burnt-over areas (Wein and Moore 1979). This, in turn, is causing a decrease in non-budworm host stands that form the forest cover after burns; consequently, spruce-fir stands are becoming more continuous, and possibly more prone to budworm attack.

Reconstructing the history of past outbreaks through ring-growth studies from old trees has not been attempted for Newfoundland. This approach would present a problem since spruce-fir stands on the Island, unlike on the Mainland, are periodically infested by the hemlock looper (Warren 1966, Otvos *et al.* 1979); radial growth suppression caused by looper could not be differentiated from that caused by budworm. Because there are no records of spruce budworm outbreaks on the Island prior to the 1940's (Otvos and Moody 1978), it does not follow that none occurred. It is quite possible, however, that conditions on the Island are now more favourable to budworm outbreaks than in earlier years, as appears to be the case for other regions.

No outbreaks have occurred in the eighteenth century on the Gaspé Peninsula, a region that resembles Newfoundland in many respects including weather and forest cover. The first known infestation on the Gaspé began in 1912, lasted a few years and probably caused only scattered tree mortality (Blais 1961). A second much more severe outbreak began in 1950 and lasted till 1958; losses averted through a five-year aerial spraying program are estimated at 46 000 000 $m^3$ of pulpwood (Blais and Martineau 1960). Finally, some 20 years later a third outbreak, still in progress, began in the same region. Conditions definitely appear to have become more favourable to budworm in recent times in the Gaspé Peninsula; the same situation could very well apply to Newfoundland.

Continued aerial application of insecticides over vast regions may also prolong the duration of outbreaks or shorten the interval between them, because extensive stands of fir, that otherwise would succumb to budworm attack, are kept alive through treatment (Blais 1973, 1974).

No widespread or severe budworm outbreaks are known to have occurred in Newfoundland prior to the current one that began in 1971. Some sporadic and local infestations by this insect were observed between 1940 and 1970, but they resulted in little or no damage (Otvos and Moody 1978).

The current outbreak in Newfoundland began in 1971 in the western region. The infestation spread rapidly, and by 1977, nearly all productive forests on the Island were attacked; the total volume of wood destroyed had already reached an estimated 5 100 000 $m^3$ (Otvos and Moody 1978). Since then, tree mortality has progressed every year, and insect populations have decreased for lack of food in areas of high tree mortality, especially in the western region.

Cause of the outbreak is probably related to the presence of extensive stands of fir on the Island; many of these stands had reached maturity by the late 1960's. According to early records eastern white pine 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 forest less vulnerable to budworm outbreaks. The elimination of white pine stands with an increase in balsam fir may have increased the susceptibility of the forest to budworm attack (Otvos and Moody 1978). Also, the balsam fir content of the forests has increased through the harvesting practice of clearcutting and the control of fire.

Favourable weather characterized by warm-dry conditions in late spring and early summer preceded the present infestation. This weather in combination with lack of competition from the eastern hemlock looper may be mostly responsible for the extent of the present spruce budworm outbreak. The hemlock looper outbreaks may have reduced stand susceptibility to budworm attack by killing mature and overmature stands of balsam fir during the first five looper 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 (Otvos *et al.* 1971), and this may have maintained an abundant food supply for the budworm.

Dispersal of moths from the mainland may also have contributed to the increase of local populations. In 1972, spruce budworm moths were repeatedly encountered flying over the sea between New Brunswick and Prince Edward Island, and on aircraft flight paths extending 20 km over the Cabot Strait. Later, moths were observed by airborne radar at sea (Greenbank *et al.* 1980). These authors mention that:

> "8 July 1973, a Chipman radar showed high density migration of relatively long duration taking place in a high layer and travelling with a ground speed of about 18 m/s heading east-northeast. Synoptic charts showed westerly winds stretching to Newfoundland by dawn, following an eastward moving warm front, a distance of 450 km or 7-9 flying hours from the nearest budworm populations in New Brunswick or Gaspé. The following day, large number of live and dead moths were found on beaches in southwest Newfoundland (Smithsonian Institute 1973). On 19 July 1976, a DC-3 radar encountered moths flying over Cabot Strait, halfway between the exceptionally dense budworm populations of Cape Breton Island, 70 km upwind, and the southwest corner of Newfoundland, downwind..."

This influx of moths is supported by the report that in 1976 budworm males were caught in traps baited with synthetic sex pheromone in western Newfoundland prior to the emergence of local adults (Otvos and Moody 1978).

Although moths may be transported from the mainland to Newfoundland, budworm populations are capable of reaching outbreak levels in Newfoundland without any influx of moths from the outside. Local infestations of short duration that occurred on the Island in the 1940's, when no outbreaks existed on the mainland, attest to this.

It is quite possible that widespread spruce budworm outbreaks have occurred in Newfoundland in the past. Because weather conditions in this region are marginal for budworm, outbreaks may take place less frequently than on the mainland and generally may be of shorter duration. However, outbreaks of the same magnitude as the present one will likely recur. Authorities responsible for protection and management of the forest should be aware of this threat.

## SUMMARY

Spruce budworm outbreaks are a natural phenomenon associated with the biota of the boreal forest. Two main conditions are required for the development of outbreaks: favourable weather and extensive stands of mature balsam fir. Past outbreaks in eastern Canada occurred more frequently in the Atlantic region than in Ontario, and they appear to have become more frequent and more severe in recent times. This situation may be attributed in part to cutting practices, forest fire control, and chemical treatment of infested stands. Between 1940 and 1970, only sporadic and local infestations were observed in Newfoundland. The current outbreak began in 1971 and rapidly spread to nearly all productive forests on the Island. An infestation in Labrador began in 1975 and terminated in 1979 through natural factors. Causes of the outbreak are probably attributable to presence of extensive fir stands and to favourable weather. Influx of moths from the mainland may have contributed to increasing local populations on the Island although these can attain epidemic levels independently.

# IV. BIOLOGY, HABITS, POPULATION TRENDS OF THE SPRUCE BUDWORM, CHARACTERISTICS OF OUTBREAKS, AND ASSOCIATED PESTS

## 1. BIOLOGY AND HABITS

C.A. Miller

The life cycle of the budworm spans two calendar years. The eggs are laid in August of one year and larvae feed in the following year (Table IV-1). Budworm development is largely temperature dependent, so that the chronological dates in the table are only approximations (Crummey and Otvos 1980).

The major mortality factors affecting an outbreak budworm population are most readily explained by a life-table, i.e. a census of the number of individuals present in the population at various stages within a generation, an estimate of how many have died, and their probable cause of death (Morris 1963a). An average life-table for the budworm is as follows with the approximate number of individuals in each stage:

Eggs (200) - A typical female lays about 200 eggs but in severely defoliated stands larval starvation results in small females with a fecundity of only about 100 eggs. Parasitism, predation and infertility cause about 19% egg mortality.

Instar I (162) - Within one generation, the largest number of individuals die as a result of losses during the fall dispersal of first-instar larvae. Average mortality is 58%. The lowest mortality occurs in areas with a dense cover of host trees. This implies that stand manipulation (mixedwood stands, isolating susceptible stands into small blocks, creating boundaries of host stands/non-host stands) would tend to maximize the loss of first-instar larvae.

Instar II (68) - (In overwintering sites in fall.) Most second-instar larvae survive the winter. Average mortality is 15%.

Table IV-1. Spruce budworm life history in Newfoundland.

| Time[1] | Heat units[2] | Stage | Head capsule size[3] | Activity |
|---|---|---|---|---|
| Early August | | Egg | | |
| Mid-August | | Instar I | 0.25 | First-instar dispersal. |
| September | | Instar II | 0.32 | First-instar does not feed; spins overwintering shelter on host tree; moults to instar II; enters diapause. |
| Late May of following year | 50 | Instar II | | Emerges from overwintering site and disperses within and between trees; begins feeding on old needles, expanding current buds, staminate flowers. |
| Early June | 130 | Instar III | 0.45 | Continues feeding on flowers or migrates from old needles to expanding current shoots. Time for application of aerial control. |
| Late June | 230 | Instar IV<br>Instar V | 0.68<br>0.98 (M)<br>1.10 (F) | Continues feeding on expanding shoots. Time for application of aerial control. |
| Early July | 360 | Instar VI | 1.60 (M)<br>1.70 (F) | Instar VI causes most of the damage to current shoots. |
| Mid-July | 460 | Pupa | | Developing adult. |
| Late July | 600 | Adult | | Females mate soon after emergence; lay up to 50% of their eggs in 3-4 days. May migrate to new downwind sites with remaining eggs. |

[1]Based on data from Crummey and Otvos (1980).

[2]Cumulative degree days above $5.6^{\circ}C$, beginning 1 April.

[3]Mean width (mm) of larval head capsule (M) male, (F) female.

Instar II (58) - (In overwintering sites in spring.) Activity in the spring depends upon temperature. Larvae leave their overwintering sites and either migrate to branch tips of 'resident' trees to begin feeding or disperse between trees and stands to locate feeding sites. Losses during this spring dispersal period are highly variable but average 37%. The factors and processes that determine second-instar dispersal losses in the spring are:

(a) Stand density: Minimum losses occur in a dense cover of host trees.

(b) Type of feeding site: Second-instar larvae mine old needles, mine current buds, or feed on male and female flowers. They prefer flowers. If flowers are absent, most larvae will mine old needles. Flowering periodicity of the spruces is erratic and little is known of the role of spruce flowering on second-instar survival. Balsam fir has a more regular flowering pattern, and evidence suggests that the presence of flowers enhances budworm survival. However, few trees produce flowers during a severe budworm outbreak because of the destruction of the flower-producing current shoots.

(c) Availability of feeding sites: Maximum losses occur in severely defoliated stands because it contains no flowers, few old needles and few current buds.

(d) Weather: Second-instar mortality increases with decreasing temperature. Wind and rain also increase dispersal losses.

(e) Local topography: Population gains rather than losses occur in some stands where topographic features coupled with particular weather conditions favor the concentration of dispersing larvae.

Instar II (37) - (In feeding sites.) Mortality of second-instar larvae after they reach their feeding sites is unknown but is assumed to be low.

Instar III (36) - (In feeding sites.) Third-instar larvae migrate from mined needles to expanding current shoots. Mortality during this migration has been assessed at 20% at low densities on non-defoliated balsam fir. It could be higher on defoliated fir or on red and black spruce where the late-flushing current buds are more difficult to mine (Blais 1957). Third-instar larvae feeding on balsam fir flowers do not migrate but feed on flowers until the fourth-instar.

Instar III-VI (29) - Once a third-instar larva becomes established on a current shoot it will remain there, or in a group of terminal shoots webbed together, until pupation. The exception occurs at high population densities when maturing larvae destroy all the current shoots and migrate to feed on old needles or drop to feed on understory trees. Arthropod predators kill third- and fourth-instar larvae, parasites kill fourth-, fifth- and sixth-instar larvae, diseases infect small larvae and kill large larvae, birds feed on large larvae, and lack of food results in the migration of large larvae and ultimately in mortality. This complex of factors and processes causes an average of 86% larval mortality, but this may vary from 40% to 95%. In general, the highest rate of within generation mortality occurs during the large-larval stage. Large-larval mortality decreases with increasing population density indicating that the budworm escapes from its natural enemies to reach outbreak levels. The fate of large larvae determines the survival rate within the generation and, within limits, determines whether the population density will be higher or lower in the next generation (Morris 1963b).

Pupae (4) - Parasites, birds and diseases kill pupae. Average pupal mortality is 34%, and is generally correlated with mortality of large larvae.

Emerging adults (3) - There is little direct information on adult mortality. Birds and other predators kill some adults, perhaps in significant numbers at low budworm densities, and the effect of diseases on longevity and male/female reproductive processes are uncertain (Neilson 1963). Indirect evidence of female mortality comes from field data on the estimated female density in a plot and the sampled egg-mass density (Miller and Renault 1973). The female to egg relationship suggests that, at moderate densities, females lay about 100 eggs (with the basic assumption that in most years and at most sites female immigration equals emigration). Assuming an average fecundity of 200, then the reproductive rate of 100 is equivalent to about a 50% female mortality. The causes of this mortality and whether they are density dependent are unknown.

Reproducing adults (1.4) - The above life-table has 1.4 adults surviving from 200 eggs, or in other words, a total generation mortality of 99.3%. Obviously, two adults would have to survive (99.0% mortality) to maintain a constant population level. The above life-table thus shows a declining population as is to be expected because most of the field data used in the analysis were collected from declining populations.

If spruce budworm moths did not disperse then a life-table analysis of within-generation survival could be used to predict between-generation changes in budworm density. But female moths are prone to disperse in large numbers and may carry up to 50% of their eggs many kilometres to downwind sites. Radar studies have provided extensive data on the dispersal process (Greenbank *et al.* 1980) but the factors that trigger dispersal and those that determine the oviposition success of dispersed females are still obscure. Thus, adult dispersal can result in sudden and dramatic changes in budworm density and is largely unpredictable in the absence of detailed data on local weather phenomena. In other words, we can make reasonable predictions of changes on budworm density within a generation, but generation to generation changes are very difficult to predict because of the dispersal characteristics of egg-carrying females.

## 2. POPULATION TRENDS OF THE SPRUCE BUDWORM AND CHARACTERISTICS OF OUTBREAKS

J.R. Blais

Spruce budworm outbreaks usually originate in small local areas, and can spread very rapidly. The current infestation in eastern Canada covered 3 000 000 ha in 1969; six years later it covered 56 000 000 ha extending without interruption from central Ontario to Newfoundland (Davidson 1976). Outbreaks generally spread from west to east as prevailing winds transport adult moths from areas of high populations to as yet uninfested stands. Moths may be transported between 180 to 240 km in a single night (Greenbank *et al.* 1980). Also, favourable weather conditions (early summer drought periods) that occasion endemic populations to increase to epidemic proportions may occur in successive years from west to east. Progress of outbreaks across the province of Quebec between 1939 and 1952 was attributed to the concurrent action of climatic release and moth dispersal (Pilon and Blais 1961). Climate is important; it not only contributes to the initiation of budworm outbreaks, but also influences population fluctuations during outbreaks (Hamel and Hardy 1980). Extended periods of warm, dry weather during May, June and July favour the survival of the insect.

In parts of Quebec, New Brunswick, Newfoundland and Maine, favourable weather prevailed in 1975 and 1976 when populations maintained at very high levels averaging 60 to 90 larvae per 45 cm branch tip. The insect at such levels not only destroys the current year's foliage, but also feeds on old foliage; thus hastening the death of trees. Also, chemical control measures are much less effective at very high population levels. The percent of larvae killed may be high but sufficient numbers remain to cause severe defoliation. Amount of foliage saved through treatment is therefore often unsatisfactory. Unfavourable weather conditions (cool and wet) depress populations during outbreaks, and when these conditions are pronounced and sustained they may contribute to the collapse of an outbreak as was the case in the

Gaspé in 1958 (Blais and Martineau 1960). This situation is more likely to happen in regions such as Newfoundland, where the prevailing climate is marginal for budworm. This marginal climate would probably eliminate the need for continued annual application of insecticides.

The insect usually restricts its feeding to the current year's foliage. It is the repeated destruction of the current year's growth that causes trees to die. Balsam fir is the most vulnerable of the host trees. This species succumbs after four to five years of repeated severe defoliation (Blais 1958a, Batzer 1973). White and red spruce can withstand an additional two years of severe defoliation before dying. Black spruce is also defoliated during outbreaks but it usually survives.

Budworm populations are subject to the action of entomophagous parasites, diseases and predators. Although a portion of the population is destroyed each year by these various agents, generally, their combined action does not succeed in reducing outbreak populations to endemic levels. Food depletion through the mortality of fir and spruce is the main cause of budworm outbreak collapse. For a given region, uncontrolled infestations usually maintain themselves for eight to ten years until tree mortality is widespread. Population abatement first occurs in areas of initial attack and follows the course set by the progress of the infestation.

Swaine and Craighead (1924) were the first to recognize that damage is most severe in mature fir stands. This observation has been repeatedly confirmed by many workers (MacLean 1980). In such stands mortality often reaches 90% to 100%. Young fir stands and fir in mixed stands, although less vulnerable than mature fir stands, may also suffer severe damage, depending on their position in relation to centers of severe attack. Of the three species of spruce found in eastern Canada, white spruce is the most vulnerable. The effect of budworm on white spruce, however, varies considerably and is much harder to predict than for balsam fir. Red spruce is confined to southeastern Quebec and the Maritimes; this species is somewhat less vulnerable to budworm than white spruce. Black spruce is the most common and widespread of the spruces. Some may be killed by budworm when mixed with other host trees, but in pure stands, it usually survives outbreaks. However, some black spruce stands have been killed in central Newfoundland.

All host trees defoliated for varying periods of time lose volume through reduced radial and height growth. This loss was equivalent to one-third of the loss in the Laurentide Park in Quebec (Blais 1964). In young stands, loss in increment, especially through top killing, can account for one-half the projected volume at maturity (Baskerville and MacLean 1979).

Most trees that have lost more than 75% of the total foliage usually do not recover. Once initiated, tree mortality may progress in a stand for three to four years following the last year of defoliation. About 50% of the trees that die may do so in the years immediately following the end of an outbreak, as was recently observed in the Ottawa Valley (Blais unpublished).

Spruce budworm infestations usually result in very considerable and extensive losses through mortality and reduction in increment of fir and spruce. Losses in the aftermath of most infestations amount to millions of cubic metres (Blais 1964, Craighead 1924, de Gryse 1947, Elliott 1960, Graham and Orr 1940, Swaine and Craighead 1924, Turner 1952). Between 1910 and 1970, amount of wood destroyed by budworm for eastern North America has been estimated at 2 000 000 000 $m^3$, the equivalent of six times the current annual world production of pulpwood (Blais 1973).

Fir and spruce regeneration is generally adequate in mature budworm-killed stands (Ghent *et al.* 1957). Composition of succeeding stands does not differ greatly from that of the original ones. The situation may differ in Newfoundland where spruce and fir regeneration appears to be inadequate in some recently damaged stands (Raske personal communication). In immature stands killed by the budworm, reproduction may be lacking and succession to desirable species could pose a problem.

Spruce budworm outbreaks should not be considered as accidents of nature, they are associated with the dynamics of spruce-fir stands in eastern North America. Because infestations recur at relatively long intervals, they may come as a surprise to an unsuspecting generation of managers and administrators. Let us hope future generations will be better prepared to meet this challenge.

## 3. ASSOCIATED PESTS

H.O. Schooley

The trees attacked by the spruce budworm may also be damaged by other insect species prior to or simultaneously with the damage caused by the budworm. The insect species thought to increase the effects of budworm attack in Newfoundland include the hemlock looper, the balsam woolly aphid, the spruce coneworm, the blackheaded budworm, the balsam fir sawfly, the spruce beetle, *Dendroctonus rufipennis* (Kirby), and the larch beetle, *D. simplex* LeConte. Armillaria root rot is probably also increasing the effects of spruce budworm damage but the extent of the interaction of the two organisms is unknown.

Prior to the occurrence of the spruce budworm infestation, the hemlock looper was the most important defoliator of balsam fir in Newfoundland (Carroll 1956a, Otvos *et al.* 1971). Looper outbreaks that caused mortality have been reported in widely separated parts of the Island since 1912. The most recent outbreak began in 1966 and aerial control operations were conducted in 1968 and 1969. Many of the stands damaged, but not killed by the looper in this outbreak, were low in vigor when infested by the budworm in the 1970's. These stands died after only two or three years of budworm defoliation (Otvos and Moody 1978). Conversely, similar accelerated mortality would probably occur if a looper infestation were to follow the present budworm outbreak. Increasing looper population levels have been reported in the western and central areas of the Island during the past two years (Clarke *et al.* 1980). However, these two insect pests would not reach epidemic levels at the same time in the same stand because high budworm populations would deplete the current year's growth required for looper survival.

The balsam woolly aphid, a minute sucking insect, feeds on the inner bark of balsam fir branches and stems. This insect originated in Europe and now occurs in most of the Island's fir stands. Aphid infestation reduces growth, causes dieback and may kill trees after several years of attack (Schooley and Bryant 1978). During the late 1960's, this pest was causing an estimated volume loss of about 50 000 $m^3$/year (Anon. 1972). However, in the early 1970's population levels declined. They remained low except for an occasional resurgence in localized areas until 1979 when high populations were recorded in most areas between Codroy and Stephenville in western Newfoundland (Clarke *et al.* 1980).

The aphid and the spruce budworm may infest fir trees at the same time. However, high populations of both insects have never been observed to persist together for more than a year. Aphid populations declined (Schooley unpublished). Nearly all the areas where severe aphid damage has occurred in the past have been attacked by the spruce budworm during the current infestation (Schooley 1981). Many of the mature stands that recovered when the aphid infestation subsided were killed rapidly by only two or three years of severe budworm defoliation. Young sapling size trees previously damaged by the aphid were also more severely defoliated by the budworm than previously undamaged trees (Schooley 1976). Aphid damage probably contributed to the unprecedented mortality of large areas of balsam fir regeneration near Stephenville in western Newfoundland.

The spruce coneworm may occur with the spruce budworm on white spruce, black spruce and occasionally on balsam fir. The coneworm's life history is similar to that of the budworm and larvae of both species may occur on the same branch. Coneworm larvae have been observed as predators of spruce budworm pupae (Warren 1954, Thomson 1957). The same factors that favour spruce budworm development appear to also favour the coneworm. Outbreaks of this pest alone or in combination with the spruce budworm should be expected to occur in the future.

The spruce coneworm prefers to feed on cones but when they are scarce it readily feeds on foliage. Combined budworm and coneworm infestations have been reported in Newfoundland since 1977. In many black spruce stands between Halls Bay and Gander, the coneworm has surpassed the budworm in numbers and caused about 60% of the total, moderate to severe defoliation recorded (Moody 1980).

The blackheaded budworm is a common defoliator on balsam fir, black spruce and white spruce. Populations occasionally reach outbreak levels and cause top kill and mortality in localized areas (Clark and Pardy 1972). Feeding by this pest probably contributes to decreased tree vigour making trees more vulnerable to spruce budworm damage. The blackheaded budworm is frequently collected on spruce budworm infested trees. However, blackheaded budworm larvae start feeding later than the spruce budworm and compete less successfully for a limited food supply.

The balsam fir sawfly is occasionally an important defoliator of balsam fir, particularly in immature stands (Clark and Pardy 1972). Outbreaks appear to be cyclic, lasting three or four years. Defoliation causes some growth reductions but mortality seldom occurs. However, the sawfly feeds only on old foliage which makes infestations of this pest very important when combined with other pests like the spruce budworm which feed on the new foliage. Combined spruce budworm and sawfly damage may have been a major factor in the mortality of sapling size balsam fir in large areas in western Newfoundland (Moody 1979).

Bark beetles of the genus *Dentroctonus* attack trees of low vigor. Severe budworm defoliation reduces the vigor of trees and predisposes white spruce to spruce beetle and larch to eastern larch beetle attack (Magasi 1979, Raske *et al.* 1978). These beetles kill the trees they infest which may otherwise recover from defoliation only.

Armillaria root rot is expected to increase tree mortality in spruce budworm damaged stands. An increase in the incidence and intensity of infection has been demonstrated in relation to increasing balsam woolly aphid damage (Hudak and Wells 1974). Also, root rot has been indicated as a possible cause of the discontinuous nature of mortality caused by various amounts of hemlock looper defoliation (Otvos *et al.* 1971). Armillaria root rot has not been investigated in spruce budworm damaged stands. However, this disease will probably become important in severely damaged, low vigour stands following the collapse of budworm infestation. The disease may also become important in stands periodically re-infested by the budworm or other insect pests.

## SUMMARY

The life history of the spruce budworm spans two calendar years. Eggs are laid in early August of one year, and emerging larvae spin hibernacula for overwintering. These larvae emerge the following spring and feed on buds, flowers and needles. Mature larvae pupate in mid-July and adults emerge in late July. Major within-generation mortality occurs before hibernation in fall, small larval stage in spring, and in the mature larval stage. The extent of mortality of mature larvae determines the population trend. Population dispersal occurs when larvae hatch in August, when larvae emerge from hibernacula in spring and particularly when adults emigrate.

Spruce budworm outbreaks originate in small areas, spread rapidly to cover very extensive regions. Uncontrolled outbreaks usually last 8 to 10 years and terminate when the food supply becomes scarce and tree mortality widespread. Balsam fir is the most vulnerable host tree and dies after 4 to 5 years of severe damage to the current year's foliage. White and red spruce may withstand up to 6 years of severe defoliation before dying. Black spruce trees, especially in pure stands, usually survive. However, some black spruce stands have been killed in central Newfoundland. Fir stands tend to replace stands killed by the budworm in the Maritimes, but in Newfoundland regeneration may be lacking and succession to shrub species may occur.

In Newfoundland preceeding, concurrent or successive damage by other defoliators, such as the hemlock looper, black-headed budworm, spruce coneworm, balsam fir sawfly, or damage by the balsam woolly aphid may result in increased mortality rates of the host trees. Armillaria root rot may also hasten the death of trees damaged by the budworm.

# V. DAMAGE CAUSED BY THE SPRUCE BUDWORM

## 1. DAMAGE TO TREES

A.G. Raske

Severe defoliation of trees results in reduced growth and eventually in death. Radial growth is reduced the earliest and also the most in that part of the bole where defoliation occurs (Mott 1955, Mott *et al.* 1957, Church 1949, McLintock 1955). Persistent severe defoliation will reduce radial increment in other parts of the bole below the crown. Therefore growth loss calculations based on lower bole data do not reflect average tree conditions (Kulman 1971). However, the effect of budworm defoliation is so severe that the growth loss estimate obtained on the lower bole is thought to be a reasonable approximation.

Radial growth loss during an outbreak generally ranged between 35% and 90% (Blais 1958b, Kulman 1971, Blais 1961, Batzer 1973, McLintock 1955). This percent of loss over large areas is considerable. It averaged 963 000 $m^3$ annually for a six year period in a 400 000 ha balsam fir stand in Maine (McLintock 1955).

Reduction of height growth and also loss of height through top killing is a common form of damage. Budworm outbreaks usually leave a high percentage of trees with dead tops; often more than 50% (Swain and Craighead 1924, Schmiege 1961, Brown 1963, Miller 1977, Batzer and Bean 1962, Kulman 1971). Height growth ceased during an outbreak and total tree height often decreased due to top killing. During a five year outbreak height growth of damaged trees averaged 48 cm compared to 130 cm in undamaged trees (Batzer 1973). The average reduction of height may range from 0.5 m to 4.0 m (Miller 1977, McLintock 1955, Belyea 1952, Baskerville and MacLean 1979, Batzer and Bean 1962). Dead tops are more likely to occur in the lower crown classes where crowns are already at a competitive disadvantage (Devine *et al.* 1978). Trees with top-kill in mixed stands are at a severe competitive disadvantage to non-host species (Williams 1966). By the end of the stand rotation the average height of a damaged stand may remain 3 m to 4 m below undamaged stands (Baskerville and MacLean 1979). A greater volume loss through top-kill occurred in young stands than in mature stands (Ferrell and Scharpf 1978).

In pulpwood stands volume loss is the most important and is caused by reduced tree size, by tree deformities and increased wood decay. Miller (1977) reported a volume loss of 23% in New Brunswick on surviving trees at the end of an outbreak. Trees with their top killed lost three or four times as much volume as trees without top-kill. Volume losses at the end of rotation caused by reduction in height appear to be considerable (Baskerville and MacLean 1979). Volume losses through reduced radial and height growth was about 6 500 000 $m^3$ in the Laurentide Park area in Quebec and was about one-third the loss caused by tree mortality (Blais 1964).

Stem deformities, such as forked tops, multiple tops, crooks, and sweeps are common in damaged stands. Percent of trees affected ranged from 23% (Schmiege 1961) to 100% (Baskerville and MacLean 1979) with several values between (Collis and Van Sickle 1978, Schmidt and Fellin 1973). Entrance of heartrot is virtually assured if the top is killed back to a diameter of 1.5 cm or more (Stillwell 1956, Baskerville 1960, Collis and Van Sickle 1978). Estimates of volumes lost per tree due to either deformity or decay are not available but they also appear to be considerable.

Rootlet mortality was first reported to be associated with budworm defoliation by Craighead (1924) who noted that all roots less than 2 mm in diameter had died on severely defoliated trees. This form of damage was confirmed (Redmond 1957, 1959) and may be the most important cause in the death of a tree. Defoliation of 70% caused more than 30% of rootlet mortality and 100% defoliation more than 75%. Young trees are able to produce new rootlets after defoliation, but mature and overmature trees were unable to produce new rootlets before death (Redmond 1959). Stillwell (1960a) reported that rootlet recovery lagged behind foliage recovery by three years.

A reduction in starch content of roots caused by defoliation has been reported for other insects on other host trees (Parker 1970, Kozslowski and Winget 1964, Wargo *et al.* 1972, Jensen and Masters 1973, etc.). This reduction has not been investigated for spruce budworm defoliation though it probably occurs and depletes the food reserves in a tree. Defoliation of the new growth deprives the tree of growth hormones (Kozlowski 1971) and possibly other hormones resulting in several stresses, such as an imbalance of metabolites, minerals and water which cause the other forms of damage and decline of vigour discussed so far. The general deterioration of vigour may also predispose trees to other destructive agents that normally do not damage a tree, such as bark beetles (Thomas 1958) or diseases (Giese *et al.* 1964, Wargo and Houston 1974). Decrease in vigour also affects the trees in several other ways, such as retarding wound closure (Wargo 1977).

The spruce budworm also feeds on the reproductive structures of its host trees (Tripp 1950, Ghent 1958, Woodwell 1962). It feeds on the reproductive buds after flowers have started to develop (Schooley 1978). Most cones are damaged even when defoliation is light or moderate (Schooley 1978, 1980b) and stands in outbreak areas produce practically no cones (Ghent 1958, Woodwell 1962), and therefore no seeds. Cones that escape early damage and are fed upon as they mature have very few seeds (Dewey 1971, Schooley 1978). Therefore, for the duration of the outbreak no seed crop is produced. This lack of seed has far-reaching implications in the natural replacement of damaged stands.

## 2. DAMAGE TO FOREST STANDS

D.A. MacLean

### a) STAND MORTALITY FROM UNCONTROLLED OUTBREAKS

Quantitative data on the rate and amount of tree mortality resulting from uncontrolled budworm outbreaks exist from several regions and outbreaks (Table V-1). This information has recently been reviewed and analysed and the following is summarized from that analysis (MacLean 1980).

Past surveys of mortality have been done over extensive areas and therefore tree mortality data must be viewed as broad estimates. During the 1910's and early 1920's 720 000 000 $m^3$ of fir and spruce were killed in eastern Canada, or 40% to 50% of the host tree volume (Swaine and Craighead 1924); 90 000 000 to 110 000 000 $m^3$ were killed in Maine from 1909 to 1919 (McLintock 1955); 60 000 000 $m^3$ in northwestern Ontario from 1943 to 1955, or 58% of the host-tree volume (Elliott 1960); and 18 000 000 $m^3$ were killed in New Brunswick from 1914 to 1921, equivalent to 75% of the merchantable fir or 56% of the total fir (Tothill 1921).

Fir mortality usually started four or five years after the beginning of a severe uncontrolled budworm outbreak, but in some cases it has taken six or seven years for the first mortality to appear (Fig. V-1). In mature highly vulnerable stands 95% to

Table V-1. Summary of quantitative studies of fir and spruce mortality resulting from spruce budworm outbreaks in the forests of eastern North America. The range of mortality values are presented where data were available for more than one sampling area (from MacLean 1980).

| Location | No. plots[a] | Time period | Type of study[b] | Fir mortality: % no. | Fir mortality: % basal area | Spruce mortality: % no. | Spruce mortality: % basal area | Spruce mortality: species[c] | Reference |
|---|---|---|---|---|---|---|---|---|---|
| **New Brunswick** | | | | | | | | | |
| Bathurst, Miramichi areas | 8 | 1914-23 | B | 10-100 | 11-100 | 0-65 | 0-72 | rS | Craighead 1924 |
| Tabusintac drainage | 9 | 1912-20 | B | 61-100 | na[d] | 5-79 | na | rS,wS | Craighead 1925 |
| Kedgwick Control Area | 10 | 1956-61 | A | 34-84 | 21-81 | 0-24 | 0-41 | bS | Baskerville and MacLean 1979 Baskerville 1960 |
| Charlo Control Area | 1 | 1955-61 | A | 58 | 61 | 18 | 13 | wS | Macdonald 1962 |
| Kedgwick drainage | 3 | 1956-59 | A | 31-73 | 39-70 | na | na | -- | Mott 1968 |
| **Nova Scotia[e]** | | | | | | | | | |
| Cape Breton Highlands | 1 | 1976-78 | A | 32 | na | na | na | -- | Sterner *et al.* 1977 and Magasi 1978 |
| Cape Breton Lowlands | 1 | 1976-78 | A | 15 | na | na | na | -- | |
| Cape Breton Highlands | 5 | 1976-79 | A | 4-49 | 2-45 | 0 | 0 | wS | MacLean 1979 and unpublished data |
| **Quebec** | | | | | | | | | |
| Lake Kenogami | 9 | 1914-23 | B | 1-100 | na | na | na | -- | Craighead 1924 |
| Fief St. Claire | 4 | 1911-23 | B | 68-96 | 74-98 | 17-56 | 16-51 | rS | Craighead 1924 |
| Metis Lake | 1 | 1912-20 | B | 39 | na | 12 | na | wS,rS | Craighead 1925 |
| Gatineau River | 2 | 1948-52 | A | 26-79 | na | na | na | -- | McLintock 1955 |
| Laniel | 7 | 1950-55 | B | na | 34-100 | na | na | -- | Ghent *et al.* 1957 |
| Trois Rivières | 2 | 1951-61 | B | 31-64 | na | 0 | na | bS,wS | Hatcher 1964 |

Table V-1 - Concluded

| Location | No. plots[a] | Time period | Type of study[b] | Fir mortality % no. | Fir mortality % basal area | Spruce mortality % no. | Spruce mortality % basal area | Spruce mortality species[c] | Reference |
|---|---|---|---|---|---|---|---|---|---|
| Ontario | | | | | | | | | |
| Algoma region | 7 | 1935-45 | B | 23-93 | 19-89 | na | 19-59 | wS | Turner 1952 |
| English River | 9 | 1949-56 | A | 62-100 | na | na | na | -- | Blais 1958a |
| Black Sturgeon Lake | 13 | 1950-55 | B | na | 26-100 | na | na | -- | Ghent *et al.* 1957 |
| Cedar Lake | 6 | 1950-55 | B | na | 78-98 | na | na | -- | Ghent *et al.* 1957 |
| Minnesota | 1 | 1957-66 | A | 55 | 68 | 25 | 37 | wS,bS | Batzer 1973 |

[a]Number of plots refers to number of sampling areas for which individual mortality data and stand characteristics were available. In certain studies a larger number of plots were sampled but only averaged data were presented and data were used as one value, therefore only one data set was available.

[b]Type of study: A = annual assessment of mortality on permanent plots during and possibly following an outbreak.
B = single, postmortem analysis of mortality.

[c]Species of spruce: rS = red spruce, wS = white spruce, bS = black spruce.

[d]Data not available

[e]The studies of spruce budworm-caused mortality in Nova Scotia are assessments of mortality losses resulting from a severe, on-going infestation on Cape Breton Island.

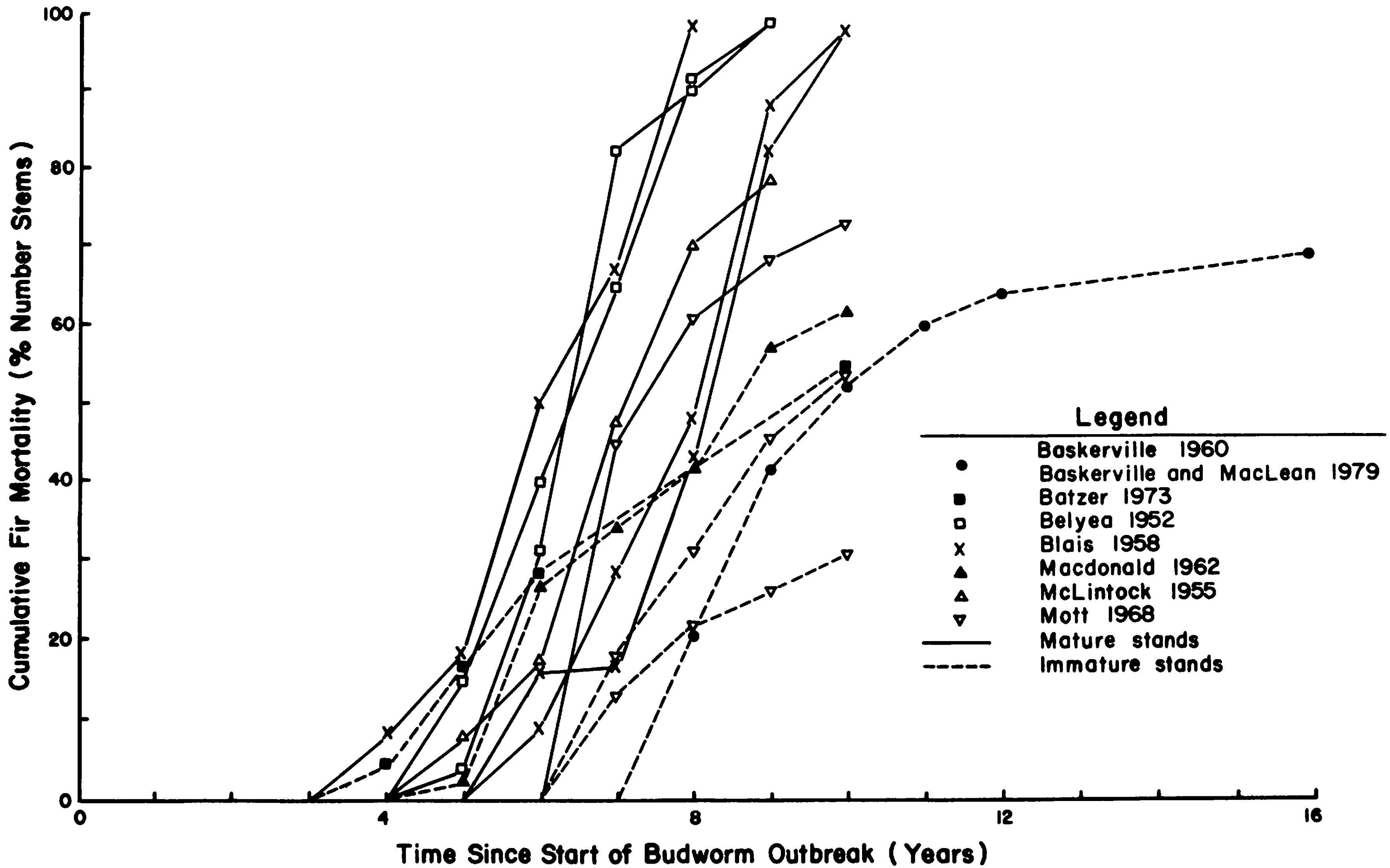


Figure V-1. Cumulative percentage fir mortality in relation to time during various spruce budworm outbreaks (from MacLean 1980).

100% of the fir may be killed during an outbreak (Belyea 1952, Blais 1958a) (Fig. V-1). In general, mortality in mature fir stands ranged from 70% to 100%, while mortality in immature stands varied from 30% to 70%.

Total expected mortality from a budworm outbreak in a given stand is difficult to predict and the relation of mortality to stand characteristics is not easy to discern. It is possible to group the data from past outbreaks (Table V-1) so as to obtain a rough estimate of mortality for mature or immature stands of the various host species (Fig. V-2). Fir mortality in mature stands, based on 63 plots, averaged 85%, while fir mortality in immature stands, based on 26 plots, averaged 42%. Mean spruce mortality in mature stands was 36% (26 plots) and in immature stands it was 13% (18 plots). Most mature fir and immature spruce plots fell into specific mortality classes, while immature fir and mature spruce were more variable (Fig.V-2). It is noteworthy that only fir in mature stands sustained consistently high mortality.

Spruce mortality includes data for three species, white spruce, red spruce, and black spruce (Fig. V-2, Table V-1). Although the data are relatively sparse, particularly for black spruce, in general they support the theory that black spruce is less vulnerable than white or red spruce. Mortality of black spruce ranged from 0% to 24% in some immature fir-spruce stands in New Brunswick (Baskerville and MacLean 1979), whereas mortality of red, white or a mixture of the two species has been reported as high as 79% (Table V-1).

Several studies of tree mortality during budworm outbreaks have examined the hypothesis that variability in mortality is a function of the structural characteristics of the stand. This hypothesis is attractive, since it would permit predicting expected mortality from easily measurable stand characteristics. So far, this approach has not been successful. Some general trends between amount of mortality and stand characters have been demonstrated, but quantitative analyses have failed to determine strong relationships (MacLean 1980). A correlation and multiple regression analysis for pooled data from all the available studies in the literature (Table V-1) explained less than 50% of the variation (MacLean 1980). This means that tree mortality in any one stand may differ widely from the average for all stands indicated by the regression line (Fig. V-3). However, for approximation purposes in a management sense, fir and spruce mortality increases with increasing fir and spruce density in the stands (Fig. V-3). There appears to be relatively little difference between the amount of mortality sustained by mature fir in pure or mixed stands (Fig. V-3).

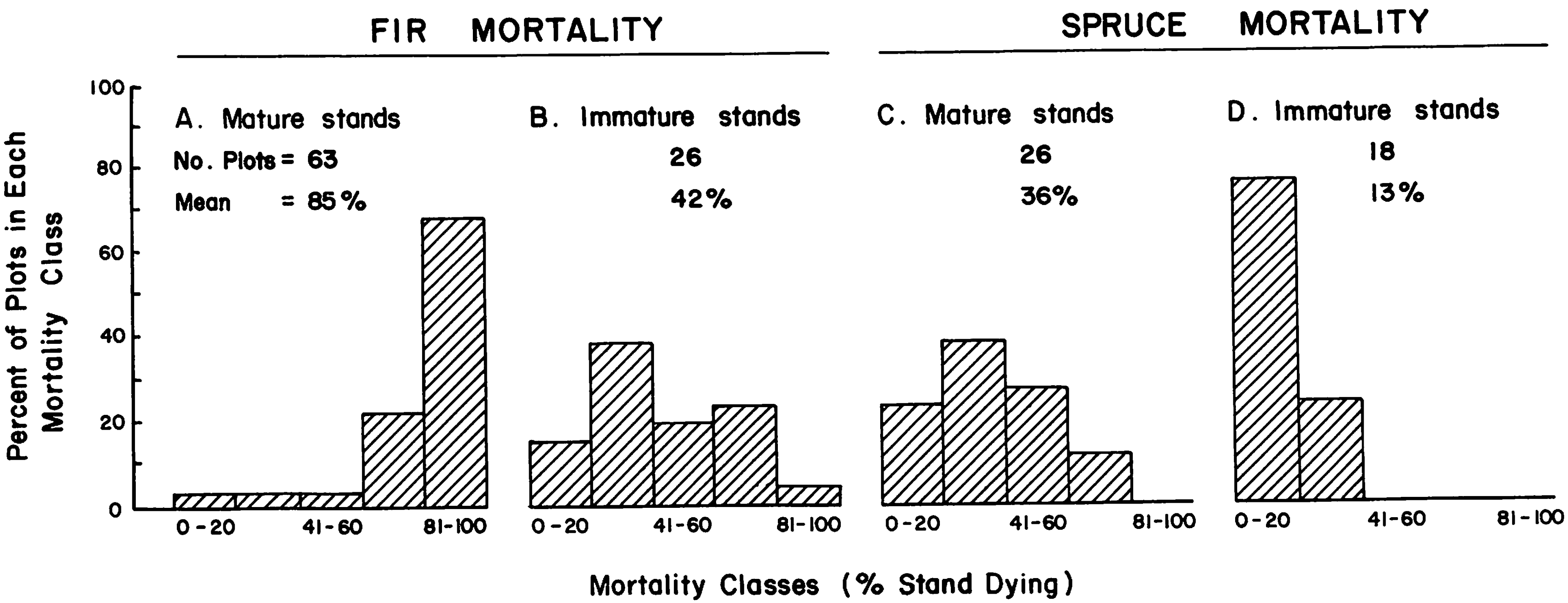


Figure V-2. Distribution of fir and spruce mortality during budworm outbreaks (from the studies in Table V-1) in 20% mortality classes. Separation of mature and immature stands was 60 years (from MacLean 1980).

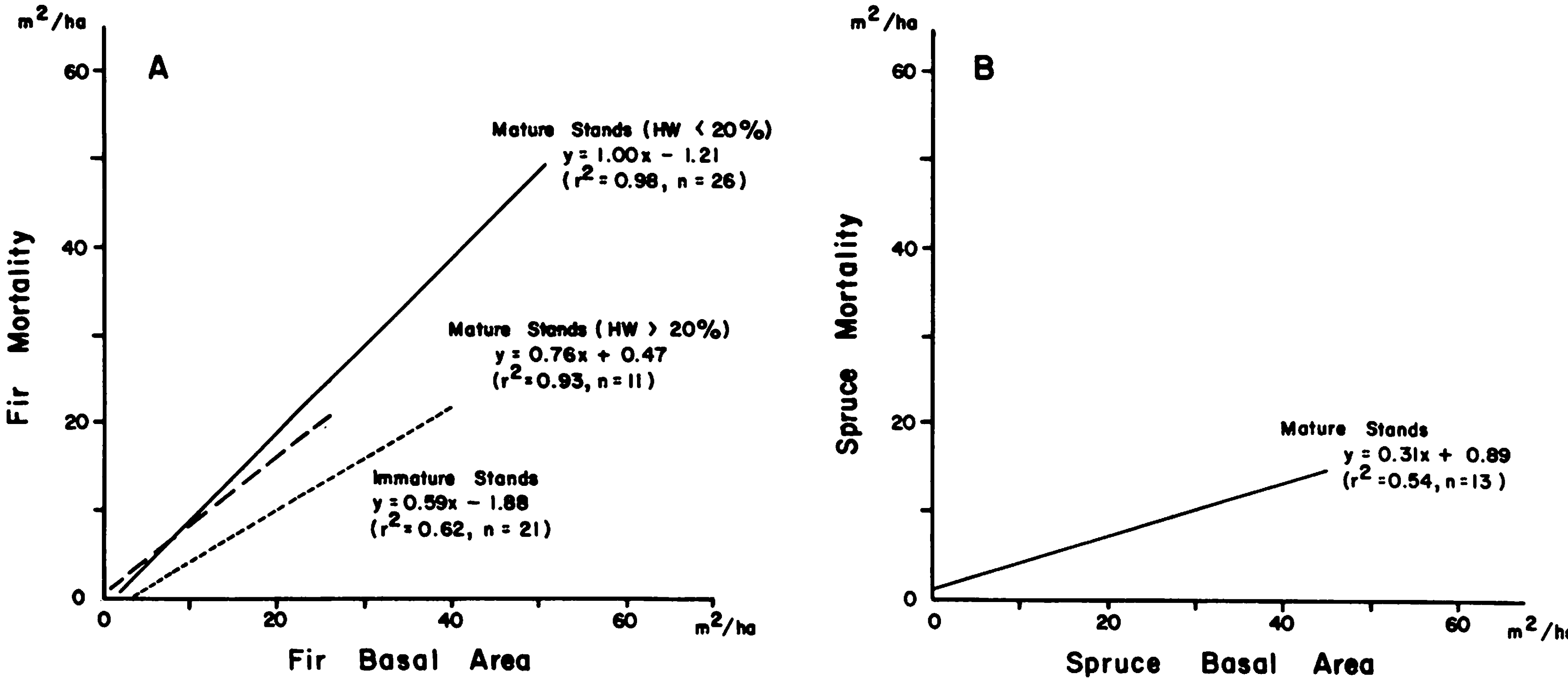


Figure V-3. Relationship between tree mortality and basal area for balsam fir and spruce (from studies listed in Table V-1)(from MacLean 1980).

### b) LOSS OF WOOD PRODUCTION FROM UNCONTROLLED OUTBREAKS

Only two recent studies have quantified the loss of wood production by stands. Baskerville and MacLean (1979) have examined budworm-caused mortality and growth loss, as well as 20-year recovery in immature balsam fir stands in northwestern New Brunswick. The period of defoliation coincided with greatly reduced diameter growth and reductions in tree height as a result of top-killing (Figs. V-4, V-5). Within five years of the cessation of defoliation, the crowns of surviving trees appeared fully recovered, and diameter and height growth were similar to that in unaffected stands. However, recovery on a stand basis was poor; only one plot out of 10 had regained its pre-defoliation volume 15 years after defoliation ceased, because of the 18% to 80% mortality of trees and the growth reductions caused by the outbreak (Fig. V-6). Kleinschmidt *et al.* (1980) studied the reduction in volume increment in the fir-spruce stands in Maine with varying degrees of nonfatal defoliation (Table V-2). Stands which sustained less than 20% defoliation of current shoots for five years had negligible growth loss, whereas 90% to 100% defoliation for five years resulted in a 60% annual growth loss, or a cumulative loss of 34% over the five-year period. This was equivalent to 15 $m^3$/ha of wood production lost to the stand during five years of non-fatal defoliation.

## 3. DAMAGE BY THE PRESENT OUTBREAK TO THE FORESTS OF NEWFOUNDLAND TO 1979

### a) COMMERCIAL FIBRE PRODUCTION

#### i) <u>Mature Stands</u> -- A.G. Raske and B.H. Moody

The productive softwood forests of Newfoundland and Labrador were surveyed in 1979 to detect and assess the cumulative damage caused by the present spruce budworm outbreak. Surveys by the Forest Insect and Disease Survey, Canadian Forestry Service (CFS) have been described by Moody (1980), and the results reported by him are here summarized. In addition some results from the impact study of the Newfoundland Forest Research Centre, CFS, have been added.

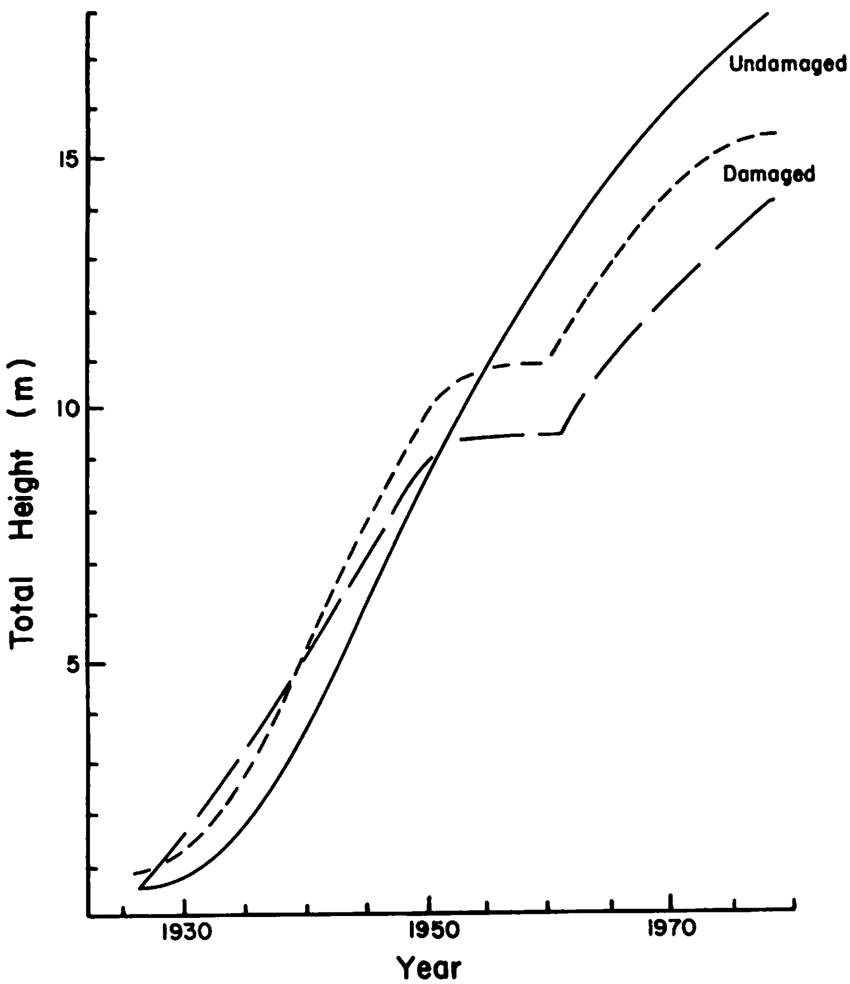


Figure V-4. Height of two trees damaged by the spruce budworm and of one undamaged tree. Defoliation occurred from 1950 to 1958 (from Baskerville and MacLean 1979).

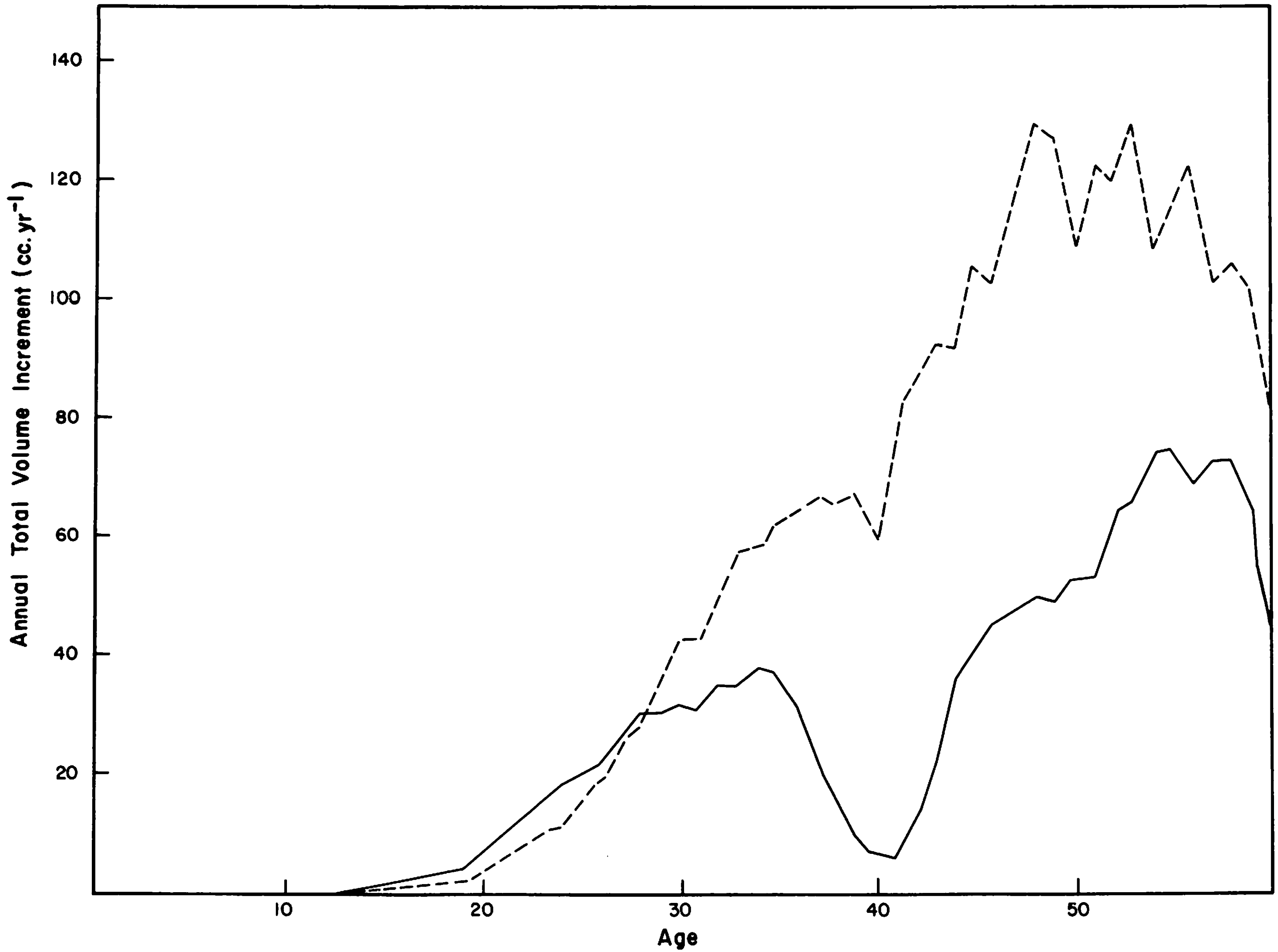


Figure V-5. Annual volume growth of an undamaged tree (broken-line) and of a tree severely defoliated by the spruce budworm from 1952 to 1961 (solid line) (from Baskerville and MacLean 1979).

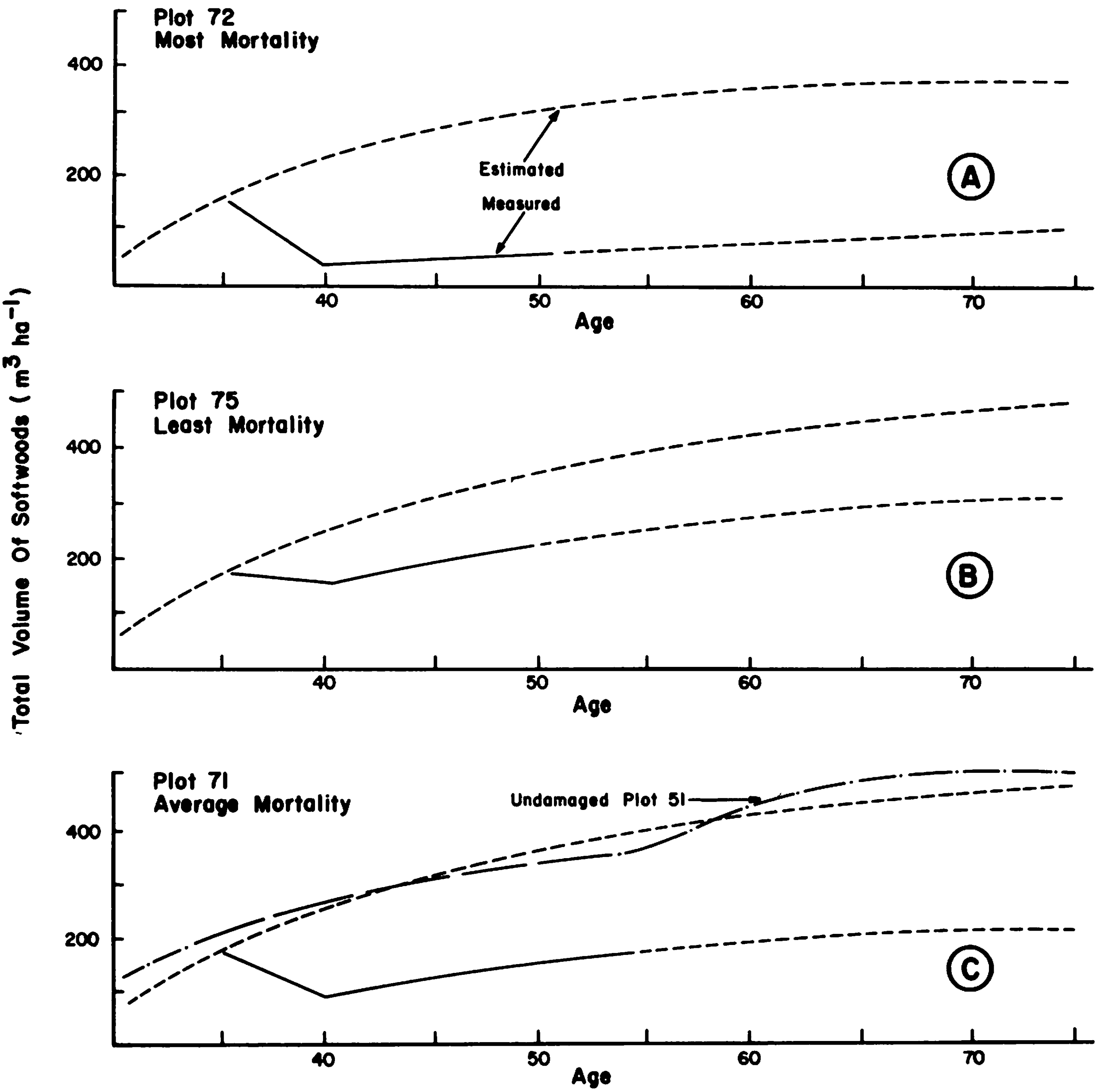


Figure V-6. Actual and simulated growth in softwood stands damaged by the spruce budworm and in undamaged stands (from Baskerville and MacLean 1979).

Table V-2. Reduction of volume increment in fir-spruce plots in Maine resulting from varying degrees of non-fatal defoliation (from Kleinschmidt *et al.* 1980).

| 5-year defoliation history (for fir) | Annual fir growth loss (%) after 5 yrs defoliation | Mean cumulative fir growth loss % | $m^3$/ha |
|---|---|---|---|
| A. Light (less than 20%) | No growth loss measurable. | | |
| B. Increasing for 4 years (from 20% to 90%) | 40 | 12 | 4 |
| C. Increasing for 5 years (from 20% to 90%) | 40 | 19 | 7.5 |
| D. Severe for 5 years (continuous 90 to 100%) | 60 | 34 | 15 |
| E. Increasing for 4 years, sprayed in 5th year | 55 | 30 | 17 |
| F. Increasing for 3 years, sprayed in 4th year | 30 | 18 | 13 |

Defoliation - The total area of defoliation on the Island in 1979 was 1 251 300 ha, or about 33% of the productive forest area (Fig. V-7). This is an increase of nearly 100 000 ha from 1978. It should be noted that nearly all of the productive forests of Newfoundland have been moderate to severely defoliated for two or more years during this outbreak. The area of moderate and severe defoliation in 1979 was 972 600 ha; an increase of nearly 200 000 ha from 1978. In Labrador no noticeable defoliation occurred in 1979, and the outbreak there has terminated.

The progression of the outbreak in Newfoundland is indicated by the number of hectares with moderate to severe defoliation annually since the beginning of the outbreak in 1971 (Table V-3). The largest was a moderate to severe defoliation in 1975 to 1976 in eastern Canada and 1976 to 1977 in Newfoundland. In Newfoundland the outbreak is currently concentrated in the central and eastern regions of the Island (Fig. V-7), with localized infestations in western Newfoundland.

Damage Assessment - The area of damaged stands and the severity of mortality within them is surveyed from the air annually, and supplemented with ground checks. All merchantable stands damaged by the budworm were classified as follows:

Table V-3. Area of moderate to severe defoliation by the spruce budworm in Newfoundland and eastern Canada.

| Year | Defoliation (ha) | |
|---|---|---|
| | Newfoundland | Eastern Canada |
| 1967 | - | 186 000 |
| 1968 | - | 886 000 |
| 1969 | - | 2 200 000 |
| 1970 | - | 4 016 000 |
| 1971 | Trace | 10 400 000 |
| 1972 | 364 000 | 20 440 000 |
| 1973 | 119 000 | 22 339 000 |
| 1974 | 715 000 | 43 981 000 |
| 1975 | 668 000 | 54 026 000 |
| 1976 | 1 058 000 | 50 878 000 |
| 1977 | 1 289 000 | 40 031 000 |
| 1978 | 794 000 | 30 805 000 |
| 1979 | 973 000 | 26 291 000 |

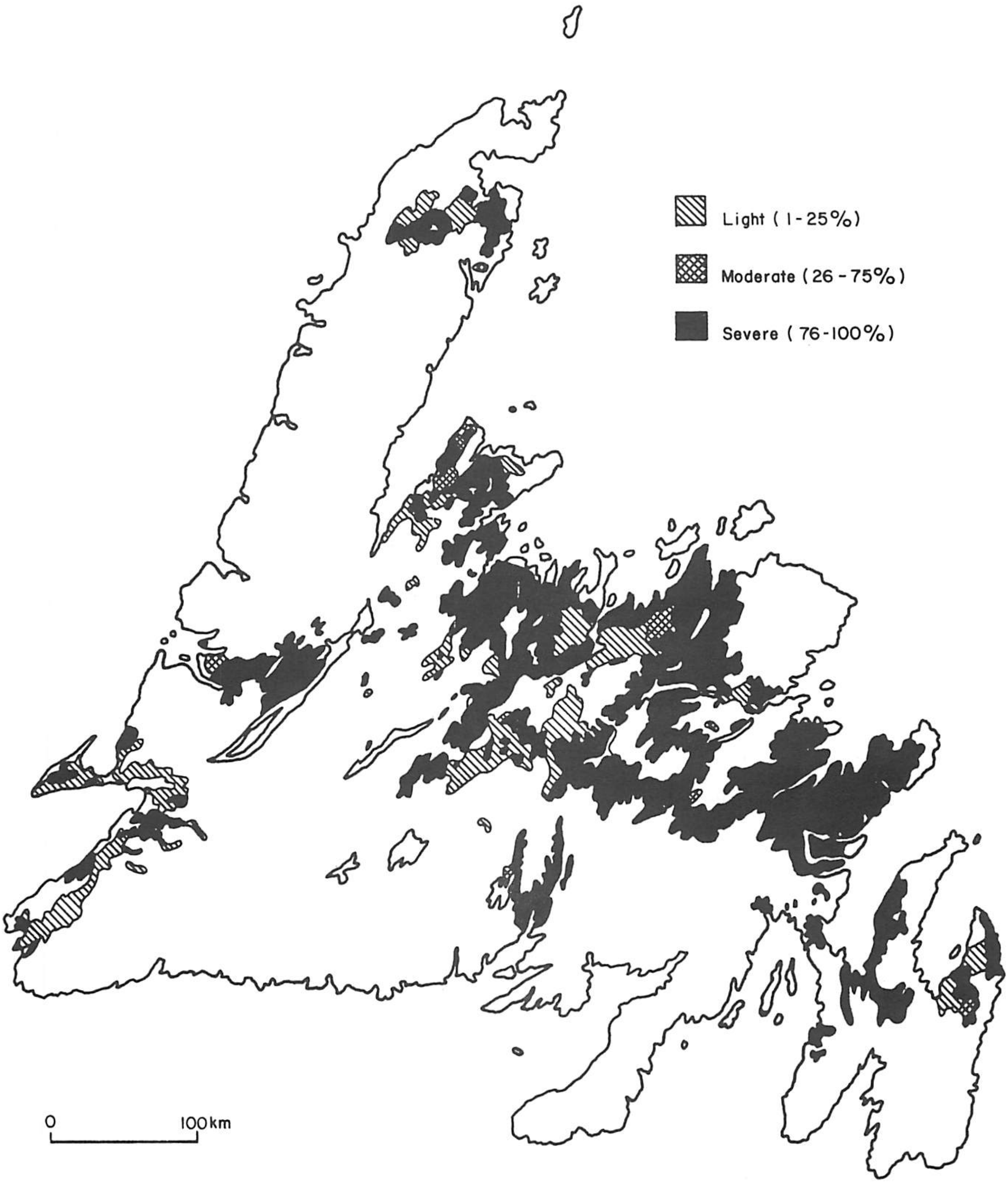


Figure V-7. Areas of light, moderate and severe defoliation caused by the spruce budworm in Newfoundland in 1979.

A = Dead; 50% or more of total volume of stand dead

B = Moribund; 20% to 49% of total stand volume dead, or more than 50% of total stand volume dying (dying = 75% or more total defoliation)

C = Very severely damaged; 5% to 19% of total stand volume dead, or less than 50% of total stand volume dying

D = Severely damaged; severe damage but less than 5% of total volume dead or dying.

The total area of merchantable softwood stands (classes A, B, C) containing dead and dying trees was 518 000 ha in 1979 (Table V-4) an increase of about 300 000 ha over 1978. These stands contained 10 257 000 $m^3$ of dead trees, 11 665 000 $m^3$ of dying trees and 16 491 000 $m^3$ of trees with lesser damage, for a total volume of 38 412 000 $m^3$ (Table V-4). In these stands over half of the volume was dead or expected to die, and all of these stands were in need of salvage harvesting. The distribution of these stands by management units and land ownership is presented in Appendix III.

The trend in the development of damage, since the inception of damage assessment surveys in 1977, was an annual increase in dead and dying trees (Fig. V-8). Cumulative budworm damage to 1979, both in terms of area and volume of trees was still increasing. The volume of dead trees comprised about 5% of all softwood stands on the Island, dying trees comprised another 5%, but the total volume of stands with mortality (classes A, B, C) comprised about 17% of all productive forests. However, almost all dead and dying volume was balsam fir. This volume of dead trees comprised 9% of the fir stands, the volume of dying trees comprised 10% of fir and the total volume of stands with mortality was about 30% of all the fir on the Island (Fig. V-8).

Dead trees may be salvaged up to five years after the time of death. In 1979, 79% of the dead trees had been dead for one or two years, 6% for three to four years and 15% for five years or more. The trees in the last category (15%) were killed in the early years of the outbreak and had been previously damaged by other insects, such as the hemlock looper or the balsam woolly aphid.

Annual radial growth decreased during the outbreak in all four damage categories; A, B, C and D. Categories A and B during the period of 1975 to 1980 have averaged annually only 14% of the average annual growth of the 10 year period (1965 to 1974) prior to the outbreak. Category C had 19% of the growth and D 53% (Raske unpublished). Therefore, even trees in the lowest damage category (D) have sustained considerable increment loss.

Table V-4. Area and volume of productive, merchantable softwood stands where tree mortality caused by spruce budworm was evident in 1979 in Newfoundland.

| | Damage category[1] | | | |
|---|---|---|---|---|
| | A | B | C | Total |
| Total area, ha | 97 159 | 238 864 | 181 810 | 517 832 |
| Dead vol., $m^3$ | 4 771 528 (63)[2] | 4 562 434 (26) | 922 712 (7) | 10 256 724 (27) |
| Dying vol., $m^3$ | 1 672 692 (22) | 6 661 387 (38) | 3 330 507 (25) | 11 664 802 (30) |
| Lesser damagd vol., $m^3$ | 1 127 171 (15) | 6 520 696 (36) | 8 843 184 (68) | 16 490 784 (43) |
| Total vol., $m^3$ | 7 571 391 (100) | 17 744 517 (100) | 13 096 403 (100) | 38 412 310 (100) |

[1]A = Dead; 50% or more of total volume of stand dead.

B = Moribund; 20% to 49% of total stand volume dead, or more than 50% of total stand volume dying (dying = 75% or more total defoliation).

C = Very severely damaged; 5% to 19% of total stand volume dead, or less than 50% of total stand volume dying.

[2]Figures in parentheses are percentages.

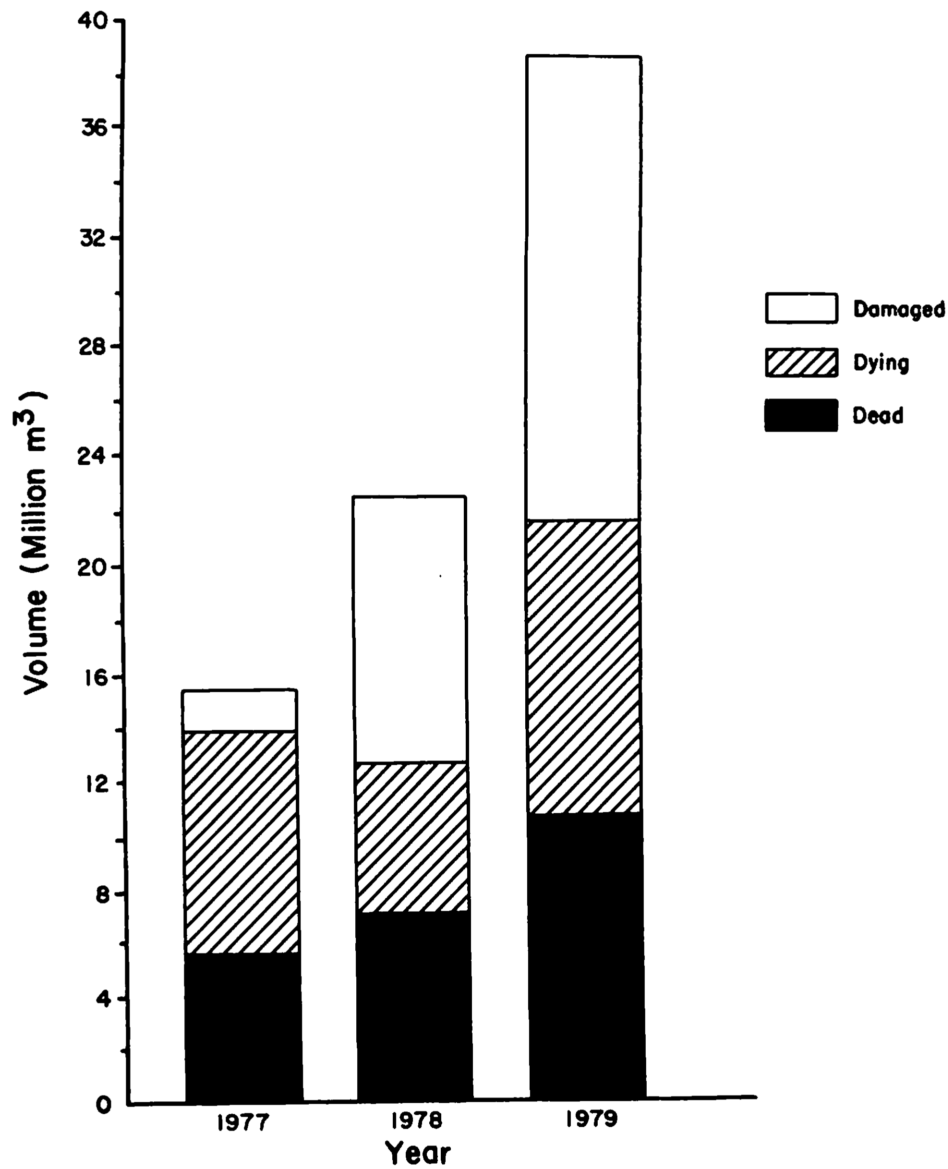


Figure V-8. Total softwood volume of dead, dying and damaged trees caused by spruce budworm defoliation in Newfoundland.

Tree height has also been affected by the budworm. Practically no increase in height has occurred on fir trees in plots located in damaged stands throughout the Island. In addition, an average of 38% of surviving fir trees had their height reduced by more than 20 cm through top-killing, and an average of 15% by 1 m or more (Raske unpublished).

Tree Vigour and Hazard Rating - Tree vigour is an expression of the health of a tree estimated by the total foliage remaining and the number of new shoots produced. Hazard is tree vigour plus severity of expected defoliation the following year.

A hazard-rating system was used to assess the severity of expected damage in 1980 to Newfoundland's forests (Moody 1980). Moderate-to-high hazard category indicates greatly reduced vigour where some top-killing can be expected. In areas of very high hazard extensive top-killing and tree mortality is likely to occur. About 902 000 ha of forest were forecast in 1979 to be in the moderate-to-high hazard class in 1980 (Fig. V-9). The high-hazard areas corresponded almost completely to areas forecast to have moderate to severe defoliation in 1980, i.e. the vigour of stands in areas of expected severe defoliation was low and tree mortality was imminent. These areas occurred predominantly in central and eastern Newfoundland.

The infestation subsided in most areas of western Newfoundland in 1978 and 1979 and some stands showed good recovery. Recovery growth has provided food for the budworm, and another outbreak could occur. Therefore, spot infestations of the budworm now current in the west could spread to recovering stands. Recovering stands are weakened stands and not likely to survive another outbreak in such close succession.

### ii) Immature Stands -- B.H. Moody

Little information is available on budworm damage in young or immature balsam fir stands, probably because these stands are less frequently damaged than mature or overmature stands. Balch (1946), Blais (1958a), Craighead (1925) and Graham and Orr (1940) concluded that immature fir stands, while not necessarily immune to attack by the spruce budworm are usually more resistant to damage than mature or overmature stands. Baskerville (1960) in New Brunswick, observed the thinning effect of a budworm epidemic on a young stand which lost about half of the balsam fir stems and the survivors sustained top-killing.

Nevertheless, the spruce budworm outbreak in Newfoundland has been unusual in that severe infestations have occurred and maintained themselves in large areas of balsam fir regeneration. In western Newfoundland, previous small outbreaks also

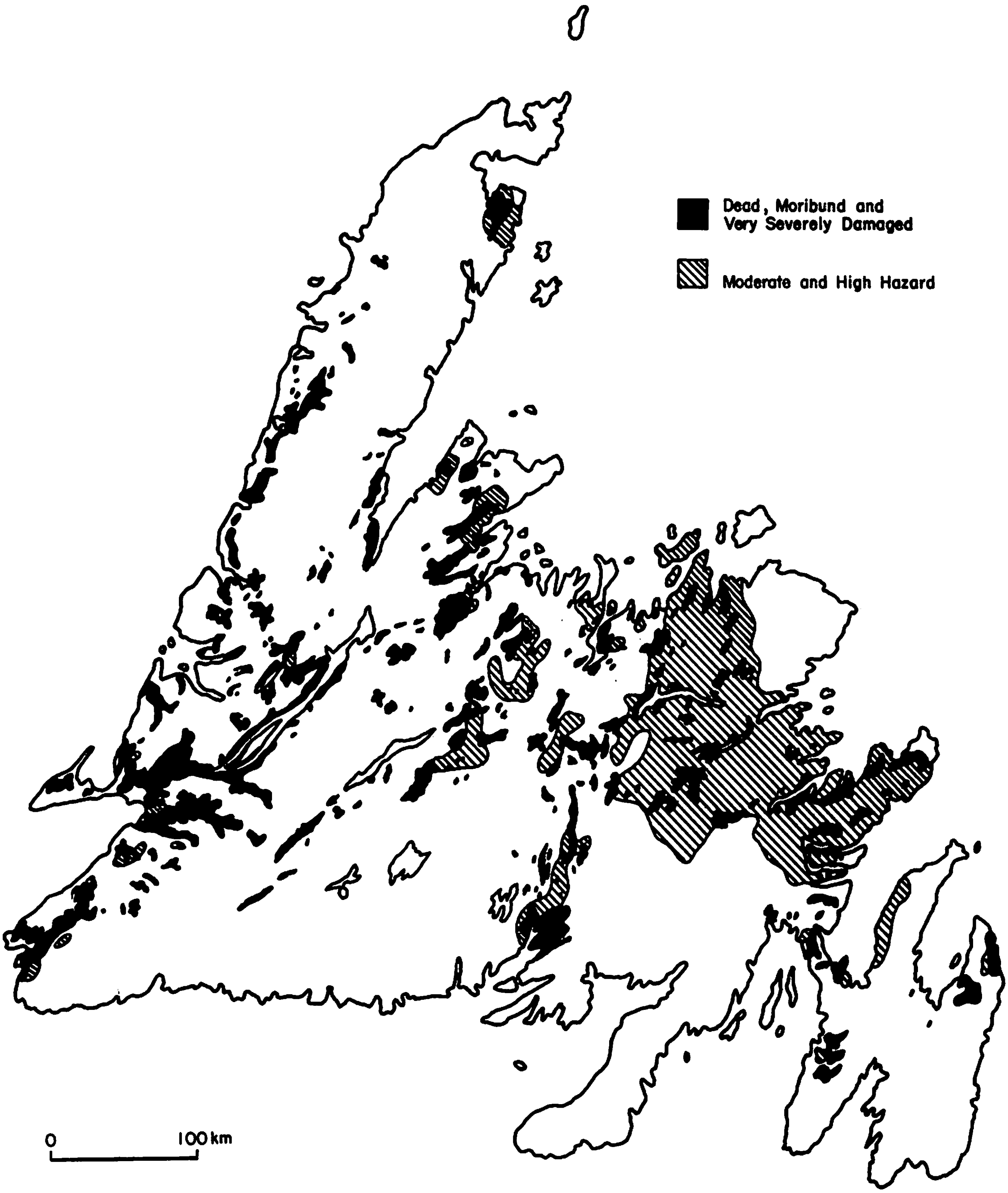


Figure V-9. Areas of dead, moribund and very severely damaged stands in Newfoundland, and forecast of moderate and high hazard areas for 1980.

affected younger, immature stands (Carroll 1956b and Carroll *et al.* 1962). The present infestation has severely damaged 46 600 ha of immature stands in 1979, an increase from 32 000 ha in 1978. In 1979, the area with 50% or higher fir mortality reached about 23 300 ha (Table V-5) (Moody 1980).

Tree mortality continued in stands with three to four years of moderate to severe defoliation and included stands under initial stress from damage previously caused by other insects, such as the balsam fir sawfly and the balsam woolly aphid. Cumulative tree mortality in stands in the Harry's River, Furries Brook, White's Road, Trout Brook and Barachois areas (Management Unit 14) (Table V-5) ranged from 15% to 100%. Most stands in western Newfoundland except Barachois and Barry's Brook areas, sustained no budworm defoliation in 1978 and 1979 and showed good recovery. However, stands at Barachois Brook are dead or dying and at Barry's Brook severe damage, including bare tops are common. Other areas in central and eastern Newfoundland have also been damaged (Table V-5).

Tree mortality from budworm defoliation in dense immature stands has been viewed as natural thinning, beneficial to growth. But tree mortality, caused by the budworm, is uncontrolled, uneven and patchy, resulting in poor quality stands. The number of hardwoods may also increase forming mixed stands.

Young stands do not produce seeds and therefore understory seedlings are absent. When these stands are killed replacement can be very costly. To date, about 240 ha of these immature stands with more than 50% tree mortality have been cleared and scarified for planting with black spruce by the Provincial Department of Forest Resources and Lands.

Immature stands that have been severely damaged and have recovered, may still have one to six years of height growth killed. This damage to young trees retards development, and also puts these trees at a disadvantage in competing for light and space. Other forms of damage are deformed stems or bushy crowns, making trees unfit for some later uses.

### iii) Future Stands -- W.J. Meades and H.O. Schooley

Loss of Seed – The spruce budworm is a major factor limiting the production of cones on balsam fir and black spruce during an outbreak (Schooley 1978, 1980b). The decrease in cone production has greatly reduced the availability of seed for stand replacement following cutting and mortality. The seed required by the Province's tree nursery and silviculture programs has also been difficult and expensive to obtain.

Table V-5. Area of productive, immature softwood stands where balsam fir tree mortality caused by the spruce budworm was evident in 1979 in Newfoundland (Moody 1980).

| Management unit | Ownership | Area(ha) by damage categories* a | b | c | Total area (ha) |
|---|---|---|---|---|---|
| 4 | Price | - | 1 486 | - | 1 486 |
| 5 | Crown | - | 468 | - | 468 |
| 5 | Price | - | - | 220 | 220 |
| 6 | Bowater | - | 2 862 | - | 2 862 |
| 7 | Crown | - | 440 | 1 679 | 1 679 |
| 8 | Bowater | - | - | 199 | 199 |
| 8 | Price | - | - | 199 | 199 |
| 9 | Bowater | - | 440 | - | 440 |
| 9 | Price | - | 2 307 | 413 | 2 720 |
| 10 | Price | 1 377 | 1 311 | - | 2 688 |
| 11 | Price | - | 468 | 1 569 | 2 037 |
| 12 | Price | - | 185 | - | 185 |
| 14 | Crown | 4 706 | 4 977 | - | 9 683 |
| 14 | Bowater | 8 732 | 1 899 | - | 10 631 |
| 15 | Bowater | 8 536 | 2 106 | - | 10 642 |
| ALL | Crown | 4 706 | 5 885 | 1 679 | 12 270 |
| | Bowater | 17 268 | 7 307 | 199 | 24 774 |
| | Price | 1 377 | 5 757 | 2 401 | 9 535 |
| Total Island (ha) | | 23 351 | 18 949 | 4 279 | 46 579 |

*a - 50% or more of total stems in stand dead.

b - 20% to 49% of total stems dead or more than 50% of total stems dying (dying = 90% or more total defoliation)

c - 5% to 19% of total stems dead or less than 50% of total stems dying.

Spruce budworm feeding that severely defoliates trees or destroys vegetative buds results in the shortening or elimination of shoots upon which the cones develop. This reduction in cone bearing sites, together with lower tree vigour caused by defoliation, limits the formation of cone buds. Production of cone buds was reduced by 50% on balsam fir trees severely defoliated one year and by 75% on trees severely defoliated for two or more successive years (Schooley 1978). A similar absence of cone production occurred on budworm damaged black spruce trees (Schooley 1980b).

Spruce budworm larvae also reduce cone production by feeding directly on developing cone structures. The budworm does not damage cone buds, but feeds on cone flowers and conelets that form after flowering. On undamaged balsam fir, 50% or more of the cone buds usually develop into mature cones but less than 5% reach maturity on severely defoliated trees. On undamaged black spruce over 90% of the cone buds develop into mature cones. However, virtually all flowers are destroyed when only a small population of budworm larvae are present because black spruce needles and vegetative buds are less favourable feeding sites for young budworm larvae than are the flowers (Schooley 1980).

Undesirable Succession – Few studies have considered the long term successional implications of large scale spruce budworm outbreaks (Ghent *et al.* 1957, Ghent 1958, Baskerville 1978). Extrapolation from these studies to the Newfoundland situation is limited because of differences in forest composition and climate. However, natural succession, as well as succession following logging and fire have been documented for Newfoundland (Damman 1964, 1967; Meades 1982). These publications are based on the life history of dominant trees and comparative examination of successional trends in disturbed and undisturbed stands on the same site type. This information provides considerable insight into the successional trends that may occur following spruce budworm devastation of balsam fir and black spruce stands.

The type and timing of successional trends expected following budworm caused mortality for the most common sites in central and western Newfoundland have been modelled (Fig. V-10). These two models have been constructed under the following assumption: 1) at least 50% of the softwood crown cover in a stand is dead, and 2) the area exceeds several ha to discount the influence of "seeding in" from adjacent, less affected stands. Additional models for other site conditions and damage levels are also feasible.

The model for central Newfoundland considers succession in forests of medium moisture and nutrient status (Fig. V-10). It includes the following forest types described by Damman (1964, 1967); *Pleurozium*-balsam fir forest type (*Abietetum typicum*), *Gaultheria*-balsam fir type (*Abietetum gaultherietosum*), black

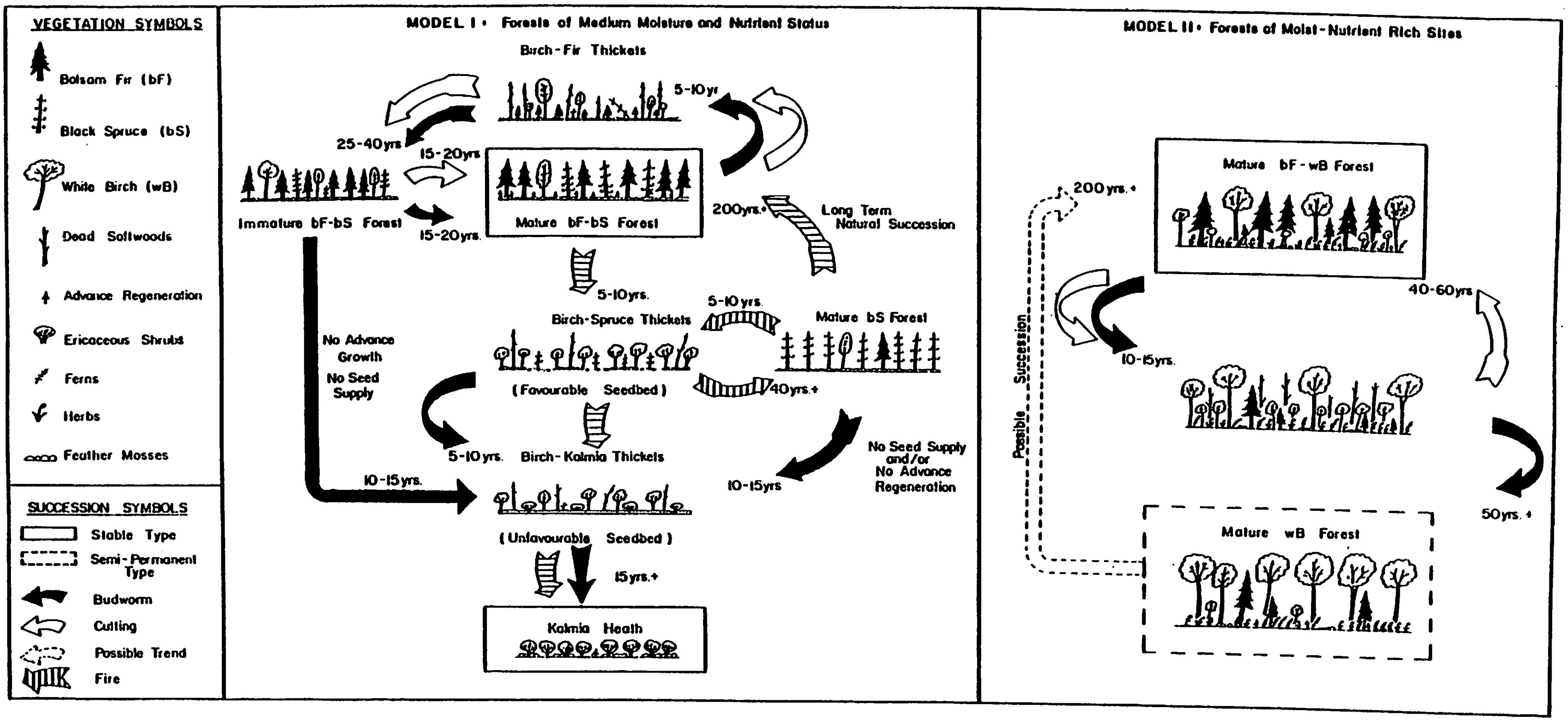


Figure V-10. Successional trends in Newfoundland forests following severe spruce budworm defoliation.

spruce-moss type (*Piceetum marianae*), and *Kalmia*-black spruce type (*Kalmio-Piceetum typicum*). Succession following budworm-caused mortality would proceed almost identically to that following timber harvesting were it not for two factors:

1. Logging does not interfere with seed production until the trees are cut; however, budworm feeding significantly decreases seed production for several years prior to causing mortality (Schooley 1978, 1980b).

2. Logging occurs in 50 to 60 year cycles whereas the budworm can kill stands at any stage of their development.

Mature mixed fir-spruce forests with advanced fir regeneration in the understory should be able to recover from budworm-caused mortality as would be expected following cutting. In such stands the percent composition of fir usually increases following cutting. If mixed stands are destroyed at a young age before they produce seed and establish advance growth then the site may be taken over by competing hardwood and shrub species. This type of succession usually terminates in a stable Kalmia heath. This pathway is similar to that which led to the extensive barrens of eastern and southern Newfoundland except that their development was accelerated by frequent fires rather than insect-caused mortality (Damman 1971, 1975; Meades 1973, 1982).

Mature black spruce stands rarely have adequate black spruce advance growth to provide fully stocked replacement stands (LeBarron 1948, Heinselman 1957, Nickerson 1956, 1958). Successful regeneration of black spruce does not occur unless a favourable seedbed is present. Such seedbeds are usually provided by forest fire but may also be provided by scarification (Candy 1951, Place 1955, van Nostrand 1971, Richardson 1975, Howard 1970, Jeglum 1979). Fire also induces the release of seed from the semi-serotinous cones of black spruce (Damman 1964, LeBarron 1939, Wilton 1963, Black and Bliss 1980). An evenly distributed minor stand component of balsam fir could result in succession to mixed fir-spruce stand type in the absence of a favourable spruce seedbed. Given the low levels of seed production associated with budworm infestation and the lack of favourable seedbeds, succession to Kalmia heath will probably occur where black spruce stands are killed by the budworm.

The model for western Newfoundland considers succession in forests on moist to wet nutrient rich sites (Fig. V-10). It includes the following forest types described by Damman (1964, 1967); *Dryopteris*-balsam fir type (*Abietetum dryopteretosum*), *Rubus*-balsam fir type (*Abietetum rubetosum*), and *Hylocomium*-fir type (*Abietetum hylocomietosum*). In these stand types the hardwood and softwood stocking levels are quite variable and strongly influence the direction succession may take. Where softwood stocking levels are adequate, succession to mature fir-birch stands should not be impeded by mortality caused by the spruce budworm. However the cover of hardwoods, especially birch will probably increase each time a stand is damaged by the budworm. Where hardwoods are dominant in a stand because the softwood of the overstory has been killed, the growth rate of the fir understory will be suppressed. This kind of stand structure could originate from the repeated occurrence of budworm-caused mortality. The stability of hardwood stands of this type is uncertain and needs further study (Richardson 1979b).

## b) WILDLIFE AND FISH HABITAT

A.G. Raske and A.B. Case

The effect of the spruce budworm outbreak on wildlife and fish habitats has not been documented, though several studies are currently underway in western United States and one study has been started in Newfoundland. Therefore, the impact of a spruce budworm outbreak on these habitats is surmised from general knowledge of events following the opening of forest stands.

Severe defoliation and large-scale mortality of stream bank vegetation may increase stream water temperatures, and reduce the input of terrestrial insects. Water temperatures of small tributary streams may be raised by severe defoliation or mortality of stands adjacent to the stream. Such streams often serve as principal spawning and rearing habitats for salmonids. However, stream temperatures are not likely to reach critical levels for any native fish species in Newfoundland. A major food supply for trout is terrestrial insects that drop from over-hanging branches. Severe defoliation would decrease the insect fauna on fir branches which might affect the food supply of fish. However, this would not be critical as alternate in-stream food sources are probably available. Riparian vegetation is usually a mixture of balsam fir and non-susceptible plant species. Therefore, there is little possibility of large-scale absence of all vegetation along streams and thus remote likelihood of significant impact upon fish habitat.

Changes in the structure of the forest canopy could have significant effects on songbird population levels. At the beginning of an outbreak songbird populations in the upper canopy should increase because budworm larvae present an abundant food source. Most forest songbirds are insectivorous and opportunistic feeders. None are obligate feeders of the budworm. As the budworm outbreak continues foliage in the upper canopy gradually decreases, and tree crowns die. Now the habitat structure is unsuitable for insect species and therefore also unsuitable for upper canopy songbirds (Titterington *et al.* 1979). However, such severe changes would unlikely be uniform over large areas, and bird populations would simply move from one locality to another. An overall decrease in upper canopy songbirds caused by budworm outbreaks seems unlikely.

Wildlife habitats for ungulates are more likely to benefit from budworm outbreaks than to be harmed by them. Harmful effects would be partial loss of cover and reduced shade needed for concealment of large ungulates such as moose (*Alces alces* (L.)). This would occur in young fir thickets. Beneficial effects would be increased browse production by the rejuvenation of mature and overmature stands, which tend to contain little browse. Defoliation and mortality may result in the thinning of dense thickets allowing passage for wildlife and more uniform utilization of the habitat. Twig mortality caused by defoliation of young stands may decrease the amount of fir browse available; however, on richer sites this would be compensated for by an increase in hardwood browse.

Spruce budworm outbreaks affecting balsam fir stands generally favour increases in snowshoe hare (*Lepus americanus* Erxleben) populations. This results from increases in the amount of suitable browse and cover corresponding to changes in understory vegetation. Normally the greatest population increases will occur where the replacement vegetation is principally hardwood, though a predominantly softwood understory will also encourage population increases.

Black spruce stands that revert to *Kalmia* barren following harvesting, destruction by fire or by insects, will not likely provide conditions conducive to increased populations of hare or other small mammals.

Masked shrew (*Sorex cinereus* Kerr) populations will likely benefit from severe budworm outbreaks resulting in a habitat of mixed hardwood-softwood regeneration, but are unlikely to be noticeably affected by other types of regeneration or plant succession. Populations of mink (*Mustela vison* Schreber) and the short-tailed weasel (*Mustela erminea* L.) are probably affected in similar fashion as those of the masked shrew. The meadow vole (*Microtus pennsylvanicus* (Ord)) is principally a grass-eater and therefore is unlikely to be significantly affected by outbreaks.

Mature forest, characterized by a dense tangle of living and dead trees, is considered to be the favoured habitat of the pine marten (*Martes americana* Turton). Because a spruce budworm outbreak may both create and destroy patches of suitable habitat, there will likely be little net overall effect on pine marten populations. However, trends toward a highly managed forest will exert a greater negative effect on marten populations than any budworm outbreak.

Extensive tree mortality in fir and spruce stands will probably have a detrimental effect on populations of upper canopy birds (Gage and Miller 1978) and on red squirrels (*Tamiasciurus hudsonicus* Erxleben). Preliminary studies by Lapierre (1980) suggest that squirrel populations decrease because of decreased cone production by trees during an outbreak.

Habitat changes brought about by the natural, unchallenged cycling of budworm populations are likely to be neither detrimental nor beneficial to wildlife in the long term. In the process of forest destruction and renewal, populations of some species are reduced for several years while other species gain a temporary advantage. In the latter stages of a budworm outbreak there may be a decrease of upper canopy birds, red squirrels and possibly moose. Later, bark-probing and cavity-nesting birds may benefit, as will rabbit, moose, masked shrew and weasel. Later still, as the regenreation matures, a different fauna will flourish. The pattern of changes is predictable. Overall these changes in wildlife habitat are minimal, both economically and aesthetically, and are dwarfed by more obvious and important impacts of the spruce budworm.

## c) AMENITY FORESTRY

A.B. Case

The consequences of insect infestation on amenity values have not been quantified but there is little doubt that much of the public reaction to the current spruce budworm epidemic can be traced to its visual impact. Visual appearance is becoming increasingly important as people are coming to expect better living conditions in the home, place of work, and in the environment (Twiss 1969).

The budworm infestation exerts a negative impact on aesthetic quality by changing vegetational texture, colour, or form, such as the red and grey color of defoliated and dead trees. Much deterioration in aesthetic quality is caused by reductions in "forest view" by the stimulation of understory vegetation and the prolific ingrowth of weed species (Smyth and Methven 1978). Moreover, deteriorating stands with clusters of leaning and windthrown trees present a chaotic scene that is offensive to most recreationalists.

Greatest aesthetic impacts are felt in areas that are heavily frequented by the public, such as parks and picnic areas, where hanging larvae are a nuisance, and along highways and recreation corridors such as canoe routes and wilderness trails. Such impacts can adversely affect visitor use patterns, perceptions and satisfactions that may result in a loss of revenue from tourism.

Significant effects are experienced in urban and suburban areas where the budworm causes destruction of ornamental firs and spruces, and seriously damages trees in green belts. In recent years budworm infestation in juvenile and immature fir stands has reduced the quality of Christmas trees.

## d) FIRE HAZARD

B.J. Stocks and D.B. Bradshaw

Historical information indicates that severe forest fires may follow spruce budworm infestations, e.g. the Miramichi Fire of 1825 in New Brunswick and the Chapleau-Mississagi Fire of 1948 in Ontario. However, fire control personnel in eastern Canada have been divided in their opinions as to whether balsam fir mortality subsequent to budworm outbreaks actually increases fire potential in this fuel type (Alexander and Stocks 1978). No quantitative data have yet been gathered on the budworm-fire interrelationship in spite of an abundance of qualitative statements on the subject. To date, two spring and two summer experimental areas have been burned in Ontario with widely different results: the spring fires resulted in sustained crowning and spotting with extremely fast spread rates whereas the summer fires were unable to sustain themselves and did not spread. A proliferation of lush green understory vegetation following mortality and crown opening, appears to be the major reason for this substantial difference between spring and summer fires.

In Newfoundland, there has been no previous record of stand mortality over extensive areas resulting from spruce budworm infestation (Otvos and Moody 1978), and therefore, there has been no history of fire developing and spreading in such areas. However, some general statements concerning the fire hazard resulting from insect-killed forest stands are possible.

First, a faster drying out of fuels will occur as canopies of dead stands allow both sun and wind to enter. This will be of particular importance during the spring period between snow melt and "green-up". Fuels in these stands will be in a burnable condition for a longer period than fuels in corresponding living stands.

Second, rate of fire spread will be affected by two characteristics of a dead forest. Although the quantity of bark on standing dead trees may vary, it nevertheless can be expected to serve as flankers (wind carried firebrands). Appropriate wind conditions will produce greater rates of spread than in living forests. Generally the higher average wind speed in Newfoundland than other parts of eastern Canada may increase fire hazard. The quantity of dead material on the forest floor, a second feature of a budworm killed forest, will serve as excellent ignition sites for fires caused by flankers.

The nature of the fuel in a budworm-killed forest may make fire suppression more difficult in several ways. Fallen dead material will impede access to the fire's perimeter and slow the laying of hose lines as well as interfering with other suppression activity. Also, standing dead trees are easily felled by wind, water bomber activity and the action of other machinery. This presents a serious danger to fire fighters. Such factors favour a change from traditional fire fighting methods. If an initial attack has failed, fire fighters will not likely be able to work directly on the perimeter. Instead, natural barriers such as lakes, rivers, bogs and roads, lying some distance ahead of the fire, will be sought out. The area between the barrier and the head of the fire will be burned off. Such an approach should present less danger to fire fighters.

## e) UTILIZATION OF DAMAGED FORESTS

### i) Harvesting and Utilization -- J. Hudak and J.T. Basham

Periodic outbreaks of the spruce budworm, the hemlock looper and the balsam woolly aphid have caused extensive tree mortality in balsam fir forests in various parts of eastern North America. The dead and dying trees are prone to attack by decay fungi which degrade the wood quality and the trees in time become unsuitable for pulpwood, the major industrial product of balsam fir. Information on how long dead trees will remain useful for pulpwood is basic for planning efficient salvage operations. Deterioration of trees killed during previous outbreaks of the spruce budworm has been studied in Ontario (Basham 1951, Basham and Belyea 1960) and in New Brunswick (Stillwell and Kelly 1964). Deterioration of balsam fir killed by the balsam woolly aphid and the hemlock looper was investigated in Newfoundland (Hudak 1975, Hudak *et al.* 1978). Regardless of geographic locations and differences in the causal agents of tree mortality, the type of sapwood deterioration was similar throughout eastern Canada. A reddish brown discoloration caused by *Amylosterium chailletii* (Fr.) Boid. occurred in the early months after death and this was followed by a white pitted rot caused by *Polyporus abietinus* Dicks ex Fr. This type of decay degrades lignin primarily and leaves the cellulose relatively intact. Decay that destroys the cellulose was sometimes present, but not common. The major difference in deterioration among the various regions was the much faster development of saprot in Ontario than in other parts of eastern Canada. Advanced saprot by *P. abietinus* which appreciably reduced the hardness of the wood was evident within a year after death in Ontario but it did not occur until the third year in Newfoundland. Similar results were obtained by studying artificially girdled trees in Ontario, Quebec, New Brunswick and Newfoundland (Basham *et al.* 1976). Girdled trees died and developed saprot first in Ontario and were followed by those in New Brunswick, Quebec and Newfoundland. The principal cause of these differences appears to be regional differences in the climate and in the intensity of attack by secondary insects, particularly bark beetles that invade weakened and dead trees (Stillwell 1960b, 1966). Differences in rate of deterioration are becoming evident even among regions of Ontario where striking differences exist in intensity of bark beetle attack of trees killed by the spruce budworm (Basham 1980). Such differences have a major influence on the success or failure of salvage operations of damaged stands. The general problem of deterioration and salvage following budworm damage has been reviewed recently (Lee and Field 1978, Sewell and Maranda 1978).

In Newfoundland the present outbreak of the spruce budworm is the first one with appreciable tree mortality. Deterioration of trees killed by this pest has not been studied, but is expected to be the same as that reported for trees killed by the balsam woolly aphid and the hemlock looper (Hudak 1975, Hudak *et al.* 1978). Major biological, physical, and chemical parameters of wood that influence pulping characteristics were measured in trees dead for various periods of time. The moisture content in the sapwood decreased much more rapidly after death than in the heartwood but it levelled off in both sapwood and heartwood at about 50% in the third year after death. This moisture content would not influence pulping quality (de Montmorency 1964, Keays and Bagley 1970). The average basic density of wood decreased by about 5% in five years after death indicating an equivalent loss in wood substance (Hudak *et al.* 1978). However these losses are compounded with those caused by debarking as much of the decayed saprot is lost in that process (Hiscock *et al.* 1978, Hatton 1978). The major cellulose content of decayed wood influencing pulp yield and quality did not change drastically even five years after death. These results were confirmed by pulping trees with increasing amounts of saprot (Table V-6). It is evident that both pulp yield and quality decreased with the use of dead trees and such losses would increase the cost of manufacturing paper (Hiscock *et al.* 1978). However, trees dead for up to five years may be used for pulpwood. A similar conclusion was reached for dead trees from New Brunswick (Hatton 1979). Apparently it is technically feasible to use trees dead for even six years in the production of bisulphite and kraft pulps; the limiting factor appears to be one of economics, i.e. the loss of sapwood in debarking, rather than quality (Hiscock *et al.* 1978).

Additional losses of wood during harvesting and transportation must be considered to assess the increased costs of utilizing damaged stands (Kohrt 1978). The Newfoundland Forest Research Centre has initiated a study in 1980 to determine wood losses during harvesting. Preliminary results in a stand of timber dead for three years had a ten-fold increase in logging residues compared to logging a living stand (Warren unpublished).

Table V-6. Yield and quality of bisulphite pulp from balsam fir killed by hemlock looper (from Hiscock *et al.* 1978).

| Parameter | Groups[1] | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Total saprot, % of merch. vol. | 0.0 | 28.3 | 34.7 | 40.1 | 54.5 |
| Advanced rot % of merch. vol. | 0.0 | 3.9 | 7.1 | 14.2 | 21.0 |
| Yield, % total | 67.9 | 67.8 | 65.5 | 65.0 | 63.1 |
| CSF @ 2 min. refining | 363 | 298 | 256 | 255 | 202 |
| Burst factor | 108.6 | 104.3 | 101.6 | 98.8 | 93.5 |
| Tear factor | 64.7 | 66.7 | 68.5 | 64.0 | 63.3 |
| Strength factor | 70.3 | 69.6 | 69.6 | 63.2 | 59.2 |
| Breaking length; km | 15.10 | 14.98 | 14.38 | 14.19 | 14.28 |
| Brightness (Elrepho) | 50.8 | 48.7 | 49.1 | 48.5 | 46.2 |
| Opacity (Elrepho) | 54.1 | 55.5 | 58.9 | 59.2 | 58.0 |

[1] Increasing amounts of saprot.

All the above information on deterioration may well be academic to the current situation in Newfoundland. A severe windstorm caused severe and extensive blowdown in the winter of 1979-1980. This blowdown may shatter the prospect of salvaging many stands killed by the budworm in Newfoundland. The harvesting of these stands will be very difficult and dangerous at best; if not impossible.

ii) Harvesting and Storage -- J. Hudak and G. Warren

Accelerated harvesting of stands killed by the budworm and storing of this harvested wood is an alternative option to the regular practice of harvesting only as needed. This option has been contemplated on Cape Breton Island in Nova Scotia following extensive tree mortality (Routledge 1980). In 1977 the Government appointed a Task Force "to plan the orderly redistribution of wood resources of the Province so as to maintain as orderly a supply-demand pattern as possible". The Task Force engaged a consulting firm to make recommendations. The report recommended the salvage-harvest of 10 200 000 $m^3$ over a five year period with the participation of all pulp and paper companies and an eventual storage of 1 564 000 $m^3$. The study estimated that over a five year period carrying charges would be about $35/$m^3$ based on storing 1 200 000 $m^3$ and recovering it over a three year period at 10% interest rate. The report also analized the feasibility of various storage methods and provided estimates for capital costs and other categories. The recommendations proved to be impossible to implement because of extra transportation costs and other inherent problems.

The Task Force modified the plan to store 240 000 $m^3$ annually from 1978 to 1982 with consumption of stored wood from 1983 to 1985 and with a maximum cumulative storage of 1 200 000 $m^3$ in 1982. These recommendations were followed by consultation among Department of Lands and Forest, DREE and the Nova Scotia forest industry which led to a salvage and storage agreement.

The primary purpose of the agreement was to accelerate harvest and storage in excess of present requirements, thus generating additional employment and possibly afford some relief from short term wood shortages. The agreement allows for the storage of a total of 1 300 000 $m^3$ of pulpwood in 1978, 1979, 1980, 1981. The industry produces and puts the surplus wood in storage and the Province in turn purchases the stored wood. The industry has agreed to repurchase the pulpwood from the Province in 1982, 1983, 1984 and 1985 at current prices at the time of purchase. In addition a Joint Monitoring Group has been established to assess the condition of the timber being harvested and stored. The parties will accelerate the schedule of purchase depending on recommendation of the Joint Monitoring Group.

The salvage, storage agreement came into effect in 1978. In 1974 the industry harvested only 216 000 $m^3$ but through the accelerated program harvesting in 1979 reached 740 000 $m^3$ with 613 000 $m^3$ in storage. Deterioration of trees has not been a problem. But in areas where the mortality occurred in 1976 and 1977 trees broke during harvesting. Also the dense shrub growth is becoming a serious obstacle to the workers.

The excess wood is being stored on land as storage in water was not possible. The company has estimated that the utilization of damaged stands has increased the wood consumption/ton of paper by about 7% during the past four years. Hatton (1979) estimated that the use of standing trees dead for more than four years after death will increase the wood needed to produce a unit of paper by about 44% and, similarly, the wood costs/ton of paper by about 50%.

It is difficult to predict the pathway of deterioration of trees in storage because most of the trees died before harvesting and thus contain some decay. Healthy trees cut and stored apparently deteriorate differently than those left standing. In standing dead trees in eastern Canada, most of the deterioration is caused by white rot which leaves the cellulose relatively intact. The volume affected by brown cubical rot which destroys the cellulose is negligible (Basham 1951, Stillwell and Kelly 1964, Hudak *et al.* 1978). However in windthrown trees, in stored wood and in logging slash, brown cubical rot becomes more prevalent (Davidson and Newell 1953, Stillwell 1959; Loman 1962, 1965). It is likely that such deterioration will be a part of the deterioration in stored trees even if they were cut after death.

In anticipation of possibly opting for wood storage in Newfoundland wood cut by the Labrador Linerboard mill and left in piles in the forest were examined in 1978 (Laflamme and Meades 1978). Tree length logs had deteriorated the most, and short pulpwood bolts the least, with 3 m logs showing intermediate deterioration. Brown cubical rot was prevalent in the upper half portion of logs in most wood tree-length wood piles and in some 3 m piles, whereas pulpwood piles mostly had sapstain and sapwood defects (Warren unpublished). Further measurements and analyses are required before conclusive recommendations can be made. However, the overall expenditure of capital and other costs of accelerated harvest and the speed of wood deterioration make the storage option appear uneconomical in spite of the benefits of preventing large scale windthrow.

# 4. STATUS OF OUTBREAK AND DAMAGE AND FORECAST FOR 1981

J. Hudak, K.P. Lim, B.H. Moody and L.J. Clarke

## a) INTRODUCTION

The Forest Insect and Disease Survey, Canadian Forestry Service, Newfoundland Forest Research Centre, conducted surveys in 1980 for spruce budworm development, larval population levels, egg-masses and overwintering larvae, biological control agents, and for severity of defoliation and damage throughout the Province of Newfoundland. These surveys continued from mid-May to October. Aircraft time and casual assistance during the latter surveys were again provided by the Provincial Department of Forest Resources and Lands. Data on areas of recent cutovers and volume estimates were provided by provincial and industrial forest agencies.

## b) LARVAL DEVELOPMENT AND DEFOLIATION

The egg-mass and overwintering larval surveys in the fall of 1979 indicated moderate to severe defoliation in 1980 for 970 300 ha and moderate to high hazard for 901 900 ha. The areas of moderate to high hazard forecast coincided with those of moderate to severe defoliation. In moderate to high hazard areas tree vigour would be reduced and some top-killing and tree mortality could be expected.

Generally low temperatures and above normal precipitation prevailed throughout the Island for most of the season. This weather had little effect on budworm survival, but delayed budworm development for about two to three weeks, in comparison to 1979, and severe defoliation did not occur until the latter part of July. A few days of favourable weather resulted in spectacular and sudden increase in defoliation intensity in many parts of the Island.

In western Newfoundland most of the isolated patches of infestation reported in 1979 between Codroy Valley and the Baie Verte Peninsula became more widespread in 1980 (Fig. V-11). Isolated patches of infestation in three separate locations coalesced; one spread from Crabbes River to Bay St. Georges, the other from Corner Brook Lake to Hughes Brook and the third covered the northern section of the Baie Verte Peninsula. Population levels also increased in the St. Andrews area where the outbreak had previously collapsed.

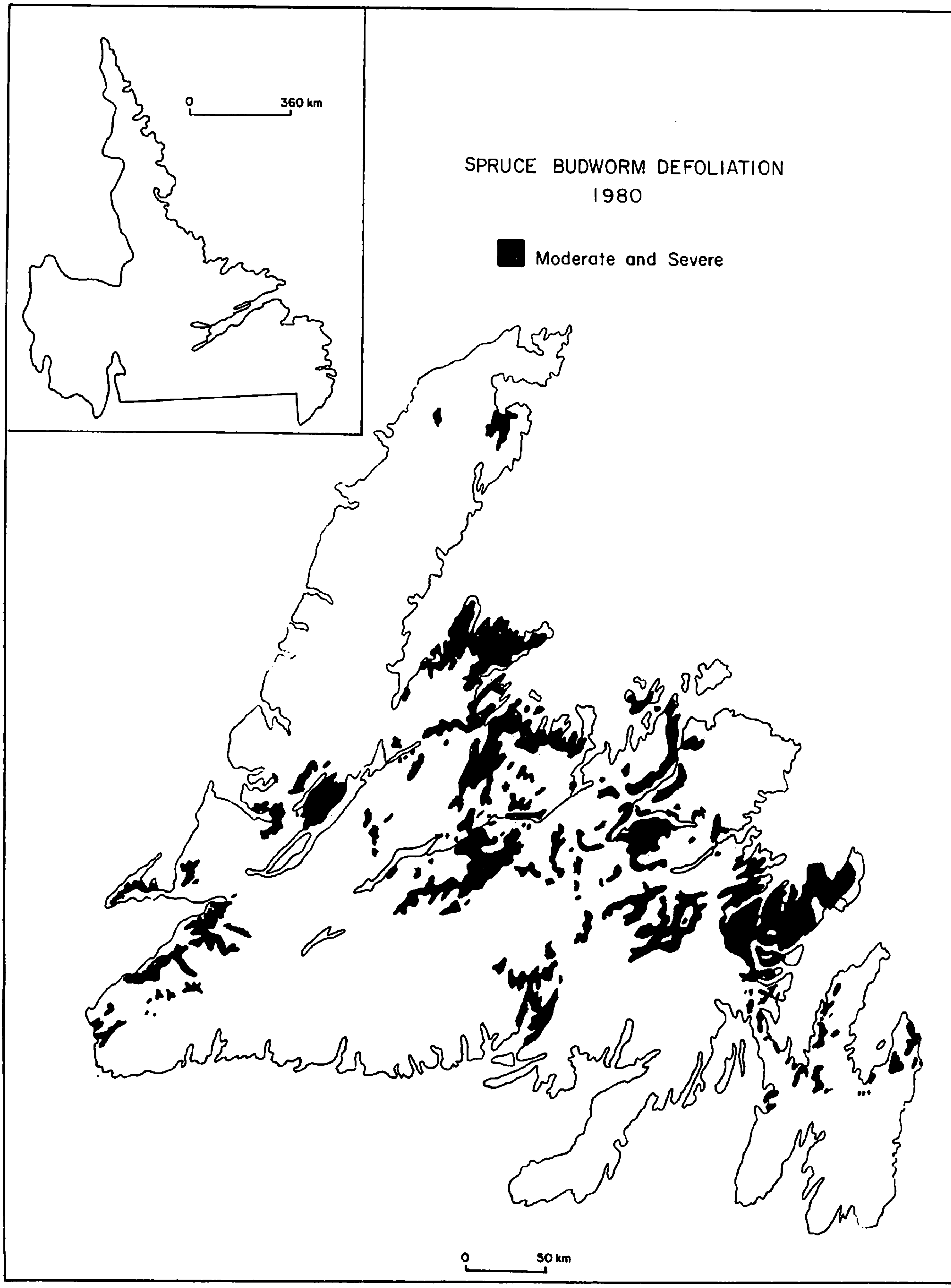


Figure V-11. Areas of moderate and severe defoliation in Newfoundland in 1980.

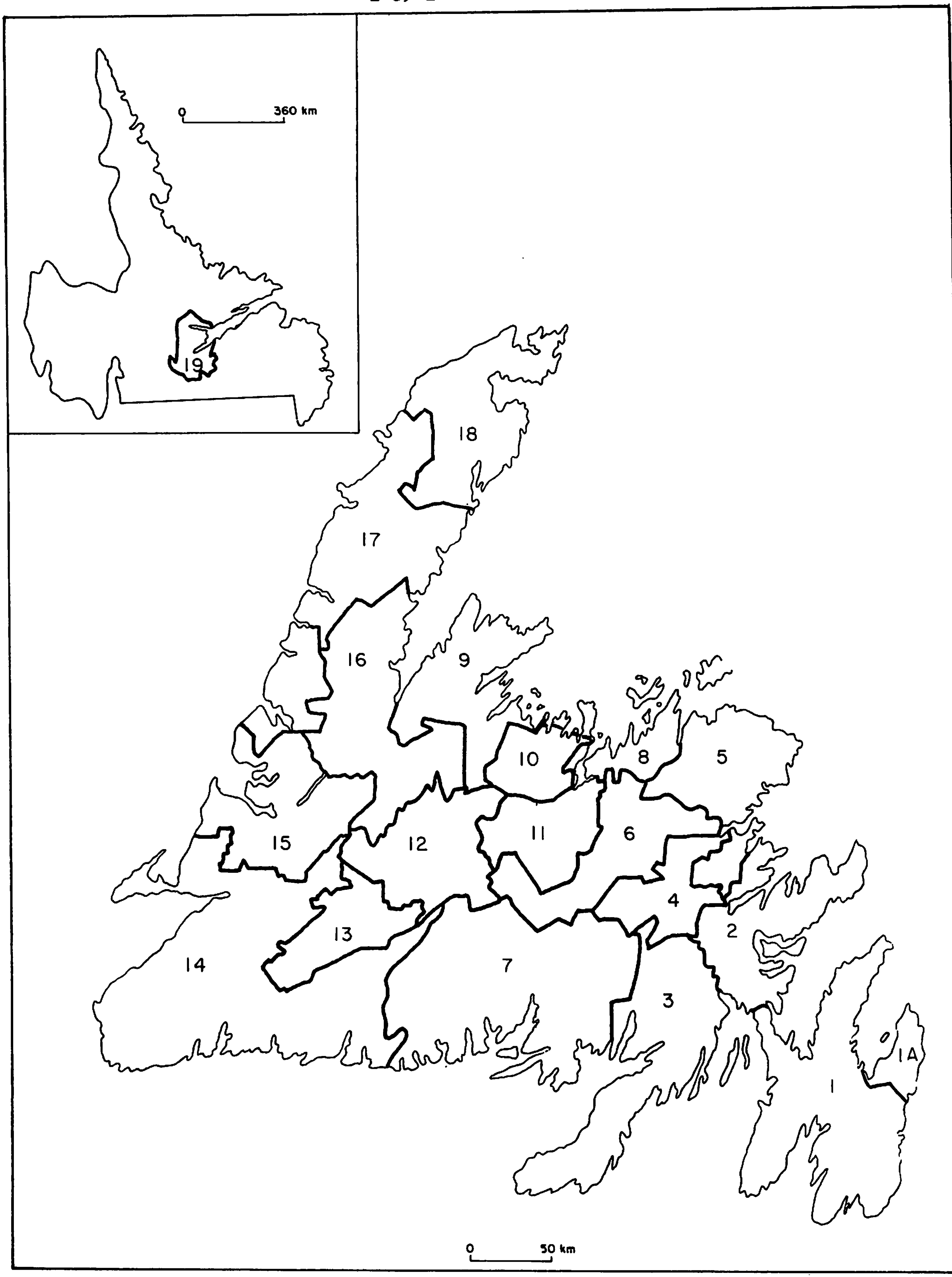


Figure V-12. Forest Management Units in Newfoundland.

The main segment of the outbreak remained the same in size throughout central and eastern Newfoundland from Red Indian Lake and Twin Lakes to Bay d'Espoir east to Random Island including the Bonavista Peninsula. However, the extent of severe defoliation in central Newfoundland decreased in some areas; the reddening of the foliage was less evident as the trees produced only small amounts of new shoots following several years of severe attack. Severe defoliation also occurred in isolated areas on the Avalon Peninsula and the separated infestations near St. John's coalesced. Most of the black spruce stands from Bishops Falls to Terra Nova in central and eastern Newfoundland were also infested by the spruce coneworm.

The total area of light, moderate and severe defoliation in the productive forests of the Island decreased slightly from 1 251 300 ha in 1979 to about 1 071 700 ha in 1980 (Table V-7). The area of softwood stands with moderate to severe defoliation in 1980 was 926 000 ha in comparison to 972 600 ha in 1979 (Table V-7, Fig. V-11). There was no active budworm infestation in Labrador in 1980.

## c) NATURAL CONTROL FACTORS

The combined larval and pupal parasitism was about 15%, a decrease from 25% in 1979. Larval parasitism was 5% and pupal parasitism 10%. Both larval and pupal parasitism decreased since 1978. The most common larval parasite was *Glypta fumiferana*. *Phaeogenes hariolus* and *Apechthis ontario* continued to be the two most numerous pupal parasites recovered. Egg parasitism by *Trichogramma minutum* was less than 1% in 1975, 1976 and 1977, absent in the samples in 1978 and 1979, and only one parasitized egg mass found in 1980.

Fungal infection by *Entomophthora egressa* and *Zoophthora radicans*[1] was about 10%, a considerable increase from 1979. These fungi occurred in both larval and pupal stages of the host, and were widely distributed across the Island. Some budworm larvae were infected by *Hirsutella* sp., a fungus reported to have caused mortality of spruce budworm in Ontario. Another fungus, identified as *Paecilomyces* sp., killed some pupae of the budworm. A microsporidian pathogen, *Nosema fumiferanae*, was detected in the midgut tissues of many larvae.

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[1] *Zoophthora radicans* (Bref.) Batko = *Entomophthora sphaerosperma* Fresnius = *Erynia radicans* (Bref.) Humber and Ben-Ze'ev.

Table V-7. Area (ha) of defoliation caused by the spruce budworm in productive forests of Newfoundland in 1980.

| Management Unit No.[2] | Defoliation Class[1] | | | |
|---|---|---|---|---|
| | Light | Moderate | Severe | Total |
| 1A | 212 | 1 032 | 17 325 | 18 569 |
| 1 | 6 852 | 942 | 31 213 | 39 007 |
| 2 | 5 095 | 5 225 | 138 642 | 148 962 |
| 4 | 11 656 | 331 | 59 294 | 71 281 |
| 5 | 21 850 | - | 57 888 | 79 738 |
| 6 | 2 381 | 1 606 | 53 840 | 57 827 |
| 7 | 946 | 6 565 | 36 721 | 44 232 |
| 8 | 29 240 | - | 55 645 | 84 885 |
| 9 | 12 632 | 8 214 | 210 911 | 231 757 |
| 10 | 2 551 | - | 33 319 | 35 870 |
| 11 | 2 938 | - | 46 993 | 49 931 |
| 12 | 24 412 | 1 874 | 36 661 | 62 947 |
| 14 | 24 309 | 4 907 | 61 135 | 90 351 |
| 15 | - | 2 030 | 32 789 | 34 819 |
| 16 | 192 | 102 | 4 961 | 5 255 |
| 18 | 435 | - | 15 845 | 16 280 |
| Total | 145 701 | 32 828 | 893 182 | 1 071 711 |

[1]Light: 1% to 25%
Moderate: 26% to 75%
Severe: 76% to 100%.

[2]Map of Management Units, see Figure V-12.

## d) DAMAGE ASSESSMENT

### i) Mature Stands

Data from aerial assessment surveys supplemented with ground checks in late July and August 1980 were used to determine the area and volume of dead and budworm damaged stands. The survey classified the merchantable forest stands according to the categories used in 1979 (see p. 44).

The total area of merchantable softwood stands with dead and dying trees, class A, B and C, decreased from about 517 800 ha in 1979 to 427 500 ha in 1980 (Table V-8, Fig. V-13). These stands contained about 17 105 460 $m^3$ of dead trees representing an increase of more than 6 825 300 $m^3$ since 1979. The volume of dying trees in stands classified as A, B, and C decreased from 11 661 300 $m^3$ in 1979 to about 4 734 200 $m^3$ in 1980. The total volume of A, B, and C stands damaged was 40 086 300 $m^3$ in 1980 compared to 38 412 000 $m^3$ in 1979 (Appendices IVA and B, VA and B). It is difficult to compare the actual volume figures of 1980 with those of 1979 as the damaged areas were more accurately demarcated in 1980 and volume figures were obtained from the recently updated inventory tables. However, comparing the total volume of stands classified as A, B, and C in 1979 and in 1980 with their corresponding inventory data, the volume in these stands increased from about 17% of the total softwood volume in 1979 to about 23% in 1980.

A portion of the merchantable stands with tree mortality, class A, B, and C, were examined to determine the age since the death of trees. Of the areas containing 9 067 043 $m^3$ of dead wood ground-checked, about 16% had been dead for more than six years and 55%, 10%, 11%, 7% and 1% have been dead for one, two, three, four, and five years respectively. The volume of timber dead for six or more years include stands weakened by previous insect outbreaks. The volume of blowdown trees was estimated at 25% of the total volume of 17 105 464 $m^3$ of dead wood in damage classes A, B, and C. The area of severely damaged forests, class D, was 627 000 ha in 1980; up from 446 000 ha in 1979.

### ii) Immature Stands

Budworm damage in young balsam fir stands on the Island was assessed in 1980. These stands were classified for the second year by the damage categories used in 1979 (see Table V-5, p. 50).

The total area of very severely damaged immature stands, classes a, b, and c, with tree mortality increased from 46 600 ha in 1979 to 62 590 ha in 1980 (Table V-9). This addition was due

Table V-8. Area and volume of productive, merchantable stands where tree mortality caused by spruce budworm was evident in Newfoundland in 1980.

| | Damage category[1] | | | |
|---|---|---|---|---|
| | A (Dead) | B (Moribund) | C (Very severe) | Total |
| Total area ha | 169 094 | 187 427 | 70 959 | 427 480 |
| Dead, volume $m^3$ | 1 181 206 | 5 188 595 | 735 663 | 17 105 464 |
| Dying, volume $m^3$ | 1 443 529 | 2 612 968 | 677 739 | 4 734 236 |
| Total, volume $m^3$ | 16 033 206 | 17 495 283 | 6 557 829 | 40 086 318 |

[1]A (Dead): 50% or more of total volume of stand dead.

B (Moribund): 20% to 49% of total volume of stand dead or more than 49% of total dying. Dying = more than 75% total defoliation.

C (Very severely damaged): 5% to 19% of total volume dead or 5% to 49% of total volume dying.

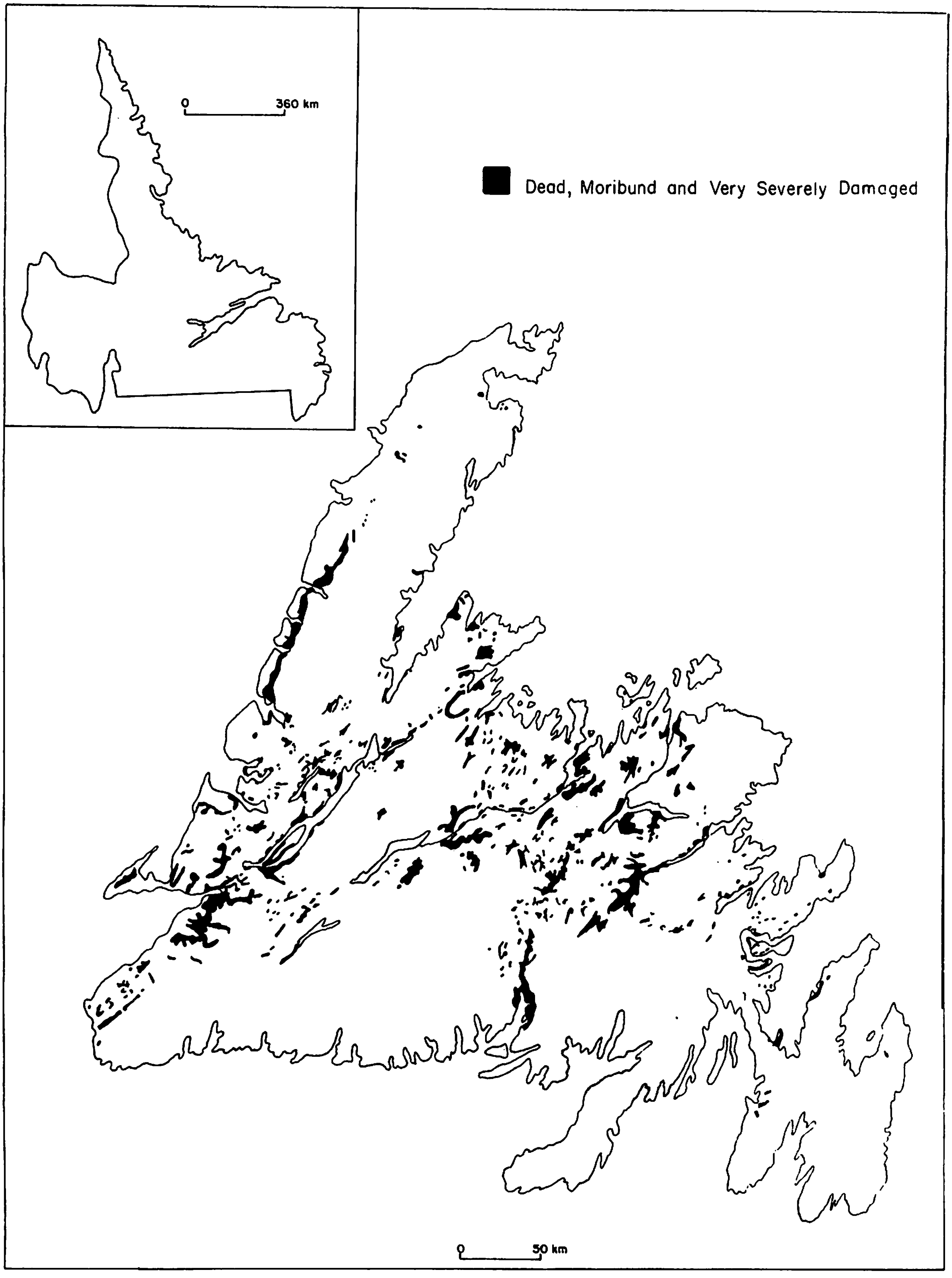


Figure V-13. Areas of dead, moribund and very severely damaged stands in Newfoundland in 1980.

Table V-9. Area of productive submerchantable stands where tree mortality was evident in 1980 in Newfoundland.

| Management unit | Ownership | Area (ha) by damage category[1] a | b | c | Total area (ha) |
|---|---|---|---|---|---|
| 4 | Price | 4 720 | 1 965 | 6 693 | 13 378 |
| 5 | Crown | - | 2 220 | - | 2 220 |
| | Bowater | - | 183 | - | 183 |
| 6 | " | - | 6 496 | 3 348 | 9 844 |
| | Price | - | 1 323 | 195 | 1 518 |
| 7 | Crown | - | 327 | 2 483 | 2 810 |
| 9 | " | 443 | 973 | - | 1 416 |
| | Bowater | - | 1 401 | - | 1 401 |
| 10 | Price | 2 096 | - | - | 2 096 |
| 11 | " | 3 293 | 5 669 | 923 | 9 885 |
| 14 | Crown | 8 600 | 1 161 | - | 9 761 |
| | Bowater | 5 368 | 1 242 | 595 | 7 205 |
| 15 | " | 873 | - | - | 873 |
| | Crown | 9 043 | 4 681 | 2 483 | 16 207 |
| All | Bowater | 6 241 | 9 322 | 3 943 | 19 506 |
| | Price | 10 109 | 8 952 | 7 811 | 26 877 |
| Total Island | | 25 393 | 22 960 | 14 237 | 62 590 |

[1] a: 50% or more of total stems in stand dead.

b: 20% to 49% of total stems dead or more than 50% of total stems dying. Dying = 90% or more total defoliation.

c: 5% to 19% of total stems dead or less than 50% of total stems dying.

mainly to the increase in the area of damaged stands in central and eastern Newfoundland where the budworm was more active. Most of the immature stands in the western areas have had no defoliation since 1977 and there tree mortality did not increase appreciably in 1980.

The major differences between the 1979 and 1980 figures by management units were the result of improved delineation of damaged stands, by more intensive aerial survey from a helicopter, by the recent update of the forest inventory, and by reclassification of cover types.

## e) FORECAST FOR 1981

The forecast for 1981 is based on egg-mass and overwintering larval surveys of over 800 sample points across the Island. The area of moderate to severe defoliation is forecast to decrease along the northeast coast from Green Bay to Bonavista Bay (Fig. V-14). However, inland in central Newfoundland severe defoliation is expected to occur from Red Indian Lake to Random Island including the Bonavista Peninsula. Severe defoliation is also forecast for the Bay d'Espoir area and two separate areas on the Avalon Peninsula. In western Newfoundland the extent of severe defoliation is expected to increase between Codroy Valley and Deer Lake and on the northern section of the Baie Verte Peninsula (Fig. V-14). The total area of moderate and severe defoliation in the productive forests of the Island is forecast to be about 800 000 ha in 1981 (Table V-10). Population levels, as indicated by the number of egg-masses per 10 $m^2$ of foliage, are expected to remain about the same as in 1980 (Table V-11).

Spruce budworm damage hazard areas were delineated. Hazard is based on: the egg-mass and overwintering larval surveys, the severity of current and previous year's defoliation, and on tree vigour. A moderate to high hazard rating indicates that tree vigour will be reduced and some top killing is expected. Very high hazard denotes extensive top killing and tree mortality are expected. Moderate to high hazard is expected in about 780 000 ha in 1981 (Table V-10, Fig. V-15). This total includes some areas already in the very high hazard category as indicated by the presence of tree mortality. Almost all of the area of moderate to severe defoliation forecast for 1981 falls in the moderate to very high hazard category indicating the need for foliage protection to prevent further accumulation of damage in these areas.


Figure V-14. Areas of moderate to severe spruce budworm defoliation forecast in Newfoundland for 1981.

Table V-10. Area of moderate to severe defoliation and moderate to high hazard forecast in productive forests of Newfoundland for 1981.

| Management unit no. | Ownership | Moderate to severe defoliation (ha) | Moderate to high hazard (ha) |
|---|---|---|---|
| 1A | Crown | 11 982 | 11 982 |
| 1 | Crown | 1 503 | 1 503 |
| 2 | Crown | 136 564 | 136 564 |
| 4 | Price | 123 880 | 123 880 |
| 5 | Crown | 25 090 | 24 887 |
| 5 | Bowater | 14 954 | 18 789 |
| 5 | Price | 7 052 | 13 237 |
| 6 | Crown | 1 321 | 1 321 |
| 6 | Bowater | 104 179 | 104 179 |
| 6 | Price | 7 283 | 7 283 |
| 7 | Crown | 23 465 | 23 465 |
| 7 | Bowater | 19 030 | 20 063 |
| 8 | Crown | 11 831 | 6 017 |
| 8 | Bowater | 1 397 | 1 397 |
| 9 | Crown | 14 240 | 22 435 |
| 9 | Bowater | 52 024 | 52 840 |
| 9 | Price | 2 071 | 2 071 |
| 10 | Crown | 181 | 181 |
| 10 | Price | 14 557 | 16 596 |
| 11 | Bowater | 491 | 491 |
| 11 | Price | 41 398 | 38 430 |
| 12 | Price | 32 900 | 18 436 |
| 14 | Crown | 58 491 | 43 311 |
| 14 | Bowater | 20 538 | 20 580 |
| 15 | Crown | 7 188 | 7 188 |
| 15 | Bowater | 31 614 | 31 614 |
| 16 | Bowater | 1 020 | 1 020 |
| | TNNP | 25 784 | 25 784 |
| | Private | 5 468 | 4 058 |
| All | Crown | 291 856 | 278 854 |
| | Bowater | 245 247 | 250 973 |
| | Price | 229 141 | 219 933 |
| | TNNP | 25 784 | 25 784 |
| | Private | 5 468 | 4 058 |
| Total Island | | 797 496 | 779 602 |

Table V-11. Summary of spruce budworm egg-mass numbers per 10 $m^2$ of foliage for sample points with moderate and severe defoliation forecast in Newfoundland from 1978 to 1980.

| | Moderate defoliation forecast* | | Severe defoliation forecast* | |
|---|---|---|---|---|
| Year | No. sample points | Avg. EM/10 $m^2$ | No. sample points | Avg. EM/10 $m^2$ |
| 1980 | 49 | 149 | 123 | 437 |
| 1979 | 65 | 149 | 149 | 438 |
| 1978 | 72 | 154 | 124 | 491 |

*Class limits for defoliation forecast based on egg-masses per 10 $m^2$ of foliage.

| No. egg-mass/10 $m^2$ | | Defoliation forecast | |
|---|---|---|---|
| Nil | 0 | Nil | 0% |
| Low | 1 to 106 | Light | 1% to 25% |
| Medium | 107 to 257 | Moderate | 26% to 75% |
| High | 257+ | Severe | 76% to 100% |

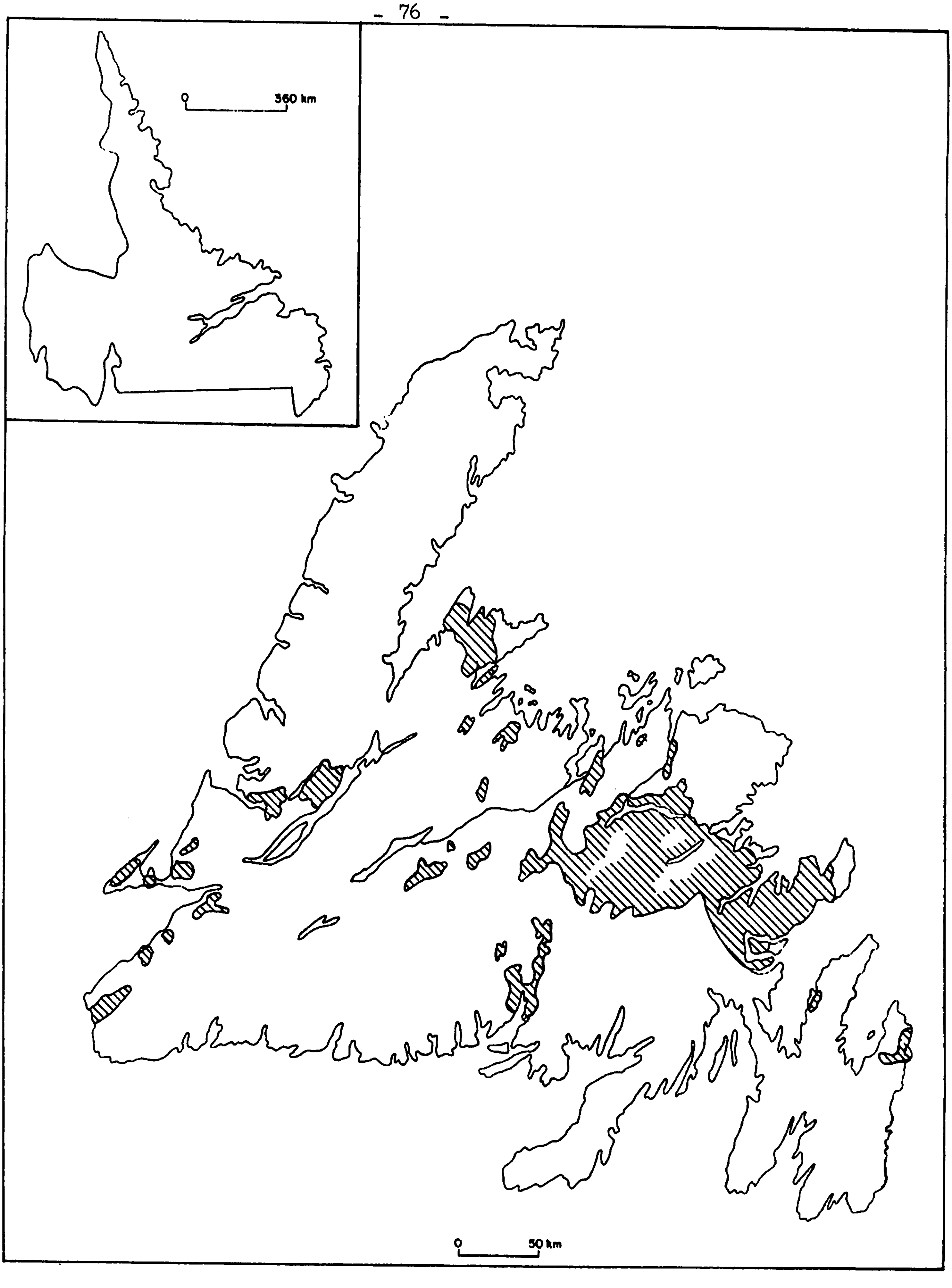


Figure V-15. Areas of moderate to high hazard with high spruce budworm population levels forecast in Newfoundland for 1981.

Note: Because this report is being published in late 1981, a summary of budworm defoliation in 1981 can be appended. The budworm caused moderate and severe defoliation of about 380 000 ha in 1981; about half of the area forecast. Defoliation extended in a broken pattern from the Codroy Valley in the southwestern part of the Island to the Avalon Peninsula in eastern Newfoundland. The area of defoliation was reduced in all regions of the Province except in southwestern Newfoundland where it doubled. The decrease in the defoliated area was caused by a collapse of mid- to late-instar larvae throughout the Island. A further decrease in area of defoliation is forecast for 1982.

## Summary

Consecutive severe defoliation of trees causes a reduction in stored food, loss of growth hormones and seed crops, reduction in radial and height growth, rootlet mortality and eventual death. Most mature trees do not survive when more than 75% of their total foliage had been destroyed. In past budworm outbreaks in mainland Canada height growth losses averaged 2 m to 4 m and reduction of increment ranged between 30% to 90%. Volume loss through reduced radial and height growth in an outbreak in Quebec was estimated at one-third of the loss caused by tree mortality.

In uncontrolled outbreaks in the mainland, mortality of balsam fir ranged between 70% to 100% in mature stands, and 30% to 70% in immature stands. Mortality of white spruce was 10% to 40%, and that of black spruce even less. Volume loss through reduced increment and stocking in surviving stands is substantial and most stands never regain their pre-defoliation volume.

The present spruce budworm outbreak in Newfoundland is unprecedented in size and severity. Tree mortality in merchantable stands in 1979 was about 10 280 000 $m^3$, the volume of dying trees increased to 11 661 000 $m^3$ and the total volume of stands containing some tree mortality has reached 38 412 000 $m^3$. Radial growth in damaged stands has been reduced by an average of 80%. Damaged fir trees have not increased in height during the outbreak and an estimated 15% of the surviving trees have had 1 m or more of their top killed. In addition about 46 600 ha of immature stands of fir have also been very severely damaged of which 23 300 ha had tree mortality ranging from 50% to 100%.

Loss of seed, both in balsam fir and black spruce, is detrimental to the establishment of future stands both natural and artificial. Where the advanced fir regeneration or stands younger than seed-bearing age have been killed by the budworm, the site may be taken over by competing hardwood species. In damaged black spruce stands, the trend is toward Kalmia-heath vegetation.

The effect of budworm outbreak on fish and wildlife habitat is of minor importance and may be somewhat beneficial to ungulates. Though the consequences of outbreak on emenity forest values are not quantified, they are considered important. The aesthetic value of forests is greatly reduced, especially in parks and suburban areas. Damage to young fir stands made them unsuitable for the harvesting of Christmas trees.

There is a lack of agreement as to whether budworm-killed stands pose a serious fire hazard. Hazard may be higher in central than in western Newfoundland. Also spring fires may be more severe than normal and summer fires less severe because of the proliferation of green understory vegetation in the summer.

Salvaging of damaged stands for pulpwood will increase the cost of harvesting, manufacturing and ultimately the price of pulp and paper. Killed stands may be utilized for pulpwood for 4 to 5 years but losses through breakage or windthrow may make the harvesting uneconomical and very dangerous.

Accelerated harvesting of damaged stands and storage of wood to circumvent the detrimental effect of possible windthrow entails increased expenses through additional capital and labour costs and interest. Also cellulose-destroying deterioration is more common in stored wood than in standing trees. Accelerated harvesting and log storage is uneconomical.

The total area of moderate and severe defoliation in the productive forests of the Island was about 926 000 ha and about 428 000 ha of merchantable stands contained dead trees. Dead volume within this area was estimated at 17 000 000 $m^3$; an increase of almost 7 000 000 $m^3$ since 1979. The volume of dying trees was estimated at almost 5 000 000 $m^3$ and the total living and dead volume within these damaged stands was about 40 000 000 $m^3$ in 1980, or about 23% of the total softwood volume on the Island. A total of 65% of the dead trees have died within the last two years. The total area of submerchantable stands with tree mortality was about 63 000 ha in 1980. A slight decrease in area of moderate and severe defoliation, to 800 000 ha, is forecast for 1981, and the area with some tree mortality is expected to increase to about 780 000 ha.

# VI. ECONOMIC IMPACT OF THE PRESENT OUTBREAK OF THE SPRUCE BUDWORM IN NEWFOUNDLAND

J. Munro

## 1. INTRODUCTION

In 1978 to 1979 a special government-industry committee was formed to assess the economic impact of the spruce budworm outbreak in Newfoundland (Munro *et al.* 1979). The committee classified the economic impact into four levels: Light, Moderate, Serious and Severe; based on the costs of an outbreak to a region or province.

Light economic impact implied no significant costs. Moderate impact implied a modest increase in wood cost to forest industries for salvaging and processing damaged timber. Serious impact implied significant mortality of standing timber, loss of stumpage values, disruption of normal harvesting operations and increased cost of transporting and processing dead timber. Future timber supply to major processing plants might be constrained but any shortfall could be made up from adjacent areas. Severe impact implied regional wood shortages due to budworm losses so great that industrial production would be reduced in the future, with resulting lost output of forest products and regional employment and income.

The committee concluded that western Newfoundland should be classed as likely to experience Serious economic impact while the central region would receive Moderate impact. The committee also concluded that the western region could move into the Severe category and the central region into the Serious category if protection was not provided in 1979 and thereafter as required.

It is now felt that the spruce budworm outbreak has progressed to the stage where both the western and central regions will be in the Serious impact category in the future. Further, if the outbreak continues both regions will likely move into the Severe category in the late 1980's or early 1990's, once the initial salvage period for dead timber has passed and the full impact of timber shortages begins to be felt.

The approach taken in this report is to put the damage sustained to date and the projected losses into perspective with regard to the size of the forest resource on the Island and the industry that is dependent upon this resource. A major spruce budworm outbreak is a very dynamic phenomenon. Assessment of the current level of the outbreak and its impact, and projections of future impacts are especially risky because of the many uncertainties involved. Yet such projections have to be made to highlight the seriousness of the present problem and to give a general idea of possible future economic losses to the provincial economy.

Part two of this section on economic impact outlines the importance of the forest resource and dependent industries to the Province. Part three assesses the minimum future wood requirements for established forest industry and domestic users. Part four provides overall estimates of the outbreak and its impact upon the Island's softwood supply to the present, with projections to 1984. Part five examines the economic consequences of future reductions in wood supply. The silvicultural problems associated with the outbreak and the possible cost of forest rehabilitation measures are discussed in part six. Part seven compares the cost of a conventional protection program from 1974 to 1979 with some of the possible costs of the no protection option.

## 2. ECONOMIC IMPORTANCE OF THE FOREST RESOURCE

### a) INDUSTRIAL USE

In assessing the importance of forestry to the provincial economy, several features of the economy itself should be borne in mind. First, Newfoundland has traditionally experienced rates of unemployment considerably above the national average. From 1975 to 1979 for example, the unemployment rate in Newfoundland ranged from 13.4% to 16.4% while the national unemployment rate ranged between 6.9% and 8.4% (Statistics Canada 1979). Further, the unemployment rate for the central and western regions of the Island, where the bulk of the forest industry is located, is characteristically higher than the rate for the province as a whole. For the 1975 to 1979 period the unemployment rate for western Newfoundland ranged from 16.0% to 20.8% while the range for the central region was 13.8% to 17.1%.

Also, the Province has a rather narrow natural resource base. The agriculture sector is weak because of scarcity of good soils and marginal climatic conditions for some crops. Agriculture makes a relatively low contribution to regional employment and income. Thus, the three other main primary sectors, fishing, forestry and mining, are the main sources of income and employment throughout much of the province. A reduction in activity in any one of these sectors will lead to further deterioration in employment levels in rural areas.

The forestry sector, which includes logging and processing of forest products, is important to the economy of the Province (Fig. VI-1)[1]. Primary resource harvesting and processing accounts for a large proportion of the total value added for all goods producing industries (Fig. VI-1a). In 1977 and 1978, the proportion was about 55%. In 1978, forestry harvesting and processing accounted for about 13% of the total value added for all industries and 23% of the value added for the four primary resource-based industries (fishing, forestry, mining and agriculture).

From 1971 to 1978 forestry employment fluctuated between 4 200 and 6 200 (Fig. VI-1b), about equal to that of mining and far above the level for agriculture. Numbers employed in the fishing industry could not be included because the large numbers of part time fishermen make direct comparisons difficult.

Total wages and salaries for forestry ranged between \$41 000 000 and \$84 000 000 per year for this period (Fig. VI-1c). Wages and salaries in mining were considerably higher than forestry, while those for agriculture were considerably lower. Again, a comparison with the fishing industry was not possible because comparable estimates of total income of fishermen were not available.

The value of mineral shipments exceeds that of the other resource-based industries (Fig. VI-1d) and went 'off the chart' after 1973. Value of shipments for fishing and forestry was about equal for 1971 to 1976 but the value of shipments for fishing was considerably higher in 1977 and 1978. Compared to forestry and fishing, value of agriculture shipments was quite low during this period.

Forest industries contribute significantly to the Provincial manufacturing sector. In 1977, forest based industries accounted for 31% of the value of shipments, 31% of the value added, 29% percent of the wages and salaries paid and 20% of the employees in Newfoundland manufacturing industries.

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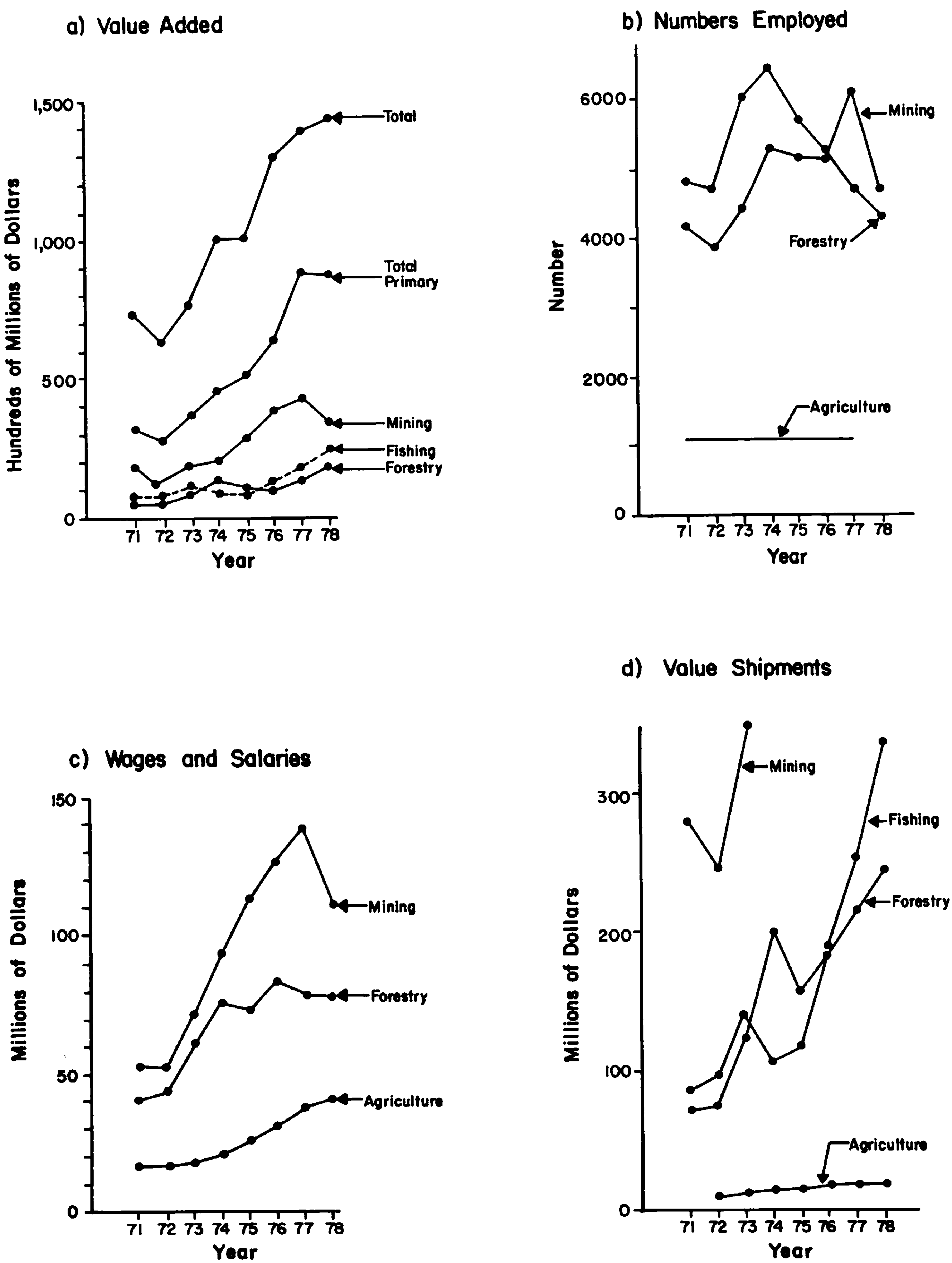
[1]Data for this figure and the following discussion were compiled by the writer from various published and unpublished sources including Statistics Canada, the Newfoundland Statistics Agency and the Newfoundland Department of Forest Resources and Lands.




Sources: Statistics Canada and Nfld Statistics Agency

Figure VI-1. Relative contribution of primary resource industries in Newfoundland from 1971 to 1978.

The pulp and paper industry is by far the most important segment of the forest industry in Newfoundland. In 1978, the pulp and paper industry accounted for about 83% of the annual roundwood production, 93% of the value of shipments of forest products, 77% of the forestry value added and about 95% of the wages and salaries paid in forest based industries.

Sawmills and other small wood-using industries shipped goods worth $17 140 000 in 1978, employed 414 people and paid $4 431 000 in wages and salaries (Statistics Canada 1978). Statistics Canada tends to underestimate the economic contribution of these industries because many establishments are too small to be included in their national surveys. In 1978 Newfoundland sawmills produced an estimated 115 000 $m^3$ of lumber which accounted for about 53% of the Provincial market. The balance was imported, mainly from other Canadian provinces.

The forest industry is an important contributor to provincial revenues through payment of various taxes and fees (Milne 1981). During 1974 to 1978, the Newfoundland forest industry firms and employees paid an average of $16.7 million per year in sales, income and forest land management taxes. During the same period, the industry paid an average of $700,000 per year in Provincial forestry fees including cutting permits, sawmill licences, timber rentals and stumpage.

## b) DOMESTIC USE

Approximately 65% of Newfoundland's population or about 350 000 people, live in communities with less than 10 000 inhabitants. The forest resource is an important source of low cost fuelwood and building materials for this rural population.

## c) OTHER USES

The forest is part of the total provincial endowment of natural resources and its management must be integrated with other uses such as outdoor recreation, wildlife and water supplies for drinking and power generation. Recreational use of forest land has increased considerably in recent years, especially within provincial and federal parks. Wildland recreation is also provided to thousands of hunters and anglers each year. Forests are also important to the regulation of water levels in municipal water supply areas and for hydro-electric power projects.

# 3. FUTURE WOOD SUPPLY REQUIREMENTS

The importance of softwood pulpwood production to the Province is obvious from Figure VI-2. The peaks in pulpwood and total wood production for the years 1973 to 1975 reflect the impact of woods operations in support of the Labrador Linerboard Mill at Stephenville. Wood production for this mill was phased out in 1976 when it became apparent it would not continue as a linerboard producer. The relatively small proportion of total wood production accounted for by sawlogs, fuelwood and other uses is also apparent.

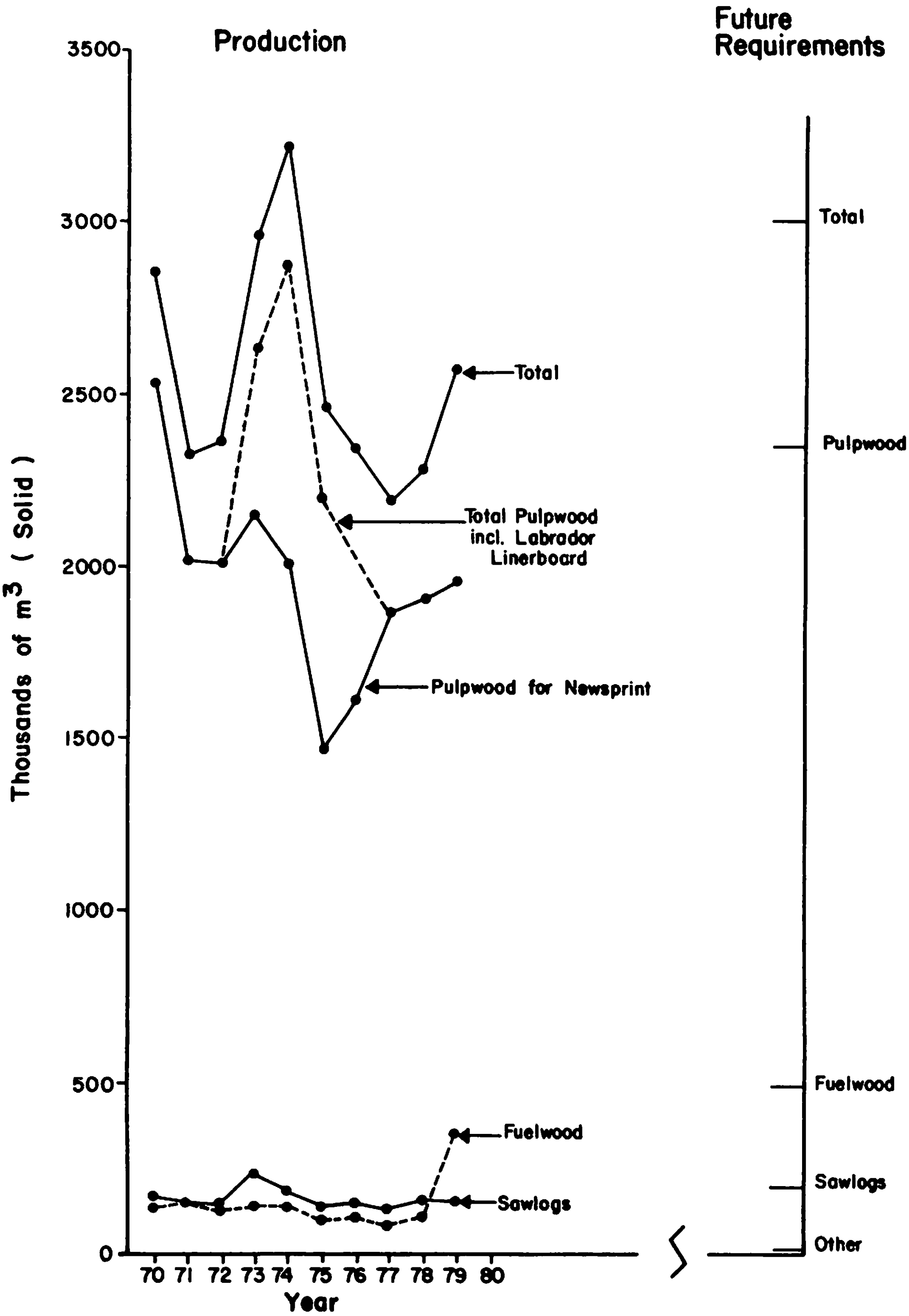
Attempts to predict future wood requirements are difficult because of the many uncertainties associated with market demand for wood products, technological change and the impact of rising energy prices on local, national and international economies. The simplified approach taken here is to project minimum future annual requirements based on historical trends in wood production and to anticipate the impact of likely changes in wood use over the next few years. All major utilization plants in Newfoundland will be newsprint mills which require practically a 100% softwood supply of pulpwood.

## a) PULPWOOD REQUIREMENTS

For 1970 to 1979, softwood pulpwood production averaged 1 960 000 $m^3$/year, excluding wood harvested for Labrador Linerboard at Stephenville. The average for the first half of the period was 2 155 000 $m^3$ while the average for the second half was 1 764 000 $m^3$. Production was down in 1975 and 1976 because of unfavorable conditions in the pulp and paper industry. Production during 1977 to 1979 was close to 1 960 000 $m^3$/year.

In estimating future pulpwood requirements, the 10 year average of 1 960 000 $m^3$ was used for the two established pulp and paper mills at Grand Falls and Corner Brook plus an estimate of 400 000 $m^3$ per year for the newsprint mill at Stephenville. Total annual pulpwood requirements for the Provincial newsprint industry as of 1981 are estimated at 2 360 000 $m^3$/year.

Future pulpwood requirements will be influenced by two main factors. Technological improvements in the mills will tend to decrease the wood requirements per ton of paper produced. Offsetting this factor will be the tendency of the mills to gradually expand production capacity. Because of the difficulty of predicting the outcome of these two opposing trends, it is simply assumed that pulpwood production for the three mills will remain about 2 360 000 $m^3$/year in the foreseeable future.




Sources: Statistics Canada 25-202
Nfld. Dept. Forest Resources and Lands

Figure VI-2. Roundwood production for Newfoundland from 1970 to 1979 and estimated future requirements.

## b) SAWLOG REQUIREMENTS

Roundwood production for sawlogs has averaged approximately 200 000 $m^3$ for 1970 to 1979. Production has been fairly steady over the period in spite of government efforts to encourage expansion. It is assumed that requirements will remain unchanged.

## c) FUELWOOD REQUIREMENTS

Fuelwood production averaged 125 000 $m^3$ for the period 1970 to 1978 (Statistics Canada 1978), with a trend towards decreasing production. These figures probably reflect the general situation for the early 1970's but underestimate production for the latter part (Northland 1980).

Fuelwood consumption on the island of Newfoundland has increased rapidly in the late 1970's, as people in rural areas substituted wood for expensive oil and electricity for home heating (Northland 1980). Fuelwood consumption for 12-months in 1977 to 1978 was estimated at 307 000 $m^3$. Fuelwood consumption has undoubtedly increased considerably since and is conservatively estimated at 370 000 $m^3$ for the Province in the current year. Future requirements are difficult to predict, but an average of 500 000 $m^3$/year will be used, of which 350 000 $m^3$ is expected to be softwoods.

## d) OTHER REQUIREMENTS

Miscellaneous industrial wood requirements are small relative to total production with an average for the last 10 years of only 7 000 $m^3$. For purposes of this estimate, a figure of 10 000 $m^3$/year will be used.

In summary, the minimum future annual softwood roundwood requirements are assumed to be as follows:

| Item | Million $m^3$ |
|---|---|
| Pulpwood | 2.360 |
| Sawlogs | .200 |
| Other | .010 |
| Total industrial | 2.570 |
| Fuelwood | .350 |
| Total | 2.920 |

# 4. ESTIMATE OF IMPACT ON WOOD SUPPLY

Estimated impacts of the current spruce budworm outbreak on overall wood supply on the Island are of considerable magnitude (Table VI-1). The estimates of dead and dying volume are mainly balsam fir because this species is most susceptible to damage. However, all of the balsam fir in a stand is not necessarily dead and dying at the time it is surveyed. Also, many damaged stands contain spruce which is much more resistant to budworm attack. The volume in stands classed A (dead), B (dying) and C (very severely damaged) is the total amount of damaged as well as undamaged timber that would have to be harvested in a salvage operation.

In 1979, 85% of A, 64% of B and 32% of C stands were estimated to be dead or dying (Moody *et al.* 1979). An average of 57% of the volume of A+B+C stands was dead or dying. Loss of such a large proportion of the volume within stands would probably render them uneconomic to harvest in the future; even if the remaining 43% survived the outbreak.

The estimated dead and dying volume in 1980 was 24% of the total balsam fir volume on the Island (Table VI-1). The total volume in A+B+C stands was 23% of the total softwood volume.

One can only speculate on the amount of damage likely to be incurred in the future as the outbreak continues in the absence of an effective protection program. If the outbreak follows patterns established elsewhere, it is estimated that by 1984 the total volume of dead and dying timber could be anywhere between 40% and 90% of the total balsam fir volume on the Island (Raske personal communication). Fifty percent of the current balsam fir volume would be 45 000 000 $m^3$ and the total volume[2] in A+B+C stands could be in the order of 68 000 000 $m^3$ or 39% of the softwood volume on the Island (Table VI-1). Seventy percent of the balsam fir volume would be 63 000 000 $m^3$ and the total volume[2] in A+B+C stands could be in the order of 95 000 000 $m^3$, or 55% of the total softwood volume on the Island.

At this time it is impossible to predict 1984 losses with any degree of certainty. The above estimates and projections illustrate the level of current losses and the general magnitude of losses that are possible in future without protection.

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[2]The volume in A+B+C stands assumed to be 1.5 times the dead and dying volume.

Table VI-1. Summary of the 1980 and projected budworm impact on gross merchantable volume for productive forests of the island of Newfoundland (volumes in millions $m^3$).

| Item | Years 1980 | Two possible projections for 1984 low | Two possible projections for 1984 high |
|---|---|---|---|
| **Volumes** | | | |
| 1. Total softwood volume | 174 | | |
| 2. Total balsam fir volume | 90 | | |
| 3. Estimated dead and dying volume (mainly balsam fir) | 22 | 45 | 63 |
| 4. Estimated total volume in A+B+C stands[1] | 40 | 68 | 95 |
| **Percentages** | | | |
| 5. Dead and dying volume as percent of total balsam fir volume | 24 | 50 | 70 |
| 6. Volume in A+B+C stands as a percent of total softwood volume[1] | 23 | 39 | 55 |

[1] A = stands dead, B = stands dying, C = stands very severely damaged.

Notes

1. Estimates of total volume of softwood and balsam fir for productive forest area ($\geq$ 35 $m^3$/ha) based on data obtained from the Newfoundland Department of Forest Resources and Lands.

2. Estimates to 1980 of dead and dying timber and volume in A+B+C stands from FIDS survey.

3. Projections for 1984 based on assumptions of 50% and 70% mortality of balsam fir on the Island. Volume of A+B+C stands 1.5 times the dead and dying volume.

If such large losses occur there will be difficulty in maintaining full scale operations in the pulp and paper industry after the salvage period ends, probably between 1985 and 1990. The initial impact will likely be reflected in increasing wood costs as the companies try to compensate for wood losses by harvesting more remote and also low volume/ha stands. Physical shortages of wood may very well result in curtailment of plant operations, especially at Stephenville and Corner Brook. Wood shortages on the Island may be partly compensated by importing wood from Labrador or possibly from Quebec. However, this imported wood will be expensive when compared to traditional Island supplies.

The sawmilling industry in Newfoundland is especially vulnerable to any reduction in the supply of raw material. There are over 1 500 mills, mainly on non-alienated crown lands around the coast. For the most part, these mills operate on annual cutting permits obtained from the Department of Forest Resources and Lands. For most commercial operators, log supply has historically been an ongoing problem and the main limiting factor to increasing mill output. Many areas of non-alienated crown lands are overcut for sawlogs leaving no reserve. The current budworm outbreak is subtracting from the limited log supply. Once the salvage period is over, there is the likelihood that a large number of mills will close.

The impact of the spruce budworm on domestic fuelwood supplies is not expected to be as severe as the impact on supply of pulpwood and sawlogs. To a limited extent, fuelwood cutters can utilize dead and damaged timber and stands unfit for other uses. Fuelwood can also be obtained from hardwood and submerchantable softwood stands. However, long term shortages of fuelwood are likely in predominantly softwood areas. Fuelwood supply will be reduced because of budworm impact, while demand will be increasing because of the rising cost of alternative fuels.

Commercial and industrial use of wood biomass is developing in Newfoundland. Plans are well advanced for the utilization of whole tree chips to supplement oil for firing boilers at the Grand Falls newsprint mill. The Gander Hospital may use sawmill residues for heating by 1981. Many other opportunities exist for using wood biomass to decrease dependence on imported oil. However, because of the spruce budworm, reduced wood supplies may limit the industrial use of fuelwood in the future.

# 5. ECONOMIC CONSEQUENCES OF REDUCED WOOD SUPPLIES

The spruce budworm outbreak is in an advanced stage and serious wood supply problems are predicted for forest based industries. The timing and magnitude of these shortages are difficult to quantify. Much will depend on how swiftly and to what extent trees receive relief from defoliation over the next few years.

The estimate of the volume of timber in A+B+C stands for 1980 was 40 000 000 $m^3$ (Table VI-1). At a stumpage value of $1.25/$m^3$, a total value of $50 000 000 is obtained. The volume in this category will increase as the outbreak continues. Two projections of the possible volume in this category for 1984 are presented in Table VI-1 as 68 000 000 and 95 000 000 $m^3$ which would have stumpage values of $85 000 000 and $119 000 000 respectively.[3] While some of this estimated volume could be salvaged most will be lost because of the limited capacity to utilize dead timber and the short time that salvage is feasible.

The longer term economic impact will be reflected as an increasing cost of harvesting and utilizing wood fibre from dead and damaged stands. Initially, the costs of salvaging dead and dying stands are not much different than for normal healthy stands. However, costs soon rise. Dead timber becomes difficult to handle because of breakage and blowdown. Hazards to workers increase. Recoverable volumes/ha decrease while the costs of harvesting and transportation remain essentially the same or increase. Utilization at the mill is difficult and product yields are diminished because of reduced fibre quality (Sewell and Maranda 1978).

As mature timber stands near mills become exhausted, wood must be obtained from more distant sources. These areas, such as the Northern Peninsula, have high transportation costs. They may also be damaged by budworm and recoverable volumes/ha may be low. Approximately 500 000 $m^3$/year might be available from Labrador but this wood will cost even more.

The salvage and post-salvage period of rising wood costs may be followed by a period of physical wood shortages for major industrial users. The allowable annual cut on many forest management units of the Island may be reduced below levels required to sustain industrial capacity. Table VI-2 has been prepared to give some idea of the kinds of economic losses that could result. The data were statistics on the industry for 1978, adjusted for inflation at 9% to 1980 dollars. It is felt that 9% is a good average rate of inflation for the period.

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[3]The values obtained above are rather simplistic 'book' values and may not accurately reflect the eventual stumpage value of the wood. The volumes involved are large and would have to be harvested over a period of many years. Many factors can affect the future stumpage values.

Table VI-2. Principal statistics for Newfoundland forest manufacturing and logging, for 1978. Calculated in terms of 100 000 $m^3$ of roundwood produced (values in terms of 1980 dollars).

| Item | Units | Quantity per 100 000 $m^3$ roundwood produced |
|---|---|---|
| Total employment | number | 196 |
| processing | " | 135 |
| logging | " | 61 |
| Total wages and salaries | ($000) | 4 270 |
| processing | " | 3 078 |
| logging | " | 1 192 |
| Total value added | ($000) | 10 093 |
| processing | " | 8 102 |
| logging | " | 1 991 |
| Value shipments | | |
| processing | ($000) | 13 308 |
| logging | " | 2 860 |

Source: Values calculated from data in Statistics Canada Annual Publication 25-202 (1978).

Notes: Inflation rate of 9% used to convert 1978 values to 1980.

Quantity estimates based on industrial wood production for 1978 of 2 178 000 $m^3$.

For every 100 000 $m^3$ of reduced wood supply to the forest industry, there would be an estimated loss of 196 jobs; 135 in processing and 61 in harvesting (Table VI-2). Losses in terms of direct wages and salaries would be $4 270 000; made up of $3 078 000 in processing and $1 192 000 in logging. Value added losses would be $10 093 000; $8 102 000 in processing and $1 991 000 in logging. Value of shipments will be reduced by $13 308 000 for processing and $2 860 000 for logging.

The full impact of the spruce budworm outbreak will probably be felt after 1990. Then wood supplies may be constrained more than the 100 000 $m^3$ outlined above. Shortages of industrial roundwood in the order of 10%, 20%, 30% and greater are possible.

Future minimum industrial wood requirements (excluding fuelwood) were earlier forecast to be 2 570 000 $m^3$. A reduction of 20% would amount to 514 000 $m^3$ or approximately 500 000 $m^3$. In terms of the values shown in Table VI-2, a reduction of this magnitude would mean the loss of 980 direct jobs in forest industries; $21 350 000 in wages and salaries; $66 540 000 in value of shipments and $50 466 000 in value added. This assumes that forest industries could sustain losses of 20% of wood fibre and still continue operating. This may not be possible.

To predict exact levels of future losses is impossible at this time, but the above estimates provide some idea of the kinds of impacts that could be incurred. These estimates refer only to direct employment and income to workers in provincial forest industries. The overall impact on provincial employment and income would be roughly twice as great because every worker directly employed in forest based industry supports at least one additional worker in service industries.

Large scale capital intensive processing plants like newsprint mills must operate reasonably close to capacity over the long term if they are to remain economically viable. If wood supply places a serious long term constraint on production, plant closure is likely. The exact level of reduced wood supply that can be tolerated by individual plants will depend upon a variety of factors and cannot be detailed here. The mills on the west coast at Stephenville and Corner Brook may be more vulnerable than the mill at Grand Falls. Such mill closures would have a serious negative impact on the overall provincial economy and on regional incomes and employment. This has important social implications. The Newfoundland Medical Association has identified unemployment as a serious threat to the health of the Newfoundland population (Newfoundland Medical Association 1979).

Economic losses on a smaller scale will be experienced by other wood processing industries, especially sawmills. As log supplies are reduced, local lumber production will fall and an increasing share of the local lumber market will be supplied by mainland producers.

Wood shortages due to the spruce budworm will increasingly be felt during the late 1980's and 1990's. At that time, the energy crisis is expected to be at a critical stage. Demand for domestic fuelwood will be high as more and more people in rural areas seek alternate energy supplies. Also, there may be significant industrial demand for fuelwood by the mid 1980's. There will be increasing competition for limited wood supplies between fuelwood and other industrial uses. In many cases priority use to the resource will likely go to domestic fuelwood because of the high cost of alternative energy supplies. To the extent that fuelwood supplies are reduced by the budworm outbreak, there will be economic hardship for the rural population as more expensive coal, oil, natural gas or electricity have to be utilized for home heating.

Because of the large numbers of people and the extensive areas of forest land involved, domestic fuelwood cutting is difficult to control. Uncontrolled cutting can be very damaging to forest management. Satisfying rural fuelwood demand while still controlling cutting will likely become a major problem in the future.

The economic impact upon other users of the forest will probably be light compared to the impacts upon industrial and domestic wood consumers. There already is some impact on prime recreation areas. Campers are disturbed both by large numbers of insects and the downgraded aesthetic attributes of these sites. However, there is doubt as to whether these factors will result in any serious long-term reduction in the recreational use of these areas. Similarly, the economic impact on water supply areas and hydro-electric power generation is not expected to be very significant.

## 6. COSTS AND FEASIBILITY OF REHABILITATION OF DAMAGED FORESTS

The naturally grown forests of Newfoundland in a sense are free gifts of nature. All man must do to capture the potential industrial benefits is to provide protection and ensure that harvesting is conducted in such a manner that a new desirable forest will grow. When protection is not provided, the growing stock can be destroyed. This destruction is occurring in the present outbreak. At best, the result is that commercial species will regenerate naturally on damaged areas. At worst, damage will be so severe that seed and advance regeneration are destroyed and productive forest areas will be occupied by non-commercial species and shrubs.

The extent of the regeneration problems associated with the current outbreak have not been quantified. However, indications are that there may be significant areas which will require silvicultural treatment if they are to produce useful forest crops in the future. These silvicultural treatments will vary with the extent of damage, the kind of forest sites involved and the species to be established. All treatment options have a gestation period of 30 to 60 years or longer and are expensive to implement and maintain. Some treatments involving direct seeding can be implemented for costs ranging between \$100 to \$250/ha. However, these relatively low cost treatments are not suitable in all areas and require an abundant seed supply. Seed is presently in very short supply because of the budworm outbreak. Therefore, higher cost silviculture treatments, possibly ranging from \$600 to \$1 000 will likely be required, if damaged areas are to be rehabilitated.

The area of productive submerchantable stands that had received tree mortality to 1979 is about 46 600 ha (Moody 1980). The extent of this area increased in 1980 to 62 600 ha. However, a total area of 46 600 ha required rehabilitation at \$800/ha, a total of \$37 000 000 would be spent.

Problems are also expected with the regeneration of some mature forest areas. No accurate estimate has yet been made of the extent of the area that will require treatment but it could be substantial. The total area of dead, dying and very severely damaged (A+B+C) stands in 1980 was approximately 427 000 ha. If 20% (85 400 ha) requires silvicultural treatments at a cost of \$800/ha, the total cost of returning such an area to a productive condition would be \$68 000 000. Much larger areas may eventually require treatment, and costs may very well be higher. The economic feasibility of undertaking such large scale rehabilitation programs may be doubtful, and the cost may prove to be beyond the financial capability of resource owners.

# 7. COMPARISON OF LOSSES WITH COST OF CONTROL

An estimate of the cost of providing protection against the spruce budworm on the island of Newfoundland for the period 1974 to 1980 has been attempted (Table VI-3). The cost/ha figures for the scale of operation indicated and the area figures are best estimates available of the minimum areas that required protection each year. The estimated cost of a protection program from 1974 to 1980 is $18 000 000 in 1980 dollars. The estimated average area of treatment was approximately 339 000 ha and the average annual cost was $2 571 000 in 1980 dollars.

A spray program to control the present outbreak would have to be continued beyond 1980. How much longer is very difficult to predict. Using the average area and costs identified above, an additional cost of approximately $10 000 000 in 1980 dollars would be required to continue a spray program to 1984. Total cost of a program on this scale from 1974 to 1984 is thus estimated at $28 000 000.

One may wish to compare the estimated cost of protection with order of magnitude estimates of the kinds of losses that have been incurred over the same period. Time and information limitations precluded a detailed cost-benefit analysis but the following discussion provides some idea of the kinds of values involved.

The estimated total volume in dead, dying and severely damaged stands to 1980 is 40 000 000 $m^3$ (Table VI-1). If 15% of this could be salvaged, the net loss in volume would be about 34 000 000 $m^3$. If a further 20% of this volume would be lost, even with a spray program, or would be inaccessible for harvesting, the net loss is about 27 200 000 $m^3$. At a stumpage rate of $1.25 per $m^3$, this represents a value loss of about $34 000 000 from the provincial forest inventory.

The $34 000 000 estimated is a convenient book value but it implies that the total volume could be harvested in one year at a stumpage value of $1.25 per $m^3$. A more realistic assumption for valuation would be that the wood could be harvested over a period of 10 years at 2 720 000 $m^3$ per year. This would yield an annual cash flow for stumpate of $ 3 400 000 for 10 years. At a real discount rate[4] of 3%, this cash flow would have a present value in 1980 of approximately $29 000 000. This approach provides a more realistic economic estimate of the value of this wood. Different assumptions could also be made to arrive at different values.

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[4]By using a real interest rate of 3%, one avoids the problem of predicting future rates of inflation.

Table VI-3. Estimated costs for operational spray program for Newfoundland from 1974 to 1980.

| Year | Protection area[2] (000 ha) | Cost/ha[1] ($) | Total cost ($ millions) (Current $) | (1980 $)[3] |
|---|---|---|---|---|
| 1974 | 121 | 4.30 | 0.5 | 0.8 |
| 1975 | 243 | 5.00 | 1.2 | 1.8 |
| 1976 | 243 | 5.40 | 1.3 | 1.8 |
| 1977 | 607 | 5.90 | 3.6 | 4.5 |
| 1978 | 368 | 6.40 | 2.4 | 2.8 |
| 1979 | 304 | 7.20 | 2.2 | 2.4 |
| 1980 | 486 | 8.00 | 3.9 | 3.9 |
| Totals | 2 372 | | 15.1 | 18.0 |

Notes

1. Cost/ha estimates based on 1978 Newfoundland data and cost estimates for other years derived with the assistance of N. Carter, Department of Forest Resources and Lands.

2. Protection area for 1978 is the approximate area actually sprayed. Figures for other years were prepared with the assistance of N. Carter and are based on the minimum area estimated to require protection.

3. An annual inflation rate of 8% is used to convert total cost values to 1980 dollars compared to a rate of 9% used previously for the period 1978 to 1980. The 8% rate takes into account lower inflation experienced in the mid 1970's.

4. The cost of the 1981 spray program was $2 500 000 at $10.42/ha. Adjusted to 1980 dollars at an inflation rate of 9% these figures are $2 275 000 and $9.48/ha.

It is also interesting to speculate on the unit cost of protecting the estimated 27 200 000 $m^3$ lost between 1974 and 1980. Assuming that the protection program outlined in Table VI-3 could have successfully protected this wood, the cost would have been \$0.66 per $m^3$ (\$18 000 000 ÷ 27 200 000 $m^3$). This would appear to be acceptable, bearing in mind that the cost of wood delivered to a newsprint mill would be in the order of \$30.00 per $m^3$. However, additional costs might have to be incurred to protect this wood beyond 1980.

Another major cost to be considered is the rehabilitation of certain forest areas where damage is so severe that expensive site treatments may be required to re-establish commercial species for the next rotation. The cost of rehabilitation of 46 600/ha of submerchantable stands damaged to 1979 was estimated at \$37 000 000 and the cost of 85 400 ha of mature stands at \$68 000 000 for a total of \$105 000 000. As already indicated, resource owners may find the financing of this kind of a rehabilitation program economically unfeasible.

The \$18 000 000 cost of a protection program for the period 1974 to 1980 can be compared with the estimated costs of not spraying. These can be summarized as follows:

| | | |
|---|---|---|
| 1) | Loss of stumpage values to 1980 | \$29 000 000 |
| 2) | Possible forest rehabilitation costs | \$105 000 000 |

It must be stressed that the above are very rough order of magnitude estimates, subject to a very wide margin of error. They are provided only to illustrate the kinds of losses that are possible in the absence of an effective protection program.

Another major cost, also very difficult to quantify at present, which should be considered, is the potential lost production and lost income resulting in the future, if forest industries have to curtail production because of wood shortages. As indicated earlier, a 20% reduction in industrial activity because of wood supply would mean the loss of 980 jobs, annual wages and salaries of about \$21 000 000 and annual value added to the provincial economy of \$50 000 000. If this loss will start to be experienced in 10 years, for a period of 10 years (i.e. from 1990 to 2000) the result is a present value loss in 1980 dollars of \$318 000 000[5]. Future annual reductions in forest industrial output could be greater or less than 20%, depending upon the eventual impact of the current outbreak on wood supply. This example is provided to indicate the general magnitude of the losses that are possible should forest industries be curtailed because of wood shortages.

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[5]The present value of a \$50 000 000 annual payment for 10 years at a real interest rate of 3% is \$427 000 000. This would be the present value in 1990. Discounting this lump sum value to 1980 at 3% gives a value of \$318 000 000.

# SUMMARY

The forest resource and dependent industries are important to the Newfoundland economy. Harvesting and wood-using industries provide a major source of employment and income, especially in central and western regions. The forest resource provides sawlogs and fuelwood for the many thousands of people who live in rural communities. Significant recreation benefits are also provided. An adequate wood supply at competitive cost is of crucial importance to all forest based industries. Reduction in wood supply would have serious social and economic implications for the provincial economy in the future.

The spruce budworm outbreak has already incurred a serious impact on the forest resource and future wood supplies are threatened. A large proportion of the balsam fir on the Island may be killed by 1984 if the outbreak continues and protection is not provided. Total volume in dead, dying and severely damaged stands could reach 68 000 000 to 98 000 000 $m^3$ by 1984, representing 39% to 55% of the total softwood volume on the Island. If these losses occur there will be a drastic impact on provincial forest industry with wood shortages leading to reduced output and possibly to mill closures.

The costs of providing protection to 1980 by chemical spraying ($18 000 000) are modest compared to the possible value losses through failure to protect. Major cost estimates associated with not spraying include lost timber values ($29 000 000), and possible cost of forest rehabilitation measures ($105 000 000). Another possible cost would be lost value added to the provincial economy. In an example, a 20% reduction in industrial activity for the period 1990 to 2000 was estimated to result in a loss of $318 000 000 value added.

Future wood shortages will not only affect large newsprint mills but also small sawmills and fuelwood supplies as well. Wood shortages will coincide with increased industrial and domestic demand for fuelwood.

# VII. NATURAL FACTORS AFFECTING SPRUCE BUDWORM POPULATIONS

## 1. WEATHER

I.S. Otvos

The influence of weather on spruce budworm abundance has been extensively studied (Wellington and Henson 1947, Wellington *et al.* 1950, Greenbank 1956, 1963c, Greenbank *et al.* 1980, Hamel and Hardy 1980). In general, dry, sunny and warm weather favours development and survival of the budworm. The relationship between such favourable weather and the initiation of an outbreak has been demonstrated in several regions (Wellington 1952, Greenbank 1963c, Pilon and Blais 1961, Ives 1974). Recently Royama (1978) has questioned the methods of analyses used to relate weather data to budworm populations. However, Hamel and Hardy (1980) used a different method and supported the general opinion on the role of weather on budworm abundance. They also concluded that precipitation is more important than temperature.

Unseasonably cold temperatures during winter appear to have minimal 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).

Several consecutive days of rain or late frost in the spring can decimate populations of young budworm larvae. Frost may kill the young larvae directly or indirectly by freezing the new, tender shoots of the host trees and cause starvation.

Weather can also be responsible for asynchrony between emergence of the young larvae and the development of the host. The larvae may emerge before suitable food is available. This can be important in stands severely defoliated for at least one year. This condition occurred on the Baie Verte Peninsula in 1975 when the presence of pack ice offshore delayed spring thaw and bud development. The emerging second instar larvae mined and killed the buds before flushing, leaving the old needles as the only food. Most of the larvae were too young to feed on old foliage, consequently many of the larvae died of starvation.

Weather also affects budworm behaviour and activity during later instars. During continuous rainy periods larvae do not feed readily (Wellington and Henson 1947, Greenbank 1956). Wet and cool weather prolongs larval and pupal development and increases the period during which the budworm is exposed to predators, parasites and pathogens. In the adult stage, rain, overcast conditions, and strong winds adversely affect mating and flight activity and reduce chances of moth dispersal (Greenbank 1973). Recent radar studies have demonstrated the long distance mass dispersal of budworm moths (Greenbank *et al.* 1980). Chemical "fingerprinting" of spruce budworm moths also provided evidence for moth influx into Newfoundland from the Maritimes (Otvos unpublished).

Weather before and during the current outbreak in Newfoundland was highly favourable for budworm development (Fig. VII-1). 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 below normal for four of the ten summers between 1968 and 1977, with three consecutive dry summers starting with 1974. This provided favourable conditions for larval development in June and July, and the drier than normal August was favourable for mating of budworm adults and egg laying. In 1977, the weather in July and August was slightly warmer but considerably wetter than the normal favouring the fungal disease which reduced budworm populations in numerous areas (Otvos and Moody 1978).

Favourable weather during the past 15 years also occurred in other parts of Canada which may have contributed to the build-up of budworm outbreak over widely scattered areas and to the unprecedented size of the outbreak in this century.

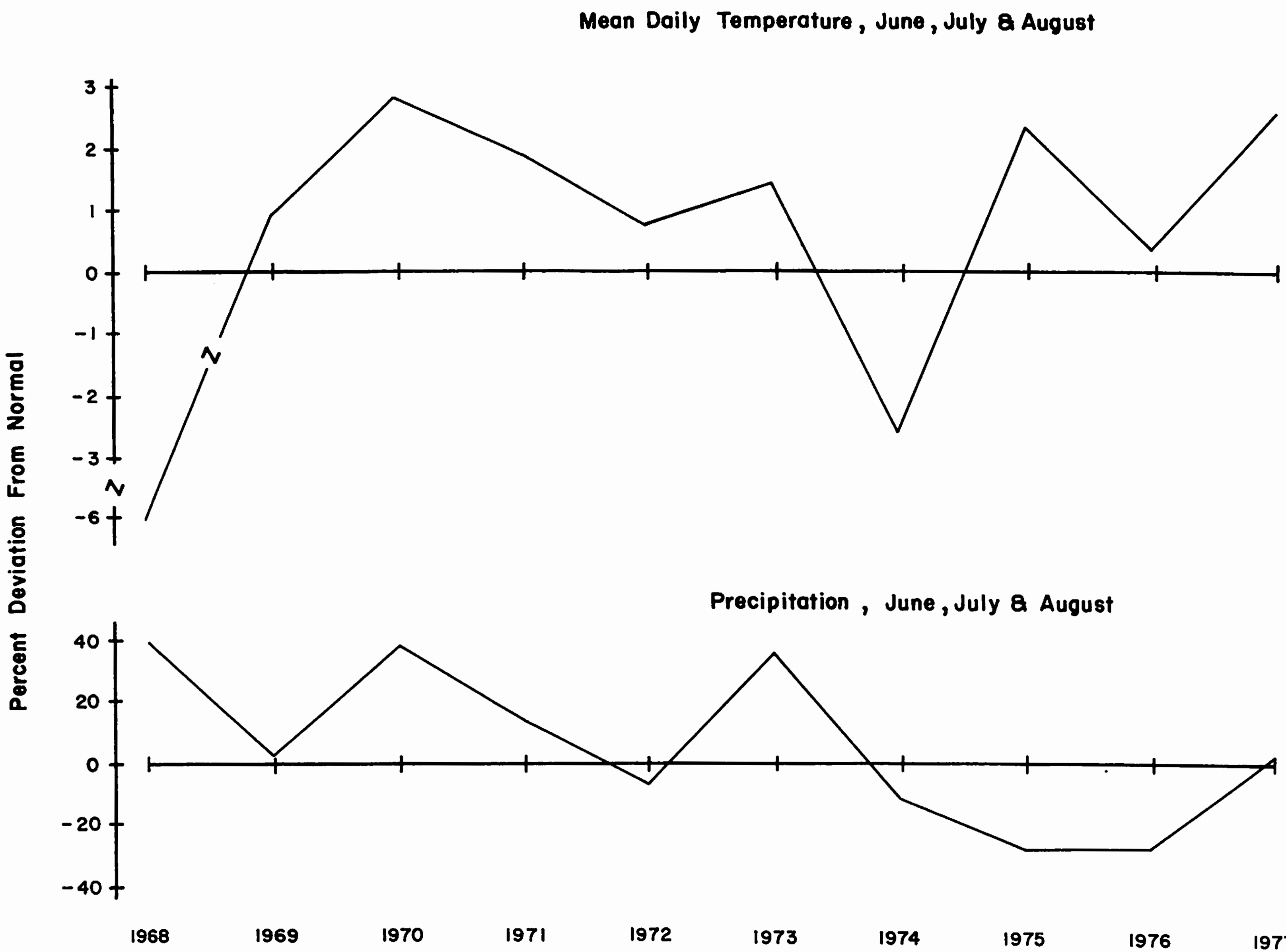


Figure VII-1. Mean daily temperature deviation from the normals (1941-1970) of June + July + August, and precipitation deviations from the normals of June + July + August from 1968 to 1977. Based on the following meteorological stations: Port aux Basques, Stephenville Airport, Corner Brook, Daniel's Harbour, Deer Lake Airport, Buchans, Exploits Dam, Grand Falls, Glenwood, Gander, Bonavista, Colinet, St. John's Airport, Newfoundland.

# 2. PREDATORS

I.S. Otvos

## a) VERTEBRATES

Birds are the most important vertebrate predators of the spruce budworm. The role of birds in budworm control has been investigated by several authors including Tothill (1922), Kendeigh (1947), George and Mitchell (1948), Mitchell (1952), Dowden, Jaynes and Carolin (1953), Mook (1963) and Otvos (unpublished data). Based on stomach analysis spruce budworm contributed from 3% to 40% of the diet in the birds examined, depending on the density of budworm population levels. Generally, birds have the greatest control value at low or endemic budworm population levels, and do not have an appreciable influence at outbreak levels, even though some species of birds show numerical (Mook 1963) as well as functional response (Zach and Falls 1975) to budworm population levels.

A total of 13 bird species feed on spruce budworm larvae and pupae in Newfoundland. Budworm composed 4%, 31%, 21%, 14% and 24% of the diet of the birds examined in the years from 1973 to 1977 respectively. The more important species were boreal chickadee, *Parus hudsonicus* Forster, several warbler species, *Dendroica* spp., robin, *Turdus migratorius* L., white-throated sparrow, *Zonotrichia albicollis* Gmelin, and blue jay, *Cyanocitta cristata* L. Although, in some cases, the entire stomach content was composed of budworm, it appears that birds had only a limited control value during the present outbreak in Newfoundland (Otvos unpublished).

Three small mammals may also feed on the budworm in Newfoundland; the meadow vole, *Microtus pennsylvanicus*, the masked shrew, *Sorex cinereus* and the red squirrel, *Tamiascirus hudsonicus*. The first two feed probably only on larvae dropped from severely defoliated trees but the squirrel may also feed on the budworm in the tree crowns. The effect of these mammals on spruce budworm populations is minimal.

### b) INVERTEBRATES

Invertebrate predators of the spruce budworm include ants, other insects, spiders, and mites but their role in budworm control at epidemic levels is limited. The spruce coneworm, another defoliator, can also feed on spruce budworm pupae (Warren 1954, Thomson 1957). The coneworm caused 6% mortality, various other insects 5% mortality, and the remaining 7% was undetermined for a total of 18% pupal mortality by predators. However, in spruce stands where the ratio of coneworm to budworm is about 50:50, predation on budworm pupae is likely to be higher (Otvos unpublished).

Some authors consider spiders and mites as important predators of budworm larvae at endemic population levels (Loughton *et al.* 1963, Renault and Miller 1972). Although spiders are abundant in the forest environment, their role in budworm control, probably even at endemic population level, is limited.

## 3. PARASITES

C.A. Miller and I.S. Otvos

Over 70 species of parasitic insects have been reared from the spruce budworm, 30 of which occur throughout the geographic range of their host (Wilkes *et al.* 1948, Jaynes and Drooz 1952, McGugan and Blais 1959, Miller 1963, Otvos and Moody 1978). The species composition varies with time, space and geographic location. The major parasite studies by region are as follows: New York - Dowden and Carolin (1950); Maine - Jaynes and Drooz (1952); Ontario - McGugan and Blais (1959); Quebec - Blais (1960); New Brunswick - Macdonald and Webb (1963), Miller (1963); Newfoundland - Otvos and Moody (1978). These combined studies have produced an impressive list of parasites, but for practical purposes this list can be reduced to about 10 to 15 species that are relatively common in eastern North America (Table VII-1). Of these, 12 occur in Newfoundland, and only eight are common (Otvos and Moody 1978).

Table VII-1. Common parasites of the spruce budworm in eastern North America.

| Stage attacked | Parasite species | Common in Newfoundland |
|---|---|---|
| Egg | *Trichogramma minutum* Riley | |
| First-second instar larvae | *Tranosema rostrale* (Brischke) | |
| | *Apanteles fumiferanae* Vier. | X |
| | *Glypta fumiferanae* (Vier.) | X |
| Third-fourth instar larvae | *Elachertus cacoeciae* Howard | |
| | *Enytus montanus* (Ashmead) | |
| | *Apanteles petrovae* Wall. | |
| Large larvae, prepupae | *Meteorus trachynotus* Vier | X |
| | *Actia interrupta* (Curr.) | |
| | *Eumea caesar* (Ald.) | |
| | *Lypha setifacies* (West.) | |
| | *Winthemia fumiferanae* Toth. | |
| | *Phryxe pecocensis* (Tns.) | |
| Pupae | *Apechthis ontario* Cress. | X |
| | *Itoplectis conquisitor* (Say) | X |
| | *Phaeogenes hariolus* (Cress.) | X |
| | *Agria housii* Shewell | |
| | *Mesopolobus verditer* (Nort.) | X |
| | *Psychophagus tortricis* (Brues) | X |

*Trichogramma minutum* - This egg parasite occurs both in Canada and the United States, but authorities cannot agree on its control value. Hewitt (1912) reported parasitism by this species from 1% to over 70%. Miller (1963) reported up to 48% egg parasitism and that parasitism appeared to vary irrespective of host density.

*Apanteles fumiferanae* and *Glypta fumiferanae* - In Canada *Glypta* appears to be more important (Miller 1963, McGugan and Blais 1959, Otvos and Moody 1978) but in the eastern United States *Apanteles* is considered to be more important (Jaynes and Drooz 1952). The combined parasitism by these two species have been reported to vary between 20% to 30% (Jaynes and Drooz 1952, Miller 1963). Apparent larval parasitism by these species reached a high of about 25% in Newfoundland.

*Meteorus trachynotus* - Varying degree of importance is attributed to this parasite, depending on the location and age of the budworm outbreak (McGugan and Blais 1959, Miller 1963, Blais 1965). Parasitism by this species may increase during the outbreak period, and a marked increase occurs in the years of collapse. Therefore this parasite is considered an indicator of decline of budworm outbreaks. This increase by *M. trachynotus* has not been observed in Newfoundland, and its numbers have been low during the current outbreak.

*Apechthis ontario, Itoplectis conquisitor, Phaeogenes hariolus, Psychophagus tortricis* - Of these, *P. hariolus* and *A. ontario* are generally more important (McGugan and Blais 1959, Jaynes and Drooz 1952, Miller 1963, 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. *P. hariolus* is another species which becomes abundant during the latter years of an outbreak (Miller 1963). According to Blais (1960) *I. conquisitor* may also show spectacular increase in numbers as an outbreak declines. The other three species are never abundant.

Only limited data have been collected on the effect of parasites on endemic populations of the spruce budworm. In northwestern New Brunswick (Miller and Renault 1976) 18 parasitic species attacked the larval stages of sparse budworm populations, killing more than 50% of the budworm. Parasites may play a regulating role between outbreaks, but when other processes become highly favourable for budworm survival (favourable climate, mature susceptible forests), or if sudden increases in density occur (influx of egg-carrying females) the parasites either respond only slowly to increasing host density or show an inverse response.

Most parasites require alternate hosts to complete their life cycle. This can severely limit their ability to increase (numerical response) when budworm epidemics develop. In the early phase of the epidemic the proportion of budworms killed (15%) is insufficient to have any significant effect on the course of the outbreak. The level of parasite attack slowly increases as the epidemic progresses and maximum attack (60%) generally occurs during the 'collapse' phase of the epidemic (Macdonald and Webb 1963). Even those parasites that are relatively specific to the budworm (i.e. do not require alternate hosts), such as *A. fumiferanae*, and *G. fumiferanae*, do not respond quickly to increasing budworm abundance. Other processes trigger the collapse of the epidemic and parasites tend to hasten the process. No field data suggest that parasites can regulate the collapse of uncontrolled epidemics.

Some local populations of budworm fail to reach epidemic levels because of a complex of factors including host-stand composition, host-tree density, local topography, local climate, and isolation. In these stands parasitism is often significantly higher than in severely attacked stands in the core of the outbreak (Miller 1963), and under these conditions parasites play a more positive role in damping budworm increases and enhancing population decline.

During the current outbreak in Newfoundland apparent parasitism gradually increased over the years from a low of about 3% in 1972 to 35% in 1977. The most important parasites 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 1978 and 1979. A rapid increase in the numbers of *P. hariolus* and *Meteorus trachynotus* has been associated elsewhere with the decline of spruce budworm outbreaks.

## 4. PATHOGENS

T.A. Angus

The spruce budworm, as any other living form, suffers from disease induced by infectious microorganisms; the symptoms induced range from chronic and debilitating to acute and lethal. The causal agents include four classes of microorganisms: protozoans, fungi, viruses and bacteria.

Of the protozoans, by far the most common is *Nosema fumiferanae* (Thom.) (Microsporidia), a ubiquitous debilitating parasite of all life stages. Infected larvae usually complete development into functioning adults, but they are smaller and less vigorous than healthy individuals and their egg production is reduced (Thomson 1958, Wilson 1980).

A number of fungal pathogens have been isolated from spruce budworm but their frequency is usually very low and only one, *Zoophthora radicans* (Bref.) Batko[1], causes any significant amount of mortality. Epizootics caused by this pathogen are sporadic and very localized. However, in Newfoundland fungi may be important control agents. Disease caused by two species,

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[1]*Zoophthora radicans* (Bref.) Batko = *Entomophthora sphaerosperma* Fresnius = *Erynia radicans* (Bref.) Humber and Ben-Ze'ev.

*Entomophthora egressa* MacLeod and Tyrrell and *Z. radicans*, was first recorded in 1972 and was widespread by 1975. In 1977 the disease caused about 30% mortality in the late larval and pupal stages and about 60% in some locations where precipitation was higher than in the rest of the Island (Otvos and Moody 1978). These fungi require warm, moist conditions for optimal infection and development. Such weather usually does not prevail in Newfoundland until mid to late July and budworm development is normally well advanced by that time. In addition, dry, hot sunny weather arrests fungal development and sporulation and prevents subsequent infection. The sensitivity of the fungi to weather limits their effectiveness as control agents.

Four kinds of viruses are known from the budworm, and all of them are eventually lethal (Cunningham *et al.* 1981). Their occurrence in natural populations is generally so low that their effect on budworm abundance is minimal. Undoubtedly the solitary habit of budworm larvae is of great importance in limiting the spread of viruses.

Infectious bacterial disease conditions in budworm are extremely rare, and most isolates from moribund or dead larvae or pupae are saprophytes or at best opportunistic pathogens exploiting damage by some other predator or parasite.

Surveys for epizootic disease have been conducted intermittently since early 1970's. These studies indicate that infectious disease is not an important factor in budworm abundance. This agrees with the findings of a four-year survey for disease conducted in New Brunswick during 1954-1958.

Although some pathogens occur widely (Microsporidia), sporadically and locally (fungi) or widely at low frequency (viruses), none of these have been observed to have the dramatic impact on budworm populations noted in some other forest insect pests. The conclusions of Miller (1963) with respect to the role of parasites is probably valid also for natural (unmanipulated) pathogens, i.e. "when climatic and edaphic factors combine to produce a favourable environment for budworm increase, parasites [including pathogens] cannot prevent population release".

When natural pathogens can be manipulated artificially, such as the introduction at increased densities, the use of more lethal strains or seeding the pathogens earlier than they would occur naturally in the outbreak cycle may result in significant control. However, the artificial manipulation of pathogens is only in the experimental stage.

# 5. COMPETITION

C.A. Miller

A large number of insect pests defoliate balsam fir and the spruces in eastern North America (Rose and Lindquist 1977), but only five species have been recorded as serious pests in maturing stands. The blackheaded budworm, periodically erupts to outbreak levels in balsam fir and can cause top kill and localized tree mortality. Two closely allied species of *Zeiraphera* attack white spruce but do not cause tree mortality. The spruce coneworm is often relatively abundant on the spruces and can cause serious damage to foliage and cones. The hemlock looper is a serious pest of balsam fir, particularly in Newfoundland, and may cause severe tree mortality in maturing stands. However, none of these species are serious competitors of the budworm because outbreaks do not occur at the same time as those of the budworm and do not result in direct competition for a common food resource. Usually the spruce budworm develops earlier in the spring than its possible competitors, and therefore is not adversely affected by them.

The ability of the budworm to reach extremely high densities within a few generations is its own worst enemy. Larval competition at the peak of an outbreak for a limited food resource results in a marked change in larval feeding behaviour as the current foliage is depleted, maturing larvae are forced to feed on old foliage or to cascade through the crown seeking a new food source (Morris 1963c). These dispersing larvae quickly consume the limited food on understorey trees and young or reproduction and are subject to a complex of mortality factors and processes near ground level. Thus intra-specific competition for a depleted food supply can ultimately result in a marked reduction in budworm density in a few generations at the peak of an outbreak. In an unmanaged outbreak this triggers the decline and ultimate collapse of the epidemic.

Maturing larvae compete for a limited food resource, but there is little evidence of active competition during other life stages. In severely defoliated stands with a low production of current buds there is a scarcity of suitable feeding sites for second-instar larvae in the spring but it is doubtful if this results in active competition for these sites. There is no evidence that competition is a limiting factor in the mating process. There may be a minor level of competition among ovipositing females for the scarce oviposition sites in severely defoliated stands, but the extent to which it may enhance the emigration response is unknown.

# 6. FOOD QUANTITY AND QUALITY

G.T. Harvey

The presence of a good supply of suitable food is accepted as one of the conditions favouring a spruce budworm outbreak (Baskerville 1975b). Loss of this food supply is considered to be the principal factor leading to outbreak collapse. During the early phases of population build-up food supply is generally ample and differences in its quality do not appear to have a major effect on the course of outbreak development. The third and fourth years of moderate to severe defoliation seriously reduces the capacity of the trees to produce leaves and probably decreases their quality as food for the budworm. These progressive changes lead to reduced larval survival, smaller adult insects and reduced fecundities (Miller 1957, Miller 1963a). Despite emigration of moths from severely damaged areas (Greenbank 1963b) sufficient insects remain to continue the destructive process which usually kills most of the trees. At this stage the insect population in the area collapses. Where trees have been protected by pesticides or other treatments and not harvested, the infestation may continue as long as there is food for the insects.

Differences in foliage quality undoubtedly play a part in the above pattern. The significance of such differences in the early stages of outbreak development is not well understood. Large areas of mature or overmature balsam fir and white spruce are conducive to population increases that produce an outbreak (Blais 1961). In such forests, where heavy flowering is common, flowers have been considered a better quality food and thought to contribute to high survival and rapid development of early instars and thus, lead to population increases (Blais and Thorsteinson 1948, Jaynes and Speers 1949, Blais 1952, Greenbank 1963a). However, life table studies failed to show that staminate flowers improved survival of small larvae, although in years with favourable weather larvae in such sites developed faster than in other sites (Greenbank 1963a, Miller 1963a). Moreover fecundity of the surviving moths was not greater from flowering than from non-flowering trees (Blais and Thorsteinson 1948, Jaynes and Speers 1949, Greenbank 1963a). Greenbank (1963a) concluded that the more rapid development in staminate flowers was probably a physical rather than a nutritional effect.

Year-to-year, geographical and phenological variations in foliar nutrient content have been reported for balsam fir (Kimmins 1971, Shaw and Little 1977, Czapowskyj 1979) and for white spruce (Durzan 1968, Kimmins 1971, Pollard and Ying 1979). Such differences have been considered to be of some importance to budworm population dynamics (Miller 1963a, Kimmins 1971). The demonstration that both survival and mature size of budworm developing on young balsam fir can be increased by addition of fertilizers is direct evidence of a link between foliage constituents and insect dynamics (Shaw *et al.* 1978). Furthermore, amino acid composition of budworm larvae reflected the amino acid composition of the host on which they feed (Durzan and Lopushanski 1968). However, attempts to demonstrate a relationship between insect survival and mature size and natural variations in foliar constituents has not been achieved (Macdonald 1963, Harvey unpublished).

Host species differences must also be considered in any review of the effects of foliage quality. Both balsam fir and white spruce appear to be highly suitable nutrient sources for feeding larvae, in spite of differences between them (Kimmins 1971, Durzan and Lopushanski 1968). White spruce is preferred for oviposition by female moths (Jaynes and Speers 1959, Wilson 1963). Larvae develop more rapidly on white spruce and pupal weights in paired tree experiments were significantly greater on spruce than on fir (Harvey unpublished). However, such differences are not great, and developmental performance on both hosts is usually at a high level. Both red and black spruces support development to maturity and may be close to balsam fir in quality for the budworm even though they are somewhat less suitable as hosts. The budworm can also complete development on larch, pines and hemlock during outbreaks. The apparent adequacy of such a wide range of food sources and the results of experimental studies so far show clearly that food quality is not a key factor, or even a major factor in the population dynamics of the spruce budworm. Kimmins (1971) considers that nutrition is, nonetheless, one of the natural factors that influence population increases. The effects of food qualitiy differences would appear to be in the fine tuning of the budworm-forest system. Their exact nature and the use to which such knowledge can be put in management of this species have yet to be determined.

The magnitude of the forest susceptible to budworm attack has discouraged attempts to exploit differences in host quality or to directly manipulate it to limit budworm attack. Some differences between trees in the extent of budworm attack in the early stages of outbreaks suggest differences in susceptibility. Such differences largely disappear when insect numbers increase. Theoretically, selection of such trees could lead to the development of resistant stocks for planting and, if extensive enough, could produce a forest of low susceptibility to budworm. However, on the basis of present knowledge such trees are unlikely to survive a severe outbreak. Other attempts to manipulate foliage quality do not have much better prospects. Use of fertilizers that improve tree growth are most likely to increase budworm success rather than diminish it (Shaw and Little 1972).

Substances which inhibit or decrease the palatability of foliage for larval feeding have had some success in agricultural crops but have not been studied for the budworm. Utilization of such substances might reduce feeding and bring about outbreak collapse. However, such a feeding inhibitor must be very effective for the spruce budworm as well as environmentally acceptable, and delivery systems must be developed for operational control.

## SUMMARY

Numerous biotic and abiotic factors such as predators, parasites, diseases and weather affect spruce budworm populations. These factors may be more important at endemic population levels but cannot prevent epidemics if conditions favour budworm development and survival. The collapse of a budworm epidemic is associated with many factors, such as the increased activity of parasites, predators, pathogens, and increased competition for food. The most important of these is the competition for food which leaves the forest dead, dying or in a severely stressed condition. Differences among trees in the severity of defoliation in the early stages of outbreak suggests differences in susceptibility based on food quality. However, such differences largely disappear when insect numbers increase and manipulation of foliage quality will not likely prevent or control epidemics.

# VIII. APPLIED CONTROL MEASURES REGISTERED FOR COMMERCIAL USE AND POTENTIAL CONTROL METHODS

## 1. REGISTERED COMMERCIAL METHODS

### a) AERIAL SPRAYING WITH CHEMICAL INSECTICIDES

J.A. Armstrong and E.G. Kettela

The aerial application of chemical insecticides is the most effective and widely used method for the protection of large areas of forests from insect attack (Prebble 1975). The objective of chemical spraying is crop protection, i.e. keeping trees alive and growing, and not insect population control. With a suitable formulation and properly calibrated spray equipment it is possible to provide acceptable protection with spray volumes as low as 1.5 ℓ/ha. This is achieved by the atomization of the pesticide mix into a cloud in which the majority of the droplets are between 50 to 100 µm and with the largest droplet no bigger than about 250 µm. At this rate of atomization there is good spray coverage. Most of the spray is deposited on the outer parts of the tree on the new shoots and foliage where most of the larvae are found (Armstrong and Yule 1978).

Effective coverage of the forest is also achieved by the drift of the cloud of insecticide to provide an extended swath of coverage. Small aircraft with a load capacity of 400 to 600 ℓ flying 20 to 30 m above the tree tops, have an effective swath width of approximately 65 m; the Grumman Avenger TBM's used by the province of New Brunswick and flown in a flight formation of three have combined swath width of approximately 500 m. The large, four-engined aircraft used extensively in Quebec and New Brunswick, with a load capacity of from 10 000 to 14 000 ℓ, have effective swath widths of up to 800 m. The use of planes with electronic guidance systems (Boivin and de Lamp 1975) assures minimum overlap of spray swaths or of forest strips missed by the spray cloud. Prebble (1975) has presented an historical and scientific account of the development of aerial spraying technology in Canada for forest insect control. In his report the effective use of drift to provide environmentally acceptable spray coverage is documented. Admittedly, off-target drift might be a problem but studies to date show that even though pesticides drift up to 80 km down wind of the target, the amount of material in the atmosphere at this distance is very small. It should be remembered that by making use of drift it is possible to achieve coverage (Randall 1975) that is impossible with a spray comprised of very large droplets and minimal drift. A hazard of the very coarse, narrow swath sprays is that if there is any overlap of swaths environmental damage may occur or there may be gaps in the treatment area and contamination of the ground could be increased. Fine spray particles tend to accumulate on the foliage of the trees while the large droplets tend to penetrate the forest canopy and be deposited on the ground.

In Canada there are seven chemical insecticides registered for forestry use against the spruce budworm. The registration of these products is based on an extensive program of long term research by industry, private organizations and departments and services of the Canadian Government (i.e. CFS, DFO, CWS, NH & W) and on a broad background of agriculturally oriented research. The cost of this research is so high that unless an insecticide has a market in agriculture it is not economical to develop for forestry use. The registration of pesticides is carried out by Agriculture Canada under the terms of the Pest Control Products Act. In this process, documentation on target and non-target toxicology, human health, degradation and translocation and the ultimate fate of the particular pesticide are submitted. Copies of appropriate sections are sent to Health and Welfare, Canadian Wildlife Service, Canadian Forestry Service, Dept. of Fisheries and Oceans, Environmental Protection Service and specific groups of Agriculture Canada for comments. Each of these organizations has the opportunity to recommend acceptance or rejection of the product or to offer suggestions as to other work needed. Based on these comments, Agriculture Canada makes the final decision to grant or refuse registration.

Table VIII-1 shows the registered products, their application rates, and basic toxicity to budworm, fish, birds and mammals (Nigam 1975). For comparison, and interest, DDT is included. The decision to use any one of these products is based on an assessment of its relative toxicity to different organisms in the environment. In interpreting the LC (lethal concentration) and LD (lethal dosage) values a guideline is "the larger the number the safer the material". Thus in comparing Acephate with DDT, and acknowledging that the DDT fish data pertain to salmon and the acephate to trout, acephate with a fish $LC_{50}$ of 1 000 ppm

Table VIII-1. Chemical pesticides registered in Canada for use in forestry against the spruce budworm.

| Common name | Trade name | Reg. appl. rate g AI/ha | Contact toxicity 72 hrs. (μg/cm²) $LD_{50}$ | $LD_{95}$ | Residual toxicity[1] after weathering periods at 0 day | 1 day | 3 day | 5 day | 10 day | Toxicity to fish (salmon) $LD_{50}$ ppm (48 hr) | Toxicity to birds $LD_{50}$ (mg/kg) | Mammalian toxicity Rat $LD_{50}$ (mg/kg) Oral | Dermal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Chemical Pesticides** | | | | | | | | | | | | | |
| DDT[2] | DDT | 280-2280 | 1.32 | 6.64 | 73 | 84 | 52 | 37 | 30 | 0.05 | 2 240.0 | 87-500 | 1931-3263 |
| Acephate | Orthene[R] | 425-550 | 0.42 | 3.50 | 95 | 88 | 38 | 15 | 18 | 1000 ppm (trout) | 350.0 | 1 494 | 10 250 |
| Aminocarb | Matacil[R] | 55-90 | 0.04 | 0.11 | 95 | 89 | 66 | 70 | 66 | 1.30 | 22.5 | 30 | 275 |
| Carbaryl[3] | Sevin[R] | 1090 | - | - | - | - | - | - | - | 1.00 | >2179 | 307-986 | >500->4000 |
| Fenitrothion | Folithion[R] Sumithion[R] Novathion[R] | 150-275 | 0.31 | 0.67 | 81 | 71 | 46 | 43 | 32 | 1.4 | 1190 | 250-670 | 200->3000 |
| Phosphamidon | Dimecron[R] | 280-560 | 0.39 | 0.75 | 85 | 70 | 50 | 45 | 15 | 11.0 | 3.1 | 15-33 | 640 |
| Trichlorfon | Dylox[R] Dipterex[R] | 840-1700 | 0.22-0.28 | 0.38-0.57 | 94 | 39 | 18 | 0 | 8 | 1.6 | >5000 | 450-469 | >2000 |

[1] Application rate equal to 220 g AI/ha except DDT which was applied at 560 AI/ha.
[2] Can be used only in an emergency situation and only under special restrictions.
[3] Registration based on U.S. data. FPMI do not have data on Insect Toxicology.

is 20 000 times safer than DDT with a fish $LC_{50}$ of 0.05 ppm. Conversely DDT with a bird $LD_{50}$ of 2240 mg/kg is approximately 6.5 times safer to birds than acephate with a bird $LD_{50}$ of 350 mg/kg. Comments on each product are given.

DDT - This product was used for many years in the spruce budworm program in New Brunswick and was withdrawn from use when it became evident that it accumulates in the food chain and new, more effective compounds appeared. It should be stressed that an acknowledgement of DDT problems and the identification and selection of other pesticides by CFS was made prior to the banning of this product (Fettes 1962). DDT can still be used in forestry only under special restrictions and only in an emergency situation.

Acephate[1] - Marketed as Orthene[R], this product is a water soluble material registered for use at 425-550 g AI/ha. Advantages are its relative safety to fish and its ease of formulation in water. Disadvantages are that it is most effective late in the budworm development period when timing is critical, susceptibility to evaporation and toxicity to bees. The material is a powder and hence must be handled in bags rather than pumped which some operators have not liked. With proper application rates and timing acephate is very effective (Armstrong and Nigam 1975).

Aminocarb - Marketed as Matacil[R], this insecticide is an oil soluble formulation registered for use of two applications per season of 55 to 90 g AI/ha each. This product has been used extensively since 1973 with an accumulated total of more than 12 000 000 ha treated. The product is most effective against $L_3$ to $L_4$ budworm larvae. Advantages of aminocarb are its effectiveness, good safety record, ease of handling, and, being an oil formulation it does not evaporate. The safety of the primary solvent, nonyl phenol used in the Matacil formulation, has been questioned. Laboratory studies by DFO at St. Andrews showed that this product was toxic to juvenile salmon (Zitko *et al.* 1980). In subsequent field studies by the Forest Pest Management Institute, nonyl phenol applied at approximately five times the maximum seasonal treatment had no significant effect on the fish population (Holmes and Kingsbury 1980, Sundaram *et al.* 1980). Therefore the pesticide regulatory section of Agriculture Canada concluded that because of the amounts used and considering its safety with respect to mammalian toxicity, nonyl phenol was acceptable as a primary solvent.

Carbaryl - Marketed as Sevin[R], carbaryl has been used as Sevin-4-oil on the spruce budworm program in the United States. It is registered for use at 1090 g AI/ha in Canada but has not been used operationally in Canada. It is registered for use because it is usually used at the high application rate of 4.6 ℓ/ha whereas the chemical control operations in Canada are normally at 1.5 ℓ/ha. This may change as Union Carbide has developed a new formulation allowing the application of lower volumes. Generally carbaryl meets safety standards although it is at present under an

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[1]Acephate was under temporary registration till the end of 1981. New toxicity data have been submitted, and upon completion of the review process it is anticipated that acephate will receive full registration.

RPAR (Rebuttable Presumption Against Registration) in the U.S.A. arising from some long term carcinogenicity studies and as a result of questioning its toxicity to bees and the aquatic environment.

Fenitrothion - Marketed as Sumithion$^R$, Folithion$^R$, Novathion$^R$, this material has been used extensively on the spruce budworm operations in eastern Canada. The operational rates are 150-275 g AI/ha with a season maximum of 425 g AI/ha. Fenitrothion is applied as either a water emulsion or an oil solution, and is effective against the early ($L_2$) as well as the later instars ($L_5$ to $L_6$) of the spruce budworm.

Phosphamidon - Marketed as Dimecron$^R$, this product was used for a few years in New Brunswick at the end of the DDT era; it was effective against spruce budworm at 210 g AI/ha. The main reason for its introduction was its safety to fish, however, as a use pattern developed, evidence accumulated that it was highly toxic to birds. Following intensive monitoring of phosphamidon treated areas this product was withdrawn from use. It was effective against the adult spruce budworm and for this reason it has been used as a research tool in areas where the plan of the study is to reduce the adult budworm populations.

Trichlorfon - Marketed as Dylox$^R$ or Dipterex$^R$, this product was effective only when applied against the later instars ($L_5$ and $L_6$) when the insects are more exposed. The rate of application is 850-1700 g AI/ha which is uneconomical. For these reasons this product has never been used extensively.

The cost of pesticide application will vary greatly according to the size of the area to be treated, type and numbers of aircraft and the pesticide used. Generally speaking the application of recent chemical insecticides ranged from $3.30 to $6.70/ha in 1980.

## b) AERIAL SPRAYING WITH *Bacillus thuringiensis*

### i) CANUSA Working Group Guidelines -- O.N. Morris

*Bacillus thuringiensis* Berliner (= *B.t.*) has been aerially applied against at least 14 species of forest insect pests with varying degrees of success. Variations in efficacy have been due mainly to differential susceptibility of the species and inadequate deposit of active ingredient at the feeding sites.

Although the spruce budworm is highly susceptible to *B.t.* (Morris 1973) its field effectiveness has been unpredictable due to low deposit efficiencies of water-based formulations and to the feeding habits of the pest. The only fully registered commercial *B.t.* product for spruce budworm control is Thuricide 16B[R]. Other products, e.g. Dipel SC, Dipel 45B and Novabac-3 have only temporary registration or use permit for small woodlots. A new oil emulsion formulation, Dipel 88[R] has just received registration.[1]

The effectiveness of *B.t.* against spruce budworm was most recently demonstrated in the 1979 CANUSA cooperative aerial spray trials (Morris 1980). Preliminary to these trials, application guidelines were agreed on by CANUSA working groups and were followed during the spray trials. These technical guidelines for *B.t.* are as follows:

A. Trial Objectives

1. To limit average current defoliation to 50% or less. Some loss in tree growth is acceptable but reasonable tree vigor should be maintained.

2. To achieve 75%-85% budworm control. This is calculated as mortality in treatment plot corrected for natural mortality in check block.

B. Formulations

1. Minimum formulation:

| | |
|---|---|
| 50 parts: | Thuricide 16B |
| 50 parts: | Water (avoid chlorinated water) |
| 1%: | Chevron sticker |
| 0.25 gm/ℓ: | Erio Acid Red XB 400% tracer dye (= EAR) |

(This may be predissolved in water and taken to the field as a liquid.)

This is mixed to achieve a total emission rate of 20 BIU/ha and is preferably applied at 2 x 10 BIU in 4.7 ℓ/ha (i.e. 1 ℓ 16B + 1 ℓ water etc./ha sprayed twice). This may also be applied as a single application of 20 BIU in 9.4 ℓ/ha (i.e. 2 ℓ 16B + 2 ℓ water etc./ha, sprayed once). The first spray is applied when the shoots start to flare. Thuricide 16B and Dipel 88 and Novabac 3 are fully registered in Canada for spruce budworm control. Chevron spray sticker is not registered in Canada but necessary-use permits may be obtained from Agriculture Canada (Ottawa). The use of tracer dyes should be limited to trials where precise ground or tree deposit measurements are needed.

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[1]A list of manufacturers and their addresses of supplies needed for a *B.t.* spray program has been provided in Appendix VI.

2. Other formulations:

| | | |
|---|---|---|
| (a) | 50 parts: | Thuricide 32B |
| | 20 parts: | Sorbitol |
| | 1/1600: | Chevron sticker |
| | 0.25 gm/ℓ: | Erio Acid Red XB 400% tracer dye |
| | 10 000: | Nephelometric units of chitinase per ha |
| | 30 parts: | Water (avoid chlorinated water) |

(b) Same as (a) but without chitinase

Options (a) and (b) should be mixed to achieve total emission of 20 BIU/ha at minimum emission rate of 4.7 ℓ/ha. The province of Quebec has special permits to use Thuricide 26B and 32B. Use in other provinces will require permits from Agriculture Canada and notice of intent sent to Federal Interdepartmental Committee on Pesticides.

C. Operational Constraints

1. Pre-spray populations -- Selection of the treatment blocks should be limited, for the most part, to areas supporting a moderately high population of 25 to 30 larvae/45 cm branch with at least two visible current buds per larva on a 45 cm branch tip (a small number of the operational trials should be done against significantly higher populations of 50 to 60 $L_3$/45 cm to determine the effect on such populations).

2. Timing of operations

Balsam fir or spruce stands - Spraying should begin when the shoots start to flare and continue to when 30% of the larvae are in the 5th instar. In general treatment would be applied when the larvae are in the 3rd and 4th instars and would limit the number of spraying days to about 10.

Mixed stands - In mixed stands the presence of white, red and black sprue creates application problems because bud caps remain on the expanding shoots of spruce longer than they do on fir thus protecting the budworm from the first spray. In fir-white spruce stands, *B.t.* seems more effective on fir than on spruce and therefore two applications of 10 to 20 BIU each would be desirable. In fir-red spruce or fir-black spruce stands, the shoots of spruce flare about 9 days later than fir and therefore two applications of 10 to 20 BIU each are necessary to obtain good protection.

D. Deposit Specifications

Two different sets of sample units should be used for double applications. If glass plates and Kromekote cards are used, they should be marked with block number, plot and treatment number, and sent to FPMI in slotted boxes. If millipore filters are used they should be sent to FPMI in individual envelopes. If petri dishes of agar are used to collect spore deposits, the colonies should be counted by the agency in charge of the spray. If millipore filter membranes are used, the filters should be pinned to the sample kit board, placed on the ground with grid-side up, close to but not under the sample tree. Sampling on the upwind side of tree will further standardize the trials.

1. Drop density -- At least 25 drops/$cm^2$ for each Kromekote card with EAR dye should be obtained in the formulations. At 4.7 ℓ/ha and an average droplet size of 80 μ, the expected drop density is about 150/$cm^2$ and actual deposit density should then be about 50/$cm^2$. The above estimate of 25/$cm^2$ may therefore be conservative.

2. Spot size -- Spray nozzles should be calibrated to provide a mean median diameter of not less than 80 μ, range of 80 to 200 μ, on Kromekote cards. This does not include a spread factor of an impinged drop.

3. Colony counts -- With Agar petri dishes or millipore filter membranes, a minimum of 25 colonies/$cm^2$ following 18 hour incubation at $28^{o}C$ should be obtained. The drop counts may or may not equal the colony counts as this varies with droplet size.

4. Deposit unit configuration -- The various measures to assess the volume of spray deposited should be placed together on the ground: the 7.5 cm x 5 cm glass plates, the agar-filled petri plates, the millipore filters, and the Kromekote cards. These are to be located in the open, and to be arranged perpendicular to the flight path. A minimum of 10 sample stations should be used across the spray block, with 5 deposit units per station. Sample units should be placed on the upwind side of a sample tree. The 50 + sample units per block should be spaced within the block as evenly as possible.

E. *B.t.* Batch Quality Control

All batches of *B.t.* will be sampled for quality control with sufficient lead time before the operational spray to allow adjustments to formulations. A sample of 10% of the drums received is considered acceptable for operational sprays.

Bioassays for BIU content is to be done at FPMI, and spore viability assessments at the LFRC by W. Smirnoff. Samples of 500 ml should be removed from the drums according to Dr. Smirnoff's method (Morris 1980) and sent directly to LFRC and to FPMI.

Thuricide should be ordered at least two months before expected delivery date. For most spray operations, *B.t.* should be on hand by 1 April and batch samples for quality control tests sent as soon as the *B.t.* arrives.

F. Monitoring of Effects

1. Pre-spray population counts -- A minimum of five check plots should be randomly located in each operational block and a minimum of 10 plots for each 4 000 ha block. In each assessment plot, five trees of each species involved should be sampled. Samples should consist of one branch/tree from the mid-crown and the number of larvae/45 cm branch tip recorded. Branch samples should be collected on the upwind side of tree with respect to flight direction. Trees should be sampled when larva are in the 3rd instar.

2. Post-spray population counts -- Sample as for the pre-spray population count but when the population is in pupal stage. This is minimum sample frequency. However, the number of trees per plot should be doubled to 10 and the number of branches per tree increased to two.

3. Estimates of tree vigour -- Sometime during the season, a count of the number of current shoots per 45 cm tip should be obtained as an index of tree vigour. These data may also explain variations in defoliation relative to budworm abundance. For this, a sample of 20 branches per species should be used.

4. Defoliation estimates -- For each tree sampled for post-spray population counts in each plot, all new shoots from the 45 cm branch samples are removed, mixed and 20 shoots selected at random for each branch sampled. The defoliation of each shoot selected is then estimated with Fettes' method.

Of a total 29 spray trials with *B.t.* from six eastern Canadian provinces and the state of Maine, 55% gave acceptable foliage protection of white spruce and balsam fir stands based on 50% or greater retention of current year's growth. This overall success rate is obviously not as good as the success rates with some chemical pesticides. However, the relatively high environmental safety of *B.t.* must be balanced against its generally lower level of effectiveness compared with the chemical pesticides.

At present, the greatest disadvantage to the use of *B.t.* is cost. In 1979, the average cost of materials and applications above ranged from $9 to $22/ha, or about three to six times the cost of chemical insecticides.

### ii) Alternative Methods for Use of *B.t.*[2] -- W.A. Smirnoff

*Bacillus thuringiensis* serotype 3a3b *kurstakii* is a bacillus specific to lepidopterous larvae. It causes septicemia (= blood poisoning) through the action of its spores and an element of enterotoxicosis by the action of the crystal-like parasporal inclusions (α endotoxin) (Heimpel and Angus 1960). It is widely used against Lepidoptera in agriculture. *B.t.* is easy to culture in large quantities on inexpensive protein sources and small amounts of other nutrients.

The pathogenic action of *B.t.* on spruce budworm depends upon the dose absorbed, age and physiological state of larvae, air temperature, relative humidity, and presence of natural infections by microsporidia. Third and fourth instar larvae are more susceptible to *B.t.* than fifth and sixth instar larvae. It took an average of 8 and 20 days to obtain 50% and 100% mortality of third and fourth instar larvae but 15 days to obtain 50% mortality of fifth and sixth instar larvae, and some larvae survived (Smirnoff 1973, 1977). The optimal temperature for the action of *B.t.* on spruce budworm is $20^{o}$ to $22^{o}$C (Smirnoff 1967).

The penetration of *B.t.* spores into the insect hemolymph through the peritrophic membrane is difficult and occurs mostly during moulting if budworm larvae are not infected with microsporidia. Addition of minute quantities of chitinase, an enzyme which hydrolyses the chitin contained in the peritrophic membrane, facilitates penetration of *B.t.* spores into the hemolymph (Smirnoff 1971, 1977). This addition of chitinase improved the pathogenicity of *B.t.*; the time required to obtain 100% mortality of third instar healthy larvae at $20^{o}$C was nine days with chitinase and 20 days without chitinase. Such mortality of larvae infected with microsporidia occurred after eight days with or without chitinase (Smirnoff 1977). Also, larvae infected with *B.t.* + chitinase stopped feeding two days after infection whereas those infected with *B.t.* alone continued to feed for eight days after infection.

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[2]There are some differences of opinion between the Canada-USA Working Group and the author of this article; hence the presentation of these Alternative Methods (Editors).

Formulations - Three formulations were developed for use of *B.t.* over large areas. Formulation (1) and (2) have been used in Quebec since 1973; formulation (3) was developed in 1978 to 1979, used for aircraft calibration in 1979, and field tested against spruce budworm during experimental aerial spraying in 1980.

(1)

| | |
|---|---|
| 50 parts: | bacillus concentrate $8.45 \times 10^9$ IU/ℓ |
| 50 parts: | 30% aqueous solution $NaH_2PO_4$ |
| 1/1600: | Chevron sticker |
| 10 000: | Nephelometric units of chitinase/ha |

(2)

| | |
|---|---|
| 50 parts: | bacillus concentrate $8.45 \times 10^9$ IU/ℓ |
| 20 parts: | 70% sorbitol solution |
| 30 parts: | water (avoid chlorinated water) |
| 1/1600: | Chevron sticker |
| 10 000: | Nephelometric units of chitinase/ha |

(3) Futura: An ultra concentrated formulation permitting dispersion of 20 BIU/ha *B.t.* in only 2.5 ℓ/ha is prepared from highly concentrated *B.t.* primary powder (Smirnoff unpublished). It also contains sorbitol to control density and to prevent evaporation:

| | |
|---|---|
| 250 gm: | *B.t.* powder (80 000 IU/mg)/ha |
| 3 parts: | 70% sorbitol solution |
| 7 parts: | water (avoid chlorinated water)<br>(sorbitol + water = 2.5 ℓ/ha) |
| 10 000: | Nephelometric units of chitinase/ha |
| 1.56 ml: | Chevron sticker/ha |

The potency of the product has to be determined before it is used in formulations. The spore-crystal ratio is basically one to one, therefore determining the number of viable spores provides the number of crystals, and thus the general potency of the product. A sample is removed from the middle of the drums, diluted, grown on nutrient agar, and then the number of spores counted (Smirnoff 1980). The count is compared with the potency on the manufacturer's label to determine whether inactivation occurred in storage. The quantity of *B.t.* used in the formulation is then adjusted accordingly. During experimental sprayings, the potency of each drum is assessed whereas during operational spraying, 10% of the drums in each manufacturer's lot is sampled. A method was also developed to check *B.t.* concentrates on sensitive insect species to detect the presence of foreign toxic substances in *B.t.* concentrates.

It is felt that formulations should not contain compounds incompatible with *B.t.* such as various dyes (Smirnoff unpublished). Also *B.t.* is a biological control agent and should not be used in oil formulations.

Calibration of spray equipment and assessment of deposit - It was estimated that deposit should be at least 60% of the emitted volume. To determine that the formulations meet this requirement, they were dispersed during experimental aircraft calibration. In 1976, the Thuricide sorbitol water formulation was tested with a Sikorsky S55-T helicopter, and in 1978 with a DC-6B aircraft. With the latter, spraying 4.7 ℓ/ha, a swath width of 414 m was obtained with an average deposit of 32 *B.t.* colonies/$cm^2$. This deposit made the formulation operationally acceptable.

In 1977, 1978 and 1979, the $NaH_2PO_4$ formulation (1) and the sorbitol formulation (2) were tested with a Grumman AgCat aircraft. These formulations gave a deposit of 70% to 80% of emitted volume over a 38 m swath width, which is satisfactory for operational use (Smirnoff 1979a).

To reduce final volume/ha and associated costs, the Futura formulation (3) was tested with the Grumman AgCat in 1979. This formulation proved to be satisfactory (Smirnoff 1979b).

The use of Beecomist spray heads was satisfactory on the Sikorsky helicopter. However, a boom and nozzle spray system composed of Teejet 8004 flat fan nozzles gave better results with a Grumman AgCat fixed-wing aircraft (Smirnoff 1979a). Droplets obtained with Micronair were too fine and evaporated in the air, therefore this system needs to be modified to increase droplet size. A larger aircraft, such as the DC-6B with open type nozzles provided with a pumping system able to produce a 42 180 to 49 210 kg/$m^2$ pressure in the booms, should prove to be efficient for commercial operations.

Chemical insecticides are applied in numerous small droplets (60 to 80 μ) but for *B.t.* it is desirable to obtain larger droplets (150 to 200 μ) which will form clusters of spores. For example, droplets 150 μ and 250 μ in diameter theoretically contain 15,000 and 70,000 spores respectively, whereas droplets 60 μ and 80 μ in diameter, used with chemical insecticides, contain only 1,000 and 2,000 spores respectively.

Application of 20 BIU/ha in a volume of 4.7 ℓ/ha yielded an average of 30 to 40 *B.t.* colonies/$cm^2$. Although this deposit resulted in a high larval mortality (75% and over) and sufficient foliage protection (70% and over) the methods of deposit assessment (petri dishes and Kromekote papers) could not determine the quantity of spores deposited. A new method, consisting of exposing a given volume of peptonized water to the spray, was used to determine the number of spores deposited per unit area (Smirnoff, 1982). For *B.t.* treatments, this value is far more important than the total volume of liquid deposited.

*B.t.* sprays should be applied when balsam fir shoots are partially opened and most larvae are in the third instar. The efficacy of *B.t.* varied inversely with the number of larvae per 45 cm branch tip.

As with chemical insecticides, best results were obtained when spraying *B.t.* in high relative humidity and in low or no wind. These conditions occur mostly early in the morning or late at night.

Field tests - Aerial sprays of *B.t.* have been used against spruce budworm experimentally since 1971 with a variety of aircrafts, including small size AgTruck, Stearman and Grumman AgCat (380 to 1100 ℓ capacity), the TBM Avenger and CL-215 (1330 to 2400 ℓ capacity) and the large DC-6B and Super Constellation (11 400 ℓ capacity). Helicopters (945 ℓ capacity) have also been tested. For a population of 30 to 35 larvae per 45 cm branch tip, with the same dosage and deposit of *B.t.* results will be as follows:

| Foliage potential (%)[1] | Foliage protection (%)[2] | Foliage next year (%)[3] |
|---|---|---|
| 100 | 70 | 100 |
| 70 | 60 | 95 |
| 40 | 10 | 55 |

[1]Foliage potential is the percentage of apical buds present in the spring prior to treatment.

[2]Percent of shoots protected after the feeding season.

[3]Percent of next year's buds formed in the fall. It is the foliage potential of the next year.

In 1979 the Quebec Department of Energy and Resources sprayed *B.t.* sorbitol water formulation with the DC-6B aircraft at a rate of 4.7 ℓ/ha and obtained 95% larval mortality and 67% foliage protection (33% defoliation). The use of different *B.t.* concentrates in the same formulations and applied at different rates averaged 86% larval mortality and 53% protection (47% defoliation). In untreated areas, these figures were 76.5% mortality and 73% defoliation (Dorais *et al.* 1980). The Quebec Department of Energy and Resources confirmed recently that the 1980 operations with *B.t.* were also successful (Dorais and Pelletier, personal communication). *B.t.* treatments permitted recovery of severely damaged stands when treated for one or more consecutive years.

A new method was developed based on the total amount of current year's growth to determine the overall efficacy of *B.t.* more realistically. It was estimated that a 15 m balsam fir, uninfested by spruce budworm, produces 12,000 new shoots annually, or 10 500 000 new shoots/ha; 4 kg of new shoots/tree/year, or 4 000 kg/ha; which is 6 $m^2$ of new growth/tree, or 5 500 $m^2$/ha. In a stand with 90% or more defoliation, each tree has only 190 g of current year shoots, 860 shoots and 0.5 $m^2$ of current year growth. The stand would contain 770 000 current year shoots/ha, 170 kg of new growth, and 414 $m^2$ of new foliage.

Then the above figures of *B.t.* efficiency/tree and per ha (in parentheses) for a population of 30 to 35 larvae/45 cm branch tip would be as follows:

| Foliage potential | | Foliage protected | | Foliage potential for next year | |
|---|---|---|---|---|---|
| % | kg/tree | % | kg/tree | % | kg/tree |
| 100 | 3.9 (6 700) | 70 | 2.7 (4 600) | 100 | 3.9 (6 700) |
| 60 | 2.3 (3 900) | 40 | 1.4 (2 400) | 90 | 3.5 (6 000) |
| 40 | 1.4 (2 400) | 5 | 0.1 ( 170) | 60 | 2.3 (3 900) |

Costs of formulations - The cost of *B.t.* is getting closer to that of chemical insecticides. Reduced costs may be achieved by increased use of *B.t.* by an improved production technology, by using higher concentrations, and possibly by a higher competition among producers including establishment of a factory in Canada. Obviously, according to basic economic rules, these measures would lower costs. Presently, the cost of the formulations recommended is $7.35/ha.

Difficulties inhibiting the operational use of *B.t.* - Factors adversely affecting the operational use of *B.t.* included the lack of concensus concerning formulations and application technology; the deviations from recommendations during field trials or commercial operations which has lead to inconsistent foliage protection. Unjustified criticism, such as possible undesirable mutations, inactivation by sunlight and unavailability in sufficient quantities also had an adverse effect on the wider use of *B.t.* Public discussion of problems associated with *B.t.* operations would contribute to the wider acceptance of this control method.

## 2. POTENTIAL METHODS

### a) NEW CHEMICAL INSECTICIDES

P.C. Nigam

Chlorpyrifos-methyl, Bolstar$^R$ and permethrin are three new chemical insecticides, which appear promising for the control of spruce budworm larvae (Table VIII-2). Chlorpyrifos-methyl and Bolstar$^R$ are organophosphorous compounds and permethrin is a synthetic pyrethroid. Chlorpyrifos-methyl and Bolstar$^R$ are slightly more toxic than fenitrothion to spruce budworm larvae. Permethrin is more toxic to budworm larvae than fenitrothion and aminocarb but field trials indicate adverse effects on fish food organisms. Permethrin and chlorpyrifos-methyl have been field tested for several years for efficacy and environment impact, and may be recommended for registration in the near future. Bolstar$^R$ could not be tested in the field because it has lower priority for development by the manufacturer.

A number of other insecticides belonging to the carbamate, pyrethroid and organophosphorous groups are being tested in the laboratory. If they appear promising, they will be recommended for field evaluation.

### b) NEW STRAINS AND FORMULATIONS OF *B.t.*

W.A. Smirnoff

*Bacillus thuringiensis* serotype 3a3b *kurstakii* is the strain most commonly used against spruce budworm (Smirnoff 1979c). This serotype can easily be produced and its action on the budworm is well documented (Smirnoff and Valero 1979). Other serotypes that could be promising are far from the development stage for operational use.

Table VIII-2. Toxicity of potential insecticides against the spruce budworm.

| | TOXICITY | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Budworm Larvae | | | | | | | | Fish | Birds | Mammals | |
| | Contact toxicity to lab insects (72 hrs) µg/cm$^2$ | | Residual Toxicity to field insects (72 hrs) | | | | | | Trout | Mallard | Rats | |
| | | | Application rate (g AI/ha) | Weathering period (days) | | | | | $LC_{50}$ ppm (96 hrs) | $LD_{50}$ mg/kg | $LD_{50}$ mg/kg | |
| INSECTICIDE | $LD_{50}$ | $LD_{95}$ | | 0 | 1 | 3 | 5 | 10 | | | oral | dermal |
| | | | | % Mortality | | | | | | | | |
| Bolstar[R] | .034 | .053 | 220 | 98 | 87 | 57 | 43 | 37 | 29.7 | 70-110 | 304 | 1200 |
| Chlopyrifos-methyl | .054 | .124 | 220 | 99 | 91 | 85 | 78 | 60 | .014-.301 | 2500-5000 | 1630-2140 | n/a |
| Permethrin | .015 | .030 | 220 | 96 | 96 | 79 | 69 | 20 | .009 | 23 000 | 430->4000 | > 4000 |

In coming years, more concentrated *B.t.* formulations in a smaller volume of liquid will likely be developed. This will reduce costs and will permit the application of the required *B.t.* dosage of 20 BIU/ha. One can foresee this progress as a few years ago only 2.1 BIU/ℓ concentrates were available for forestry use, whereas 4.2 and 8.4 BTU/ℓ concentrates are now being produced industrially and eventually 15.7 BIU/ℓ should become available. Adequate formulations permitting the dispersion of 2.5 ℓ/ha are being studied (Smirnoff unpublished) and will eventually replace those requiring 9.4 ℓ/ha and 4.7 ℓ/ha. An increased use of *B.t.* and the improvement of production technology will contribute to greater cost reduction.

### c) VIRUSES

J.C. Cunningham

Four different types of viruses have been found in eastern spruce budworm: a nuclear polyhedrosis virus (NPV), a granulosis virus (GV), a cytoplasmic polyhedrosis virus (CPV) and an entomopoxvirus (EPV). All have been recorded at very low levels in budworm populations and termination of an outbreak due to a virus epizootic has not been observed.

The NPV was regarded as the most promising candidate for spruce budworm regulation and this virus has been disseminated over about 2 000 ha in a series of aerial spray trials which commenced in 1971 (Bird *et. al.* 1972; Cunningham *et al.* 1975b, 1975c, 1978, 1979; Cunningham and Howse 1979, 1980; Howse *et al.* 1973; Kaupp *et al.* 1978). Extensive tests have proven this virus safe for birds and mammals (Valli *et al.* 1976) and other non-target organisms (Buckner *et al.* 1975a, 1975b). Viruses can be propagated only in living cells and, as insect cell cultures are too costly to maintain for this purpose, host insect larvae are used. The dosage of NPV giving adequate budworm control requires 7 500 infected larvae to treat one ha. Presently, the production process is labour-intensive and the cost is high. Most sprays have been applied after budflush when larvae were mainly in the fifth instar, but a few attempts have also been made to treat highly susceptible second instar larvae as they emerge from hibernacula. NPV may persist in a treated spruce budworm population for up to five years following application (Cunningham *et al.* 1975a), but it does not spread from sprayed areas. Results are generally better on white spruce than balsam fir trees.

A mixture of NPV and CPV was field tested in 1971 (Howse *et al.* 1973), in 1979 (Cunningham and Howse 1979), and in 1980 (Cunningham and Howse 1980). In 1979 a substantial population reduction and significant foliage protection were obtained with a mixture of NPV and CPV at a ratio of 200:1 on second instar larvae, but these results require verification.

Currently, the use of viruses for spruce budworm population regulation is at the experimental stage. Major obstacles to operational use which must be overcome include reduction in the cost of virus production and development of a suitable formulation which will maintain the virus on the foliage in a viable state for several days, thereby facilitating a reduction in dosage. The search for new, more virulent virus strains continues and research goals include an investigation of the NPV genome with a view to genetically manipulating viruses to make them highly pathogenic for spruce budworm.

Several NPVs have been used successfully in Canada for control of such forest insect pests as European pine sawfly, *Neodiprion sertifer* (Geoffroy) (Cunningham *et al.* 1975d), red-headed pine sawfly, *Neodiprion lecontei* (Fitch) (de Groot *et al.* 1979) and Douglas fir tussock moth, *Orgyia pseudotsugata* (McDunnough) (Stelzer *et al.* 1977), but the use of viruses for spruce budworm population regulation does not appear promising in the near future.

## d) INSECT GROWTH REGULATORS

A. Retnakaran

Insect growth regulators (IGRs) upon ingestion selectively inhibit the synthesis of chitin in larvae and prevent normal moulting (Bijloo 1975, Van Eck 1979, Verloop and Ferrell 1977). They do not appear to have any adverse effects on adult insects and also have no obvious deleterious effects on non-target species such as birds, mammals, and fish (Wilcox and Coffey 1978). Development and possibly use of such IGRs for insect control may progressively decrease our dependence on broad-spectrum, neurotoxic insecticides and pave the way for an ecologically acceptable method for pest control.

Diflubenzuron (or Dimilin$^{R}$), the harbinger of moult-inhibiting IGRs, was ineffective at economic dosage levels on the spruce budworm (Dimond 1975, Retnakaran 1978, Retnakaran *et al.* 1978, Retnakaran and Smith 1975). Moreover, younger instars were less sensitive to this compound than older ones (Granett and Retnakaran 1977). Some analogues of diflubenzuron appear more effective on the spruce budworm than diflubenzuron (Retnakaran 1979).

A new IGR, UC-62644, was studied in 1979 and 1980 in the laboratory, greenhouse and in the field. It is a potent control agent for the budworm and is effective at dosages below 140 g/ha, surpassing the efficacy of aminocarb and *B.t.* (Retnakaran unpublished).

IGRs have to be ingested in order to be effective and may affect many non-vertebrate animals (Retnakaran *et al.* 1980). Certain crustacean larvae are susceptible, but unaffected adults repopulate the habitat in a short period (Ali and Mulla 1978). Unlike microbials whose mass production is limited by a fermentation process, IGRs are chemicals and can be synthesized efficiently on a large scale that will eventually reduce costs. Unlike chemical pesticides IGRs are not neurotoxic and are harmless to cholinesterase systems common in insects and vertebrates (Van Eck 1979, Verloop and Ferrell 1977).

Some of the IGRs may be registered for use in two to three years, and they probably will be cheaper than microbials, less hazardous to the environment than most insecticides, and probably the logical choice for foliage protection.

## e) SEX PHEROMONES

C.J. Sanders

Sex pheromones are chemicals emitted by virgin female moths which the male moths use to locate the females. The main components of the natural pheromone have been identified and synthesized (Sanders and Weatherston 1976, Silk *et al.* 1980) and the synthesized pheromone is known as 'fulure'. When sufficient fulure is diffused through the atmosphere males are unable to locate the females, resulting in fewer matings and fewer fertile eggs. For the spruce budworm the use of fulure to 'trap out' males is impractical because of the large numbers of traps required, and the large areas involved. Since virgin female spruce budworm do not disperse, fulure may disrupt the spread of outbreaks by reducing dispersal of fertile females from high-density populations. It is also possible that fulure may contribute to mating failure by affecting female behavior (Palinaswamy and Seabrook 1978).

Although other chemicals affect budworm mating behavior (Sanders 1976, 1980, Schmidt *et al.* 1980) fulure is the most effective. It is commercially available at $1 to $2/g. It is specific to the spruce budworm, and is non-toxic to mammals, with minimal irritation in eye and skin-irritation tests (Daterman, personal communication).

Field trials of several formulations applied aerially reduced the numbers of male spruce budworm captured in traps baited with virgin females by up to 90% at application rates of 5 to 10 g AI/ha (Sanders 1976, 1978). A field trial using a hollow fibre formulation in Ontario in 1977 was only partially successful because of late application and female moth immigration (Sanders 1978). A similar formulation failed in the Maritimes in 1978 because the attractant evaporated within a week instead of the expected six-week period (Miller 1978, Wiesner *et al.* 1980). A different formulation, Hercon plastic laminate flakes, is being evaluated in Maine in 1980. If it proves adequate CFS will continue testing in 1981 to collect dose/response data, with population reduction as the criteria.

The effects of fulure are seen only in the following generation; it will not protect foliage in the year of application. Also there is mounting evidence that sex attractants are less effective at higher population densities. It is probable therefore, that the use of fulure for controlling outbreaks of spruce budworm may be limited. Its application will more probably be in such areas as the suppression of incipient outbreaks, or the protection of high value stands.

## f) MICROSPORIDIA

G.G. Wilson

Microsporidia are protozoan parasites often pathogenic to many insect species. Of all the diseases of spruce budworm, i.e. viruses, fungi, bacteria, and microsporidia; the microsporidia are the most prevalent in natural populations. They are true parasites, living at the expense of, but not immediately killing the host. Most often they are debilitating rather than lethal. *Nosema fumiferanae* and *Pleistophora schubergi* adversely affect larval and pupal vigour and reduce adult longevity and fecundity of the spruce budworm (Thomson 1958; Wilson 1974, 1977, 1978). Microsporidia can be propagated by infecting living insects and collecting spores about 21 days later (Wilson 1976). The spores with suitable protective additives, can be sprayed with a conventional method (Wilson and Kaupp 1975, Wilson and Kaupp 1976). The most attractive feature of these parasites is their persistence; their self-propagating characteristics would result in a continuation of stress within the treated populations. The use of microsporidia for control of epidemic populations is not promising (Wilson 1980, 1981).

## g) FUNGI

D. Tyrrell

Fungi of the genera *Entomophthora* (*sensu lato* MacLeod 1963), *Zoophthora*, *Conidiobolus*, *Hirsutella*, *Beauveria*, and *Isaria* infect the spruce budworm. Of these six, the most frequent and widely distributed are the *Zoophthora radicans* and *Entomophthora egressa*. They occur in Newfoundland, Ontario and probably British Columbia in Canada, and also in Maine in the U.S. (MacLeod 1949, Vandenberg and Soper 1975, Otvos and Moody 1978, Harvey and Burke

1974). Infection levels in Maine during 1975 to 1977 averaged 11% with maximum of 45% of individual samples (Vandenberg and Soper 1978). Infection levels in Newfoundland averaged 10% to 40% with a maximum of 60% in one localized area (Otvos and Moody 1978). In Ontario, infection levels are generally low, but outbreaks of fungal disease occurred in 1974 and 1979. *Z. radicans* was dominant in Ontario, *E. egressa* and *Conidiobolus* sp. in Maine and *E. egressa* in Newfoundland. The climate of Newfoundland is probably more conducive to the development of natural and artificial infections than other parts of eastern Canada. Fungal infection in the field has only been reported in fifth and sixth instar larvae and in pupae. *Z. radicans* attacked primarily fifth and sixth instar, while *E. egressa* and *Conidiobolus* spp. attacked sixth instar and pupae.

Laboratory and field studies have confirmed the potential of fungi as a tool for controlling spruce budworm populations. A technique for the mass production of spores is needed to produce the large quantities required for field application. Research is continuing on such techniques and progress depends upon a scientific breakthrough. Two major obstacles must be overcome; to produce large quantities of spores cheaply and to induce spore germination at the right time. If these problems can be solved, then special spray technology will have to be developed suitable for spore dissemination. The research for spore production is basic in nature and it is difficult to predict future progress.

## h) PARASITES AND PREDATORS

C.A. Miller and I.S. Otvos

Control by the introduction of parasites and predators has the greatest potential for success if used against an introduced pest. Introduced pests may increase to high population levels in a new environment because of the absence of their native biological control agents. The major successes and biological control by introduced parasites or predators have generally occurred in situations where the parasite or predator was known to attack the pest species in its native habitat. Only limited success has been achieved in establishing a parasite in a 'new' host, or in controlling a native pest by exotic parasites.

The spruce budworm is native to North America and 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.

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 introduced in the late 1940's into other parts of Canada (excluding Newfoundland) and 12 species were introduced from Europe between 1948 and 1956. A number of these were from *Choristoneura muriana* (Hbn.), a close relative of the spruce budworm. All these attempts apparently failed (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 *et al.* 1973). In the early 1970's two species were introducted from the todo-fir budworm, *Choristoneura diversana* Hbn., from Japan into New Brunswick. This introduction was later abandoned because of host-parasite incompatibility (Varty 1976a). 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).

The manipulation of native species of parasites and predators to increase their effectiveness presents an even more difficult problem. The technique involves rearing and releasing large numbers of native parasites or predators, or modifying the environment to increase their numbers.

A limited effort has been given to introducing arthropod predators as potential budworm control agents. One positive program has been the introduction of the red wood ant, *Formica lugubris* Zett., into a localized area of Quebec (Finnegan 1978). Observations at one nest indicated that large numbers of late instar larvae were brought to the nest and defoliation was noticeably reduced on trees in the vicinity of the nest. Finnegan speculated that this ant might be important at low budworm densities. The use of ants for forest insect control, a favored concept in Europe, may have limited potential in eastern North America.

Other known predators of the budworm do not lend themselves to manipulation for control of population. Birds are probably the most important predators of the spruce budworm. Bird populations have been increased in the small forests in Europe by providing birds with nesting boxes (Gillmeister 1963). However, this is most impractical in North America and of doubtful control value.

### i) GENETIC CONTROL

T.J. Ennis

Release of sterile or genetically altered insects to reduce reproduction and survival of their own species has been successful against some agricultural pests and replaced insecticides in the control of those species (Lachance 1979). Outram (1969) first discussed the theoretical potential for genetic control of a forest insect pest, the spruce budworm. Recently, Thiotepa and cobalt ($Co^{60}$) irradiation have been shown to induce complete sterility in male spruce budworm (Retnakaran 1970, 1971).

Males sterilized by Thiotepa are more competitive than normal males, and can suppress fertility of caged laboratory populations up to 90% (Ennis 1982). However, fertility of field populations was not reduced because adult mating behaviour was adversely affected. Males irradiated with 20 to 30 kR of $Co^{60}$ are fully sterile but non-competitive (Ennis 1982). Treatment with 2 to 5 kR reduces fertility by about 40% and does not affect competitive ability. Offspring of these males are more likely to be sex ratio distorted males, are of reduced viability and are almost completely sterile (Ennis 1979a, 1982). Tests of their effectiveness in suppressing the fertility of field populations are in progress. The behaviour of released males is also being studied (Ennis 1979b, 1982).

Successful genetic control of any forest insect pest has yet to be demonstrated. Five to ten years of development and testing are still required. The potential of the method lies in the integrated control of low level populations to prevent outbreaks.

## j) PATHOGENS AND SUBLETHAL DOSES OF CHEMICAL INSECTICIDES

O.N. Morris

Where *B.t.* by itself does not provide acceptable foliage protection or population density reduction, the strategy of the combined use of the pathogen with low doses of selected chemical pesticides is logical. The combination treatment may be applied separately at strategically timed intervals or as mixtures. Low concentrations of several chemical insecticides especially carbamates, are compatible with *B.t.* (Morris 1977a). Both acephate and fenitrothion enhance the effectiveness of *B.t.* against the spruce budworm and the white-marked tussock moth in laboratory tests orris 1975).

In field trials, the addition of 6% to 10% of the recommended operational rate of acephate to *B.t.* increased larval mortality by 34% compared with *B.t.* alone when applied at 20 BIU in 4.7 ℓ/ha. Total budworm population reduction due to treatment was 97 to 99% (Morris 1977b). Field trials by Dimond and Spies (*In* Morris 1980) corroborated these results both in terms of foliage protection and population reduction but these authors recommended further evaluation of the technique before large scale use.

The major advantage of such a technique would be the reduction of the amount of chemical pesticide released into the forest environment, and a higher level of foliage protection than that provided by *B.t.* alone. The strategy has considerable potential for spruce budworm and other forest defoliators but large scale use should await further field trials.

## k) ANTIFEEDANTS

G.M. Strunz and W.H. Fogal

The chemical composition of plants is a major factor influencing their acceptability as food for insects. Chemicals which determine host preference include feeding and oviposition stimulants, attractants, feeding and oviposition deterrents, and repellents (Hedin *et al.* 1977). Included among feeding deterrents is a class of compounds known as antifeedants, defined as substances which cause cessation of feeding either temporarily or permanently (Kubo and Nakanishi 1977).

Many new compounds with antifeedant activity are being reported; most are of plant origin. They display a wide diversity of molecular structures and many appear to be specific to certain insects. One of the most powerful insect antifeedants known is azadirachtin, which is isolated from the Indian neem tree, and exhibits strong antifeedant activity against a number of insect species. Some will starve to death rather than feed on leaves surface-treated with only a few nanograms. Little attention has been devoted to studies of antifeedants for forest defoliating insects though they are effective in modifying feeding behaviour (Ikeda *et al.* 1977). The spruce budworm is sensitive to chemicals which act as feeding stimulants and deterrents (Heron 1965) and behavioural and electrophysiological assays have been developed for testing antifeedants. For example, a convenient and reproducible assay for observing antifeedant effects on sixth-instar budworm larvae has been developed by U.S. investigators (Leonard and Bentley personal communication) for use in a screening program of non-host plant extracts and other materials. More than 100 extracts have been tested for antifeedant activity with encouraging results.

Finding and characterizing chemical compounds with antifeedant properties against spruce budworm is a first step towards their eventual use in field operations to control the pest. They need to be further tested under field conditions to determine whether they can disrupt host selection by second-instar larvae and minimize feeding by late-instar larvae which are responsible for most feeding damage. Chemicals which influence feeding behaviour may also influence oviposition (Hedin *et al.* 1977). Thus, antifeedants selected for field tests should also be considered for disruption of host selection by egg-laying adults. A compound which displays strong antifeedant and/or antioviposition activity against the budworm in preliminary tests must satisfy additional criteria before it can be considered as a potential control agent: its toxicity must be low; it must be capable of being produced in large quantities either by extraction from natural sources or by syntheses; and production must be inexpensive.

The discovery of effective antifeedants would add an invaluable new dimension to current strategies aimed at reducing damage caused by the spruce budworm. Prospects for discovering antifeedants are excellent because basic behavioural information on budworm is available to devise adequate biological assay techniques to assess chemicals derived from plants and because of improved capability for identification of chemicals which control insect behaviour.

## 1) BREEDING FOR INSECT RESISTANCE

W.H. Fogal and G.M. Strunz

Trees may possess various complex chemical, physiological and morphological properties to resist and survive attack by insects. These properties discourage oviposition or feeding, impair insect growth, or allow the tree to survive severe attacks. Interactions between insects and host trees and the genetics of defense mechanisms underlying insect host preference and selection are not fully understood. However, empirical knowledge of natural variation in susceptibility of trees to insects is available.

Blais (1957) compared spruce budworm larval survival on balsam fir, white spruce and black spruce in Ontario. He attributed high mortality on black spruce to late budbreak which forced young larvae to feed on old needles. Young larvae did not survive on old foliage, perhaps because old needles contain feeding deterrents or toxicants or are nutritionally inferior or are physically unacceptable. Asynchrony between food availability and budworm larval emergence appears to confer degrees of resistance within and among fir species also. In New Brunswick, survival was reduced on balsam fir when bud development was delayed or too far advanced (Eidt and Cameron 1971). Budworm development was very slow on exotic firs with late needle flush. Some genotypes are unacceptable to other insect species, including the balsam twig aphid (*Mindarus abietinus* Koch) and the balsam gall midge (*Dasineura balsamicola* (Lint.)). For the latter insect, needle flush of unacceptable trees was poorly synchronized with oviposition (Eidt and MacGillivray 1972).

In New Brunswick introgressive hybridization occurs between black spruce and red spruce. Susceptibility varies directly with nearness to red spruce though there is little difference in bud phenology between the two species (Manley and Fowler 1969). The difference appears to be chemical. Foliage of red spruce lacks the chemical known as pungenin (a glycoside of 3-4 dihydroxy acetophenone) (Wilkinson 1970, Heron 1965). Differences in susceptibility of black spruce and red spruce and their introgressive hybrids may be related to levels of pungenin.

Current information suggests that there are variations in susceptibility to forest defoliating insects among related host species, geographic strains of a particular host species and among interspecific hybrids (Fogal *et al.* 1982). This variation provides the base for resistance breeding which can be integrated into tree improvement programs as one of a number of economic characteristics such as growth rate, straightness or wood quality. Breeding for economic characteristics, such as straightness or wood qualities, and breeding for broad adaptability to pests and other adverse environmental factors can be done simultaneously because the two sets of characteristics are usually controlled by multiple genes which are inherited independently.

The use of resistant trees is a highly desirable long-range pest-management strategy, especially when chemical control, biological control or forest management fail. However, breeding for resistance takes time. For example, progeny from a plus-tree selection program needs to assessed for the period of time required for a plantation to reach maturity. Much longer time will be required before resistant trees are used in forest management practice.

## m) FOREST MANAGEMENT

D.A. MacLean

As a potential method for control of spruce budworm outbreaks, forest management might be broadly considered to include: 1) forest protection activities, 2) programs designed to minimize economic losses to budworm such as pre-salvage and salvage harvesting, and 3) all activities designed to prevent or minimize the impact of budworm outbreaks by changing the structure of the forest into a less vulnerable form. Protection activities are discussed elsewhere in this report. Salvage programs have a timing limitation because of fungal deterioration of the dead trees, and are undesirable because the need to harvest areas killed by budworm results in loss of control over the sustained yield harvest pattern. The third management option, changing the structure of the forest, will be discussed in this section. Forest management activities are only a potential long-term control method or an option for ameliorating impacts; they are not short-term and will not eliminate the budworm.

As early as 1924, it was stated that "the prevention of a recurrence of the budworm is purely a question of forest management. Conditions must be developed that are least favourable to the enormous multiplication of this insect and least susceptible to injury so that future outbreaks can be rendered much less potent, and the losses reduced to a minimum" (Craighead 1924). This type of statement, and discussions revolving around the notion that forest management is an answer to the budworm 'problem' are common in the literature (e.g. Balch 1946, 1963; Blais 1964; Craighead 1924; Graham 1956; Macdonald 1968; McLintock 1947; Prebble and Morris 1951; Tothill 1921, 1922; Westveld 1946, 1954). Turner (1952) summarized the recommendations for reducing damage: reduce amounts of mature and overmature fir, enhance less susceptible or less vulnerable species, use a short rotation, and prevent the development of large areas of susceptible forests. Thus, forest management activities would change the species composition of the forest, alter the age class structure, and/or change the spatial structure of stands.

The majority of discussions that favour forest management as the answer to the budworm problem are over-simplified, and have not considered what would be necessary to reduce budworm susceptibility or vulnerability. Van Raalte (1972) concluded that management of the forest over the past 25 years in New Brunswick had not reduced the susceptibility to budworm, and it would be safe to reiterate that statement for the present. Baskerville (1975b, 1976) discussed the possibilities of forest management as a means of reducing the probability of outbreaks or increasing the resistance of the stand to injury. The four main host management techniques, block cutting, selection (including partial) cutting, short rotation management and altering forest composition, all have a time and space limitation; it would take at least 50 to 100 years to restructure a forest and areas of more than 1 000 000 ha would require treatment (Baskerville 1976). In addition, certain of these management strategies have substantial drawbacks. Selection cutting maintains a fairly open, almost mature canopy condition which is probably ideal for budworm, and because a limited volume/ha is harvested, larger areas are maintained in the risk condition. Also it appears that selection cutting could not change species composition sufficiently (Croome 1970). Altering forest composition would require large-scale site preparation and planting programs, very substantial expenditures, and would have unknown ecologic consequences because of the drastic changes involved over large areas. Short rotation management may not be effective because there is little scientific evidence that managed forests at age 40 are less susceptible than unmanaged mature forests. Block cutting may appear to hold the most promise for reducing susceptibility to budworm, but it would require a major planning and regulatory effort, and the choice of block size to be used in such a program would have to be somewhat arbitrary. A more detailed discussion of the shortcomings of the various forest management options are given by Baskerville (1975b, 1976). The major difficulty in implementing any management strategy other than block cutting arises because balsam fir out-competes most species on productive sites, which tends to result in fir repeating itself in ecological succession. The budworm seems to enhance that process (Baskerville 1975a). To establish less vulnerable species, e.g. black spruce, the advance regeneration of fir on cutover areas would have to be removed, and intensive site preparation would be necessary. Even then it is doubtful that the new species would out-compete the native balsam fir.

In addition, conventional forest management techniques to enhance wood production may be at cross purposes to managing for decreased budworm impact. Thinning and fertilization of a semi-mature black spruce stand in Newfoundland resulted in better budworm development and increased damage than in adjacent non-treated stands (Roberts and Chow 1977). Fertilization alone may also result in better budworm development (Shaw *et al.* 1978).

Baskerville *et al.* (1975) modelled the outcome of a possible future scenario in New Brunswick whereby highly-susceptible forest areas were delineated and not sprayed. This area of approximately 1 200 000 ha, would likely sustain approximately 85 000 000 $m^3$ of fir-spruce mortality. The scenario included moving all the forest harvesting operations of the Province into this area for pre-salvage cutting and salvage up to two years after death. It was felt that over one-half of the potential mortality would be utilized over a five-year period and the rest lost. Furthermore, the remaining less-susceptible forest in New Brunswick would be sufficient to support the present mill capacity. However, it was concluded that although the proposed policy could be implemented, the costs (dollar, social and environmental) outweighed the total benefits. Increased transportation costs of wood to the mill alone more than offset the expected 20-year savings in spray operations. Even a massive program to reduce the susceptibility of the new regenerating forest could not logistically treat all the area involved, and thus a future outbreak would still be probable.

Clearly, there are no simple solutions to the budworm problem. The spruce budworm and the spruce-fir forest have evolved together into a very efficient ecological succession system whereby spruce-fir replaces spruce-fir, and the budworm acts as the causal agent for this replacement. Although we can propose a number of forest management options in the face of a budworm constraint, we can also effectively rule out the majority of these suggestions. We do not know whether any specific forest management plan would be effective in reducing susceptibility or vulnerability to the budworm. However, it is clear that if we do nothing other than harvest wood and allow natural succession to take its course, the budworm problem will always haunt us. Forest management should not be regarded as a panacea for dealing with the budworm problem. However, over the long term, management which includes site preparation and planting of larger portions of the currently budworm-prone forests with less susceptible species following harvest or budworm kill, as well as stringent control of cutting to enhance diversity of age-class and spatial structure would probably help to limit future budworm damage.

## n) INTEGRATED PEST MANAGEMENT

J. Hudak and C.H. Buckner

Integrated pest management has been defined as a "... management system that in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economic injury." (Glass 1975). The concept of pest management in forestry is not new: it dates back to the turn of this century with emphasis upon the augmentation of natural controls and the manipulation of forest conditions to make them less susceptible to outbreaks and less vulnerable to damage over the long term (Waters and Stark 1980). In reality, however, the "wait-and-see" attitude usually prevails and short term crisis management becomes inevitable for most pest problems. The recent increase in promotion of integrated pest management as a solution to major pest problems stems in part from the fear of the side effects of chemical pesticides and in part from recent advances in computer science and mathematical modelling. The latter provides a powerful tool for a comprehensive analysis, including cost-benefit evaluation, and for optimizing alternative management options.

The general structure of an integrated pest management system usually consists of the research and development phase and the operational phase (Waters and Cowling 1976). The research and development phase includes four basic components (Fig. VIII-1): (1) the population dynamics and epidemiology of pests, (2) the dynamics of forest stand development, (3) the socioeconomic impacts of pests on resources values, and (4) the treatment strategies. The impacts and treatment strategies feed directly to the cost-benefit analysis; the basic mechanism of decision making. It must be stressed that each component is a complex subsystem in itself, with primary information flow among the components and numerous feedbacks. The basic nature of forest pest management in this concept requires that predictive models closely simulate three attributes of the forest-pest system; (1) the spatial distribution and characteristics; (2) the temporal changes, and (3) the quantitative variations. The operational phase of the system is dependent on efficient, reliable monitoring of pest populations and forest conditions. This monitoring provides the data inputs required for analysis of projections by the predictive models. Computer projections may be made with or without any combination of treatments or control options, and each will be included in the associated cost-benefit analysis. This system provides an operational tool for the forest resource manager to simulate and assess various management options, and aides in making decisions to minimize destructive pest losses or at least to regulate them.

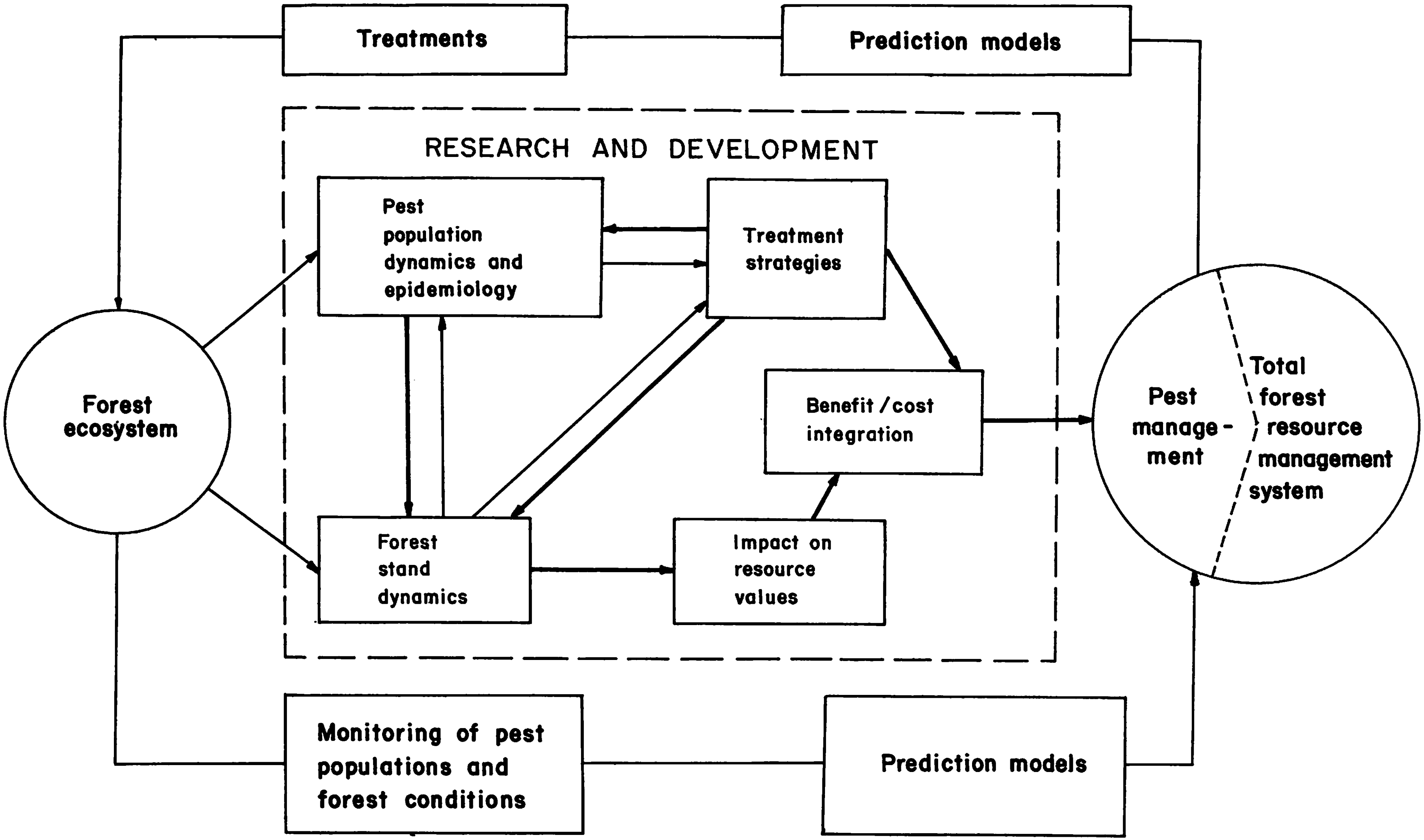


Figure VIII-1. Structure of an integrated forest pest management system (from Waters and Cowling 1976).

Considerable progress has been made in developing the various components of an integrated pest management system for the spruce budworm: the dynamics of budworm populations especially in the epidemic state (Morris 1963a), and more recently the stand dynamics component and the overall development of mathematical modelling of the whole system (Holling *et al.* 1977, Jones 1977, Stedinger 1977).

Holling and co-workers (1977) developed the spruce budworm-fir forest model and associated management options for New Brunswick in collaboration with the Canadian Forestry Service in New Brunswick. Stedinger (1977) modified and adapted the system to Maine conditions. The Quebec Government has also modified the system to suit local requirements. Baskerville (1976) used the model to evaluate budworm control alternatives in New Brunswick. He considered several options: (1) Historical crop protection. This option assumed the forest was sprayed as it actually occurred. The option protects the forest from substantial mortality but about 12% of the forest must be sprayed annually. (2) No control from 1952. New harvesting would have maintained the industry just below the 1952 level with some shortages in wood supply but expansion of the wood-based industry would have been impossible. (3) No control from 1977 with regular harvesting. This option would deplete the forest inventory by 1995 with no recovery until after 2025. The 1952 to 1976 protection program cost $95 000 000 in 1976 dollars, but this protection has allowed a doubling of the forest industry's capacity between 1952 and 1975, it increased the value of shipments by $4 700 000 000, added value of $2 700 000 000, and increased wages by $889 000 000. In addition, New Brunswick has maintained a forest inventory of 283 000 000 $m^3$. The above assessment of various management options would have been nearly impossible without the aid of modelling.

The pest management system by modelling also allows for the evaluation of alternative control measures through optional changes in the main components of the model. The forest dynamics or host management techniques are usually suggested as logical approaches to reduce susceptibility and vulnerability to budworm attack. Host management is considered essential to the long-term amelioration of the budworm forest management problem. However, all these techniques are long term and some of them are even counter productive, such as selective cutting (Baskerville 1975b, 1976). Also some of the desirable stand characteristics for reduced susceptibility and vulnerability may be more apparent than real. Quantitative analyses deny a direct relationship between stand characteristics and amount of tree mortality (MacLean 1980). Conversely, Hardy (1978) reported that several widely separated epicentres of outbreaks were similar in stand characteristics, but differed from expected belief that spruce budworm outbreaks start from large tracts of mature and overmature balsam fir. The forest cover types in all epicentres were principally mixed hardwoods.

The ineffective control of epidemic populations by natural control factors dictates the present use of insecticides to prevent extensive tree mortality (Blais 1973; Baskerville 1975b, 1976). Such a need for pesticides in the future cannot be ruled out even if the forest resource is managed under the best conceivable integrated pest management system. It has been suggested that increased host management will reduce the effectiveness of natural controls and hence increase the need for artificial control which may be the application of biological or chemical insecticides.

Changing species composition through extensive plantations of black spruce has been suggested as a means to ameliorate the budworm problem over the long term and reduce the reliance on pesticides. Such plantations most likely will need pesticide treatment to control other pests such as the yellow-headed spruce sawfly, *Pikonema alaskensis* Rohwer, which feeds on current and old foliage and causes damaged trees to become shrubby.

The practice of integrated pest management does not imply the elimination of pesticides but provides an intelligent framework which may only reduce the dependence on pesticides for pest control. Therefore the implementation of integrated pest management should be promoted.

Forest insect pest management in Canada has adopted an integrated approach, although the system is embryonic and requires substantial refinement. Unlike control of many agricultural pests that frequently utilize regular and repeated treatments irrespective of pest densities the forest insect protection programs in Canada have made use of several tactics to eliminate indescriminate broadcasting of toxic insecticides. An elaborate detection and appraisal system operates to define the limits of infestation of the various forest insect pests, measures the pest population levels, and forecasts damage. From these data a control strategy evolves that provides a decision support system to identify areas that should be treated, indicates control product alternatives, suggests treatment strategy, evaluates the environmental risks, and forecasts the consequences of not applying treatment. This system has evolved because of the economic and environmental constraints of forest insect pest control. The topic that the system has not yet addressed is the incorporation of a long-term management plan to assist in reducing the vulnerability of managed forests.

Comprehensive integrated pest management systems have been developed for only a few major pests. A new program, the Canada-USA Spruce Budworm Program, was initiated in 1978 to develop an integrated system for this major pest. The agreement, with a commitment of about $9 000 000 in total from the two countries annually over six years, has as its objective to design and evaluate strategies for the management and control of spruce budworm that will assist resource managers in obtaining their objectives in an economically and environmentally acceptable manner.

In response to this agreement, the Canadian Forestry Service has re-examined its budworm program and implemented a new program to better address this responsibility. The research focuses on eight activity areas: impact, product quality, fire risk, management strategy, improving registered insecticides, new control materials, materials for population manipulation, and environmental risks. The new program consists of existing studies, redirected studies, and new thrusts. The resources committed to the budworm project, expressed in person-years are identified by establishment and activity area in Table VIII-3. For purposes of this discussion, activities E, F and G can be amalgamated and thought of as control methods, including the development of management or control materials and the technology of application. Accordingly, impact studies receive 14.7% of the CFS total budworm effort, product quality 5.3%, fire risk 3.9%, management strategies 24.0%, control methods 40.0%, and environmental risk 12.1%. Within the total control methods effort, 19.4% is devoted to application technology, 14.5% to chemical insecticides, and 66.1% to pathogens and biological materials. A significant portion (24%) of the CFS effort relates to the development and refinement

Table VIII-3. Base person years resources for spruce budworm research in CFS for the fiscal year 1980 to 1981.

| Activity | Nfld. FRC | MFRC | LFRC | GLFRC | FPMI | PNFI | Total |
|---|---|---|---|---|---|---|---|
| A (Impact) | 2.6 | 2.6 | 3.2 | 2.6 | - | 4.2 | 15.2 |
| B (Product quality) | 2.3 | 1.9 | - | 1.3 | - | - | 5.5 |
| C (Fire risk) | 1.0 | - | - | 1.5 | - | 1.5 | 4.0 |
| D (Management strategy) | 2.1 | 15.5 | 1.3 | 5.9 | - | - | 24.8 |
| E (Improved chemicals) | .2 | .3 | .8 | .5 | 7.6 | - | 9.4 |
| F (New controls) | .9 | .6 | .5 | 1.0 | 12.6 | - | 15.6 |
| G (Population control) | .3 | .2 | - | 1.0 | 14.8 | - | 16.3 |
| H (Environmental risk) | .3 | 1.0 | - | - | 11.2 | - | 12.5 |
| Total | 9.7 | 22.1 | 5.8 | 13.8 | 46.2 | 5.7 | 103.3 |

of management strategies, and it is in this sphere that the most noticeable response has taken place. The total output of the program is expected to deliver new and improved budworm management strategies to the land managers.

The Canadian effort is integrated with the U.S.A. research and development program, which in turn addresses those areas in which it has developed expertise. The total program is managed in such a way as to reduce areas of overlap and stimulate complementary programs.

## SUMMARY

Six chemical insecticides and one biological insecticide are registered for forestry application against the spruce budworm in large forest areas. Fenitrothion and aminocarb have been used successfully over millions of hectares in recent years. Acephate was used extensively and effectively in Ontario; its relatively low toxicity to fish makes it a good choice for use near streams. Carbaryl, just recently registered, has not been used in Canada because higher volume applications are required relative to aminocarb and fenitrothion. Phosphamidon and trichlorfon have very limited use.

*Bacillus thuringiensis* (= *B.t.*), the only registered biological insecticide, has been effective when its limitations are acknowledged. It is most effective when used at 4.6 $\ell$/ha at the registered dose of 20 BIU/ha and when applied by small aircraft. *B.t.* sprays cost 3 to 5 times more than chemical insecticide sprays. A new oil formulation may prove to be effective and economical.

Intensive research is in progress to develop new methods and techniques to reduce dependence on chemical insecticides. Insect growth regulators when ingested prevent maturation to the adult stage by inhibiting moulting in larvae and show potential for control. Some insect growth regulators are being field tested and may be registered in a few years. They probably will be cheaper to produce than microbials and less hazardous to the environment than chemical insecticides. Sex pheromones are substances emitted by female moths to attract male moths for mating. When synthetic attractants are diffused into the atmosphere, male moths become adapted to the odours and do not respond to the females. Theoretically the number of fertile egg masses laid and the incidence of moth dispersal will also be reduced. Sex pheromones appear promising but several technological problems need to be solved, which may take years of research. Control of epidemic populations by either microsporidia, fungi, viruses, parasites or predators, all natural agents, does not as yet appear promising. Probably fungi and viruses show the most potential but each requires continued research as major obstacles have to be overcome. Control through the mass release of sterile or genetically altered insects to reduce reproduction and survival awaits at least 5 to 10 years of development and testing. The potential of genetic control is in its being incorporated into an integrated control program of endemic populations. The strategy of using pathogens together with sublethal doses of chemical insecticides has considerable potential for spruce budworm control, but laboratory and field testing are needed to better assess this potential. Antifeedants are chemicals which inhibit pest feeding. They may be produced in minute quantities by the host plant. These and chemicals of non-plant origin are being tested for their antifeeding affect on the spruce budworm. Trees possess various complex chemical, physiological and morphological properties in their gene pool to resist and survive insect attack. Breeding and using insect resistant trees is a desirable long-range pest-management strategy. However, breeding trees for resistance takes a long time, and much longer still to establish resistant trees in the natural forest.

Budworm control by forest management is a very long term strategy that could potentially ameliorate impacts; not eliminate them. Management practices could alter species composition, change the age-class distribution and the spatial structures of forest stands. These practices would take 50 to 100 years, and would need to be applied over large regions to be effective. Also each management strategy has substantial drawbacks. However, forest management techniques will play a role in the integrated control of the balsam fir-budworm problem.

Integrated control or pest management is the intelligent use of all practical methods of control applied in harmony with the environment to minimize economic damage. Present budworm control practices are in agreement with this concept of integrated control. The only effective methods to control epidemic populations are chemical and biological insecticides and they are used sparingly, and only when and where necessary. Research seeks the development of other methods to reduce the dependence on chemicals and as they become operational they may be incorporated into the control program.

# IX. ENVIRONMENTAL EFFECTS OF FOREST PEST MANAGEMENT OPTIONS

## 1. APPLICATION OF CONTROL METHODS

### a) CHEMICAL INSECTICIDES AND THEIR BREAKDOWN PRODUCTS

#### i) Toxicity to Fish and Fish Food Organisms -- D.C. Eidt and P.D. Kingsbury

Forest ecosystems are integrally linked to aquatic ecosystems and the application of insecticides for forest pest control on an operational scale inevitably results in some contamination of aquatic systems. Aerially broadcast insecticides may fall directly on water surfaces, may be washed in from terrestrial deposits, or may settle on water after drifting considerable distances in air.

The potential for undesirable effects in aquatic systems is apparently high because of the convergence of water, with all the substances dissolved and suspended in it, into ponds, lakes, estuaries and ultimately the sea. Physical concentration of insecticides in elements of the system (floating on the water surface or partitioning to mud or water plants), and biological concentration in plants and animal food chains may increase the hazard to certain organisms. However, almost immediate dilution and loss of insecticide through decomposition and dissipation alleviate insecticide impact and partitioning.

Monitoring and experimentation by various agencies in parts of Canada and the USA with spruce budworm problems, established that the forest insecticides in current use decompose, disperse and dilute quickly in their downstream travels. Formulations are important because solvents and surfactants may present some hazards, and they affect the behaviour of the insecticides in nature (Zitko *et al.* 1980).

The principal insecticides used in Canada in recent years have been fenitrothion and aminocarb. Other, less frequently used insecticides are trichlorfon, phosphamidon, carbaryl, and acephate. The relative toxicities of each of these to aquatic invertebrates and fish in forest streams are known but sub-lethal effects that may affect community integrity are not. The existence of such subtle effects may be difficult or impossible to prove or evaluate but, in our experience, forest streams harbor healthy, diverse invertebrate communities even in areas sprayed most years. Increasing fishing pressure and habitat changes, largely due to industrial activity make the evaluation of any insecticide role in sports fish productivity a very difficult research proposition.

Acephate - Acephate differs significantly from the other insecticides used to control spruce budworm in that it is very soluble in water, which results in a very low toxicity to fish and tadpoles (Klaverkamp *et al.* 1975, Lyons *et al.* 1976). Residual levels of acephate in tadpole tissue closely paralleled ambient levels in water (Lyons *et al.* 1976). Boscor and O'Connor (1975) did not detect any effects of acephate spraying on plankton, aquatic invertebrates, fish or amphibians. Rabeni and Stanley (1979) reported minor, brief increases of invertebrate drift, especially of black flies. No changes in benthos populations or in trout or Atlantic salmon growth were recorded, though feeding habits of salmonid fishes were temporarily modified as the fish exploited the increased quantities of terrestrial insects knocked into the water by the spray.

Aminocarb - The results of a large number of recent aquatic impact-studies are available from aminocarb-treated forest areas in Newfoundland, New Brunswick, Quebec, Ontario and Maine. All involve the Matacil formulation, and these have been recently reviewed (Holmes and Kingsbury 1980, Eidt 1980). Some of the studies have reported very modest, short-lived increases in invertebrate drift following aminocarb applications, others modest reductions of benthic populations of some groups of aquatic invertebrates (primarily stonefly nymphs and blackfly larvae), and yet other studies reported no effects on aquatic invertebrates. Eidt (1979) failed to document any kill of aquatic invertebrates following injections of aminocarb (as Matacil and as emulsifiable concentrate) into small streams at concentrations more than three times greater than those expected under operational sprays. He questions whether there is any effect on aquatic invertebrates attributable to registered aminocarb spray regimes.

No mortality occurred among caged salmon and trout in aminocarb treated streams in New Brunswick and no effect on either population structure or growth rates of native stream populations (Anon. 1978, Gillis 1980).

One of the primary concerns had been a lack of studies on aminocarb residue persistence due to a lack of suitable analytical techniques for measuring such residues. But this difficulty has been overcome and a number of suitable methods for analyzing residues in water have been developed (Sundaram *et al.* 1978, Mamarbachi 1980, Brun and MacDonald 1980). Numerous residue studies in Newfoundland, New Brunswick, Quebec and Ontario have confirmed aminocarb residues in water to be short-lived (Coady 1978, Mathieu *et al.* 1979, Varty 1980c, Anon. 1979a,b).

Recently, concerns have been raised over the toxicity to fish of nonyl phenol, a solvent present in the commercial aminocarb preparation (Matacil[R]) used in Canada (Zitko *et al.* 1980). Field studies on the effects of a seasonal maximum application of nonyl phenol did not demonstrate any effects on aquatic invertebrates or evidence of toxic effects on fish (Holmes and Kingsbury 1980). The formulation of aminocarb used to control spruce budworm in the field has a toxicity to fish similar to that demonstrated by Nelson (1979) for end use technical Matacil[R] which includes nonyl phenol. Therefore the hazard to fish is far lower than has been suggested. Nonyl phenol does not persist in water (Sundaram *et al.* 1980), and does not tend to bioaccumulate in Atlantic salmon or bivalves (McLeese *et al.* 1980b, Caldwell 1980). Caldwell (1980) and Holmes and Kingsbury (1980) both concluded that Matacil[R] formulation, including nonyl phenol, does not pose any significant hazard to the integrity of aquatic environments under present forestry usage patterns.

Carbaryl - Carbaryl has been used extensively in Maine for a number of years in its commercial preparation SEVIN[R]. At operational application rates of 840 to 1120 g AI/ha it has caused substantial reductions of, or eliminated completely, populations of some stonefly and mayfly nymphs, caddis fly larvae and amphipods (Anon. 1979e, Courtemanch and Gibbs 1980). The reductions on some groups may still be apparent more than a year after treatment (Courtemanch and Gibbs 1980). Two successive applications of carbaryl of 280 g AI/ha into a stream in New Brunswick in 1980 caused only a slight increase in drift of some groups of aquatic insects, and caused population reductions for only a short period after spray application. No reductions in benthos populations occurred (Holmes unpublished). However, at present operational application rates, carbaryl is more hazardous to fresh water fauna than fenitrothion or aminocarb.

Fenitrothion - Research to 1975 on fenitrothion as an adverse influence in fresh water systems was reviewed by Symons (1977b). The effects on aquatic invertebrates are small, infrequent and readily tolerated at aerial emission rates of 210 g AI/ha or less per application. Communities retain their diversity, and kills of invertebrates occasionally detected with drift nets in streams seldom result in measurable changes in standing crop (Eidt 1975). Where the standing crop of invertebrates has been reduced by occasional high concentrations of fenitrothion in stream water, a lasting reduction or changes in community structure the following spring has never been reported. Similar results have been recorded in Newfoundland (Anon. 1979a). All aquatic insects, including the most sensitive species and those that do not rapidly colonize under-populated habitats, are not noticeably fewer in bottom samples following fenitrothion usage, except in streams receiving large experimental or accidental doses. Even then recovery is rapid (Eidt 1981).

Effects on fish in natural systems have never been demonstrated, although temporary behavioural differences are suspected from laboratory experiments (Kingsbury 1977, Symons 1977a). Salmonids, being opportunistic feeders, exploit without apparent harm the abnormally high daytime drift of aquatic insects and the abundant terrestrial insects that tumble into streams following sprays. A New Brunswick survey tentatively concluded that the long history of fenitrothion usage has not depleted populations or biomass of salmon parr and trout (Anon. 1978, Gillis 1980).

Fenitrothion has been demonstrated to briefly accumulate in some water plants (Weinberger personal communication, Moody *et al.* 1978), but it has not affected their viability, or that of the organisms that fed on them. Decomposing fungi, a vital link in the transfer of energy from organic detritus to aquatic animals, were not affected by contaminated water (Eidt *et al.* 1979).

The effect of normal and high dosages of fenitrothion in lake systems had few evident effects except temporary reductions in cladocerans and other crustaceans in some instances (Kingsbury 1977, 1978a,b; McLeese *et al.* 1980a).

Fenitrothion disappears rapidly from streams (Eidt and Sundaram 1975, Symons 1977a, Coady 1978) and lakes (Kingsbury 1977, 1978a) in treated areas. Fish and amphibians accumulate residues for a short period but rapidly lose them (Lockhart *et al.* 1973, Lyons *et al.* 1976, Kingsbury 1977) without having incurred effects on serum chemistry (Lockhart *et al.* 1973).

The degradation of fenitrothion in water and its accumulation in and flushing from fish have been studied, and an upper limit to its bioaccumulation in fish at 200 to 250 times greater than the concentration in water has been documented by Miyamoto (1977). The degradation products of fenitrothion are generally similar or less toxic to fish than the parent compound (Zitko and Cunningham 1975, Miyamoto 1977).

<u>Phosphamidon</u> - Phosphamidon at the usual aerial emission rates had no significant effect on aquatic invertebrates (Grant 1967, Eidt 1976). Effects on fish and aquatic insects were noted only in phosphamidon-treated riparian safety zones within DDT treated forest, and the effects were attributed to DDT from upstream sources (Kingsbury 1975).

Trichlorfon - Studies of the possible effects of trichlorfon on stream and lake fauna began in 1977 in New Brunswick (Saunders personal communication), but have not been sustained because the insecticide has not been used since. Studies done elsewhere suggest a slight increase of drift or of diversity of drift of aquatic invertebrates in streams following treatment (Haugen 1978).

ii) Toxicity to Birds and Mammals -- P.D. Kingsbury and B.B. McLeod

Germain and Tingley (1980) investigated the effect of forest sprays on forest songbird populations and reviewed the work of others. They conclude:

"Accumulated evidence suggests that registered use-patterns for fenitrothion and aminocarb have no catastrophic effects on songbird populations. Therefore, it is not recommended that extensive monitoring be conducted in 1980, given the same spray regimes and same monitoring methodology. Nothing would be gained. Extensive monitoring should be made only when immediate and major mortality is suspected. Intensive coverage of a more limited area should be made if determination of sub-lethal effects is the objective."

Other studies suggest similar results for songbirds where fenitrothion (McLeod 1977), aminocarb (Buckner and McLeod 1977, Kingsbury *et al.* 1979) and sequential applications of different insecticides were used (Kingsbury and McLeod 1980).

Conventional fenitrothion and aminocarb treatments have had no major impact on small mammal populations. Buckner *et al.* (1975b) reviewed the results of laboratory studies, field monitoring, and a research program involving five annual applications of fenitrothion each at 280 g AI/ha. They concluded: "it is unlikely that repetitive treatments of fenitrothion would provide any major impact on small mammal populations". Aminocarb spray regimes in Quebec, New Brunswick and Newfoundland did not noticeably effect small mammal populations (Buckner *et al.* 1975b, Sarrazin 1977, Varty 1978a, Anon. 1979a). A healthy small mammal population was evident in an experimental area following treatment with a seasonal maximum application of aminocarb in 1979 (Kingsbury *et al.* 1979).

iii) Toxicity to Arthropods -- I.W. Varty

Native arthropods, in general, can be considered beneficial since collectively they contribute to the integrity and stability of forest systems. The forest manager is obligated to a management system incorporating a balance of populations of all species compatible with his economic criteria of sustained growth and stable inventories of forests.

Some adverse effects following large-scale use of insecticides in agricultural practice include: pests developing resistance to increasing doses of insecticide; minor pests reaching major status; reduction of predatory and parasitic species populations; persistent residues in animal habitats and human foodstuffs; and damaged reproductive processes; the latter especially in birds. Environmental activists claim that while such effects may be tolerable in agriculture, they are unacceptable in forestry because of a greater dependence on natural processes. Forest scientists should attempt to detect and measure any such side effects and determine their long-term significance.

In spite of hazards claimed, 29 years of forest spraying in New Brunswick and spraying elsewhere have generated few case histories of serious environmental damage. However, surveillance over the years has been light, discontinuous and sometimes inconclusive. Nevertheless, there is enough evidence on the effect on beneficial arthropods to provide guidance to resource managers.

Immediate Impact - Most chemical insecticides used in budworm management kill a large fraction of the exposed arthropod population in tree crowns (Leonard 1971, Kettela and Varty 1972, Dorais and Gaboury 1979, Varty 1977, Anon. 1979a, Miller *et al.* 1980, Kingsbury *et al.* 1980). Except for bumble bees the fate of arthropods in the shrub, herb and litter zones has not been investigated intensively. Mortality is variable because of uneven distribution of the chemical, the variability in genetic susceptibility among species, developmental stages and individuals; the habitat or temporal vulnerability; the behavioral patterns; and spray timings. A fraction of an arthropod population in a sprayed habitat always escapes; there is never eradication of any species.

The exposure of forest arthropods to larvicidal spray operations is generally in one or two narrow bands of three or four days each in late May and June in New Brunswick and Quebec, or as late as early July in Newfoundland and northern Ontario. Over the rest of the year, most faunal habitats are free of significant concentrations of insecticides and their toxic degradation products. There are a few exceptions to this generality; low level residues of fenitrothion persisting on pine foliage were enough to kill hatching sawflies weeks after spray treatment (McNeil *et al.* 1979). Other spray tactics, such as adulticidal sprays in July, alter the spectrum of vulnerable animals. Exposure to larvicidal or adulticidal treatments effects hundreds or thousands of species of forest arthropods in the most diverse habitats (Varty 1975). The percentage kill of an exposed arthropod population is hard to measure, and, except for target pests, such measurements are rare. Typically, two successive sprays of fenitrothion at 210 g AI/ha may kill 70% to 80% of the larval budworm population (Miller and Kettela 1975). Since spruce budworm is a susceptible species at a susceptible stage, and since it is vulnerable to the timing and delivery system, it can be extrapolated that many non-target species are less susceptible and less vulnerable and thus suffer lower losses. In practice, mortality varies widely: around 50% of the population exposed on spray day (Varty unpublished). Winged insects on fir, birch and alder in Newfoundland, showed a broad impact from aminocarb of 15% reduction and from fenitrothion up to 45% reduction of arthropods (Anon. 1979a). Each kind of insecticide has its own selectivity; fenitrothion (2 x 210 g AI/ha) produced less than 10% mortality of spiders on balsam fir crowns, whereas with aminocarb (2 x 70 g AI/ha) produced about 60% (Varty 1980b). Adulticidal operations, of two or three low-dosage sprays in late July, resulted in relatively severe mortality (50%) of parasitic wasps, moths and beetles (Miller *et al.* 1980).

Immature parasitoids inside their host arthropods at spray time are a special case of insecticidal mortality; they die, not because of direct insecticide poisoning, but because their hosts succumb. This does not alter parasitism in the succeeding host generation.

Most adult parasitoids are highly susceptible to contact poisoning. Aminocarb (2 x 70 g AI/ha) sprayed in spring killed 60% to 70% of the chalcidoid wasps present in fir crowns (Varty 1978a). However, larvicidal sprays do not normally kill many adult parasitoids attacking spruce budworm (Leonard 1971). Adulticidal sprays (July) with phosphamidon (3 x 70 g AI/ha) reduced the population of *Apanteles* adults by 90% before they could oviposit on host budworm (Miller *et al.* 1980).

Mortality of flying insects, by adulticidal and larvicidal treatments, has implications for wildlife feeding on them. Azamethiphos appeared to deplete the availability of flying insects, and this may have caused the abandonment of some flycatcher territories, although warblers and kinglets were not seriously stressed (Kingsbury *et al.* 1980). On the other hand, poisoned insects provide a temporary increase of prey for trout, without causing secondary stresses in the fish stocks (Sarrazin 1978, Hydorn *et al.* 1979).

<u>Effects on Population Dynamics</u> - Fenitrothion use-patterns are not a key factor in the population dynamics of major arthropod groups in the balsam fir community even when spray operations are repeated for several years (Varty 1977). The cycles of abundance of many taxa (aphids, syrphid-flies, lacewings, spiders, mirids, mites, scales, etc.) were parallel in sprayed and unsprayed plots, indicating that insecticide intervention was not a population depressant or releaser.

A few species of fir-dwelling arthropods such as common lady-bird beetle, thrips and springtails have declined in population density in New Brunswick since fenitrothion came into large-scale use (Varty 1977); possibly from hypersensitivity to insecticides.

Attempts have been made to detect any within-season decline of arthropod abundance following insecticide usage. Generally losses to insecticides are quickly absorbed. The index of activity for a number of insects was about the same in sprayed (phosphamidon) and unsprayed plots one month after aerial application in Quebec (McLeod 1968). In Newfoundland, neither aminocarb nor fenitrothion had any marked seasonal effects on flying insects (Anon. 1979b), and one year after aminocarb operations there was no reduction in diversity or abundance of non-flying arthropods (Anon. 1980a). More winged insects and litter-dwelling species occurred in a perennially sprayed plot (fenitrothion) than in a rarely sprayed plot (Varty and Carter 1974). Arboreal spiders continued to be diverse and abundant regardless of spray history, and that is important because spiders are major regulators of many other arthropod populations (Varty 1980b). Short- and long-term depressions of arthropod abundance, such as spiders and ground beetles (Freitag and Poulter 1970) and bumble bees (Plowright 1980, Wood 1980) occurred following spray operations in a few cases.

Long-term Effects on Parasitism - The bulk of the evidence suggests that insecticide sprays have not resulted in selective reduction in the rate of parasitism of small larval budworm (Leonard and Simmons 1974, Blais 1977, Simmons 1976, Varty 1976b, 1978a, b, Magasi *et al.* 1980, Sarrazin 1978, Dorais 1979). Similarly, *Trichogramma* parasitism of budworm eggs in the Maritime Provinces (Magasi *et al.* 1980) and in Quebec (Dorais 1979) was unaffected by the regional distribution of spray operations. Less is known about the status of parasitism in large-larval and pupal populations of budworm, but each of these stages has a large and diverse complex of parasites. Some species (*Meteorus trachinotus*, *Actia interrupta*) are known to be active as adults at spray time, but there is no evidence that their contribution to parasitism of the large larvae is being altered in treatment areas.

DDT had no effect on the current season rate of larval parasitism (Blais 1960) even when sprayed for a number of years (Macdonald 1959), though a slight increase in the percentage of parasitism for *Apanteles* occurred the year following spray application. A slight increase in parasitism by larval parasites also occurred when Zectran was sprayed (Williams *et al.* 1979, Leonard and Simmons 1974), but the application of naled resulted in decreased parasitism (Williams *et al.* 1969). Fenitrothion had little or no effect on parasitism of small larvae (Varty *et al.* 1971, Kettela and Varty 1972, Varty 1978a, Otvos and Raske 1980a). Spraying very early in spring (late April, early May) had no effect on parasitism (Varty 1976b, Blais 1977). Operational sprays with

Matacil[R] did not affect parasitism by larval parasites and by pupal parasites (Otvos and Raske 1980a,b). Hamel (1977) and Otvos and Raske (1980a) reported increases in percentage of parasitism when *Bacillus thuringiensis* (*B.t.*) was applied. Both authors attributed the increased survival of parasitized larvae to larval behaviour rather than to bacterial action. The suspicion that spraying small larvae with fenitrothion may reduce pupal parasitism (Varty *et al.* 1971) has not been substantiated by later studies. However, spraying larvae with Zectran appeared to reduce pupal parasitism by tachinids (Leonard and Simmons 1974).

Adulticide spraying, in spite of its lethality to small-larval parasitoid adults (*Apanteles fumiferanae, Glypta fumiferanae*) has not resulted in lowered percentage of parasitism in the next generation of budworm (Miller *et al.* 1980).

Studies of the interaction between insecticide usage and rates of parasitism have concentrated on spruce budworm because it is the most convenient host to sample. However, there are thousands of other host-parasite relationships potentially under stress by spray operations. Few assessments of these relationships have been attempted, and therefore the hypothesis of ecological stress on parasite-host interactions, remains largely untested.

Toxicity to Pollinators - Fenitrothion, aminocarb and acephate have been studied for their effects on both honey bees and wild pollinators. These chemicals sometimes cause mortality to foraging honey bees, but the effects on overall colony strength and vigour generally was negligible (Buckner 1974, Buckner and McLeod 1975, Buckner *et al.* 1975b). Fenitrothion caused substantial mortality to caged bumble bees directly exposed to the spray cloud (Plowright *et al.* 1978). Late emerging bumble bee species tend to increase within sprayed areas and ameliorate adverse effects on pollination (Plowright and Rodd 1980). Aminocarb did not adversely affect bumble bees but caused some mortality among caged solitary bees. Aminocarb applications in New Brunswick in 1979 caused mortality of solitary bees and syrphid flies and reduced seed production of two insect-pollinated plant species (Plowright and Rodd 1980).

Minor Pest Outbreaks - The CFS through its FIDS unit has routinely documented the rise and fall of significant minor pest outbreaks on various tree species. The distribution of these outbreaks has been examined in relation to spray block patterns without disclosing any relationships (Magasi *et al.* 1980). The outbreak of the lesser maple spanworm, *Itama pustularia* (Guen), in central New Brunswick in 1972 to 1975, suspected of being induced by insecticide use patterns, but it was concluded that insecticide usage did not induce the outbreak, did not destabilize the community on red maple foliage, nor interfere with host-parasite and predator relationships (Volney 1976).

Productivity of Forest Goods and Values - Insecticides are only a minor factor in population dynamics of all types of forest animals, and will likely remain minor as long as the forest protection strategy uses low and infrequent dosages employed across a small fraction of the spruce-fir forest. It must also be recognized that insecticides are a stabilizing factor in preserving animal habitats from drastic degradation due to defoliation and stand mortality. On the one hand, it is not easy to identify "environmental damage" (loss of present resources or future productivity) due to insecticide toxicity, but it is easy to measure such damage due to unrestrained budworm numbers.

iv) Development of Resistant Strains of Spruce Budworm -- P.C. Nigam

Fenitrothion has been used experimentally in New Brunswick since 1965 and operationally since 1969, and aminocarb since the early 1970's (Nigam 1975, 1980). Populations of spruce budworm collected from two areas treated with fenitrothion for seven years in New Brunswick were compared to populations from untreated areas in Ontario to detect development of resistance to fenitrothion (Table IX-1). There was no shift in $LD_{50}$ and $LD_{95}$ values of spruce budworm populations from untreated and treated areas. The chances for developing resistance in spruce budworm are remote for the following reasons:

(1) Low population control - The average percent larval mortality is less than 80% in most spraying operations (Kettela 1975, Nigam 1980). This is insufficient insecticide pressure to select for and increase insecticide-tolerant strains in the population. In comparison, in horticultural and agricultural crops more than 98% of the pest populations are killed with every spray.

(2) Area treated in relation to infestation - Only an average of 10% of the infested area has been treated with fenitrothion annually in Canada (Nigam 1980). Therefore, the insecticide pressure on the total population of spruce budworm is insufficient to initiate development of resistance.

(3) Migration of populations - Consistent large scale and long range immigration and emigration of populations from untreated to treated areas and vice versa further dilutes the gene pool in treated areas and decreases the chances for development of resistance.

Table IX-1. Toxicity of fenitrothion to fifth instar spruce budworm larvae collected from fenitrothion treated and untreated areas in New Brunswick.

| | Number of Operational spraying of fenitrothion (years) | $LD_{50}$ (72 hrs.) | | $LD_{95}$ (72 hrs.) | |
|---|---|---|---|---|---|
| | | $\mu g/cm^2$ | Fiducial limits (95%) | $\mu g/cm^2$ | Fiducial limits (95%) |
| Lower Jemseg N.B. | 7 | 0.045 | 0.040-0.050 | 0.065 | 0.058-0.080 |
| Castaway Brook N.B. | 7 | 0.073 | 0.064-0.080 | 0.104 | 0.092-0.146 |
| Lanark Ont. | Nil | 0.043 | 0.036-0.048 | 0.070 | 0.061-0.092 |
| Pakenham Ont. | Nil | 0.069 | 0.063-0.075 | 0.096 | 0.087-0.110 |

### v) Drift of Insecticides -- I.W. Varty

Hazards from Drift - At present the protection of forests from spruce budworm defoliation is economically feasible only through the use of broad spectrum chemical insecticides dispersed by aircraft. The spray delivery tactic involves the emission of mists in parallel swaths over large spray blocks such that downwind drift achieves overlapping but homogeneous coverage of foliage with minute droplets. Spray operations are regulated so that environmental contamination is minimized, but drift has not been amenable to routine measurement.

In New Brunswick, the inadequate accounting drifting insecticide was recognized by the Pesticides Advisory Board in 1978. The Board also recognized that set-back of spray blocks one mile from year-round habitations are imposed without support from well-defined data, and intimated that future permits might be conditional upon better documentation of drift. In response, the New Brunswick Department of Natural Resources established a provincial

Task Force on Long-distance Drift with a mandate to assemble a statement of the art and recommendations for research to close information gaps. The Task Force includes scientists from the University of New Brunswick, the N.B. Research and Productivity Council, Health and Welfare Canada, the National Aeronautics Establishment, and the Canadian Forestry Service, and is supported by a Steering Committee with broad representation. In the two years since its formation, the Task Force has hosted an international conference on drift, has identified the main problems and selected a modelling approach, and has collaborated with various research agencies to develop methods for improved accounting of emitted insecticides. The Task Force is preparing its final report.

Pesticide drift is a complex problem involving four scientific fields: 1) aerosol and vapor transport, 2) atmospheric chemistry, 3) ecological effects and risks, and 4) public health risks. The important questions are: (a) how to minimize environmental contamination without losing target efficacy; (b) how to monitor drift and deposit by quantity and quality; (c) how to measure human exposure by various pathways of contact, how to set acceptable standards for environmental contamination, and how to regulate drift under those criteria; (d) how to monitor ecological effects and evaluate hazard; (e) how to inform the public on the nature of risks and win confidence in mature judgments of safety.

Atmospheric Transport of Aerosols and Vapors - A spray cloud is a mix of large, small and minute droplets. The main mass of an insecticide spray cloud is held in the relatively small numbers of large droplets, which sediment rapidly by gravity. The problem of drift is the downwind suspension of a large number of small and minute droplets, which account for only a small fraction of the total emitted spray, yet are detectable at least 50 km from the source.

A model of near-field drift (300-1500 m downwind) has been developed (Picot *et al.* 1980, Picot and Kristmanson 1980). The reliability of the model has been tested by field experiments, and less than 20% of the active ingredient emitted was still airborne at 300 m from the swath line. There was provisional evidence that light winds under inversion conditions, typical of early morning spraying, may result in more low-level drift than windier conditions later in the day. The model also predicts deposit on the ground and on the needles, and provides a guide to contamination of human and animal environments.

A long-distance model of spray and vapor transport is under development by the National Aeronautics Establishment (Crabbe *et al.* 1980a,b; Crabbe and Reid 1980), based on cloud behavior in relation to meteorological and terrain factors. The provisional model demonstrated greater long-distance drift of small and minute droplets at low level and calm inversion conditions than under windier neutral conditions. Droplet flow and droplet size were measured at distances from 7.5 to 45 km from the emission source. Trace contamination of the air decreased rapidly with distance from the source as well as droplet diameter.

Field and laboratory research in 1980 on concentrations and droplet size spectra in and around a spray block, provided data for toxicological evaluation of human exposure to fenitrothion, through inhalation of minute droplets. Concentration levels were less than 1 ppb and exposure durations very brief. The relationship between exposure to insecticide and distance from the swathline has been determined and field exposure kept at acceptable levels of luman respiratory intake (Crabbe *et al.* 1980b).

These models represent a major advance in accounting of drift from a single swath line or block. However, monitoring of extensive drift from discontinuous aggregates of blocks and sporadic spray sorties presents further problems. Two approaches are possible: a) modelling of windfields, and b) ground-truthing by a sampling grid. The feasibility of these two approaches has not been fully explored.

Atmospheric Chemistry - Vapor pressures of formulated fenitrothion and aminocarb, and the rate of atmospheric degradation of these chemicals in aerosols and vapors are currently being studied. Preliminary results indicate that both insecticides have short-term stability as aerosols in near-field drift. Therefore, fears of rapid conversion to more poisonous oxidation products appear unfounded. More work is needed on the problem of vapor flux from aerosols and deposited residues.

Ecological Effects - Monitoring agencies have investigated such aspects of drift as the exposure of bees, reduction of fruitset in blueberries and other plants, the accumulation of residues in shellfish remote from spray blocks, and the deposition of drift residues in rainfall. Current operational strategy does not pose any serious economic problems or create alarming ecological disruption. The most challenging issue is the rationalization of no-spray buffer zones around commercial blueberry fields to reduce hazard to pollinating insects (Varty 1980a).

Public Health - The risks to people are (a) dermal contact and inhalation exposure from aerosols and vapors at various distances from spray operations: woodworkers in spray blocks, rural residents nearby, and remote urban populations; and (b) ingestion toxicity due to contamination of water, food and air. The data needed are therefore: (i) concentrations of aerosols and vapors over time, and size classes of droplets, (ii) exposure patterns by human activities, (iii) synoptic distributions by monitoring or modelling, (iv) rates of absorption, partitioning, metabolism, and elimination in the human body in acute and chronic exposures. The probabilities of exposure are being modelled for worst-case forest workers, and available data on exposure are being examined by toxicologists. Not yet fully addressed by medical reviewers are problems of low-level insecticide effects on tissues, detoxification mechanisms, and indices of viral enhancement by chemicals.

Further Aspects of the Drift Problem - Drift problems should receive expanded federal research input. The Province of New Brunswick, and specifically Forest Protection Ltd., have funded research in default of an adequate national program. The New Brunswick Task Force may recommend that the provincial effort be continued and expanded over the whole field of spray technology as the fastest way to achieve better accounting for spray distributions and effects. Costs may be reduced as well as environmental contamination as a result of research in spray technology. Research may improve spray delivery hardware, and facilitate better choice of spray timing and weather appropriate to greater efficacy against the pest with lower quantities of insecticide. It is important that the medical profession as a whole be well informed on risk assessment from chemical spray operations, so that they may lend their judgments to the public debate on the safety and cost/benefit of crop protection programs.

### vi) Hazards to Human Health -- A. Sundaram

The effect of pesticides and spray mixes on humans is under the jurisdiction of National Health and Welfare. The Forest Pest Management Institute (FPMI) does not claim medical expertise, but is the lead agency within CFS with responsibility for testing and developing new pesticides for forestry use. Therefore FPMI staff maintains a keen interest in potential health problems of these new materials. The comments expressed in this article are based on a review of the available literature and personal communications with acknowledged experts.

Information on human health effects can be obtained from two different sources: i) from epidemiological studies and medical reports on humans who were exposed to pesticides, and ii) from toxicological studies conducted on laboratory animals. Each source has its own disadvantages. Although human studies are more meaningful than toxicological data on animals, human exposure to pesticides rarely occurs under strictly controlled conditions. Therefore scientists have to rely on animal data for supportive evidence. Animal studies, on the other hand, indicate hazards but cannot quantitatively measure human risk or predict human sensitivity to chemicals. Consequently, a knowledge of both human and toxicological data are used to estimate the health implications of pesticide exposure. In addition, it is important to subject animals to similar dose regimes and exposure durations, as humans exposed to the spray in normal spray operations. For example, animal studies that evaluate occupational health hazards should involve an exposure duration of 8 hours/day for 5 days/week; within one month with an 11-month period of no exposure. It is very unfortunate that many laboratory experiments had unrealistically high dose levels and inappropriate exposure duration. This makes it very difficult to predict human health effects from animal data.

Potential harmful effects of pesticides, on humans or animals, can be grouped into four distinct categories: acute poisoning from severe exposure; toxicity due to short-term repeated exposures; chronic effects from long-term exposure; and mutagenic effects.

<u>Acute Poisoning</u> - Accidental oral intake by children has occasionally occurred in the home resulting in death. In pesticide workers, however, accidental severe exposure can occur by spilling on to the skin or by inhalation of vapours. Such accidental deaths have occurred in the manufacturing area; but in recent years, there has been a significant decline in the number of deaths. In the United States in 1961, 111 people died; in 1969, 87; and in 1974, 52 (Savage 1980). This decline is probably due to the use of proper protective equipment and hygienic practices. A similar compilation of Canadian medical reports is not available either on agricultural or forestry workers.

<u>Short-term Repeated Exposures</u> - Two types of adverse health effects can result from repeated short-term exposures: delayed neurotoxicity and reproductive abnormalities. Recent medical reports in the United States indicate severe neurological damage in a few farm workers who had handled certain types of organophosphorous pesticides for a period of several years. However, there is no evidence of neurotoxicity in forestry workers in any country from handling fenitrothion or aminocarb (Miyamoto 1978; Lamb personal communication). Even the threshold toxic sign, depression of cholinesterase activity, was not noticeable in the majority of exposed humans except in a few cases where slight anticholinesterase activity was observed with mild clinical symptoms of toxicity. All reverted back to normal within a short period of time following withdrawal from exposure (Hladka *et al.* 1977, Shelanski *et al.* 1977, Miyamoto 1978).

Laboratory animals failed to indicate delayed neurotoxicity with fenitrothion or aminocarb (Okuno *et al.* 1978, Lamb personal communication). A minimal incidence of reversible anticholinesterase activity was observed in a few animal species, but health implication of such reversible processes is very minor, especially when they occur without any significant clinical symptoms.

Fenitrothion or aminocarb had no embryotoxic nor teratogenic effects in laboratory animals at exposure levels comparable to those encountered in forestry spray operations (Kohda *et al.* 1976, Rutter and Nelson 1974a, Benes *et al.* 1974, Lamb personal communication). Furthermore, there is no evidence in support of any type of reproductive abnormalities in humans from exposure to the above two chemicals.

Chronic Exposure - Many of the chronic effects observed in humans including carcinogenicity, caused by long-term exposure to low levels of toxic chemicals, are highly non-specific. Most of such effects are extremely difficult to associate with any one chemical.

Chronic toxicity studies with experimental animals can be of great assistance in predicting human health effects. However, the current test protocols involve long exposures unrealistic for evaluation of the effects of forest sprays. This is especially true for carcinogenicity studies where dose levels and induction periods play significant roles in tumour incidence. Long exposures even to low dose levels become important in tumour induction. However, in the forestry spray operations, the exposure duration for humans is short, less than one month/year and excessively high dose levels would be needed to cause a significant increase in tumour incidence.

Chronic toxicity can be of either: local injury to the exposed site such as the skin or lung, and systemic damage to other organs. The latter can be grouped under: organ dysfunction, tumourigenicity, and enzyme effects.

Humans exposed to fenitrothion have not been adversely affected by any type of chronic toxicity though the chemical has been used world-wide for years in forest spray operations. Laboratory animals with lifetime exposure exhibited no hepato- or nephrotoxicity nor tumourigenicity (Rutter and Nelson 1974b, Rutter and Banas 1975). The only discernible chronic effect of fenitrothion in experimental animals was inhibition of cholinesterase activity at unrealistically high exposure levels. Such inhibition was not observed at doses comparable to those used in forest spray operations (Miyamoto 1978).

Mutagenicity - Several methods have been proposed to test mutagenic potential of chemicals in the laboratory both *in vitro* and *in vivo*. The suitability of these methods for validation of mutagenicity is currently being reviewed by Canadian and international panels of mutagenicists, and the decisions are yet to come. However, it is apparent that fenitrothion and aminocarb are not mutagenic according to current mutagenicity tests, conducted *in vitro* and *in vivo* (Miyamoto 1978, Lamb personal communication).

Finally, it is relevant to mention the claim that Reye's syndrome is associated with the emulsifiers and solvents used in fenitrothion formulations (Crocker *et al.* 1976; Rozee *et al.* 1977), or aminocarb-shell 585 formulation (Thurlow 1979). A panel of medical experts and scientists (Schneider 1976) reviewed this problem and were unable to link the occurrence of Reye's syndrome to the forest spray program with either of the two insecticides. Moreover, in a preliminary *in vitro* study with mouse fibro-blasts and vesicular stomatitis virus, Ritter and Franklin (1979) were unable to validate the claim of Thurlow (1979) on the viral enhancement capacity of aminocarb-shell 585 formulation.

## b) BIOLOGICAL CONTROL AGENTS

P.G. Fast and O.N. Morris

### i) *Bacillus thuringiensis*

*Bacillus thuringiensis* - Studies on the effects of aerial application of *B.t.* on forest streams have not revealed any effects on fish or aquatic invertebrates (Todd and Jackson 1961, Buckner *et al.* 1974, Buckner and Sarrazin 1975, MacDonald 1979, Anon. 1980a). *B.t.* has been recovered from stream water and freshwater clams following aerial treatments, but does not seem to persist for extended periods beyond the time of actual spray application (Buckner *et al.* 1974, Menon 1979).

Any decision to use an insecticide should balance the benefits against potential risks to the environment. Based on the massive amount of data published on safety, the commercially available, exotoxin-free *B.t.* can be considered safe. Earlier reports of deleterious effects of *B.t.* on non-target organisms (Forsberg 1976) were based on *B.t.* isolates known to produce exotoxin. Forsberg did not sufficiently emphasize this part, resulting in a somewhat misleading document. The relative safety of *B.t.* for terrestrial and aquatic non-target organisms in general has been reviewed (Bailey 1971, Ignoffo 1973, and Laird 1973), and no significant impact on non-targets have been reported at field application rates of exotoxin-free *B.t.*

Harmful genetic mutations in *B.t.* may occur during manufacture or after dissemination in the field. The probability of harmful mutations occurring during manufacture can be readily evaluated. In production, a master seed culture sufficient for 5 to 10 years is freeze-dried in individual portions sufficient to begin each fermentation. This starter culture is passaged no more than three to five times in the course of a production run. Under such conditions Connaught Laboratories (Walcroft personal communication) has never detected a mutant strain. Abbott Laboratories which operates sixteen 120 000 ℓ fermentors has never detected a mutant (Couch personal communication). The same statement applies to Sandoz, the other major *B.t.* manufacturer (Shieh personal communication). Each individual fermentor load is tested in mice for vertebrate pathogenicity. The risk of releasing undesirable mutants into the environment from production runs is therefore virtually non-existent.

The potential for development of undesirable mutants in the field is more difficult to evaluate. *B.t.* is a variant of *Bacillus cereus* that has developed the toxic paraspore allowing it to propagate efficiently as an insect pathogen. It is not well adapted to the soil or to forest environments and it does not effectively compete there with other micro organisms (Saleh *et al.* 1969, 1970a, 1970b, Pruett *et al.* 1980). Since mutants are almost invariably less competitive than the parent, the risk from a *B.t.* mutant is equivalent or less than the risk of mutation from any other species of common soil bacteria.

Activity of *B.t.* spores degrade 76% in soil and pathogenicity degrades 99% in 135 days (Pruett *et al.* 1980). Under laboratory conditions, *B.t.* exchanges extrachromosomal elements of DNA (plasmids) with lysozyme techniques or under very high temperature (42°C). Such temperatures do not normally occur in Canadian forest environment. Therefore, the probability of mutation by these methods is remote. Furthermore, plasmid transfer does not take place in the bacterial spore stage which is the stage designed for survival of the species (Ilzuk personal communication).

There is little chance of *B.t.* forming a new "species" of micro organisms by uniting with another bacteria. If two soil bacterial A and B, exchange some of their genetic material, a process which occurs, the result would be A with some characteristics of B, or B with some characteristics of A, both of which are still adapted to life in the soil; not a "new" organism.

Finally, spraying *B.t.* at 20 BIU/ha does not swamp the microbial environment. Assuming that 1 acre-inch (0.404 ha - 2.54 cm deep) of soil weighs 1.3 x $10^8$g (Forsberg 1976) and 2 000 spores/IU (Couch personal communication), then the load of *B.t.* spores deposited is $10^5$/g soil or about 1 g of spores/acre (2 x $10^{-13}$ g/spore, Burges personal communication) in a soil that can contain $10^9$ bacteria/g or 400 lb of bacteria, 4 000 lb of fungi and an equal amount of protozoa and actinomycetes/acre (Wyss 1963).

### (ii) Other Methods of Biological Control

No biological control agent other than *B.t.* is presently registered in Canada for operational use against spruce budworm, or other forest insect pests.

Permits for experimental use in aerial and ground trials on limited areas and under rigidly specified conditions have been issued for nuclear polyhedrosis virus of spruce budworm, and certain insect growth regulators.

The nuclear polyhedrosis virus is the most important virus infecting the spruce budworm. The safety of this virus to mammals, birds and fish has been tested extensively (Valli *et al.* 1976). Test animals were exposed to the virus in a wide range of dosage regimes and no ill effects were noted during or following exposure. Similarly, no ill effects were noted in selected forest fauna following an experimental aerial application of nuclear polyhedrosis virus (Buckner *et al.* 1975b).

Nuclear polyhedrosis viruses affecting gypsy moth, corn-ear worm and Douglas fir tussock moth have been registered for use in the U.S.A. and viruses of this type are widely accepted as being safe for birds, mammals, fish and other non-target organisms.

The use of microsporidia and fungi against budworm is still in the developmental stage and field testing of these has not progressed beyond single-tree experiments. Mass production and dissemination methods are still to be developed. These organisms are obligate pathogens and effect a narrow range of insects and their experimental use would seem to pose no hazards.

## c) OTHER CONTROL AGENTS

P.G. Fast and O.N. Morris

Insect growth regulators (IGR) are chemicals that inhibit normal insect development. A wide range of experimental compounds have been developed and these are presently being screened for use against agricultural, and forest pest insects. In some cases the precise mode of action is incompletely understood. All IGR's accepted for screening in ground or aerial trials have been routinely tested for acute toxicity to mammals and birds. No IGR is presently registered for use in Canada against the spruce budworm. Dimilin$^{R}$ is registered for use against the gypsy moth. Pheromones or any chemical that may be used for genetic or other control of the spruce budworm will have to be subjected to the same screening program as a chemical insecticide. Thus, there will have to be tests to assess the effects of these compounds and their solvents on the non-target organism of the forest ecosystem, and humans as well as studies on bioaccumulation and degradation of the compound in water, soil, stream sediment and forest foliage.

## 2. NO CONTROL OPTION

### a) EFFECTS ON FISH AND FISH FOOD ORGANISMS

P.D. Kingsbury

No specific studies have been done to determine the effects of uncontrolled spruce budworm damage on aquatic ecosystems, but the most likely consequences would be changes in water quality in runoff from areas which had suffered severe tree mortality.

Death of stream bank conifers would likely lead to less shading of streams, higher water temperatures and reduced terrestrial insect material entering streams, but might also increase in-stream cover in the form of toppled logs. Loss of the mature forest cover from stream watershed areas may reduce buffering effects on water flow, leading to increased runoff as floods and greater drops in water levels during droughts. In extreme cases, this might result in greater erosion of stream banks and siltation of stream beds.

Higher water temperatures and siltation can combine to reduce dissolved oxygen content of stream and intragravel water, and these changes would tend to select against salmonids which require cold, oxygen-rich water and well aerated, silt free gravel beds for incubation of eggs and sac fry. Although these effects would be similar in nature to changes which might occur with forest harvesting, extensive tree mortality over large areas would likely have an impact similar to those resulting from total clear-cuts of watershed areas, which have been shown to be far more damaging to stream water quality and salmon survival than patch-cut practices leaving protective strips of timber along streams (Hall and Lantz 1969).

## b) EFFECTS ON BIRDS AND MAMMALS

B.B. McLeod

Few long-term ecological monitoring programs have been done to determine the environmental impact of uncontrolled budworm infestations upon populations of forest song birds and small mammals (Crawford 1980). Some bird species are directly influenced by fluctuating budworm populations, while others appear to be only mildly influenced. Drastic habitat changes resulting from conifer mortality caused by budworm infestations is also a factor in shifts and changes in populations and species composition (Morris *et al.* 1958, Gage and Miller 1978).

Small mammal populations do not appear to be directly influenced by budworm population levels; however, tree mortality and associated loss of a seed as food supply may indirectly influence populations.

## c) EFFECTS ON ARTHROPODS

C.A. Miller

Some of the factors that determine the abundance of arthropods that attack the spruce budworm are their searching ability, reproductive capacity, the presence of required alternate host, and the abundance of the budworm itself. How a no-control option, i.e. high budworm density, changing stand characteristics, changing stand microclimate, affects one or all of the above factors has not been studied. More large larvae survive at high budworm densities (Watt 1963) and one of the causes is that parasites are less effective at high budworm densities (Miller 1963b). However, whether the low parasitism is simply a response to budworm density or a response to fauna/microclimatic changes in the habitat, or both, is open to question. The basic implication is that a no-control option and its ultimate effects on the habitat permit populations to increase at a rate far beyond the numerical response rate of parasites. The same holds true for the arthropod predator complex (Watt 1963). Furthermore, changes in the host-tree habitat could drastically reduce the alternative food sources required by many predators.

## d) EFFECTS ON PLANT SUCCESSION

W.J. Meades

The impact of the spruce budworm on coniferous seed supply and future forest succession in Newfoundland has been discussed in chapter five. Of greatest concern to forestry operations is the takeover of productive forest sites by species which retard or totally inhibit the growth of commercial softwood stands. This type of problem is already apparent following cutting and fire (Richardson 1975, 1979a).

Remedial measures necessary to restore sites to natural successional trends are outlined in Figure IX-1 with approximate costs in 1978 dollars (Munro 1979). These prescriptions and estimates are based on sites with poor stocking levels following cutting and wildfire. The estimate of $1500/ha for site preparation could be much higher if windthrown timber is present (Richardson personal communication). Also, treatment in the first ten years will obviously be less expensive because softwood competitors will not have fully occupied the site. However, when areas with regeneration problems caused by logging are combined with the extensive areas that have regeneration problems caused by the budworm, it is unlikely that treatments can be applied on all sites in the 10-year period without considerable amount of aerial seeding.

The lower cost for prescribed burning as compared to scarification is not so substantial when the costs of site preparation are added. Also, the heterogenous mix of killed and unkilled stands may make prescribed burning impractical as a remedial measure. The longer we delay remedial measures the more expensive they will be.

## e) HAZARDS TO HUMAN HEALTH

A. Sundaram

Harvesting of dead and deteriorated stands killed by the spruce budworm is probably the first human health hazard associated with an uncontrolled outbreak. Dead trees remain firm for two to three years but decay in subsequent years reducing the strength of wood considerably. Frequent top-breakage during felling is hazardous and loggers are reluctant to work under such conditions.

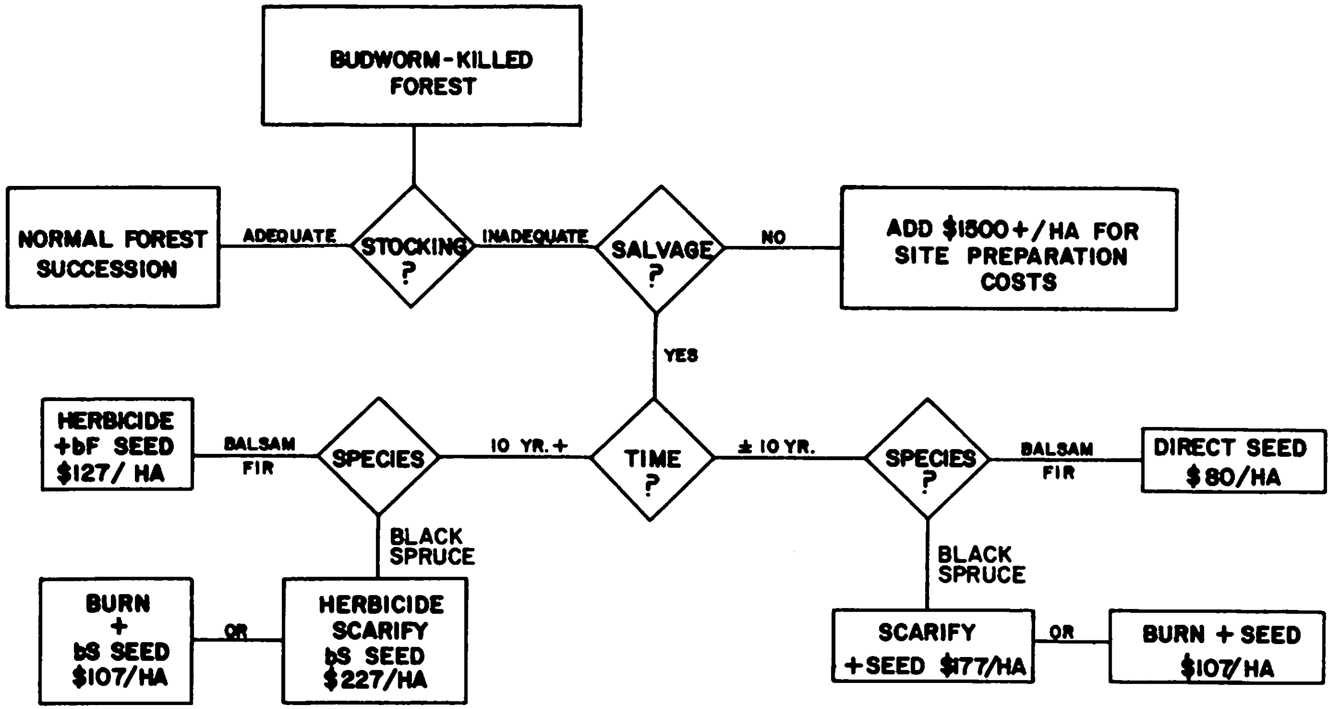


Figure IX-1. Forest management options following severe spruce budworm infestation (1978 dollars).

Another danger to human safety is probably the increased fire hazard in spring in budworm-killed stands, especially to loggers working in extensive forest areas killed by the budworm.

Undoubtedly the most serious hazard to human health and welfare posed by uncontrolled budworm epidemic is the loss of economic basis through extensive tree mortality. The Newfoundland Medical Association (1979) investigated the human health aspects of the present outbreak on the Island and concluded that:

"The major loss of forest which will arise if the current budworm epidemic continues unchecked will have major socio-economic consequences, including increased unemployment. This is a major threat to the health of the Newfoundland population. In the light of this the postulated health hazards from the current short-term spraying program with aminocarb in Newfoundland are deemed to be insignificant."

## SUMMARY

There is no evidence of persistent environmental damage from presently used insecticides on fish, fish food organisms, birds or mammals. The effect of sprays on the community of terrestrial arthropods, including parasites and predators of the budworm, pollinators are either minimal or temporary. Influx of populations from surrounding areas and reproduction rapidly replace any short term reduction caused by the spray.

The possibility of budworm populations developing resistance to insecticide is very remote. Seven years of spraying fenithrothion has produced no evidence of resistance.

Over 80% of the sprayed material sediments to the ground rapidly under gravity. The remainder of the spray is in very minute droplets and form clouds that may drift more than 300 m from the swath line. Gentle updrafts cause greater drift than light winds. Chemicals suspended as aerosols or vapors appear to degrade rapidly in the air without conversion into toxic substances. Drift has not caused recognizable ecological side effects.

The aerial application of chemical insecticides in current use have caused no known adverse effects from repeated short-term exposure. Spray chemicals have no mutagenic activity in humans and chronic effects, including carcinogenetic activity, are not known to occur from long-term exposure. Also Reye's syndrome has not been linked to forest spray programs. The claimed viral enhancing effects of chemical insecticide formulations have not been substantiated.

Current formulations of *B.t.* are considered environmentally safe, as are other potential natural control methods, such as viruses, fungi, sex pheromones and insect growth regulators. However, insect growth regulators must meet very strict safety standards before use is permitted.

The no-control option during epidemics normally leads to the death of the mature forest stands. The environmental impacts of considerable tree mortality is unlikely to have detrimental effects on aquatic or terrestrial fauna. The greatest impact of a no-control option is the socio-economic impact caused by increased unemployment through the loss of the forest. This impact has been identified as a major threat to the health of the Newfoundland population dependent on the forests.

# X. REVIEW OF THE STATUS OF FOREST INSECT CONTROL AND THE CFS STAND ON PEST MANAGEMENT

G.W. Green

Canadian forests are particularly susceptible to devastating insect attack because they are comprised of only a few major forest cover types which are relatively simple in species composition and occur over extremely vast areas. The fir-spruce Forest Type of eastern Canada is a good example. The eastern spruce budworm shares an evolutionary history with fir-spruce forests culminating in a complex biological forest-insect system, which left to its own devices assures natural perpetuation of both the budworm and the forest type.

In the previous chapters, it has been amply demonstrated that natural control factors, other than starvation and adverse weather at critical stages in the budworm's development, play only minor roles in the natural regulation of budworm numbers following release to the outbreak stage. Although parasites and predators exert a regulatory role at low budworm densities and thus contribute to the maintenance of endemic populations, the budworm's tremendous capacity for increase completely swamps these natural regulatory forces when stand and weather conditions favour population release. These outbreaks normally cause almost complete depletion of the food source and thus the death of the forests. It would appear, therefore, that we have two options - either we live with this insect and accept its periodic depredation of an important component of our forest resource, or we develop forest management and protection strategies and tactics that will reduce budworm-occasioned losses to acceptable levels. Given the importance of the forest resource to provincial and national socio-economic well-being only one of these options is reasonable and viable.

Over the last four decades, Canada has emerged as a world leader in the development and utilization of environmentally conscious aerial spraying technology aimed at protecting our forest resource from unacceptable damage caused by a variety of economically and aesthetically important forest insect pests (Prebble 1975).

Throughout the history of forest spraying in Canada, the CFS has played a lead role in all phases of research and development from screening of new and improved chemical and biological insecticides to assessment of the effects of budworm control methods on the environment.

To provide some perspective of this involvement, in 1980-81 the CFS committed 54 person-years of professional and technical support expertise to budworm research aimed at improved control. Approximately 17% of the effort is directed at improvements in the use of currently registered pesticides; 29% at the development of new pest control products designed primarily for foliage protection; 30% at the development of new products (largely biological control materials) for population manipulation (i.e. prevention of outbreaks), and 24% at the environmental impact and chemical accountability of products and techniques utilized in all aspects of forest protection relating to the eastern spruce budworm. The majority of this research and development (86%) is carried out by the Forest Pest Management Institute with the remainder (14%) by the Newfoundland, Maritimes, Laurentian and Great Lakes Forest Research Centres. Additional 49.5 person-years of professional and technical support expertise at these CFS Research Centres and the Petawawa National Forestry Institute are devoted to other aspects of spruce budworm research such as impact studies, product quality, fire risk and management strategies which relate directly to the management of spruce budworm susceptible forests.

The quest for solutions to the budworm problem by no means ends with the CFS. On the federal side, Agriculture Canada, Department of National Health & Welfare, the National Research Council, Department of Fisheries and Oceans, Canadian Wildlife Service, Environmental Protection Service, Atmospheric Environment Service and Inland Waters are all involved to varying degrees in research directed at the impact of pest control products and forest protection practices on non-target components. These agencies also critically review data packages supporting the registration for forestry use of new pest control products under the Pest Control Products Act administered by Agriculture Canada. On the provincial side, considerable investments are made in the operational and experimental testing of new or improved pest control products and strategies; in the environmental monitoring of pest control operations and in the conduct or funding of research aimed at providing information on various aspects of forest protection practices of specific interest to the province concerned.

With all of this on-going research and with some 40 years of experience, where do we stand in forest protection in Canada today? With respect to the spruce budworm, there is no question that we have come a long way since the days of DDT, the 'miracle pesticide' which dominated the scene immediately after World War II and persisted until late in the 1960's. Significant advances since the immediate post-Second World War period include:

- a change in the philosophy of forest spraying from one of attempting to achieve maximum budworm kill to one of protecting sufficient foliage to keep trees alive;
- a shift from massive dosages of insecticides (active ingredient/ha) in high application rates (litres/ha) to low dosages and low application rates;
- development of less persistent and more environmentally acceptable pesticides (organophosphates, carbamates and synthetic pyrethroids);
- utilization of large aircraft and electronic guidance systems;
- development and utilization of the concept of incremental spraying to achieve even coverage over large areas with minimal amounts of emitted material;
- development and utilization of effective technologies to detect and measure the occurrence, distribution and persistence of pesticides, spray adjuvants and their breakdown products in various strata of the forest environment;
- development and utilization of improved techniques for assessing and monitoring the impact of applied materials on non-target components of the forest ecosystem;
- development and utilization of *B.t.* as a biological pesticide with virtually no deleterious environmental side effects;
- and many more (Prebble 1975).

During this most recent spruce budworm outbreak in eastern Canada, a number of provincial jurisdictions have utilized these modern technologies to keep their forests alive. The green and living forests in the treated areas of New Brunswick, Quebec and Ontario, in contrast to the dead and dying forests in untreated areas of these Provinces, and in the Cape Breton Highlands and Newfoundland are testimony to the effectiveness of such treatments. Forests can and are being protected and forest management options are being kept open for the future via these approaches. Where the decision has been made not to protect, the forests are dead and dying and forest management options for these areas have been drastically reduced.

Over the past decade, the utilization at registered dosages of non-persistent organophosphate, carbamate and biological insecticides in operational spraying programs against the spruce budworm in eastern Canada have had absolutely no documented, significant, long-term detrimental effect on birds, mammals, fish, amphibians or reptiles in the forest environment or on crustacea and shellfish in coastal locations contiguous to areas which have been sprayed. There is no question that the chemical insecticides utilized during this same decade have caused some mortality of non-target terrestrial and aquatic insects and spiders and mites in the forest environment, but there is no evidence to suggest that such perturbations have led, or are likely to lead, to any long-term ecological imbalance. Although it is beyond this author's scope to comment authoritatively on the human health hazards of modern-day spruce budworm spraying operations, suffice it to say that the incidence of Reye's Syndrome is no less or no greater in or near the budworm sprayed areas of eastern Canada than it is in other parts of this country far removed from budworm or other forest insect spraying programs. Nor is there any other documented evidence which links any other significant human health problem with forest spraying.

Utilizing currently available chemical insecticides and improved technologies for their use, forests can and are being protected against catastrophic damage by the spruce budworm with few, if any, documented and significantly detrimental side effects; including human health. In spite of this, however, political over-reaction to the largely unsubstantiated claims of vociferous environmental groups, and precipitous reaction to results of preliminary laboratory experimentation that suggests that a specific chemical (the active ingredient of an insecticide, a formulation adjuvant or a breakdown product) might affect some component of the forest ecosystem or human health, continually mitigates against the conduct of effective and environmentally conscious forest protection operations. At its worst, this kind of reaction has resulted in decisions not to protect, e.g. Cape Breton Highlands and Newfoundland, with the result that very significant elements of the forest resource have been lost. At its least, it has resulted in the institution of crash research programs to generate data required to refute these unsubstantiated claims - research effort that could have been much more productively directed to the solution of real problems in forest pest management. This is not to suggest that we should not be reactive to such claims - we must be - but this reaction must be kept in perspective and in line with the seriousness of the claims if forest pest management technology in Canada is to advance in an orderly and progressive manner.

What alternatives for protection of our forests from unacceptable damage by the spruce budworm are available today and on the horizon for future use? This subject has been comprehensively reviewed (Baskerville 1976), and the treatment of alternatives is essentially as viable today as it was in 1976. Updates on most of the 15 alternatives considered by Baskerville are in Chapters VII and VIII of this report.

Of all control techniques considered, only aerial treatments of larval populations with chemical insecticides or with *B.t.* have been effective in limiting budworm-caused mortality in fir and spruce during spruce budworm outbreaks. Chemical insecticides have provided consistently better protection than *B.t.* although new oil-based formulations of *B.t.* may not have the application problems that plagued water-based formulations. If continued testing with oil-based formulations confirms this indication, the use of *B.t.* in certain operational situations will increase. One fact is certain, however, if we wish to protect our forests from damage resulting from the current outbreak of the spruce budworm in eastern Canada, we will have to rely predominantly on the wise and careful use of chemical insecticides. Indeed, with a general move towards more intensive forest management and attendant increase in the economic investment in growing stock in our forests, it seems highly likely that we will have to continue to rely to a considerable degree on these agents to protect this investment during recurring outbreaks. This situation will continue until research brings us to the stage where we can truly manage the budworm-forest system. When we reach this stage, the management solution will most likely include utilization of a number of techniques, none of which would likely be totally effective if used alone. In the interim, we will have to utilize those techniques that we have in a responsible manner adding new methodologies as they become available.

The Federal Department of the Environment, of which the CFS is an integral component, has adopted a policy on forest spraying which recognizes that forests cannot be considered in isolation from the rest of the environment and which reflects its concerns both for responsible forest management and for protection of the natural environment. This policy recognizes that responsibility for the institution of forest management practices which minimize damage caused by insects and disease rests predominantly with provincial agencies; that aerial spraying of chemical insecticides be utilized only where required and when other methods of pest control have failed; and that the Department plays a lead role in researching and testing aimed at development of improved approaches to forest pest management. These approaches include the development of biological control methods to reduce our reliance on chemical pesticides. This policy also states that "in dealing with outbreaks of pests, the Department will collaborate with the provinces by providing any of its research, advice and services that may be relevant to the particular outbreak, and within its mandate will undertake any initiatives considered necessary to ensure the protection of the natural environment" (Department of the Environment, Policy Statement on Aerial Spray Programs for Forest Pest Control, December 14, 1977).

The implementation of this policy requires close collaboration with provincial agencies responsible for forest management and with all federal and provincial agencies concerned with any and all aspects of natural resource management. It recognizes forests as an essential, basic component of our natural environment and a component that must be managed and adequately protected. Such forests can continue to contribute not only to our socio-economic well-being, but also to the continuing provision of essential habitats for birds, fish, mammals and other wildlife, erosion prevention, stabilization of stream flow, minimization of flooding and maintenance of fresh water quality and quantity.

But sound policies are useful only if they can be implemented. Unfortunately, with respect to forest protection, this has not always occurred in Canada. Political over-reaction to unfounded claims by anti-spray groups has mitigated against the implementation of sound forest protection practices. This must be corrected. Somehow we must arrive at a mutually acceptable working philosophy that embraces the management and protection of all of our renewable natural resources, not just specific components of them, and which places in proper perspective the inevitable trade-offs that will be involved as these resources are managed and protected to the optimal benefit of all Canadians.

Hopefully the deliberations of the Newfoundland Royal Commission on Forest Protection and Management will bring us closer to this goal.

## SUMMARY

Canadian forests are susceptible to severe insect damage because one cover type may occupy vast areas. The spruce budworm and the fir-spruce forest form a complex cyclic system in which budworm outbreaks rejuvenate mature fir stands periodically. Natural factors, other than a limited food supply, play only a minor role in regulating epidemic budworm populations.

Only aerial treatments with chemical pesticides or with *B.t.* have been effective in limiting tree mortality. Chemicals have provided consistently better protection than *B.t.* and current spray operations are not known to be detrimental to the environment. The aim of operational control programs is to maintain a live forest inventory rather than to control budworm numbers. There is no documented evidence that such spraying has been detrimental to human health. Alternate means of protection against budworm damage are still in the research stage and are not yet available for operational use.

Forests will be more intensively managed in the future, and will need even greater protection from economically important forest pests to assure benefits from silvicultural treatments. Therefore, the need for chemical spraying will likely increase until alternative protection methods become available. In the meantime the wise use of chemical pesticides on current forest crops allows management options to be kept open.

It is the policy of the Canadian Forestry Service to provide support to Provincial agencies and forest industries by researching in all areas of the spruce budworm and other forest pest problems; from the screening of new insecticides to monitoring the environmental effects of spray operations and to the

development of effective alternative control methods. The Canadian Forestry Service also provides advice and services; such as budworm population forecasts, damage surveys and developing silvicultural management techniques. The Canadian Forestry Service has played a lead role in developing ecologically sound principles and methods of pest management, has transferred pertinent information to outside agencies, and provided needed services to forest users and managers.

# XI. FOREST MANAGEMENT PRACTICES IN NEWFOUNDLAND

J.M. Butler, A.B. Case, J. Richardson and A.G. Raske

## 1. HISTORICAL REVIEW OF FOREST MANAGEMENT PRACTICES IN NEWFOUNDLAND

Forest management is: (1) the overall administrative, economic, legal, and social aspects of forestry, and (2) the scientific and technical aspects of forestry, especially silviculture, protection, and forest regulation (Reed and Associates 1978). The history of forest management in Newfoundland is closely linked to the development of government-industrial development policies and the establishment of various forest agencies as a result of these policies. The most important period in the history of forest management in Newfoundland is from about 1890 to the present. This time span can be divided into three distinct periods of development: (a) 1890 to 1949, (b) 1950 to 1972, (c) 1973 to the present.

### a) 1890 to 1949

At the beginning of the twentieth century the Government was concerned with developing the Island's two main land resources, forestry and mining. Three major events occurred early in this period: the construction of a railroad across the Island by R.G. Reid; the construction of a pulp and paper mill in 1909 at Grand Falls by the Anglo-Newfoundland Development Company (A.N.D.) (Griffin 1979); and the construction of a newsprint mill by Bowater Newfoundland Ltd. at Corner Brook in 1925.

The late 1890's and early 1900's was a period of feverish development activity in Newfoundland. In an effort to promote establishment of forest industries, the government made the interior forest resource available to the private sector under fairly generous terms. Many timber licences were issued to companies and private individuals. In addition, as part payment for operating the railway, the Reid interests were awarded fee simple grants to approximately 1 000 000 ha. Most of this area was later acquired by the pulp and paper industry. In 1905, the Anglo-Newfoundland Development Company acquired a 99-year renewable lease to about 518 000 ha (Newfoundland 1905) for its wood supply. The original wood supply area for the Bowater mill was about 694 000 ha comprised of freehold grants acquired from Reids and timber licences (Munro 1978). Both mills expanded plant capacity and also enlarged their timber holdings by buying timber licences originally issued to others (Munro 1978). By 1938 they controlled the forest resources on about two-thirds of the Island. The mill holdings were mostly in the interior, well removed from the coastal communities where the bulk of the population lived.

Under their agreements the two major forest-based companies were required to manage their lands so as to ensure a permanent timber supply. As was the norm for the industry in North America at the time, they were not required to practice intensive forest management. They did, however, practice extensive forest management of their holdings by implementing forest protection programs, conducting forest inventories and implementing planned harvesting operations.

Until 1920 the government did not issue timber licences within three miles of the coast (Munro 1978). The timber in this area was reserved for the use of people in local communities. Between 1920 and 1928 some timber licences were issued within the three mile limit. Inhabitants of coastal communities protested strongly against this practice. As a result, a clause prohibiting the issuing of timber licences within the three mile limit was included in the Crown Lands Act of 1930. This enabled individual Newfoundlanders to continue long established practices of indiscriminate timber cutting on unalienated Crown land (Munro 1978).

A series of Acts, passed in the early 1900's, gave joint responsibility for forest protection to the Crown and industry. As a result, the first fire-suppression organization in Newfoundland was formed. A forest fire detection agency was formed in 1910 jointly funded by government and industry (Griffin 1979). In 1944 this agency became known as the Newfoundland Forest Protection Association (Newfoundland Forest Protection Association in 1960). For the first half of the twentieth century, logging, compilation of inventories, and fire suppression and detection, were the main forest management activities practised by government and industry. Management of the forests to minimize damage from either diseases or insects was not practised but the potential destruction by insects and diseases was recognized and the companies cooperated in the detection of forest pests through the Newfoundland Forest Protection Association. Forest pest control activities included biological control through the release of introduced parasites and disease (Carroll 1948).

In 1933, a Royal Commission on the future of Newfoundland recognized the economic importance of forestry (Amulree *et al.* 1933). As a result, a permanent provincial Forestry Division was established as part of the Department of Natural Resources in 1934 (Griffin 1979). The main duties of the division were to inventory unalienated Crown land, inspect logging and sawmill operations, train loggers, collect forest revenues, and prevent or control forest fires. However, it did not have any real control of company logging operations and there was only very limited supervision of cutting on unalienated Crown land.

Despite many difficulties the Department of Natural Resources did make a major contribution. Surveys of timber resources on unalienated Crown lands were initiated and the first forest tree nursery in Newfoundland was opened at Back River, Salmonier in 1938. Between 1938 and 1951, 800 ha on the Avalon, Burin, and Bonavista peninsulas were planted with three million conifer seedlings. The program was discontinued in 1951 because of plantation failures, but it provided a basis for future reforestation programs.

b) <u>1950 to 1972</u>

After Confederation in 1949, the emphasis on forestry development increased and there was a noticeable improvement in interest in the management of the forest resource.

In 1950, a district office of the Dominion Forest Service was opened in St. John's and in 1952 a forest biology laboratory of the Canada Department of Agriculture was opened in Corner Brook. The two laboratories established intensive research programs in forest protection and silviculture, the results of which are available for improving and developing forest management technology in the fields of insect and disease control, reforestation and forest improvement. In 1966 these two offices amalgamated to become the Newfoundland Forest Research Centre (Page *et al.* 1974).

In the 1950's the Provincial Government attempted to regulate cutting on unalienated Crown lands (Griffin 1979). Amendments to the Crown Lands Act in 1951 and 1954 required permits for cutting timber on unalienated Crown Land. More importantly, provision was made for establishment of restricted cutting zones or Forest Management Areas. Commercial and domestic cutting permits were required for these areas. Unfortunately, the number of Forest Management Areas was limited, enforcement of regulations was weak, and unregulated domestic cutting continued to be a serious impediment to good forest management.

In 1955 the report of the first Newfoundland Royal Commission on Forestry was completed (Kennedy *et al.* 1955). Its recommendations were comprehensive and laid the foundation for the further development of extensive forest management in the Province. The commission's recommendations included strengthening forest protection systems, initiation of a comprehensive forest inventory and improved administration and control over cutting on unalienated Crown lands.

During the period 1950 to 1972 numerous small scale operational silviculture trials were started by the Provincial Government and industry. The Newfoundland Forest Service opened a small pilot nursery at Mount Pearl in the mid 1960's.

Forest protection received much attention during this period. Major improvements were made to the forest fire suppression and detection program following disastrous forest fires in 1961. During the 1950's and 1960's, productive forests sustained widespread insect damage. Two insect species threatened the wood supply; the balsam woolly aphid and the hemlock looper. The balsam woolly aphid attacked the fir forests of the Island (Schooley and Bryant 1978), reducing annual growth of these forests by 7% (Anon. 1972). Hemlock looper populations built up to a major outbreak in the late 1960's and in 1968 and 1969 the Provincial Government and industry sprayed against the looper (Otvos *et al.* 1971). These outbreaks made foresters aware that forest insects could cause major losses in provincial forests.

In 1970 the second Newfoundland Royal Commission on Forestry made major recommendations which included the improvement of present forest management practices and the continued protection of the forests against fire, insects, and diseases (Rousseau *et al.* 1970).

### c) 1973 to Present

Substantial advances were made in provincial forest policy since 1973. In 1973 a Federal-Provincial Task Force on Forestry examined all aspects of the forestry sector (Sheppard & Carroll 1973). As a consequence of the recommendations of this

Task Force, three milestone events occurred in 1974. First, a statement of policy on the proper management and utilization of Newfoundland forests was read to the House of Assembly. Second, a Forestry Subsidiary Agreement was negotiated between the Provincial and Federal Governments. Many of the recommendations of the Task Force were to be implemented under this agreement. Third, the Forest Land (Management and Taxation) Act of 1974 was passed by the Provincial Government.

To facilitate the management of the Province's forest resources, 19 sustained-yield forest management units were established encompassing all forested land (see Fig. V-12). Legislation requires that all major land owners within each unit submit a forest management plan to the Province. The Provincial Government reviews these plans to determine if the land owners are managing their forests in the best interests of the Province. The Forest Land (Management and Taxation) Act provides for penalties, in the form of higher taxation, to be levied on those land owners deemed to be mismanaging their forests.

The Forestry Subsidiary Agreement (anon. 1974b) strengthened the Provincial Forest Service to administer forest policy. The Agreement also provided funding for a much improved forest management program. This included major expenditures for forest access roads, Crown acquisition of timber rights to some Reid Lots, reforestation and forest improvement. The reforestation expenditures included the development of a major Provincial forest tree nursery at Wooddale capable of producing 20 000 000 trees annually.

In 1976, the Provincial Government appointed a Forest Improvement Steering Committee. This joint Federal-Provincial-Industrial committee was established to define the role of forest improvement in Newfoundland and its direction for the next few years. As a result the Province and Industry have cooperated in a number of very successful forest improvement programs which include pre-commercial thinning, site preparation and tree planting.

In 1978, the Provincial Forest Service completed a Five-Year Forestry Development Plan which proposed major increases in expenditures for silviculture, forest protection and wood utilization. The Province has also now developed a long term forest management strategy.

In 1979 a task force on spruce budworm research within the CFS made several recommendations regarding the direction of future budworm research (Anon. 1979d). Its recommendations were adopted and incorporated into a Canada-United States spruce budworm cooperative research program called CANUSA. A major emphasis of CANUSA research is the development of meaningful guidelines for foresters who must cope with spruce budworm problems.

The 1970's was a decade of many major advances in the development of forest management, policy, legislation, technology and practices.

## 2. ASSESSMENT OF PRESENT FOREST MANAGEMENT PRACTICES

The techniques of forest management presently employed in Newfoundland are the means whereby forest policy, whether stated or implied, is put into practice. These techniques are generally designed to maintain or improve forest productivity, though this may not be the primary reason any technique is used. They may also have some effect on major forest pests. This section will discuss briefly the most important forest management practices currently in use and assess their effects, if any, on sustained forest productivity and major forest pests. The use of forest management specifically as a possible control measure for spruce budworm outbreaks is considered in Chapter VIII.

Forest management in Newfoundland is practised principally by the Provincial Government, Department of Forest Resources and Lands, and by the two major pulp and paper companies: Bowater Newfoundland Limited and Price (Nfld.) Pulp and Paper Limited. Management includes three areas: yield regulation and harvesting, silviculture, and forest protection. Forest protection is discussed in Chapter VIII of this report; the remaining two areas will be considered here.

### a) YIELD REGULATION AND HARVESTING

The Province is currently divided into 19 forest management units. Planning at the unit level requirs detailed inventories to estimate Annual Allowable Cut (AAC). Determination of meaningful net AAC figures has been made difficult by inadequate data on how much timber on the provincial inventory is on steep slopes (> 30% gradient) and how much is on inaccessible areas. The problem is compounded by budworm losses and by forest land withdrawals for non-forestry uses such as municipal expansion, park development, and hydro-electric development. As yet, the exact magnitude of such withdrawals is not known, and there is no statistical measure of their impact.

Additional withdrawals of productive forest land result annually from logging operations. Bulldozing for access road and landing construction causes deep mineral soil exposure on 9.6% of the area harvested. This removes 1 500 to 2 000 ha of forest land from production annually (Case 1979, Case and Donnelly 1979) (Figure XI-1). The potential loss in AAC from this source averaged 0.15 $m^3$/ha/yr on affected areas. Compaction caused by wood piles and by heavy vehicle traffic affects an additional 26.1% of the area logged, or about 4 000 ha/yr. Softwood growth on such areas tends to remain sparse and suppressed for much of the rotation period. Thus, in terms of productivity, additional potential reductions in AAC of up to 0.36 $m^3$/ha/yr may occur on logged areas. These losses have only recently been considered in forest management planning. If ignored they will lead to over-estimates in the calculations of AAC.

To some extent technological changes in logging methodology over the past 15 to 20 years have aggravated the problem by decreasing the amount of economically accessible wood. For example, stands of small-diameter trees with volumes of less than 80 to 90 $m^3$/ha have not been economical to log with conventional equipment. However data used for AAC calculations are based on stands containing 45 $m^3$/ha or more.

In the overall analysis the profile of available mature forest was obviously much less attractive than the AAC calculations available before 1980 had indicated. Consequently, anticipated timber deficits would have been greater than projected. However, adjustments in forest management strategy are being implemented.

Some short-term solutions have already been developed. Harvesting on steep slopes has become technologically and economically possible with the recent introduction of cable yarding by both pulp and paper companies. By this method it is possible to increase net AAC by as much as 12%. Salvage cutting to liquidate over-mature, insect-damaged and killed timber has accelerated in the past few years. Salvage logging may be economical in areas near wood conversion sites, but extending such practices to more distant stands is questionable because of higher cost of road construction and transportation.

Recent efforts by the two pulp and paper companies to rehabilitate abandoned bulldozed sites is a responsible approach to sound forest management. Such practices effectively ensure that average future withdrawals of productive sites will be reduced by up to 10%.

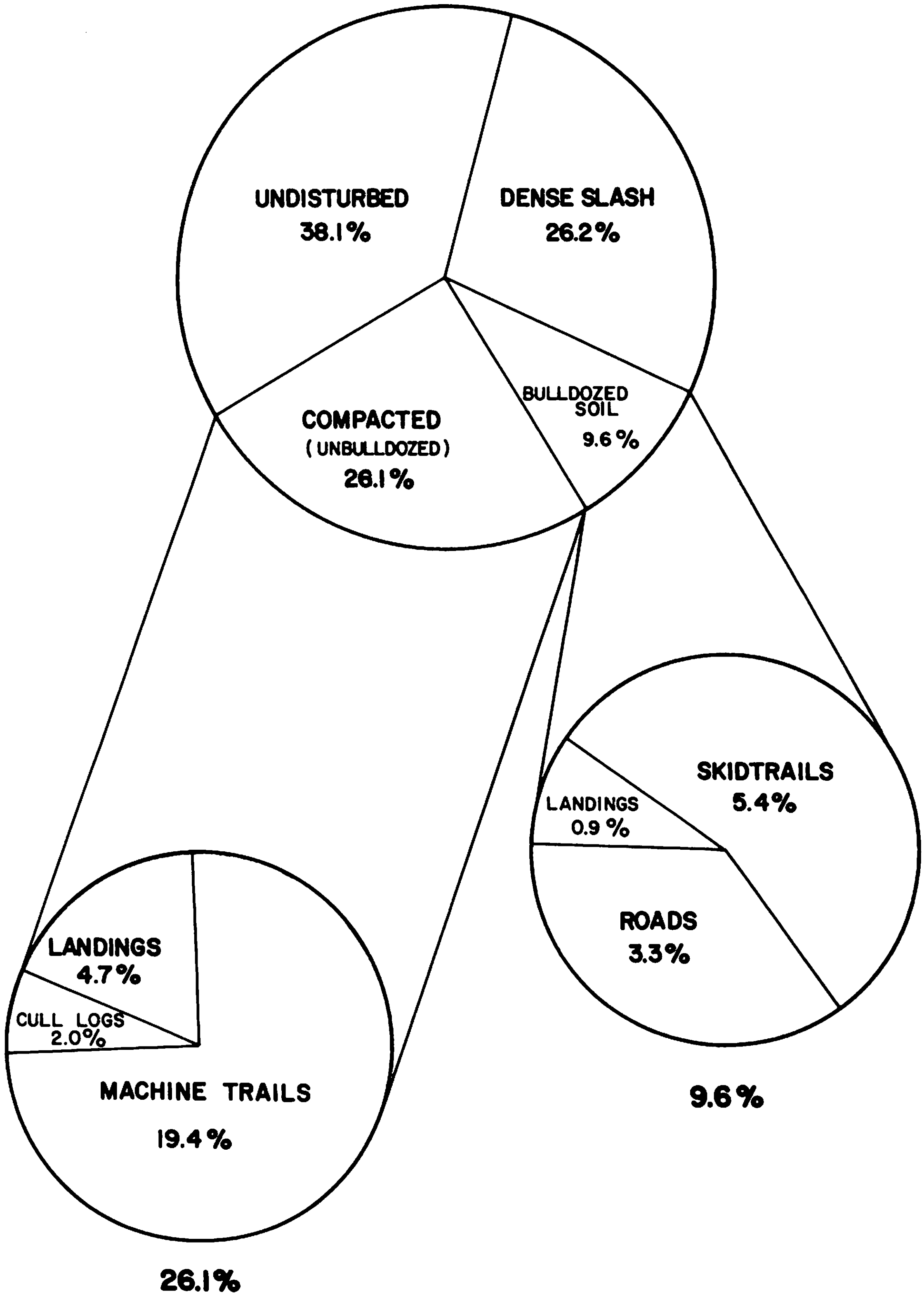


Figure XI-1. Ground disturbance on skidder-logged clearcuts (from Case 1979).

Conceivably, future trends in logging and processing equipment development may make harvesting in low-volume and currently inaccessible stands economically feasible, as well as the utilization of small-diameter stems. This will increase yield and therefore the AAC. However, the timing and extent of technological advances that would make such increases possible are uncertain and are usually not considered in short-term management plans.

The practice of clearcutting has traditionally been the most economical method of timber harvesting in Newfoundland and Labrador. This practice has influenced the character of most of the forest by shifting species composition toward, and perpetuating the development of large areas of, balsam fir. Thus, the susceptibility of the forest to insects such as the spruce budworm has increased gradually during the Province's logging history.

To bring about a planned reduction in a forest's vulnerability and susceptibility to insect pests requires comprehensive regulation of location, timing, and extent of harvesting activities over a long time period. Moreover, full utilization through clearcutting is currently necessary. Selection harvesting techniques are costly because only a portion of the wood is harvested at any one time. Selection harvesting preserves large areas of mature forest which are ideal for budworm survival and population build-up (Baskerville 1975a). The difficulty is, as Baskerville states, "That selection forests maintain indefinitely a deep-crowned mature and near-mature canopy with abundant sun foliage and flowering" - the kind of forest defined by van Raalte (1972) as being most susceptible to outbreak and most vulnerable to damage.

## b) SILVICULTURE

### i) Pre-commercial Thinning

Approximately 55% of the forested land in Newfoundland is overstocked with softwoods (Sheppard and Carroll 1973). Overstocking causes a slowdown in tree growth resulting in longer rotation periods. In extreme cases, trees never reach merchantable size.

In 1975, the Provincial Forest Service began an extensive pre-commercial thinning program in young overstocked fir and spruce stands. The objectives of the program are to increase merchantable fibre yields and to shorten stand rotation. From 1975 to 1979 the Province and industry thinned 6 182 ha of pre-commercial fir and spruce. By 1985, the Province estimates that 20 000 ha will have been thinned. Pre-commercial thinning is expected to increase forest productivity by 42 $m^3$/ha. Future improved yields of up to 840 000 $m^3$ (total for 10 year period) could result from this program by 1985. Although pre-commercial thinning may be good management practice, it may have one major drawback. Thinned stands may be more susceptible to insect damage than unthinned stands (Roberts and Chow 1977). Therefore, if the benefits of these thinning operations are to be gained and the money spent on them not wasted, the thinned stands must be protected.

### ii) Forest Fertilization

Approximately 59% of Newfoundland forest soils are deficient in plant nutrients (Sheppard and Carroll 1973). Deficiencies usually result in retarded plant growth.

Over the past 15 years the CFS, the Province and industry have fertilized a variety of stands. The most promising results have occurred in pre-commercially thinned fir and spruce stands. Although results are preliminary, further reductions in rotation ages and increases in fibre production are expected. Limited operational trials in thinned stands will continue in the next five years.

As with pre-commercial thinning, protection of fertilized areas from insect attack is necessary if the benefits of fertilization are not to be lost.

### iii) Reforestation

The process of reforestation involves the establishment of new forests on sites from which previous forest stands have been removed, most often by cutting or fire. It includes a variety of activities such as site preparation, direct seeding, seedling production, planting, and tree improvement.

Site Preparation - Cutover and burned areas cannot normally be planted or seeded successfully without some form of ground treatment. The soil surface may be covered with a thick inhospitable organic layer in which most tree seedlings cannot survive. Logging slash may cover the site, making access difficult for planters. With the passage of time the site often becomes progressively more densely occupied by unproductive herb, shrub or tree species. All of these conditions warrant the use of site preparation for planting. Indeed, it is widely considered that even where it is not indicated biologically, site preparation is advantageous for planting because it assists the planters in finding suitable planting spots and maintaining regular spacing (Brown 1976, O'Donnell 1976).

Scarification is an integral part of the reforestation process. Over 1 700 ha were scarified in Newfoundland from 1975 to 1979. It is an essential preparation for planting or seeding on many sites, and is therefore a requisite for sustained forest productivity after disturbance on those sites. Since it does not directly affect trees, it has no influence on major forest pests.

Herbicides are applied in forestry for two purposes: to destroy all unwanted vegetation on a site prior to reforestation, and to eliminate competing vegetation in young established stands of natural regeneration or of planted seedlings. To date, herbicides have only been used in Newfoundland for the second purpose. Sites prepared with herbicide for seeding or planting may also need to be scarified because herbicides can not reduce slash and humus accumulations. On most Newfoundland sites, scarification alone will provide sufficient control of competing vegetation. Thus, it may be necessary to use herbicides only in unusual cases.

The use of herbicides to eliminate competing hardwood vegetation, while leaving softwood species virtually unharmed, is likely to have increased application in Newfoundland. From 1975 to 1978 about 50 ha have been treated experimentally, and released softwood stands seem to respond with improved growth rates (Richardson unpublished). Although no direct evidence has yet been obtained, it seems unlikely that the susceptibility of released softwoods to spruce budworm attack would be changed once the 'protective' cover of hardwoods has been eliminated.

Prescribed burning is an effective means of site preparation. Used appropriately, it will remove slash and unwanted vegetation from a prospective reforestation site, and under favourable circumstances reduce the depth of organic layer. However, this latter result, requires burning under high fire-hazard conditions when the humus layer is dry (Richardson 1976, Artley *et al.* 1978). The fear of the fire escaping has prevented burning under these conditions in Newfoundland. Thus, for adequate site preparation, scarification is still needed after burning and prior to planting. However, on a well burned site, scarification is easier and faster than without burning. Several areas have been experimentally burned in Newfoundland since 1962 (Howard 1963, 1966; Richardson 1972) and 25 ha were burned in the spring of 1980. Burning is the surest method of destroying balsam fir regeneration on cutover areas, and could pave the way for stand conversion to more insect-resistant tree species (Hall and Richardson 1973). Prescribed burning is unlikely to have any direct effect on pest populations, such as the spruce budworm.

Fire is an integral part of the boreal forest ecology, and there is no valid reason why prescribed burning should not be used more extensively in Newfoundland. The fear of fire escape has been the main limiting factor in the past. However, burning is regularly employed for site preparation with minimal adverse effects in other parts of Canada and in the United States (Chrosciewicz 1978, Dimock *et al.* 1976, McNab 1976, Norum 1977). There, fire hazards are much greater than in western Newfoundland, where prescribed burning would have most application. Environmental problems associated with prescribed burning are temporary air pollution and the possible loss of soil nutrients, but these disadvantages are far outweighed by the potential benefits in site preparation.

Direct Seeding - The establishment of new stands by sowing directly on the site to be reforested can be an efficient and effective reforestation technique in Newfoundland (Richardson 1974). It is quick, flexible, and cheaper than planting seedlings. On the other hand, results with seeding are less reliable than with planting. Scarification is normally a pre-requisite for seeding as it is for planting, but some freshly-burned sites can be seeded with satisfactory results without site preparation (Richardson 1970). Tree seed for reforestation is a valuable commodity, and has become even more so in recent years with increasing costs of seed collection and the destruction of seed crops of black spruce caused by the spruce budworm outbreak (Schooley 1980). This has led most forest managers to reserve seed for the production of planting stock which is considered to be a more efficient use of seed. Whether it is or not, is debatable (Vyse 1974). Since direct seeding is much cheaper than seedling production and planting, it may be more economical to spend money on increasing the seed supply rather than to use the limited seed supply for planting.

Only negligible areas have been seeded in Newfoundland. Interest in the technique revived, and the Province seeded 50 ha in 1980. Seeding may present the opportunity to establish more insect-resistant black spruce rather than balsam fir.

Planting - The most commonly accepted method of reforestation involves planting of nursery- or greenhouse-raised stock. The traditional bare-root nursery stock is grown one or two years in seedbeds followed by one or two years in transplant lines. More recently, three-year-old seedlings have been raised for planting out without prior transplanting. The development of the container planting concept has led to the greenhouse production of large quantities of seedlings in small containers. The seedlings receive intensive care and are normally planted out after four to six months at which stage they are smaller than traditional bareroot stock. Container seedlings are planted either with the container intact, or as 'plug seedlings'; the container removed but the 'plug' of roots and soil undisturbed.

The Province is almost the sole producer of planting stock in Newfoundland through its Wooddale Nursery. Most of the seedlings are also planted by the Province, but Price (Nfld.) Pulp and Paper Ltd. have also planted an appreciable number of seedlings in recent years. A total of 600 ha were planted between 1975 and 1979. Planting, like seeding, obviously helps to sustain forest productivity, but at the present scale of reforestation, only 4 000 ha can be reforested annually or only 10% of the area harvested on the Island. This level of effort may be insufficient to reforest logged areas which are not regenerating, and will not reduce the backlog of non-regenerated areas accumulated from earlier years.

Tree improvement - Programs attempting to select, propagate and breed superior tree species and provenances and superior individual trees are closely associated with reforestation. The results of tree improvement are introduced to forest management practice by means of reforestation. Major emphasis has been placed on improvement of the native black spruce (Khalil 1972). Attention has also been given to white spruce, exotic spruces, such as red spruce and sitka spruce; fast-growing hybrid poplar clones; and native larch and several exotic larches. A cooperative Tree Improvement Working Group has been recently established (Hall 1979).

Tree breeding is of necessity a slow process because of the reproductive habits of trees, but faster procedures such as grafting and vegetative reproduction techniques have been developed. Significant gains can be achieved by tree breeding even within the span of one rotation, but it is basically a long-term method of improving forest productivity (Carlisle and Teich 1971). The possibility exists of selecting and breeding trees resistant to attack by major insect pests but several factors, such as the time-scale required to make a significant impact, make this approach unrealistic.

## SUMMARY

Over the past 80 years, forest management in Newfoundland has developed gradually from early policies of resource allocation to encourage industrial development, to extensive forest management, techniques in the 1970's, and now to the initiation of some intensive forest management practices.

Withdrawals of productive land from forestry use and site damage caused by logging operations represent significant losses in growth capacity. Practices which rehabilitate sites lost from production, such as reforesting bulldozed landings, and those which improve utilization, such as cable yarding, should be encouraged.

Clearcutting is the traditional and most economic method of harvesting in Newfoundland. This practice will likely continue, although it tends to increase the proportion of budworm-susceptible fir forest over the years. Alternative harvesting techniques are more costly and would not make forests less susceptible to the spruce budworm.

Stand improvements such as pre-commercial thinning and forest fertilization increase forest productivity and improve yields but treated stands may be more susceptible to insect pests than untreated stands.

Herbicide treatment eliminates competing vegetation in young softwood stands giving improved growth, but the released trees are probably more susceptible to insect attack. Prescribed burning is an efficient site preparation tool which can eliminate fir regeneration permitting stand conversion to species less susceptible to pests. Scarification is an essential preparation for planting or seeding on many sites. Direct seeding is an efficient and effective reforestation practice in Newfoundland.

Planting bareroot or container-grown seedlings is the traditional method of reforestation. Despite recent increases in areas reforested, it is questionable if the present scale of reforestation in Newfoundland is adequate.

It is theoretically possible to breed trees resistant to attack by certain insect pests, but the time-scale required to achieve practical results makes this method unrealistic.

# XII. FOREST POLICY AND IMPLEMENTATION

F.C. Pollett, J.A. Munro and J. Hudak

## 1. FEDERAL FOREST POLICY

### a) NATIONAL IMPORTANCE OF FORESTRY

The Canadian forest-based industries are of vital importance to the national economy. The forestry sector directly and indirectly provides for one out of every ten jobs, and accounts for 13% of manufacturing employment. Forest products exports amount to $9 000 000 000 annually and account for 18% of all Canadian exports. This is a larger net contribution to the balance of payments than that of agriculture, mining, fisheries and fuels combined. About 300 communities are solely dependent upon forest based industries (Fraser 1979).

There is still potential for growth in the forestry sector. Based on projections by the Canadian Council of Resources and Environment Ministers (CCREM) there will be a 60% increase in lumber exports by the year 2000, an 80% increase in paper exports and a 125% increase in pulp exports. Forest biomass is also expected to contribute about 10% of the nation's primary energy supply by the year 2000, and possibly increasing proportions thereafter (Anon. 1979f). However, the forest must be intensively managed to fulfill these projections.

The environmental and social benefits of the forest are also important. Forests provide a scenic backdrop for a $3 000 000 000-a-year outdoor recreation industry. Forests enrich the lives of the majority of Canadians and provide crucial support for native people. They moderate climate, clean air, improve water quality, check erosion, regulate stream flow and provide habitat for game and fish.

## b) NATIONAL FORESTRY PROBLEMS

It is increasingly being recognized that the benefits outlined above can only be sustained if the forests are well managed and the forest industry remains competitive.

There are some serious problems. For example, about 12% of the productive forest land in Canada is inadequately stocked to commercial tree species and this area is increasing annually at the rate of 200 000 ha. Local shortages of timber are causing supply problems in some areas. Harvestable log size is decreasing. Inadequate investment has eroded the efficiency and competitiveness of some Canadian processing plants, and costs of harvesting, processing and delivering forest products have risen more rapidly in parts of Canada than in other competing areas.

## c) FEDERAL ROLE IN FORESTRY

Under the British North American Act the provinces were given primary jurisdiction over management of provincial forest lands. However, federal policies and programs in such areas as taxation, regional development, industrial efficiency, research, and trade and commerce also affect the use and management of the resource. The federal role in forestry has been described as follows:

"The federal role in the forestry sector is to encourage development and use of the resource for all purposes on a sound environmental basis by: (1) providing coordinated federal policies to promote forest industry development and better resource management; (2) providing scientific and technical leadership through research and development; (3) providing and analyzing national and international information and statistics as a basis for policy; aiding in developing and certifying codes and standards for product performance; (5) protecting Canada's forests from foreign pests; (6) fostering and negotiating better access of Canadian forest products to foreign markets, and (7) fostering the potential use of the forest resource for energy." (Frazer 1979).

The overall level of federal interest and commitment in the forestry sector has fluctuated over the years. During the early 1960's, forestry enjoyed a relatively high profile within the federal system while there was a Department of Forestry.

During the late 1960's and the 1970's, federal interest and concern with forestry seemed to wane. During this period the CFS lost importance as a federal agency. Staff was reduced by about 50% and the organization was downgraded to the level of a directorate within the Environmental Management Service of the Department of the Environment.

Because of a growing awareness of the economic importance of forestry and pressure from the provinces, industry and the public, the federal government has recently reviewed its involvement in the forestry sector and has demonstrated its concern over national forestry problems by:

- introducing of a shared cost program for the modernization of the forest products industry
- increasing federal inputs to forest management through Subsidiary Agreements with the provinces
- raising the status of the Canadian Forestry Service to a separate service headed by an Assistant Deputy Minister (ADM)
- establishing a Federal Forestry Sector Strategy Committee chaired by the ADM of CFS to coordinate and assess federal initiatives and actions relating to the forestry sector
- preparing a public statement on federal forestry policy

## d) FEDERAL ROLE IN NEWFOUNDLAND

The two federal agencies involved most directly with forestry in Newfoundland are the CFS of the Department of the Environment and the Department of Regional Economic Expansion (DREE). The CFS undertakes forest research and certain advisory services while DREE provides funding for forest industry development and for shared-cost forestry programs with the Province.

As part of the terms of union under which Newfoundland joined Confederation in 1949, the federal government established a small forestry research office in St. John's. This facility has grown and is now called the Newfoundland Forest Research Centre (NFRC), a part of the CFS. Current person year allocation for the Centre is 65, of which 24 are professional researchers, 29 are technicians and 12 are administrative support staff.

The forest research program of the research centre can be divided into: 1. Forest Resources and Environmental studies and 2. Forest Protection studies. Research on forest resources and the environment includes studies on forest regeneration, forest productivity, tree improvement, forest ecology and environmental impact of forestry practices and industrial pollutants. The forest protection program includes research on the biology and control measures for major insect and disease pests. The protection program also includes the Forest Insect and Disease Survey (FIDS) which annually monitors population levels of important forest pests; assesses damage in terms of defoliation, volume loss and tree mortality; and forecasts conditions for the coming year. This information is made available to the Province, major timber limit holders and the public. The FIDS data enables the Province and the major companies to assess insect and disease conditions and to prepare protection plans.

DREE funds are made available as direct grants to entrepreneurs establishing or expanding forest based industries and through shared cost forestry subsidiary agreements with the Province. DREE's main objective in providing funds is the expansion of forest based industrial activity which will increase employment opportunities. Grants to industry accomplish this directly. Forestry subsidiary agreements with the Province are more long term and are aimed at helping the Province maintain and expand wood supplies for existing and potential industries.

Other federal agencies involved to a lesser extent with forestry in Newfoundland include the Department of Industry, Trade and Commerce which administers various industrial assistance programs, Parks Canada which adminsters the Terra Nova and Gros Morne National Parks, and the Department of Energy, Mines and Resources which funds the "Energy from the Forest" (ENFOR) program. The objective of ENFOR is to assess the potential contribution of forest biomass to energy production. The program is administered for the Department of Energy, Mines and Resources by the CFS.

## 2. PROVINCIAL FORESTRY POLICY

### a) FEDERAL-PROVINCIAL TASK FORCE

During the early 1970's, increased emphasis was being placed on further development of natural resources to expand employment and incomes in rural Newfoundland. Generally, existing government administrative systems and relationships with industrial forest users were thought to be out of date. New initiatives were required in a number of areas if the full potential of the forest resource was to be realized. In 1972 a special federal-provincial task force reviewed in-depth the forest policy, forest management and forest resource development potential. The task force submitted its report in 1973 (Sheppard and Carroll 1973). This important report contained 22 major recommendations to government for an improved system of forest administration and management which would allow the province to capitalize on resource development opportunities in the future.

### b) IMPLEMENATION OF NEW POLICY

The recommendations of the task force were generally accepted by the Province and formed the basis for major new policy initiatives in the 1970's (Maynard 1974). In a move to establish government management control over interior timber limits held by the two large pulp and paper companies (Price (Nfld.) Pulp and Paper Limited at Grand Falls and Bowater Newfoundland Limited at Corner Brook) the Province passed the Forest Land (Management and Taxation) Act (Newfoundland 1974). This act required limit holders to submit management plans of their holdings for government approval for the first time. Lands deemed to be properly managed would be taxed at a low rate while those declared unmanaged were to be taxed at a higher, punitive rate. The objective was to increase the level of management on lands really required by limit holders while encouraging them to relinquish to government areas surplus to their needs. These surplus areas could then be made available for development by other resource users.

The report of the task force and the new provincial commitment to improve resource management formed the basis for a federal-provincial agreement for joint government funding of a major forestry development program. The 1974 DREE Forestry Subsidiary Agreement for Newfoundland provided for the expenditure of approximately $54 000 000 over a five year period (Anon. 1974b). Briefly, the agreement provided funding on a 90:10 (90% federal - 10% provincial) cost shared basis for the following main program areas:

- strengthening the administrative capabilities of the provincial forestry department
- improved inventory and forest management systems
- improved forest fire protection
- access road construction, harvesting and utilization
- initiation of a forest improvement program.

The DREE agreement enabled the Province for the first time to assume management control over all forest lands. This control included responsibility for forest protection on company limit areas as well as unalienated Crown lands. The new legislation provided for the collection of a protection tax from limit holders to offset the increased forest protection cost to the Province.

### c) EMERGENCE OF PROTECTION PROBLEMS

Historically, the main forest protection problems in Newfoundland related to forest fires. In the 1950's the forests were severely damaged by the accidentally introduced balsam woolly aphid and in the 1960's there was a large outbreak of the native hemlock looper. Damage was limited by aerial spraying operations. However, this outbreak was considered an unusual occurrence and in the early 1970's, forest protection was still mainly identified as fire protection.

A major protection problem in the form of the spruce budworm outbreak developed in the early 1970's. This was a relatively new phenomenon. While provincial policies and programs were firmly in place to deal with fire protection problems, there was no clearly established policy with respect to protection against insects. Although widespread public and political support existed for fire protection programs, there was no such support for aerial spraying of insecticides; the only effective measure available to save trees from the spruce budworm. Decisions to spray or not to spray were made annually by Cabinet after status reports on the outbreak were received from government forestry advisors and from special committees (Rendell 1977, 1978, 1979). There was widespread public concern about possible harmful side effects of chemical spraying and the decision on spraying became a difficult, emotionally charged, political issue. Consequently, as the budworm outbreak spread across the Island from 1971 to 1980, an operational spray program was undertaken in only one year, 1978.

During this period the damage caused by the budworm was far more extensive than the damage caused by forest fires. For example, during 1974 to 1979 the merchantable forest area damaged by forest fires in the Province was 43 646 ha. This area could be expected to contain approximately 3 000 000 $m^3$ of merchantable timber. On the other hand, by 1979, the area of dead, dying and very severely damaged budworm stands was approximately 518 000 ha containing a total volume of 38 400 000 $m^3$ (Moody 1980).

### d) CONSEQUENCES OF LACK OF PROTECTION POLICY

The lack of an effective protection program against forest insects in the 1970's has had serious implications for the new forest policies and programs initiated as a result of the 1973 task force report. Effective forest protection is basic to all other progress in forest management, especially to forest improvement programs. Without protection, potential gains in future wood supply through forest improvement will be voided by losses to forest insects and diseases. In addition to large losses of mature timber, some forest stands that have been silviculturally improved at considerable expense have been destroyed by the spruce budworm. These investments of public money have been lost. Other improved areas will also be destroyed over the next few years unless protection is provided.

In short, the progress made during the early 1970's in implementing new forest policies and programs have been more than offset by the losses to the uncontrolled budworm outbreak. Instead of providing additional wood supplies to support expansion of the forest industry, it is now likely that after salvage operations are over, future wood supplies will be curtailed resulting in reduced real output, employment and incomes in the forestry sector.

### e) PROTECTION POLICY ISSUE

To be effective, forest land management must be established on firm scientific principles. It must be consistent and long term. For Newfoundland, consistent long term fire protection policy has been established, but insect and disease protection policies and programs have been lacking. The absence of such long term policy can have disastrous negative impact on well intentioned government efforts to promote better management and increase forest based industrial development. Before further progress can be made in other policy areas, a protection policy must be clarified so that appropriate long term programs can be developed by resource managers. The development of a protection policy is, of course, a political decision that can only be made by the Province.

If protection against insects and disease can be provided, then planning for long term forest improvement can be re-established. If the decision is not to protect against insect and disease outbreaks, it is difficult to see how significant progress in forest management will be possible. The best management strategy in this situation would be to minimize expenditures on forest improvement programs and encourage salvage harvesting of budworm killed and damaged stands to sustain established industry until present wood supplies become exhausted.

## 3. FEDERAL-PROVINCIAL COORDINATION AND COOPERATION

Forestry is a vital part of the Canadian socio-economic fabric and numerous departments and agencies of both the provincial and federal governments have direct and indirect influence on the forestry sector. The number of the federal agencies exceeds a dozen and on the provincial scene it varies in each province. It is not only logical but imperative that the action of these agencies be coordinated within the two levels of government and also between them.

Important recent developments on the national and inter-provincial scene concerning the forestry sector include the Forestry Ministers and First Ministers meeting in 1978, the Canadian Council of Resource and Environment Ministers meeting in June 1979 and January 1980. The Ministers agreed that a national forest policy is needed. They accepted in principle the paper entitled "Forestry Imperatives for Canada" which summarized the national forestry goals and outlined the strategy to achieve them (Anon. 1979f). In addition an inter-governmental study was initiated to define the funding mechanisms for intensive forest management.

At the provincial level CFS and DREE are the two prominent federal agencies concerned with forestry. The CFS has been an advisor and member of the Steering Committee of the Forestry Subsidiary agreement between the Province and DREE. However, the major role of CFS in the Province is research and development conducted by the Newfoundland Forest Research Centre. Continuous and productive consultation and cooperation has existed between the Research Centre and the provincial and industrial forest agencies. This consultation is in part achieved by a Forest Research Advisory Committee. This committee includes the ADM of the provincial Department of Forest Resources and Lands and representatives of forest industry, labour, Agriculture Canada, Memorial University and the Environment Branch of the provincial Department of Consumer Affairs and Environment. The Committee advises the Research Centre in identifying problems requiring research and reviews research progress.

The Forest Improvement Steering Committee of Newfoundland was established in 1975 and is composed of representatives of the Province, industry and the CFS. The Committee's original function was to steer developments in the emerging forest improvement program in the Province. However, because of natural linkages among the components of forestry, the Committee had dealt with all major, topical issues of forestry in Newfoundland. The Committee functioned very well initially but meetings are now in abeyance pending expansion of the terms of reference. This is important and steps should be taken to revitalize the Committee to include all aspects of forestry in Newfoundland for the overall coordination of activities by all agencies. Such coordination and co-operation is considered vital for the success of forestry in Newfoundland. Ontario has entered into a formal, federal-provincial, forestry research agreement administered by a joint committee with a coordinating role. The establishment of such an agreement in Newfoundland appears desirable unless the equivalent function can be absorbed by the revitalized Forest Improvement Steering Committee.

# 4. INTENSIVE FOREST MANAGEMENT PLAN FOR NEWFOUNDLAND

## a) INTENSITY OF FOREST MANAGEMENT

Most developing forested regions pass through three main stages in the evolution of administrative control over the resource: exploitation, extensive management and intensive management.

During exploitation the resource is made available to the private sector for development. There is no regulation of harvesting, no protection and certainly no intensive forest management. During the second stage of extensive management, there is some recognition of the long term, renewable nature of the resource. Long term planning and regulation of harvesting is initiated and management planning is introduced. Also basic protection is provided. Allowable cuts are established but wood requirements can be met with the existing inventory of overmature forests and by natural growth of forest stands. The third stage, intensive forest management, is reached as industrial wood requirements are forecast to exceed available long term supplies and silvicultural expenditures are warranted on the better forest areas to improve quantity and quality of forest yields.

Until the early 1900's Newfoundland was essentially in the exploitation stage. Progress into the extensive management stage occurred during the mid 1900's when effective fire protection was provided, a Province-wide forest inventory was undertaken and forest management planning was introduced. During the mid and late 1970's serious efforts were underway to move into intensive forest management. A forest nursery was established and a beginning was being made on the introduction of various forest improvement treatments on better quality forest lands.

At this critical time in the evolution of forest management in the Province the spruce budworm outbreak developed. This arrested and set back any progress made towards the intensive forest management stage. Unless damage by this kind of insect outbreak can be minimized through an effective pest management program, the Province may turn back toward the exploitation stage. The following discussion assumes that some type of protection program will be adopted and that the Province will be able to maintain its position in the extensive forest management stage and progress to the intensive management stage.

## b) COMPONENTS OF AN INTENSIVE FOREST MANAGEMENT PLAN

An intensive forest management plan for Newfoundland must be developed, keeping in mind the massive fibre losses already incurred and the diversity of silvicultural problems inherited because of past land use practices, heterogeneity of site conditions and lack of a pest protection program. The objective of the plan should be to maintain the present level of forest activity in the short and medium term, and to enable expansion of activity in the long term. The programs must aim at reducing the backlog of unproductive land while simultaneously implementing preventative measures to avoid unwarranted additions to this existing backlog.

Implementation of the intensive management plan has to be based on sound economic and technical analysis to ensure its practicality. Indeed, it must be realized that intensive forest management is an all-encompassing activity involving much more than silviculture. Forest management actions require effective, yet environmentally conscious, pest management strategies to protect investments. The more intensive the management, the more intensive and often more expensive the protection and maintenance.

The main components of the intensive forest management program are:

(i) Resource Inventory
(ii) Protection
(iii) Regulation
(iv) Short/Medium Term Ameliorative Measures
(v) Measures for Maintaining and Expanding Forest Resources
(vi) Administration

i) Resource Inventory

Solandt (1979) noted that: "an expanded forest management program can only be firmly based on a greatly improved forest inventory. The techniques now available for remote sensing and the immense capabilities of modern digital data storage and management systems make this difficult task infinitely easier than it was in the past".

It is imperative that the base of a management program be detailed knowledge and an up-to-date information bank of the amount, distribution and quality of forests and recovering wood supply. Once this base information has been obtained and stored, it can be modified as depletion data (e.g. losses to budworm) become available or silvicultural improvements (areas thinned) change the data base. The inventory should also include losses of forest lands, e.g. alienation by non-forestry agencies and soil erosion as well as gains through such programs as site reclamation.

To assist in forest management for fibre-fuel balance, for new product development, and for closer utilization, the inventory data should possibly include all age classes for each major tree species. Additionally, it should include both volume and biomass information, wherever possible, on a stand basis.

Forest management data collected by all agencies should be coordinated with the provincial inventory system to ensure data compatability for input and accurate, quick retrieval. Examples of such data are FIDS surveys, problem area surveys, and biomass information.

> "The cost effectiveness of such a venture [expanded inventory] would be high since the cost would be recovered several times over by the improved effectiveness of every plan for forest management or use" (Solandt 1979).

ii) Protection

Forest protection must be included as part of intensive forest management. The inventory in place must be protected to maintain current level of activity and improved areas must be protected. In short, there should be no intensive silviculture operations without an integrated pest management program. When and wherever chemical insecticides are to be used, they must be applied after full justification of the need for resource protection has been established and with environmental consciousness.

Because of the current quantity of dead and dying wood left over from the budworm outbreak it will be necessary to incorporate improved fire detection and suppression techniques.

iii) Regulation

Regulation of land use and harvesting operations will be an essential part of any future forest management plan. It will be important to define productive forest land more precisely. Such areas may have to be designated for forest production and given a degree of long-term protection against alienation for other uses. This will be especially important for areas that have received silvicultural treatments. Any zoning system should not be so rigid as to prevent land from being utilized for its highest economic use. However, if land is removed from forest production, the resource owner should receive adequate compensation.

Over the past several years the Province has established an administrative mechanism for regulating harvest of forests owned or controlled by the two pulp and paper companies. The Province can now regulate more intensively to minimize depletion due to forest harvesting practices. Preventive measures should be adopted to ameliorate site damage and ensure crop replenishment. This will require further development of harvesting guidelines relative to terrain conditions.

There is also a need for more intensive regulation of harvesting on unalienated Crown forest lands. Harvesting on these lands, which account for almost 40% of the productive forest area of the Island, is done by thousands of domestic fuelwood cutters and small scale commercial operators. This cutting is regulated by annual cutting permits issued by the Department of Forest Resources and Lands. However, the Department, with limited staff and budget, is faced with a difficult administrative task in supervising thousands of small harvesting operations, scattered over a very wide geographic area. In addition, much of the harvesting is done in the evenings, on weekends and holidays, outside of the normal working hours of civil servants. The problem will increase as the energy crisis intensifies. Unregulated cutting can be very destructive, resulting in reduced fibre yields and site damage, on improved as well as unimproved areas. Departmental field supervision services will require considerable strengthening to deal with this problem.

### iv) Short and Medium Term Ameliorative Measures

Over the next decade there will be a need to utilize the forest resource more completely to mitigate future wood supply deficits. The industry will have to place more reliance on materials previously considered undesirable. Salvage operations should continue as well as access road programs to clean-up damaged stands. Harvesting of undamaged spruce stands should be postponed while stands that are more susceptible to insect attack are utilized. There should also be incentives or imperatives to use a higher fir component in the pulping process, and also to use wood from less dense stands. The use of residuals, including birch, should be advocated. This may require some effort to modify existing wood processing methods.

The above utilization concepts could be put into practice through integrated logging operations, such as those in progress and planned under the ENFOR program. In addition, operational harvesting trials in dense, small diameter stands should be initiated.

There may be merit in evaluating the harvest of more distant wood supplies such as those in Labrador.

### v) Measures for Maintaining and Expanding Forest Resources

Prior to the implementation of a large scale silvicultural program, a thorough economic and technical analysis of achievements to date is desirable. The objective of this analysis would be to identify treatments that promise reasonable cost-benefit ratings. Once these treatments have been identified, a long term plan can be drawn up and implemented.

New operational activities should focus on preventative measures to ensure that the amount of productive land lost in forestry operations is minimal. This could be achieved by giving the industry more responsibility in bringing harvested land back into production. There should be harvesting guidelines and silvicultural prescriptions prepared for different terrain conditions. Harvesting, site preparation, stand establishment and maintenance would then be more closely allied and thought of as a complete process. Future research and development should focus on such management systems.

The backlog of land in need of silvicultural treatment is increasing at an alarming rate by budworm kill. In many areas this is compounded by blowdown. Meanwhile, there are still large areas of land with other successional problems. Based on experience to date, the various kinds of problem sites should be priorized with respect to payoff in future wood supply following prescribed treatments.

In addition to a good forest inventory, adequate protection and improved utilization, a long term intensive forest management plan for Newfoundland should include other program elements as outlined below.

The forest genetics program should be encouraged and developed at a more rapid pace. Orchards should be established to provide superior seed and growing stock for use in seeding and planting operations. Species or varieties showing promise of insect and disease resistance should be utilized in conversion programs wherever possible. Research in forest breeding should also focus on developments of fast growing hybrid poplars and willows suited to local ecological conditions.

Forest nurseries will form an integral part of any long term management program. One major nursery has been developed by the Province at Wooddale. This installation is not yet fully operational and by itself will probably not be able to supply all long term requirements for planting stock. Additional nurseries will likely be needed. It might be advantageous for limit holders to establish and operate their own nurseries to meet their anticipated needs for growing stock. Such development, however, should be undertaken in full cooperation with the provincial and federal forest agencies.

The forest management plan should include provision for the establishment of forest plantations in certain areas. Such plantations will involve both bareroot and containerized stock. There will be problems with losses due to insects, diseases and ecological site factors. These losses may be reduced considerably if the federal research programs in entomology, pathology and silviculture are closely integrated with the operational programs of the Province and industry.

Direct seeding is a relatively low cost treatment for the re-establishment of desirable species after harvesting on some sites. This has been carefully researched by the Canadian Forestry Service and treatment prescriptions have been prepared. In the management plan, direct seeding should be encouraged wherever practical because of the low cost compared to most other treatments.

Pre-commercial thinning is one of the most common improvement treatments practiced in Newfoundland to date. The technique is well understood and a core of workers has been trained. It is likely that some thinning techniques will form part of future intensive forest management plans. However, it is felt that more research is required to determine optimum spacing and to assess the relationship between thinning and biomass production.

Site reclamation treatments have also been developed in Newfoundland recently. In such treatments, the damaged stand is removed, and the site is prepared and planted or seeded to new species. A major drawback of this treatment is the high cost which would be a detriment to including it in a long term management plan. This cost might be significantly reduced if the existing biomass on the site could be harvested and sold for fuel. Research under the ENFOR program should evaluate this opportunity.

vi) Administration

Funding - The Province will be responsible for the administration of any long term intensive forest management plan. The more intensive the level of management, the more costly and difficult the administrative task will be. It should be stressed that an intensive forest management plan implies a long term commitment to a certain level of funding. If this long term commitment cannot be maintained, then progress made in the early years can easily be lost in later years if funding becomes inadequate. For an intensive forest management plan to be effective in the long run, the questions of level of funding, and who pays, will have to be resolved.

To date the lead in development of a forest improvement program has been taken by the Province using DREE funds. In the future, the major forest companies should be encouraged to bear an increasing share of the financial and administrative responsibility for forest improvement activities within their wood supply areas. This would ease the financial burden on the Province. Faced with the requirement to establish a second crop, the companies would be encouraged to modify harvesting techniques and develop and utilize low cost, effective forest improvement treatments.

Ideally, investments in intensive forest management should be recovered from the increased value of the resulting products or services received at the end of the investment period. Such a program would tend to be self sustaining and not subject to arbitrary interruption through changes in personnel, administration or funding sources. For forest improvement projects the direct revenues from the sale or utilization of wood products should bear some relationsip to the value of the investments made.

Clarification on funding is also required from the federal side. Will DREE agreements continue to be available to fund provincial forestry programs or will some other mechanism be developed? Will federal funds continue to flow for this purpose in the long run at all? What share of provincial funding will the federal government be willing to bear? The answers to these questions will have a significant impact on the future level of intensive forest management in Newfoundland.

Tenure - The degree to which large scale forest-based industries will be willing or able to help fund an intensive forest management program will be related to their perceived ability to capture the benefit of their investments. This will require effective protection of improved areas and adequate tenure arrangements. Companies will want to be assured that additional wood produced as a result of their improvement programs, will be available to them at time of harvest. Long term tenure arrangements with the companies should take into account their legitimate requirements for a secure wood supply. Satisfactory performance under government approved management plans could be rewarded by ownership rights to the additional wood supplies produced, after payment of appropriate government fees and royalties.

Organization - If a new long term intensive forest management plan is to be implemented for the Province, an appropriate organizational framework will be required. The structure of existing provincial, federal and industrial agencies should be reviewed to ensure that roles are clearly defined and that resources are adequate for the programs that are planned. Interrelationships between agencies should be examined to make sure that good communications and coordination are established.

## 5. ROLE OF RESEARCH AND DEVELOPMENT IN FOREST MANAGEMENT

The export of forest products contributes more to the Canadian trade balance than agriculture, mining, fishing and fuels combined (Fraser 1979). This export has been sustained largely by utilization of extensively managed old-growth forests. The competition for international markets is intensifying and it is important for Canada to maintain or improve the position of her forest industries. This goal cannot be achieved without intensive forest management incorporating long term research and development. A continued, long term commitment is required because of the long term, renewable nature of the resource.

The ownership and management of the forest resource in Canada is largely a provincial jurisdiction, but research is conducted largely by the Federal government, and some by the provinces, universities and forestry industry. However, there is a distinct need for federal leadership including funding, in conducting and coordinating Canadian forest research and development.

The funding of research in Canada over the past decade has declined in total expenditure (Smith and Lessard 1971; Solandt 1979). Only expenditures by some provincial departments of forestry and by research councils has increased. Real financial support of the CFS, has declined considerably. Total man-years decreased from 2181 in 1968 to 1969 down to 1063 in 1979 to 1980 and expenditures from 28 600 000 dollars to 16 100 000 in constant 1971 dollars (Solandt 1979). In addition, the career oriented summer student employment program was also recently curtailed. This action has reduced the productivity of research staff and effectively eliminated an excellent opportunity for fostering development of future professionals, particularly for regions such as Newfoundland and Labrador. There is difficulty now in recruiting in some fields of forest research and if corrective action is not taken the situation will deteriorate further.

Almost all forest research in Newfoundland and Labrador is conducted by the Newfoundland Forest Research Centre of the Canadian Forestry Service with considerable cooperation and support from the Province and forest industry. The Research Centre is the youngest and smallest of CFS establishments and it has never reached the staffing level recommended in the early 1960's because of government fiscal restraints.

The small number of staff in protection research has traditionally concentrated on current, major problems, such as the balsam woolly aphid, the eastern hemlock looper, root and stem decays of balsam fir, and recently the spruce budworm. The research program has had a history of crisis management; allocating scarce manpower and funding resources from one urgent problem to the next. Consequently, important work on major pests has been in abeyance (e.g. predictive sampling systems for the hemlock looper) and some important areas of research are either not covered or efforts are fragmented. A similar situation exists within the regeneration and tree growth elements of the forest resources program.

The expansion of the protection and related silvicultural research program without additional man years and funds is not possible as each study is carried by only a fraction of a man-year and the present person-year allocation is fully committed. If additional resources became available at least 10 person years could be justified.

# 6. PUBLIC PARTICIPATION IN FOREST MANAGEMENT

Government agencies have been established to serve the public interest. This responsibility has not been fully discharged in the development and dissemination of information on important resource management issues. It is this lack of communications that has contributed to the public anxiety over a protection program against the spruce budworm.

Education and information from the user to the client (public) is in need of an enlightened approach. The public is becoming more educated and more elements of society wish to be consulted in the decision-making process. In recent years information services have been given a high priority on paper. Yet, these services are still looked upon as expendable items by many managers and are often the first to be cut from programs in periods of restraint.

The decline of the Newfoundland Forest Protection Association (NFPA) illustrates the extent to which communications have been allowed to deteriorate in recent years. Membership in the NFPA included major forest companies, the provincial department of forestry, federal forestry agencies and other agencies such as the Department of Education. Budget was provided by industry and government and there was much volunteer support. The NFPA was a vital, active force in forestry education and conservation in the Province, and had ties with the national Canadian Forestry Association which had similar aims and objectives. The role of the NFPA could have been expanded. However, the organization is slowly dying through neglect and lack of funding. Its public education programs have been allowed to lapse at the time when vigorous public education is most needed.

The failure to maintain and expand communications caused a credibility gap between resource managers, major forest agencies, the public, environmental groups, and politicians. Resource managers suddenly found themselves helpless to deal with a massive forest protection problem, because they were unable to convince public and government leaders of the seriousness of the situation. Protection measures were not taken because of public concern with environmental and public health aspects of spraying.

It will take a major effort to close the existing credibility gap. Members of the forestry community must become communicators. Communications is a two-way process. Resource managers must first develop listening skills so they properly understand public concerns. Only then can they be in a position to develop an effective public information program. Then resource managers themselves must become more articulate in presentation of their message to the public.

Communications efforts must be those directed toward the younger generation. Forest agencies should work with the Department of Education in developing materials for use in the science and socio-economic curricula. There is an opportunity to work with 'councils' established by the Department to develop new materials. The objective would be to produce useful information on Newfoundland forest ecosystems and man's interactions with it. In this way insect pest management would become an important topic for discussion and debate. Debate should be encouraged with all facts presented. The overall problems of forest management could also be addressed in this manner enabling a two-way communication on important resource issues.

## SUMMARY

Federal forest policy recognizes the national importance of forestry to the economy and the growth potential in forest-based industries. Serious problems exist, such as inadequate stocking, wood supply, and competitive position of Canadian industry that have to be corrected if forest industries are to remain competitive in the long run. After a period of neglect there now appears to be a renewed awareness of the importance of forestry in the federal bureaucracy. In Newfoundland the federal government provides forestry research and advisory services through the Canadian Forestry Service and special funding assistance for provincial forestry programs through the Department of Regional Economic Expansion.

Considerable progress was made in the early 1970's in forest policy development by the Province and significant improvements were made in the intensity of forest management. Some improved forests have been killed and others are threatened because of inadequate protection policies and programs. A protection policy must be developed and implemented before further progress can be made.

There is ongoing cooperation between federal and provincial forestry agencies in the Province through committees established for this purpose. Communications appear to have weakened in recent years and these committees should be strengthened.

Essential elements in an intensive forest management plan are inventory, protection, regulation and administration. Short-term utilization measures and longer-term forest improvement practices that ensure maximum recovery of wood fibre from forest stands are suggested for Newfoundland. Important questions of funding and tenure, remain to be resolved.

Research and development play a vital role in long-term forest management. Existing capabilities in Newfoundland should be strengthened if research is to keep ahead of the needs of resource managers.

Forest agencies and resource managers in Newfoundland have failed to maintain healthy two-way communications with the public and politicians. This has led to a credibility gap and lack of support for vital protection programs. Strenuous efforts are needed to establish communications and promote mutual understanding between managers and the public.

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# APPENDIX I. LIST OF CONTRIBUTORS

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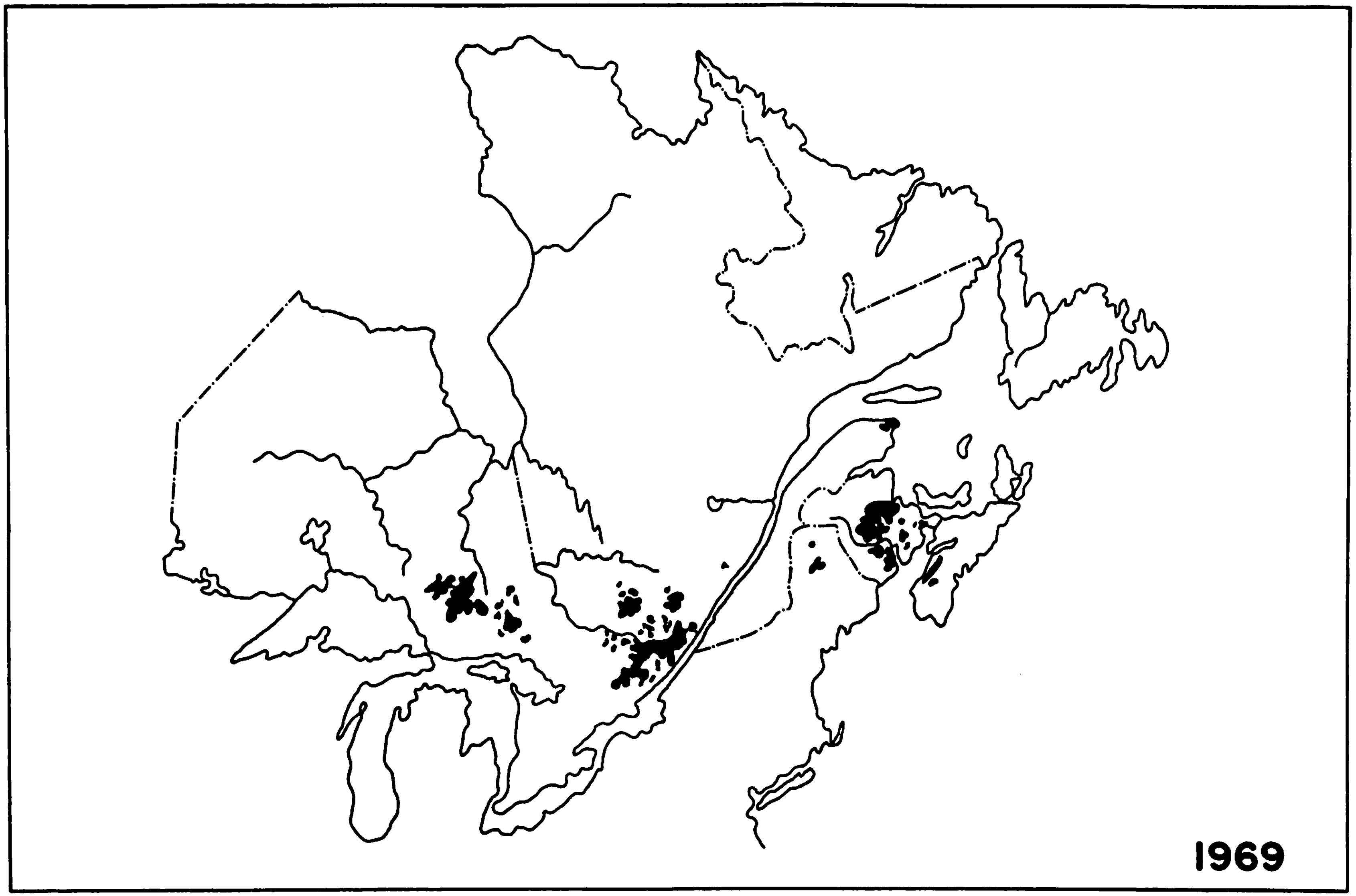
# APPENDIX II. LIST OF ABBREVIATIONS AND SYMBOLS

| | | |
|---|---|---|
| AAC | = | annual allowable cut |
| AI | = | active ingredient |
| BIU | = | billion international units |
| *B.t.* | = | *Bacillus thuringiensis* |
| C | = | centigrade |
| CANUSA | = | Canada United States Spruce Budworms Programs |
| CFS | = | Canadian Forestry Service |
| CWS | = | Canadian Wildlife Service |
| cm | = | centimetre |
| DFO | = | Department of Fisheries and Oceans |
| DREE | = | Department of Regional Economic Expansion |
| ENFOR | = | "Energy from the Forest" Program |
| F | = | female |
| FICP | = | Federal Interdepartmental Committee on Pesticides |
| FIDS | = | Forest Insect and Disease Survey |
| FPMI | = | Forest Pest Management Institute, Sault Ste. Marie, Ontario |
| g | = | gram |
| GLFRC | = | Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario |
| ha | = | hectare |
| hrs | = | hours |
| IGR | = | Insect growth regulator |
| IU | = | International units |
| kg | = | kilogram |
| $\ell$ | = | liter |
| L | = | larva |
| $LC_{50}$ | = | lethal concentration which will kill 50% of the test organisms, usually expressed as ppm (parts per million) |
| $LC_{95}$ | = | lethal concentration which will kill 95% of the test organisms |
| $LD_{50}$ | = | lethal dose which will kill 50% of the test organisms, usually expressed as mg/kg (milligrams per kilogram of weight) |
| $LD_{95}$ | = | lethal dose which will kill 95% of the test organisms |

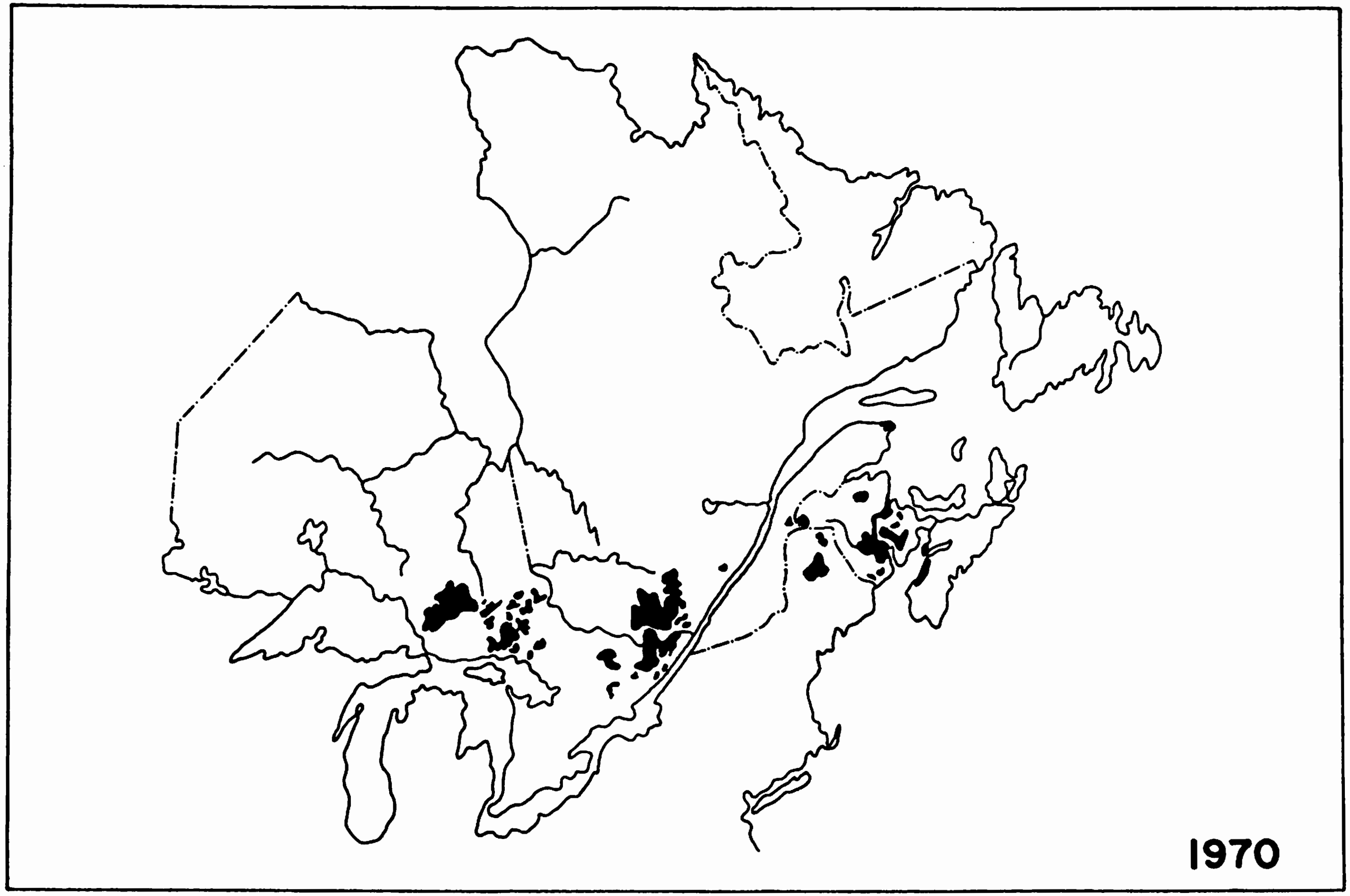
| | | |
|---|---|---|
| LFRC | = | Laurentian Forest Research Centre, Ste. Foy, Quebec |
| m | = | metre |
| M | = | male |
| MFRC | = | Maritimes Forest Research Centre, Fredericton, New Brunswick |
| mg | = | milligram |
| mm | = | millimetre |
| Nfld. | = | Newfoundland |
| Nfld.FRC | = | Newfoundland Forest Research Centre, St. John's, Newfoundland |
| NFPA | = | Newfoundland Forest Protection Association |
| NH & W | = | National Health and Welfare |
| PNFI | = | Petawawa National Forest Institute, Chalk River, Ontario |
| ppm | = | parts per million |
| µ | = | micro (= 1/1000) |
| yr | = | year |
| R ——— | = | patented trade name of an insecticide, which includes the chemicals plus additives, such as solvents, emulsifiers, etc. |

# APPENDIX III. CARTOGRAPHIC HISTORY OF THE SPRUCE BUDWORM OUTBREAK IN EASTERN CANADA AND THE NEW ENGLAND STATES OF THE UNITED STATES FROM 1969 TO 1979.

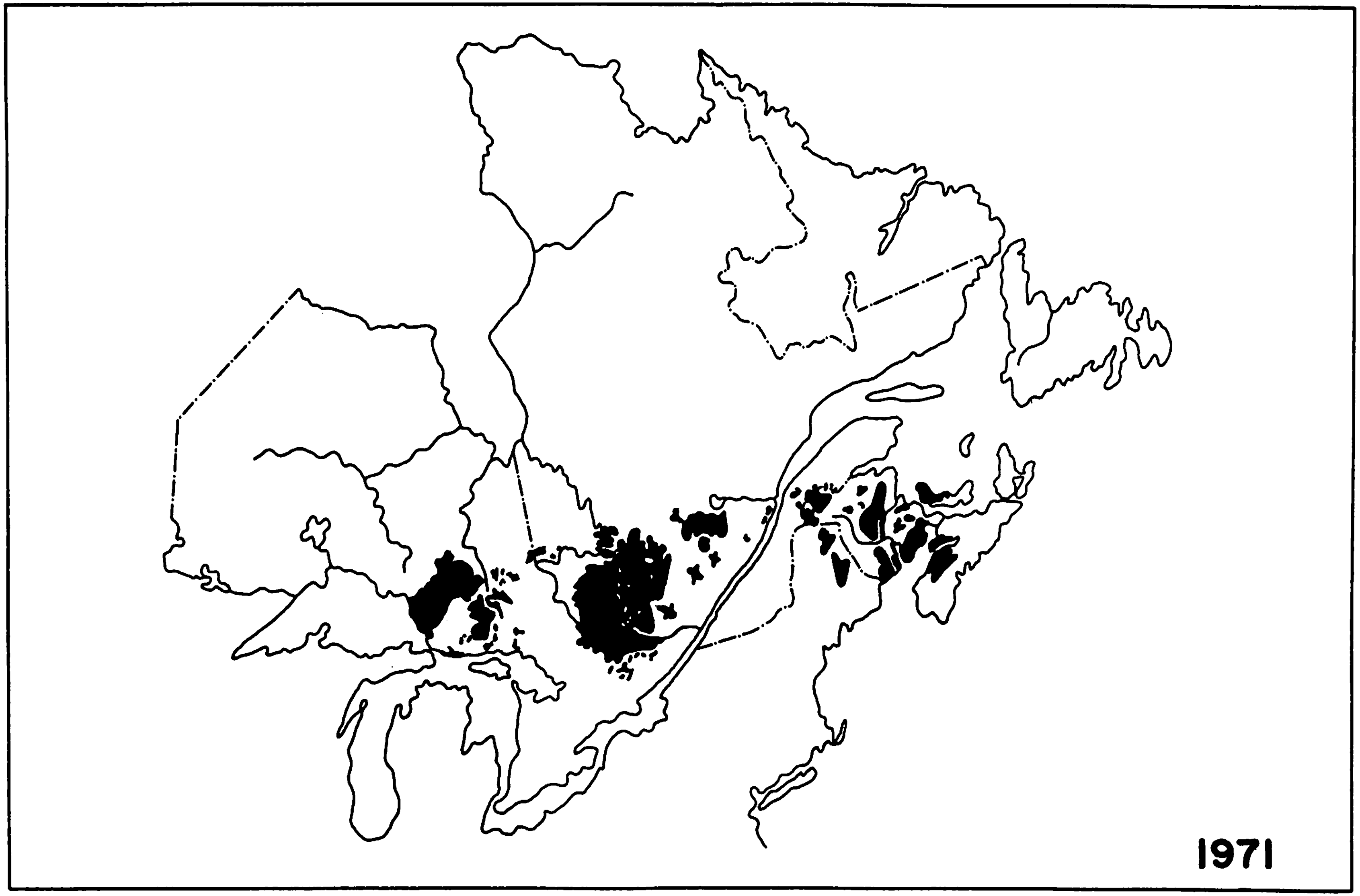
The following is a set of maps compiled by Dr. E.G. Kettela, Maritimes Forest Research Centre, CFS. Moderate to severe defoliation is pictured for each year of the most recent budworm outbreak beginning in 1969. Cumulative damage; dead, dying, and severely damaged forests; to 1979 is also included.



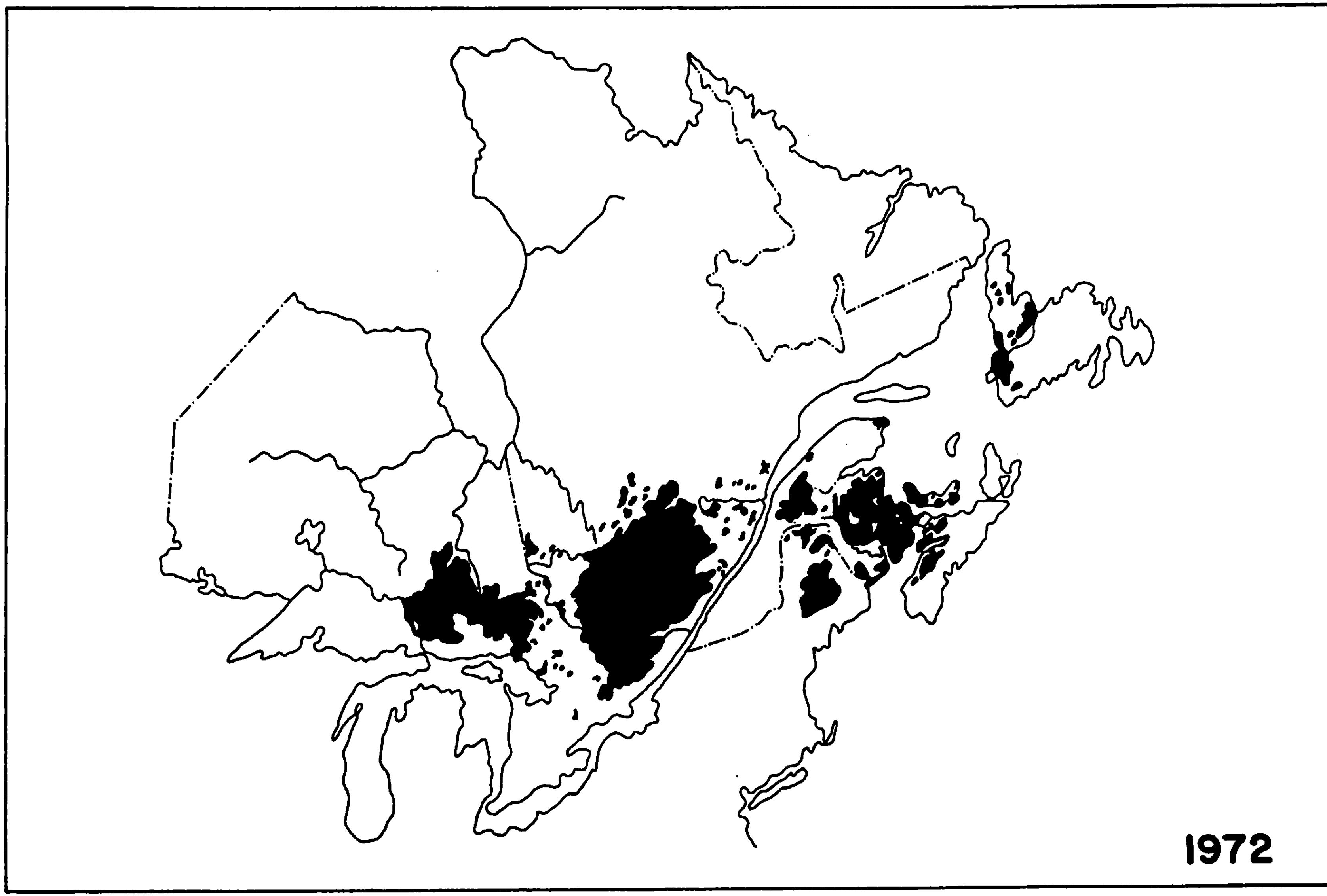

Moderate to severe defoliation of balsam fir and spruce caused by the spruce budworm in eastern Canada and the New England States of the United States.



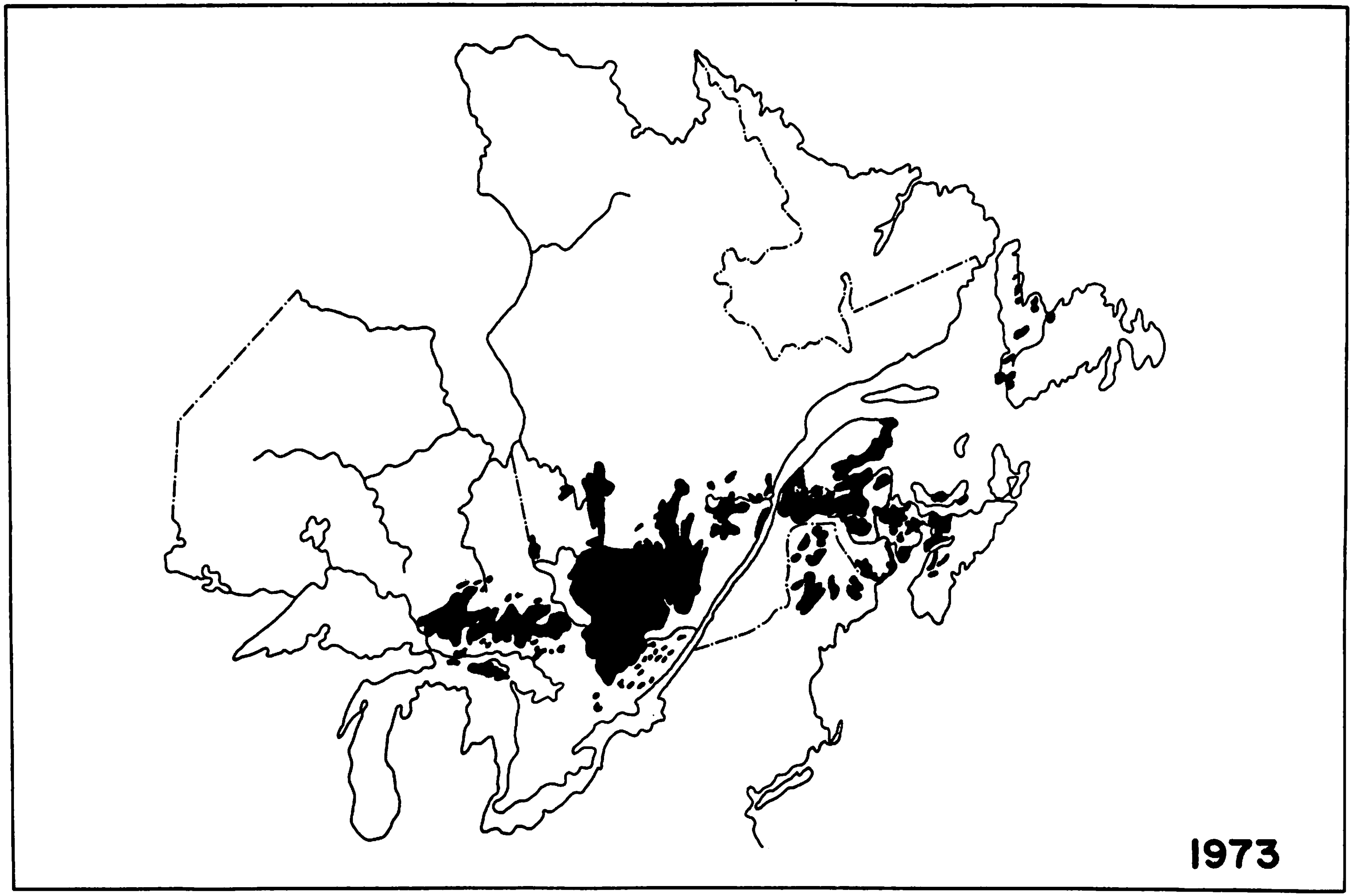

Moderate to severe defoliation of balsam fir and spruce caused by the spruce budworm in eastern Canada and the New England States of the United States.



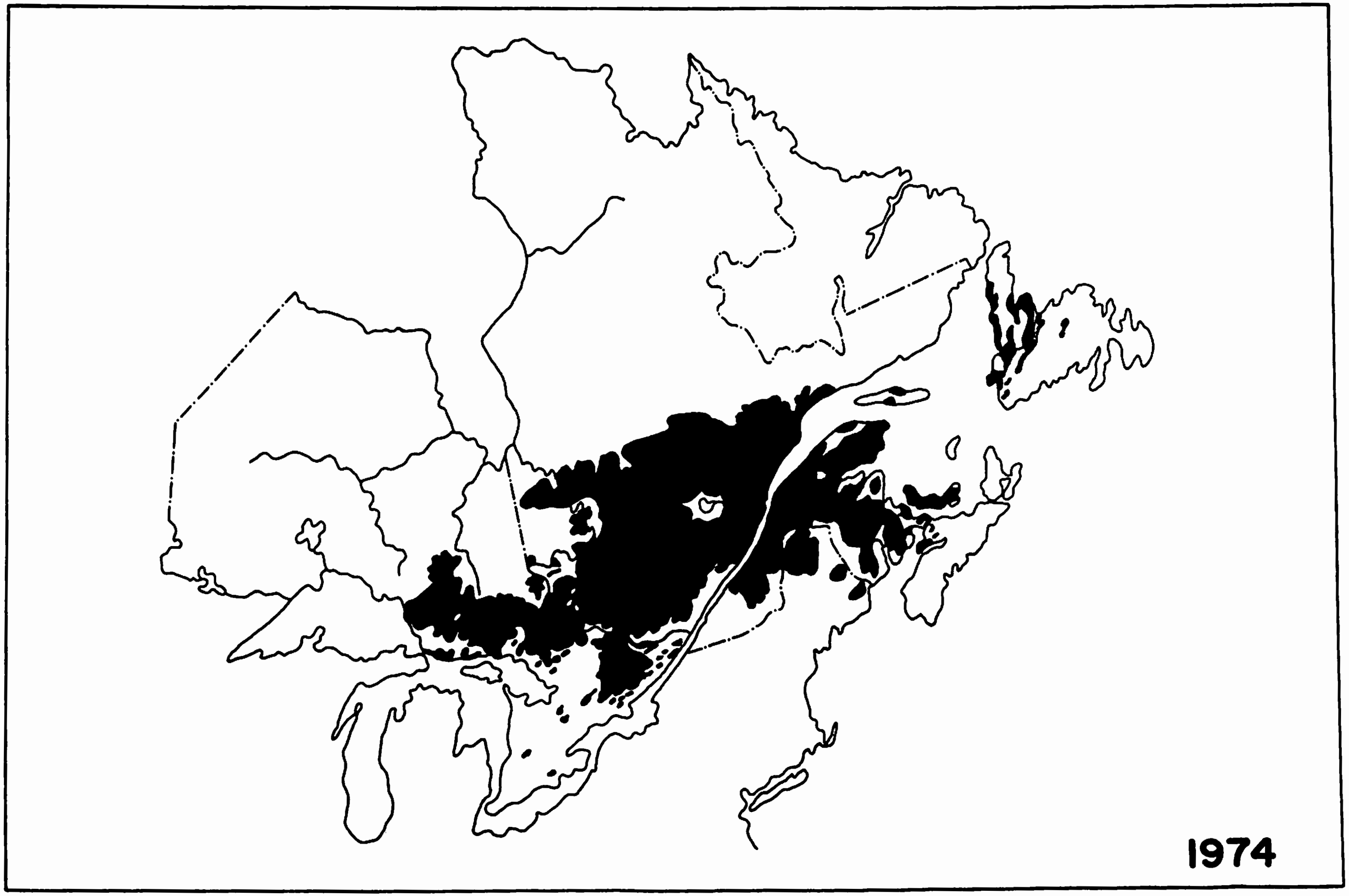

Moderate to severe defoliation of balsam fir and spruce caused by the spruce budworm in eastern Canada and the New England States of the United States.



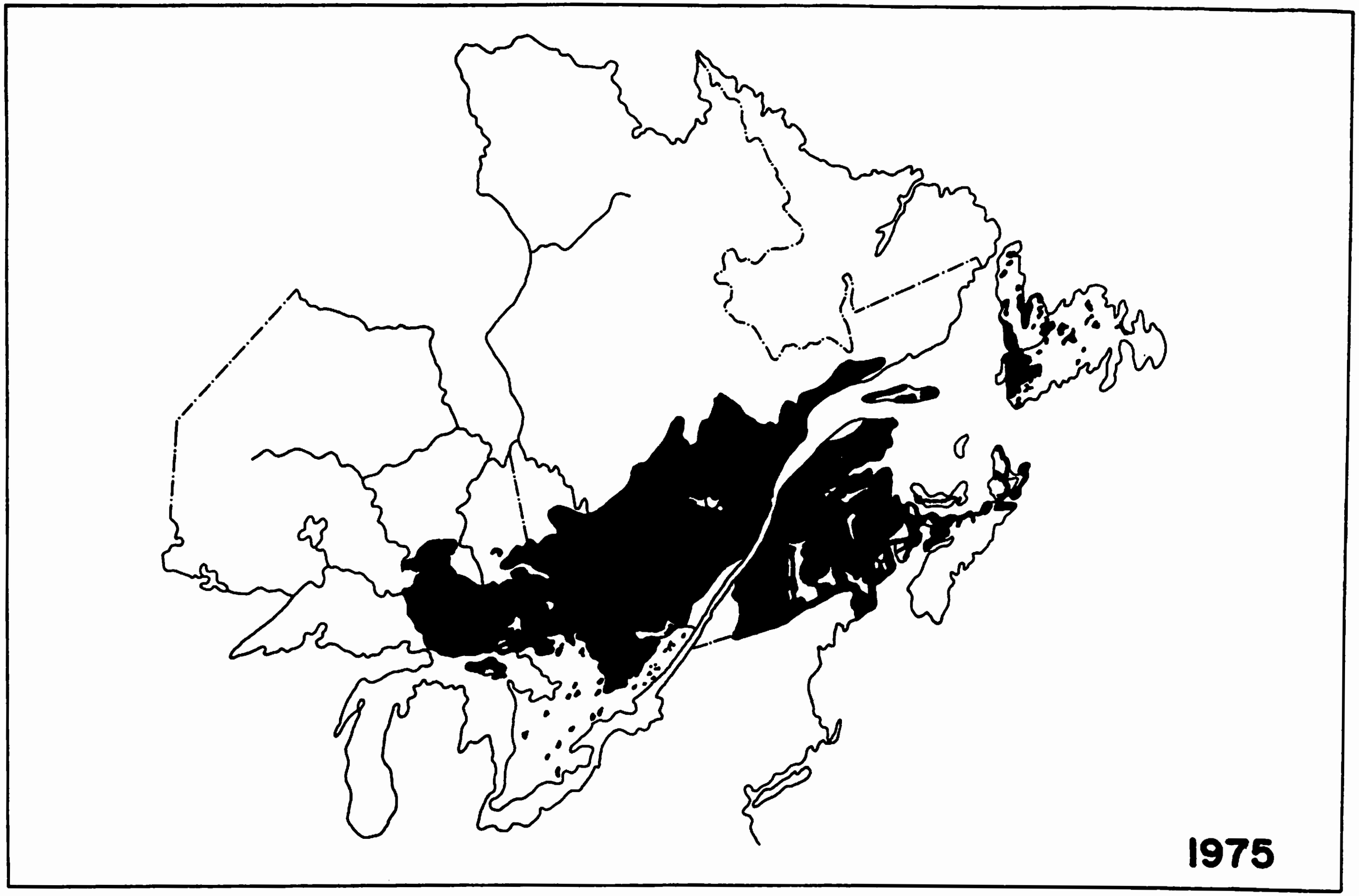

Moderate to severe defoliation of balsam fir and spruce caused by the spruce budworm in eastern Canada and the New England States of the United States.



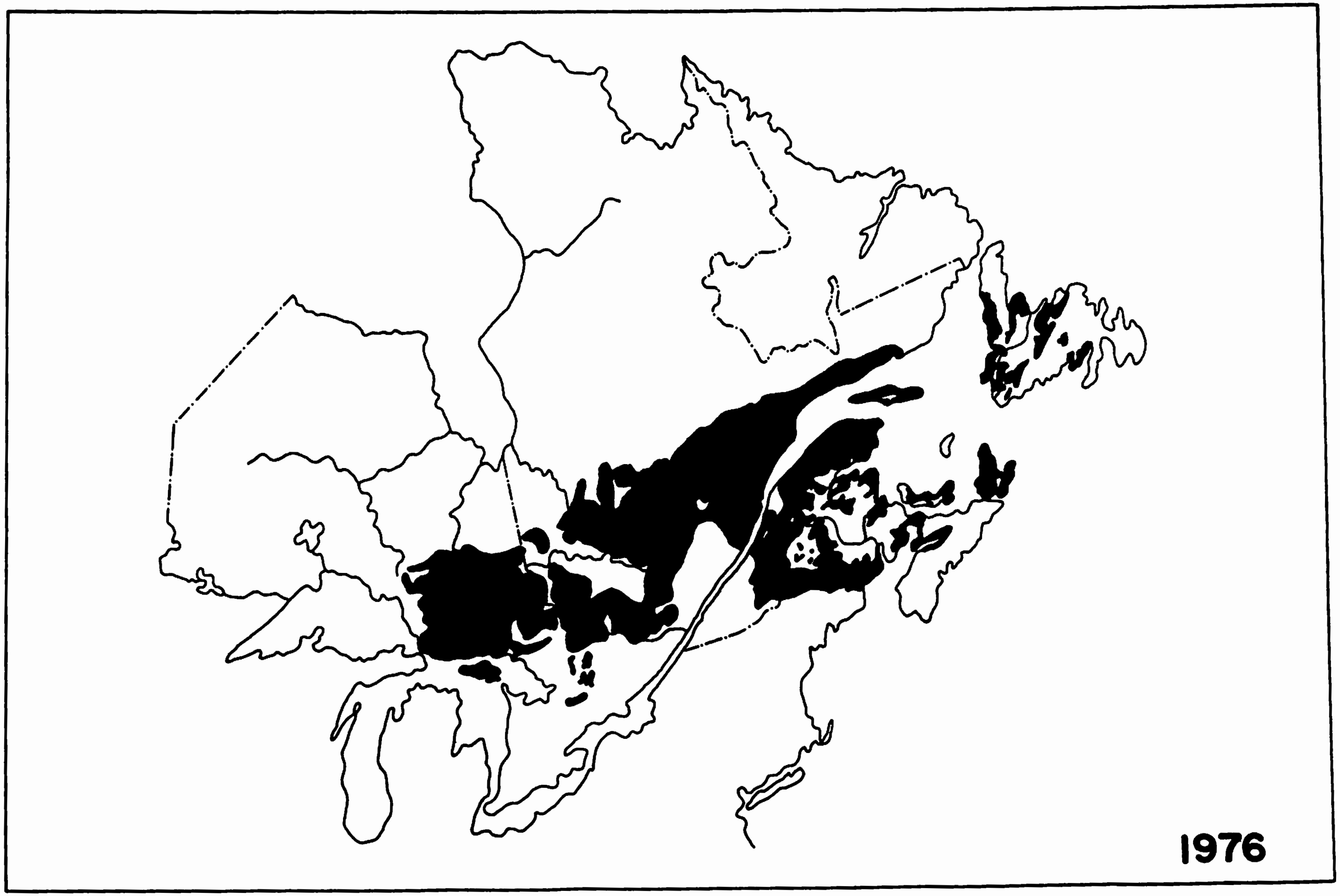

Moderate to severe defoliation of balsam fir and spruce caused by the spruce budworm in eastern Canada and the New England States of the United States.



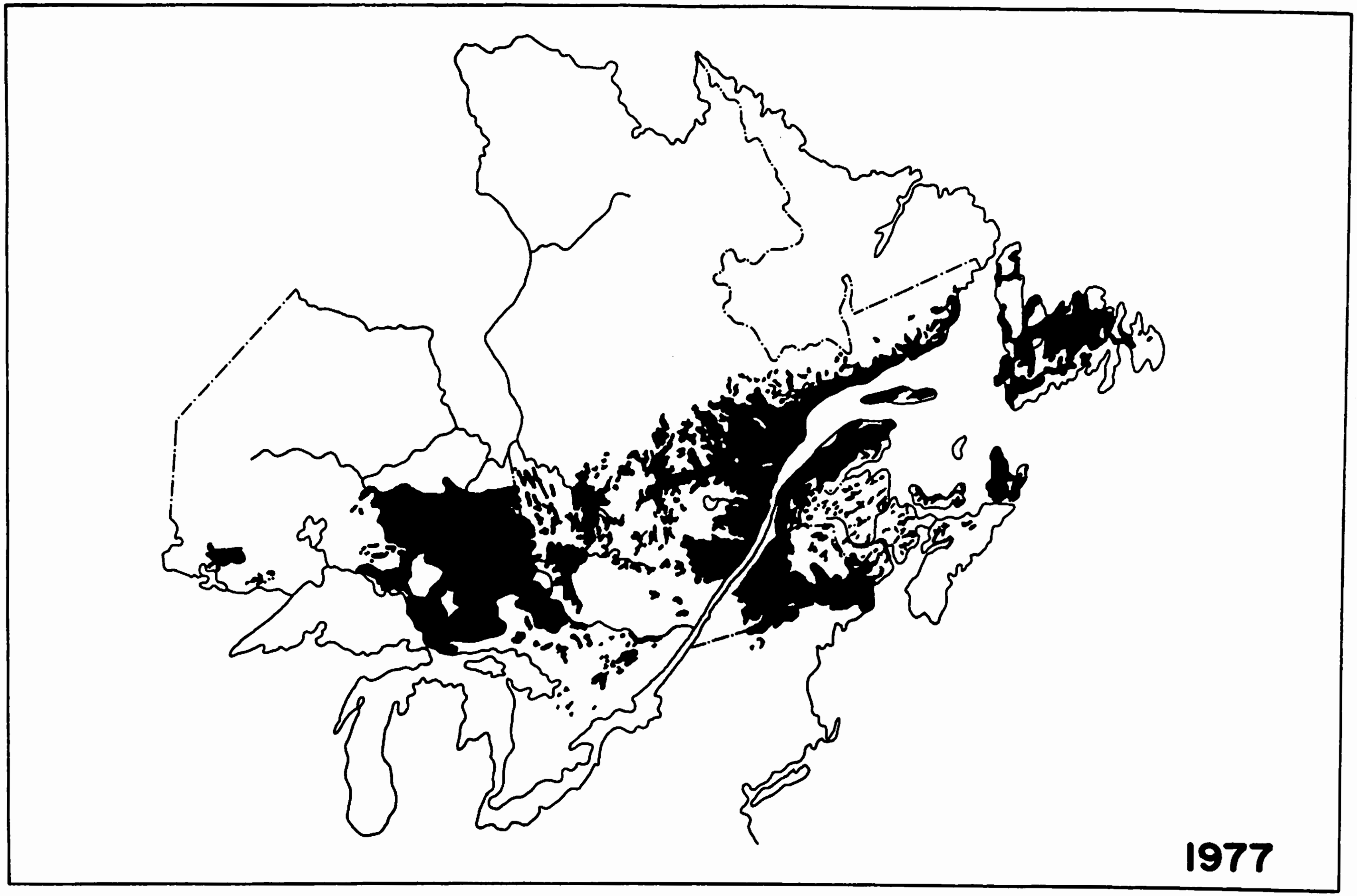

Moderate to severe defoliation of balsam fir and spruce caused by the spruce budworm in eastern Canada and the New England States of the United States.



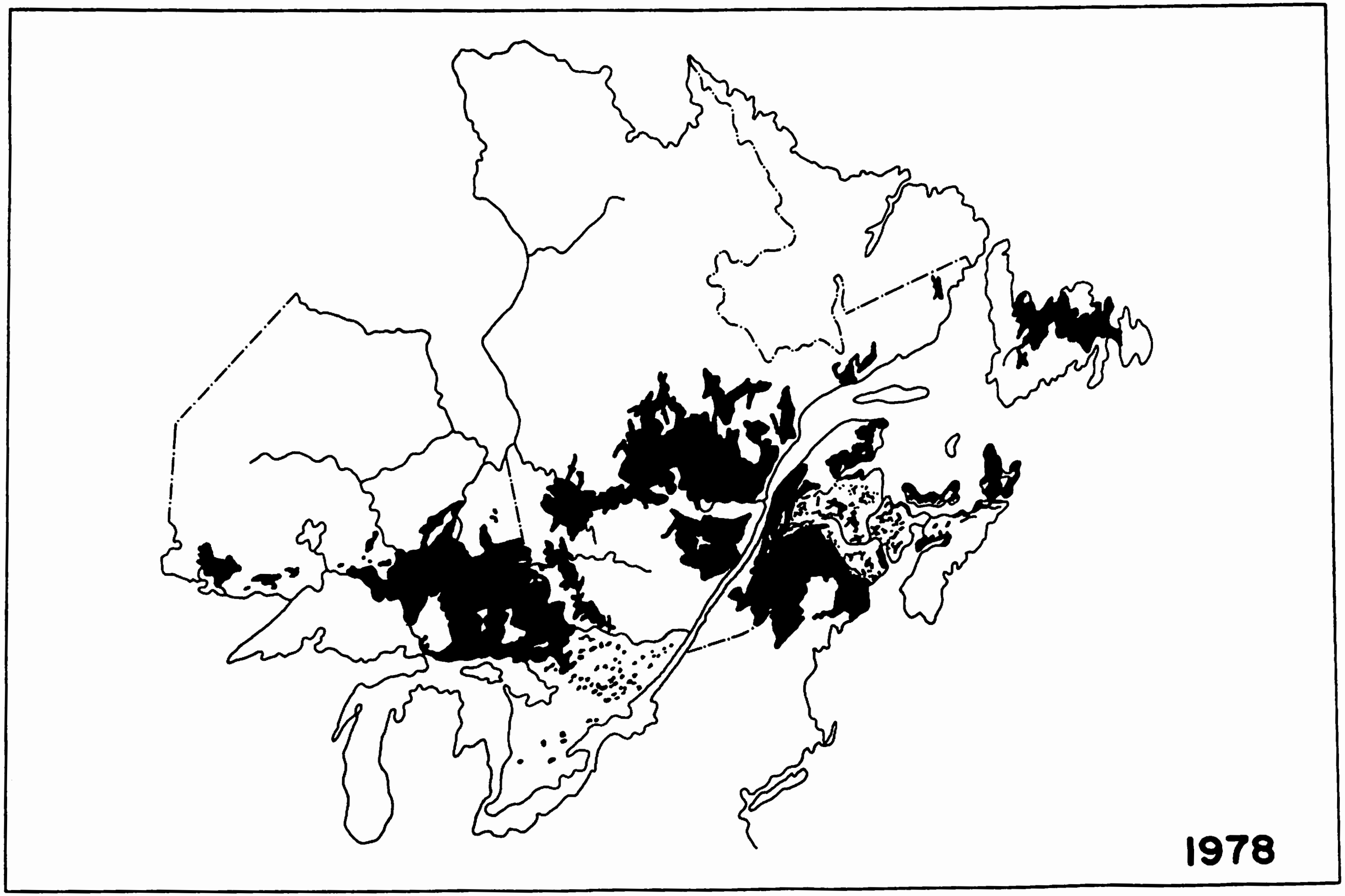

Moderate to severe defoliation of balsam fir and spruce caused by the spruce budworm in eastern Canada and the New England States of the United States.



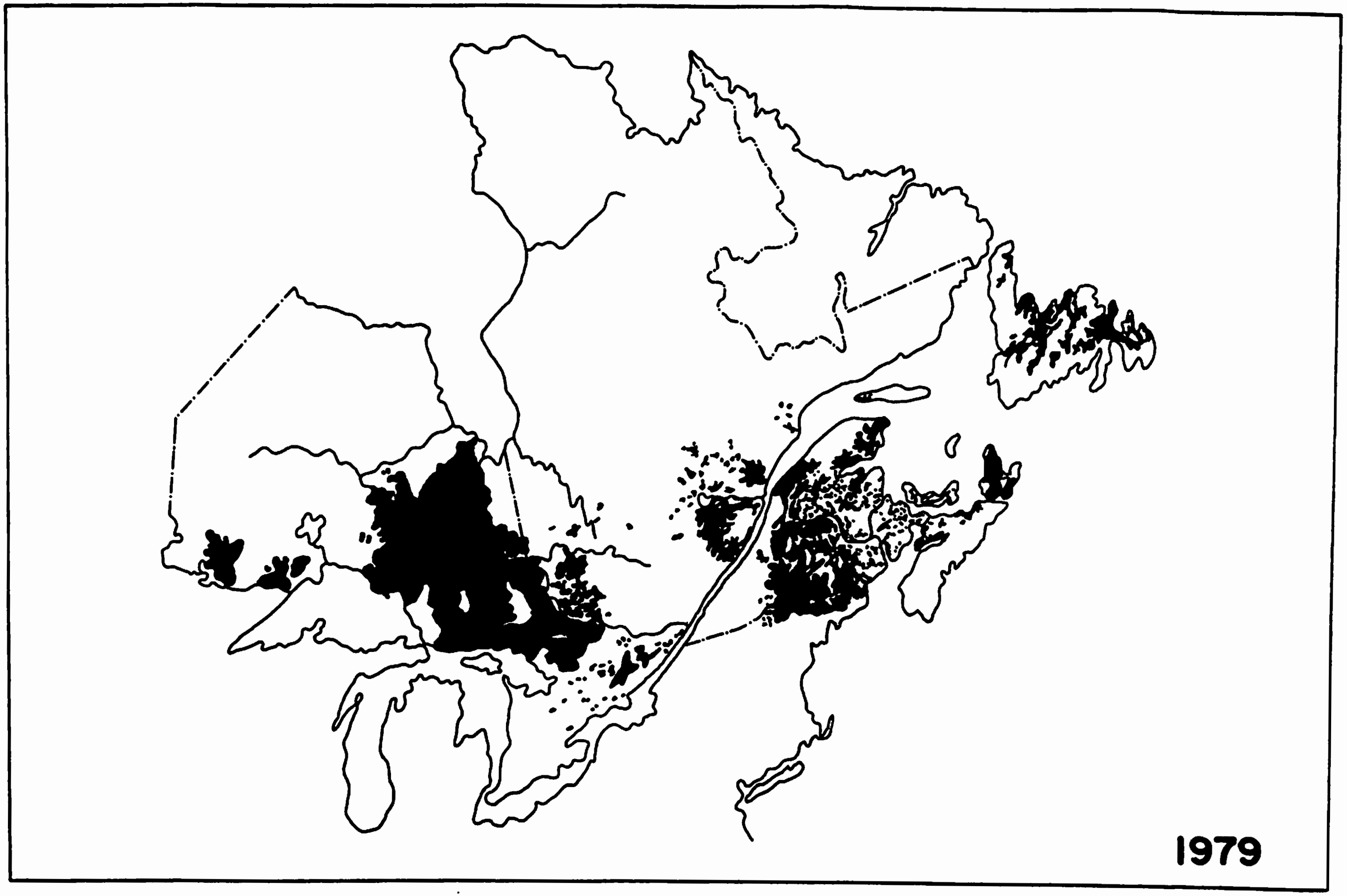

Moderate to severe defoliation of balsam fir and spruce caused by the spruce budworm in eastern Canada and the New England States of the United States.



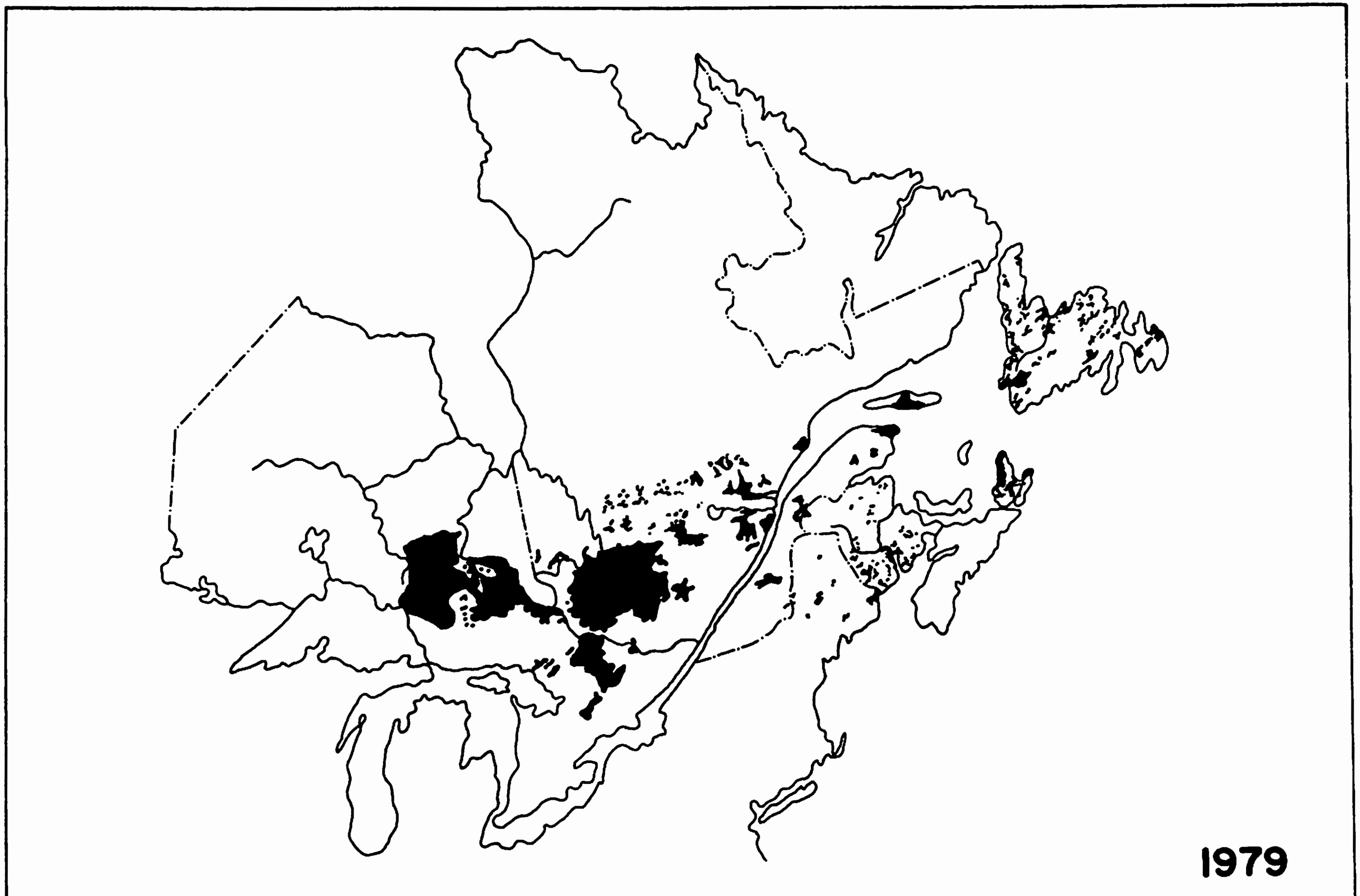

Moderate to severe defoliation of balsam fir and spruce caused by the spruce budworm in eastern Canada and the New England States of the United States.




Moderate to severe defoliation of balsam fir and spruce caused by the spruce budworm in eastern Canada and the New England States of the United States.




Moderate to severe defoliation of balsam fir and spruce caused by the spruce budworm in eastern Canada and the New England States of the United States.




Area of forest inside which a major proportion of the balsam fir and spruce are either dead, dying, or very severely damaged through feeding of spruce budworm larvae.

APPENDIX IVA. AREA AND VOLUME OF PRODUCTIVE MERCHANTABLE STANDS WITH DEAD AND DYING TREES FROM SPRUCE BUDWORM DAMAGE IN NEWFOUNDLAND IN 1979.

| Management unit no. | Ownership | Area and volume affected: A (Dead)* Total area (ha) | A (Dead)* Total volume ($m^3$) | A (Dead)* Dead volume ($m^3$) | A (Dead)* Dying volume ($m^3$) | B (Moribund)* Total area (ha) | B (Moribund)* Total volume ($m^3$) | B (Moribund)* Dead volume ($m^3$) | B (Moribund)* Dying volume ($m^3$) | C (Very severe)* Total area (ha) | C (Very severe)* Total volume ($m^3$) | C (Very severe)* Dead volume ($m^3$) | C (Very severe)* Dying volume ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Crown | - | - | - | - | 8794 | 267832 | 49870 | 128884 | 18721 | 744977 | - | 152175 |
| 2 | " | - | - | - | - | 432 | 39487 | - | 23693 | 24661 | 2006253 | 1116 | 464773 |
| 4 | " | - | - | - | - | 4320 | 286556 | 71073 | 74120 | - | - | - | - |
| 4 | Price | - | - | - | - | 15837 | 990471 | 322947 | 355215 | 6577 | 498352 | 45961 | 145699 |
| 5 | Crown | - | - | - | - | 2522 | 239795 | 76045 | 37815 | - | - | - | - |
| 5 | Bowater | 776 | 78580 | 39290 | 7857 | 529 | 53548 | 17017 | 21926 | 778 | 68699 | 4205 | 4205 |
| 5 | Price | - | - | - | - | 7336 | 618346 | 204643 | 178024 | 1348 | 130285 | 9657 | 3736 |
| 6 | Crown | - | - | - | - | 385 | 17897 | 6442 | 4295 | - | - | - | - |
| 6 | Bowater | 2669 | 270238 | 203763 | 21174 | 11943 | 1082545 | 410175 | 189756 | 15493 | 1476033 | 170758 | 366079 |
| 6 | Price | - | - | - | - | 1321 | 133726 | 40117 | 48142 | 1376 | 139298 | - | 13930 |
| 7 | Crown | 1384 | 68846 | 59544 | 5651 | 14826 | 911491 | 130258 | 493999 | 4906 | 263073 | 25691 | 57797 |
| 8 | " | 4991 | 162256 | 103269 | 27067 | 6873 | 509773 | 144670 | 191212 | 10529 | 540238 | 42594 | 136731 |
| 8 | Bowater | 1245 | 34733 | 18241 | 2933 | 2378 | 222291 | 77802 | 48904 | - | - | - | - |
| 8 | Price | - | - | - | - | 1133 | 74264 | 24293 | 8690 | - | - | - | - |
| 9 | Crown | 368 | 29619 | 14809 | 11192 | 15882 | 1200168 | 206096 | 823379 | 2598 | 105211 | 3160 | 19991 |
| 9 | Bowater | 2908 | 310083 | 218257 | 67861 | 7527 | 614270 | 92231 | 240573 | 4001 | 463395 | 3410 | 131364 |
| 9 | Price | 3191 | 280898 | 140448 | 103577 | 10443 | 890027 | 300917 | 218269 | - | - | - | - |
| 10 | Crown | - | - | - | - | 1027 | 31316 | 10645 | 1253 | - | - | - | - |
| 10 | Price | 2059 | 91982 | 51581 | 35229 | 8062 | 425772 | 116786 | 85312 | 13600 | 733177 | 77510 | 130752 |
| 11 | " | - | - | - | - | 11613 | 1101045 | 261150 | 162306 | 5531 | 362141 | 35521 | 90997 |
| 12 | " | 5145 | 360319 | 190455 | 129935 | 13280 | 987611 | 256038 | 356490 | - | - | - | - |
| 13 | " | 2159 | 168049 | 127925 | 6314 | 2449 | 195012 | 66610 | 85015 | 286 | 25399 | - | 9177 |
| 14 | Crown | 18381 | 1621838 | 1037859 | 413792 | 20070 | 1563639 | 303462 | 890244 | 11215 | 924221 | 21671 | 334036 |
| 14 | Bowater | 10095 | 888678 | 600423 | 167170 | 22639 | 1767455 | 539893 | 723306 | 13501 | 1125600 | 161424 | 308911 |
| 14 | Private | - | - | - | - | 248 | 20167 | 4839 | 6454 | 1224 | 102030 | 12243 | 35711 |
| 15 | Crown | 3522 | 377580 | 218997 | 154809 | 991 | 83579 | 24061 | 50227 | - | - | - | - |
| 15 | Bowater | 24882 | 2030227 | 1229604 | 396525 | 12366 | 962805 | 194227 | 385506 | 19716 | 1552720 | 150483 | 438960 |

Cont'd ...

APPENDIX IVA. Concluded

| Management unit no. | Ownership | Area and volume affected: A (Dead)* Total area (ha) | A (Dead)* Total volume ($m^3$) | A (Dead)* Dead volume ($m^3$) | A (Dead)* Dying volume ($m^3$) | B (Moribund)* Total area (ha) | B (Moribund)* Total volume ($m^3$) | B (Moribund)* Dead volume ($m^3$) | B (Moribund)* Dying volume ($m^3$) | C (Very severe)* Total area (ha) | C (Very severe)* Total volume ($m^3$) | C (Very severe)* Dead volume ($m^3$) | C (Very severe)* Dying volume ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | Crown | 578 | 19707 | 7649 | 4957 | 12296 | 908664 | 246485 | 261430 | 6004 | 528889 | 23736 | 107067 |
| 16 | Bowater | 3701 | 293345 | 219845 | 8915 | 4462 | 392702 | 103469 | 72490 | 2331 | 201553 | 13482 | 40257 |
| 17 | Crown | 2995 | 84350 | 48947 | 23305 | 1266 | 75385 | 24418 | 28679 | 605 | 36054 | 819 | 8850 |
| 17 | Bowater | 6107 | 400062 | 241672 | 84430 | - | - | - | - | 1844 | 158964 | 12559 | 30908 |
| 18 | Crown | - | - | - | - | - | - | - | - | 7946 | 425905 | 51109 | 114993 |
| 18 | Bowater | - | - | - | - | - | - | - | - | 2697 | 144542 | 17345 | 39028 |
| | GMNP | - | - | - | - | 13493 | 896703 | 204766 | 405454 | 3908 | 302522 | 36046 | 80530 |
| | TNNP | - | - | - | - | 2119 | 180172 | 30988 | 60542 | 413 | 36873 | 2212 | 8850 |
| All | Crown | 32220 | 2364196 | 1491074 | 640773 | 89685 | 6135582 | 1293527 | 3009230 | 87186 | 5574819 | 169895 | 1396412 |
| | Bowater | 52384 | 4305947 | 2770095 | 756863 | 61845 | 5095617 | 1434813 | 1682462 | 60361 | 5191506 | 533666 | 1359712 |
| | Price | 12254 | 901248 | 510409 | 275056 | 71474 | 5416275 | 1593502 | 1497463 | 28719 | 1888652 | 168649 | 449291 |
| | GMNP | - | - | - | - | 13493 | 896703 | 204766 | 405454 | 3908 | 302555 | 36046 | 80530 |
| | TNNP | - | - | - | - | 2119 | 180172 | 30988 | 60542 | 413 | 36873 | 2212 | 8850 |
| | Private | - | - | - | - | 248 | 20167 | 4839 | 6454 | 1224 | 102030 | 12243 | 35711 |
| Total Island | | 97158 | 7571391 | 4771578 | 1672692 | 238864 | 17744516 | 4562435 | 6661605 | 181811 | 13096402 | 922711 | 3330506 |

*A (Dead): 50% or more of total volume of stand dead.
B (Moribund): 20% to 49% of total volume of stand dead or more than 49% of total volume dying. Dying = more than 75% total defoliation.
C (Very severely damaged): 5% to 19% of total volume dead or 5% to 49% of total volume dying.

APPENDIX IVB.- DISTRIBUTION OF VOLUME OF DEAD TREES BY NUMBER OF YEARS SINCE DEATH IN PRODUCTIVE MERCHANTABLE STANDS DAMAGED BY THE SPRUCE BUDWORM IN NEWFOUNDLAND IN 1979.

| Management unit | Ownership | Volume dead and blowdown ($m^3$): A(Dead)* No. of years since death 1 | A 2 | A 3 | A 4 | A 5+ | B(Moribund)* No. of years since death 1 | B 2 | B 3 | B 4 | B 5+ | C(Very severe)* No. of years since death 1 | C 2 | C 3 | C 4 | C 5+ | Total dead[1] | Blowdown[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Crown | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2 | Crown | - | - | - | - | - | - | - | - | - | - | 1116 | - | - | - | - | 1116 | - |
| 4 | Crown | - | - | - | - | - | 61891 | 5348 | - | - | 3834 | - | - | - | - | - | 71073 | - |
| 4 | Price | - | - | - | - | - | 182707 | 91992 | 37227 | - | 4859 | 35627 | - | - | - | 5309 | 357721 | - |
| 5 | Crown | - | - | - | - | - | 40213 | 12542 | 10749 | - | 12542 | - | - | - | - | - | 76046 | - |
| 5 | Bowater | - | 39290 | - | - | - | 7693 | 4622 | 2571 | - | 2130 | 588 | - | 3617 | - | - | 60511 | 39290 |
| 5 | Price | - | - | - | - | - | 111361 | 54782 | 20873 | - | 16523 | 2453 | 612 | 6591 | - | - | 213195 | 11341 |
| 6 | Crown | - | - | - | - | - | 2863 | - | - | - | 3579 | - | - | - | - | - | 6442 | - |
| 6 | Bowater | 163981 | 18053 | 1506 | - | - | 192945 | 74067 | 42978 | - | 20789 | 124556 | 18502 | 8715 | - | 18988 | 685080 | 5717 |
| 6 | Price | - | - | - | - | - | 16048 | 20058 | 4013 | - | - | - | - | - | - | - | 40119 | - |
| 7 | Crown | - | - | - | - | 53895 | 96024 | 6738 | 6738 | - | 11161 | 14576 | 2285 | 3427 | - | 5406 | 200250 | 53895 |
| 8 | Crown | 43990 | 16631 | 31020 | - | 12527 | 62199 | 27951 | 31279 | - | 17942 | 25838 | - | 1089 | - | - | 269566 | 6558 |
| 8 | Bowater | 7526 | 5254 | 1294 | - | 4167 | 22230 | 20005 | 22230 | - | 13337 | - | - | - | - | - | 96043 | 6888 |
| 8 | Price | - | - | - | - | - | 16361 | 2861 | 3162 | - | 1906 | - | - | - | - | - | 24290 | 636 |
| 9 | Crown | - | - | - | - | - | 164709 | 16704 | 2044 | - | 15798 | 3157 | - | - | - | - | 202412 | 7235 |
| 9 | Bowater | 136302 | 32764 | 4610 | 5885 | 11452 | 38919 | 2928 | 976 | 1159 | 294 | 3013 | - | - | - | - | 238302 | 8840 |
| 9 | Price | - | - | - | - | - | 212140 | 58426 | 10271 | 8977 | 10329 | - | - | - | - | - | 300143 | 14781 |
| 10 | Crown | - | - | - | - | - | 7517 | 1253 | 940 | - | 939 | - | - | - | - | - | 10649 | 14768 |
| 10 | Price | 8611 | 1150 | 901 | - | - | 101357 | 6806 | 3752 | - | 3752 | 49351 | 1914 | - | - | 9563 | 187157 | 17586 |
| 11 | Price | - | - | - | - | - | 225311 | 6215 | 24016 | - | 4232 | 28175 | 210 | 1229 | - | 5909 | 295297 | - |
| 12 | Price | 69215 | 94347 | - | - | 21813 | 186382 | 8833 | 22478 | 2323 | 25076 | - | - | - | - | - | 430467 | 6844 |
| 13 | Price | 50063 | 24042 | 2364 | - | 9454 | 31289 | - | 11043 | - | 22085 | - | - | - | - | - | 150340 | 62241 |
| 14 | Crown | 384371 | 300317 | 14385 | 6423 | 186611 | 125402 | 34545 | 1926 | 2008 | 64766 | 84765 | 5709 | - | - | 3244 | 1214472 | 205975 |
| | Bowater | 205686 | 135341 | 2581 | 860 | 165478 | 259347 | 85109 | 5529 | 5459 | 186746 | 108628 | 23722 | - | - | - | 1184486 | 190270 |
| | Private | - | - | - | - | - | 1612 | 1007 | - | - | 2217 | 12243 | - | - | - | - | 17079 | 3463 |

Cont'd...

APPENDIX IVB.- Concluded

| Manage-ment unit | Owner-ship | Volume dead and blowdown ($m^3$) A(Dead)* No. of years since death 1 | 2 | 3 | 4 | 5+ | B(Moribund)* No. of years since death 1 | 2 | 3 | 4 | 5+ | C(Very severe)* No. of years since death 1 | 2 | 3 | 4 | 5+ | Total dead[1] | Blow-down[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | Crown | 128376 | 37757 | 7551 | - | 45310 | 20649 | 2261 | - | - | 1150 | - | - | - | - | - | 243054 | 43794 |
| | Bowater | 568413 | 259887 | 10271 | 35796 | 225750 | 102411 | 18651 | 1848 | - | 11723 | 80424 | 14301 | 3268 | 1665 | 21473 | 1355881 | 294656 |
| 16 | Crown | 590 | 778 | 63 | - | 248 | 127889 | 12440 | 2825 | 472 | 2603 | 2236 | - | - | - | 6712 | 156856 | 1798 |
| | Bowater | 80663 | 4760 | 2196 | - | 32547 | 55442 | 4451 | 5565 | 2227 | 12243 | 1289 | - | - | - | 3873 | 205256 | 19410 |
| 17 | Crown | 9510 | 21073 | 723 | - | 4360 | - | - | - | - | - | - | - | - | - | - | 35666 | 897 |
| | Bowater | 72587 | 156636 | - | - | 19102 | - | - | - | - | - | 5432 | 2827 | - | - | 2653 | 259237 | 6425 |
| 18 | Crown | - | - | - | - | - | - | - | - | - | - | 10088 | - | 15132 | 10088 | 25221 | 60529 | - |
| | Bowater | - | - | - | - | - | - | - | - | - | - | 2892 | - | 4336 | 2892 | 7228 | 17348 | - |
| | GMNP | - | - | - | - | - | 103652 | 46626 | 9283 | 4603 | 3752 | 24606 | 8522 | - | 2130 | 788 | 203962 | 11831 |
| | TNNP | - | - | - | - | - | 3967 | - | - | - | - | - | - | - | - | - | 3967 | - |
| All | Crown | 566837 | 376558 | 52842 | 6423 | 302951 | 709356 | 119782 | 56500 | 2480 | 134314 | 141776 | 7994 | 19649 | 10088 | 40583 | 2548131 | 334920 |
| | Bowater | 1235159 | 651985 | 22459 | 42541 | 458495 | 678986 | 209834 | 81697 | 8845 | 247262 | 326822 | 59351 | 19936 | 4557 | 54215 | 4102144 | 571496 |
| | Price | 127889 | 119538 | 3266 | - | 31267 | 1082957 | 249972 | 136835 | 11300 | 88763 | 115606 | 2735 | 7820 | - | 20781 | 1998729 | 113429 |
| | GMNP | - | - | - | - | - | 103652 | 46626 | 9283 | 4603 | 3752 | 24606 | 8522 | - | 2130 | 788 | 203962 | 11831 |
| | TNNP | - | - | - | - | - | 3967 | - | - | - | - | - | - | - | - | - | 3967 | - |
| | Private | - | - | - | - | - | 1612 | 1007 | - | - | 2217 | 12433 | - | - | - | - | 17080 | 3463 |
| Total Island $m^3$ | | 1929885 | 1148081 | 78566 | 48964 | 792714 | 2580530 | 627222 | 284315 | 27228 | 476308 | 621053 | 78602 | 47405 | 16776 | 116367 | 8874013 | 1035139 |
| % of Total Dead | | 22.1 | 13.1 | 0.9 | 0.6 | 9.0 | 29.0 | 7.0 | 3.0 | 0.3 | 5.0 | 7.0 | 0.9 | 0.5 | 0.2 | 1.4 | 100.0 | 11.6 |

*A (Dead): 50% or more of total volume of stand dead.
B (Moribund): 20% to 49% of total volume of stand dead or more than 49% of total volume dying. Dying = more than 75% total defoliation.
C (Very severely damaged): 5% to 19% of total volume dead or 5% to 49% of total volume dying.

[1]Excluded 1578993 $m^3$ (655184 cds) dead volume not stratified for age as no ground checks were conducted in some areas.

[2]Blowdown volume is included in Total Dead volume.

APPENDIX VA. - AREA AND VOLUME OF PRODUCTIVE MERCHANTABLE STANDS WITH DEAD AND DYING TREES FROM SPRUCE BUDWORM DAMAGE IN NEWFOUNDLAND IN 1980.

| Management unit no. | Ownership | Area and volume affected: A (Dead)* Total area (ha) | A (Dead)* Total volume ($m^3$) | A (Dead)* Dead volume ($m^3$) | A (Dead)* Dying volume ($m^3$) | B (Moribund)* Total area (ha) | B (Moribund)* Total volume ($m^3$) | B (Moribund)* Dead volume ($m^3$) | B (Moribund)* Dying volume ($m^3$) | C (Very severe)* Total area (ha) | C (Very severe)* Total volume ($m^3$) | C (Very severe)* Dead volume ($m^3$) | C (Very severe)* Dying volume ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Crown | 2556 | 178928 | 125250 | - | 4233 | 296366 | 22505 | 118135 | 1369 | 95819 | - | 26008 |
| 2 | Crown | 981 | 78525 | 48427 | 3405 | 3568 | 285512 | 56488 | 70211 | 2666 | 212553 | 11740 | 46071 |
| 4 | Price | 5755 | 494930 | 369464 | 95839 | 13073 | 1124278 | 249951 | 180843 | 3284 | 282424 | 30290 | 52407 |
| 5 | Crown | - | - | - | - | 1084 | 93224 | 29283 | 14361 | 4643 | 399298 | 36802 | 46511 |
| | Bowater | 300 | 25800 | 22403 | 2718 | 2039 | 175354 | 41247 | 47394 | 321 | 27606 | 2761 | 5522 |
| | Price | 156 | 13416 | 13416 | - | 3038 | 261268 | 77809 | 50127 | 178 | 15308 | 1531 | 3062 |
| 6 | Crown | 580 | 49880 | 19952 | 14964 | - | - | - | - | - | - | - | - |
| | Bowater | 13667 | 1175792 | 945983 | 61197 | 17641 | 1440310 | 390500 | 327346 | 2633 | 187518 | 21320 | 58048 |
| | Price | 865 | 74390 | 33660 | 24281 | 1459 | 125474 | 27531 | 36626 | 466 | 30756 | 3691 | 12302 |
| 7 | Crown | 11529 | 631411 | 432114 | 153319 | 12270 | 844214 | 162983 | 260029 | 4114 | 302955 | 24603 | 38142 |
| 8 | Crown | 8736 | 721619 | 550577 | 97175 | 9238 | 763920 | 273399 | 145630 | 5787 | 468747 | 59555 | 24776 |
| | Bowater | - | - | - | - | 1166 | 94446 | 39667 | 12278 | - | - | - | - |
| 9 | Crown | 5744 | 557168 | 270364 | 77899 | 4798 | 465406 | 113426 | 50682 | 1953 | 189441 | 20839 | - |
| | Bowater | 5607 | 549681 | 336752 | 18391 | 18136 | 1760284 | 442063 | 210381 | 4759 | 461623 | 50979 | 86438 |
| | Price | 3670 | 355990 | 193904 | 71964 | - | - | - | - | 952 | 92344 | 9234 | 27703 |
| 10 | Crown | - | - | - | - | 2383 | 240683 | 86646 | 19255 | - | - | - | - |
| | Price | 8794 | 888194 | 445570 | 67076 | 12884 | 1301284 | 434819 | 170285 | 2863 | 289163 | 41501 | 65775 |
| 11 | Price | 7619 | 700672 | 451701 | 146602 | 16529 | 1520668 | 510546 | 150194 | 2252 | 207184 | 24151 | 17094 |
| 12 | Price | 4474 | 411608 | 317866 | 50469 | 10931 | 1005652 | 362317 | 123570 | 2315 | 212980 | 25309 | 10378 |
| 13 | Price | 5139 | 472788 | 369343 | 2861 | 666 | 61272 | 26347 | - | - | - | - | - |
| 14 | Crown | 12127 | 1384971 | 950254 | 101808 | 16326 | 1779534 | 596587 | 318326 | 5988 | 652692 | 72765 | 49719 |
| | Bowater | 12054 | 1314636 | 1040898 | 172577 | 8829 | 962361 | 290522 | 113220 | 3621 | 394689 | 55396 | 26164 |
| | Private | - | - | - | - | 1341 | 146169 | 37707 | 4954 | - | - | - | - |
| 15 | Crown | 5612 | 611708 | 500364 | 32991 | 2318 | 252662 | 63022 | 19751 | 393 | 42837 | 5140 | 9424 |
| | Bowater | 28348 | 2944368 | 2198899 | 94512 | 8664 | 944376 | 345592 | 107406 | 7106 | 774554 | 78396 | 57808 |
| 16 | Crown | 2934 | 319806 | 160305 | 8531 | 1484 | 153212 | 55886 | 20719 | - | - | - | - |
| | Bowater | 6109 | 665227 | 450828 | 4433 | 4976 | 542384 | 171664 | - | 845 | 92105 | 9210 | 9210 |

Cont'd ...

APPENDIX VA. - Concluded

| Manage-ment unit no. | Ownership | Area and volume affected: A (Dead)* Total area (ha) | A (Dead)* Total volume ($m^3$) | A (Dead)* Dead volume ($m^3$) | A (Dead)* Dying volume ($m^3$) | B (Moribund)* Total area (ha) | B (Moribund)* Total volume ($m^3$) | B (Moribund)* Dead volume ($m^3$) | B (Moribund)* Dying volume ($m^3$) | C (Very severe)* Total area (ha) | C (Very severe)* Total volume ($m^3$) | C (Very severe)* Dead volume ($m^3$) | C (Very severe)* Dying volume ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | Crown | 4930 | 394679 | 293686 | 15896 | 1374 | 124512 | 42615 | 8393 | 2811 | 248250 | 24825 | - |
| | Bowater | 5333 | 405308 | 213762 | 96936 | 1366 | 107416 | 26183 | - | 934 | 87616 | 8762 | - |
| | Price | 37 | 2812 | 2812 | - | 155 | 11780 | 3298 | - | - | - | - | - |
| 18 | Bowater | 2042 | 285880 | 200004 | 8560 | 2159 | 302260 | 55692 | 21041 | - | - | - | - |
| | GMNP | 2732 | 269872 | 196069 | 12260 | 2452 | 240895 | 129496 | - | 8298 | 756672 | 113586 | - |
| | TNNP | 664 | 53148 | 26574 | 6865 | 847 | 68107 | 22804 | 11811 | 408 | 32695 | 3277 | 5177 |
| All | Crown | 55729 | 4928694 | 3351293 | 505988 | 59076 | 5299245 | 1502840 | 1045492 | 29724 | 2612592 | 256269 | 240651 |
| | Bowaters | 73460 | 7366692 | 5409529 | 459324 | 64976 | 6329191 | 1803130 | 839066 | 20219 | 2025711 | 226824 | 243190 |
| | Price | 36509 | 3414800 | 2197741 | 459092 | 58735 | 5411676 | 1692618 | 711645 | 12310 | 1130159 | 135707 | 188721 |
| | GMNP | 2732 | 269872 | 196069 | 12260 | 2452 | 240895 | 129496 | - | 8298 | 756672 | 113586 | - |
| | TNNP | 664 | 53148 | 26574 | 6865 | 847 | 68107 | 22804 | 11811 | 408 | 32695 | 3277 | 5177 |
| | Private | - | - | - | - | 1341 | 146169 | 37707 | 4954 | - | - | - | - |
| Total Island | | 169094 | 16033206 | 11181206 | 1443529 | 187427 | 17495283 | 5188595 | 2612968 | 70959 | 6557829 | 735663 | 677739 |

*A (Dead): 50% or more of total volume of stand dead.
B (Moribund): 20% to 49% of total volume of stand dead or more than 49% of total volume dying. Dying = more than 75% total defoliation.
C (Very severely damaged): 5% to 19% of total volume dead or 5% to 49% of total volume dying.

APPENDIX VB.- DISTRIBUTION OF VOLUME OF DEAD TREES BY NUMBER OF YEARS SINCE DEATH IN PRODUCTIVE MERCHANTABLE STANDS DAMAGED BY THE SPRUCE BUDWORM IN NEWFOUNDLAND IN 1980.

| Manage-ment unit no. | Owner-ship | Volume dead and blowdown ($m^3$) | | | | | | | | | | | | | | | | | | Vol. dead ground checked ($m^3$) | Vol. dead not checked ($m^3$) | Total vol. dead ($m^3$) | Vol. blowdown ($m^3$) | Vol. standing dead ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A (Dead)* | | | | | | B (Moribund)* | | | | | | C (Very severe)* | | | | | | | | | | |
| | | No. of years since death | | | | | | No. of years since death | | | | | | No. of years since death | | | | | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6+ | 1 | 2 | 3 | 4 | 5 | 6+ | 1 | 2 | 3 | 4 | 5 | 6+ | | | | | |
| 1 | Crown | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 147755 | 147755 | 8111 | 139644 |
| 2 | " | - | - | - | - | - | - | 3059 | - | - | - | - | - | 269 | - | - | 2441 | - | - | 5769 | 110886 | 116655 | 269 | 116386 |
| 4 | Price | - | - | - | - | - | - | 54649 | - | 2556 | 1704 | - | 109450 | 2916 | 2111 | - | - | - | 23339 | 196725 | 452980 | 649705 | 125833 | 523872 |
| 5 | Crown | - | - | - | - | - | - | 18560 | - | 3275 | - | - | - | 21702 | - | - | - | - | 13991 | 57528 | 8557 | 66085 | 33952 | 32133 |
| | Bowater | - | - | - | - | - | - | 16090 | 1189 | 4280 | 951 | - | 6215 | - | - | - | - | - | - | 28725 | 37686 | 66411 | 25717 | 40694 |
| | Price | - | - | - | - | - | - | 15060 | 2688 | 12542 | 2532 | - | 30759 | - | - | - | - | - | - | 63581 | 29175 | 92756 | 26625 | 66131 |
| 6 | Crown | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 19952 | 19952 | - | 19952 |
| | Bowater | 130240 | 3908 | 33014 | 1609 | - | 312700 | 107601 | 5062 | 16245 | 30753 | - | 53819 | 15412 | 900 | 1671 | - | - | - | 712934 | 644869 | 1357803 | 918796 | 439007 |
| | Price | - | - | - | - | - | - | 3442 | - | - | 2013 | - | 974 | 3691 | - | - | - | - | - | 10120 | 54762 | 64882 | 3442 | 61440 |
| 7 | Crown | - | - | - | - | - | - | 27245 | - | - | - | - | - | - | 1762 | 3272 | 1514 | - | - | 33793 | 585907 | 619700 | 79059 | 540641 |
| 8 | " | 34627 | 82240 | 28392 | 5367 | - | 124146 | 43310 | 14814 | 25358 | 17982 | - | 159285 | 17215 | - | 3859 | - | - | 25597 | 582192 | 301339 | 883531 | 59345 | 824186 |
| | Bowater | - | - | - | - | - | - | 8330 | 3173 | 2777 | 1983 | - | 23404 | - | - | - | - | - | - | 39667 | - | 39667 | 23404 | 16263 |
| 9 | Crown | 119493 | 17860 | 46004 | 33610 | 4808 | 2871 | 59808 | 5664 | 3618 | 7115 | - | 2938 | 20839 | - | - | - | - | - | 324628 | 80001 | 404629 | 43645 | 360984 |
| | Bowater | 47735 | - | 11572 | 13019 | - | - | 89259 | 1445 | 14880 | 40139 | - | - | 13862 | 1555 | 6866 | - | - | - | 240332 | 589462 | 829794 | 143925 | 685869 |
| | Price | 20414 | 11538 | 38165 | 9763 | - | 8876 | - | - | - | - | - | - | - | - | - | - | - | - | 88756 | 114382 | 203138 | 105148 | 97990 |
| 10 | Crown | - | - | - | - | - | - | 52855 | 6065 | 1733 | 2599 | - | 23394 | - | - | - | - | - | - | 86646 | - | 86646 | 12893 | 73753 |
| | Price | 79656 | 49779 | 26176 | 44700 | - | 65770 | 201261 | 38874 | 13714 | 9390 | - | 98383 | 13427 | 15392 | - | - | - | 12621 | 669143 | 252747 | 921890 | 62882 | 859008 |
| 11 | " | - | - | - | - | - | - | 119163 | 71107 | 69775 | - | - | 140724 | 17731 | - | 2780 | - | - | 1956 | 423236 | 563162 | 986398 | 159612 | 826786 |
| 12 | " | 179863 | 12080 | 8231 | 6293 | - | 2048 | 281591 | 27241 | 7106 | 30794 | - | 4738 | 9899 | - | 1293 | 8928 | - | - | 580185 | 125387 | 705492 | 122833 | 582659 |
| 13 | " | 120617 | 28526 | 25819 | 20175 | 6851 | - | 24503 | 790 | 1054 | - | - | - | - | - | - | - | - | - | 228335 | 167360 | 395695 | 355072 | 40623 |
| 14 | Crown | 398477 | 51097 | 60885 | 30834 | - | 50163 | 326766 | 112558 | 96857 | 20993 | - | 10921 | 30004 | - | - | - | - | - | 1189555 | 430051 | 1619606 | 585952 | 1033654 |
| | Bowater | 373150 | 108251 | 109302 | 90515 | 8028 | 37588 | 173225 | 45926 | 30779 | 23939 | - | - | 37219 | 5981 | 1678 | 1661 | 709 | - | 1047954 | 338862 | 1386816 | 393853 | 992963 |
| | Private | - | - | - | - | - | - | 29645 | 4995 | 1383 | 1624 | - | - | - | - | - | - | - | - | 37647 | 60 | 37707 | 27651 | 10056 |
| 15 | Crown | 185593 | 9128 | 27383 | 42595 | - | 39553 | 36924 | 4941 | 15705 | 5142 | - | - | 5140 | - | - | - | - | - | 372104 | 196422 | 568526 | 160654 | 407872 |
| | Bowater | 411023 | 46455 | 91013 | 84803 | 5154 | 50760 | 206472 | 28040 | 24330 | 7267 | 1440 | 5844 | 42662 | 9934 | 185 | - | - | - | 1015382 | 1607505 | 2622887 | 682378 | 1940509 |
| 16 | Crown | 54837 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 54837 | 161354 | 216191 | - | 216191 |
| | Bowater | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 631702 | 631702 | 76737 | 554965 |

Cont'd ...

APPENDIX VB - Concluded

| Manage-ment unit no. | Owner-ship | Volume dead and blowdown ($m^3$) A (Dead)* No. of years since death | | | | | | B (Moribund)* No. of years since death | | | | | | C (Very severe)* No. of years since death | | | | | | Vol. dead ground checked ($m^3$) | Vol. dead not checked ($m^3$) | Total[1] vol. dead ($m^3$) | Vol. blowdown ($m^3$) | Vol. standing dead ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6+ | 1 | 2 | 3 | 4 | 5 | 6+ | 1 | 2 | 3 | 4 | 5 | 6+ | | | | | |
| 17 | Crown | 154336 | 31343 | 73364 | 30453 | - | - | 26798 | 3695 | 8063 | 1984 | - | 2075 | 6146 | 4338 | 7592 | - | - | - | 350187 | 10939 | 361126 | 60034 | 301092 |
| | Bowater | 79529 | 49248 | 78135 | 7193 | - | - | 5837 | 1100 | 423 | 1015 | - | - | 8686 | - | - | - | - | - | 231166 | 17541 | 248707 | 10188 | 238519 |
| | Price | - | - | - | - | - | - | 989 | 759 | 330 | - | - | 1220 | - | - | - | - | - | - | 3298 | 2312 | 6110 | 4219 | 1891 |
| 18 | Bowater | 128394 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 128394 | 127302 | 255696 | - | 255696 |
| | GMNP[2] | 101965 | 12435 | 9947 | - | - | - | 34041 | - | - | - | - | - | 81087 | - | - | - | - | - | 239475 | 199676 | 439151 | 56541 | 382610 |
| | TNNP[3] | - | - | - | - | - | - | 12716 | 2586 | - | 6250 | - | - | 1999 | - | - | 1278 | - | - | 24829 | 27826 | 52655 | 1563 | 51092 |
| All | Crown | 947363 | 191668 | 236028 | 142859 | 4808 | 216733 | 595325 | 147737 | 154609 | 55815 | - | 198613 | 101315 | 6100 | 14723 | 3955 | - | 39588 | 3057239 | 2053163 | 5110402 | 1043914 | 4066488 |
| | Bowater | 1170071 | 207865 | 323036 | 197139 | 13182 | 401048 | 606814 | 85935 | 93714 | 106047 | 1440 | 89282 | 117841 | 18370 | 10400 | 1661 | 709 | - | 3444554 | 3994929 | 7439483 | 2274998 | 5164485 |
| | Price | 400550 | 101923 | 98391 | 80931 | 6851 | 76694 | 700658 | 141459 | 107077 | 46433 | - | 386248 | 47664 | 17503 | 4073 | 8928 | - | 37916 | 2263299 | 1762767 | 4026066 | 965666 | 3060400 |
| | GMNP | 101965 | 12435 | 9947 | - | - | - | 34041 | - | - | - | - | - | 81087 | - | - | - | - | - | 39475 | 199676 | 439151 | 56541 | 382610 |
| | TNNP | - | - | - | - | - | - | 12716 | 2586 | - | 6250 | - | - | 1999 | - | - | 1278 | - | - | 24829 | 27826 | 52655 | 1563 | 51092 |
| | Private | - | - | - | - | - | - | 29645 | 4995 | 1383 | 1624 | - | - | - | - | - | - | - | - | 37647 | 60 | 37707 | 27651 | 10056 |
| Total Island | | 2619949 | 513891 | 667402 | 420929 | 24841 | 694475 | 1979199 | 382712 | 356783 | 216169 | 1440 | 674143 | 349906 | 41973 | 29196 | 15822 | 709 | 77504 | 9067043 | 8038421 | 17105464 | 4370333 | 13735131 |
| % of dead ground checked | | 29 | 6 | 7 | 5 | 0.3 | 8 | 22 | 4 | 4 | 2 | 0.02 | 7 | 4 | 0.5 | 0.3 | 0.2 | - | 0.8 | 100 | | | | |

*A (Dead): 50% or more of total volume of stand dead.
B (Moribund): 20% to 49% of total volume of stand dead or more than 49% of total volume dying. Dying = more than 75% total defoliation.
C (Very severely damaged): 5% to 19% of total volume dead or 5% to 49% of total volume dying.

[1] Total volume dead = Volume of dead ground checked + Volume of dead not checked = Volume of blowdown + Volume of standing dead.

[2] GMNP - Gros Morne National Park.

[3] TNNP - Terra Nova National Park.

## APPENDIX VI. SOURCE LIST OF SUPPLIES FOR A B.T. SPRAY PROGRAM

| | |
|---|---|
| Thuricide 16B, 32 B | Mr. Tom Holt<br>District Manager<br>Sandoz Inc.<br>Rte. 3, Box 115<br>Albany, MO. 64402<br>(816) 726-3025 |
| Chevron spray sticker | Mr. Jack Oakley<br>Chevron Chemicals<br>Toronto, Ontario<br>(416) 681-2201 |
| Erio Acid Red<br>XB 400% | Ciba-Geigy Canada Limited<br>1 Westside Drive<br>Etobicoke, Ontario<br>M9C 1B2<br>(416) 622-3710 |
| Sorbitol 70% | Atlas Chemical Industries Limited<br>Brantford, Ontario<br>(519) 756-6181 |
| Millipore filters<br>(47 mm gridded)<br>cat. no. HABG04700 | Millipore Limited<br>3610 Nashua Drive<br>Mississauga, Ontario<br>L4V 1L2 |
| Chitinase | Dr. Peter Zeigler<br>Canada Packers Limited<br>2211 St. Claire Ave. W.<br>Toronto, Ontario<br>M6N 1K4<br>(416) 766-4311 |
| Plastic culture plates | Fisher Scientific<br>Toronto, Ontario |
| Kromekote paper<br>(deposit cards cut<br>to 10 x 10 cm) | Mfg. by Kruger Pulp & Paper<br>Montreal, Quebec<br>Available from Inter-City Papers<br>2455 Kaladar Drive<br>Ottawa, Ontario<br>(613) 733-1744 |