THE SPRUCE BUDWORM

INTEGRATED MANAGEMENT APPROACH TO OUTBREAKS

Photo 1 - Mature caterpillar

BIOLOGY, HOSTS AND BEHAVIOUR

The spruce budworm, *Choristoneura fumiferana* [Clem.], is the most destructive insect in North America's conifer stands (photo 1). This native defoliator is found in all Canada's provinces, from British Columbia to Newfoundland. In Québec, it is common throughout the distribution area of its main hosts, the white, red and black spruce and the balsam fir, which is by far its favourite species. During outbreaks, it can also be found on other softwood species.

The spruce budworm's life cycle spans a single year. It begins with an egg stage, six instars, a pupal stage and an adult (moth) stage. During its second instar, the insect spends the winter in a small silk cocoon known as a *hibernaculum*, woven into bark crevices, bud scales, tree lichen or the cupules of its host's flowers (photo 3).

In late April or early May, the young caterpillars, measuring approximately 1.5 mm long, come out of hibernation. Attracted by the light, they crawl to the ends of the branches, where they feed on flower pollen as they wait for the buds to open (photo 4). If there are no flowers, they mine old needles and closed buds (photo 5). However, as soon as the new shoots appear, the caterpillars weave a cocoonlike shelter composed of their own excrement and needle debris mixed with silk threads. They feed off the shoots (photo 6) until their sixth and last instar, i.e. until the end of June (photo 7). It is at this point that the damage is most apparent (photos 2 and 11). Sometimes, when the year's foliage is entirely destroyed, caterpillars in their last two instars eat the previous year's needles. In fact, fifth and sixth instar caterpillars are responsible for more than 85% of all defoliation (photo 12).

Photo 2 - General appearance of severe damage in early July

During outbreaks, it is common to see large numbers of caterpillars hanging from the ends of silk threads. This allows them to spin further down the tree canopy, or to be carried considerable distances by air currents.

THE SPRUCE BUDWORM'S LIFE CYCLE, *Choristoneura fumiferana* [Clem.]

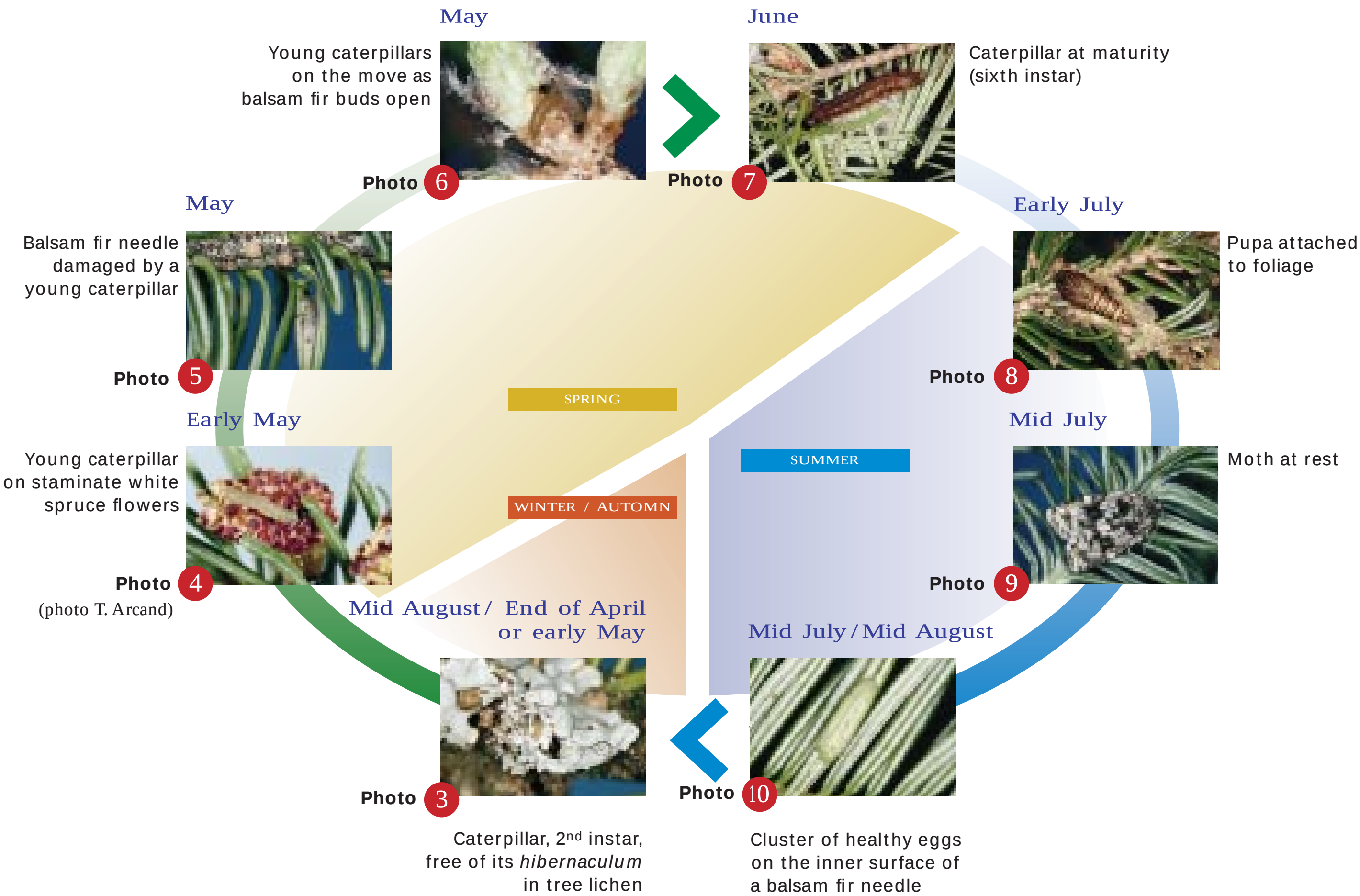


Photo 11 - Complete destruction of balsam fir buds and foliage

(photo G.Therriault)

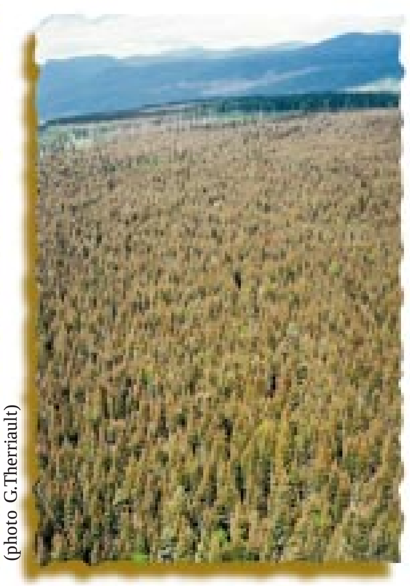
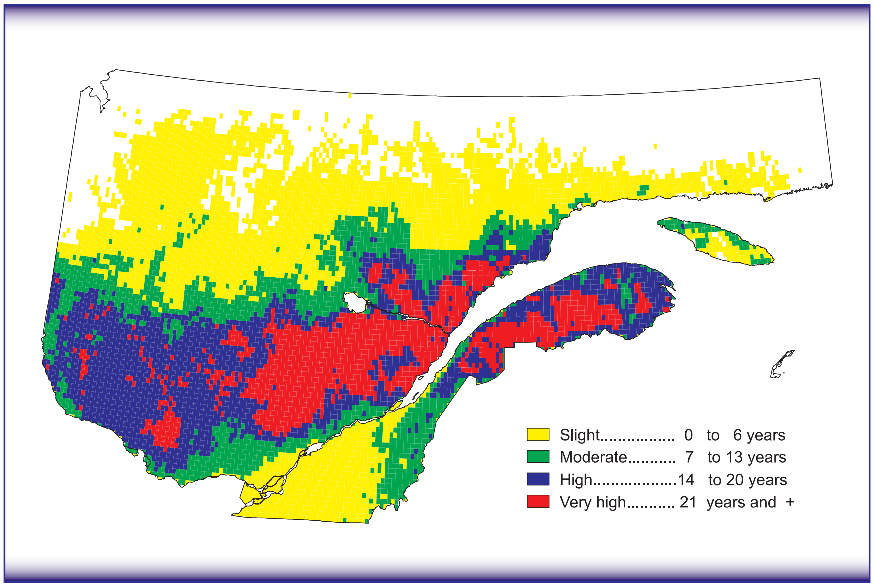


Photo 12 - Fir stand in July, after heavy defoliation

By the time it reaches maturity, the caterpillar measures between 20 mm and 30 mm long. It has a dark brown back with yellow and occasional white markings. Its head and the upperside of the first thoracic segment are dark brown or black (photo 7). In early July, the caterpillar turns into a pupa. This stage occurs either in the shelter, or on a lower branch of a defoliated tree, and the insect hangs on silk threads (photo 8). The pupal stage lasts between 10 and 14 days, after which the moth emerges. The moth does not feed, and it lives for approximately 10 days, just long enough to mate. It is drab in colour (brown-grey) and its wings, measuring approximately 22 mm, have numerous dark, often greyish markings (photo 9). Air currents sometimes carry the moths over large distances, thereby promoting the insect's dispersal.

In July and August, the female lays up to 200 eggs, which it leaves in clusters of 10 to 50 on the lower side of the host tree's needles, in the upper part of the canopy. The eggs are imbricated, and form masses of apple green colour (photo 10). After incubation, which lasts between 10 and 14 days, the young caterpillars emerge. Instead of feeding, they quickly weave a silk cocoon, in which they will spend the winter months after their first instar.



Map 1 - Frequency of Spruce Budworn Outbreaks from 1938 to 1992

OUTBREAK HISTORY

Spruce budworm outbreaks have devastated huge areas of forests on a more or less regular basis since the 18th century. In Québec, only the outbreaks occurring in the 20th century have been documented, i.e. those beginning in 1909, 1938, 1967 and 1992 (map 1). The first three infestations damaged 30 Mha, 26 Mha and 35 Mha of softwood forests respectively. The outbreak that began in 1967 and ended in 1992 is estimated to have caused tree mortality in 12.9 Mha of commercial forests. It is difficult to say exactly how much timber was involved, although data collected from the public forest suggest that the insect destroyed between 139 Mm^3 and 238 Mm^3 of fir and spruce. At the time, the forest industry was harvesting approximately 23 Mm^3 of softwood timber per year from Québec's public forests.

EPIDEMIOLOGY

Our perception of spruce budworm epidemiology has progressed significantly. Until recently, it was thought that populations remained relatively stable, and then increased suddenly during outbreaks. However, the experts now know that spruce budworm populations fluctuate constantly. The earlier misconception can be explained by the survey methods used to measure population densities, which are much more reliable with large populations than with smaller ones. In fact, spruce budworm populations increase gradually, reaching outbreak proportions approximately once every 30 years (the interval between outbreaks is slightly shorter in the eastern portion of the province).

These cyclical changes in the number of insects occur simultaneously over huge areas. Contrary to former belief, outbreaks do not start at the infestation sites that are simply the first areas where spruce budworm proliferate in a given region, due to forest composition or climate. Population growth, which occurs throughout the entire region, simply manifests itself more quickly at this site.

Since spruce budworm populations fluctuate naturally, outbreaks are not triggered by specific phenomena and do not originate at specific sites, but are the result of normal cyclical changes. The experts are therefore no longer attempting to identify the factors that cause infestations, but are concentrating instead on the mechanisms underlying the cyclical fluctuations. These factors could include predation, parasitism, diseases, available food and climate, all of which are considered briefly in the following paragraphs.

According to current knowledge, climate does not change the cyclical nature of infestations, but it might alter the frequency or length of outbreak cycles, and may also affect the average number of insects during the cycle. Some researchers think reductions in spruce budworm populations are caused by defoliation and the death of trees damaged by repeated attacks. However, the findings suggest that, at the end of an outbreak, populations decline simultaneously over very large areas, even where defoliation is not significant. Availability of food therefore does not seem to be as important as was first thought.

Two groups of natural enemies, predator birds and several parasitoid species, help reduce spruce budworm populations at the end of outbreaks. They often feed off the insects, but their efforts have little effect until populations start to decline due to other causes. They are therefore not responsible for the initial drop in numbers, but simply enhance the decline when it begins. The diseases affecting the spruce budworm have received little attention so far, because the experts thought they did not have much impact on populations. However, some recent findings have suggested that their role may be somewhat greater.

It is therefore clear that none of the five factors, taken alone, explains the fluctuations in spruce budworm populations. Interactions undoubtedly take place that we do not yet understand. Each factor probably produces different effects depending on the cycle phase and the sites involved. Further research is needed to achieve a better understanding of spruce budworm epidemiology.

IMPACTS

The most spectacular effect of a spruce budworm epidemic is without question the number of dead trees in old fir stands. Succeeding stands contain a large number of fir trees, and sometimes white birch trees.

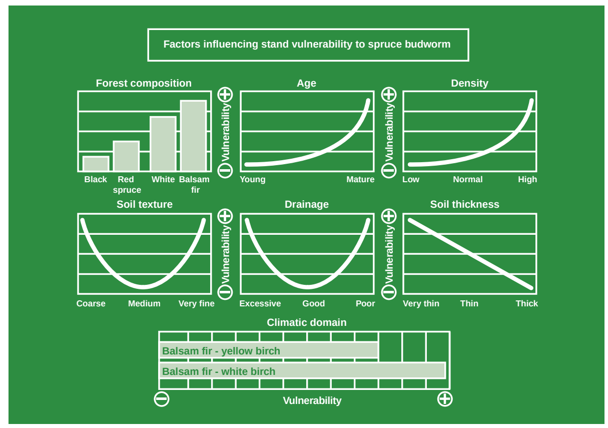
In young, very dense stands, repeated defoliation kills varying percentages of trees. The less resistant specimens die first. If defoliation does not occur, the same thinning process still takes place, but over a much longer period.

All trees that undergo defoliation of 20% or more exhibit lower annual growth rates. This decline can last several years, and inevitably leads to volume losses. However, the losses are compensated at least in part by improved growth among companion species following natural thinning. Several years after an epidemic, the species most vulnerable to the spruce budworm also undergo a growth revival, especially in immature stands, although the initial growth slowdown may still delay final harvesting.

Current knowledge of host-insect-environment relations allows us to explain and even forecast the effects of outbreaks. For example, we know that stand vulnerability depends on the characteristics of the stands themselves, the sites on which they grow (photo 13) and the factors that influence the insect's population dynamics.

For instance, the fir is more vulnerable than the spruce, partly because its foliage is less abundant, and partly because insect development is better synchronized with the growth of new shoots.

At the same time, a number of physiological mechanisms also explain why older and denser stands, and stands growing on excessively or poorly drained ground, are more vulnerable (photo 13).



R. Gagnon et M. Chabot

Photo 13 - Factors affecting stand vulnerability to the spruce budworm

(photo G.Therriault)

Photo 14 - Appearance of a dead fir stand after several heavy defoliations

Stand vulnerability also depends on the duration of the outbreak and the extent of the defoliation. Some of the most vulnerable stands are therefore found in areas where epidemics are frequent or very frequent, where the climate is particularly suited to the spruce budworm, or where the vegetation is not favourable to the insect's natural enemies. In mature stands growing in such areas, a spruce budworm outbreak kills an average of 75% of all fir trees, although actual figures can range from 30% to 95%, depending on stand density and site quality (photo 14). In immature stands, mortality is around 50%, but can range from 20% to 95%. In spruce stands, mortality rates are generally below 30%.

During an outbreak, the weaker trees usually die after three or four years of heavy defoliation, and most of the trees die between six and 10 years after the first attack (photo 14). The damaged trees continue to die even when the spruce budworm population returns to its endemic level.

The dead trees are attacked by a range of insects and fungal species, and deteriorate quickly. Three or four years after death, half are broken, and for fir trees, sap rot has taken over 30% of the tree's volume. After a further two years, more than 80% of the dead trees are broken at different heights.

In addition to their direct impact on timber harvesting and processing, spruce budworm outbreaks produce a number of difficult-to-quantify consequences, both positive and negative, for wildlife, lanscapes and leisure activities.

INTEGRATED MANAGEMENT OF SPRUCE BUDWORM OUTBREAKS

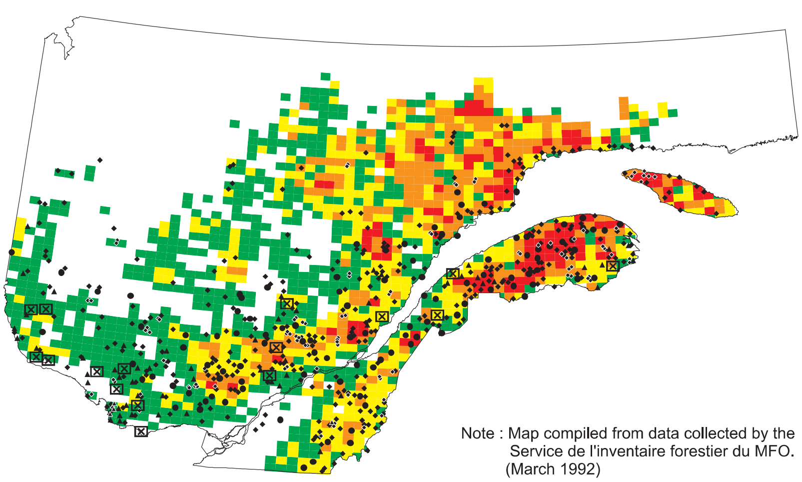
In 1994, the Québec government adopted a *Forest Protection Strategy* in which it proposed a number of approaches to counter the negative effects of spruce budworm epidemics. These approaches are based on current knowledge of the insect, its hosts and the forest environment. Before the strategy was adopted, direct control methods were used, and the damaged timber was salvaged. Since adoption, however, emphasis has been placed on prevention of outbreaks and timber losses. Preventive measures must now be incorporated into forest management, from the planning stage onwards. To be effective, they must obviously take into account the dynamics of stands and insect populations.

DETECTING AND MONITORING OUTBREAKS

Québec now has a system to detect and monitor spruce budworm populations and the damage caused by the insect. The system, which allows Québec to apply its *Forest Protection Strategy*, is based on a network of permanent observation stations, with other stations added on a case-by-case basis where necessary (map 2). Station selection is dictated by outbreak history and current forest profiles.

The experts use sampling techniques that allow them to measure fluctuations at the insect's different development stages (a network of pheromone traps) (photo 15), even when numbers are very low. Based on the data collected (photo 16), not only can they measure population size, but they can also predict short-term and medium-term trends.

By measuring seasonal and cumulative defoliations, they can monitor the health of the forests. They begin



Network of Stations	Spruce Budworm
Intensive monitoring of destructive insect (Experimental forests)	⊠
Early detection of populations (Sites of canopy traps)	▲
Long-term monitoring of populations (Sites of traps under forest cover)	●
Extensive monitoring of damage	◆

Forestry Statistics
White Spruce - Balsam Fir

	Area (ha)	Area (%)	m³ / ha (± C.L. 95 %)	Stem / ha (± C.L. 95 %)
	8875 and +	36 and +	74,2 ± 4,4	682 ± 46
	5126 to 8875	21 to 35	52,5 ± 2,3	484 ± 20
	2626 to 5125	11 to 20	40,9 ± 1,5	397 ± 14
	876 to 2625	4 to 10	29,8 ± 1,3	282 ± 12
	875 and -	3 and -	23,7 ± 1,6	233 ± 15

Map 2 - Network of permanent Spruce Budworn observation stations

Photo 15 - Pheromone trap

Photo 16 - Branch sampling

by taking intermittent measures in the sampling network, and by carrying out aerial reconnaissance (using aircraft or helicopters) to assess the scope and severity of the damage. Lastly, they make periodic use of satellite imaging to complete their data on certain forest areas.

PREVENTION

If timber losses are to be prevented, the most vulnerable stands must be harvested first, well before outbreaks occur. The stands at risk must therefore be identified and classified according to vulnerability. Access, in the shape of forest roads, must also be developed.

Stand resistance to the spruce budworm can also be enhanced by modifying their composition and reducing their density. For example, precommercial (photo 17) and commercial thinning carried out in outbreak-free periods helps reduce the percentage of fir trees, which are replaced with less vulnerable species. This type of cutting improves the growth rate and vigour of the residual trees, strengthens their defences against both insects and diseases and promotes more abundant foliage. If care is taken to maintain a broad plant diversity during thinning of mixed stands, it is possible to promote natural spruce budworm control agents.

(photo G.Therriault)

Photo 17 - Precommercial thinning

Some of the anticipated losses can also be compensated by intensive management work in less vulnerable stands. Lastly, the plants used in reforestation must be of species that are well suited to the sites and resistant to the insect.

Inclusion of these measures in forest management planning is the first step in the implementation of the *Forest Protection Strategy*. It is at the planning stage that the measures to be applied are decided, the areas concerned are established, and the schedule of work is drawn up. The sectors in which indirect measures alone will be insufficient to achieve anticipated yields, and where direct control and salvage will be required, are also identified at this stage. In some cases, yield losses must be expected.

DIRECT CONTROL

Direct control is sometimes the only effective way of countering the socio-economic impact of spruce budworm outbreaks on some vulnerable forest tracts. The Société de protection des forêts contre les insectes et maladies (SOPFIM), a private non-profit organization, is responsible for planning and implementing aerial biological insecticide spraying programs.

Contrary to popular belief, the goal of the spraying programs is not to eliminate the spruce budworm, but to reduce population levels in order to protect at least 50% of annual foliage.

Since 1987, the only insecticide that may be used in Québec against the spruce budworm is *Bacillus thuringiensis* var. *kurstaki*, commonly known as *B.t*. This is a biological insecticide that acts exclusively on the larvae of lepidoptera, and is known to be safe for human health and the environment. When ingested in sufficient quantities, *B.t.* paralyses the intestines of the insects, which are consequently unable to feed and die some hours later.

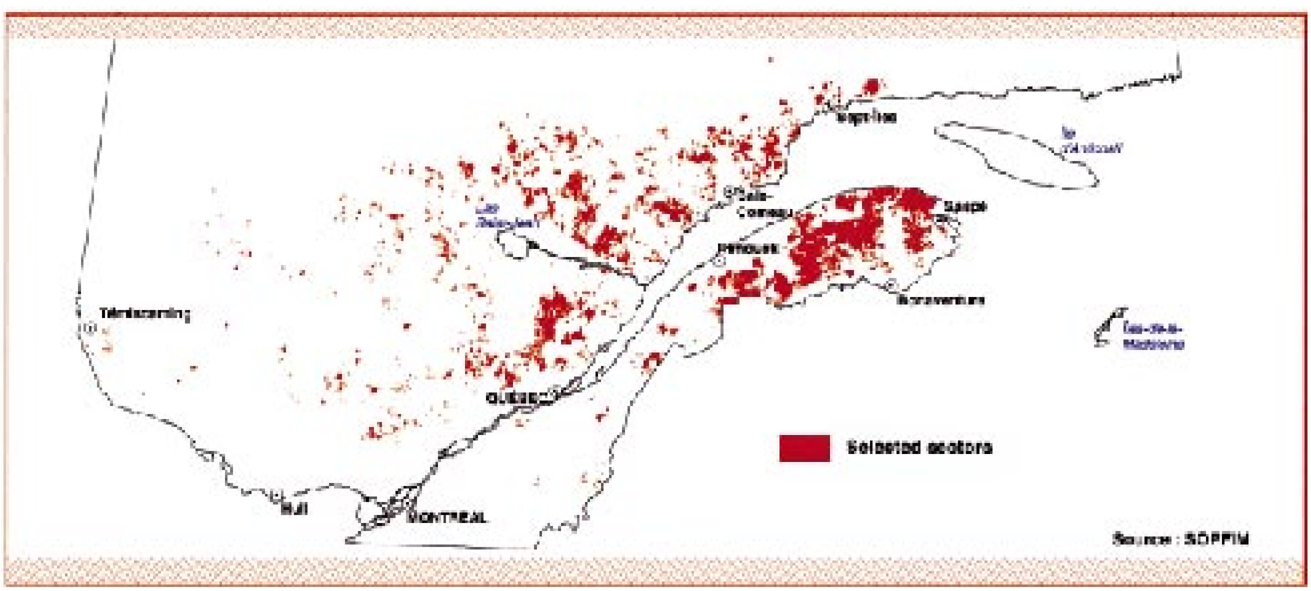
B.t. is sprayed only in areas that qualify for protection programs (map 3). The areas are selected on the basis of very strict forest-related criteria (stand vulnerability to the insect), operational criteria (topography and size) and entomological criteria (levels of larval populations).

Insect populations are counted in the fall, when the areas to be sprayed are identified and treatments are prescribed. The type and number of aircraft, as well as the amount of insecticide needed, are also decided at this time.

In the spring, aerial spraying (photo 18) is carried out when the annual growth is fairly advanced, so that the insecticide lands on the needles. If the product is to have its maximum effect, it is important that no rainfall should occur either before or after spraying. In addition, spraying must take place when winds are light and relative humidity is adequate. Such conditions can generally be found in the early morning and early evening.

(photo SOPFIM)

Photo 18 - Spraying plane in action



(Map SOPFIM)

Map 3 - Sectors eligible for protection against the Spruce Budworn. Five-year program (1996 - 2000)

Spraying programs are subjected to environmental supervision and monitoring, to ensure that they are respectful of the environment and provide sufficient protection for the forest. In addition, the insecticides themselves are tested extensively in the laboratory, to verify their safety and effectiveness.

On residential land, if only a handful of trees are infested, the larvae can be removed by shaking the branches, so that they fall to the ground. The larvae and pupae can also be eliminated by hand, or by spraying the ends of the branches with a powerful water jet. Severe infestations can be treated with B.t., in accordance with the manufacturers' instructions.

SALVAGE

Timber losses can be reduced by salvaging dying trees or trees that have been dead for a short period. In stands, timber can be salvaged up to 10 years after the first severe defoliation. The salvage period varies according to the nature and value of the products, the processing methods used and the demands of the market. Generally speaking, it is much shorter for saw timber, since the sawyer beetles start to dig tunnels in the second year after the tree death, causing extensive damage to the timber.

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Coordination
Jean-Guy Davidson, MRN

Text
Gilles Bonneau, MRN
Clément Bordeleau, MRN
Bruno Boulet, MRN
Michel Chabot, MRN
Jean-Guy Davidson, MRN
Josée Garneau, SOPFIM
Denise Moranville, SOPFIM
Pierre Therrien, MRN

Photos
Lina Breton, MRN

Maps
Sylvie Jean, MRN

Revision of text
Réjeanne Bissonnette, MRN

Secretarial support
Nicole Fontaine, MRN

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