Comparisons of *Btk* aerial spraying strategies against the eastern spruce budworm, based on protection timing and intensity during a complete outbreak episode.

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ABSTRACT

Large-scale aerial spraying operations against the spruce budworm (*Choristoneura fumiferana* Clem.) with the biological insecticide *Bacillus thuringiensis* subsp. *kurstaki* (*Btk*), aims at maintaining trees alive during outbreak episodes. This objective is achieved when ≥ 50% of current-year foliage in balsam fir [*Abies balsamea* (L.) Mill.] stands is preserved. However, it is unknown if this standard approach used in Quebec province is always justified, or if less frequent interventions can provide similar results at lower cost. We conducted between 2010 and 2017 field experiments in Quebec's North Shore region to determine the efficacy of five different protection scenarios in protecting balsam fir, white spruce [*Picea glauca* (Moench) Voss], and black spruce [*Picea mariana* (Mill.) BSP] mixed stands. We hypothesized that less frequent *Btk* applications can provide an adequate level of protection. After nine years of defoliation, our results show a clear effect of protection scenarios on host tree species mortality caused by the spruce budworm. As the protection intensity decreases, the volume of balsam fir mortality increases (0% to 25%). Moreover, balsam fir mortality remains higher then spruce trees, but dead volumes are similar between white and black spruce species. At this stage of the outbreak, our observations suggest that balsam fir stands could be treated every 2 years, and white spruce every 3 years without significant mortality level (< 4%). Based on this study, it is possible to apply the required protection level at lower cost or on a greater forested area at a comparable cost.

RÉSUMÉ

Les pulvérisations aériennes d'insecticide biologique (*Bacillus thuringiensis* var. *kurstaki*) sur de vastes superficies infestées par la tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* Clem.), visent à maintenir les arbres vivants jusqu'à la fin de l'épidémie. Cet objectif est atteint lorsque ≥ 50% du feuillage annuel du sapin baumier [*Abies balsamea* (L.) Mill.] est maintenu. Toutefois, on ignore si cette approche standard utilisée au Québec demeure toujours justifiée ou si des interventions moins fréquentes permettent d'obtenir des résultats similaires à moindre coût. Entre 2010 et 2017, nous avons réalisé une étude dans la région de la Côte-Nord du Québec, afin de comparer l'efficacité de cinq différents scénarios de protection dans des forêts composées de sapins baumiers, d'épinettes blanches [*Picea glauca* (Moench) Voss], et d'épinettes noires [*Picea mariana* (Mill.) BSP]. L'hypothèse de départ stipule que des applications moins fréquentes de *Btk* peuvent fournir un niveau de protection adéquat. Après neuf années de défoliation, les résultats démontrent un net effet des scénarios de protection sur la mortalité des essences hôtes causée par l'insecte. À mesure que l'intensité de la protection diminue, le volume de sapin mort augmente (0 à 25%). De plus, la mortalité du sapin baumier demeure plus élevée que celle des épinettes, mais les volumes morts sont similaires entre l'épinette blanche et l'épinette noire. À ce stade de l'épidémie, nos observations suggèrent que les peuplements de sapins baumiers peuvent être traités aux 2 ans, tandis que les forêts d'épinettes blanches aux 3 ans sans subir une mortalité significative (< 4%). D'après les résultats obtenus jusqu'à

maintenant, il semble possible d'appliquer la protection requise à moindre coût ou de protéger une superficie plus vaste à un coût similaire.

INTRODUCTION

During the previous spruce budworm (SBW) outbreak (1967-1992), forest pest managers have adapted their protection strategy according to the infestation development. In the province of Quebec, aerial spraying programs involving insecticides have been increasingly targeted between the 1970s and the late 1980s (Dorais 1992). Indeed, approaches such as reducing the infestation intensity (1970-72), eradicating new epicentres (1971), slowing the spread of the outbreak (1973-74), protecting the current shoots (1975-84), and protecting the new foliage of the most vulnerable forests were implemented successively. The last strategy is still applied against the spruce budworm in Quebec. The first spray is carried out after one year of moderate to high defoliation level, to protect at least 50% of the annual foliage. The achievement of this objective throughout the outbreak results in a low risk of balsam fir mortality (Hardy and Dorais 1976).

However, this approach has major limitations and it also raises several issues. First, this strategy constitutes a form of annual subscription to the same infested areas for the whole outbreak. This allows limited room for additional area of forest requiring a protection, given the tight budgets. Thus, the average of protected / infested forest ratio stays around 4% since the beginning of this SBW outbreak. This is quite small regarding protection needs to maintain socioeconomic activities related to various forest resources. Currently, only a portion of the forest lands dedicated to wood production are included in spraying programs against the SBW in Quebec. According to the use of forest lands, the type of production, and the host tree species affected by the insect, it is important to determine if the protection target should always be 50% of the current foliage. Moreover, as current wood products available on the market require high quality fiber, lowering protection costs would allow protecting larger areas with the same budget, thus reducing tree mortality and increasing wood supply stability.

Considering the availability of financial resources dedicated to forest pest management, it is crucial to use these funds the most efficiently as possible. The major challenge remains to do more effective protection with the available financial resources. To achieve this, it becomes reasonable to work on aerial spray programs optimization from the beginning of an outbreak and until the end. Even if many authors have studied forest management and protection combinations in relation with intervention priorities and economical concerns, the results associated with variable protection regimes are not well known by forest pest managers. On the other hand, the current SBW outbreak occurs in a forest multiple use context, within which protection objectives should be established for other values than wood production.

In 2007, we initiated a long-term study in which we compare four spray scenarios, along a gradient of intensity, with unsprayed forest stands, in a region affected by a severe outbreak of the spruce budworm in Quebec (table 1). Our main goal is to evaluate and compare the efficacy of these protection scenarios against the SBW, using biological insecticide *Bacillus thuringiensis* var. *kurstaki* (*Btk*) aerial applications. The studied scenarios are defined as follows:

1) No protection or control (real SBW impacts);
2) *Btk* treatment every 3 years (extensive protection);
3) *Btk* treatment every 2 years (average protection);
4) Standard *Btk* protection (intensive protection or annual defoliation ≤ 50%);
5) *Btk* very intensive protection (Very light to no SBW impact).

TABLE 1 AREA OF DEFOLIATION BY SBW IN QUEBEC'S NORTH SHORE REGION FROM 2006 TO 2017 (MFFP 2017).

Year	Defoliation category (ha)			Total
	Light	Moderate	Severe	
2006	1 780	435	104	2 319
2007	18 109	18 795	17 086	53 990
2008	20 550	30 729	40 311	91 590
2009	47 937	59 167	82 177	189 281
2010	140 346	189 915	206 081	532 342
2011	474 310	450 877	397 425	1 322 612
2012	567 999	592 261	585 054	1 745 314
2013	287 502	712 711	1 465 507	2 465 721
2014	457 193	937 419	1 551 744	2 946 357
2015	914 548	1 652 384	1 187 673	3 754 605
2016	1 375 034	1 550 427	825 414	3 750 875
2017	809 955	1 378 952	1 197 007	3 385 915

The intensity of spraying interventions and associated costs are directly related to the protection scenarios included in the study (table 2).

TABLE 2 ANTICIPATED INTERVENTIONS AND TREATMENTS

Strategy	Year												
	0	1	2	3	4	5	6	7	8	9	10	11	12
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
No protection	0	0	0	0	0	0	0	0	0	0	0	0	0
Every 3 Years		1			2			2			2		
Every 2 Years		1		2		2		2		2		2	
Standard			2	2	2	2	2	2	2	2	2	2	1
No SBW impact		1	2	3	3	3	3	3	3	3	3	2	1

The study will be conducted along five major perspectives: efficacy of *Btk* treatments, timber quality, wood losses (growth, mortality), effects on carbon balance, and protection investments. Using a benefit / cost analysis, the project will lead us to determine the more efficient scenario or complementary scenarios, that can be considered as an optimal strategy to minimize the impact of spruce budworm on susceptible forests.

The forest pest managers are interested in annual and long-term efficacy of *Btk* against the spruce budworm. In practice, this biological insecticide has been operationally introduced at the end of the previous outbreak. Therefore, several of them are speculating about its effectiveness in high SBW population levels. This is a key issue in this research because when *Btk* treatments are not applied every year, it is common to observe some SBW population buildup.

SBW impacts on softwood production are widely documented in unprotected forest stands, but in protected forests the literature is quite scarce. Regarding variable protection regimes against the SBW, the assessments of growth losses and mortality levels remains non-existent. The timber quality following a spruce budworm epidemic and woodboring insect attacks has become increasingly important for the forest industry.

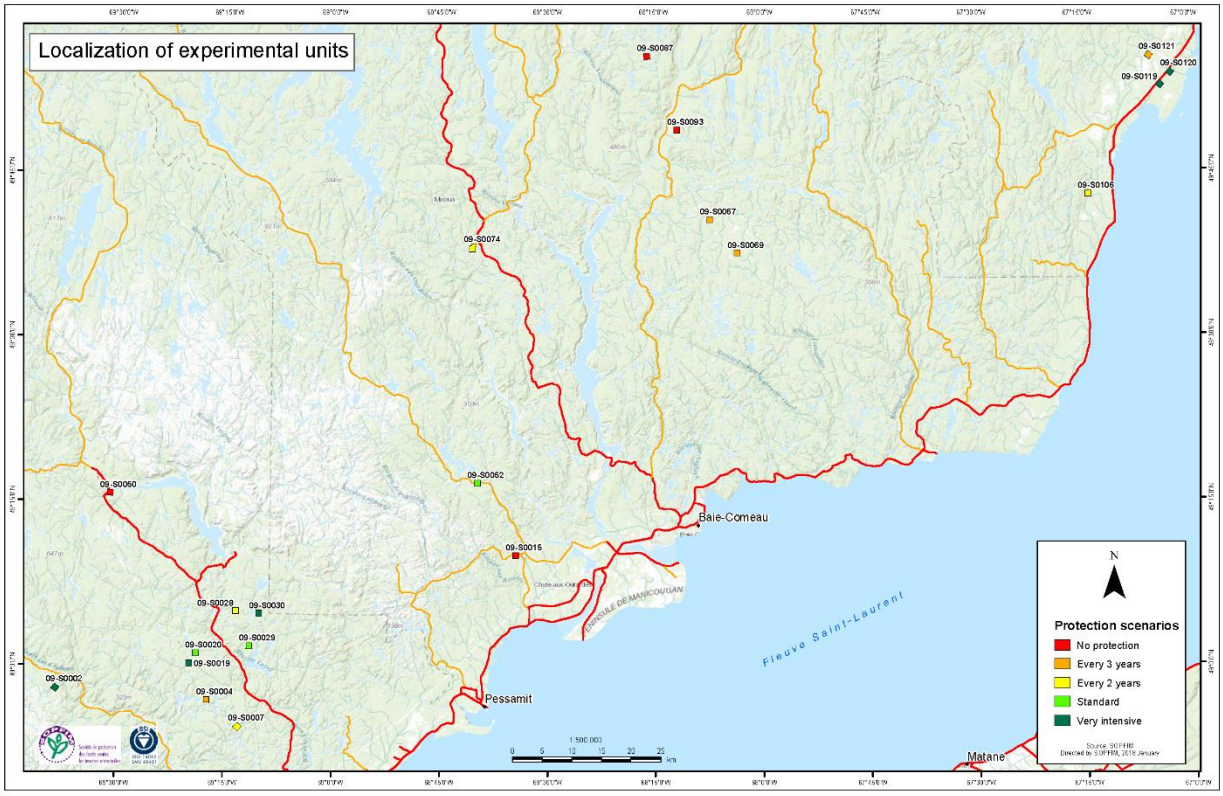
The carbon balance represents a new reality in forestry and in integrated forest pest management (Hennigar and MacLean 2010; Dymond *et al.* 2010). Natural disturbances like SBW outbreaks can create an additional carbon source, but forest protection with *Btk* could help to reduce CO_2 emissions. If this hypothesis is founded, it becomes possible to obtain more support from the environmental community opposed to the use of pesticide.

MATERIALS AND METHODS

Study area

The study area is located in Quebec's North Shore region, more specifically between Forestville and Rivière-Pentecôte, where the SBW has affected softwood stands over the last 10 years. The experimental design refers to 20 experimental units (100 ha each) established at least one year prior to spruce budworm defoliation in balsam fir – white spruce – black spruce mixed forests, belonging to 30, 50 and 70-year old stands, and divided into five (5) protection scenarios (figure 1).

FIGURE 1 LOCALIZATION OF EXPERIMENTAL UNITS



Btk application and efficacy

The insecticide applications were carried out on an operational basis using all the available resources in terms of aircraft and registered *Btk* products. Foray 76B^{TM} and Bioprotec HP^{TM} are *Btk* strain HD-1 commercial formulations at nominal potency of 20.0 billion international units per litre (BIU/L) (Abbott Laboratories, Chicago, IL; on behalf of Valent Bio-Sciences Corporation, Libertyville, IL and AEF Global Inc, Lévis, QC, respectively). Both *Btk* formulations were applied to the experimental blocks, which are described above. Over the years, many aircrafts were used (Cessna 188; Dromader M-18; Air Tractor 402, 502, 504, 602 and 802) with six or eight Micronair

atomizers (Micronair Sprayers Ltd, Bromyard, UK), respectively. Micronair atomizers, spinning at 3,195 g, were located within 75 % of the total wingspan. These aircrafts were flown between 161 and 210 km/h, with 50, 80 or 100-m spray widths. Aerial treatment occurred early in the morning or at dusk under good weather conditions (wind speed < 6 km/h; no rain). The flow rate through the nozzles was calibrated to deliver 1.5 L/ha or 30 BIU/ha. *Btk* formulations were applied one to three times to the sprayed plots according to protection goals of each scenario. The first aerial application of *Btk* against the spruce budworm was targeted at third to early fourth-instar larvae (beginning to mid-June), whereas the second and third applications were carried out 5 and 10 later respectively. *Btk* treatments were timed to coincide with early flushing of balsam fir shoots. This timing provides optimal protection to balsam fir and does not reduce treatment efficacy in reducing final defoliation in white spruce and black spruce (Cadogan and Scharbach 1993, Carisey *et al.* 2004).

In each block, two 45-cm branch tip were collected from the upper midcrown of 15 balsam fir trees selected along three transects perpendicular to the flight lines. The first sample was collected 24-48 hours before the spray (pre-spray assessment) and the second, at the end of the insect feeding period (post spray at 85% pupae stage). For both samples, all the standard information has been collected (shoot development index, insect development index, insect count by branch and bud, current foliage defoliation).

Timber quality and growth losses

At the end of the outbreak, growth loss and timber quality assessments are planned on balsam fir, white spruce and black spruce belonging to 30, 50 and 70 years old. A subsample among 135 trees per experimental unit (15 trees-per species and age classes) will be cut down for the analysis.

Mortality of host species

In each block, tree plots (r = 11,28 m) is measured every year in order to evaluate the volume of mortality caused by the insect. The natural mortality is retrieved from the total amount of dead trees.

Carbon balance

All the information regarding defoliation, growth losses and tree mortality will be collected for the carbon balance evaluation. Available models and others in development by the scientific community are susceptible to be used for this issue.

Benefit-cost analysis

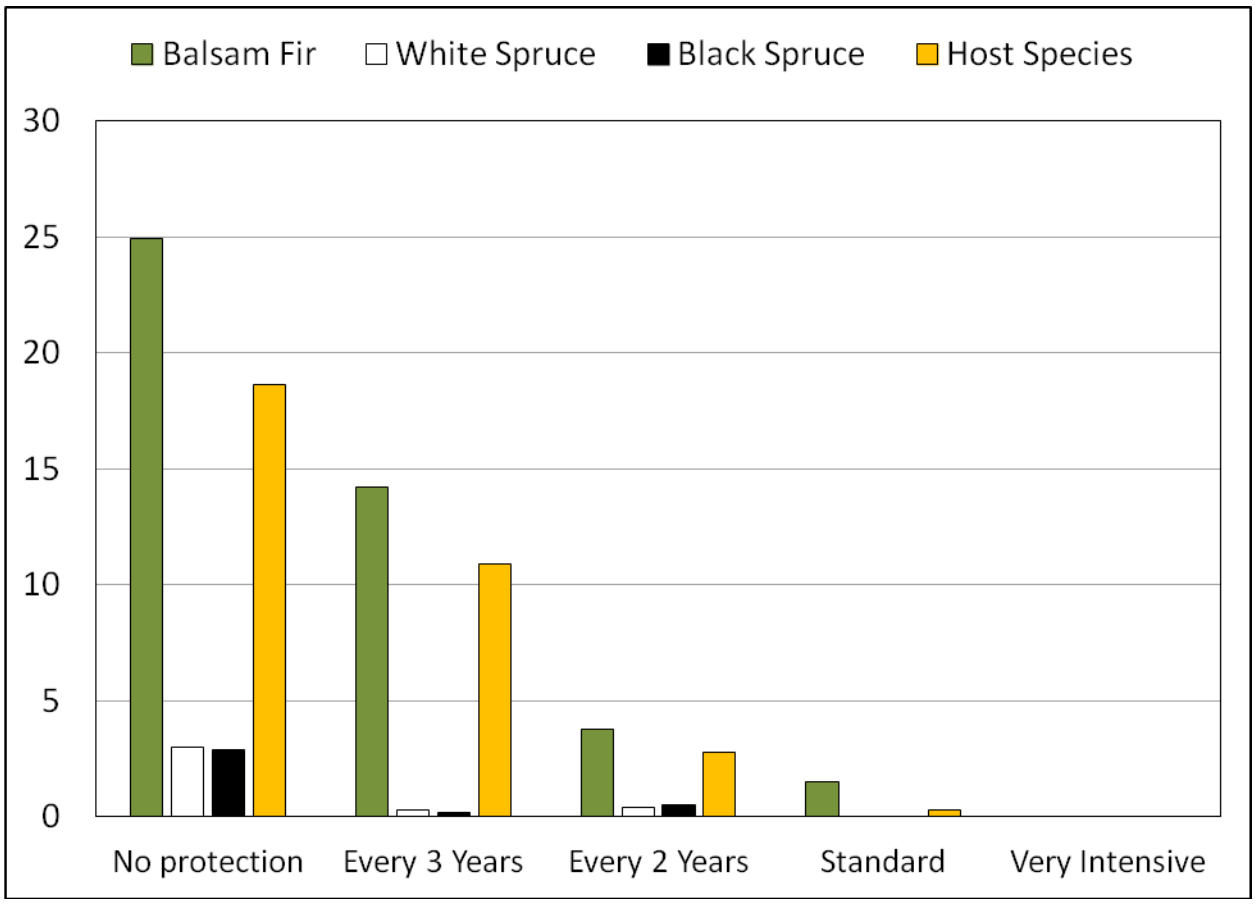
Every year, spraying operation costs are calculated and reported in actual cash value. At the end of the outbreak, the total investment for each protection scenario will be compared to the wood volume saved by the interventions.

PRELIMINARY RESULTS

Wood losses (mortality)

This year, SBW host tree species mortality assessment shows a clear increase in wood volume losses comparatively with 2016. Most of the insect impact remains on the most vulnerable species (balsam fir). At this stage of the outbreak, mortality of the spruce trees is very low. After 10 years of defoliation, we are entering in the most critical period of the outbreak because the mortality will increase very rapidly in the next five years.

FIGURE 2 SBW HOST SPECIES MORTALITY (% VOLUME) BY PROTECTION SCENARIO 2017



However, at the present stage of the outbreak, our results show that mortality of host tree species is related to the protection intensity represented by the different protection scenarios. At this time, it seems possible to suggest that balsam fir stands could be treated every 2 years and white spruce every 3 years without significant mortality levels.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support of SERG International (SERG-I), AEF Global Inc. (*Btk*), Valent Bioscience Corp.(*Btk*), Forest Protection Limited (aircraft), Nova Scotia Department of Natural Resources ($2k), USDA Forest Service ($1k), Ministère des Forêts, de la Faune et des Parcs (L2 processing), the Department of Natural Resources of the Government of Newfoundland and Labrador ($7k), and Canada Economic Development ($200k).

REFERENCES

Archambault, L., R.R. Gagnon, G. Pelletier, M. Chabot et L. Bélanger. 1990. *Influence du drainage et de la texture du dépôt sur la vulnérabilité du sapin baumier et de l'épinette blanche aux attaques de la tordeuse des bourgeons de l'épinette.* Can. J. For. Res. 20 : 750-756.

Bauce, É., N. Carisey, A. Dupont and K. van Frankenhuyzen. 2004. Bacillus thuringiensis subsp. kurstaki prescriptions for balsam fir stand protection against spruce budworm (Lepidoptera: Tortricidae). For. Entomol. 97(5): 1624-1634.

Bergeron, Y., A. Leduc, H. Morin and C. Joyal. 1995. *Balsam fir mortality following the last spruce budworm outbreak in northwestern Quebec.* Can. J. For. Res. 25: 1375-1384.

Carisey, N., É. Bauce, A. Dupont and S. Miron. 2004. *Effects of bud phenology and foliage chemistry of balsam fir and white spruce trees on the efficacy of Bacillus thuringiensis against the spruce budworm, Choristoneura fumiferana.* Agric. For. Entomol. 6: 55-69.

Clark, J. 1961. *Photosynthesis and respiration in white spruce and balsam fir.* State University, College of Forestry, Syracuse, NY. 72 p.

Dupont, A., L. Bélanger and J. Bousquet. 1991. *Relationships between balsam fir vulnerability to spruce budworm and ecological site conditions of fir stands in central Quebec.* Can. J. For. Res. 21: 1752 – 1759.

Dymond, C. C., E. T. Neilson, G. Stinson, K. Porter, D. A. MacLean, D. R. Gray, M. Campagna and W. A. Kurz. 2010. *Future spruce budworm outbreak may create a carbon source in eastern canadian forests.* Ecosystems 13:917-931.

Fettes, J.J. 1950. *Investigations of sampling techniques for population studies of the spruce budworm on balsam fir in Ontario.* Annual Tech. Rep. 4, Forest insect Lab., Canadian Forest Service, Sault Ste. Marie, ON, pp. 163-401.

Fournier, C., E. Bauce, A. Dupont and R. Berthiaume. 2009. *Wood losses and economical threshold of Btk aerial spray operation against spruce budworm.* Pest Manag. Sci. 66: 319-324.

Fox, G., J. Beke, T. Hopkin and D. McKenney. 1997. *A framework for the use of economic thresholds in forest pest management.* For. Chron. 73(3): 331-339.

Hennigar, C. R. and D. A. MacLean. 2010. *Spruce budworm and management effects on forest and wood product carbon for an intensively managed forest.* Can. J. For. Res. 40: 1736-1750.

MacLean, D. A. 1979. *Spruce budworm-caused balsam fir mortality on the Cape Breton Highlands, 1974-1978.* Can. For. Serv., Maritimes For. Res. Centre, Fredericton, N.B., Inf. Rep. M-X-97. 24 p.

MacLean, D. A. 1980. *Vulnerability of fir-spruce stands during uncontrolled spruce budworm outbreaks: a review and discussion.* For. Chron. 56: 213-221.

MacLean, D. A. 1981. *Impact of defoliation by spruce budworm populations on radial and volume growth of balsam fir: a review of present knowledge.* Mitt. Forstl. Bundes. Wien 142: 293-306.

MacLean, D. A. and T. A. Erdle. 1984. *A method to determine effects of spruce budworm on stand yield and wood supply projections for New Brunswick.* For. Chron. 60: 167-174.

MacLean, D. A., T. L. Hunt, E. S. Eveleigh and M. G. Morgan. 1996. *The relation of balsam fir volume increment to cumulative spruce budworm defoliation.* For. Chron. 72: 533-540.

MacLean, D. A., A. W. Kline and D. R. Lavigne. 1984. *Effectiveness of spruce budworm spraying in New Brunswick in protecting the spruce component of spruce-fir stands.* Can. J. For. Res. 14: 163-176.

MacLean, D. A. and D. P. Ostaff. 1989. *Patterns of balsam fir mortality caused by an uncontrolled spruce budworm outbreak.* Can. J. For. Res. 19: 1087-1095.

Ostaff, D. P. and D. A. MacLean. 1989. *Spruce budworm populations, defoliation, and changes in stand condition during an uncontrolled spruce budworm outbreak on Cape Breton Island, Nova Scotia.* Can. J. For. Res. 19: 1077-1086.

Ostaff, D. P. and D. A. MacLean. 1995. *Patterns of balsam fir foliar production and growth in relation to defoliation by spruce budworm.* Can. J. For. Res. 25: 1128-1136

Piene, H. and D. A. MacLean. 1984. *An evaluation of growth response of young, spaced balsam fir to 3 years of spruce budworm spraying with Bacillus thuringiensis.* Can. J. For. Res. 14: 404-411.

Raske, A. G. and W. J. Sutton. 1986. *Delayed decline and mortality of black spruce caused by spruce budworm and secondary organisms.* Environ. Can., Can. For. Serv., Nfld For. Res. Centre, Inf. Rep. N-X-236, St. John's, Nfld. 32 p.

Solomon, D. S. and T. B. Brann. 1992. *Ten-year impact of spruce budworm on spruce-fir forests of Maine.* USDA For. Serv., Gen. Tech. Rep. NE-165, 44 p.

Solomon, D. S., L. Zhang, T. B. Brann and D. S. Larrick. 2003. *Mortality patterns following spruce budworm infestation in unprotect spruce-fir forests in Maine.* North. J. Appl. For. 20(4): 148-153.