IMPACT OF THE 1982–1986 JACK PINE BUDWORM INFESTATION ON JACK PINE IN NORTHEASTERN ONTARIO

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ABSTRACT

The jack pine budworm (*Choristoneura pinus pinus* Free.) infestation that occurred in northeastern Ontario from 1982 to 1986 was assessed for its impact on the province's jack pine (*Pinus banksiana* Lamb.) resource. Jack pine stands were monitored to provide a basis for identifying impact estimators to be applied to defoliation maps and timber inventory data. Stand defoliation history was determined by applying geographic information system technology to aerial sketch maps that showed the annual extent and intensity of defoliation. Loss estimators were then programmed and applied to stand growth increment and standing volume data contained in the Ontario Ministry of Natural Resources' Forest Resource Inventory.

Timber volume losses caused by budworm for the years 1983–1988 were estimated at 2.1 million m^3 growth loss and 5.1 million m^3 mortality. An additional 12.0 million m^3 standing volume had trees with dead tops. The actual volume loss caused by the dead tops was not assessed, however, it seemed negligible as the dead portion usually did not extend into the merchantable part of the stem.

Methods of generating impact estimates as part of an operational insect control program and the effectiveness of aerial spraying for foliar protection and impact reduction are discussed.

RÉSUMÉ

Les auteurs ont évalué l'impact sur les ressources en pin gris (*Pinus banksiana* Lamb.) de l'infestation de la tordeuse du pin gris (*Choristoneura pinus pinus* Free.) qui a sévi dans le nord-est de l'Ontario de 1982 à 1986. Ils ont surveillé les peuplements de pins gris afin d'obtenir des données de base permettant d'identifier des facteurs d'estimation de l'impact de ce ravageur applicables aux cartes de défoliation et aux données d'inventaire. Ils ont déterminé l'historique de la défoliation des peuplements en traitant des croquis cartographiques aériens de l'étendue et de l'intensité annuelles de la défoliation à l'aide de systèmes d'information géographique. Ils ont ensuite numérisé les facteurs d'estimation des pertes et les ont appliqués aux données sur le volume sur pied et sur l'accroissement des peuplements présentes dans l'inventaire des ressources forestières du ministère des Richesses naturelles de l'Ontario.

Les pertes de volume de matière ligneuse causées par la tordeuse du pin gris de 1983 à 1988 ont été estimées comme correspondant à des pertes d'accroissement de 2,1 millions de mètres cubes et à une mortalité à 5,1 millions de mètres cubes. Les auteurs ont aussi estimé que 22 millions de mètres cubes (arbres sur pied) souffraient de mort en cime. Ils n'ont pas évalué les pertes de volume réelles attribuables à ce dernier phénomène, mais celles-ci semblaient toutefois négligeables puisque la portion morte de la tige n'atteignait pas la partie marchande de l'arbre.

Les auteurs examinent également les méthodes permettant d'obtenir des estimations de l'impact dans le cadre d'un programme opérationnel de lutte ainsi que de l'efficacité des pulvérisations aériennes destinées à protéger le feuillage et à réduire l'impact du ravageur.

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Cover photo:
Area of moderate-to-severe defoliation caused by the jack pine budworm in northeastern Ontario (Northeast and Central regions) between 1981-1987 as mapped by the Forest Insect and Disease Survey Unit.

INTRODUCTION

Jack pine (*Pinus banksiana* Lamb.) is one of the most important tree species in Ontario. The Forest Resource Inventory (OMNR 1986) shows a total volume of 653 million m^3 on an area of approximately 5 million ha for the jack pine working group in Ontario. Ontario's annual harvest is from 5 to 5.7 million m^3 (Howse 1986). Howse discussed the importance of jack pine and the history of its most important pest, the jack pine budworm (*Choristoneura pinus pinus* Free.). Defoliation by jack pine budworm causes reduced growth and seed production, mortality, and top kill (Kulman et al. 1963, DeBoo and Hildahl 1968, Benzie 1977, Cerezke 1986, Howse 1986, Mallett and Volney 1990, Gross 1992). Budworm larvae feed mostly on the new foliage and male flowers, but "backfeeding" on older needles is common in years of severe defoliation (Howse 1986). Mallett and Volney (1990) noted an association of Armillaria root rot (*Armillaria spp.*) with dead and dead topped jack pine that had experienced budworm defoliation. Hence, defoliation may stimulate root rot or predispose trees to attack. Descriptions of the insect, its feeding habits, and its life cycle are given by Deboo and Hildahl (1968), Rose and Lindquist (1973), and Ives and Wong (1988).

Outbreaks in Ontario tend to occur, on average, every 8 to 10 years, and to last for 2 to 4 years (Howse 1986). Volney (1988) noted a similar 10-year periodicity for outbreaks in the prairie provinces and noted that outbreaks appeared to follow periods of high fire occurrence. He also discussed weather influences, flowering intensity, and stand history in relation to outbreaks.

Clancy et al. (1980) and Batzer and Jennings (1980) discussed interpretation of weather data for prediction of outbreaks, and Nealis (1990) reviewed the relationship of budworm with staminate flower production. Methods for making short-term population forecasts are based on egg-mass or larval surveys (Meating 1986, Moody 1986). Simulation models that examine control strategies, timber management options, and budworm impact were presented by Rose (1973) and Nyrop et al. (1983). Both studies indicated that reducing stand rotation age reduces budworm impact.

The infestation that was the basis for this study was detected in 1982 when noticeable defoliation occurred over 1,000 ha in the Georgian Bay area of southern Ontario (Howse 1986). In 1983 the infestation covered 60,172 ha, and expanded dramatically in 1984 and 1985 affecting areas of 626,212 and 1,896,845 ha, respectively (Fig. 1). The expansion included large parts of the Northeastern and Northern administrative regions of Ontario. The situation was considered unprecedented as outbreaks had been absent from these locations for at least 50 years (Howse 1986). The infestation began to collapse after 1985. Only 158,196 ha were mapped as having defoliation in 1986 (Fig. 1), and defoliation was not detected in 1987.

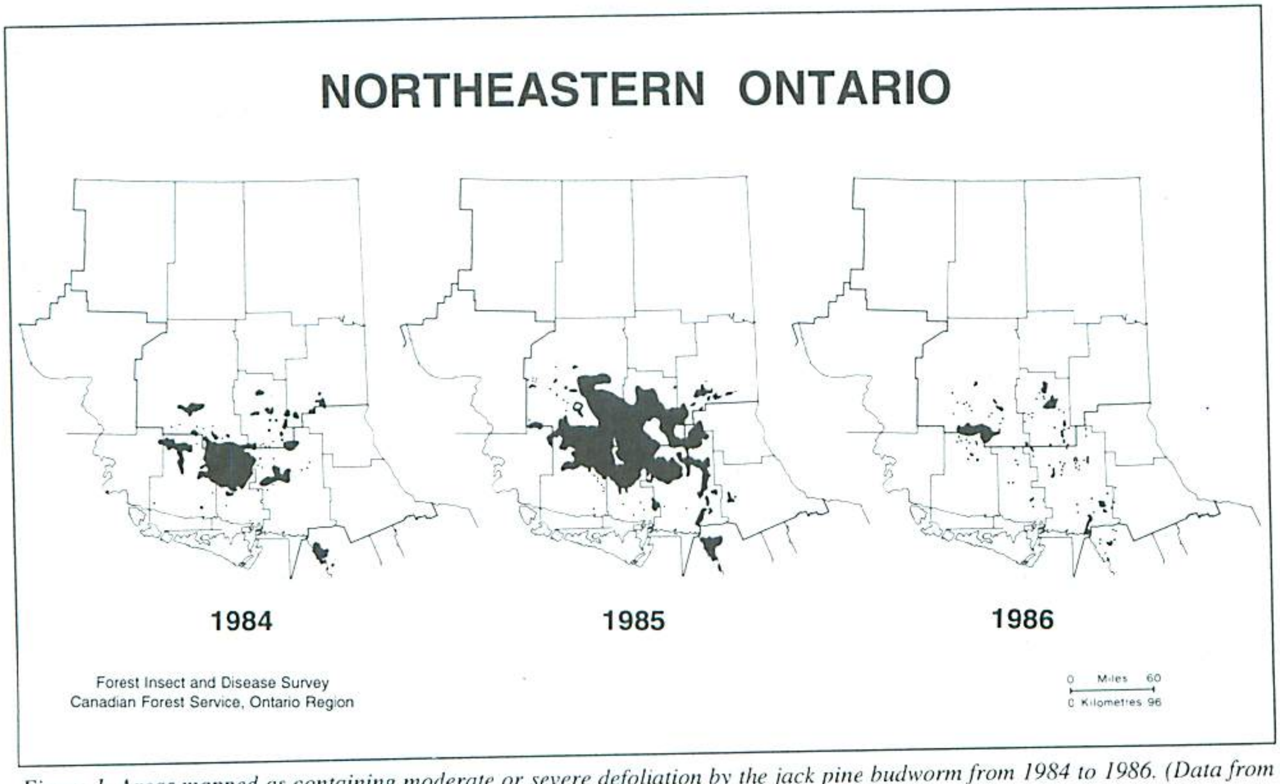

Figure 1. Areas mapped as containing moderate or severe defoliation by the jack pine budworm from 1984 to 1986. (Data from Howse and Applejohn 1984, 1985, 1986.)

Concurrently, another budworm infestation was present in northwestern Ontario. More complete descriptions of these infestations are contained in the Annual Reports of the Forest Insect and Disease Survey (FIDS) Unit (Kondo and Taylor 1984, 1985, 1986; Kondo and Moody 1987; Moody 1988).

Jack pine budworm control programs were conducted in 1985 and 1986 when 221,000 and 252,000 ha, respectively, were treated by aerial application of a spray formulation containing *Bacillus thuringiensis* (*B.t.*). The program is described in the 1985 and 1986 FIDS Survey Bulletins (Howse and Applejohn 1985, 1986).

Methods for characterizing the impact of budworm defoliation on jack pine trees and stands were described by Gross (1992). A negative bias can be present when estimates of growth loss are based solely on the loss reflected at 1.3 m height (Mott et al. 1957, Thomson and Van Sickle 1980, Cerezke 1986, Gross 1992). Gross (1992) used stem-analysis methods (Fayle and MacIver 1986) to identify growth relationships and then attempted to identify regression models for estimating loss as a function of growth at 1.3 m height. He was able to identify satisfactory models for specific stand estimates, but was unsuccessful in providing a universal model that could be used for the entire infestation. The study did estimate impact as growth loss, mortality, and dead topped trees for a selection of stands and presented methods for rating impact for defoliated stands. In the present report, the methods are applied to a more extensive set of stand samples, which then provided a basis for identifying estimators that were applied to the Forest Resource Inventory (FRI) of the Ontario Ministry of Natural Resources (OMNR). Impact estimates (Gross et al. 1992) were prepared, and these, along with methods of estimation and analysis, are presented herein to provide a basis for examining other infestations. Impact is an important consideration for rating the effectiveness of pest control strategies. One objective of the study was to provide impact estimates relative to the aerial spray control program. The information is expected to be useful in conjunction with other characteristics of budworm infestations for the design of decision support systems.

METHODS

Stands were monitored using three kinds of plot samples that varied in the amount and precision of data recorded. S-PLOTs provided the greatest detail. D-PLOTs had intermediate detail and were used to provide additional samples for tree mortality estimates. O-PLOTs were used to record observations of defoliation and stand condition at a large number of sites. Actual plot design is discussed later.

In 1985, S-PLOTs were installed in 19 jack pine stands that were randomly selected from a listing of 54 stands being monitored as part of other FIDS studies. These stands were candidates for spraying to control budworm and were being monitored to predict defoliation, characterize populations, and rate the effectiveness of control by insecticide application. As such, they were recognized as probably being biased because they were from the more intensively defoliated areas of the infestation. The sample was expanded in 1986 to get more extensive coverage of the infestation and to provide a more random sample. Twenty townships were randomly selected from a listing of all townships that had mapped defoliation. O-PLOTs were installed in up to 10 jack pine stands per township. These stands were selected randomly from a listing of all stands in the township that were accessible by road. Then, a stand, which was randomly selected from those containing O-PLOTs, was sampled by a D-PLOT. Townships that contained S-PLOTs and that were not selected as part of the 20-township random sample were also sampled by the same O-PLOT and D-PLOT procedure. This provided a basis for comparing data from the 20-township random sample with data from the 19-township sample selected from stands being monitored for other purposes.

General levels of defoliation are defined as the percentage of needle volume missing, as follows: high = more than 75%, moderate = 26 to 75%, light = 6 to 25%, and trace or nil = 0 to 5%. Unless otherwise specified, these refer to defoliation of current needles. During the analysis, defoliation data were interpreted to identify trees that had upper-crown defoliation at the high (>75%) level. These were considered to be severely defoliated. The proportion of trees in a stand that were severely defoliated was frequently more responsive to damage than ratings of the percentage of needle volume defoliated by a crown level.

In the text, defoliation descriptions are abbreviated as follows: year for defoliation is prefixed by U, M, or S signifying upper-crown level, mid-crown level, or severe defoliation, respectively and suffixed by C, O, or T signifying needle age as: C = current, <1 year old; O = older, >1 year old; and T = total, all ages. For example, U85C references 1985 defoliation for current (C) needles in the upper crown (U).

S-PLOTS

S-PLOTs (n = 19) were 10 or more 0.01-ha (33.3 m x 3.0 m) randomly located subplots that had a minimum sample of 80 jack pine >5 cm in diameter. Data recorded annually for each dominant or codominant tree and for the first intermediate and suppressed tree on each plot were: (a) tree condition as dead, dead topped, and undamaged, and (b) percentage defoliation rated to the nearest 10% for current, older, and total needle foliage in both the upper and mid-crown levels. Percentage defoliation was estimated by examining trees through binoculars. Prior to estimating defoliation, branches were pruned and examined from the upper and mid-crown of two trees that were not on the plot. Site variables sampled were: items contained in the FRI stand code (age, height, percentage stocked, percentage jack pine content, and site class); vegetation type (V); soil type (S); and moisture regime (MR) as defined by the Forest Ecosystem Classification (FEC) manual (Sims et al. 1989). Tree height and diameter were measured in 1985 and 1988.

D-PLOTS

D-PLOTs (n = 28) were randomly located 3-m-wide transects that contained 100 numbered dominant and codominant jack pine. D-PLOTs were similar to the mortality plots used by FIDS. Data recorded annually for D-PLOTs were: (a) tree condition as dead, dead-topped, and undamaged; (b) percentage defoliation of current and older needles for the upper and the mid-crown levels; (c) moisture regime (MR); and (d) site variables contained in the FRI stand codes. Stand age was changed to reflect current age and, occasionally, other FRI items were changed to agree with plot data.

The height and age of every 20th tree were measured, and at a point near these trees, species composition and percent stocked, based on basal area content, was sampled using a wedge prism. Percent stocked was the sampled basal area for all species divided by the basal area listed by Plonski (1974) for the appropriate age and site class.

O-PLOTS

O-PLOTs (n = 199) were locations at which impact and percentage defoliation were visually rated after a tour (>100 m long) through a stand. Data for 1985 were recorded prior to visible 1986 defoliation, and thereafter sites were rated annually after defoliation for the year had stopped. Data recorded for O-PLOTs were: tree condition as the percentage of dominant and codominant trees that were dead, dead topped, and undamaged, and percentage defoliation of current and older needles. Site variables sampled were moisture regime (MR) and those contained in the FRI stand code (e.g., current age, height, percentage stocked, percentage of jack pine content, and site class).

Spray-Impact

The S-PLOT sample was selected in order to have a selection of sprayed and control plots for which additional data such as population levels and other items were available from other studies. As discussed later, this approach encountered some problems of bias and experimental design. Another approach was to examine population data compiled by crews monitoring other aspects of the infestation. A single mid-crown branch (60-cm length) was sampled from each tree on a 10-tree plot to estimate prespray and postspray budworm populations and defoliation. In 1985, as part of other FIDS activities, 228 plots were established in spray blocks and another 124 plots in unsprayed check plots to assess the efficacy of the operational control program conducted by OMNR against the jack pine budworm in northeastern Ontario. In 1986, 233 spray plots and 84 check plots were assessed. Stands selected for use in monitoring the spray program were generally those thought to be most vulnerable to budworm attack. The criteria used to assess stand vulnerability included stand composition, stand age, previous defoliation history, and expected budworm population density. Other factors such as site class and harvest schedules were also considered.

ANALYSIS

No attempt was made to provide statistics for items such as average defoliation level or percentage of dead trees for the entire infestation. Bias problems with data for townships being monitored for other purposes left a sample size of only 20 townships, many of which had low numbers of stands with significant defoliation. The desired product was a table of estimators that could be applied to the various mapped defoliation histories that were encountered.

The data set contained information for 199 sites in 28 townships, and 47 of the sites were sampled by either an S-PLOT or a D-PLOT. These were considered case histories. Growth loss was a function of a defoliation based model (Model 23; Gross 1992). Mortality and dead top estimators were based on estimates of the volume or proportion of trees affected on the plots. Then, in consultation with FIDS entomology staff, the desired table of estimators was devised based on these case histories and information from other FIDS studies.

FIDS aerial sketch maps (1:50,000 scale) of the area defoliated each year were digitized and transferred to FRI base maps. Then Geographic Information System (GIS) technology was used to identify the defoliation history of each stand. Based on this history, the appropriate impact estimator was applied to stand data contained in the FRI for jack pine content, annual volume increment (AVI), and gross standing volume (GSV). The data were compiled as part of a FIDS pest-impact exercise for the years 1982 to 1987 (Gross et al. 1992) and are presented later in Table 8. Some additional impact for this infestation occurred after the 1982–1987 period. Since the GIS approach will ultimately be applied for these additional years, only a preliminary impact estimate for the period after 1987 has been included in the present report.

Data analysis used SAS software (SAS Institute Inc. 1985). Linear regression analysis was by the STEPWISE procedure with selected models processed by the REG procedure to provide various model review data such as residuals, etc. Correlation analysis was by the CORR procedure and t tests were performed within the MEANS procedure. When data failed to satisfy tests of normalcy, data were ranked using Tukey's approximation, but actual data, rather than rank scores, are presented in the text. All correlation results are referred to only by correlation coefficient (r). As only data for the S-PLOT and D-PLOT samples (n = 47) are reported, r values of 0.280 and 0.350 are significant at the p = 0.05 and 0.01 levels, respectively, and only significant correlations are listed.

RESULTS AND DISCUSSION

Stand Character

The site characteristics of the S-PLOT and D-PLOT samples are summarized in Table 1. Most stands were well-stocked, site class 1 or 2, and had a high content of jack pine. There were only two stands rated as site class 3. Hence, the possibility that jack pine budworm is more prevalent and destructive on poor sites or in open stands is not really tested by the study.

The levels of defoliation present in stands with S-PLOTs or D-PLOTs are presented in Tables 2 and 3. The stands are numbered in a manner that reflects a decreasing amount of defoliation as number size increases. This ranking was based mostly on the percentage of current needle volume defoliated in the year of the most severe feeding.

FEC classifications for the S-PLOT samples (Table 1) indicated most stands (n = 11) were on V29 Jack Pine–Ericaceous Shrub–Feathermoss sites. Other V-types were: V28 Jack Pine–Low Shrub (n = 3); V17 Jack Pine Mixedwood–Shrub Rich (n = 2); V30 Jack Pine–Black Spruce–Blueberry–Lichen (n = 2); and V31 Black Spruce–Jack Pine–Tall Shrub–Feathermoss (n = 1). Soil types were predominately S1 Dry–Coarse Sandy (n = 14), mostly medium sands; and S2 Fresh–Fine Sandy (n = 5), mostly fine sands.

V-type was not a very informative variable with respect to defoliation or impact mostly because the magnitude of the number assigned did not correspond with position along a scalar such as moisture or productivity. Moisture regime (MR) was recorded for all S-PLOTs and D-PLOTs and ranged from MR = 1 (moderately fresh) to MR = 4 (moderately moist). As discussed later, MR did correlate reasonably well with some of the defoliation and impact variables.

Sample Performance

Data for the randomly selected S-PLOTs (n = 7) and D-PLOTs (n = 19) were compared with data from the S-PLOTs (n = 19) and D-PLOTs (n = 17) in the original selection to detect differences in defoliation levels and the occurrence of dead tops and mortality. As mentioned previously, the original selection was biased by the need for budworm control at the sites being sampled. Candidates for control were to be stands in which additional defoliation was expected to cause significant mortality and that were scheduled for harvest within 10 years. Not surprisingly, impact estimates based on data from the original selection were biased upwards.

The accuracy of defoliation ratings for O-PLOTs was checked by comparing O-PLOT data with S-PLOT data for the 19 stands that were rated by both methods. Average defoliation ratings for each S-PLOT were compared to the midpoint of the general defoliation level estimated for the corresponding O-PLOT sampled in each stand. For example, in an O-PLOT with high (76–100%) defoliation, the midpoint (88%) was used for comparative purposes. No bias was detected.

The accuracy of the ratings of tree characteristics for O-PLOTs was checked by comparing the visual O-PLOT estimates with S-PLOT data for the 19 sites that were rated by both methods. Estimates of dead top and dead tree damage based on O-PLOT visual ratings were positively biased for 1985 but not for 1986 or 1987. Hence, ratings for 1985 are not included in this report. The experience influenced accuracy of visual ratings for 1987 and 1988. This quality check did not address the bare- or dead-topped character of the damage. Visual ratings at O-PLOTs for 1985 status were made early in the 1986 season. At that time tops could only be classed as bare-topped or undamaged. In fact, based on individual tree data for S-PLOTs and D-PLOTs many of the bare-topped trees did flush new foliage in all or most of the affected crown portions in 1986. By 1987 the dead character of affected tops was distinct and the term "dead top" is used for the remainder of this report to reference tree status in 1987.

The S-PLOT and D-PLOT samples (Tables 1–4, Figs. 2 and 3) were treated as case histories for the sites affected. The samples were considered satisfactory for correlation and regression analysis. Although some samples were not completely random, the data did refer to site conditions across a continuum and sampling within sites was random. O-PLOT data were used to characterize conditions within townships.

Defoliation

The defoliation levels present from 1984 to 1986 are presented in Tables 2 and 3 and are illustrated for a selection of S-PLOT samples in Figure 2. Defoliation was slightly more intense in the upper crown than in the middle and lower crown levels (Fig. 3). Trees in the intermediate and suppressed crown classes experienced greater

Table 1. Characteristics of stands sampled to assess the impact of the 1982–1986 jack pine budworm infestation that occurred in northeastern Ontario.

Stand	Township	Defoliation history[1]	Plot type	Age (yrs)	Height (m)	Stocked (%)	Site class	Site index	Moisture regime	FEC[2] classification V type	S type
1	Monestime	HMV	S	68	20	120	1	17	2	30	1
2D	Westbrook	MHV	S	41	18	100	1	22	3	29	2
3	Sagard	LHV	S	59	21	90	1	20	3	29	1
4B	Moses	LHV	S	61	21	100	1	19	3	29	2
5	Cartier	HMV	S	65	17	60	2	15	3	30	2
6	Garvey	–HL	D	65	16	100	2	14	2	–	–
7C	Gaunt	LMM	S	35	14	90	1	21	2	29	2
8	Gaunt	–MM	D	35	13	100	1	20	3	–	–
9	Voorman	–MM	D	31	7	90	3	14	3	–	–
10	Martel	–MM	D	35	18	100	1	25	3	–	–
11	Cartier	MLV	S	80	20	100	2	16	2	31	1
12	Moses	–MV	D	50	18	90	1	19	1	–	–
13	Invergarry	–MV	D	75	20	80	2	16	3	–	–
14	Sagard	–MV	D	59	17	50	2	16	2	–	–
15	Deans	–MV	D	40	16	90	1	21	3	–	–
16	Lumsden	MLV	S	60	21	70	2	19	4	17	1
17	Ermatinger	–MV	D	85	22	100	1	17	4	–	–
18	Ulster	LMV	S	78	20	80	2	16	4	29	1
19	Invergarry	LMV	S	83	23	100	1	18	4	29	1
20	Ulster	–MV	D	85	17	100	3	13	4	–	–
21	Marquette	–MV	D	80	20	100	2	16	4	–	–
22	Monestime	–MV	D	68	20	100	1	17	3	–	–
23	Cavell	–MV	D	85	20	100	2	15	4	–	–
24	Viel	LMV	S	28	14	50	1	26	4	29	1
25	Westbrook	–MV	D	60	18	80	2	17	3	–	–
26	Strom	–MV	D	65	20	90	1	18	3	–	–
27	Teasdale	LMV	S	49	16	60	2	17	3	29	1
28	Neelands	MLT	S	79	21	110	1	16	3	27	1
29	Neelands	–MV	D	79	21	90	1	17	3	–	–
30	Ogilvie	MTV	S	60	21	90	1	20	4	27	1
31	Antrim	–MV	D	70	20	90	1	17	4	–	–
32	Cartier	–MV	D	73	21	90	1	18	3	–	–
33	Mickle	TMV	S	60	22	100	1	21	4	29	1
34	Cortez	LMV	S	115	21	100	2	14	4	29	1
35	Cortez	–MV	D	95	21	–	1	16	3	–	–
36	Moncrief	–MV	D	76	20	100	2	16	3	–	–
37	Lane	–LL	D	80	23	100	1	18	3	–	–
38	Martel	LLL	S	40	14	60	2	18	3	17	1
39	Teasdale	–LV	D	75	22	100	1	18	3	–	–
40	Edinburgh	–LV	D	90	25	90	1	19	4	–	–
41	Ermatinger	LLV	S	80	19	90	2	15	4	28	1
42	Ogilvie	–LV	D	60	20	90	1	19	4	–	–
43	Mandamin	–LV	D	65	19	100	2	17	2	–	–
44	Wardle	–LV	D	40	15	100	1	19	3	–	–
45	Weeks	–TV	D	70	18	100	2	15	3	–	–
46A	Weeks	VTV	S	33	13	80	1	21	2	29	2
47	Viel	–TV	D	95	24	100	1	18	4	–	–

[1] Defoliation history (1984, 1985, 1986) coded as follows: void (V) = 0%, trace (T) = 1–5%, light (L) = 6–25%, moderate (M) = 26–75%, high (H) >75%, and – is missing data.

[2] Vegetation type (V) and soil type (S) are defined by the Forest Ecosystem Classification System for northwestern Ontario (Sims et al. 1989).

Table 2. Average defoliation levels in stands sampled to assess the impact of the 1982–1986 jack pine budworm infestation that occurred in northeastern Ontario.

			Defoliation (%)[2]					
			1984		1985		1986	
Stand	Township	Defoliation history[1]	Current needles (U84C)	Total needles (U84T)	Current needles (U85C)	Total needles (U85T)	Current needle (U86C)	Total needles (U86T)
1	Monestime	HMV	98	84	64	76	0	50
2D	Westbrook	MHV	25	17	91	65	0	54
3	Sagard	LHV	19	18	91	68	0	54
4B	Moses	LHV	7	10	80	51	0	42
5	Cartier	HMV	78	62	45	62	0	36
6	Garvey	–HL	–	–	75	62	16	59
7C	Gaunt	LMM	11	11	61	42	42	45
8	Gaunt	–MM	–	–	59	44	42	39
9	Vrooman	–MM	–	–	66	49	30	41
10	Martel	–MM	–	–	35	43	25	51
11	Cartier	MLV	71	54	16	42	0	25
12	Moses	–MV	–	–	65	51	0	34
13	Invergarry	–MV	–	–	57	37	0	25
14	Sagard	–MV	–	–	56	55	0	53
15	Deans	–MV	–	–	55	40	0	27
16	Lumsden	MLV	5	43	28	50	0	26
17	Ermatinger	–MV	–	–	53	33	0	22
18	Ulster	LMV	16	15	52	36	0	23
19	Invergarry	LMV	21	15	47	28	0	17
20	Ulster	–MV	–	–	47	27	0	18
21	Marquette	–MV	–	–	46	28	0	19
22	Monestime	–MV	–	–	44	30	0	20
23	Cavell	–MV	–	–	43	23	0	15
24	Viel	LMV	9	11	42	22	0	15
25	Westbrook	–MV	–	–	41	20	0	13
26	Strom	–MV	–	–	41	23	0	15
27	Teasdale	LMV	24	36	38	29	0	20
28	Neelands	MLT	38	26	22	27	3	17
29	Neelands	–MV	–	–	35	23	0	15
30	Ogilvie	MTV	35	27	3	23	0	11
31	Antrim	–MV	–	–	32	25	0	17
32	Cartier	–MV	–	–	32	17	0	11
33	Mickle	TMV	3	3	31	15	0	10
34	Cortez	LMV	16	12	30	21	0	9
35	Cortez	–MV	–	–	28	8	0	5
36	Moncrief	–MV	–	–	27	14	0	9
37	Lane	–LL	–	–	22	11	8	4
38	Martel	LLL	11	11	6	11	21	14
39	Teasdale	–LV	–	–	21	11	0	7
40	Edinburgh	–LV	–	–	21	6	0	4
41	Ermatinger	LLV	7	4	19	12	0	7
42	Ogilvie	–LV	–	–	17	6	0	4
43	Mandamin	–LV	–	–	16	13	0	9
44	Wardel	–LV	–	–	9	3	0	2
45A	Weeks	–TV	–	–	2	0	0	0
46	Weeks	VTV	0	1	2	2	0	2
47	Viel	–TV	–	–	2	0	0	0

[1]Defoliation history (1984, 1985, 1986) coded as follows: void (V) = 0%, trace (T) = 1–5%, light (L) = 6–25%, moderate (M) = 26–75%, high (H) >75%, and – is missing data.

[2]Data are the percent of current or total needle volume defoliated in the upper crown of dominant and codominant jack pine.

Table 3. The frequency of severe upper crown defoliation in stands sampled to assess the impact of the 1982–1986 jack pine budworm infestation that occurred in northeastern Ontario.

			Defoliation (%)[2]					
			1984		1985		1986	
Stand	Township	Defoliation history[1]	Current needles (S84C)	Total needles (S84T)	Current needles (S85C)	Total needles (S85T)	Current needles (S86C)	Total needles (S86T)
1	Monestime	HMV	97	71	52	62	0	7
2D	Westbrook	MHV	2	0	95	34	0	14
3	Sagard	LHV	0	0	96	41	0	0
4B	Moses	LHV	0	1	78	19	0	13
5	Cartier	HMV	68	28	12	28	0	0
6	Garvey	–HL	–	–	70	50	0	50
7C	Gaunt	LMM	0	0	42	18	16	20
8	Gaunt	–MM	–	–	50	25	20	25
9	Vrooman	–MM	–	–	60	30	15	15
10	Martel	–MM	–	–	10	30	5	35
11	Cartier	MLV	61	25	2	10	0	25
12	Moses	–MV	–	–	55	35	0	0
13	Invergarry	–MV	–	–	40	20	0	0
14	Sagard	–MV	–	–	30	40	0	0
15	Deans	–MV	–	–	40	20	0	0
16	Lumsden	MLV	37	10	1	9	0	0
17	Ermatinger	–MV	–	–	30	10	0	0
18	Ulster	LMV	1	1	34	10	0	0
19	Invergarry	LMV	0	0	24	0	0	0
20	Ulster	–MV	–	–	25	5	0	0
21	Marquette	–MV	–	–	30	10	0	0
22	Monestime	–MV	–	–	30	10	0	0
23	Cavell	–MV	–	–	30	10	0	0
24	Viel	LMV	0	0	11	0	0	0
25	Westbrook	–MV	–	–	25	0	0	0
26	Strom	–MV	–	–	30	10	0	0
27	Teasdale	LMV	2	15	19	4	0	0
28	Neelands	MLT	5	1	0	0	0	0
29	Neelands	–MV	–	–	10	10	0	0
30	Ogilvie	MTV	4	0	0	0	0	0
31	Antrim	–MV	–	–	20	10	0	0
32	Cartier	–MV	–	–	15	5	0	0
33	Mickle	TMV	0	0	9	0	0	0
34	Cortez	LMV	1	1	6	1	6	3
35	Cortez	–MV	–	–	0	0	0	0
36	Moncrief	–MV	–	–	15	5	0	0
37	Lane	–LL	–	–	5	0	0	0
38	Martel	LLL	0	0	0	0	1	0
39	Teasdale	–LV	–	–	0	0	0	0
40	Edinburgh	–LV	–	–	0	0	0	0
41	Ermatinger	LLV	0	0	9	0	0	0
42	Ogilvie	–LV	–	–	0	0	0	0
43	Mandamin	–LV	–	–	0	0	0	0
44	Wardle	–LV	–	–	0	0	0	0
45	Weeks	–TV	–	–	0	0	0	0
46A	Weeks	VTV	0	0	0	0	0	0
47	Viel	–TV	–	–	0	0	0	0

[1] Defoliation history (1984, 1985, 1986) coded as follows: void (V) = 0%, trace (T) = 1–5%, light (L) = 6–25%, moderate (M) = 26–75%, high (H) >75%, and – is missing data.
[2] Data are the percent of trees that experienced severe (>75%) defoliation in the upper crown of dominant and codominant jack pine.

defoliation than dominant and codominant trees. These characters are typical of budworm feeding (Kulman et al. 1963, Gross 1992). Most of the data in the present report apply to dominant and codominant trees and to defoliation in the upper crown.

Defoliation varied widely for trees within stands (Fig. 2 and 3). Defoliation also varied widely among stands (Fig. 4). For example, in 1985 average defoliation of current needles in the upper crown (U85C) among stands in Sagard Township ranged from 10 to 68%. These stands were not sprayed in 1985; therefore, although some of the variation in defoliation level (Fig. 4) was no doubt a response to the control program, the phenomenon occurred enough times, exclusive of spray operations, to indicate that high stand-to-stand variability in defoliation level was a true character of the infestation.

Defoliation in 1984

Defoliation for 1984 was rated prior to significant feeding in 1985 for S-PLOTs, and most stands had evidence of some feeding on current needles (Table 2). S-PLOT 1 experienced high levels of defoliation and many trees were stripped of all needles in the upper crown (Fig. 2). Six other S-PLOTs (2D, 5, 11, 16, 28, and 30) sustained moderate or high defoliation (Table 2, Fig. 2). Data describing conditions within townships in 1984 are not available as only S-PLOTs were in place at that time.

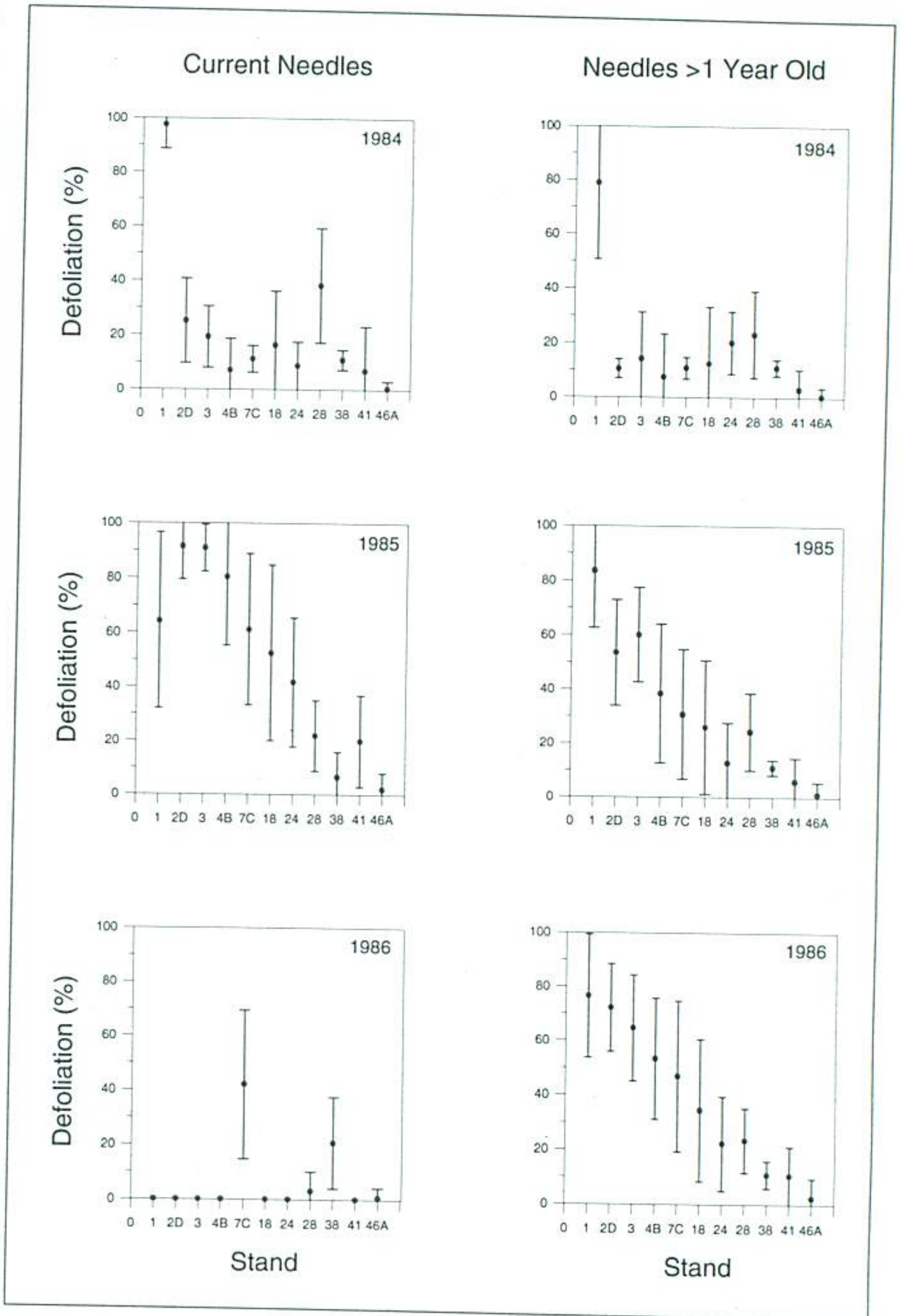

Figure 2. Percentage defoliation by the jack pine budworm in the upper crowns of dominant and codominant trees from 1984 to 1986. The stands shown represent a range in defoliation intensity. Values plotted represent stand average defoliation level and +/– one standard deviation.

Defoliation in 1985

Most of the stands in the area infested in 1985 (Fig. 1) experienced at least moderate defoliation (Table 2, Fig. 2). Feeding on current (U85C) and older needles (U85O) (Fig. 2) was intense in many stands. Stands 1, 2D, 3, 4B, 7C, and 18 contained trees with high levels of both U85C and U85O defoliation. The magnitude of "backfeeding" was reflected by defoliation of older needles (U85O) in S-PLOTs 3, 4B, 7C, 18, and 24 where only light feeding had occurred in 1984 (Fig. 2).

Moisture regime (MR) was correlated with feeding on needles of all ages (U85T) (r = –0.360) and the percentage of trees experiencing severe defoliation (S85T) (r = –0.509). The correlation seemed to indicate that the severity of defoliation increased as sites ranged from moist (MR = 4) to dry (MR = 1). As discussed later for the correlation with U86T, the association of defoliation with MR was not distinct based on the magnitude of correlation

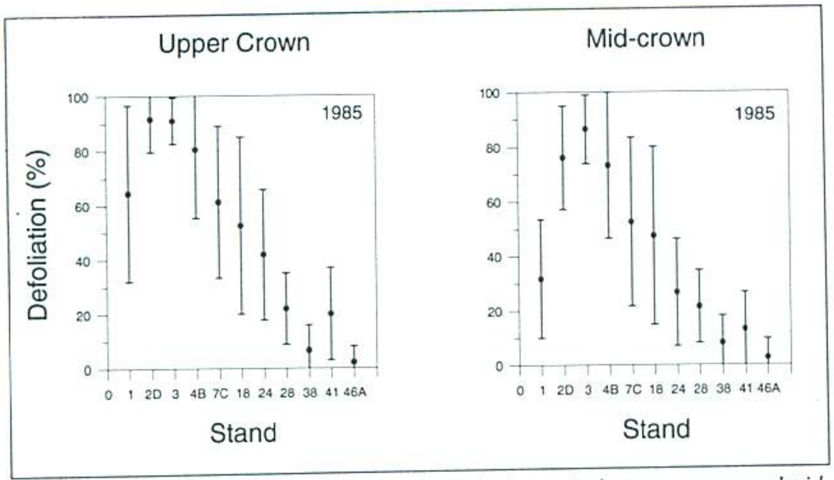

Figure 3. Percentage defoliation by the jack pine budworm in the upper crown and mid-crown of dominant and codominant trees in 1985. The stands shown represent a range in defoliation intensity. Values plotted represent stand average defoliation level and +/– one standard deviation.

coefficients. Correlation with current or older needle feeding was not identified as significant.

Defoliation in 1986

In 1986 the infestation collapsed in many areas thereby making analysis of site relationships with 1986 defoliation difficult. Current needle defoliation (U86C) occurred in four S-PLOTs and five D-PLOTs (Table 2). Defoliation levels for the S-PLOTs are illustrated in Figure 2. S-PLOT 7C had moderate defoliation and S-PLOT 38 had light defoliation. Current needle feeding (U86C) was correlated with age ($r = -0.496$), height ($r = -0.581$), and percentage of stocking ($r = 0.283$). A regression model ($R^2 = 0.491$) was identified that featured U86C as a function of height and stocking. The model and these correlations seemed to reflect where the infestation persisted in 1986 rather than a strong relationship with U86C. A large part of the 1986 infestation occurred in the area affected by the massive 1948 Mississauga forest fire. Jack pine stands that originated after the fire are typically semimature and well stocked. Examples are S-PLOTs 7C and 38 and D-PLOTs 8, 10, 15, and 37 (Table 1). The budworm were active in all of these stands except D-PLOT 15.

Moisture regime (MR) was correlated with feeding on needles of all ages (U86T) ($r = -0.425$), age ($r = 0.379$), and height ($r = 0.375$). As well, U86T was correlated with age ($r = -0.396$) and height ($r = -0.375$). The association of MR with U86T seemed to be independent of the stand age and tree height and of the fire influence mentioned above for U86C; however, the positive association of MR with age and height indicates that the MR–U86T correlation could be a reflection of these factors. U85T was not shown to be significantly correlated with age or height, and hence, association of U86T with MR is considered similar to that of U85T and it is probably independent of an age or height influence. However, the correlation coefficient of –0.425 is not high and the association is regarded as not very distinct. Correlation with U86C, S86C, and S86T was not shown to be significant, probably because the infestation collapsed.

Growth Loss

Growth loss caused by defoliation is presented in Table 4 as a percentage of the annual volume increment (AVI). Gross (1992) showed that the growth of defoliated stands was reduced through 1988 and that it probably returned to preinfestation levels in 1989. Stands that experienced moderate or high levels of defoliation lost about 30 to 40% of their growth over the 1985–1988 period. This loss estimate does not include growth lost by trees that were killed by defoliation; however, that loss was included in the estimators presented in Tables 5 and 6, and thus was included in the impact estimates. This loss can be estimated by interpreting the percentage volume killed (Table 4) and AVI for the appropriate stand parameters. If one examines the growth loss data presented in Appendix 1, which includes losses for survivors as well as killed trees, it is apparent that growth losses totaling 1.0 to 1.5 times AVI occurred in many of the severely defoliated stands.

Mortality

Jack pine mortality for the 1984–1988 period is listed in Table 4. Most of the mortality occurred in the year following high levels of defoliation. Mortality data (Table 4) are presented as a percentage attributable to budworm and to an all cause total. Most of the damage not attributed to the budworm was due to windthrow, root rot, logging, road construction, or old age. The approach taken was to assign budworm defoliation as the cause of mortality if moderate or high levels of defoliation had been present at a site and if other causes were not obvious. Hence, some mortality ascribed to budworm could have been partially a response to other factors.

Mortality caused by budworm throughout 1988 for S-PLOTs and D-PLOTs ranged from 0 to 10% for stands that experienced moderate or high levels of defoliation (Table 4, Fig. 4). This seemed to be the situation for the entire infestation, as reflected by the township summaries in Figure 4. Stands with up to 10% mortality caused by the budworm occurred in Sagard and Gaunt townships, but

Table 4. Impact as mortality and dead top injury and growth loss caused by the 1982–1986 jack pine budworm infestation that occurred in northeastern Ontario.

Stand	Township	Defoliation history[1]	Age (yrs)	Dead: Total (%)	Dead: Budworm (%)	Dead top: Total (%)	Dead top: Budworm (%)	Annual growth loss[2] (%)
1	Monestime	HMV	68	6	5	46	46	38.6
2D	Westbrook	MHV	41	1	1	15	15	41.7
3	Sagard	LHV	59	29	1	7	7	41.7
4B	Moses	LHV	61	1	0	0	0	32.4
5	Cartier	HMV	65	3	2	2	2	27.8
6	Garvey	–HL	65	0	0	0	0	45.5
7C	Gaunt	LMM	35	1	1	5	5	34.7
8	Gaunt	–MM	35	0	0	4	3	30.1
9	Vrooman	–MM	31	0	0	2	0	31.6
10	Martel	–MM	35	1	1	1	1	39.3
11	Cartier	MLV	80	7	5	3	3	19.3
12	Moses	–MV	50	1	1	0	0	25.9
13	Invergarry	–MV	75	6	6	10	10	19.0
14	Sagard	–MV	59	1	1	5	5	40.9
15	Deans	–MV	40	1	1	1	1	20.5
16	Lumsden	MLV	60	4	0	3	0	20.1
17	Ermatinger	–MV	85	5	1	0	0	17.0
18	Ulster	LMV	78	3	3	3	3	17.7
19	Invergarry	LMV	83	9	3	0	0	13.1
20	Ulster	–MV	85	0	0	0	0	13.6
21	Marquette	–MV	80	0	0	1	0	14.4
22	Monestime	–MV	68	2	2	2	2	15.4
23	Cavell	–MV	85	2	2	2	2	11.8
24	Viel	LMV	28	5	0	0	0	11.6
25	Westbrook	–MV	60	0	0	0	0	10.0
26	Strom	–MV	65	3	0	0	0	11.8
27	Teasdale	LMV	49	0	0	6	6	15.4
28	Neelands	MLT	79	6	0	1	0	13.1
29	Neelands	–MV	79	2	0	0	0	11.8
30	Ogilvie	MTV	60	0	0	1	0	8.5
31	Antrim	–MV	70	5	0	1	0	12.8
32	Cartier	–MV	73	1	0	0	0	8.5
33	Mickle	TMV	60	9	0	1	0	7.7
34	Cortez	LMV	115	10	0	1	0	6.9
35	Cortez	–MV	95	5	0	0	0	4.1
36	Moncrief	–MV	76	6	6	0	0	6.9
37	Lane	–LL	80	0	0	1	0	3.1
38	Martel	LLL	40	0	0	0	0	10.8
39	Teasdale	–LV	75	4	0	1	0	5.6
40	Edinburgh	–LV	90	5	0	0	0	3.1
41	Ermatinger	LLV	80	10	0	1	0	5.4
42	Ogilvie	–LV	60	1	0	1	0	3.1
43	Mandamin	–LV	65	0	0	0	0	6.6
44	Wardel	–LV	40	1	0	0	0	1.5
45	Weeks	–TV	70	0	0	0	0	0.0
46A	Weeks	VTV	33	1	0	0	0	1.5
47	Viel	–TV	95	2	0	0	0	0.0

[1] Defoliation history (1984, 1985, 1986) coded as follows: void (V) = 0%, trace (T) = 1–5%, light (L) = 6–25%, moderate (M) = 26–75%, high (H) >75%, and – is missing data.

[2] Average annual growth loss from 1985 to 1988 as a percent of annual volume increment (AVI).

stands with more than 5% mortality were not common even for townships in the more intensely defoliated parts of the infestation. Mortality levels were highly variable (Fig. 4), probably reflecting the variable nature of the defoliation discussed previously.

Windthrow was extensive in some stands in the winter of 1985–1986. Trees in S-PLOTs 1, 3, 4B, 5, 18, 28, and 34 sustained windthrow. Data for S-PLOT 4B were based on eight surviving plots. Thus, the 1% total mortality shown for stand 4B in Table 4 does not reflect the complete devastation of two subplots by windthrow. In 1986, the exposed root systems of many of the windthrown trees were examined for evidence of root rot. Most were unaffected or had only negligible rot. As well, no evidence of Armillaria root rot was observed at the root collars of the trees rated as killed by defoliation when the trees were first noted as dead.

Dead Tops

Stands that had severe defoliation had from 0 to 46% of the trees with dead tops (Fig. 4, Table 4). The average length of top killed was 1.6 m (range 0.5–10.0 m). The percentage of trees with dead tops was correlated (r = 0.480) with the percentage killed by budworm. Dead tops occurred at the ratio of about 3 for every tree killed by defoliation. Stands averaged 6.2% dead topped to 2.0% dead. The relationship was also reflected by the slope (27%) of a regression model ($R^2 = 0.236$) comparing the two kinds of injury.

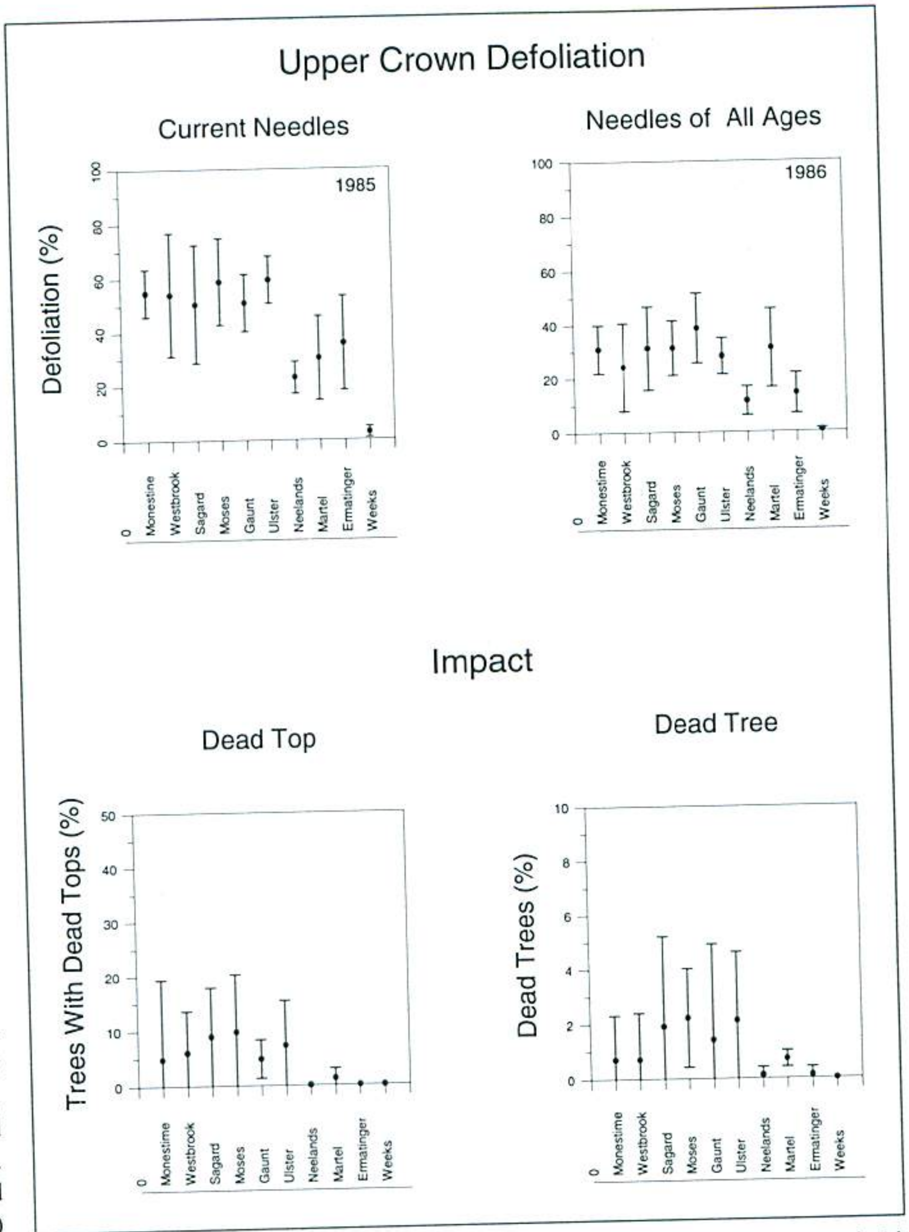

Figure 4. Average stand levels of defoliation, mortality, and dead top injury associated with the 1982–1986 jack pine budworm infestation. The townships shown represent a range in defoliation intensity. Values plotted represent stand average defoliation level and +/– one standard deviation.

Most of the dead tops occurred in the year after high defoliation. The dead character of tops was difficult to discern at that time because some tops were merely void of needles. All trees that were ultimately rated as having dead tops in 1987 had previously sustained high defoliation in the upper crown. Dead tops were well correlated with upper-crown defoliation (U86T) (r = 0.433) and other variables that rated defoliation. The percentage of trees that had severe needle defoliation (S85T) showed the highest correlation (r = 0.609), and a regression model that featured S85T and S86T was highly significant ($R^2 = 0.458$), indicating that many of the dead tops were associated with trees that suffered high levels of defoliation in the upper crown. High variability among stands, similar to that noted for defoliation and mortality, also occurred for dead tops (Fig. 4).

Impact Estimators

Estimators used for application to mapped infestation histories are presented in Table 5 for growth loss and Table 6 for mortality. An earlier study (Gross 1992) indicated that growth loss was greatest in the year following defoliation and that losses for the succeeding two years occurred at about half the rate of the previous year. There also was evidence for a loss of 10 to 20% of AVI for the initial year of a moderate or high level of defoliation. As an example, applying loss estimators (Table 5) to areas having one year of high defoliation indicates a cumulative loss of 0.9 x AVI, with loss for the year of high defoliation at 0.2 x AVI, and then at 0.4, 0.2, and 0.1 x AVI for the succeeding three years.

Dead tops were estimated to be a constant three times the mortality estimate based on the dead top to dead tree ratio discussed previously. Since trees with dead tops are more likely to die than those with green tops, this statistic should be considered as an ultimate fate distinct from the percentage that may have dead tops early in an infestation.

The estimators (Tables 5 and 6) are the same as were devised for use in the FIDS impact exercise reported by Gross et al. (1992) for the period 1982 to 1987. Most of the analysis for the present report was completed at that time. The approach taken for this study, as well as the previous FIDS report, was to apply mapped infestation histories to township summaries (n = 30) for the damage variables. These summaries were considered to reflect the damage that resulted from these levels of mapped defoliation. In consultation with the FIDS entomology staff, who had experience with the mapped histories and information from FIDS reports and other studies, Tables 5 and 6 were devised.

The estimators listed in Tables 5 and 6 are designed to be applied to mapped infestation histories and not to actual stand situations such as those illustrated in Figures 2, 3, and 4. The estimators were designed to be applied as an average stand condition expected for the appropriate mapped history. For example, Monestime Township was mapped as having high levels of defoliation in 1984 and 1985. In preparing Tables 5 and 6, this was interpreted to indicate that most stands in the township had a high level of defoliation for at least one year and that some stands (e.g., S-PLOT 1) had either a moderate or high level of defoliation in both years. The probable occurrence of stands with less than these defoliation levels was incorporated in the estimators. Stands that were defoliated twice at the high (>75%) level were not encountered in the samples. Mapped histories of areas that had high levels of defoliation for three successive years were encountered, as were most of the mapped histories listed in Tables 5 and 6. The impact estimators in Tables 5 and 6 indicate the amount of growth loss and mortality that occurred in these areas based on experience and data from this and other studies.

Table 5. Growth loss estimators applicable to the 1982–1986 jack pine budworm infestation that occurred in northeastern Ontario. Loss is expressed as the percent of annual volume increment (AVI) that is lost relative to the mapped defoliation history.

Defoliation history[1]	Annual rate of growth loss (%) by year						Cummulative total
	1	2	3	4	5	6	
M	10	20	10	0	0	0	40
H	20	40	20	10	0	0	90
MM	10	30	30	20	0	0	90
M_M	10	20	30	30	10	0	100
MH	10	30	50	20	10	0	120
M_H	10	20	40	30	10	0	110
H_M	20	40	30	20	10	0	120
HM	20	50	40	20	10	0	140
H_H	20	40	40	40	20	10	170
MMH,HMM,MHM	10	30	60	40	20	10	170
HH	20	60	60	40	20	0	200
MHH,HMH,HHM, H_HM,HH_M	20	30	60	60	40	20	230
HHH,HHHM,H_HH	20	60	60	60	40	20	260

[1] Defoliation history coded as follows: high(H) >75%, moderate(M) = 26-75% and (_) defolation <26% for light, trace, and void. Some estimator sequences apply to several defoliation histories.

Impact

The budworm infestation was estimated by Gross et al. (1992) to have caused a growth loss of 1.8 million m^3 and mortality of 4.1 million m^3 gross standing volume (GSV) for the 1982–1987 period in Ontario. Those data with summaries by OMNR administrative region are reproduced as part of Table 7. Trees with dead tops occurred in a volume of about 12 million m^3, but no estimate of actual volume lost was attempted. Losses for 1988 and 1989 will be estimated by applying the same estimators (Tables 5 and 6) to the mapped histories for the infestation, as some stands were still recovering in these years. Since most stands in 1988 and 1989 will be in the third or fourth year of recovery after defoliation in 1985 and 1986, additional 1988–1989 loss is expected to be about 0.2 times AVI for growth and 0.005 to 0.01 times GSV for mortality. The additional loss amounts to about 0.3 million m^3 for growth and 1.0 million m^3 for mortality. Total loss for the infestation then was 5.9 million m^3 for the 1983–1987 period (Gross et al. 1992) and approximately 1.3 million m^3 for the years 1988 and 1989. A more precise estimate will be available for 1988 and 1989 when the estimators are applied to the FRI inventory data and individual mapped stand histories as identified by GIS in the expected FIDS exercise. Annual volume increment (AVI) and GSV for the area infested is presented in Table 7 for the years 1983–1987. If one accepts that the AVI affected in 1986 (1,650,291 m^3, Table 7) represents AVI for the total infested area, then total growth and mortality losses were equivalent to 1.3 and 3.1 years of growth, respectively, for the affected jack pine population through 1989. Mortality expressed as a percentage of GSV (142,216,132 m^3, Table 7) was 3.6%.

Effect of Spraying with *Bacillus thuringiensis* (*B.t.*)

An objective of this study was to evaluate the effectiveness of the *B.t.* spray program with respect to stand impact. This proved to be a difficult assignment. Stands selected for protection generally had moderate-to-high levels of defoliation in the year preceding their selection. They also tended to have the highest defoliation forecasts for the year in which protection was scheduled based on egg-mass and larval (L-2) densities. Therefore, the criteria used to select stands for protection tended to make data for these selections biased for various comparisons.

The selection policy for protecting stands seems to have been interpreted differently in the various OMNR administrative districts engaged in the program. Some districts proposed stands for control to prevent mortality. Others proposed these stands as well as stands that had very little defoliation damage but that were scheduled for harvest. Some proposals also included semimature stands. As a result, many of the sprayed stands had significant damage and defoliation present prior to being sprayed.

A simple comparison of sprayed and unsprayed S-PLOTs showed that the sprayed stands had significantly more defoliation, mortality, and dead tops than unsprayed

Table 6. Mortality estimators applicable to the 1982–1986 jack pine budworm infestation that occurred in northeastern Ontario. Loss is the percent of gross standing volume (GSV) that is lost relative to the mapped defoliation history.

Defoliation history [1]	Annual rate of mortality loss (%) by year						Cummulative total
	1	2	3	4	5	6	
M	0	0.5	0.5	0	0	0	1
H	0	1	1	0.5	0	0	2.5
MM	0	0.5	1	1.5	1	0	4
M_M	0	0.5	0.5	1	1	0	3
MH	0	0.5	1.5	1.5	1.5	0	5
M_H	0	0.5	0.5	1	1	0.5	3.5
H_M	0	1	1	0.5	1	0.5	4
HM	0	1	1.5	1.5	1.5	0	5.5
H_H	0	1	1	1.5	1	1	5.5
MMH,HMM,MHM	0	0.5	1.5	4	4	2	12
HH	0	1	2	2	2	1	8
MHH,HMH,HHM,	0	1	2	6	6	2	17
HHH,HHHM,H_HH	0	1	2	8	10	5	26

[1] Defoliation history coded as follows: high(H) >75%, moderate(M) = 26-75% and (_) defolation <26% for light, trace, and void. Some estimator sequences apply to several defoliation histories.

Table 7. Growth loss and mortality caused by the 1982–1986 jack pine budworm infestation that occurred in northeastern Ontario and the forest resource affected by the defoliation.

			Impact		Forest Resource Inventory[1]	
Region	Year		Growth loss (m^3)	Mortality (m^3)	Annual volume increment (m^3)	Gross stand volume (m^3)
Northern	1983		0	0	0	0
	1984		37,440	0	187,202	0
	1985		256,448	143,676	968,573	14,637,597
	1986		424,029	929,861	976,241	83,222,795
	1987		251,075	1,011,305	933,997	83,569,724
		Total	968,992	2,084,842		
Northeastern	1983		1,640	0	8,199	0
	1984		60,255	8,354	291,235	835,420
	1985		233,048	288,908	666,537	28,679,530
	1986		300,765	810,584	664,134	57,773,577
	1987		175,733	817,589	596,844	57,562,089
		Total	771,441	1,925,435		
Algonquin	1983		951	0	4,757	0
	1984		2,688	5,233	5,936	523,334
	1985		3,897	9,495	9,959	645,092
	1986		4,692	33,965	9,916	1,090,355
	1987		2,793	39,293	9,584	1,084,319
		Total	15,021	87,986		
Total	1983		2,591	0	12,956	0
	1984		100,383	13,587	484,373	1,358,754
	1985		493,393	442,079	1,645,069	43,962,219
	1986		729,486	1,774,410	1,650,291	142,086,727
	1987		429,601	1,868,187	1,540,425	142,216,132
		Total	1,755,454	4,098,263		

Total loss = 5,853,717

[1] The Forest Resource Inventory of the Ontario Ministry of Natural Resources in 1990. Data are the volumes of jack pine in the defoliated area.

stands ($p < 0.01$, t test). The analysis, however, was not sound because of the biased character of the sprayed stands that often were more heavily damaged than unsprayed stands prior to selection. Also there was an allocation problem in that the decision to spray a specific stand was not known when the stands were selected for sampling in 1985, and their spray status for 1986 was also unknown. This resulted in a sample of only five sprayed stands for 1985, and while ten sample stands were sprayed in 1986, the population collapse prevented a satisfactory test for those data. Other tests of spray effectiveness, conducted independently, compared sprayed to nonsprayed blocks and had good experimental control (Meating, FCOR, unpublished data). The general impression of the authors was that stands in the sprayed blocks were well protected by the spray program.

Based on a comparison of expected and observed defoliation levels for a limited number of S-PLOTs, spraying was somewhat successful (Table 8). Forecasts for 1985 based on egg-mass samples and second-instar (L-2) larval samples show that observed defoliation levels were reduced compared to expected levels for S-PLOTs 4B, 27, and 28. S-PLOT 1 experienced high defoliation in 1985; however, new shoots and needles produced in 1985 were greatly reduced in size compared with those of previous years. Hence, budworm defoliation prior to spraying was concentrated on a reduced volume of foliage. This situation seemed to indicate that feeding by early-instar larvae eliminated the small volume of foliage produced prior to spraying and therefore spraying at the usual time was less effective. Data for stands that were not sprayed showed that predicted defoliation levels sometimes failed to occur.

The ability to forecast population and defoliation levels accurately appears to decrease with increasing infestation age (Meating, CFS – Ontario, unpublished data). Expected levels of defoliation occurred in most stands in 1985. In 1986, however, budworm populations collapsed

Table 8. Jack pine budworm population and defoliation levels in relation to *Bacillus thuringiensis* spray and defoliation history for stands (S-PLOTs) sampled to assess the impact of the 1982–1986 jack pine budworm infestation that occurred in northeastern Ontario. Data for the 1986 control program reflect the general collapse of the infestation in 1986.

1985 CONTROL PROGRAM

	Stand	Defoliation history[1]	Egg masses[2] 1984 (n)	Larvae[3] 1985 (n)	Upper crown current needle defoliation (U85C) (%)
Forecast = high					
Sprayed	1	HMV[3]	22	121	98
	4B	LHV	9	89	7
	27	LMV	10	121	24
	28	MLT	22	156	38
	34	LMV	0	76	16
Not sprayed	2D	MHV	11	-	25
	5	HMV	4	140	78
	11	MLV	11	76	71
	18	LMV	5	95	16
	30	MTV	2	263	35
	33	TMV	21	83	3
Forecast = moderate					
Not sprayed	3	LHV	0	22	19
	7C	LMM	0	40	11
	16	MLV	7	40	54
	19	LMV	3	44	21
	41	VTV	16	27	7
Forecast = nil to light					
Not sprayed	24	LMV	2	-	9
	38	LLL	2	9	11
	46A	VTV	1	1	1

1986 CONTROL PROGRAM

	Stand	Defoliation history[1]	Egg masses[2] 1984 (n)	Larvae[3] 1985 (n)	Upper crown current needle defoliation (U86C) (%)
Forecast = high					
Sprayed	1	HMV	7	1	0
	2D	MHV	10	-	0
	3	LHV	6	28	0
	7C	LMM	10	50	42
	28	MTV	6	18	3
Forecast = moderate					
Sprayed	27	LMV	3	-	0
Not sprayed	18	LMV	5	-	0
	19	LMV	5	-	0
	30	MTV	8	2	
	34	LMV	5	21	0
Forecast = nil to light					
Sprayed	4B	LHV	2	8	0
	5	HMV	1	-	0
	11	MLV	3	-	0
	16	MLV	0	5	0
Not sprayed	24	LMV	-	-	0
	33	TMV	0	-	0
	38	LLL	2	-	21
	41	LLV	1	-	0
	46A	VTV	4	-	0

[1] Defoliation history (1984, 1985, 1986) coded as follows: void(V) = 0%, trace(T) = 1-5%, light(L) = 6-25%, moderate(M) = 26-75%, and high(H) = >75%.

[2] Defoliation forecasts based on egg masses are as follows: light 1-2, moderate 3-5, high > 5 (eggs per 60-cm length branch sample), and (-) is missing data.

[3] Defoliation forecasts based on Larvae L-2 are as follows: light 1-15, moderate 16-54, and high >54 (larvae per 60-cm length branch sample).

throughout most of the infestation and in many stands the observed defoliation was considerably below the forecast level. Budworm populations did not collapse completely in stands 7C, 28, and 38 as evidenced by the occurrence of some defoliation (Table 8). Spray effectiveness for S-PLOT 7C, where moderate defoliation occurred in 1986, was limited. Defoliation of current needles (U86C) was 42% (Fig. 2). Spraying appeared to be effective for S-PLOT 28. The egg-mass forecast was for a high level of defoliation, but the sample of second-instar larvae indicated a forecast change to moderate defoliation. Actual defoliation was at the trace level so some effect seemed present. S-PLOT 38 was not sprayed and it experienced light current needle defoliation (U86C).

The 10-tree plots used to monitor the spray program were not designed to assess the budworm's impact. Data for these plots did provide evidence that spraying reduced the amount of defoliation that occurred. In 1985, budworm population levels were generally higher in spray plots than in check plots. Overall, 1985 prespray budworm larval densities in spray plots averaged 15.8 per branch (s = 15.8) compared with an average of 10.2 per branch (s = 10.1) for check plots. Defoliation estimates were, however, significantly lower ($p < 0.05$) in spray plots (av. 25.0%, s = 22.2%) compared with levels in the check plots (av. 40.0%, s = 26.5%). Defoliation rates were kept below 20% in more than half of the sprayed plots and below 40% in three-quarters of the plots (Fig. 5). A comparison of defoliation in spray and check plots that had similar prespray budworm densities showed that defoliation was lower by an average of about 50% in plots treated with *B.t.* (Fig. 6).

In 1986, prespray larval populations averaged 2.4 per branch (s = 2.8) in spray plots and 3.0 per branch (s = 3.3) in check plots. Defoliation was generally light throughout most of the area infested in 1986, averaging 5.0% (s = 9.1) in spray plots and 7.0% (s = 8.9) in check plots.

The population studies showed that stands treated with *B.t.* in 1985 had defoliation levels reduced to acceptable levels; whereas, moderate-to-severe defoliation occurred in stands left unprotected. The benefits of the aerial protection program were minimal in 1986 when budworm populations declined substantially throughout most of the infestation and there was little difference in defoliation level between sprayed and check plots. The collapse seems to have occurred after the L-2 larval samples were taken in April 1986 because population levels sufficient to predict at least moderate defoliation existed at that time in S-PLOTs 3, 7c, 28, and 34 (Table 8), as well as in many of the proposed spray blocks.

The experience of trying to assess the effectiveness of an operational spray program did provide some clues for consideration in future attempts. Population estimates made just prior to spraying provided the best estimates of expected defoliation. It would be useful to know how much foliage was missing just prior to spraying in order to estimate the benefit of spraying based on the amount of damage prevented. Data from this study does provide an estimate of the damage that occurred for various mapped defoliation histories and this can be the basis for damage prediction. If one could confidently state that a certain level of defoliation would have occurred, but that spraying resulted in a lower level, then some estimate of the amount of damage prevented is possible. The expected defoliation can be mapped based on forecasted populations. These data can be processed by GIS through the FRI, or a similar inventory, in the same manner described for this exercise to get an expected impact. The difference (expected minus observed) is the amount of impact prevented by spraying budworm. The process can accommodate forecast mapped histories in the same manner as actual histories using the estimators in Tables 5 and 6 and can be applied at the stand, spray block, or infestation level. As an example, consider that light defoliation causes minor growth loss and no mortality or dead tops. If spraying prevents more than light defoliation, the impact prevented is a function of the amount of impact expected for the forecasted defoliation.

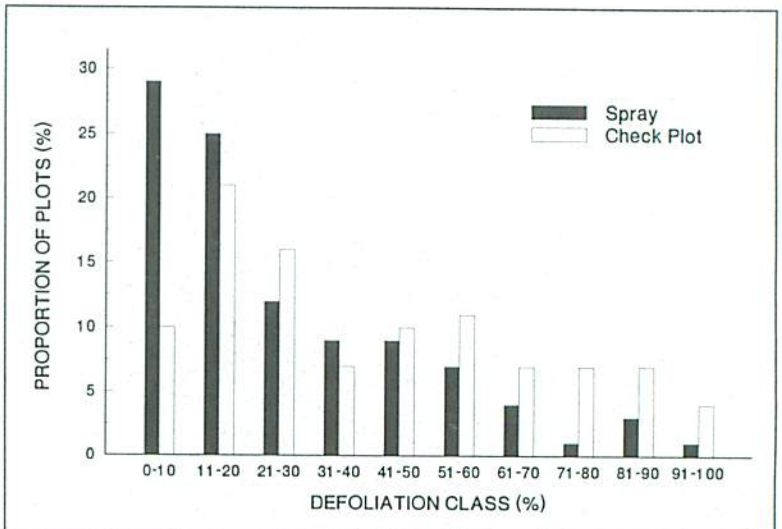

Figure 5. Defoliation by jack pine budworm in 1985 in plots sprayed with a formulation of Bacillus thuringiensis *and in control check plots over the range in defoliation that occurred in 1985.*

Survey Methods

A variety of survey methods were used in this study. O-PLOTs were invoked to rate the infestation at a suitable number of sites with the limited resources available. Fortunately, the quality of O-PLOT data was satisfactory. On review of S-PLOT data, and based on the variance encountered (Fig. 2), it became apparent that a sample of 25 dominant and codominant jack pine would provide a reasonably good estimate of average stand defoliation (95% confidence interval of +/– 10%) based on the usual sample size requirement for simple random samples (Freese 1967). A 25-tree sample for estimates of the percentage of trees that are dead or dead topped is somewhat small. However, one could sample these as a cluster of 4, 25-tree clusters on which trees are rated only for mortality and dead top injury. With little additional effort, 25-tree plots can replace O-PLOTs for defoliation estimates and then trees can be numbered for future reference. Density and basal area estimates can be sampled by means of prism plots at the random starting point for the 25-tree clusters, as these estimates are often biased when they are based on tree counts or distance sample methods (Gross et al. 1980).

Growth Models

An improvement to the growth loss models presented by Gross (1992) would be to model the defoliation data based on the severity of defoliation and the number of years an infestation had been present in a stand, rather than the amount present in one calendar year as was the case for the variable defoliation of needles of all ages (U86T), featured in many of the models. If this variable had been the most severe defoliation from among U84T, U85T, or U86T a more sensitive model would probably have been identified. As an example, the growth loss estimate for Stand 1, which had high defoliation in 1984, was probably conservative based on U86T = 50.4%. Using U85T = 75.5%, referencing the year following the most severe year of defoliation, seems more appropriate. Data for S-PLOT 2D were in Model 23 identified by Gross (1992) and used in this study. This plot also had greater U85T defoliation compared to U86T defoliation. After applying Model 23 to the entire data set, it was apparent that a model based on defoliation in the most severe year and the number of years defoliated at the high or moderate level would have been more applicable. This innovation was not applied because Model 23 had been the basis for previous estimates and most sites had 1985 as the year of greatest defoliation. Hence, not much change could be expected.

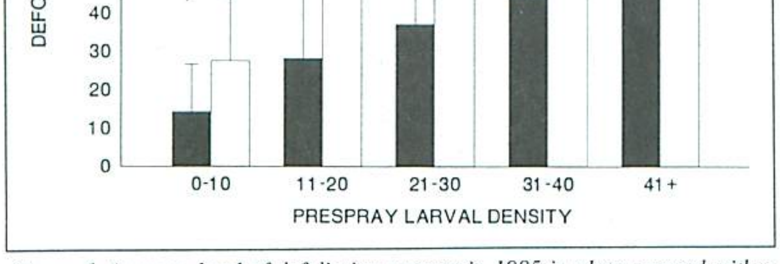

Figure 6. Average level of defoliation present in 1985 in plots sprayed with a formulation of Bacillus thuringiensis *compared with levels present in control check plots over a range of prespray larval densities. Line extensions above bars represent one standard deviation.*

SUMMARY AND CONCLUSIONS

The jack pine budworm infestation that occurred from 1982 to 1986 in northeastern Ontario caused an estimated impact of 2.1 million m^3 growth loss and 5.1 million m^3 mortality. Losses through 1987 were determined by a joint FIDS–OMNR exercise (Gross et al. 1992) that applied the estimators (Table 5 and 6) identified by the present study to aerially mapped defoliation histories processed by GIS technology and then applied to the FRI inventory. Significant growth loss and mortality continued for several years after defoliation stopped and losses for 1988 and 1989 are presented as preliminary estimates to be determined more precisely by a future FIDS–OMNR impact exercise for the 1988–1992 period. The data illustrate the importance of jack pine budworm and provide information for timber depletion and wood supply purposes.

The impact estimators (Tables 5 and 6) can also function to predict impact. Population data or forecasted defoliation can be plotted and then potential impact can be estimated in a manner similar to the way actual impact was estimated for this report. One merely treats the forecasted defoliation as an actual event and then impact is a function of previous and predicted defoliation. This is a powerful planning tool. Extensive defoliation of needles of all ages can occur rather suddenly in one year. By forecasting impact as well as defoliation, pest control strategists and foresters can include expected impact as part of decision support models.

The approach that was used to identify impact estimators based on background knowledge, case histories, and township summaries was a practical approach to providing estimators over a wide range in defoliation history. Eventually estimator models that accommodate all possible mapped histories can be identified. The authors feel, however, that such models should be based on a more extensive set of case histories and have data from several infestations.

The variety of sample methods used was, in a sense, a methods trial. The S-PLOT approach worked well to provide site specific impact estimates (Appendix 1). The provision of O-PLOTs for recording estimates based on visual observations of damage for a large number of sample sites did provide information on the diversity and range in level of defoliation, mortality, and dead top damage that was related to various mapped defoliation histories. Upgrading O-PLOTs to transects of numbered trees similar to D-PLOTs is recommended. This requires some additional effort to set up a plot, but then individual tree records are available for growth analysis and damage estimates. Also, rating individual trees reduces chances of bias such as was encountered for 1985 damage estimates based on O-PLOTs. O-PLOTs did provide an efficient way to record damage level at a large number of sites and this was vital to determining general stand conditions for the various mapped defoliation histories.

The attempt to provide an impact comparison of stands sprayed with *B.t.* with stands not sprayed was not successful. Various problems caused by sample selection criteria and insect population collapse prevented a satisfactory analysis. Sampling within an operational spray program caused problems. The decision to spray a block of timber is often made just prior to spray application based on 2-L or 3-L larval samples. Sample selection at that time for rating impact leaves little time to rate damage or defoliation prior to spraying. A solution is to sample sufficient stands to insure that an adequate number are sprayed and not sprayed. In this study only five of the 20 stands selected for S-PLOTs were ultimately sprayed in 1985.

Data were presented that show spraying with *B.t.* did reduce population and defoliation levels relative to forecasted levels for some stands. However, the goal was to rate the operational spray program with respect to impact. No doubt spraying reduced the impact of the infestation, but it was not possible to provide an estimate of the damage that would have occurred if there had been no control program. Thus, the impact data presented are reflective of the damage caused by the defoliation that actually occurred.

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