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Thomas P. Mog
The Davey Tree Expert Company

Ann M. Lynch
University of Michigan

J. A. Witter
University of Michigan

IMPACT OF THE SPRUCE BUDWORM (LEPIDOPTERA: TORTRICIDAE) ON THE OTTAWA AND HIAWATHA NATIONAL FORESTS, 1978–1980

Thomas P. Mog,[1] Ann M. Lynch,[2] and J. A. Witter[2]

ABSTRACT

The Michigan Impact Plot System was established during 1978 and 1979 to obtain a data base for quantifying the impact of the spruce budworm in the Ottawa and Hiawatha National Forests. The formulae used to estimate the mean, total, and associated standard errors of the various parameters at the national forest and forest district levels are presented. We present the 1978, 1979, and 1980 impact data for the following parameters: percent mortality, total dead volume, dead volume per ha, live volume per ha, defoliation ranking, frequency and extent of top-kill, and incidence of spruce budworm feeding on saplings and regeneration. Statistics from an annual inventory of 108 composite ground sampling units (CGSU) in 1978, and 136 CGSU's in 1979 and 1980 provide a more precise estimate of the impact of the spruce budworm in Michigan's Upper Peninsula than has been available to date.

The spruce budworm, *Choristoneura fumiferana* (Clemens), is the most important insect pest in North American spruce-fir forests and is found throughout the northern boreal forest. The present outbreak covers over 60 million ha of spruce-fir forests with losses in 1978 estimated at 283 million m^3 (Witter 1981). The current spruce budworm outbreak in the Lake States began in the 1960's. Mortality of balsam fir was first reported in 1971 (Hastings and Mosher 1976) in the eastern part of Michigan's Upper Peninsula. Currently, most of the spruce-fir stands in the Upper Peninsula are under attack. Damage in individual stands varies from light defoliation to nearly complete stand mortality. Little information is available on the impact of the spruce budworm in Michigan. Therefore, the Michigan Impact Plot System was established in 1978 and 1979 (Mog and Witter 1979). This seven-year study was designed to annually assess and evaluate tree mortality and growth impact on spruce-fir stands within the Ottawa and Hiawatha National Forests (N.F.) in the Upper Peninsula of Michigan. The third year of data collection for the Michigan Impact Plot System was completed in 1980. This paper documents the budworm impact data for the years 1978, 1979, and 1980.

METHODS

Mog and Witter (1979) and Witter and Mog (1981) described the sampling units being used in the Michigan Impact Plot System as: (1) primary sampling unit (PSU), a forest compartment; (2) secondary sampling unit (SSU), a spruce-fir stand; and (3) tertiary sampling unit (TSU), circular plots of various radii. The PSU's and SSU's were weighted according to their area of spruce-fir and then selected at random from each national forest. A SSU was divided approximately in half, and a composite ground sampling unit was located within each half of the stand. Composite ground sampling unit refers to three concentric circular plots nested around a single fixed plot center. A TSU is one of the three circular plots of 0.02, 0.04, and 0.08 ha which were established around the plot center. The particular plot size used depended on the parameter being measured or evaluated. This sampling scheme is

[1]The Davey Tree Expert Company, Kent, OH 44240.
[2]School of Natural Resources, University of Michigan, Ann Arbor, MI 48109.

an adaptation of a multi-stage cluster sampling technique (Schumacher and Chapman 1954, Yamame 1967, Sukhatme and Sukhatme 1970).

The Michigan Impact Plot System of 136 composite ground sampling units was established on the Ottawa and Hiawatha N.F.'s in Michigan's Upper Peninsula (Figs. 1–3). One hundred eight ground sampling units were established and evaluated in 1978. During 1979, an additional 28 composite ground sampling units were established, and 136 evaluated. Mog (1981) reported that an additional 28 composite ground sampling units were added to the Michigan

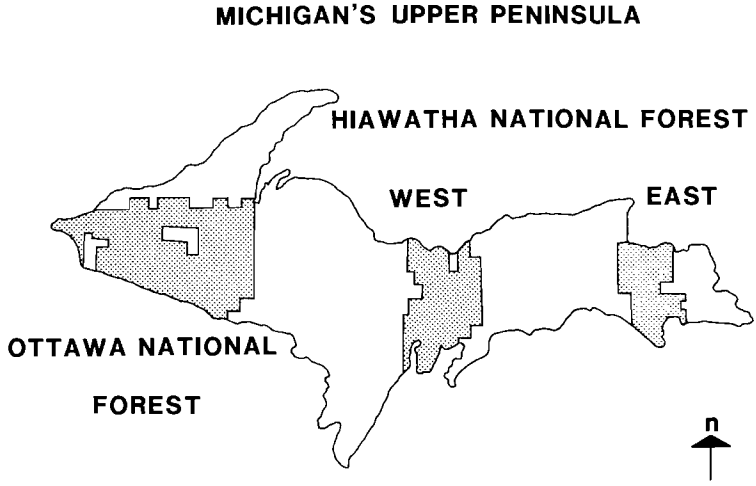

Fig. 1. Location of the Ottawa and Hiawatha National Forests in Michigan's Upper Peninsula.

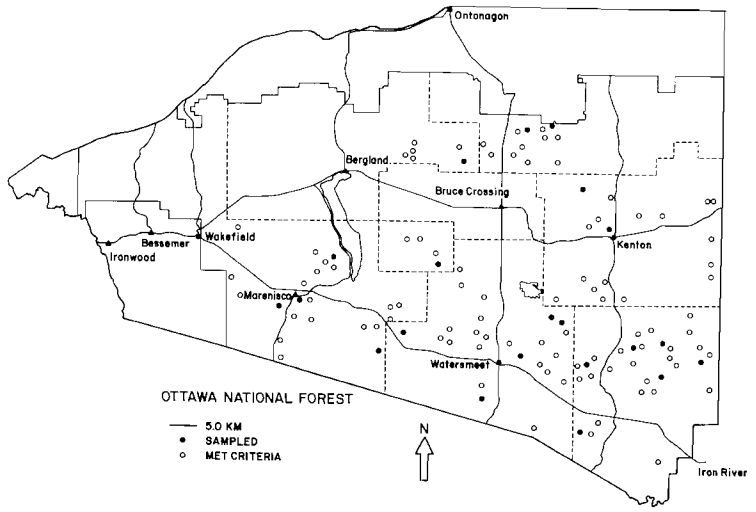

Fig. 2. Location of compartments sampled and compartments meeting criteria in the Ottawa National Forest.

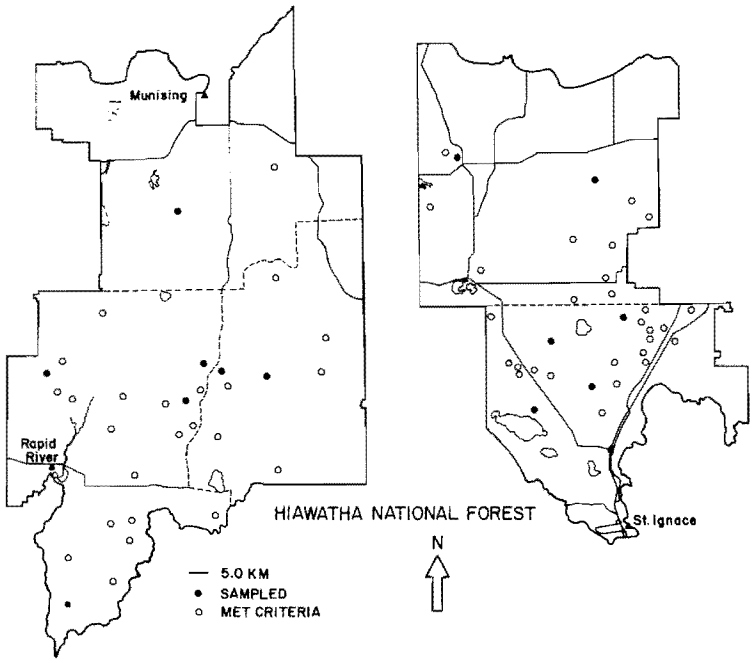

Fig. 3. Location of compartments sampled and compartments meeting criteria in the Hiawatha National Forest.

Impact Plot System in 1979 because re-examination of inventory information obtained from the United States Forest Service showed that a few forest districts and a few specific species mixtures were under-represented in the 1978 sample. The number of composite ground sampling units in the Michigan Impact Plot System totaled 136 in 1979, but will vary slightly from year to year after 1980 because a few of the sampled stands will be harvested before the study is completed in 1984. Changes in sample size may alter the accuracy and interpretation of the estimates. A reduction in the number of ground sampling units will be more important when the variability of a given variable in a national forest or district is high and/or when the original sample size is small relative to the final sample size. We will comment on this sampling size issue when it appears to be important with various parameters.

A description of the field techniques used to assess the impact of the spruce budworm was presented by Mog and Witter (1979). Statistics for the following parameters are presented in this paper: (1) percent mortality (0.04 ha), (2) total dead volume (0.08 ha), (3) dead volume per ha (0.08 ha), (4) live volume per ha (0.08 ha), (5) defoliation ranking (0.02 ha), (6) frequency and extent of top-kill (0.02 ha), (7) budworm feeding on saplings (0.02 ha), and (8) budworm feeding on regeneration (0.04 ha). The cluster sampling formulae presented in Table 1 were used to obtain the estimates for the first six parameters. The histograms for budworm feeding on saplings and regeneration were based on the total number of plots within the national forest.

Tree volume (V) was determined by using the equation $V = 0.42\ BH$, with B = basal area of tree and H = total tree height (Gevorkiantz and Olsen 1955). The tree heights entered into the equation were obtained from height curves. Separate curves for balsam fir, black spruce, and white spruce were drawn by plotting total tree height vs DBH, by 2.54-cm classes, for every tree measured on the 0.02-ha TSU's in both national forests. Additional white spruce trees from the 0.08-ha TSU's were included to increase the white spruce data base. The total

Table 1. Equations used to estimate the mean, total, and associated standard errors for parameter of interest for national forests based on a three-stage cluster sample.

MEAN

$$\hat{\mu}_{NF} = \frac{1}{L}\sum_{i=1}^{L}\frac{1}{m_i}\sum_{j=1}^{m_i}\frac{1}{n_{ij}}\sum_{k=1}^{n_{ij}} y_{ijk}$$

STANDARD ERROR OF THE MEAN

$$SE_{Mean} = \sqrt{V(\hat{\mu}_{NF})} = \sqrt{\frac{L-l}{L}\times\frac{\sum_{i=1}^{L}(\hat{\mu}_i-\hat{\mu}_{NF})^2}{L(L-1)} + \sum_{i=1}^{L}\frac{\hat{V}(\hat{\mu}_i)}{LL}}$$

TOTAL

$$\hat{T}_{NF} = \hat{R}_{NF}\times\left(\begin{matrix}\text{Area of spruce-fir}\\ \text{in national forest}\end{matrix}\right) = \left(\frac{1}{L}\sum_{i=1}^{L}\frac{1}{m_i}\sum_{j=1}^{m_i}\frac{1}{n_{ij}}\sum_{k=1}^{n_{ij}} r_{ijk}\right)\times\left(\begin{matrix}\text{Area of spruce-fir}\\ \text{in national forest}\end{matrix}\right)$$

STANDARD ERROR OF THE TOTAL

$$SE_{Total} = \sqrt{V(\hat{T}_{NF})} = \sqrt{\hat{V}(\hat{R}_{NF})\times\left(\begin{matrix}\text{Area of spruce-fir}\\ \text{in national forest}\end{matrix}\right)^2}$$

WHERE

$$\hat{V}(\hat{R}_{NF}) = \frac{L-l}{L}\times\frac{\sum_{i=1}^{L}(\hat{R}_i-\hat{R}_{NF})^2}{L(L-1)} + \frac{\sum_{i=1}^{L}\hat{V}(\hat{R}_i)}{LL}$$

L = no. of PSU's sampled in a national forest
l = no. of PSU's meeting compartment guideline in a national forest
m_i = no. of SSU's sampled in the i^{th} compartment
n_{ij} = no of TSU's sampled in the i^{th} compartment of the j^{th} stand
y_{ijk} = the value of the character of interest for the k^{th} plot of the j^{th} stand of the i^{th} compartment
x_{ijk} = the TSU (plot) size; 0.02 ha, 0.04 ha, or 0.08 ha
r_{ijk} = y_{ijk}/x_{ijk}, e.g., cu m/ha
$\hat{\mu}_i = \frac{1}{m_i}\sum_{j=1}^{m_i}\frac{1}{n_{ij}}\sum_{k=1}^{n_{ij}} y_{ijk}$ = mean of the i^{th} compartment
$\hat{R}_i$ = μ_i/x_{ijk} = ratio of the i^{th} compartment
$\hat{\mu}_{NF}$ = mean per TSU for a national forest; e.g., cu m/0.08 ha
$\hat{R}_{NF}$ = estimate of the ratio for a national forest; e.g., cu m/ha
$\hat{T}_{NF}$ = estimate of the total for a national forest; e.g., cu m

dead volume parameter is an accumulation of all dead trees in a given year for the species concerned, including standing dead trees present at the time the study was initiated.

The data for the various parameters are presented in table format at both the national forest and forest district levels. The tables contain either an estimated total or average and the associated standard error, which is printed in parentheses below the estimate (see Tables 2–16). Trends are discussed for the two national forests. Statistics at the forest district level are presented to support data for the national forests and to add greater detail to the trends detected at the national forest level.

Variability among sampling units of samples involving different units of measurement and/or plot size can be compared with the coefficient of variation of the mean (CVM) which expresses the standard error (SE) as a percentage of the estimated total or mean. Estimates based on a three-stage cluster sample are compared by tree species group and by national forest. The data are directly applicable to spruce-fir stands within the Ottawa and Hiawatha N.F.'s.

The descriptive statistics presented provide an appropriate estimate of spruce budworm impact in Michigan's Upper Peninsula from 1978–1980. However, caution should be used when making inferences about stands that are outside the national forests.

RESULTS AND DISCUSSION

We present and discuss spruce budworm impact data for 1978–1980 by national forests and forest districts for the following parameters: percent mortality, total dead volume, dead volume per ha, live volume per ha, defoliation ranking, frequency and extent of top-kill, and incidence of spruce budworm feeding on saplings and regeneration.

Percent mortality. Mortality increased in 1979 and 1980 for balsam fir, white spruce, and black spruce in both national forests (Tables 2–4). The percent of dead fir in the Hiawatha N.F. in 1978, 1979, and 1980 was nearly double that of fir in the Ottawa N.F. In 1980, percent balsam fir mortality was approximately the same as white and black spruce mortality combined in the Ottawa N.F. and approximately twice that of white and black spruce combined in the Hiawatha N.F.

Average percent fir mortality nearly doubled between 1978 and 1980 in all districts within the Ottawa N.F. except in the Bergland District which showed a six-fold increase. Percent fir mortality in 1980 was the greatest (22–26%) in the most western and northern districts (Bessemer, Watersmeet, Ontonagon, Bergland) where this outbreak first started in the western Upper Peninsula (Hastings and Renlund 1976). Percent fir mortality also had

Table 2. Average estimated percent mortality and (SE) of balsam fir, white spruce, and black spruce on the national forests.

	Ottawa			Hiawatha		
	BF	WS	BS	BF	WS	BS
1978	10.3 (2.3)	4.1 (2.5)	7.4 (2.3)	19.5 (8.5)	3.9 (2.6)	3.5 (1.8)
1979	12.3 (2.6)	7.6 (2.7)	9.9 (2.1)	28.5 (7.9)	6.8 (3.4)	9.9 (5.8)
1980	18.4 (3.4)	8.0 (2.8)	13.3 (3.5)	35.1 (8.7)	9.2 (3.7)	12.1 (6.2)

Table 3. Average estimated percent mortality and (SE) of balsam fir, white spruce, and black spruce on the six districts within the Ottawa National Forest.

	BF	WS	BS	BF	WS	BS
	Watersmeet			Iron River		
1978	10.9 (3.0)	1.9 (1.8)	9.4 (3.9)	3.9 (2.0)	10.5 (8.3)	8.0 (3.6)
1979	16.1 (6.1)	12.0 (6.8)	8.6 (3.4)	4.9 (1.4)	12.2 (6.6)	11.4 (2.8)
1980	24.5 (8.2)	12.0 (6.8)	9.4 (3.7)	8.9 (3.1)	13.1 (7.1)	14.5 (3.6)
	Bessemer			Bergland		
1978	17.2 (6.4)	0.0 (0.0)	1.2 (1.1)	3.8 (0.8)	0.0 (0.0)	0.0 (0.0)
1979	19.3 (6.8)	0.5 (0.5)	1.2 (1.1)	17.5 (12.0)	7.8 (7.5)	0.0 (0.0)
1980	25.8 (8.5)	1.0 (0.9)	1.2 (1.1)	22.4 (13.2)	7.8 (7.5)	0.0 (0.0)
	Ontonagon			Kenton		
1978	14.8 (11.8)	5.0 (5.0)	0.0 (0.0)	3.5 (0.6)	0.0 (0.0)	0.0 (0.0)
1979	15.4 (12.5)	5.0 (5.0)	0.0 (0.0)	2.8 (1.4)	0.0 (0.0)	25.0 (0.0)
1980	24.8 (18.4)	5.0 (5.0)	0.0 (0.0)	6.6 (0.9)	0.0 (0.0)	50.0 (0.0)

Table 4. Average estimated percent mortality and (SE) of balsam fir, white spruce, and black spruce on the five districts within the Hiawatha National Forest.

	BF	WS	BS	BF	WS	BS
	Rapid River			St. Ignace		
1978	3.4 (1.3)	0.0 (0.0)	3.3 (3.2)	25.8 (5.8)	4.2 (4.2)	10.4 (1.3)
1979	5.5 (2.2)	0.0 (0.0)	3.3 (3.2)	44.4 (8.4)	12.0 (6.9)	10.4 (1.3)
1980	8.7 (2.8)	1.6 (1.6)	10.0 (9.7)	53.8 (8.5)	14.1 (8.1)	10.4 (1.3)
	Sault Ste. Marie			Manistique		
1978	94.8 (0.8)	22.9 (2.7)	4.2 (1.2)	7.1 (1.8)	0.0 (0.0)	0.0 (0.0)
1979	81.1 (13.6)	13.2 (12.1)	34.4 (21.3)	3.6 (3.3)	0.0 (0.0)	0.0 (0.0)
1980	93.1 (4.8)	19.5 (7.0)	34.4 (21.3)	8.7 (5.5)	0.0 (0.0)	0.0 (0.0)
	Munising					
1978	1.6 (0.6)	0.0 (0.0)	0.0 (0.0)			
1979	1.6 (0.6)	0.0 (0.0)	0.0 (0.0)			
1980	2.1 (0.7)	0.0 (0.0)	0.0 (0.0)			

doubled between 1978 and 1980 in the eastern-most districts of the Ottawa N.F. (Iron River, Kenton), but was under 10%.

Percent fir mortality in the Hiawatha N.F. in 1980 was extremely high in the eastern portion of this National Forest (Sault Ste. Marie District, 93%; St. Ignace District, 54%) where the outbreak started. Fir mortality was under 10% in the three western districts (Munising, Rapid River, Manistique) in 1980. The decrease in the estimated percent mortality of balsam fir between 1978 and 1979 in the Sault Ste. Marie and Manistique districts was due to adding sampling units with lower mortality to existing units with higher mortality.

Elliott (1960) found that tree mortality begins after four consecutive years of defoliation and that 100% mortality of balsam fir occurred after 11 successive years of feeding. Another Canadian study reported the beginning of balsam fir mortality after 5–8 years of continuous heavy defoliation (Morris 1963). MacLean (1980) reviewed the work of eight studies in eastern North America on the vulnerability of spruce-fir stand to the budworm and reported that mature stands suffered mortality ranging from 70 to 100%, while mortality in immature stands ranged from 30 to 70%.

Total dead volume. The estimated total dead volume and standard error of balsam fir in 1980 in the Ottawa and Hiawatha N.F.'s was 287,987 ± 47,290 and 341,509 ± 80,656 m^3, respectively (Table 5). The coefficient of variation of the mean for balsam fir total dead volume was 25.0 (1978), 20.4 (1979), 16.4% (1980) and 38.6 (1978), 26.0 (1979), 23.6% (1980) for the Ottawa and Hiawatha N.F.'s, respectively. The coefficient of variation of the mean was consistently larger for the Hiawatha N.F. estimates, possibly due to fewer sampling units being located there.

Total dead volume of balsam fir, white spruce, and black spruce increased in both forests from 1978–1980. In 1980 total dead volume of fir was six times greater than that of spruce and at least nine times greater than that of either white or black spruce. Dead volume of white spruce was 1.5 times larger than that of black spruce. Total dead volume in the Hiawatha N.F. was greater than that in the Ottawa N.F. even though the Hiawatha N.F. had considerably less area of spruce-fir type, 13,000 vs 23,094 ha.

Two forest districts in the Ottawa N.F. had noticeably more total dead volume of spruce (Table 6), especially black spruce, than the other four districts. However, these stands also had considerably more live volume of spruce than any of the other districts. In 1980 the total volume of dead fir was approximately four times greater than that of spruce on plots in the Watersmeet District. Tree mortality was almost equally distributed between fir and spruce on plots in the Iron River District. Nevertheless, the trends for the two national forests and most forest districts agree with well-established patterns which show considerably less mortality of white and black spruce than that of balsam fir in mixed stands (Swaine and Craighead 1924, Turner 1952, Batzer 1973).

Table 5. Estimated total dead volume (m^3) and (SE) of balsam fir, white spruce, and black spruce on the national forests.

	Ottawa			Hiawatha		
	BF	WS	BS	BF	WS	BS
1978	167983 (41960)	15422 (11256)	18045 (7663)	154102 (59413)	3880 (2686)	4200 (2346)
1979	198392 (40516)	26384 (11834)	22968 (7981)	259753 (67589)	16389 (8944)	5778 (2598)
1980	287987 (47290)	34997 (16790)	34358 (10194)	341509 (80656)	26458 (14196)	6903 (2912)

Table 6. Estimated total dead volume (m^3) and (SE) of balsam fir, white spruce, and black spruce on the six districts within the Ottawa National Forest.

	BF	WS	BS	BF	WS	BS
	Watersmeet			Iron River		
1978	34559 (6607)	1354 (1323)	6622 (3027)	28942 (12901)	14458 (12510)	8375 (6748)
1979	44523 (9387)	1729 (1494)	9310 (4286)	27657 (9755)	17069 (10039)	10152 (4960)
1980	67623 (14471)	1756 (1521)	13017 (5682)	48619 (11182)	23481 (14584)	15904 (5416)
	Bessemer			Bergland		
1978	45664 (26493)	000 (000)	785 (785)	3200 (488)	000 (000)	000 (000)
1979	54304 (27852)	651 (651)	785 (785)	24175 (17713)	3027 (2887)	000 (000)
1980	67896 (31612)	1305 (1305)	978 (978)	30217 (19628)	3901 (3604)	000 (000)
	Ontonagon			Kenton		
1978	20935 (14689)	695 (695)	000 (000)	7722 (1287)	000 (000)	000 (000)
1979	26460 (16103)	2594 (2594)	000 (000)	10828 (3725)	000 (000)	588 (588)
1980	40283 (20298)	2742 (2742)	000 (000)	20935 (3072)	000 (000)	1784 (1784)

Table 7. Estimated total dead volume (m^3) and (SE) of balsam fir, white spruce, and black spruce on the five districts within the Hiawatha National Forest.

	BF	WS	BS	BF	WS	BS
	Rapid River			St. Ignace		
1978	9387 (1756)	000 (000)	840 (761)	75220 (19657)	790 (735)	870 (831)
1979	20452 (4962)	000 (000)	839 (760)	130701 (29819)	11431 (7906)	652 (613)
1980	35444 (9442)	1227 (1227)	1227 (1131)	174083 (31250)	18886 (12682)	652 (613)
	Sault Ste. Marie			Manistique		
1978	115809 (3550)	5375 (901)	4299 (1015)	696 (246)	000 (000)	000 (000)
1979	118064 (2981)	5063 (2046)	3370 (2621)	2435 (1633)	000 (000)	1319 (1194)
1980	140413 (9744)	6302 (1360)	3618 (2860)	4587 (2654)	000 (000)	1788 (1263)
	Munising					
1978	2223 (1071)	157 (111)	000 (000)			
1979	2944 (885)	160 (113)	000 (000)			
1980	3709 (1200)	160 (113)	000 (000)			

The total accumulated dead volume of balsam fir estimated in the Ottawa and Hiawatha National Forests in 1980 was 629.496 ± 127.946 m^3. The estimated total accumulated dead volume of spruce was 102.716 ± 44.092 m^3 (Table 5). The ratio of white spruce to black spruce total dead volume was approximately 1:1 and 4:1 for the Ottawa and Hiawatha N.F.'s, respectively. The relatively large volume of dead black spruce on plots in the Ottawa N.F. may in part be attributable to site condition and not completely due to budworm feeding.

Total dead volume of balsam fir, white spruce, and black spruce all nearly doubled between 1978 and 1980 in both national forests except for white spruce in the Hiawatha N.F. which showed a seven-fold increase (Tables 5–7). Most of the increase in total dead volume of white spruce for the Hiawatha N.F. was due to a 24-fold increase in total dead volume for the St. Ignace District.

Dead volume per ha. Dead volume per ha of balsam fir, white spruce, and black spruce for the national forests and districts for 1978–1980 is shown in Tables 8–10. The 1980 dead volume and standard error of balsam fir, white spruce, and black spruce in m^3/ha for the Ottawa and Hiawatha N.F.'s was 12.5 ± 2.0, 1.5 ± 0.7, 1.5 ± 0.4 and 26.3 ± 6.2, 2.0 ± 1.1, 0.5 ± 0.2, respectively. The Hiawatha N.F. estimate of balsam fir dead volume is double the Ottawa N.F. estimate, which is consistent with the mortality figures noted earlier.

Live volume per ha. Estimated live volume per ha of balsam fir, white spruce, and black spruce is presented in Tables 11–13. Loss of growing-stock is most evident for the fir component in the Hiawatha N.F. The loss in fir growing-stock volume, between 1978 and 1980 in the Hiawatha N.F. was 10.0 m^3/ha, an 18.7% reduction. The live volume per ha of balsam fir on the Ottawa plots was virtually unchanged over the same two-year period (e.g., 43.1 ± 4.0 m^3/ha in 1980). The coefficient of variation of the mean for balsam fir live volume was 8.4 (1978), 8.7 (1979), and 9.3% (1980) and 23.6 (1978), 21.3 (1979), 24.2% (1980) for the Ottawa and Hiawatha N.F.'s, respectively. Again, the coefficient of variation was larger for the Hiawatha N.F. estimates.

White spruce growing-stock volume increased in the Ottawa N.F. but decreased slightly in the Hiawatha N.F. The average annual change in live volume of white spruce was 1.5 and −0.2 m^3/ha in the Ottawa and Hiawatha N.F.'s, respectively. Growing-stock volume of black spruce increased annually at 0.2 and 0.7 m^3/ha in the Ottawa and Hiawatha N.F.'s, respectively. The loss of live balsam fir volume/ha in the Hiawatha N.F. was approximately ten times larger than the gain in live spruce volume.

There were large increases in the estimated volume per ha of white spruce in Bergland and Kenton districts; and of balsam fir in Kenton (Table 12), Sault Ste. Marie, and Manistique districts (Table 13) between 1978 and 1979. This increase was not the result of exceptional

Table 8. Average estimated dead volume (m^3/ha) and (SE) of balsam fir, white spruce, and black spruce on the national forests.

	Ottawa			Hiawatha		
	BF	WS	BS	BF	WS	BS
1978	7.3 (1.8)	0.7 (0.5)	0.8 (0.3)	11.9 (4.6)	0.3 (0.2)	0.3 (0.2)
1979	8.6 (1.8)	1.1 (0.5)	1.0 (0.3)	20.0 (5.2)	1.3 (0.7)	0.4 (0.2)
1980	12.5 (2.0)	1.5 (0.7)	1.5 (0.4)	26.3 (6.2)	2.0 (1.1)	0.5 (0.2)

Table 9. Average estimated dead volume (m^3/ha) and (SE) of balsam fir, white spruce, and black spruce on the six districts within the Ottawa National Forest.

	BF	WS	BS	BF	WS	BS
	Watersmeet			Iron River		
1978	7.4 (1.4)	0.3 (0.3)	1.4 (0.6)	4.7 (2.1)	2.3 (2.0)	1.4 (1.1)
1979	9.5 (2.0)	0.4 (0.3)	2.0 (0.9)	4.5 (1.6)	2.8 (1.6)	1.6 (0.8)
1980	14.5 (3.1)	0.4 (0.3)	2.8 (1.2)	7.8 (1.8)	3.8 (2.4)	2.6 (0.9)
	Bessemer			Bergland		
1978	11.7 (6.8)	0.0 (0.0)	0.2 (0.2)	1.5 (0.2)	0.0 (0.0)	0.0 (0.0)
1979	14.0 (7.2)	0.2 (0.2)	0.2 (0.2)	11.1 (8.2)	1.4 (1.3)	0.0 (0.0)
1980	17.5 (8.1)	0.3 (0.3)	0.3 (0.3)	13.9 (9.0)	1.8 (1.7)	0.0 (0.0)
	Ontonagon			Kenton		
1978	8.8 (6.2)	0.3 (0.3)	0.0 (0.0)	2.0 (0.3)	0.0 (0.0)	0.0 (0.0)
1979	11.1 (6.8)	1.1 (1.1)	0.0 (0.0)	2.9 (1.0)	0.0 (0.0)	0.2 (0.2)
1980	16.9 (8.5)	1.2 (1.2)	0.0 (0.0)	5.6 (0.8)	0.0 (0.0)	0.5 (0.5)

Table 10. Average estimated dead volume (m^3/ha) and (SE) of balsam fir, white spruce, and black spruce on the five districts within the Hiawatha National Forest.

	BF	WS	BS	BF	WS	BS
	Rapid River			St. Ignace		
1978	2.2 (0.4)	0.0 (0.0)	0.2 (0.2)	19.9 (5.2)	0.2 (0.2)	0.2 (0.2)
1979	4.9 (1.2)	0.0 (0.0)	0.2 (0.2)	34.6 (7.9)	3.0 (2.1)	0.2 (0.2)
1980	8.4 (2.3)	0.3 (0.3)	0.3 (0.3)	46.1 (8.3)	5.0 (3.4)	0.2 (0.2)
	Sault Ste. Marie			Manistique		
1978	46.9 (1.4)	2.2 (0.4)	1.7 (0.4)	0.4 (0.1)	0.0 (0.0)	0.0 (0.0)
1979	47.8 (1.2)	2.0 (0.8)	1.4 (1.1)	1.4 (1.0)	0.0 (0.0)	0.8 (0.7)
1980	56.8 (3.9)	2.6 (0.6)	1.5 (1.2)	2.7 (1.6)	0.0 (0.0)	1.1 (0.7)
	Munising					
1978	2.6 (1.2)	0.2 (0.1)	0.0 (0.0)			
1979	3.4 (1.0)	0.2 (0.1)	0.0 (0.0)			
1980	4.3 (1.4)	0.2 (0.1)	0.0 (0.0)			

Table 11. Average estimated live volume (m^3/ha) and (SE) of balsam fir, white spruce, and black spruce on the national forests.

	Ottawa			Hiawatha		
	BF	WS	BS	BF	WS	BS
1978	41.8 (3.5)	11.4 (3.1)	9.0 (2.5)	53.4 (12.6)	10.8 (3.1)	7.5 (3.3)
1979	44.8 (3.9)	14.3 (2.8)	9.5 (2.4)	47.4 (10.1)	10.9 (2.7)	8.6 (3.0)
1980	43.1 (4.0)	14.4 (2.8)	9.4 (2.4)	43.4 (10.5)	10.4 (2.6)	8.9 (3.1)

tree growth but was largely a result of adding sampling units with higher live fir or spruce volume per ha to the Michigan Impact Plot System in 1979.

Defoliation ranking. The average defoliation rankings for balsam fir, white spruce, or black spruce were similar in the two national forests. The mean defoliation ranking for balsam fir and for white spruce increased between 1978 and 1980 (Tables 14–16). The annual increase in the average defoliation ranking of balsam fir in the Ottawa N.F. was twice that of the fir in the Hiawatha N.F. The mean defoliation ranking for white spruce in both forests was basically unchanged between 1978 and 1979, but there was a moderate increase between 1979 and 1980. The ranking of black spruce increased between 1978 and 1979 and decreased between 1979 and 1980 (Tables 14–16). The increase (0.8) in the average defoliation ranking of black spruce between 1978 and 1979 was twice the decrease (0.4) in rank between 1979 and 1980 for the Ottawa N.F. sample. There was a similar trend for black spruce in the Hiawatha N.F.

The large increases in the average defoliation ranking of balsam fir on plots in the Iron River and Kenton districts (Table 15) are not due to the inclusion of new sampling units in 1979. Between 1978 to 1980 the mean defoliation ranking increased from 1.9 (20–50% defoliation) to 3.1 (50% or more defoliation with no top-kill) and from 1.5 to 2.8 for balsam fir on the Iron River and Kenton districts, respectively. The data were examined carefully and accurately reflect the large increases in spruce budworm larvae seen in stands within these two districts.

There were small differences in the average defoliation ranking for white and black spruce between the years 1978, 1979, and 1980. However, a mean defoliation ranking of 2.7 for balsam fir and 1.9 for spruce in 1980 is meaningful and parallels the pattern of greater mortality and growth loss exhibited by balsam fir in both national forests.

Frequency and extent of top-kill. The frequency of top-kill for balsam fir from 1978 to 1980 in the Ottawa and Hiawatha N.F.'s was 8.9, 10.7, 20.0%, and 17.1, 19.2, 21.2%, respectively. The frequency of top-kill for white spruce from 1978 to 1980 in the Ottawa and Hiawatha N.F.'s was 4.6, 2.7, 1.7% and 6.2, 6.2, 2.9%, respectively. Top-kill occurred in black spruce, but it was very low except for the Ottawa N.F. where it averaged ca 2.1% each year.

The extent of top-kill within an individual tree can be expressed as average dead crown length. The average length of dead crown for balsam fir in the Ottawa and Hiawatha N.F.'s during 1978–1980 was 1.7 ± 0.3, 1.2 ± 0.1, and 1.5 ± 0.1 m; and 1.5 ± 0.3, 0.8 ± 0.1, and 1.2 ± 0.2 m, respectively. The average length of dead crown for white spruce in the Ottawa and Hiawatha N.F.'s during 1978–1980 was 1.6 ± 0.4, 0.6 ± 0.3, and 0.6 ± 0.1 m; and 1.8 ± 0.2, 0.8 ± 0.4, and 0.3 ± 0.3 m, respectively.

Table 12. Average estimated live volume (m^3/ha) and (SE) of balsam fir, white spruce, and black spruce on the six districts within the Ottawa National Forest.

	BF	WS	BS	BF	WS	BS
	Watersmeet			Iron River		
1978	37.5 (6.5)	5.4 (2.0)	15.5 (3.8)	44.1 (6.5)	15.0 (3.0)	14.8 (6.8)
1979	38.1 (6.6)	5.5 (1.9)	15.7 (3.6)	45.8 (5.4)	19.5 (3.9)	17.0 (5.8)
1980	35.8 (7.2)	5.8 (1.9)	15.6 (3.5)	44.8 (5.1)	19.1 (4.0)	16.6 (5.8)
	Bessemer			Bergland		
1978	33.4 (6.8)	17.0 (10.9)	4.3 (3.6)	50.9 (3.5)	2.4 (0.5)	0.0 (0.0)
1979	32.1 (6.1)	20.4 (10.6)	4.4 (3.7)	42.3 (12.1)	9.7 (6.6)	0.0 (0.0)
1980	29.9 (6.0)	20.8 (10.8)	4.4 (3.7)	41.9 (12.5)	9.7 (6.5)	0.0 (0.0)
	Ontonagon			Kenton		
1978	53.0 (15.4)	18.2 (14.5)	0.0 (0.0)	57.2 (2.5)	0.5 (0.1)	0.0 (0.0)
1979	57.2 (20.6)	20.1 (13.1)	0.0 (0.0)	74.3 (15.9)	7.6 (7.0)	1.4 (1.4)
1980	53.3 (23.9)	20.0 (12.9)	0.0 (0.0)	73.2 (14.7)	7.8 (7.2)	1.1 (1.1)

Table 13. Average estimated live volume (m^3/ha) and (SE) of balsam fir, white spruce, and black spruce on the five districts within the Hiawatha National Forest.

	BF	WS	BS	BF	WS	BS
	Rapid River			St. Ignace		
1978	74.1 (22.9)	12.5 (5.0)	1.9 (1.0)	45.2 (12.2)	5.2 (1.5)	4.7 (4.4)
1979	73.8 (23.2)	12.8 (5.1)	1.9 (1.0)	34.6 (9.3)	8.6 (3.6)	3.6 (3.3)
1980	73.2 (22.6)	12.7 (4.8)	1.9 (1.0)	24.6 (5.8)	7.3 (2.5)	3.6 (3.4)
	Sault Ste. Marie			Manistique		
1978	6.8 (0.6)	10.7 (1.9)	23.0 (5.2)	2.9 (0.7)	0.0 (0.0)	29.3 (5.0)
1979	11.8 (4.7)	11.3 (2.2)	16.2 (7.1)	32.1 (25.5)	0.0 (0.0)	28.3 (5.9)
1980	3.5 (2.3)	10.8 (2.1)	16.3 (7.1)	32.9 (26.2)	0.0 (0.0)	29.9 (6.1)
	Munising					
1978	92.0 (7.1)	31.3 (7.6)	1.1 (0.8)			
1979	94.9 (6.5)	32.8 (8.0)	1.2 (0.8)			
1980	99.8 (6.8)	33.7 (8.2)	1.2 (0.8)			

Table 14. Average estimated defoliation ranking and (SE) of balsam fir, white spruce, and black spruce on the national forest.

	Ottawa			Hiawatha		
	BF	WS	BS	BF	WS	BS
1978	2.1 (0.1)	1.9 (0.2)	1.3 (0.1)	2.3 (0.2)	2.0 (0.3)	1.3 (0.1)
1979	2.4 (0.1)	2.1 (0.1)	2.1 (0.1)	2.4 (0.2)	2.0 (0.2)	1.8 (0.2)
1980	2.7 (0.1)	2.4 (0.1)	1.7 (0.1)	2.6 (0.2)	2.2 (0.2)	1.3 (0.2)

McLintock (1955) reported that over 50% of the surviving balsam fir in a Quebec study had dead tops as a result of repeated defoliations. Minnesota surveys have shown that as much as 78% of the balsam fir in certain stands had 1.8 m or more of top-kill after three years of complete defoliation of the current year's growth (Schmiege 1961).

Budworm feeding on saplings. Budworm feeding on saplings in plots in the Ottawa N.F. increased between 1978 and 1980 (Fig. 4). The percentage of plots which were rated "none" or "light" decreased and the percentage of plots which were rated as "moderate" or "heavy" increased with time. A similar but less pronounced trend was also observed in the Hiawatha N.F.

Mog (1981) presented histograms showing budworm feeding on saplings for each district in both national forests. For certain forest districts (Bergland, Kenton, Sault Ste. Marie, Munising) shifts from the "none" and "light" levels of feeding to the "moderate" and "heavy" levels are even more apparent. Only the Manistique District within the Hiawatha N.F. ran counter to this general pattern. All of the plots in this district were rated "none" in 1980. Nearly all of the live trees sampled on the Manistique plots in 1980 were black spruce.

Ghent et al. (1957) showed that during the first decade after devastation of a stand by the spruce budworm, changes often occur in the subsequent species composition of the new stand. However, general trends could not be predicted. Their most important conclusion was that changes in forest succession are strongly dependent upon the region in which the observations were made.

Budworm feeding on regeneration. The level of budworm feeding on regeneration on the plots in the Ottawa N.F. increased in 1979 and 1980 (Fig. 5). The percentage of plots which were rated as "moderate" or "heavy" increased from 14% in 1979 to 32% in 1980. The number of plots rated as "none" decreased from 41% to 7% between 1978 and 1980. The overall trend for the Hiawatha N.F. is similar to that observed in the Ottawa N.F., but not as apparent. Regeneration plots in the Hiawatha N.F. sustained considerably less feeding at the moderate to heavy levels in 1980 (8%) than did regeneration on plots in the Ottawa N.F. during 1980 (32%).

Mog (1981) presented histograms showing budworm feeding on reproduction for each district in both National Forests. For two districts in the Ottawa N.F., Bergland and Ontonagon, the feeding on reproduction on these plots never was more than "light." The only district that does not follow the general patterns already discussed for the Hiawatha N.F. was St. Ignace whre there was an increase in "moderate" budworm feeding from 1978 (20.0%) to 1980 (28.6%). Also the Manistique District was different from the others within the Hiawatha N.F. in that the level of spruce budworm feeding on reproduction did not change over the two-year period and was always reported as "none."

Table 15. Average estimated defoliation ranking and (SE) of balsam fir, white spruce, and black spruce on the six districts within the Ottawa National Forest.

	BF	WS	BS	BF	WS	BS
	Watersmeet			Iron River		
1978	2.5 (0.2)	1.7 (0.6)	1.6 (0.1)	1.9 (0.3)	2.1 (0.4)	1.1 (0.1)
1979	2.5 (0.2)	2.1 (0.1)	1.9 (0.1)	2.6 (0.1)	2.4 (0.2)	2.2 (0.1)
1980	2.9 (0.2)	2.6 (0.3)	1.9 (0.2)	3.1 (0.2)	2.4 (0.2)	1.6 (0.1)
	Bessemer			Bergland		
1978	1.8 (0.3)	1.8 (0.2)	1.2 (0.0)	1.9 (0.0)	2.0 (0.0)	0.0 (0.0)
1979	2.0 (0.2)	1.5 (0.3)	1.9 (0.0)	2.2 (0.1)	2.0 (0.0)	0.0 (0.0)
1980	2.3 (0.1)	2.2 (0.2)	1.9 (0.0)	2.4 (0.1)	2.0 (0.0)	0.0 (0.0)
	Ontonagon			Kenton		
1978	2.3 (0.4)	2.3 (0.3)	0.0 (0.0)	1.5 (0.0)	0.0 (0.0)	0.0 (0.0)
1979	2.4 (0.3)	2.4 (0.4)	0.0 (0.0)	2.4 (0.5)	2.5 (0.0)	2.0 (0.0)
1980	2.6 (0.1)	2.9 (0.1)	0.0 (0.0)	2.8 (0.4)	2.7 (0.0)	1.0 (0.0)

Table 16. Average estimated defoliation ranking and (SE) of balsam fir, white spruce, and black spruce on the five districts within the Hiawatha National Forest.

	BF	WS	BS	BF	WS	BS
	Rapid River			St. Ignace		
1978	1.9 (0.2)	1.3 (0.2)	1.3 (0.2)	3.0 (0.3)	2.5 (0.3)	1.1 (0.0)
1979	1.9 (0.2)	1.5 (0.2)	2.1 (0.5)	3.1 (0.2)	2.4 (0.2)	1.8 (0.1)
1980	2.2 (0.1)	1.7 (0.2)	1.7 (0.6)	3.4 (0.1)	2.7 (0.2)	1.2 (0.0)
	Sault Ste. Marie			Manistique		
1978	3.5 (0.1)	3.3 (0.0)	1.8 (0.0)	1.8 (0.0)	0.0 (0.0)	1.0 (0.0)
1979	3.3 (0.3)	2.7 (0.2)	2.0 (0.1)	1.7 (0.5)	0.0 (0.0)	1.0 (0.0)
1980	3.8 (0.1)	2.5 (0.2)	1.3 (0.1)	1.7 (0.3)	0.0 (0.0)	1.0 (0.0)
	Munising					
1978	1.4 (0.1)	1.8 (0.2)	0.0 (0.0)			
1979	1.6 (0.2)	1.6 (0.2)	0.0 (0.0)			
1980	2.0 (0.1)	2.0 (0.0)	0.0 (0.0)			

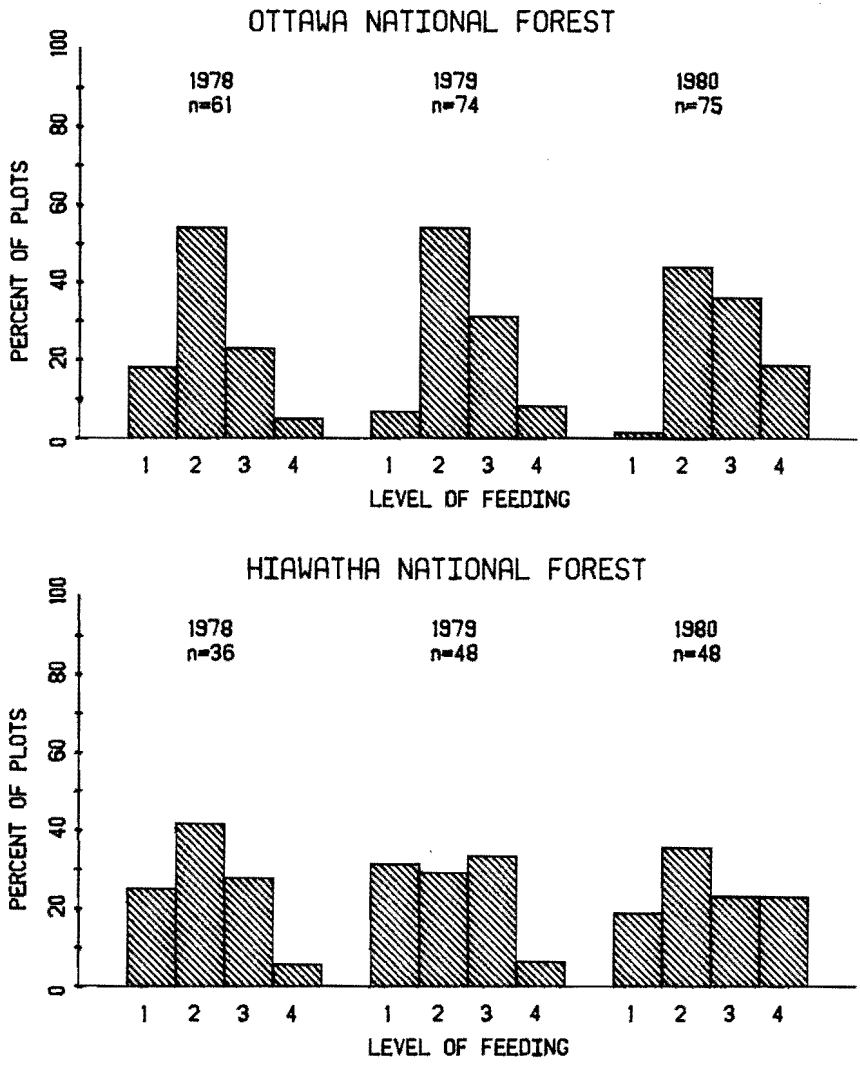

Fig. 4. Spruce budworm feeding on saplings. Level of feeding: 1 = none, 0 to 10% of total foliage missing; 2 = light, 10 to 33% of total foliage missing; 3 = moderate, 33 to 66% of total foliage missing; and 4 = heavy, more than 66% of total foliage missing.

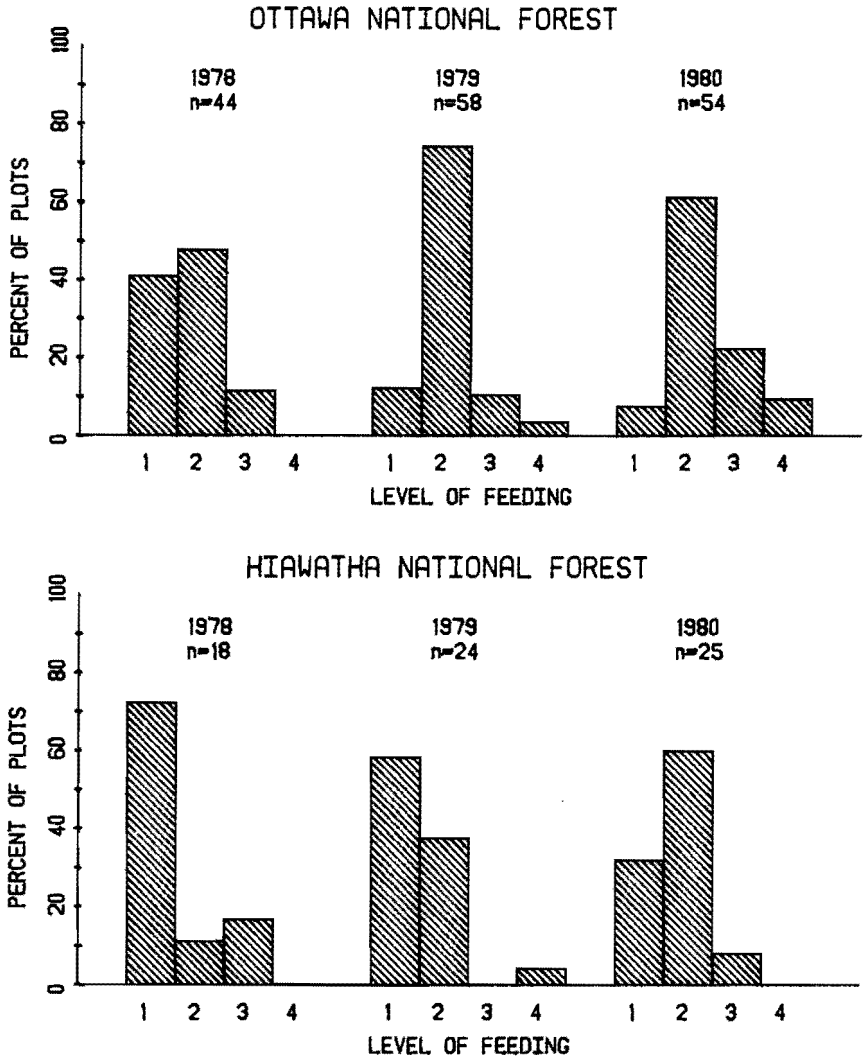

Fig. 5. Spruce budworm feeding on reproduction. Level of feeding: 1 = none, 0 to 10% of total foliage missing; 2 = light, 10 to 33% of total foliage missing; 3 = moderate, 33 to 66% of total foliage missing; and 4 = heavy, more than 66% of total foliage missing.

SUMMARY

There is little information available on the impact of the spruce budworm in spruce-fir stands in the Lake States, especially Michigan. The Michigan Impact Plot System (MIPS) was established during 1978–1979. The 136 ground sampling units in the MIPS will be evaluated once each year through 1984. A major objective of the MIPS was to obtain a data base for quantifying the impact of the spruce budworm in the Ottawa and Hiawatha N.F.'s.

The objective of this paper is to document the budworm impact data for 1978–1980 for these two national forests. Statistics for the following parameters are presented: percent mortality, total dead volume, dead volume per ha, live volume per ha, defoliation ranking, frequency and extent of top-kill, and incidence of spruce budworm feeding on saplings and regeneration. The data are presented at the national forest and forest district levels. Trends are discussed, but the interpretation on the biological reasons for these trends will be presented after the 1984 measurements are made.

The following major points were found:

(1) Balsam fir sustained higher mortality and suffered a greater loss of growing-stock volume than did white or black spruce.
(2) Percent mortality of dead balsam fir during 1978–1980 in the Hiawatha N.F. was nearly double that of balsam fir in the Ottawa N.F.
(3) Average percent fir mortality in the Hiawatha N.F. by 1980 was extremely high in the eastern portions of this N.F. where the outbreak started (Sault Ste. Marie District, 93%; St. Ignace District, 54%). Average percent fir mortality was low in 1980 (under 10%) in the three western districts (Munising, Rapid River, Manistique) of the Hiawatha N.F.
(4) Average percent fir mortality in 1980 in the Ottawa N.F. was the highest (22–26%) in the most western and northern districts (Bessemer, Watersmeet, Ontonagon, Bergland) where this outbreak started in the western Upper Peninsula. Average percent fir mortality also doubled between 1978 and 1980 in the eastern-most districts of the Ottawa N.F. (Iron River, Kenton), but was under 10%.
(5) The estimated total dead volume and standard error of balsam fir in 1980 in the Ottawa and Hiawatha N.F.'s was 287,987 ± 47,290 m^3 and 341,509 ± 80,656 m^3, respectively.
(6) Total dead volume of balsam fir, white spruce, and black spruce all nearly doubled between 1978 and 1980 for both national forests, except for white spruce which showed a seven-fold increase in the Hiawatha N.F.
(7) The dead volume and standard error of balsam fir, white spruce, and black spruce in m^3/ha by 1980 for the Ottawa and Hiawatha N.F. was 12.5 ± 2.0, 1.5 ± 0.7, 1.5 ± 0.4 and 26.3 ± 6.2, 2.0 ± 1.1, 0.5 ± 0.2, respectively.
(8) An 18.7% reduction in live fir growing-stock volume occurred between 1978 and 1980 (10.0 m^3/ha) in the Hiawatha N.F. The average estimated growing stock of balsam fir (43.1 ± 4.0 m^3/ha in 1980) in the Ottawa N.F. remained practically unchanged between 1978–1980.
(9) The average annual change in live volume of white spruce was 1.5 and −0.2 m^3/ha during 1978–1980 in the Ottawa and Hiawatha N.F.'s, respectively. Growing-stock volume of black spruce increased annually at 0.2 and 0.7 m^3/ha in the Ottawa and Hiawatha N.F.'s, respectively.
(10) The average defoliation ranking for balsam fir and white spruce increased between 1978 and 1980 with black spruce increasing between 1978 and 1979 and decreasing between 1979 and 1980.
(11) The mean defoliation ranking was considerably higher on balsam fir than on spruce (2.7 vs. 1.9 in 1980).
(12) The frequency of top-kill for balsam fir from 1978–1980 in the Ottawa and Hiawatha N.F.'s was 8.9, 10.7, 20.0%, and 17.1, 19.2, 21.2%, respectively. The frequency of top-kill for white spruce from 1978–1980 in the Ottawa and Hiawatha N.F.'s was 4.6, 2.7, 1.7%, and 6.2, 6.2, 2.9%.
(13) Budworm feeding on saplings and regeneration on plots in the Ottawa and Hiawatha N.F.'s increased from 1978–1980, but the increase was not as pronounced in the Hiawatha N.F.

(14) Fir and spruce regeneration on plots in the Ottawa N.F. sustained considerably more feeding at the moderate to heavy levels in 1980 (32%) than did regeneration on plots in the Hiawatha N.F. (8%) during 1980.

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