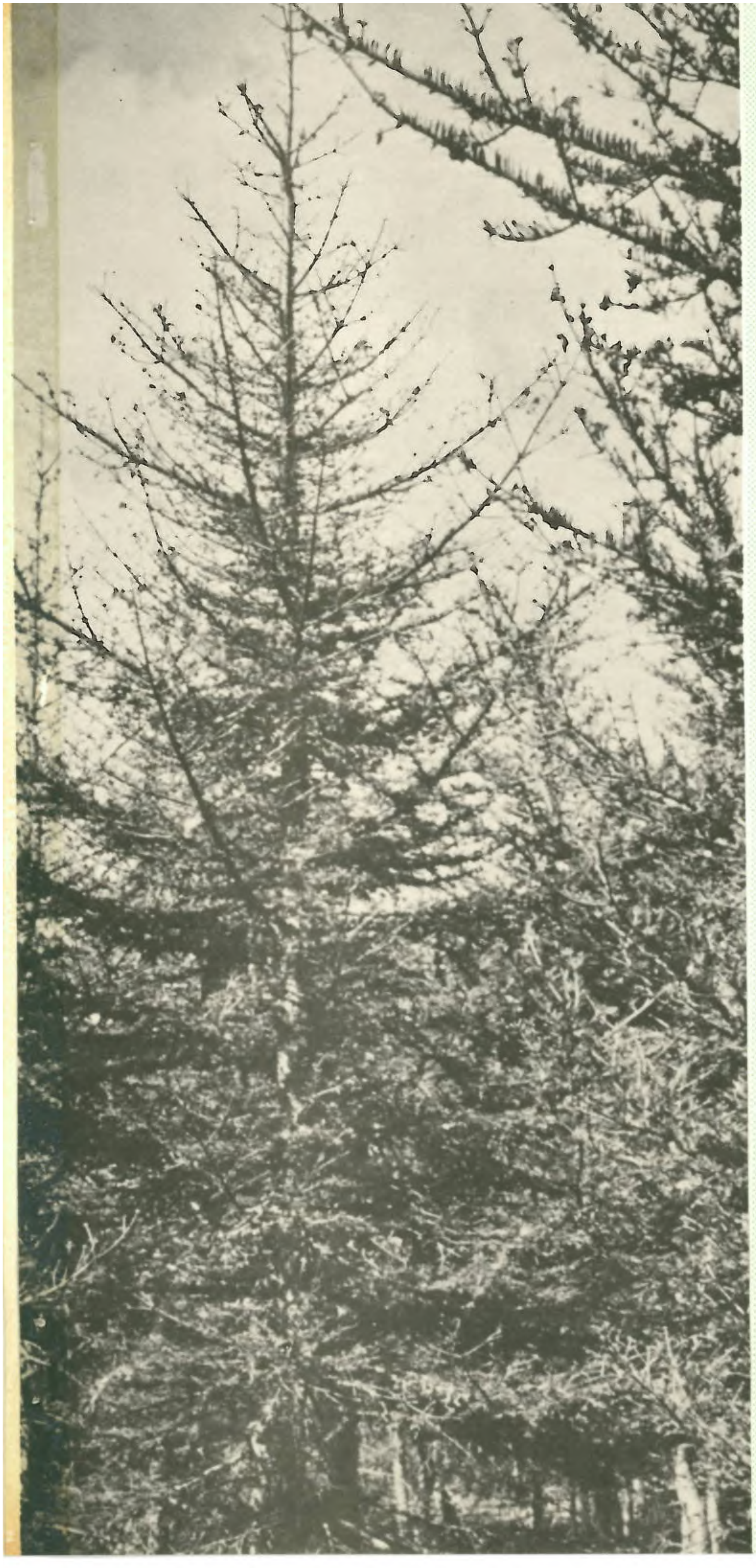

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MARITIMES

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ABSTRACT

Tree mortality resulting from a severe spruce budworm outbreak which began in 1974 on the Cape Breton Highlands was analyzed at five locations. Five permanent sampling plots at each location were measured for initial tree and stand characteristics, and assessed for tree mortality as of September 1977 and September 1978. Mortality varied considerably among and within sampling locations, with three broad groupings emerging: one location with <1% of the basal area dead by 1978, three locations with 10-15% of the basal area dead, whereas the fifth area had 36% of the basal area dead. Examination of increment cores from several trees at the sample locations indicated that growth during the infestation was considerably lower than, and correlated with, growth before the infestation. Mortality on the sample plots generally increased with increasing values of a variety of stand characteristics, including basal area, total volume, mean dbh, and mean basal area, but considerable variability was present, possibly because the infestation was more advanced at certain sampling locations than at others. Undoubtedly, further mortality will occur on these plots since budworm populations are still high and many of the trees presently surviving are in advanced states of defoliation.

RESUME

L'auteur a analysé en cinq endroits la mortalité des arbres due à une invasion massive de la Tordeuse des bourgeons de l'Epinette, qui a débuté en 1974 sur les hautes terres du Cap Breton. Cinq placettes échantillons à chaque endroit ont été mesurées pour définir les caractéristiques initiales des arbres et des peuplements, puis leur taux de mortalité a été évalué en septembre 1977 et en septembre 1978. La mortalité a considérablement varié parmi et au sein des sites d'échantillonnage. On a retenu les trois groupes généraux suivants: un site ayant perdu <1% de surface terrière en 1978, trois sites ayant 10 à 15% de perte de surface terrière et le cinquième site ayant 36% de perte. L'examen de carottes provenant de plusieurs arbres aux sites d'échantillonnage a indiqué que la croissance durant l'invasion était beaucoup plus faible que la croissance avant l'invasion et s'y trouvait corrélée. La mortalité dans les placettes échantillons a généralement augmenté avec l'accroissement des valeurs d'un certain nombre de caractéristiques des peuplements, y compris la surface terrière, le volume total, le dhp moyen, et la surface terrière moyenne, mais on a observé une variabilité considérable, possiblement reliée à l'invasion, plus grave en certains sites d'échantillonnage qu'en d'autres. Sans doute se produira-t-il une mortalité plus accentuée sur ces placettes, car les populations de Tordeuses y sont encore élevées; de plus, de nombreux arbres qui ont survécu se trouvent dans un état de défoliation avancée.

INTRODUCTION

A severe spruce budworm (*Choristoneura fumiferana* (Clem.)) outbreak began in 1974 on Cape Breton Island, Nova Scotia. No defoliation had been observed on Cape Breton Island in 1973 (Forbes *et al.* 1975), but budworm numbers at permanent sample plots increased dramatically from 1973 to 1974 (Kettela and Moran 1975), suggesting that, along with appropriate forest conditions, moth dispersal from other outbreak areas was involved in initiating the outbreak. The Central Highlands of Cape Breton (Fig. 1) are presently suffering the most serious impact of the infestation, with severe defoliation of the tree's current year foliage and substantial backfeeding occurring over most of the 162 000-ha area (Sterner *et al.* 1977; Magasi 1978). The Highlands consist mainly of continuous mature or overmature softwood stands with a high proportion of balsam fir (*Abies balsamea* (L.) Mill.), which are generally considered to be very susceptible to spruce budworm outbreak and vulnerable to damage. Early in the course of the present infestation, the Nova Scotia government decided not to use chemical insecticides against the spruce budworm, but rather to place increased emphasis on a salvage program for defoliated and dead timber. Mortality of trees has occurred to varying degrees over much of this area as a result of defoliation, and salvage harvesting operations are underway on the Highlands.

Research into the rates of fungus deterioration of balsam fir trees killed following budworm defoliation in northwestern New Brunswick (Stillwell and Kelly 1964) and in Ontario (Basham 1959), coupled with results on deterioration of girdled killed fir trees in five regions from northwestern Ontario to Newfoundland (Basham *et al.* 1976), has indicated that salvage operations must be carried out from within 1 - 1.5 years (in Ontario) to 3 years (in New Brunswick and Newfoundland) after tree mortality to avoid substantial amounts of sap rot. Therefore, it is important to accurately monitor rates of tree mortality as the budworm infestation proceeds, in order to aid the forest manager in making decisions about salvage. Also, the current budworm outbreak on Cape Breton Island represents an opportunity to follow the course of impact of epidemic population levels on a forest ecosystem in the absence of man's attempts to manipulate the population. A broad-scale study to document spruce budworm damage to balsam fir on Cape Breton Island was begun in 1976 by the Forest Insect and Disease Survey (FIDS) of the Maritimes Forest Research Centre (MFRC). Mortality on selected Highlands plots was found to average 16% of the number of stems with dbh 10 cm or greater by September 1977 (Sterner et al. 1977) and increased to an average of 32% by September 1978 (Magasi 1978). Mortality on the Lowlands plots was about one half that on the Highlands.

During the summer of 1977, a second study of budworm-caused tree mortality was initiated on the Central Highlands of Cape Breton. This study was intended to supplement the FIDS results with a more detailed examination of mortality on a limited number of replicated plots. Specific objectives included: (1) determining the variability of mortality rates (in terms of number of trees, basal area, and total volume) within stands and among various locations on the Highlands, and attempting to relate this to stand characteristics, and (2) analysis of the timing of mortality of individual trees within stands in relation to their dimensional characteristics, growth parameters, or competition stress, i.e. an attempt to predict which trees will die at what time during a severe budworm outbreak in a given stand. The present paper reports an assessment of mortality as of September 1978, and includes a preliminary analysis of mortality in relation to stand and tree characteristics.

METHODS

Sampling Locations

The Cape Breton Highlands range in elevation from about 300 - 450 m (1000-1500 ft). The area has been classified by Loucks (1959-60) as the Cape Highland District of the Gaspé - Cape Breton Ecoregion, and by Rowe (1972) as the Cape Breton Plateau of the Acadian Forest Region. The forests characteristically consist of balsam fir, white birch (*Betula papyrifera* Marsh.), and white spruce (*Picea glauca* (Moench) Voss). Fir generally dominates most forest types on the Highlands. Stands of fire origin are uncommon, and the effective agents of forest destruction and regeneration appear to be wind and insect attack (Loucks 1959-60; Rowe 1972).

Five permanent sampling locations were established on the Central Highlands during the summer of 1977 (Fig. 1). These locations were chosen from previously-established budworm egg-sampling plots, and

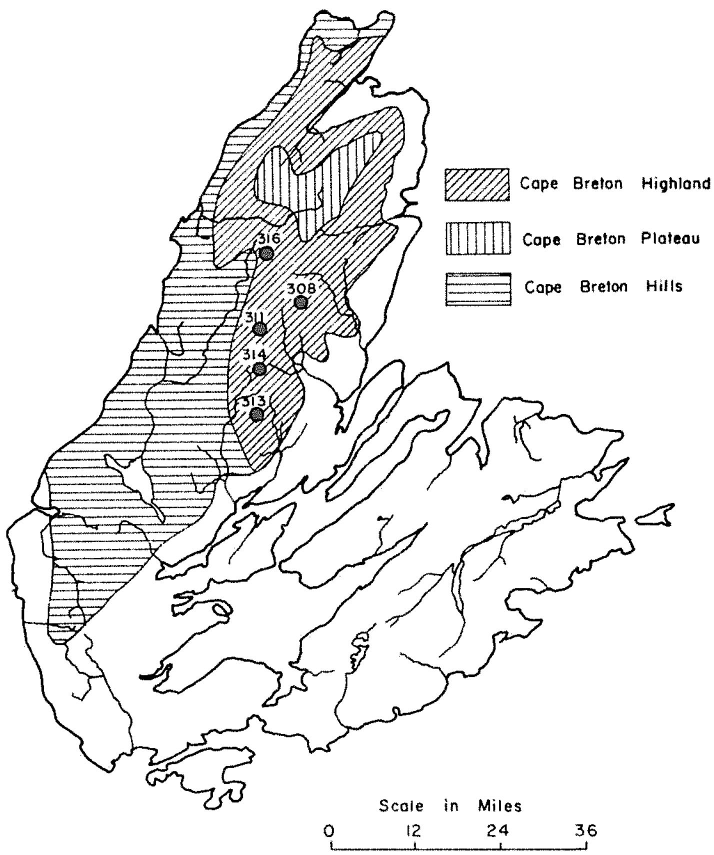

Fig. 1. Map of Cape Breton Island showing five sampling locations; forest classification is according to Loucks (1959-60).

were a subset of the permanent plots analyzed for fir mortality by Sterner et al. (1977) and Magasi (1978). The five sampling locations were selected to exemplify a variety of defoliation histories; visual estimates of defoliation made by FIDS on a light-moderate-severe scale classed locations 308 and 311 as light in 1974 and 1975, and as severe in 1976; locations 314 and 316 as nil in 1974, light in 1975 and severe in

1976; and location 313 as nil in 1974 and 1975, and as moderate to severe in 1976. The severe defoliation in 1976 often included substantial amounts of backfeeding. Therefore the locations roughly represented one, two, and three years of defoliation, although visual estimates of defoliation on a stand basis may contain high degrees of error.

Field Procedures

Five 0.01-ha circular plots were established at each sampling location, at distances of 2, 4, 6, 8, and 10 chains (1 chain = 20 m) from the roadside. If necessary to keep within the same stand type, plots were offset at right angles to the original direction of travel. Within each plot, all trees were permanently marked with a numbered metal tag placed at breast height (1.3 m). The location of each tree within the plots was mapped by measuring the distance and compass bearing from the center of the plot, which was permanently marked with a metal stake. The following data were taken for each tree within the plots: species, dbh (mm), total height (dm), crown height (dm), and crown widths (dm) in the north-south and east-west cardinal directions. In addition, all trees in the plots were checked for mortality during the third week of August in 1977 and 1978. Mortality was initially noted by a complete absence of needles on the tree, and was checked by examining the cambium near breast height with a knife for discoloration and dryness. During the 1977 examination, trees that were estimated to have been dead 1 year or less were assumed to have been killed by the budworm. Increment cores were also taken from two trees per plot during the 1977 and 1978 measurements.

Several trees outside the perimeter of the 0.01-ha circle were also permanently marked and subjected to the same measurements, if they appeared to be in direct competition with trees within the plots. This was done because of our intention to try and relate indices of competition stress to mortality on these plots. Inclusion of these trees outside the actual plots resulted in sampling trees up to 10 m from the center point (whereas the actual plot had a radius of 5.6 m) and increased the number of trees sampled for each plot by about one third.

Estimates of individual tree mortality in this paper were calculated using all of the sample trees, in order to maximize the sample size.

Data Analysis

Mortality caused by mechanical factors such as wind or snow breakage was excluded from the computations. Amounts of spruce budworm - caused balsam fir mortality before September 1977 and from September 1977 to September 1978 were calculated as percentages of the total number of trees sampled, total basal area, and total volume for each plot. In the calculation of total volume of each tree, the equation

$$\text{Total volume} = \frac{dbh^2}{a + \frac{b}{height}}$$

was used, where a and b represent specific constants for each tree species (Honer 1965, 1967). This was the formula used in the Nova Scotia Forest Inventory, Cape Breton Subdivision (1970). Plot volumes were calculated from actual dbh and height measurements on each sample tree.

To make a preliminary assessment of increment decrease or growth loss resulting from defoliation, the increment cores taken from each plot were analyzed for ring widths. The width of each annual ring was measured to the nearest 0.01 mm, using a modified Addo-X ring measuring machine, and mean ring width during the infestation (1974-77) was compared with mean ring width for the 10-year period immediately preceding the infestation (1964-73).

RESULTS AND DISCUSSION

Plot Descriptive Data

Stand structural data for the plots at each of the five locations are presented in Table 1. All plots were nearly pure balsam fir, with at least 95% of the basal area consisting of fir. These stands became established after earlier budworm infestations. Hawboldt (1955)[1/] stated that infestations in Cape Breton occurred about 1846, between 1891 and 1896, from 1911 to 1915, and the latter one flared up to a lesser extent between 1922 and 1927. An infestation also took place from 1950 to 1957, and localized patches of defoliation were noted from 1960 to 1963 (Brown 1970; Webb *et al*. 1961). The age of the stands

[1/] Hawboldt, L.S. 1955. The spruce budworm. Nova Scotia Department Lands and Forests. Unpublished paper. 15 pp.

Table 1. Stand structural characteristics of mortality sampling plots at five locations on the Cape Breton Highlands

Location	Plot no.	Density stems/ha	Basal area m^2/ha	Total volume m^3/ha	Mean dbh cm	Mean height m	Mean basal area dm^2/tree	Species composition, % balsam fir: No. of stems	Species composition, % balsam fir: Basal area
308	1	1800	39.7	195.1	15.9	8.4	2.2	94	84
	2	1200	22.8	106.9	15.4	8.7	2.0	100	100
	3	1100	27.9	148.4	18.1	10.6	2.7	100	100
	4	1200	29.7	165.2	17.3	10.6	2.6	100	100
	5	1300	33.9	191.6	18.3	11.5	2.7	100	100
	$\bar{X}(S_{\bar{x}})$[a]	1320(124)	30.8(2.8)	161.4(16.1)	17.0	10.0	2.4	99	97
311	1	1300	48.2	272.4	21.5	11.2	3.8	100	100
	2	500	36.7	222.4	25.6	11.7	6.0	80	95
	3	1100	36.7	214.8	21.5	11.6	4.1	82	88
	4	1500	35.5	186.5	17.4	10.2	2.7	67	91
	5	900	36.0	193.4	20.9	10.2	3.9	100	100
	$\bar{X}(S_{\bar{x}})$	1060(172)	38.6(2.4)	217.9(15.1)	21.4	11.0	4.1	86	95
313	1	1500	54.7	308.2	20.8	11.6	3.5	100	100
	2	3900	54.7	262.2	13.6	9.2	1.6	100	100
	3	4500	50.5	232.0	11.4	8.3	1.1	100	100
	4	3600	44.3	201.4	12.2	8.4	1.3	100	100
	5	1400	19.2	86.4	12.9	7.0	1.5	100	100
	$\bar{X}(S_{\bar{x}})$	2980(641)	44.7(6.6)	218.0(37.3)	14.2	8.9	1.8	100	100
314	1	900	51.0	291.8	24.1	11.6	4.8	89	98
	2	1600	48.6	282.9	18.8	11.8	2.9	100	100
	3	1400	53.1	313.7	21.5	12.0	3.8	100	100
	4	1200	38.4	214.4	20.1	11.6	3.3	100	100
	5	1100	43.4	259.3	22.7	12.5	4.2	100	100
	$\bar{X}(S_{\bar{x}})$	1240(121)	46.9(2.7)	272.4(16.9)	21.4	11.9	3.8	98	100
316	1	1100	32.8	184.0	19.4	11.0	3.2	91	91
	2	1700	46.1	248.9	17.6	10.5	2.6	94	96
	3	800	25.3	145.7	20.5	11.8	3.5	100	100
	4	900	26.4	138.7	19.3	10.2	3.1	100	100
	5	400	23.4	136.8	26.1	11.4	5.8	100	100
	$\bar{X}(S_{\bar{x}})$	980(213)	30.8(4.1)	170.8(21.3)	20.6	11.0	3.6	97	97

[a] Mean and standard error (in brackets) for the five plots at each location.

Table 2. Spruce budworm - caused mortality of balsam fir at five locations on the Cape Breton Highlands, as of September 1978 (Spruce mortality was nil)

Location	Plot no.	Mortality by number of stems, %			Mortality by basal area, %			Mortality by total volume, %		
		1977[a]	1978[b]	Total	1977	1978	Total	1977	1978	Total
308	1	0.0	4.3	4.3	0.0	4.4	4.4	0.0	4.4	4.4
	2	7.7	7.7	15.4	5.0	5.0	10.0	4.7	3.5	8.2
	3	0.0	6.7	6.7	0.0	3.2	3.2	0.0	3.0	3.0
	4	0.0	11.8	11.8	0.0	5.3	5.3	0.0	4.8	4.8
	5	22.2	11.1	33.3	17.1	11.9	29.0	17.5	9.7	27.2
	$\bar{X}(S_{\bar{x}})$	6.0(4.3)	8.3(1.4)	14.3(5.1)	4.4(3.3)	6.0(1.5)	10.4(4.8)	4.4(3.4)	5.1(1.2)	9.5(4.5)
311	1	0.0	11.8	11.8	0.0	13.1	13.1	0.0	13.6	13.6
	2	0.0	20.0	20.0	0.0	17.4	17.4	0.0	18.1	18.1
	3	0.0	5.3	5.3	0.0	9.6	9.6	0.0	7.3	7.3
	4	3.4	27.6	31.0	2.4	24.8	27.2	2.1	24.8	26.9
	5	0.0	7.1	7.1	0.0	4.6	4.6	0.0	4.8	4.8
	$\bar{X}(S_{\bar{x}})$	0.7(0.7)	14.4(4.2)	15.1(4.7)	0.5(0.5)	13.9(3.4)	14.4(3.8)	0.4(0.4)	13.7(3.6)	14.1(3.9)
313	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	3.8	3.8	7.6	2.5	1.0	3.5	1.8	0.7	2.5
	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	$\bar{X}(S_{\bar{x}})$	0.8(0.8)	0.8(0.8)	1.5(1.5)	0.5(0.5)	0.2(0.2)	0.7(0.7)	0.4(0.4)	0.1(0.1)	0.5(0.5)
314	1	0.0	10.0	10.0	0.0	5.8	5.8	0.0	6.1	6.1
	2	22.2	25.9	48.1	13.6	22.7	36.3	12.4	21.9	34.3
	3	33.3	11.1	44.4	29.2	10.2	39.4	28.4	10.4	38.8
	4	27.8	16.7	44.5	31.6	13.4	45.0	31.2	13.1	44.3
	5	35.3	23.5	58.8	25.9	26.4	52.3	26.4	26.6	53.0
	$\bar{X}(S_{\bar{x}})$	23.7(6.4)	17.4(3.2)	41.1(8.2)	20.1(5.9)	15.7(3.9)	35.8(8.0)	19.7(5.9)	15.6(3.8)	35.3(7.9)
316	1	5.9	17.6	23.5	1.8	13.8	15.6	1.3	13.7	15.0
	2	8.0	16.0	24.0	3.9	9.0	12.9	3.4	8.2	11.6
	3	7.7	15.4	23.1	3.3	11.9	15.2	2.9	11.5	14.4
	4	0.0	7.7	7.7	0.0	4.7	4.7	0.0	3.9	3.9
	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	$\bar{X}(S_{\bar{x}})$	4.3(1.8)	11.3(3.3)	15.6(5.0)	1.8(0.8)	7.9(2.5)	9.7(3.1)	1.5(0.7)	7.5(2.5)	9.0(3.0)
All plots	$\bar{X}(S_{\bar{x}})$	7.1(2.3)	10.4(1.7)	17.5(3.4)	5.5(2.0)	8.7(1.6)	14.2(3.1)	5.3(1.9)	8.4(1.6)	13.7(3.0)

[a] Mortality occurring before September 1977.

[b] Mortality between September 1977 and September 1978.

was about 55-60 years, indicating that they developed after the outbreaks of the 1910's and 1920's, except Loc. 308 which was about 80 years old (probably resulting from the 1890's outbreak). Location 313 was more densely stocked than the other four sampling areas, and had smaller trees in terms of mean dbh, mean height, and mean basal area (Table 1).

Fir Mortality Rates

Spruce budworm-caused mortality of balsam fir at the five sampling locations is presented in Table 2, as a percentage of the total number of stems, basal area, and total volume initially on each plot. No mortality of spruce had occurred in the sample plots as of September 1978. The data of Table 2 show considerable variability both within the five plots at each sampling location and between the various locations, because some plots had suffered no mortality. Mortality for the various sampling areas as of September 1977 ranged from <1% to 24% of the number of stems, or <1% to 20% of the basal area. From September 1977 to September 1978, mortality ranged from <1% to 17% by number, or < 1% to 16% by basal area. The total cumulative mortality as of September 1978 at the five sampling locations could be broadly subdivided into three groupings: (1) 'low' mortality, or <2% - Loc. 313; (2) 'moderate' mortality, or 10-15% - Loc. 308, 311, 316; and (3) 'high' mortality, or about 35-40% - Loc. 314. Eighty percent of the plots had suffered at least some mortality by September 1978, and four of the five plots with no mortality were from Loc. 313, the most recently infested area. Maximum mortality encountered was almost 60% of the number of stems, in one plot at Loc. 314. Table 2 also shows that all of the plots in which mortality occurred before September 1977 suffered additional mortality before September 1978. Total volume losses to mortality were negligible for Loc. 313, 9-14% for Loc. 308, 311, and 316, and 35% for Loc. 314 (Table 2). Therefore, in the fifth year of the current budworm infestation, over one third of the total volume is dead in one of the five plots.

Fir mortality distribution by diameter class is presented in Fig. 2 as a percentage of the number of stems sampled at each location. Figure 2 shows that both the number and size of dead trees differ between sampling areas, and that the initial diameter distribution of stems

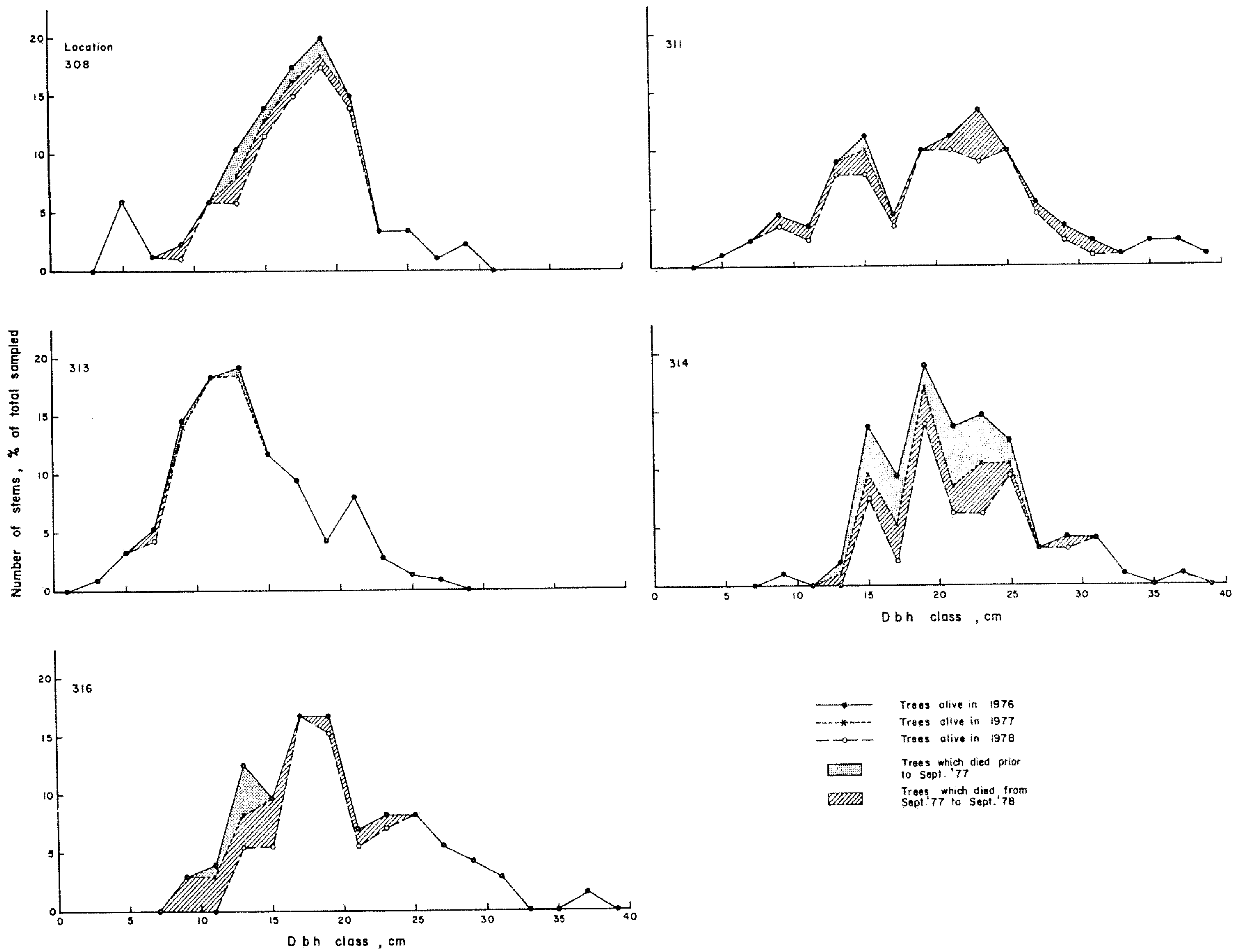

Fig. 2. Distribution of number of living and dead trees by diameter class for five sampling locations on the Cape Breton Highlands.

varied between sampling locations in approximately the same fashion as the five areas were broadly grouped into mortality classes. That is, Loc. 313 ('low' mortality) has mostly small stems, Loc. 308, 311, 316 ('moderate') have some small stems but more intermediate-sized stems, while Loc. 314 ('high') consists almost exclusively of stems >10-15 cm dbh.

Figure 2 also shows that the trees that died before September 1977 were generally of the smaller diameter classes within each plot (they were probably suppressed individuals, although it is not possible to say this conclusively, as the trees were not rated for crown class). Mortality between September 1977 and September 1978 also included a proportion of larger diameter trees. Location 314 was the only one of the five sampling areas where much mortality occurred in the intermediate or larger diameter class trees before September 1977.

Distribution of basal area by diameter classes for living and dead trees at the five sampling areas is presented in Fig. 3. This figure is a more useful assessment of loss of wood production to mortality than is the number of stems, since the death of a number of small trees may have little effect on the volume of wood in a stand. Mortality of trees >15-20 cm dbh had the greatest influence in terms of loss of basal area.

<u>Mortality in Relation to Individual Tree Characteristics</u>

Mortality of trees resulting from a spruce budworm outbreak is a gradual process, occurring over several years. Within a specific stand, certain trees die at a relatively early stage of the infestation, others die later, and in many cases, a small proportion of trees survive. It seems to be a reasonable hypothesis that certain characteristics of individual trees might be used as predictors of timing of mortality within the course of an outbreak, or, at least, as predictors of death on a "will die - will not die" basis. Batzer (1969) examined this hypothesis with respect to preoutbreak dimensional attributes of individual fir trees in Minnesota, but found in a multiple regression analysis that no variables explained more than 27% of the variation in damage. The present study was designed to reexamine this hypothesis for several

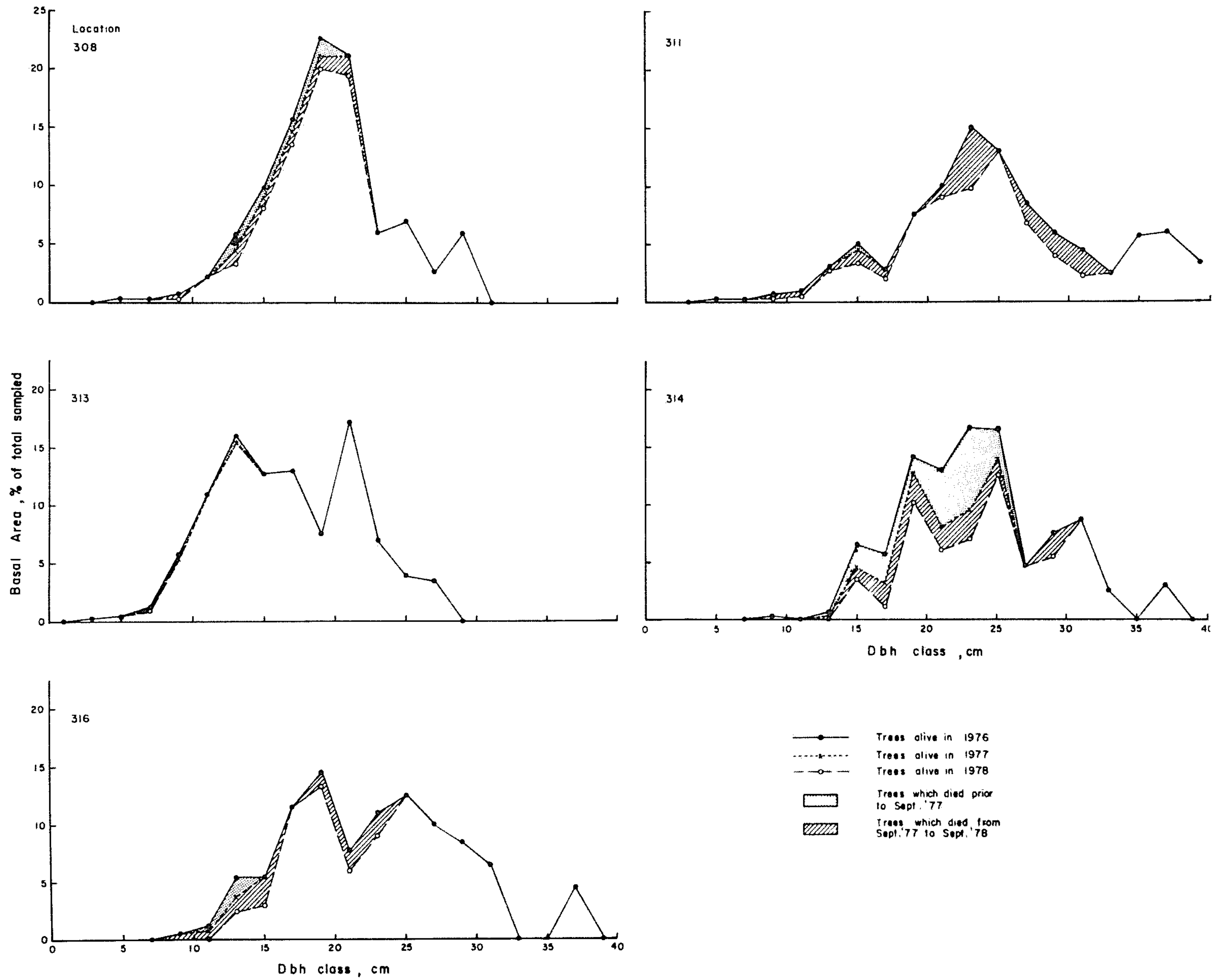

Fig. 3. Distribution of basal area of living and dead trees by diameter class for five sampling locations on the Cape Breton Highlands.

individual tree dimensional relations, such as dbh, height, crown length, crown width, crown area, and basal area, for other growth parameters such as yearly increment prior to the infestation, and for competition stress as exemplified by indices of competition which have been developed by various researchers. This paper presents a preliminary assessment of dimensional relations and growth parameters as predictors of mortality. The analysis is necessarily preliminary because the budworm infestation is still going on.

Figures 2 and 3 present data on tree mortality in relation to dbh. These data indicate that there are some relationships between dbh and mortality; in all five locations, the largest trees in the stand (generally 25-30+ cm) had not suffered any mortality as of September 1978, and in four of the five locations, the smallest trees in the stand had not suffered any mortality (Fig. 2). In general, the trees which died from September 1977 to September 1978 included some trees with larger dbh than those that had died before September 1977; i.e. mortality appeared to be moving into the larger dbh classes. This trend was also evident in fir mortality data for stands in northwestern New Brunswick (Baskerville 1960).

Table 3 presents a summary of mean dimensional data, including dbh, height, crown length, crown width, crown area, basal area, and stem volume, for live and dead trees at the five sampling locations. In general, the trees that had survived the budworm outbreak until September 1978 had larger mean values for all of the dimensional characteristics than trees that had died in 1977 or 1978 (Table 3). A one-way ANOVA, carried out to assess statistically significant differences between living trees and dead trees (combining 1977 and 1978 mortality), showed that differences were significant in several cases (Table 3). Crown width and crown area were the dimensional relations which demonstrated the most consistent differences between living and dead trees among the various sampling locations, probably because they represent to some extent the photosynthetic vigor and crown class of the trees. The small sample sizes of dead trees for certain time periods or sampling locations

Table 3. Summary of mean dimensional data on live and dead trees at five locations on the Cape Breton Highlands

Location	Tree status	No. trees	Dbh, cm		Height, m		Crown width, m		Crown area, m^2		Crown length, m		Basal area, dm^2		Stem volume, m^3	
			$\bar{X}$	$S_{\bar{x}}$	$\bar{X}$	$S_{\bar{x}}$	$\bar{X}$	$S_{\bar{x}}$	$\bar{X}$	$S_{\bar{x}}$	$\bar{X}$	$S_{\bar{x}}$	$\bar{X}$	$S_{\bar{x}}$	$\bar{X}$	$S_{\bar{x}}$
308	Live[a]	74	17.3	0.6	9.9	0.3	2.8**[d]	0.1	6.6**	0.3	6.3	0.3	2.5	0.2	13.4	1.0
	Dead-1977[b]	5	15.4	1.2	11.2	0.8	2.4	0.3	4.7	1.1	-	-	1.9	0.3	10.6	2.2
	Dead-1978[c]	7	15.0	1.4	9.3	0.8	2.0	0.2	3.2	0.6	4.7	1.0	1.9	0.3	8.6	1.6
311	Live	74	20.7	0.9	10.8	0.3	3.4**	0.1	9.9*	0.8	7.6	0.3	3.9	0.4	22.0	2.4
	Dead-1977	1	15.5	-	10.0	-	1.2	-	11.2	-	-	-	1.9	-	9.3	-
	Dead-1978	14	20.0	1.8	11.2	0.5	2.6	0.2	5.9	1.0	6.6	0.7	3.5	0.6	19.4	3.2
313	Live	209	13.5	0.3	8.9*	0.2	2.0	0.1	3.7	0.2	4.9	0.1	1.6	0.1	8.0	0.5
	Dead-1977	2	11.3	2.4	6.7	0.7	-	-	-	-	-	-	1.0	0.4	3.8	1.8
	Dead-1978	2	7.3	0.3	6.4	0.2	-	-	-	-	1.9	0.1	0.4	0.0	1.4	0.0
314	Live	50	21.6	0.7	11.9	0.2	3.1**	0.1	7.9**	0.6	7.3	0.3	3.9	0.3	22.5	1.7
	Dead-1977	23	19.0	0.8	11.7	0.3	2.4	0.2	4.9	0.6	-	-	2.9	0.2	16.7	1.4
	Dead-1978	17	20.0	1.0	11.9	0.3	2.8	0.3	6.8	1.2	6.4	0.5	3.3	0.3	18.9	2.2
316	Live	58	20.4**	0.7	11.1*	0.2	3.4**	0.1	9.7**	0.7	7.1	0.3	3.5**	0.3	19.6**	1.7
	Dead-1977	4	12.5	0.6	9.4	0.5	1.9	0.1	2.8	0.4	-	-	1.2	0.1	5.8	0.8
	Dead-1978	10	15.7	1.4	10.2	0.5	2.5	0.2	5.1	0.9	5.3	0.6	2.1	0.4	10.9	2.4

[a] Trees which were alive as of September 1978.
[b] Trees which died before September 1977.
[c] Trees which died between September 1977 and September 1978.
[d] Significant differences in a one-way ANOVA between live and dead (1977 and 1978 data combined) trees within each sampling location are represented by * ($P < 0.05$) or ** ($P < 0.01$).

likely precluded the finding of more statistically significant differences among dimensional characteristics.

It appears probable that vigor of a tree at the onset of a budworm outbreak has some relation to survival or mortality of that tree. Craighead (1925) found that budworm-caused mortality was related to increment at breast height at the time of defoliation for stands in Quebec and New Brunswick; under severe defoliation in a fir stand at Bathurst, N.B. the relation broke down, however, as severe defoliation killed even vigorous trees. Morris (1946) also noted this trend in the results of a stump-examination study. He found that the growth rate before the infestation was faster in the stands suffering less mortality. To make an interim assessment of the relation of growth before the infestation to timing of mortality in the present study, increment cores were taken from two trees per plot and analyzed in order to relate annual ring width before the infestation and during the infestation to dimensional characteristics of the sample trees. Mean growth increment during the infestation (1974 to the time of sampling in 1977) was compared with mean increment for the 10 years before the infestation, to determine a percentage increment loss. There were no apparent relationships between this growth loss figure and either dbh of the sample trees or growth before the infestation, nor between growth rates during the infestation and dbh. However, growth during the infestation was found to be strongly correlated with growth prior to the infestation (Fig. 4). Reduction of increment at breast height was about 20-60% for most of the sample trees. A full-scale analysis of the relationship of growth to mortality of trees in these sample plots will be carried out in the future, when the budworm outbreak is near collapse.

Mortality in Relation to Stand Characteristics

Several studies have attempted to relate budworm-caused mortality to a variety of stand characteristics such as density, basal area, volume, species composition parameters (such as percentage balsam fir, percentage host species, percentage hardwoods), or mean dimensions of trees (i.e. mean dbh, height, basal area). In chronological order, these studies have included: (1) Craighead (1925), who found a relation

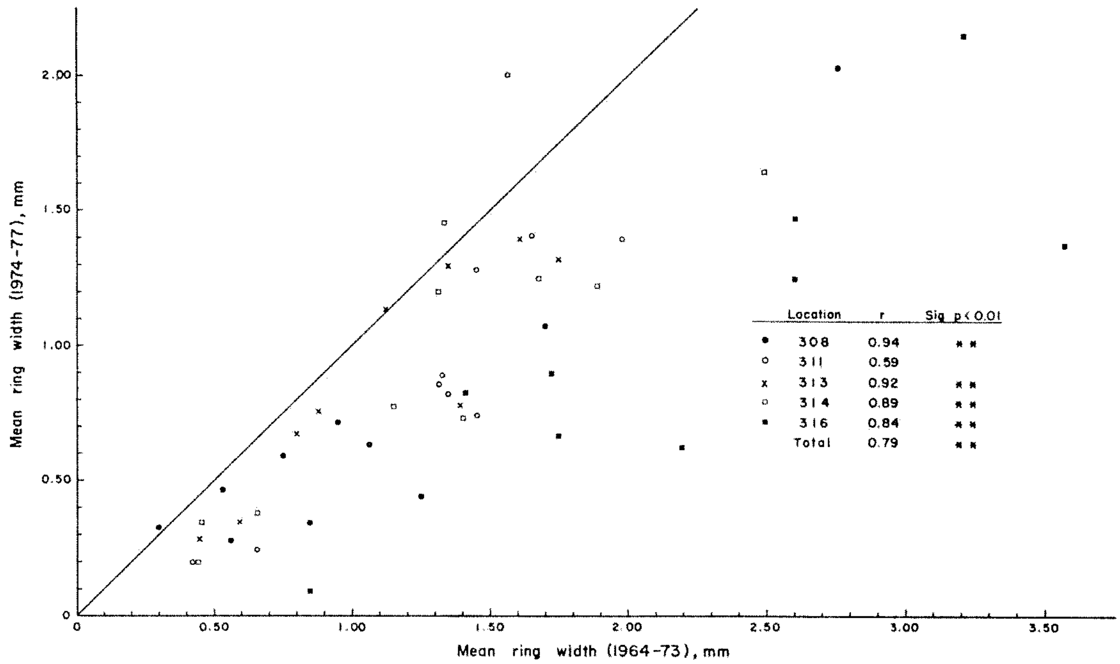

Fig. 4. Correlation of mean ring width of trees during the spruce budworm infestation (1974–77) and mean ring width in the 10-yr period before the infestation (1964–73). The line represents points where growth during the infestation would equal prior growth.

between tree vigor and mortality, but no correlation between data on density, basal area, or percentage balsam fir and mortality; (2) Turner (1952) found fir mortality was related to percentage fir in the stand and to actual basal area of fir considered independently of the other species, and that percentage mortality generally increased with relative height of fir; (3) Ghent et al. (1957) used a non-parametric rank correlation method to relate mortality to percentage balsam fir basal area and to actual fir basal area; 4) Mott (1968)[2/] found in a multiple regression analysis that mean-tree basal area was the best of 10 variables for explaining tree mortality; (5) Batzer (1969) found a combination

[2/] Mott, D.G. 1968. A study of mortality in balsam fir stands after attack by spruce budworm in northwestern New Brunswick, 1956 - 1959. Contract Rep. 1, Marit. For. Res. Cent., Fredericton, N.B.

of three stand attributes (percentage basal area in spruce, percentage basal area in non-host species, and total basal area of fir) explained 56% of the variation in mortality; and (6) Batzer (1973) calculated a cumulative defoliation index and found it was related to fir mortality. Therefore, stand attributes which may be used as mortality predictors have been found to vary somewhat in studies from a variety of geographical regions, but generally included some measure of basal area, such as mean tree basal area, fir basal area, percentage fir basal area, or total basal area.

Mortality in relation to certain stand characteristics is plotted in Fig. 5 for the Cape Breton plots. Figure 5 includes mortality data for both the individual plots and means and standard errors for the five sampling locations, in relation to basal area, total volume, mean dbh, and mean basal area. Mortality generally increased with increasing values for all four of these stand characteristics but a wide scatter occurs in the graphs. This appears to be a result of mortality being more advanced in certain plots than in others, with the latter plots having lower mortality than would be expected from their stand characteristics. In particular, the five plots at Loc. 313 had suffered almost no mortality, undoubtedly as a result of the infestation occurring later on this site. The fact that the five sampling locations were originally chosen to represent a variety of defoliation histories has introduced a high degree of variability into this initial analysis of mortality in relation to stand characteristics.

In addition to the stand characteristics and mortality data measured in this study, information on budworm population levels at the study locations is available from FIDS and other MFRC surveys. Table 4 presents a summary of data on the 1978 spruce budworm population levels on fir trees at four of the five sampling locations, and on one larval population sample taken in 1977. Tables 5a and 5b summarize defoliation data. Table 5b indicates that the budworm infestation was least advanced at Loc. 313, which had 76% of the trees with an estimated <50% defoliation as of September 1978. In comparison, Loc. 311, 314, and 316 had no trees with <50% defoliation, and Loc. 308 had only 10% of the stems in

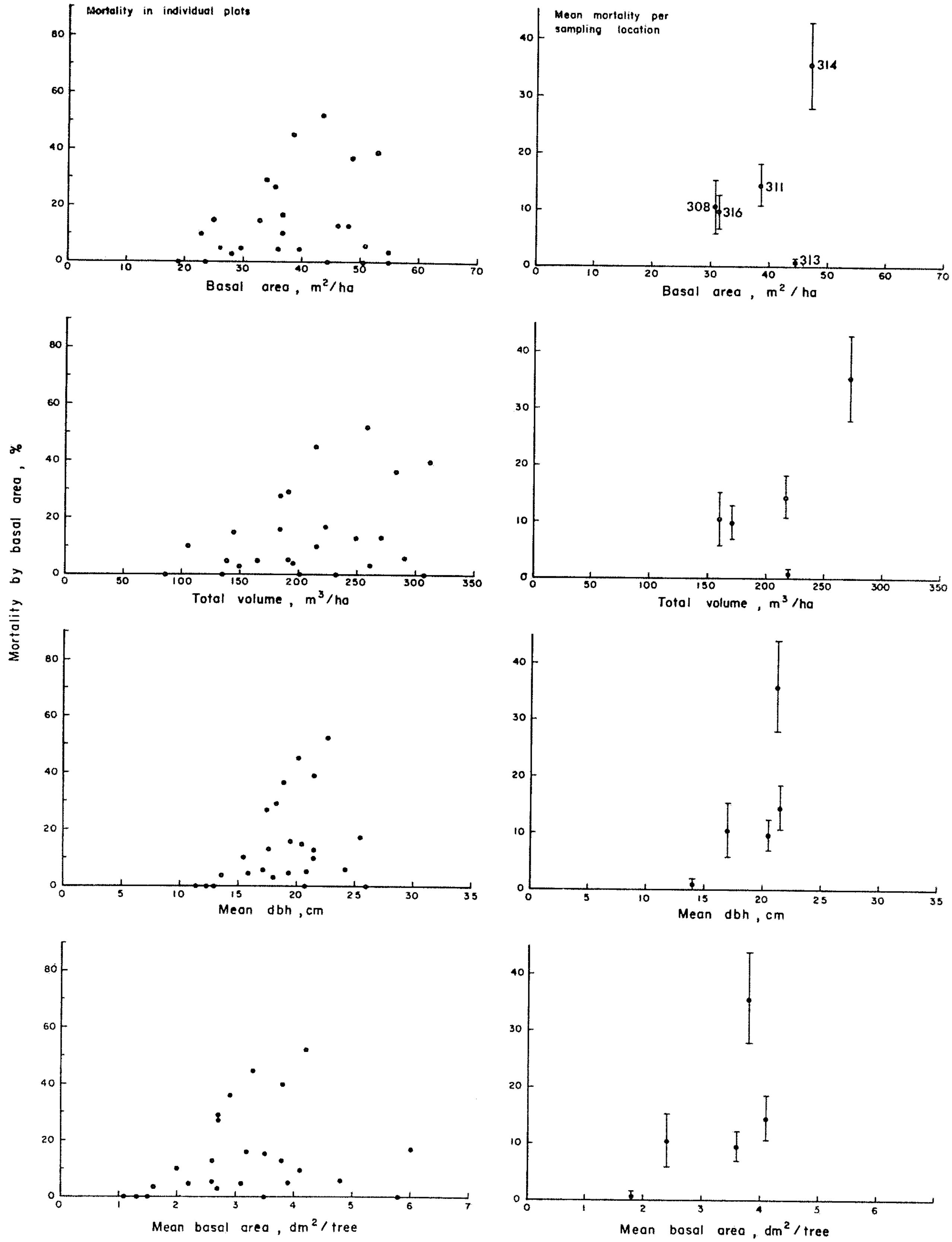

Fig. 5. Spruce budworm-caused mortality (up to September 1978) in relation to stand characteristics for a number of plots on the Cape Breton Highlands. Bars represent standard errors of the means.

Table 4. Summary of spruce budworm population levels on balsam fir trees at five sampling locations on the Cape Breton Highlands (data supplied by E.G. Kettela, MFRC)

Location	1978 Population levels						1977 Population levels
	No. budworm larvae per 45 cm branch tip, $\bar{X} \pm S_{\bar{X}}$ [a]			Pupae/45 cm tip	Larval survival [b] %	Egg-mass/10 m^2 of foliage [c]	No. larvae/45 cm tip [d]
	June 21-23	July 6-7	July 19-20	August 1-2			June 21-22
308	18	na[e]	na	na	na	na	121
311	22.6 ±2.5	6.4 ±1.1	2.7 ±0.6	1.2 ±0.4	5.3	41	60
313	61.6 ±7.8	12.2 ±2.2	2.1 ±0.7	3.9 ±0.7	6.3	591	48
314	9.6 ±2.2	7.2 ±1.2	0.9 ±0.4	0.0	0.0	25	190
316	11.0 ±1.5	6.5 ±2.4	1.7 ±0.5	1.1 ±0.5	10.0	48	58
Mean of 10 plots on the Highlands	23.7 ±4.9	7.8 ±0.8	2.3 ±0.5	1.7 ±0.4	7.2	215 ±68	

a Number of branch tips sampled at each date was 9 for 311, 10 for 313 and 316, and 8 for 314.
b Larval survival = no. pupae ÷ no. larvae (June 21) x 100.
c Egg mass estimate is from one sample for 313 and two samples for 311, 314, and 316.
d Data are based on three branch tips.
e Data not available.

Table 5a. Summary of 1978 defoliation of current balsam fir foliage at four sampling locations on the Cape Breton Highlands, August 1-2, 1978 (data supplied by E.G. Kettela, MFRC)

Defoliation category %	Number of shoots in each category[a] (%) Loc. 311	Loc. 313	Loc. 314	Loc. 316
0	48	0	70	26
1-25	21	0	16	18
26-50	16	0	8	16
51-75	8	0	6	14
76-100	3	9	0	12
76-100 with shoot axil destruction	4	91	0	14

[a] Total number of shoots sampled (two 45-cm branch tips per tree for 10 trees at each location) varied from 500 to 833 for Locations 311-316. Data are not available for Loc. 308.

Table 5b. Summary of defoliation of total fir foliage at five sampling locations on the Cape Breton Highlands for 1976-78 (data supplied by L.P. Magasi, MFRC)

Defoliation category %	Number of trees in each category (%) Loc. 308			Loc. 311			Loc. 313		
	1976	1977	1978	1976	1977	1978	1976	1977	1978
<50	64	46	10	29	7	0	98	95	76
50-90	24	30	56	59	77	65	2	0	17
90+	0	5	10	12	14	16	0	2	3
Dead	12	19	23	0	2	19	0	3	4

Defoliation category %	Loc. 314			Loc. 316		
	1976	1977	1978	1976	1977	1978
<50	0	4	0	0	0	0
50-90	88	64	53	83	78	69
90+	10	17	5	13	13	11
Dead	2	15	42	4	9	20

this class. However, during 1978, budworm population levels were generally substantially higher at Loc. 313 than at the other sampling locations (Table 4), and this resulted in more defoliation of current foliage (Table 5a). Egg-mass counts were also very high at Loc. 313 in 1978 (Table 4); budworm egg-mass counts in excess of 240 per 10 m^2 of surviving foliage indicated that severe defoliation could be expected in the coming year (Kettela et al. 1977), and the value for Loc. 313 was more than twice this figure. Egg-mass counts for the other sampling locations were substantially lower, presumably because of the mortality and severe defoliation these stands have already experienced.

CONCLUSIONS

Spruce budworm-caused fir mortality as of September 1977 and September 1978 was analyzed at five locations on the Cape Breton Highlands. Mortality varied considerably among and within sampling locations. Three broad groupings emerged: (1) Loc. 313 with < 1% of the basal area dead by 1978; (2) Loc. 308, 311, and 316 with 10-15% of the basal area dead; and (3) Loc. 314 with 36% of the basal area dead. Losses of total volume to mortality were similar to the values for basal area. Considerable further mortality is expected to occur in these plots since budworm populations are still high and many of the trees presently surviving are in advanced states of defoliation.

An initial assessment of the relation of mortality to individual tree characteristics and stand characteristics shows that trees dying from September 1977 to September 1978 included some with larger dbh than those succumbing before September 1977. It seems probable that mortality will occur in progressively larger dbh classes as the infestation proceeds. Generally the smallest and the largest trees in the stand have not died as yet. Trees in the larger diameter classes are usually the dominants in the stand and presumably are better able to withstand defoliation stress than intermediate or suppressed individuals. A statistical analysis of dimensional relations of dead and live trees indicated that crown width and crown area were the variables which demonstrated the most consistent differences between living and dead trees.

Examination of increment cores from a number of trees at the sample locations showed a correlation between growth during the infestation and growth prior to the infestation. The relation between tree growth and timing of mortality in these stands will be studied when the outbreak is nearer completion, because a larger sample of dead trees will be available. Mortality on the sample plots was generally found to increase with increasing values of various stand characteristics, including basal area, total volume, mean dbh, and mean basal area, but considerable variability was present. This variability would appear to be a function of the infestation being more advanced at certain sampling locations than at others. No attempt was made at this time to utilize stand or individual tree characteristics as quantitative predictors of mortality (as in a multiple regression analysis) because of this variability in timing of the outbreak between locations.

One point arising from this assessment of mortality which deserves to be stressed is that stands vary on the Highlands - the area is not as uniform as might be expected for a large area of nearly pure balsam fir. This is illustrated when comparing density, mean tree size, etc. of Loc. 313 with that of other sampling locations (Table 1). Amounts of mortality on the Highlands also vary considerably from one location to another, as was shown by being able to group the five locations in this study into broad groupings of 'low' (Loc. 313), 'moderate' (308, 311, 316), and 'high' (314) mortality. Hawboldt (1955) stated that one of the most outstanding features of the budworm outbreak of the 1950's in Cape Breton was its patchy nature, and this is also occurring in the current outbreak. Historically, budworm infestations in Cape Breton have shown some temporal patchiness as well, with the 1911-15 outbreak erupting again from 1922-27 and the 1950-57 outbreak continuing in localized patches from 1960-63. The fact that past outbreaks were not uniform in time or space has undoubtedly contributed to the variability of stands on the Highlands and patchiness of the current infestation. With this high degree of variability in tree mortality between various locations, it is apparent that mean mortality values for large areas (such as the Cape Breton Highlands) are inadequate for use in decision-making by forest managers. Subdivision of the forest into smaller, relatively uniform areas and accurate assessment of mortality within these areas during and following budworm outbreaks would be required to provide the proper decision-making information.

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