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DETERIORATION OF BALSAM FIR DAMAGED BY THE EASTERN HEMLOCK LOOPER IN NEWFOUNDLAND

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ABSTRACT

The progress of mortality, the development of saprot, the change in moisture content and in basic density of wood in balsam fir trees killed by the eastern hemlock looper were investigated. All trees with 80% or more defoliation died in four years of the initial defoliation. Previous damage by other insects enhanced the rate of mortality. Advanced saprot reducing the hardness of the wood did not occur until the fourth year after death; most of it was a white rot caused by Polyporus abietinus. Equations were developed to assess the number of years since death and the amount of saprot in standing trees using rot measurements at breast height. The moisture content decreased rapidly after death but stabilized at about 30-50%. The weighted average wood density in dead trees decreased by about 5% in 5 years. The amount and type of saprot and wood characteristics indicate that dead trees remain useful for at least four years for pulpwood.

RÉSUMÉ

La progression de la mortalité, le développement de la carie d'aubier, le changement en humidité et en densité du bois de sapins baumiers tués par l'arpenteuse de la pruche furent étudiés. Tous les arbres ayant eu 80% ou plus de défoliation sont morts durant les quatre années suivant la défoliation initiale. Des dégats causés précédemment par d'autres insectes stimulèrent le taux de mortalité. La carie avancée d'aubier réduisant la dureté du bois est apparue la quatrième année après la mort de l'arbre; cette carie était généralement blanche et causée par Polyporus abietinus. Des équations furent développées pour évaluer le nombre d'années depuis la mort et la quantité de carie d'aubier chez les arbres sur pied en utilisant les mesures de carie à hauteur de poitrine. Le contenu en humidité diminue rapidement après la mort mais se stabilise à environ 30-50%. La densité moyenne pondérée du bois chez les arbres morts décroit d'environ 5% en cinq ans. La quantité et le type de carie d'aubier, et les caractéristiques du bois indiquent que les arbres morts demeurent utilisables pour la pulpe durant au moins quatre ans.

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DETERIORATION OF BALSAM FIR DAMAGED BY THE EASTERN HEMLOCK LOOPER IN NEWFOUNDLAND

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INTRODUCTION

The eastern hemlock looper, *Lambdina fiscellaria fiscellaria* (Guen.), is a native species to Newfoundland and outbreaks of this insect have periodically caused extensive defoliation and mortality of balsam fir, *Abies balsamea* (L.) Mill. The latest outbreak began in 1966 in the Crabbes River watershed, western Newfoundland, where forest stands have a long history of damage caused by the balsam woolly aphid, *Adelges piceae* (Ratz.). By 1967 the looper infestation was widespread and forecasts indicated that up to 3,000,000 cords of wood may be killed if the outbreak continued (Warren, 1967). The potential loss of the wood in these stands prompted the pulp and paper industry to salvage damaged stands. To conduct efficient salvage operations it was essential to estimate how long dead trees would remain suitable for pulpwood. Information on this subject was fragmentary and contradictory (Stillwell and Kelly, 1964; Basham, 1959) therefore a study was initiated in 1967 to provide guidelines for harvesting severely damaged areas.

This report describes aphid damage, the progress of looper defoliation and tree mortality, and the development of saprot in three selected watersheds. Estimates are provided on the extent of tree mortality and subsequent decay, and the suitability of wood for pulping. Suggestions are also presented for alleviating losses.

MATERIALS AND METHODS

The study areas were located at Crabbes River and Serpentine Lake in western Newfoundland and at Rattling Brook in central Newfoundland (Fig. 1). In each area ten 0.04 hectare plots were established the year defoliation occurred and trees over 9 cm dbh were permanently numbered, measured for height and dbh, classified for species, balsam woolly aphid damage, looper defoliation and tree mortality. Total merchantable volume of pulpwood on the sample plots was computed from volume tables prepared by Honer (1967). Stand composition and density were recorded by volume and as stems per hectare.

Balsam woolly aphid damage was determined the year the plots were established and classified by the system shown in Appendix I. Hemlock looper damage has been determined annually by ocular scanning of the crowns of individual trees and expressed as a percentage defoliation. Tree mortality was indicated by the death of inner bark at breast height. Trees killed by the looper were sampled for deterioration annually as follows:

- Crabbes River from 1967 - 15 trees; five from each of light, medium and severe aphid damage classes.

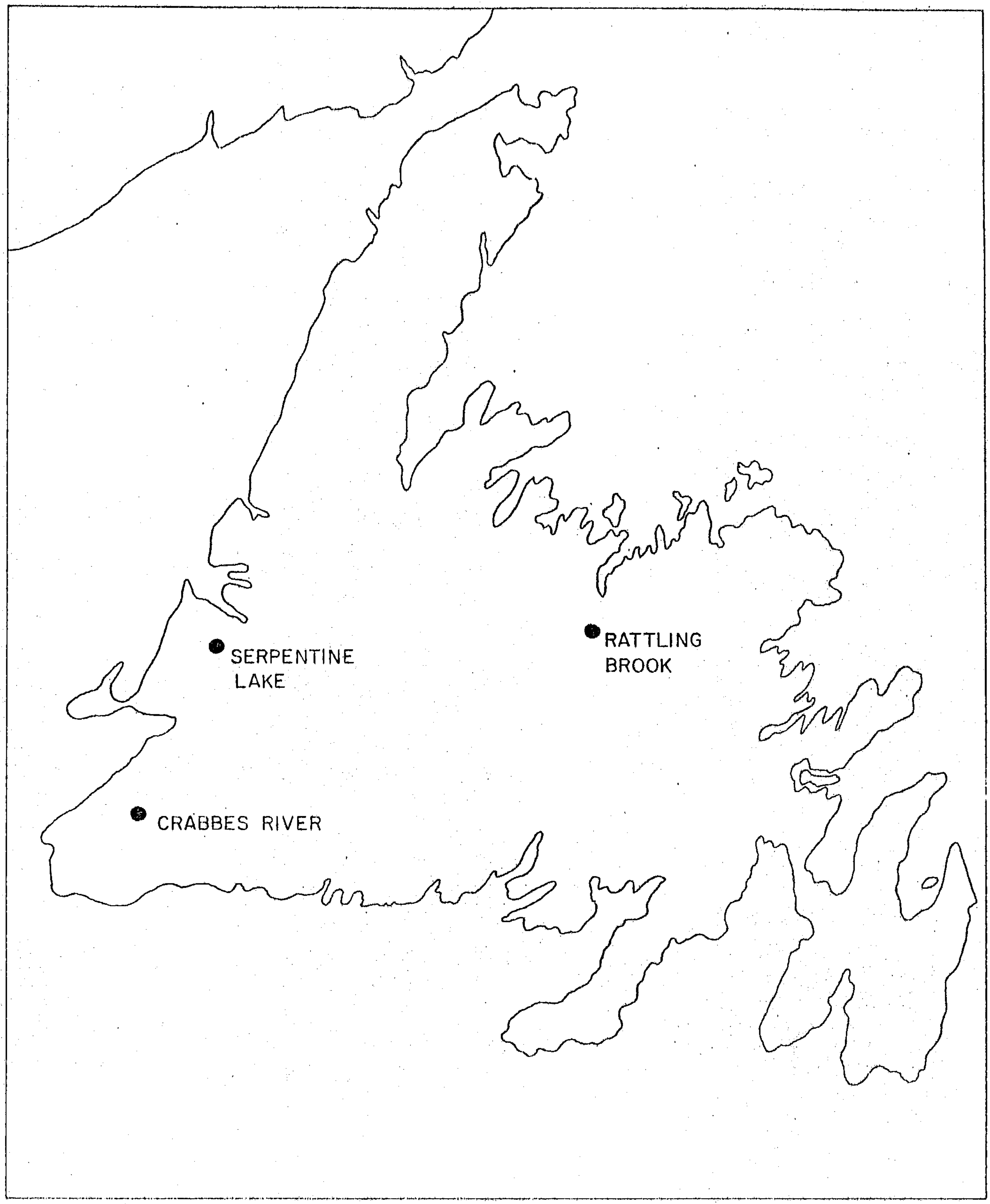


Fig. 1 Location of study areas for deterioration of balsam fir killed by the hemlock looper.

-Serpentine Lake from 1967 - 20 trees; five from each of undamaged, light, medium and severe aphid damage classes.

-Rattling Brook from 1968 - 20 trees; these trees had no aphid damage.

Additional trees were cut for replicating some of the samples and for testing the pulping characteristics of dead trees; a total 320 trees were cut and sampled.

Sample trees were felled at the 15 cm stump and cut into 1.2 m bolts. A 5-cm disc was removed from the basal end of each bolt for measuring radial penetration of saprot and diameter of heartrot, and for the identification of causal organisms. The bolts were further sectioned and split to measure the longitudinal extent of decay. Beginning in 1969 an additional 5-cm disc was removed from each bolt for determining moisture content and basic density of wood as outlined in Standard A1 established by the Canadian Pulp and Paper Association (1950). Volumes of merchantable wood and decays were computed by Smalian's formula (Husch, 1963).

Annual sampling and observations were continued until 1974 at Serpentine Lake and Crabbes River when most of the stand was windthrown. Work at Rattling Brook was halted in 1973 by the commercial harvesting of the stand.

RESULTS

Stand Characteristics

At Crabbes River, Serpentine Lake and Rattling Brook balsam fir with an average of 2214, 1814 and 1399 stems per hectare comprised 98%, 83% and 93% of all species. White spruce, white birch, and yellow birch made up the remainder of the stand. The average dbh for balsam fir at the three locations was 12.7, 16.0, and 17.5 cm; the average height was 9.7, 13.1, and 13.4 m; the average age at the 15 cm stump of the sample trees was 69, 68, and 58 years; and the mean merchantable volume of the fir was 191, 311, and 336 m^3 per hectare respectively.

Insect Damage and Progress of Tree Mortality

Damage caused by the balsam woolly aphid had been reported in the stand at Crabbes River since 1950 and at Serpentine Lake since 1957. The stand at Rattling Brook showed no symptoms of aphid attack. Aphid damage was most severe at Crabbes River where 24.1% of the trees were severely damaged and an additional 20% had been killed (Table 1). At Serpentine Lake 23.3% of the trees were severely damaged, but none had been killed.

Table 1. Percentage of balsam fir trees by aphid damage classes at Crabbes River, Serpentine Lake and Rattling Brook before hemlock looper attack.

Location	Aphid damage classes				Dead	Total No. of fir trees
	Undamaged	Light	Medium	Severe		
Crabbes River	0.0	13.2	41.9	24.1	20.0	710
Serpentine Lake	9.7	46.1	20.9	23.3	0.0	736
Rattling Brook	100.0	9.0	0.0	0.0	0.0	560

The progress of defoliation and subsequent tree mortality are shown in Figure 2 and Appendix II. It should be noted that looper population levels were high during the first two years of outbreak and defoliation was caused by larval feeding. Although the infestations all collapsed in two years, the foliage loss continued on damaged trees and was recorded as defoliation.

The three stands showed three different patterns of defoliation and tree mortality. At Crabbes River after a long history of aphid damage all trees had been defoliated to some extent in the first year of looper attack and by the fall of the second year 98.6% of them died. The stand at Serpentine Lake had a shorter duration of aphid damage, and after a very severe looper defoliation tree mortality commenced in the second year following the initial attack and it increased gradually to about 80% in the sixth year. A severe windstorm caused excessive blowdown and completely destroyed the stand in the seventh and eighth year. Finally the third stand at Rattling Brook had no previous aphid damage but a very severe looper defoliation caused about 44% mortality in the second year. Tree mortality increased gradually from this initial high level to about 80% in the fifth year; the stand was harvested in the sixth year. Comparable levels of mortality occurred about one year earlier at Rattling Brook than at Serpentine Lake.

Tree mortality by percent stems progressed more rapidly than by percent volume in all areas except at Crabbes River where almost all trees died within a year of initial looper attack (Figure 2, Appendix II). This trend of mortality was caused by the earlier death of smaller trees than that of trees in higher diameter classes (Table 2). Larger trees representing a higher proportion of the stand volume commenced to die in significant numbers in the third and fourth year after the initial defoliation at Serpentine Lake and in the second year at Rattling Brook.

The severity of defoliation by feeding larvae and the time since initial attack had a major influence on the progress of tree mortality. In all areas more than 85% of the trees with over 75% defoliation died within two years of initial looper attack. In subsequent years the remainder of these trees and others from lower defoliation classes commenced to die (Appendix II). Thus none of the trees with 80% or more defoliation survived after the fourth year and only about 4% and 18% of those with 71-80% defoliation survived at Serpentine Lake and Rattling Brook respectively (Table 3). Survival increased in the lower defoliation classes; it reached 50-60% in the 40-50% defoliation class, and about 80-90% among trees with 20-30% defoliation.

Progress of Heartrot and Saprot

The annual estimates of heartrot following the death of trees varied indiscriminately among years and locations (Table 4) but did not exceed 4.9% at Crabbes River, 9.7% at Serpentine Lake and 6.8% at Rattling Brook. There was no relationship between the amount of heartrot and the severity of aphid damage prior to looper attack in any of the study areas.

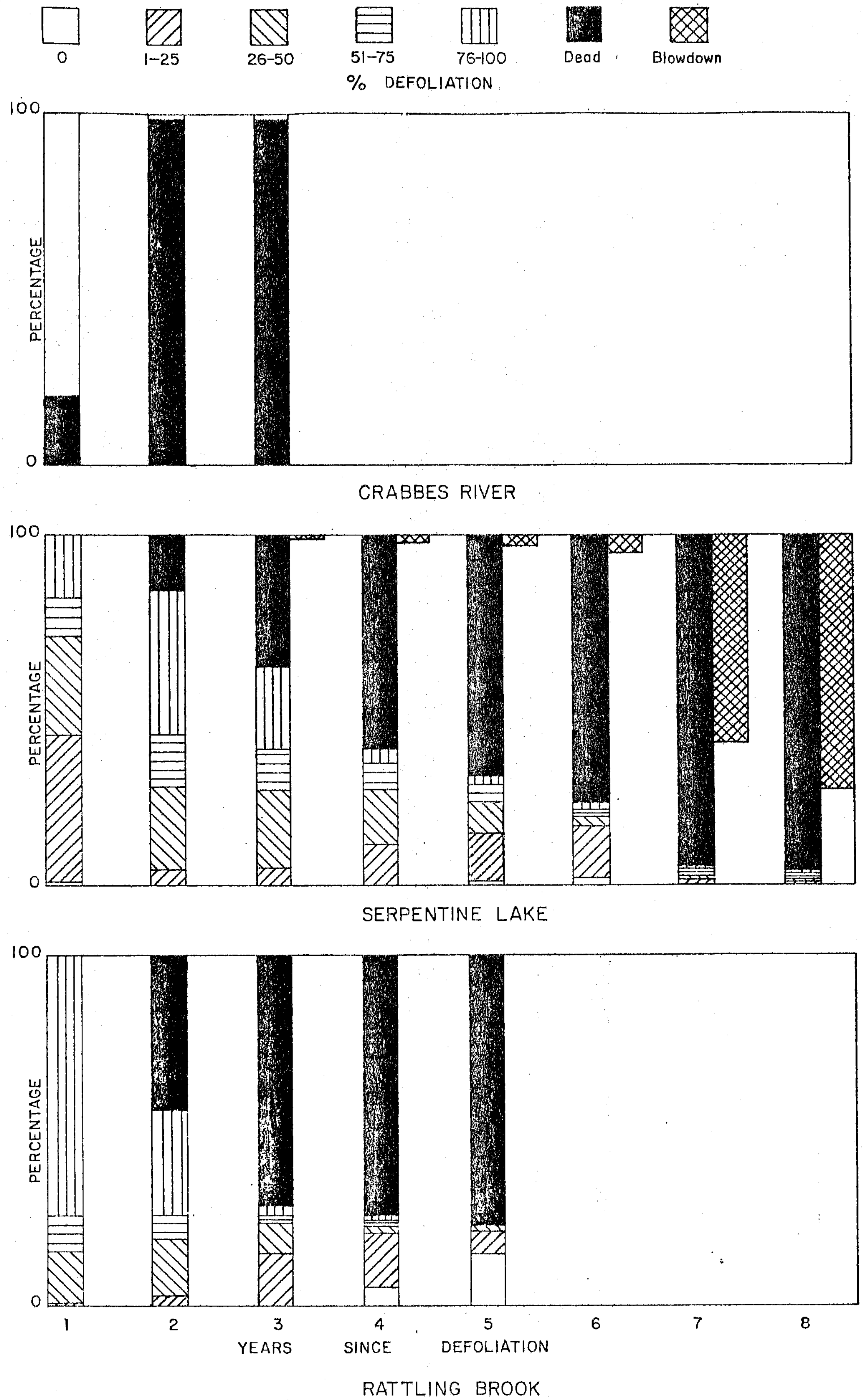


Fig. 2 Percentage of trees by hemlock looper defoliation classes.

Table 2. Distribution of mortality in two diameter classes by percent stems and percent of total merchantable plot volume.

Location	Diameter class (cm)		Year of death 1968	1969	1970	1971	1972	1973	1974	Total
Serpentine Lake	9-16	% stems	13.8	16.2	13.8	3.7	4.9	1.5	7.1	61.0
		% volume	6.3	9.3	8.3	2.5	2.7	1.0	5.0	35.1
	17+	% stems	2.3	6.0	9.7	3.9	4.0	1.5	7.6	35.0
		% volume	3.7	9.0	16.6	6.6	7.7	2.7	14.3	60.6
	All dia. classes	% stems	16.1	22.0	23.5	7.6	8.9	3.0	14.7	96.0
		% volume	10.0	18.3	24.9	9.1	10.4	3.7	19.3	95.7
Rattling Brook	9-16	% stems	0.0	26.3	16.7	1.3	0.3	-	-	43.6
		% volume	0.0	9.4	5.1	0.6	0.1	-	-	15.2
	17+	% stems	0.0	16.7	12.7	2.2	1.1	-	-	30.7
		% volume	0.0	26.7	17.5	4.2	2.3	-	-	50.7
	All dia. classes	% stems	0.0	43.0	29.4	3.5	1.4	-	-	77.3
		% volume	0.0	36.1	25.6	4.8	2.4	-	-	68.9

Table 3. Percentage of trees and volume surviving in 1972 from defoliation in 1968 the last year of high hemlock looper numbers.

Location		Looper defoliation class										Total
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	
Serpentine Lake	% trees	-	81.8	80.0	61.5	51.2	46.4	14.8	3.8	0.0	0.0	21.6
	No. trees*	0	11	45	78	43	28	43	53	38	291	630
	% Volume	-	86.2	75.8	62.7	45.4	45.6	13.6	3.1	0.0	0.0	26.9
Rattling Brook	% trees	0	0	90.9	78.6	61.9	62.5	63.2	18.2	0.0	0.0	18.0
	No. trees	0	0	11	28	21	16	19	22	19	259	395
	% volume	0	0	87.2	73.0	55.9	52.0	36.0	9.1	0.0	0.0	25.0

*Total number of trees in each defoliation class.

Table 4. Percentage of heartrot in merchantable volume of trees killed by the eastern hemlock looper at Crabbes River, Serpentine Lake and Rattling Brook.

Location	Years since death					
	1	2	3	4	5	6
Crabbes River	4.9	0.1	3.9	2.6	0.7	-
Serpentine Lake	3.7	6.6	4.4	9.7	7.4	-
Rattling Brook	0.9	0.9	4.1	6.8	-	-

The progress of radial penetration of saprot in trees killed by the looper showed no consistent relationship to the presence or absence of any level of damage caused by the balsam woolly aphid. The apparently deeper penetration of rot in more severely damaged trees during the first two years after death did not occur in trees dead for more than two years (Table 5). Radial penetration of rot averaged about 6 mm in the first year after death and it increased to about 15 mm in the fifth year (Table 5, Figure 3). Advanced saprot reducing the hardness of the wood did not occur until the fourth year after death (Table 5) and usually it first affected the butt and upper sections of the bole. Simple linear regressions developed from saprot penetrations over the years since death explains more than 50% of the variation both when the average of several rot measurements along the bole was used or only the rot penetration at breast height (Equations (1) - (8), Table 6). The relationship between the mean saprot penetration obtained from all measurements along the bole and the penetration at breast height are depicted by equations (9) - (12) (Figure 4). Over 60% of the variation is explained at Crabbes River and more than 80% at the other locations including the equation using data from all three locations.

The proportion of the merchantable volume affected by saprot varied irregularly (Table 5) because of the irregular distribution of trees by diameter classes in the groups of sample trees. However, multiple regressions using diameter at breast height and average saprot penetration for independent variables explain from 70 to 90% of the variation in the percentage of merchantable volume affected by saprot (Table 6, Equations (13) - (17)). Equation (16) was generated using data from all three locations and it explains 84% of the variation (Figure 5). Equation (17) is also based on data from all locations but using rot penetration at breast height instead of the average of penetration along the bole (Figure 6). Equation (17) explains 78% of the variation, 6% less than equation (16) but it has considerable practical advantage: equation (17) may be used to estimate saprot content in standing dead trees or in trees on the ground using the diameter at breast height and saprot penetration at breast height. Similarly, equations (18) - (22) may be used for estimating the percentage of merchantable volume affected by advanced saprot. These relationships are depicted in Figures 7 and 8.

The incipient or early stage of saprot appeared as a reddish brown discoloration and was caused mostly by Amylostereum chailletii (Fr.) Boid. This discoloration intensified during the second year. A faint blue stain along the inner periphery of the reddish brown ring of incipient saprot appeared in trees dead for three years. This stain, caused by Kirschteinella thujina (Pk.) Pom. & Eth., Ceratocystis sp. Rhinocladiella sp., Phialophora sp. and other blue staining fungi, intensified in the fourth year after death, but did not affect the hardness of the wood. Advanced saprot reducing the hardness of wood occurred in the third year only in two trees and was a brown cubical decay caused by *Fomes pinicola* (Sw.) Cke. affecting less than 1% of the merchantable volumes of the trees sampled. In the remainder of the trees advanced rot occurred only in the fourth year and most of it was a white, pitted rot caused by *Polyporus abietinus* Dicks. ex fr. A few scattered pockets of brown cubical decay caused by *F. pinicola* were also present in these trees but the volume affected was negligible.

The moisture content based on green weight of wood was determined for trees dead for two or more years at Rattling Brook and for three or more years at Crabbes River and Serpentine Lake (Table 5). The average moisture content ranged from 33 to 38% at Crabbes River, from 27 to 31% at Serpentine Lake and from 36 to 46% at Rattling Brook.

The weighted average basic density of wood at Crabbes River varied from 0.364 in trees dead for one year to 0.347 in trees dead for six years (Table 7). Similar data were 0.342 and 0.314 at Serpentine Lake and 0.346 and 0.337 at Rattling Brook.

Table 5. Radial penetration of saprot percentage of merchantable volume affected by saprot and the moisture content of wood in trees killed by the hemlock looper.

Parameter	Year sampled	Years dead	Aphid damage class: Undamaged		Light		Moderate		Severe		Average	
					CRABBES RIVER							
Total and	1968	1	No sample		0.38	0.0	0.61	0.0	0.84	0.0	0.64 (± .10)	0.0
advanced	1969	2	"		1.09	0.0	0.91	0.0	1.12	0.0	0.94 (± .05)	0.0
sap rot	1970	3	"		1.02	0.0	0.91	0.0	1.17	0.0	1.04 (± .05)	0.0
(cm)	1971	4	"		1.37	0.36	1.14	0.25	1.42	0.58	1.32 (± .08)	0.38 (± .05)
	1972	5	"		1.52	0.79	1.40	0.79	1.52	0.79	1.47 (± .13)	0.79 (± .13)
	1973	6	"		1.60	0.97	1.40	0.71	1.37	0.76	1.45 (+ .08)	0.79 (± .08)
Total and	1968	1	"		11.1	0.0	23.7	0.0	32.8	0.0	22.6	0.0
advanced	1969	2	"		32.9	0.0	34.2	0.0	32.1	0.0	33.1	0.0
sap rot %	1970	3	"		38.4	0.0	30.3	0.0	39.4	0.0	36.8	0.0
merchant-	1971	4	"		53.2	15.8	47.9	10.4	48.2	21.6	50.0	15.9
able volume	1972	5	"		53.7	22.7	48.4	28.6	52.9	30.0	52.7	29.4
	1973	6	"		57.0	38.5	49.0	26.8	48.1	28.9	51.4	31.6
Moisture	1970	3	"		27.6		38.1		34.1		33.3	
content	1971	4	"		33.0		32.4		32.7		33.4	
% green wt.	1972	5	"		42.4		36.0		37.3		38.5	
					SERPENTINE LAKE							
Total and	1968	1	0.43	0.0	0.51		0.58	0.0	0.81	0.0	0.58 (± .08)	0.0
advanced	1969	2	0.46	0.0	0.66		0.81	0.0	0.79	0.0	0.69 (± .05)	0.0
sap rot	1970	3	0.86	0.0	0.99		1.07	0.0	1.07	0.0	0.99 (± .05)	0.0
(cm)	1971	4	-		1.09	0.15	-		1.30	0.33	1.19 (± .08)	0.23 (± .08)
	1972	5	-		1.22	0.69	-		1.14	0.53	1.19 (± .05)	0.58 (± .05)
	1973	5	-		1.02	0.41	-		1.17	0.58	1.17 (± .05)	0.50 (± .05)

Cont'd.

Table 5 - continued

Parameter	Year sampled	Years dead	Aphid damage class: Undamaged		Light		Moderate		Severe		Average	
SERPENTINE LAKE												
Total and	1968	1	13.2	0.0	11.3	0.0	18.0	0.0	26.3	0.0	19.7	0.0
advanced	1969	2	16.5	0.0	22.3	0.0	24.3	0.0	24.3	0.0	21.8	0.0
sap rot %	1970	3	29.0	0.0	37.5	0.0	27.8	0.0	28.7	0.0	30.8	0.0
merchant-	1971	4	-		35.4	3.8	-		39.6	8.8	37.3	6.3
able volume	1972	5	-		41.4	24.6	-		33.1	12.6	35.0	15.4
	1973	5	-		33.4	15.8	-		36.2	19.0	35.1	17.6
Moisture	1970	3	27.4		30.1		33.7		31.2		30.6	
content	1971	4	-		28.1		-		26.5		27.1	
% green wt.	1972	5	-		31.5		-		28.9		29.5	
RATTLING BROOK												
Total and	1969	1	0.41	0.0			No sample				0.41 (± .05)	0.0
advanced	1970	2	0.91	0.0	"		"		"		0.91 (± .03)	0.0
sap rot	1971	3	0.99	0.0	"		"		"		0.99 (± .05)	0.0
(cm)	1972	4	1.45	0.36	"		"		"		1.45 (± .05)	0.36 (± .02)
	1973	5	1.52	0.33	"		"		"		1.52 (± .08)	0.33 (± .05)
Total and	1969	1	13.6	0.0	"		"		"		13.6	0.0
advanced	1970	2	30.3	0.0	"		"		"		30.3	0.0
sap rot %	1971	3	34.7	0.0	"		"		"		34.7	0.0
merchant-	1972	4	45.4	10.5	"		"		"		45.4	10.5
able volume	1973	5	51.4	12.7	"		"		"		51.4	12.7
Moisture	1970	2	46.9		"		"		"		46.9	
content	1971	3	36.5		"		"		"		36.5	
% green wt.	1972	4	41.3		"		"		"		41.3	

Table 6. Simple and multiple linear regressions for estimating the number of years since death, the average radial penetration of saprot and the percentage of the merchantable volume affected by the saprot (advanced and incipient) in balsam fir killed by the hemlock looper.

		R^2	Sy	n
Number of years since death				
(1) Serpentine Lake	Y = 0.9781 + 2.121 (Av. pen. cm*)	0.5537	1.28	134
(2) Crabbes River	Y = -0.1906 + 3.115 (")	0.6974	1.26	97
(3) Rattling Brook	Y = 0.3995 + 2.345 (")	0.8374	0.71	89
(4) All locations	Y = 0.5567 + 2.435 (")	0.6670	1.16	320
Number of years since death				
(5) Serpentine Lake	Y = 0.9182 + 1.749 (BH pen. cm)	0.5362	1.02	134
(6) Crabbes River	Y = 0.8841 + 2.288 (")	0.5207	1.51	97
(7) Rattling Brook	Y = 0.8301 + 2.218 (")	0.7744	0.83	89
(8) All locations	Y = 1.0508 + 2.121 (")	0.5843	1.27	320
Average radial penetration of saprot (advanced and incipient)				
(9) Serpentine Lake	Y = 0.2087 + 0.826 (BH pen. cm)	0.8294	0.22	134
(10) Crabbes River	Y = 0.4703 + 0.619 (")	0.6503	0.30	97
(11) Rattling Brook	Y = 0.2253 + 0.897 (")	0.8779	0.22	89
(12) All locations	Y = 0.2617 + 0.805 (")	0.8082	0.25	320
Percent of merchantable volume affected by saprot (advanced and incipient)				
(13) Serpentine Lake	Y = 24.9212 - 1.543 (DBH cm) + 25.976 (Av. pen. cm*)	0.7017	5.89	134
(14) Crabbes River	Y = 28.5539 - 2.050 (") + 31.003 (")	0.9026	4.31	97
(15) Rattling Brook	Y = 29.2434 - 2.153 (") + 29.529 (")	0.8524	5.82	89
(16) All locations	Y = 28.6616 - 2.044 (") + 29.650 (")	0.8433	5.55	320
(17) All locations	Y = 29.8925 - 1.587 (") + 24.828 (BH ")	0.7854	8.60	320

Cont'd.

Table 6 - Continued

		R^2	Sy	n
Percent of merchantable volume affected by advanced saprot				
(18) Serpentine Lake	Y = -5.7483 - 0.438 (DBH) + 21.634 (Av. pen. cm)	.6009	6.83	47
(19) Crabbes River	Y = -0.2198 - 2.234 (") + 34.762 (")	.5611	8.62	46
(20) Rattling Brook	Y = 1.2077 + .225 (") + 4.721 (")	.1153	4.49	29
(21) All locations	Y = 1.1463 - 1.121 (") + 22.166 (")	.3992	9.53	122
(22) All except Rattling Brook	Y = - .3283 - 1.490 (") + 29.195 (")	0.6512	7.84	93
(23) All except Rattling Brook	Y - .3226 - 0.756 (") + 24.301 (BH pen. cm)	0.3937	10.34	93

*Average penetration measured.

Table 7. Basic density of balsam fir killed by hemlock looper at Crabbes River, Serpentine Lake and Rattling Brook.

Years dead	Location	Outer wood	Inner wood	Whole disc	Average weighted whole disc
	Crabbes River	0.360 ± .005	0.355 ± .004	0.358 ± .004	0.364 ± .003
1	Serpentine Lake	0.362 ± .006	0.326 ± .005	0.337 ± .006	0.342 ± .005
	Rattling Brook	0.353 ± .004	0.330 ± .003	0.335 ± .007	0.346 ± .004
	Crabbes River	0.348 ± .004	0.353 ± .004	0.352 ± .003	0.356 ± .003
2	Serpentine Lake	0.365 ± .006	0.321 ± .007	0.336 ± .006	0.342 ± .006
	Rattling Brook	0.354 ± .006	0.337 ± .008	0.342 ± .005	0.347 ± .005
	Crabbes River	0.359 ± .008	0.357 ± .008	0.358 ± .007	0.365 ± .008
3	Serpentine Lake	0.350 ± .007	0.325 ± .006	0.334 ± .006	0.339 ± .006
	Rattling Brook	0.337 ± .004	0.321 ± .003	0.327 ± .004	0.333 ± .004
	Crabbes River	0.342 ± .012	0.356 ± .006	0.348 ± .008	0.356 ± .009
4	Serpentine Lake	0.347 ± .009	0.327 ± .006	0.335 ± .007	0.340 ± .007
	Rattling Brook	0.334 ± .004	0.328 ± .004	0.329 ± .003	0.336 ± .004
	Crabbes River	0.316 ± .007	0.353 ± .006	0.333 ± .006	0.342 ± .006
5	Serpentine Lake	0.324 ± .010	0.323 ± .006	0.322 ± .007	0.326 ± .005
	Rattling Brook	0.337 ± .011	0.328 ± .006	0.331 ± .008	0.337 ± .007
% loss in 5 years	Crabbes River	11.1	0.5	5.1	4.7
	Serpentine Lake	10.5	0.9	4.4	4.7
	Rattling Brook	4.5	0.6	1.2	2.6

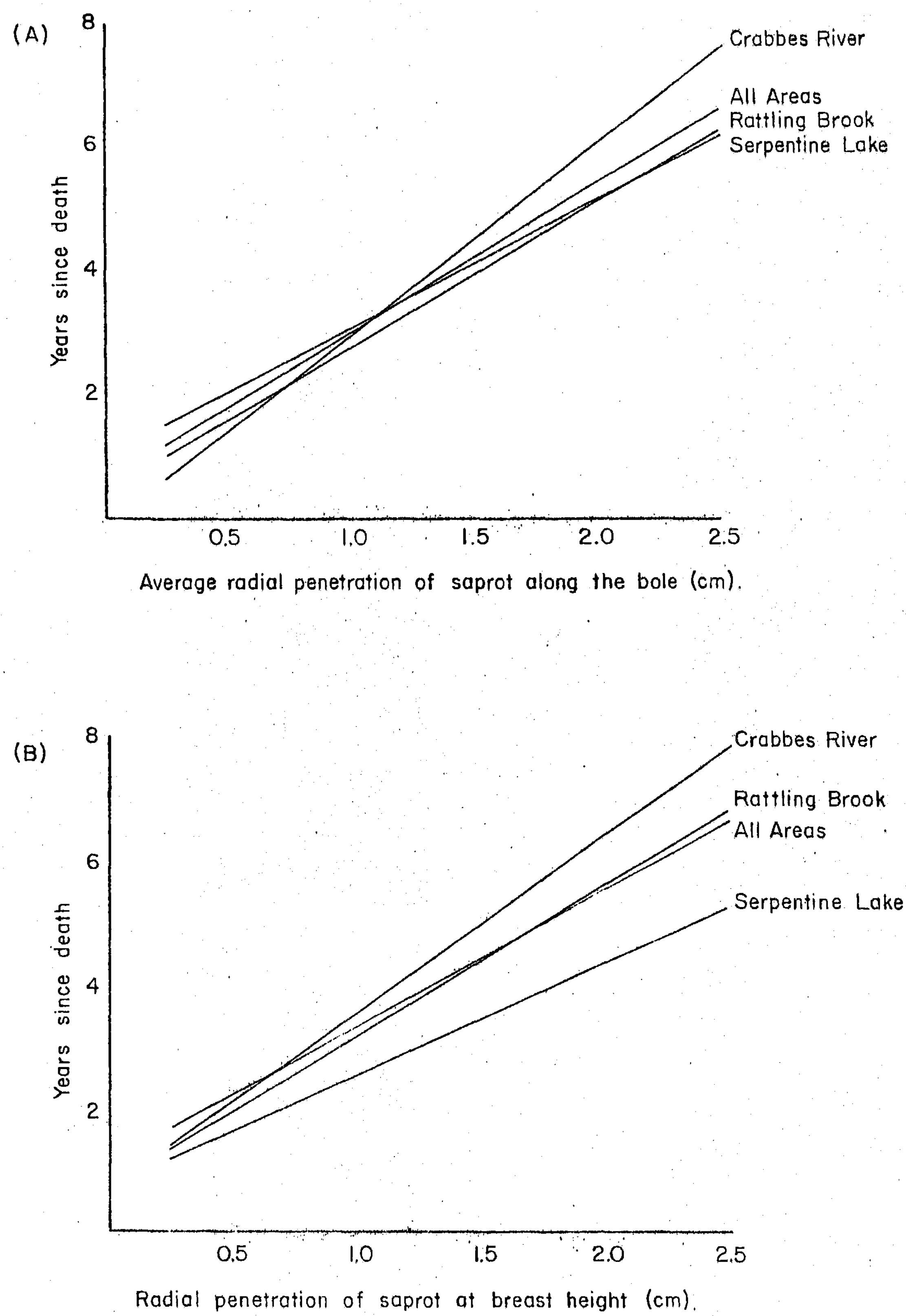


Fig. 3. Relationship between radial penetration of saprot (incipient and advanced) and the number of years since death of balsam fir killed by the hemlock looper.

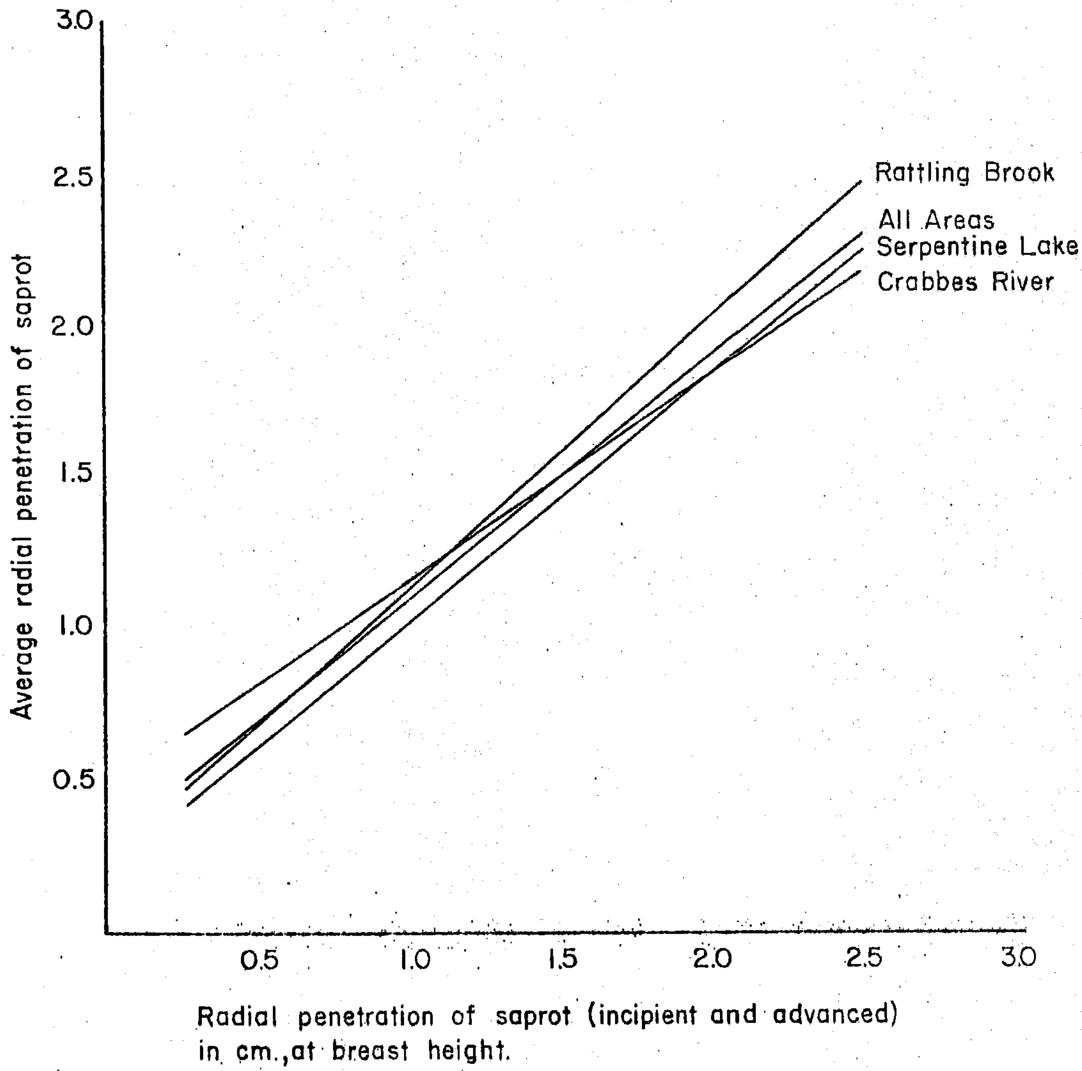
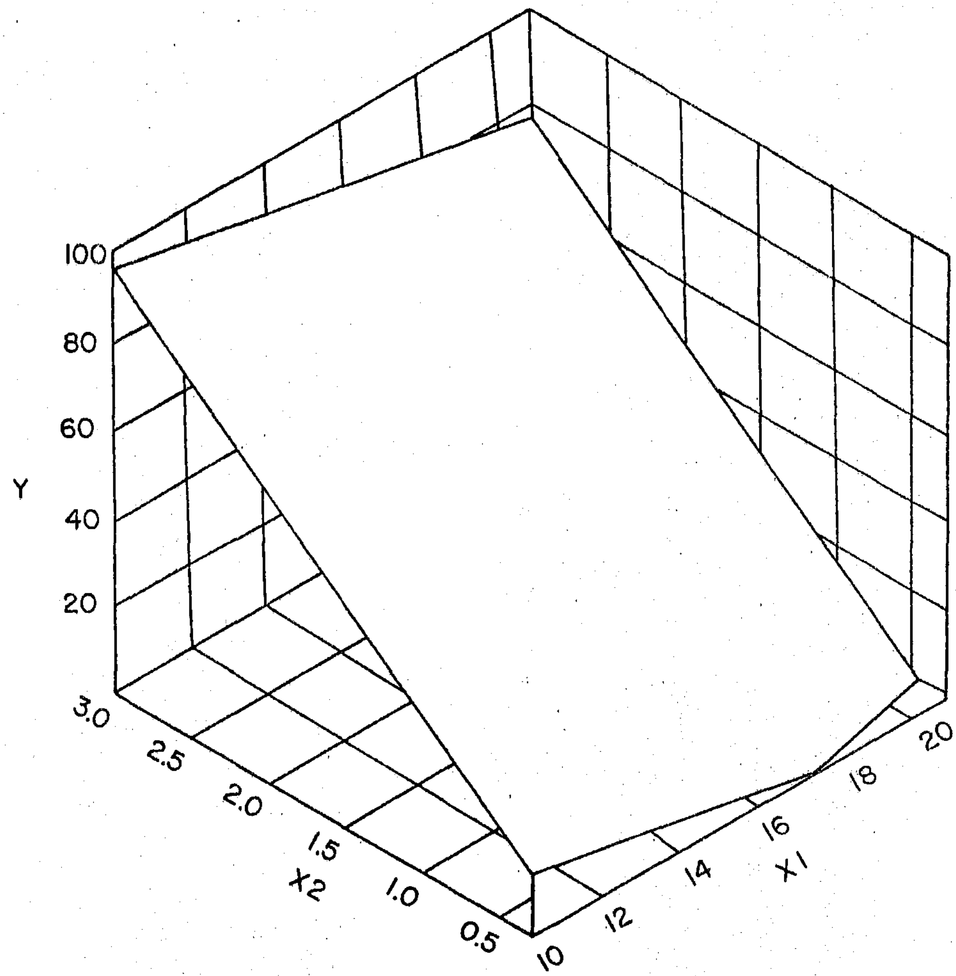


Fig. 4. Relationship between radial penetration of saprot (incipient and advanced) at breast height and the average of radial penetration of saprot (incipient and advanced) along the bole of trees killed by the hemlock looper.

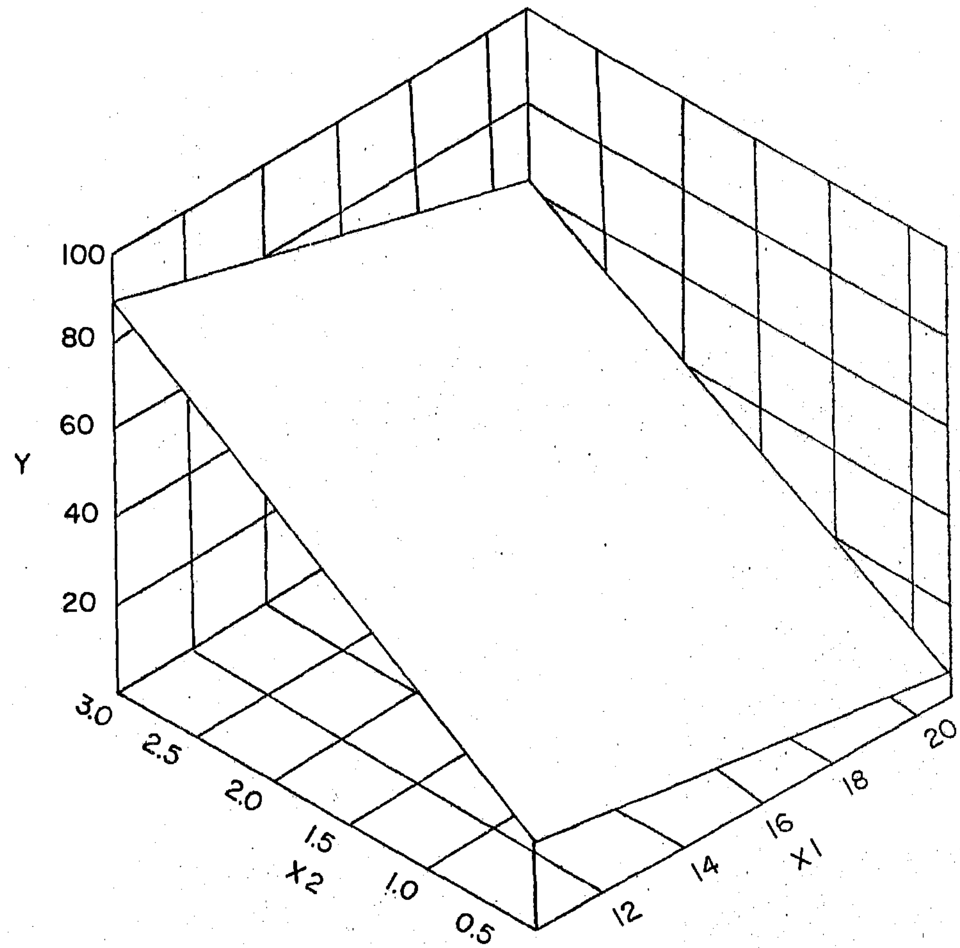


X1— DBH (cm)

X2—Average penetration of saprot, incipient and advanced (cm).

Y— % merchantable volume affected by incipient and advanced saprot.

Fig. 5. Relationship between diameter at breast height, average penetration of saprot (incipient and advanced) and the percent merchantable volume affected by incipient and advanced saprot in trees killed by the hemlock looper.

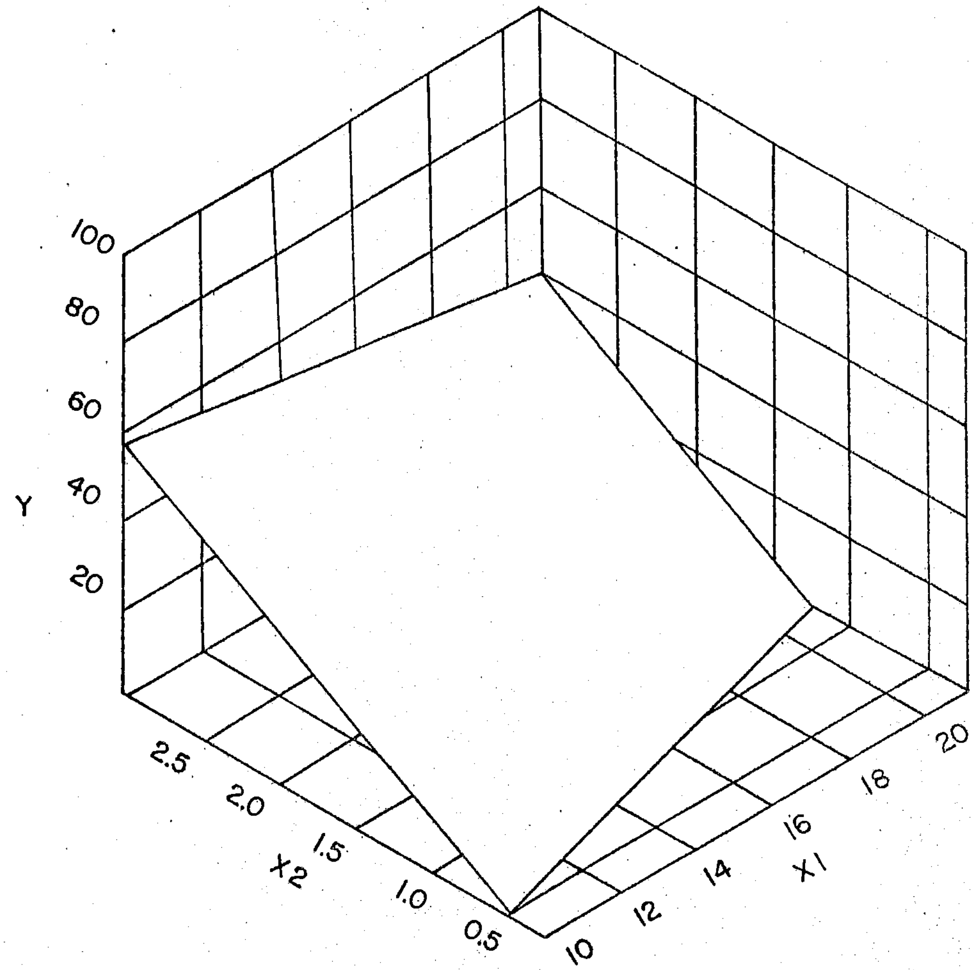


X1– DBH (cm)

X2—Radial penetration of saprot, incipient and advanced, at breast height (cm).

Y– % merchantable volume affected by incipient and advanced saprot.

Fig. 6. Relationship between diameter at breast height, penetration of saprot (incipient and advanced) at breast height and the percent merchantable volume affected by incipient and advanced saprot in trees killed by the hemlock looper.

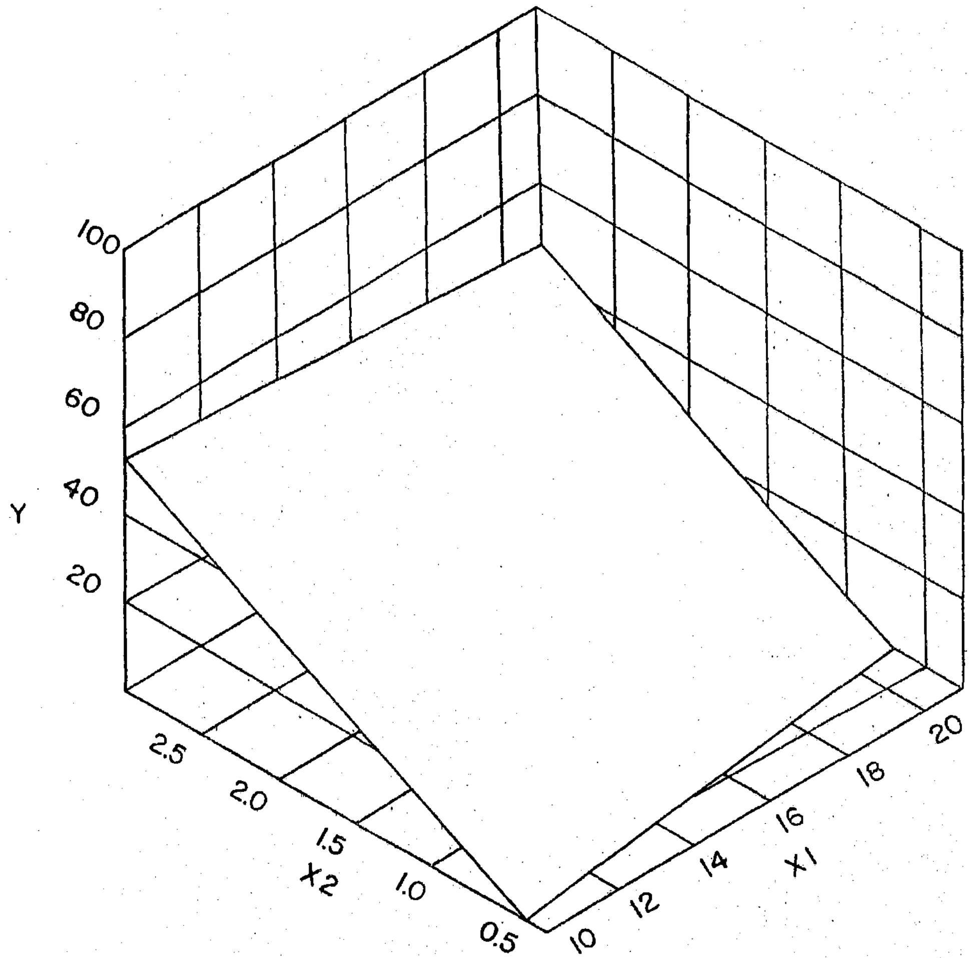


X1— DBH (cm)

X2— Average radial penetration of saprot, incipient and advanced (cm)

Y — % merchantable vol. affected by advanced saprot

Fig. 7. Relationship between diameter at breast height, average radial penetration of saprot (incipient and advanced) and percent merchantable volume affected by advanced saprot in balsam fir killed by the hemlock looper.



X1 – DBH (cm)

X2 – Radial penetration of saprot, incipient and advanced, at breast height (cm).

Y – % merchantable volume affected by advanced saprot.

Fig. 8 Relationship between diameter at breast height, penetration of saprot (incipient and advanced) at breast height and the percent merchantable volume affected by advanced saprot in trees killed by the hemlock looper.

DISCUSSION

Results of this study show that in western Newfoundland tree mortality caused by hemlock looper defoliation progressed more rapidly at Crabbes River than at Serpentine Lake. More than 80% of the trees at Crabbes River had a medium or higher level of aphid damage and 98.6% were killed during the second year of defoliation by the hemlock looper. At Serpentine Lake only 44.2% of the trees had medium or higher level of aphid damage but mortality reached 78% in six years. No aphid damage occurred at Rattling Brook in central Newfoundland but mortality caused by the looper was about one year ahead of that at Serpentine Lake. It is not clearly understook why mortality progressed more rapidly in central Newfoundland but several factors may be involved including differences in looper numbers, climate and site factors. The much higher defoliation during the first year of looper attack at Rattling Brook suggests that higher looper numbers augmented by warmer and drier weather may have been the cause of a more rapid progress of mortality in this area. The effect of such weather factors is known to promote more rapid mortality (Basham et al. 1974).

Regardless of location more than 85% of the trees with over 75% defoliation died within two years of initial looper attack and none of the trees in this defoliation class survived after the fourth year. Also there was about 10-20% mortality in the 20-30% defoliation class. The initially more rapid death of smaller than average trees in the stand has a practical significance in that the delay in mortality of larger trees extends the period the stand may be profitably salvaged.

The saprot was in the incipient stage in all but two trees dead for three years and it commenced to affect the merchantable volume in the fourth year. The incipient decay, although discoloring the sapwood, has no effect on other pulp properties of wood (Beath, 1956; Bjorkman et al. 1964 and Shea et al. 1962). Also it is significant that most of the advanced decay was the white-rot type which has little effect on the carbohydrate content of the wood (Hudak, 1975) and consequently little effect on the pulping properties of wood. Most of the soft wood with advanced decay is probably lost during the debarking and it cannot affect pulp quality.

The moisture content of wood is known to affect the grinding and chipping processes and subsequently the quality of pulp and paper. It has been demonstrated that bursting, tensile, and tearing strengths of spruce groundwood pulp are reduced substantially at 28% moisture content, but oven-dried wood remoistened to 32% yields pulp of practically the same quantity and quality as those of pulp made from never-dried wood containing 56% moisture (de Montmorency, 1964). Some of the sample dead for four and five years have dried to the threshold level but such trees would probably gain moisture in the debarking process. The relatively low moisture contents would not influence the yield and quality of chemical pulp (Keays and Bagley, 1970; Hatton and Keays, 1972).

The basic density of the wood is an important parameter influencing both the yield and quality of pulp (Besley, 1966). The density values for trees without advanced decay were similar to those reported for living fir in Newfoundland (Kennedy, Jerome and Petro, 1968). The decrease in the basic density of wood in trees dead for 5 years was about 4.7%, 4.7%, and 2.6% at Crabbes River, Serpentine Lake and Rattling Brook respectively. These lower densities represent wood losses in the utilization of dead trees, however these losses are confounded with volume losses sustained during the debarking process. Such losses probably would not exceed the volume of advanced saprot in dead trees.

Based on the progress of saprot and its effect on wood properties, it appears that trees dead for at least four years are still suitable for pulpwood. The actual losses in using dead trees can only be determined by evaluating the various pulping characteristics of dead trees and by assessing losses sustained in harvesting, transportation, and debarking of such trees. Even after such evaluation the success of salvaging dead stands is further influenced by the presence of heartrot especially in overmature stands and of saprot in trees previously killed by other insects. Wherever possible, overmature stands should be harvested between periods of insect outbreaks to minimize losses caused by heartrot. The proportion of trees dead for various periods of time in stands killed by the hemlock looper and the amount of saprot (both total saprot content and advanced saprot) in standing trees may be determined through simple cruising using the appropriate equations developed in this study. Such an assessment of individual stands together with data on pulping properties of wood and processing losses would in a given condition assure a successful salvage of stands damaged by the eastern hemlock looper.

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APPENDIX I

Aphid Damage Classification

<u>Upper and lower crown branches</u>

Undamaged	(1)	- no visible symptoms of aphid attack
Light a	(2)	- nodal swelling indistinct, apparent only at close examination of branches
Light b	(3)	- nodal swelling distinct, stunting or distortion of branches present
Medium	(4)	- nodal swelling prominent, branches thinly foliated, branch tips inhibited, but no symptoms of branch mortality
Severe a	(5)	- as in Medium, but branches bare of needles from tips to 30 cm.
Severe b	(6)	- as in Severe a, but branches bare of needles from tips to more than 30 cm.
Dead (Aphid killed)	(7)	- cambium dead at breast height, symptoms of aphid damage present in crown.

Scan visually the upper and lower halves of crown. Based on the most prevalent symptom assign one of the above numerical damage ratings separately to each half of the crown. Average these numerical ratings and assign an average damage rating for the whole tree according to the following class limits:

Range of average numerical damage ratings ($\bar{x}$)	Average damage to a tree
$\bar{x} = 1$	Undamaged
$\bar{x} = 1.5 - 3.0$	Light
$\bar{x} = 3.5 - 4.5$	Medium
$\bar{x} = 5 - 6.5$	Severe
$\bar{x} = 7$	Dead (Aphid killed)

Appendix II. Percentage of trees and merchantable volume by hemlock looper defoliation classes at Crabbes River, Serpentine Lake and Rattling Brook.

Location	Year	Years since defol-iation		Defoliation class						% Blowdown (live & dead)
				0	1-25	26-50	51-75	76-100	Dead	
Crabbes River	1967	1	% trees	No defoliation estimates mortality					20.0[1]	Not recorded
			% volume	taken caused by balsam woolly aphid					21.6	for this plot
	1968	2	% trees						98.6	
			% volume						98.0	
	1973[2]	3	% trees						98.6	
			% volume						98.0	
Serpentine Lake	1967	1	% trees	0.7	42.7	27.7	10.2	18.7	0.0	0.0
			% volume	0.5	51.3	28.9	7.5	12.0	0.0	0.0
	1968	2	% trees	0.0	4.4	23.7	14.9	40.9	16.1	0.0
			% volume	0.0	6.7	29.6	17.4	36.2	10.1	0.0
	1969	3	% trees	0.0	5.6	21.5	11.6	23.5	37.8	0.4
			% volume	0.0	8.3	26.7	13.7	23.3	28.0	0.4
	1970	4	% trees	0.0	11.7	15.4	7.6	3.8	61.2	1.6
			% volume	0.0	15.7	18.1	8.6	4.4	53.0	1.6
	1971	5	% trees	0.3	14.0	9.4	4.6	2.4	69.4	2.2
			% volume	0.3	18.1	10.1	6.4	2.3	62.7	1.8
	1972	6	% trees	2.4	14.8	2.5	0.8	1.1	78.4	5.8
			% volume	3.7	18.5	2.6	0.9	1.0	73.1	6.0

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Appendix II - continued

Location	Year	Years since defoliation		Defoliation class						% Blowdown (live & dead)
				0	1-25	26-50	51-75	76-100	Dead	
Serpentine Lake	1973	7	% trees	0.0	1.5	0.6	2.2	0.5	81.4	59.6
			% volume	0.0	1.9	0.4	2.2	0.5	79.7	61.4
	1974	8	% trees	0.0	0.5	0.3	0.9	0.6	96.7	72.0
			% volume	0.0	0.9	0.3	0.9	0.6	96.5	74.7
Rattling Brook	1968	1	% trees	0.0	0.1	15.0	10.4	74.5	0.0	0.0
			% volume	0.0	0.8	27.8	10.2	61.1	0.0	0.0
	1969	2	% trees	0.0	2.6	15.8	7.6	30.1	43.9	0.0
			% volume	0.0	7.1	24.8	6.5	25.1	36.6	0.0
	1970	3	% trees	0.0	15.5	8.1	2.1	2.8	71.5	0.0
			% volume	0.0	25.1	10.4	1.3	3.2	60.0	0.0
	1971	4	% trees	5.8	16.0	1.6	0.5	0.2	75.9	0.0
			% volume	10.1	22.8	0.8	0.9	0.1	68.4	0.0
	1972[3]	5	% trees	14.4	6.8	0.5	0.0	0.0	78.2	0.0
			% volume	20.7	9.3	0.5	0.0	0.0	69.3	0.0

[1]Mortality caused by balsam woolly aphid.
[2]Trees at Crabbes River were severely defoliated in 1967 and most of them died by 1968.
[3]Rattling Brook plot was harvested in 1973.