EFFECT OF BALSAM WOOLLY APHID DAMAGE ON THE REPRODUCTIVE POTENTIAL OF BALSAM FIR

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INTRODUCTION

Surveys have shown that the balsam woolly aphid, (*Adelges piceae* (Ratz.)) is a serious pest of balsam fir, (*Abies balsamea* (L.) Mill.)the most abundant pulpwood tree species in Newfoundland. The aphid was discovered in 1949 at St. John's on the Avalon Peninsula, and in the Codroy Valley on the west coast of the Island. Infestations now cover more than 6,000 square miles and the insect has been found in nearly all fir forests except on the Northern Peninsula. The history of spread has been documented in the annual reports of the Forest Insect and Disease Survey and the Newfoundland Forest Protection Association. Balsam fir mortality has been estimated at 70% in some stands and it averaged 12% for all stands sampled in western Newfoundland. However, the full destructive potential of this pest cannot be evaluated without a precise assessment of its effect on all stages of stand growth and development.

This report describes the impact of aphid damage on cone production, cone size and the quantity and quality of seed.

METHODS

Description of Study Area

Investigations were conducted in the upper part of the Hughes Brook watershed near Corner Brook, (48°30'N, 58°15'W). The area supported a stand of sub-merchantable to merchantable balsam fir with scattered black spruce and white birch on a "Dryopteris-Hylocomium balsam fir" site as described by Damman (1967). Tree ages ranged from 32 to 70 years and averaged 46.8 years; heights ranged from 32 to 49 feet and averaged 4.3 to 9.3 inches and averaged 6.3 inches. The first aphid infested trees were found in this area in 1956 (Parrott and Clarke, 1957). The infestation has since intensified and spread, and now covers the entire watershed. Considerable tree mortality has occurred especially in parts of the watershed where attack has persisted for several years.

Aphid Damage Classification

In Newfoundland the most prevalent form of aphid damage is caused by "twigh attack" in the crowns of trees. The symptoms of attack are swelling of nodes and the inhibition of buds and shoot growth.

Damage is first observed immediately below the cone-bearing branches, and usually spreads, causing crown-dieback and eventual tree mortality.

Seven levels of aphid damage have been recognized and classified by Warren et al. (1967). That part of the classification required for this study follows:

Undamaged.

Light - swelling apparent only on close examination.

Light to moderate - swellings distinct; some stunting and distortion.

Moderate - node swelling and distortion very distinct; some lack of current shoot development; no shoot dieback.

Moderate to severe - pronounced nodal swelling and shoot distortion; top-most laterals dead or bare of needles.

Severe - pronounced nodal swelling and shoot distortion; mainstem terminal inhibited or dead; extensive branch dieback.

Trees may support a small population of aphids without apparent damage. Therefore, it is important to emphasize that this classification is based on visual symptoms of injury. Also, damage is not equally weighted between classes.

Branching and Cone-Bearing Characteristics

A balsam fir tree annually produces one whorl of shoots that encircle a current terminal internode of the main stem and branches. Branching also occurs on the internode between whorls. These branches are irregular in both distribution and age because internodal buds are not systematically distributed and may remain dormant for several years. Whorl and internodal branches on the main stem are primary or first order branches. Second order branches arise from both secondary whorl and from internodal origins on primary branches. Branchlets of the third and succeeding orders follow the same pattern (Fig. 1).

The cone-bearing characteristics of balsam fir have been described by Morris (1951) for northeastern North America. The principal features are as follows: production starts when trees are between 20 and 30 years of age; a crop is usually borne every second year[1];

[1]Results of the present study indicate that a heavy crop is produced every four years. Heavy crops occurred in 1956, 1960 and in 1964; light crops in 1958 and 1962.

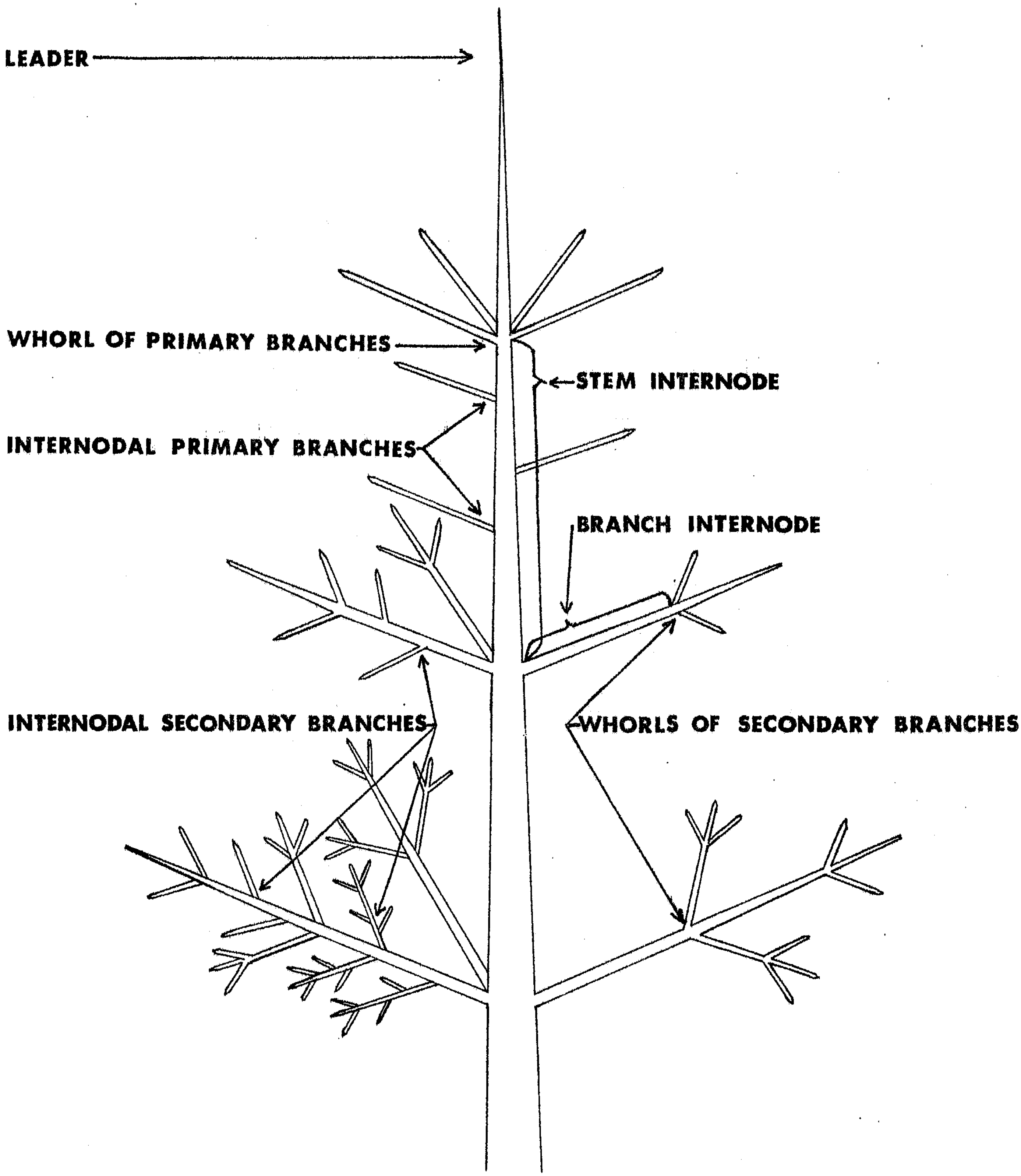

Figure 1. Branching characteristics of balsam fir.

flower buds appear on the current season's shoots and develop the following year; cones normally occur on the periphery of branches (Fig. 2), in the apical 5 feet of crown and are oblong-cylindrical in shape and stand erect; cone scales disperse in the fall carrying the seeds with them, leaving bare, spikelike central axis that persist for many years.

Collection of Data:

Cone production histories of the apical 10 years of crown were recorded on 50 dominant and co-dominant trees from six aphid damage classes (Table I). The number of spikes for 1960 and 1964 cone crops was determined by the age of the supporting branch segment from primary whorl branches (Table II) and internodal branches[2]. The percentage distribution of 1964 cones on primary branches of different ages was determined (Appendix I, A and B). One branch was randomly selected from each main stem whorl and divided along its primary axis into segments containing one year's growth. The number of cones for each crop was counted on each segment to determine the distribution of cones along the branches (Appendix I, C and D).

Collections of balsam fir cones were also taken from the tops of 42 randomly chosen damage trees classified for aphid damage. Ten or more cones were removed from each tree with pruning shears so that a small segment of supporting branch was retained. Aphid numbers were recorded from two cones from each sample. The maximum widths of five of the remaining fresh cones were measured; they were then air-dried at room temperature to constant weight. Measurements of the following cone variables were recorded from five cones for each tree.

Cone variables

- A cone width (fresh, inches)
- B cone axes length (inches)
- C total number of cone scales
- D number of insect damaged seed bearing scales
- E total number of seed per cone
- F number of seeds on scales not damaged by insects.

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[2]Average cone production on internodal branches was the difference between Tables I and II.

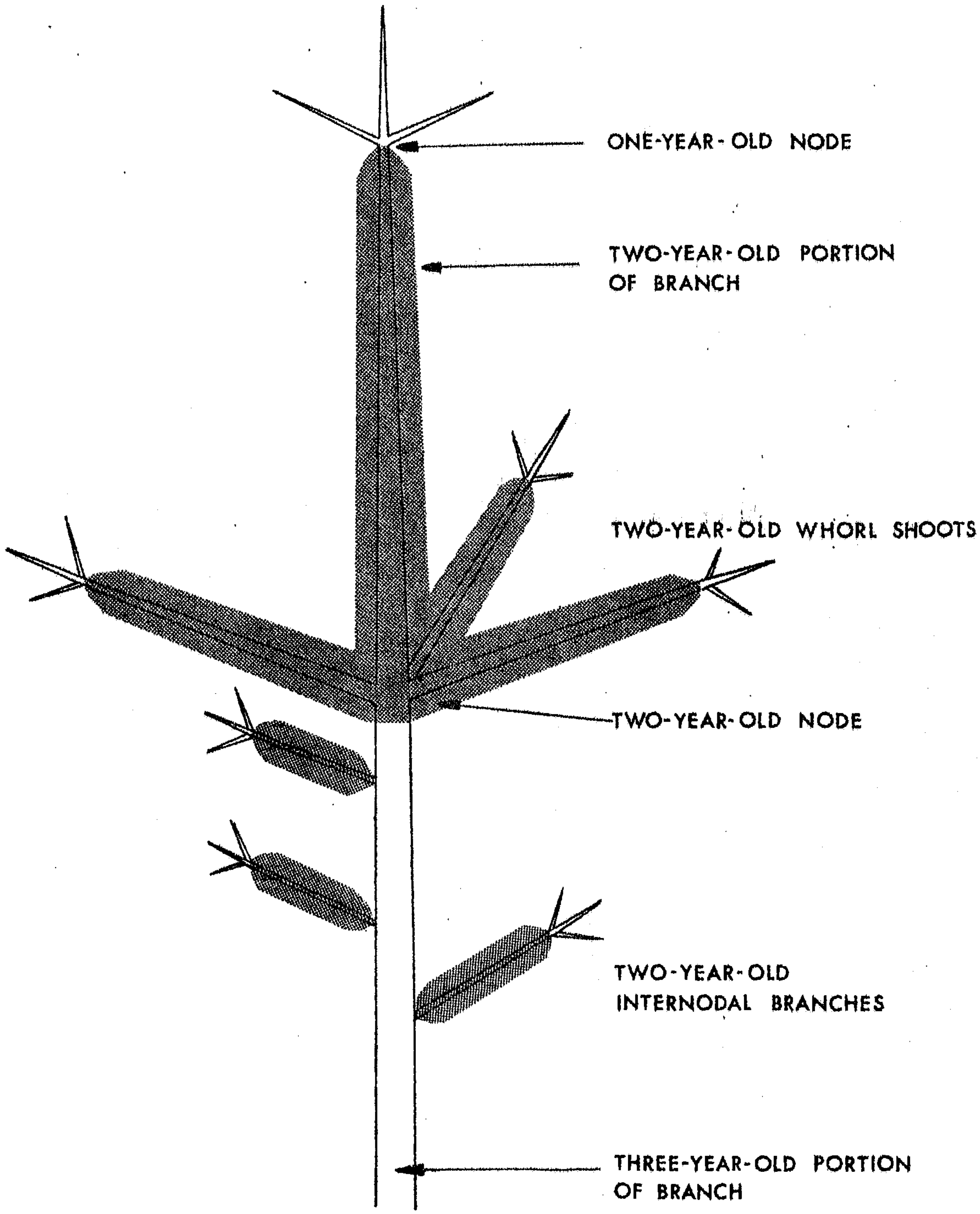

Figure 2; Cone supporting shoots found on the periphery of branches on balsam fir. Cones may be found in the shaded areas.

A random sample of 30 seeds from each of the above cones was examined to determine the number damaged by cone insects. The remaining undamaged seeds were sectioned to determine the number full of endosperm and those that were hollow. A further sample of 10 apparently healthy seed was selected from each cone for a germination test; seeds were incubated on moist filter paper, in petri dishes, at room temperature, for 30 days. Following this period ungerminated seeds were sectioned to determine the condition of the endosperm. Seed viability was determined by adding the number of seed with full endosperm to those that sprouted.

Data on cone and seed quality variability was examined using "Bartlett's test" for the homogeneity of variances. The results of the test showed that the data were not suitable for analysis of variance (Table III). However, the means of each of the variables, for paired aphid damage classes (Tables IV and V) were tested by a procedure where variances were not assumed equal (Bailey, 1959).

EFFECT OF APHID DAMAGE

On the Numbers of Cones Produced

Counts of 1964 cone spikes showed some reduction in cone numbers in the light to moderate and moderate aphid damage classes. However, 75% fewer cones were produced by trees in the moderate to severe than in the light and undamaged classes. Cone history showed that all trees were expected to produce cones in 1964 but data show that 25% of the trees in the moderate to severe damage class and 62% in the severe class did not produce cones in that year, presumably because of branch die-back.

On the Distribution of Cones Within the Crown

Counts of 1964 spikes indicated changes in distribution in various aphid damage classes. The more obvious changes are shown in Figure 3, tabulated results are shown in Appendix I and the main implications follow. In the undamaged class most cones occurred on 3, 4 and 5-year-old primary branches (Appendix I, A and B) and 4-year-old branches were most productive. Four-year-old branches retained a high rate of production in all aphid damage classes except the severe class where most spikes were found on the 3-year-old branches. However, the percentage of cones increased on the 7-year-old branches in the moderate to severe damage class and no cones were produced on branches 6 years and older in the severe class. Results also showed that cone spikes occurred most frequently on 2 and 3-year-old segments of primary whorl branches in all damage classes (Appendix I, C and D). However, there was a general decrease in the percentage of trees with cones on the 2 and 3 year old segments as aphid damage increased.

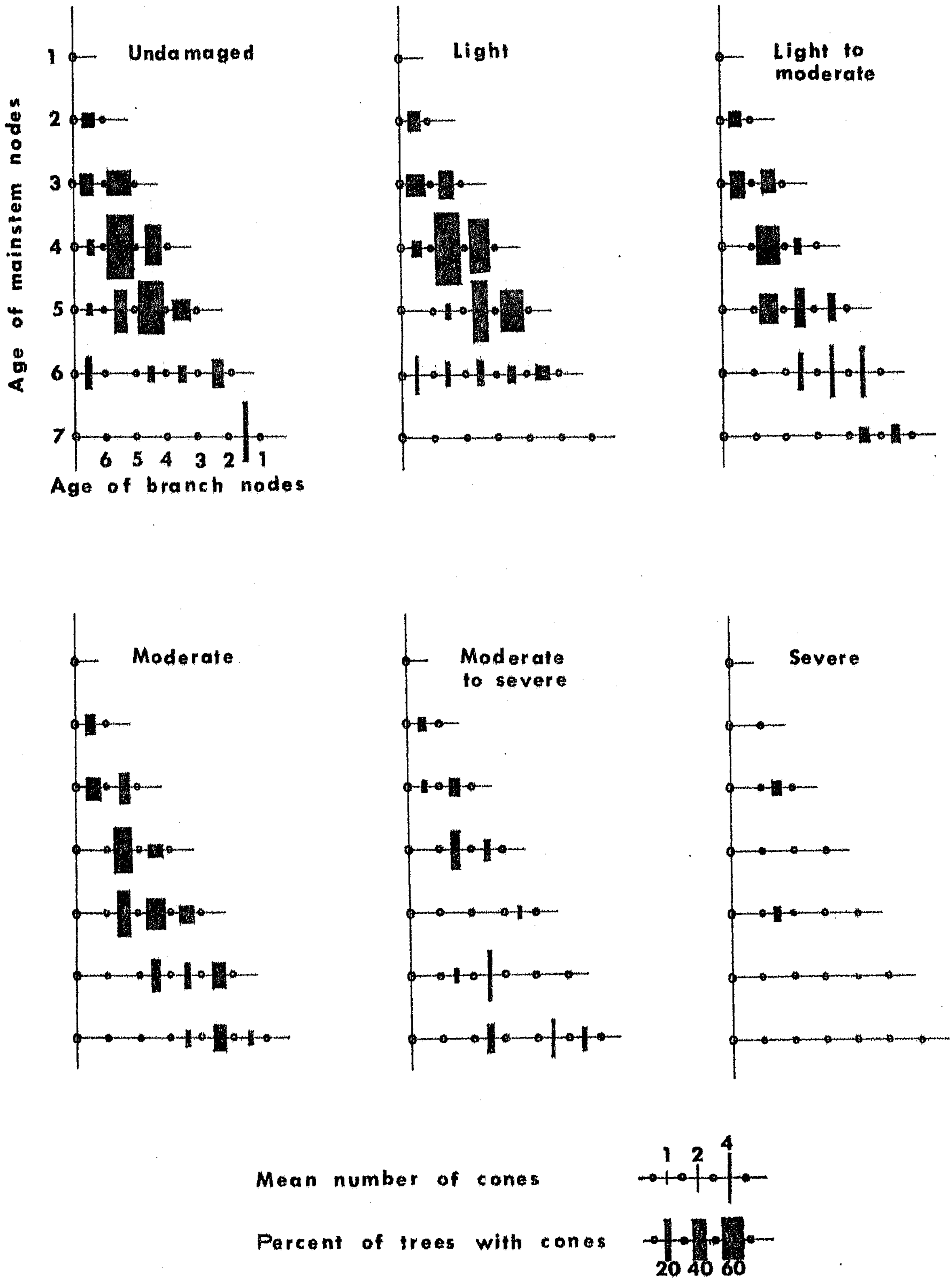

Fig. 3 : The distribution of 1964 cones on primary whorl branches of trees classified for aphid damage.

Examination of the stand indicated that aphid damage increased between 1960 and 1964. Data show total cone production was greater on the undamaged trees in the latter year (Table I). The plotting of 1964 production as a percentage of the 1960 cone crop (Fig. 4) shows that production dropped to about 80% in the light damaged class, but increased through the light to moderate class and was nearly equal to the 1960 production in the moderate damage class. Cone production decreased markedly on trees in the moderate to severe damage class and severely damaged trees produced very few cones. Figure 4 also shows that cone production increased on whorl branches on undamaged trees; decreased 20% on light and light to moderate trees and continued to decrease inversely with damage. Nearly all of the cone production increase on undamaged trees in 1964 occurred on internodal branches. Between 1960 and 1964 there was a 15% decrease in the light damage class and about the same number of cones were produced on the light to moderately damaged trees. A very large increase in cone production on internodal branches occurred in the moderate damage class. This probably represents the formation of distress cones, a common reaction to injury in coniferous species. The response was not apparent in the more severely damaged trees, probably because of crown-dieback and the resultant elimination of cone-bearing sites.

On Cone Variables

Observations indicated that the balsam woolly aphid does not feed on cones but aphids were found where the cone axis was attached to the supporting shoot on 11 of the 84 samples examined. This feeding did not cause any apparent injury to the cones. Distribution tables of the mean values of cone variables for trees did not show any consistent relationship with an increase in aphid damage; and statistical analysis of the means of cone variables, irrespective of trees, showed no consistent significant differences between aphid damage classes (Table IV).

On Seed Quality Variables

As with cone variables, there was no consistent relationship with an increase in aphid damage for trees within damage classes and between damage classes, irrespective of trees (Table V).

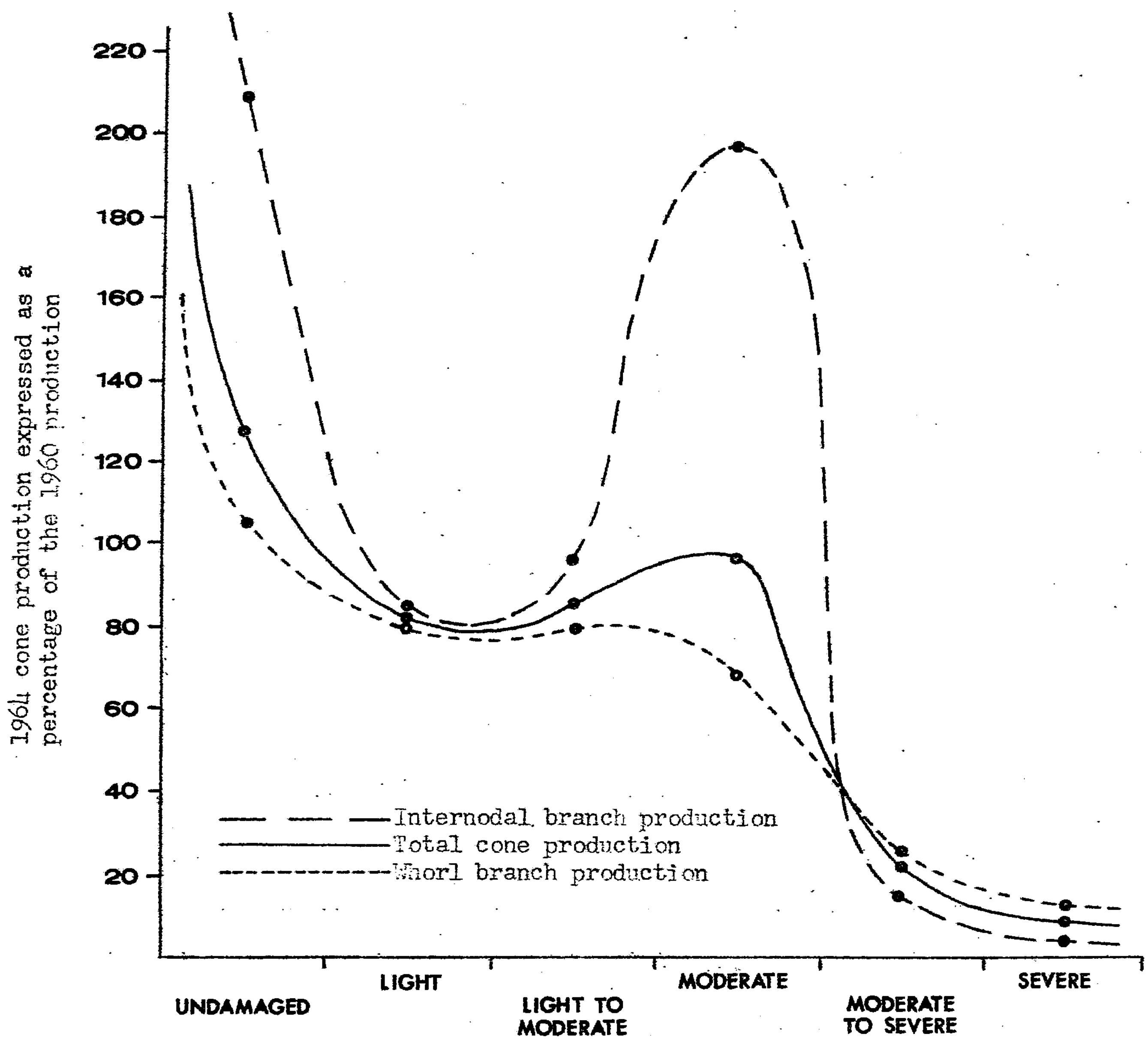

Figure 4: 1964 cone production expressed as a percentage of the 1960 crop for trees in each damage class.

DISCUSSION

This study has shown that the balsam woolly aphid had no appreciable effect on cone production until damage exceeded the moderate level. At this level, the rate of cone production decreased on primary whorl branches but the deficiency was more than compensated for by an increase in the number of cones produced on primary internodal branches; a distress symptom. Beyond the moderate level aphid damage caused crown dieback and seriously reduced production. However, as advanced damage is not reached by all trees simultaneously, and as aphid damage has no apparent effect on seed quality, it must be concluded that aphid infested stands will probably have adequate viable seed for stand replacement. Therefore, it is assumed that there will always be stands of fir to maintain aphid outbreaks.

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Table I. Average and standard deviation of total cone production of trees in different damage classes.

Damage class (in 1965)	Number of trees	Mean number of cones produced per tree in 1964 and 1960	
		1964	1960
Undamaged	10	86.8±33.97	67.7± 47.73
Light	10	86.0±61.45	104.0±145.39
Light to moderate	7	69.7±36.46	79.4± 51.24
Moderate	7	75.4±38.84	77.3± 58.28
Moderate to severe	8	18.6±22.53	82.1± 40.41
Severe	8	3.5± 4.85	37.0± 32.35

Table II. Average and standard deviation of cone production on primary whorl branches of trees in different damage classes.

Damage class	Number of trees	Mean number of cones per tree on primary whorl branches in 1964 and 1960	
		1964	1960
Undamaged	10	55.9±27.23	52.9±34.23
Light	10	50.1±43.83	62.0±72.70
Light to moderate	7	36.7±24.96	45.7±31.16
Moderate	7	41.4±26.33	60.1±52.19
Moderate to severe	8	12.9±15.80	52.1±41.15
Severe	8	2.5± 3.43	18.0±16.98

Table III. Bartlett's test of the homogeneity of variance within each damage class for cone and seed characteristics

	X^2 Value				
	undamaged	light	light to moderate	moderate	moderate to severe
	7 df	9 df	9 df	7 df	5 df
Cone variables					
cone width	3.762	13.576	5.371	8.729	9.688
cone length	9.847	23.433**	21.558*	21.729**	5.014
total number of cone scales	12.872	4.748	34.140**	13.391	3.366
number of insect damaged seed bearing scales	17.908*	35.042**	5.291	14.261*	8.330
total number of seed per cone	8.730	8.445	15.130	9.805	11.553*
number of seeds on scales not damaged by insects	12.681	15.014	21.743**	11.277	9.061
Seed variables					
number of seed full of endosperm	14.830*	13.036	10.388	9.161	17.304**
number of hollow seeds	20.715**	36.495**	14.608	9.710	1.440
number of seed damaged by cone insects	29.526**	109.202**	25.000**	88.902**	10.624
number of seeds that sprouted	353.085**	469.786**	248.422**	310.297**	156.523**
number of viable seeds	17.177*	27.705**	30.276**	10.960	5.887

* significant at 0.05 level
** significant at 0.01 level

Table IV. Comparison of the means of cone variables for trees of succeeding damage classes using probability (P) values

Variable		Damage classes: undamaged	light	light to moderate	moderate	moderate to severe
cone width (fresh)	mean	0.782	0.836	0.872	0.871	0.859
	S^2	0.061	0.061	0.052	0.057	0.074
	P	>0.05	>0.10	>0.90	>0.70	
cone axes length	mean	2.030	2.044	2.139	2.213	2.122
	S^2	0.193	0.299	0.269	0.259	0.210
	P	>0.90	>0.40	>0.50	>0.50	
total number of cone scales	mean	130.13	126.84	126.62	129.13	127.10
	S^2	11.75	14.61	12.46	7.19	15.52
	P	>0.60	>0.90	>0.60	>0.70	
number of insect damaged seed bearing scales	mean	30.18	33.82	26.26	34.68	35.57
	S^2	11.13	14.21	8.59	16.53	16.80
	P	>0.50	>0.10	>0.20	>0.90	
total number of seed per cone	mean	181.10	167.48	182.00	189.25	194.47
	S^2	42.97	31.34	21.01	25.52	21.80
	P	>0.40	>0.25	>0.50	>0.60	
number of seeds on scales not damaged by insects	mean	120.75	99.84	129.48	118.35	130.27
	S^2	42.32	22.57	26.52	29.85	38.03
	P	>0.25	>0.05	>0.40	>0.50	

Table V. Comparison of seed variable means for trees of succeeding damage classes using probability (P) values

Variables		Damage classes: undamaged	light	light to moderate	moderate	moderate to severe
number of seed damaged by cone insects	mean	27.62	49.28	28.45	25.21	39.36
	S^2	26.82	30.89	20.36	18.48	15.75
	P	>0.10	>0.10	>0.70	>0.10	
number of seed full of endosperm	mean	50.31	53.65	71.95	55.53	47.70
	S^2	31.62	24.05	24.13	21.27	26.71
	P	>0.80	>0.10	>0.10	>0.50	
number of hollow seeds	mean	103.16	64.67	81.61	108.51	107.40
	S^2	24.82	34.41	24.78	12.09	27.23
	P	>0.025	>0.20	>0.01	>0.90	
number of seeds that sprouted	mean	4.40	8.82	16.52	15.50	19.70
	S^2	7.51	16.99	20.27	20.55	19.57
	P	>0.40	>0.30	>0.90	>0.70	
number of viable seeds	mean	52.90	63.66	89.80	82.40	71.93
	S^2	18.49	34.74	33.50	33.86	32.86
	P	>0.40	>0.10	>0.60	>0.50	

APPENDIX I

Tables

A. The percentage distribution of 1964 cones produced on primary whorl branches of different ages.

B. The percentage distribution of 1964 cones produced on the primary branches of stem internodes of different ages.

C. The percentage of trees with cones or cone-bearing shoots found on the different segments of primary branches two to seven years of age. Calculations are based on a sample of one branch per whorl for the 1964 cone crop.

D. The number of 1964 cones per tree located on different segments of the primary branches of damage-categorized trees.

Table A. The percentage distribution of 1964 cones produced on primary whorl branches of different ages.

Damage class	Total number of cones counted	Percentage of total cones on primary whorl branches of different ages							
		2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years
Undamaged	559	1.3	17.7	45.4	25.2	8.1	2.3		
Light	501	3.2	20.4	31.1	21.6	22.0	1.4		0.4
Light to moderate	257	3.1	17.5	32.7	24.1	17.1	5.1	0.4	
Moderate	290	3.1	18.6	26.9	12.8	10.0	0.7	1.0	
Moderate to severe	103	5.8	15.5	27.2	15.5	9.7	25.2	1.0	
Severe	20	5.0	55.0	20.0	20.0				

Table B. The percentage distribution of 1964 cones produced on the primary branches of stem internodes of different ages.

Damage class	Tot 1 number of cones counted	Percentage of total cones on branches from stem internodes of different ages 3 years	4 years	5 years	6 years	7 years
Undamaged	309	21.0	46.0	27.5	5.2	0.3
Light	359	25.3	55.2	17.8	0.6	1.1
Light to moderate	231	19.9	38.1	26.0	14.3	1.7
Moderate	238	21.0	29.4	33.2	12.6	3.8
Moderate to severe	46	8.7	47.8	19.6	2.2	21.7
Severe	8	37.5	25.0	12.5	-	-

Table C. The percentage of trees with cones or cone-bearing shoots found on the different segments of primary branches two to seven years of age. Calculations are based on a sample of one branch per whorl for the 1964 cone crop.

Segment of primary branches	Age of primary branch in years	Percentage of trees with cones or cone-bearing shoots in each damage category					
		Undamaged	Light	Light to moderate	Moderate	Moderate to severe	Severe
2-year-old segment	2	30	40	43	29	25	--
	3	90	50	57	43	38	25
	4	60	70	14	57	25	--
	5	70	80	29	57	12	--
	6	40	40	14	43	--	
	7	10	--	29	14	12	
3-year-old segment	3	60	70	43	57	12	
	4	90	90	86	57	25	
	5	80	60	29	86	--	
	6	20	20	14	14	--	
	7	--	--	29	14	12	
4-year-old segment	4	10	20	--	--	--	--
	5	40	10	57	43	--	12
	6	20	10	14	29	12	--
	7	--	--	--	14	--	--
5-year-old segment	5	10	--	--		--	
	6	--	10	14		12	
	7	--	--	--		12	
6-year-old segment	6	20	10				

Table D. The number of 1964 cones per bearing tree located on different segments of the primary branches of damage-categorized trees.

Segments of primary branches	Age of primary branch in years	Mean number of cones per cone-bearing tree in each category					
		Undamaged	Light	Light to moderate	Moderate	Moderate to severe	Severe
2-year-old segment	2	1.00	1.50	1.00	1.50	1.00	----
	3	1.78	2.60	1.50	2.00	1.67	1.00
	4	3.33	3.29	1.00	1.00	1.50	----
	5	1.59	3.29	2.00	1.50	1.00	----
	6	1.75	1.00	4.00	2.00	----	----
	7	4.00	----	1.00	1.00	2.00	----
3-year-old segment	3	1.50	1.71	2.00	1.50	1.00	
	4	5.22	5.78	3.17	3.75	3.00	
	5	4.12	4.83	3.00	2.33	----	
	6	1.00	1.00	4.00	2.00	----	
	7	----	----	1.00	2.00	3.00	
4-year-old segment	4	1.00	1.00	----	----	----	----
	5	3.50	1.00	2.75	3.33		1.00
	6	1.00	2.00	3.00	2.50	4.00	----
	7	----	----	----	1.00		----
5-year-old segment	5	1.00	----	----		----	
	6	----	2.00	1.00		1.00	
	7	----	----	----		2.00	
6-year-old segment	6	1.33	3.00				