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BALSAM WOOLLY APHID DISPERSAL AND DAMAGE IN BALSAM FIR STANDS IN NEWFOUNDLAND

by
G. L. Warren, W. C. Parrott, and S. G. Cochran

FOREST RESEARCH LABORATORY
ST. JOHN'S, NEWFOUNDLAND
INFORMATION REPORT N-X-15

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CANADA
DEPARTMENT OF FORESTRY
AND RURAL DEVELOPMENT

FORESTRY BRANCH
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INTRODUCTION

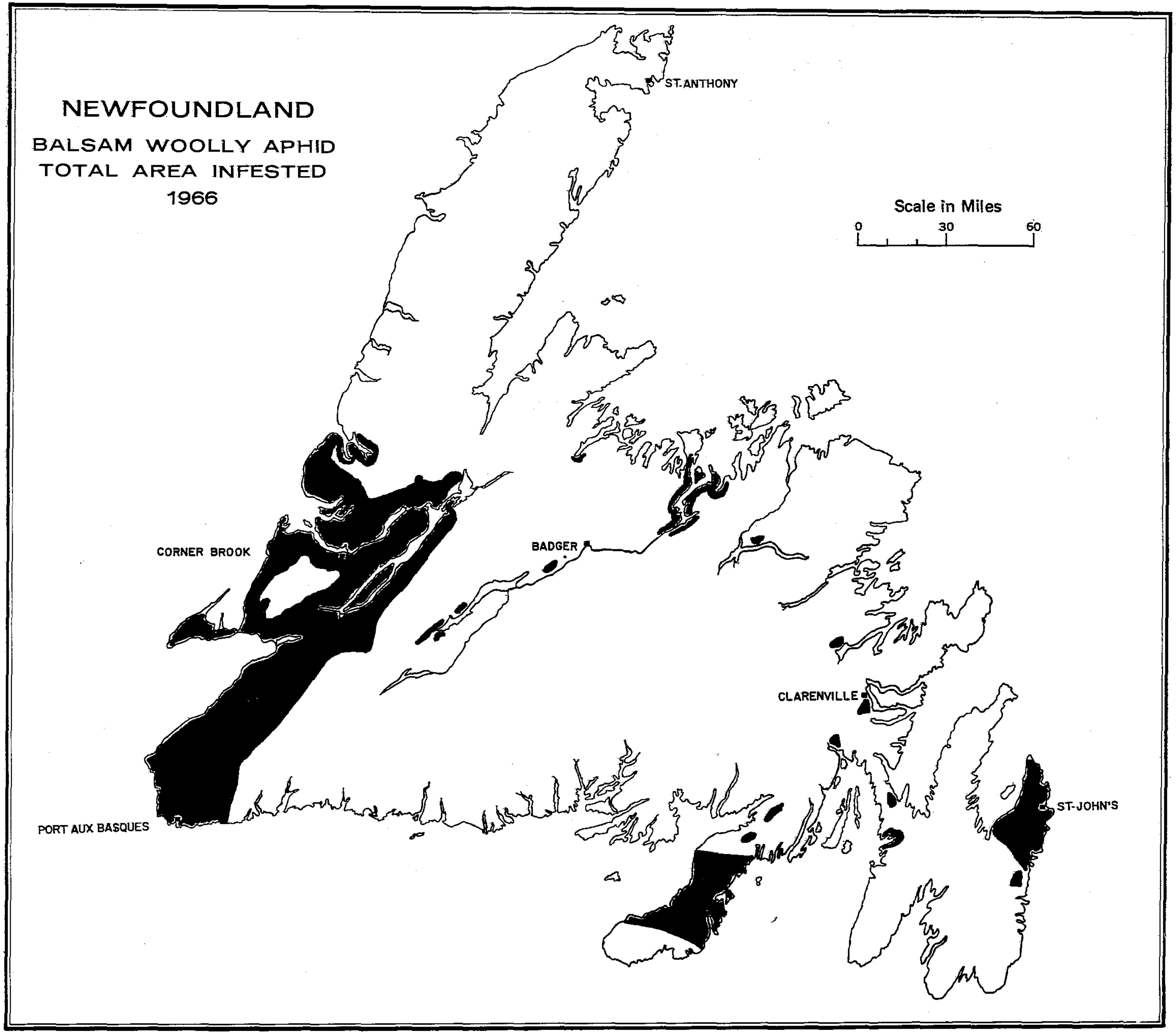
The balsam woolly aphid, Adelges piceae (Ratz.), is a European adelgid that attacks only Abies spp., the true firs (Balch and Carroll, 1958). This pest has caused considerable tree mortality to balsam fir, Abies balsamea (L.) Mill., and extensive stand stagnation in the forests of eastern North America following its introduction about the turn of the century (Balch, 1952).

The life cycle of A. piceae is complicated by multiple generations and two forms. In Newfoundland, the feeding and motile stages are present through May and June and again through August and September. The majority of the aphids are in diapause during the remainder of the year. A detailed description has been published by Balch (1952) and Carroll and Bryant (1960).

In 1949, this insect was discovered in two areas of Newfoundland: in the Codroy Valley on the west coast and near St. John's on the east coast. A third outbreak was reported near Marystown on the Burin Peninsula in 1955 (Carroll and Bryant, 1960). The infestations were small when discovered but they have since expanded to cover a total area of more than 4,000 square miles (Fig. 1).

The largest and most serious infestation occurs on the west coast where balsam fir comprises more than 75% of the softwood

Fig. 1. Total area of Newfoundland infested by the balsam woolly aphid in 1966.


NEWFOUNDLAND
BALSAM WOOLLY APHID
TOTAL AREA INFESTED
1966
Scale in Miles
0
30
60
ST. ANTHONY
CORNER BROOK
BADGER
CLARENVILLE
ST-JOHN'S
PORT AUX BASQUES

stands and currently supplies about 500,000 cords annually to the pulp and paper industry.

The Forest Insect and Disease Survey has used various sampling techniques to maintain annual records of aphid dispersal and damage. This report describes these techniques and provides a review of aphid activity in the merchantable balsam fir stands of Newfoundland.

DESCRIPTION OF DAMAGE

The Forest Insect and Disease Survey has used aphid injury symptoms to determine the occurrence and intensity of aphid attack. The three terms, 'twig attack', 'stem attack' and 'recovery' are used in describing infestations.

Twig attack is not a form of attack but a symptom caused by aphids feeding on the nodes of both lateral and terminal branches. The attack causes swelling of nodes and twigs and inhibition of the buds, a condition known as 'gout' (Fig. 2). This condition is prominent in the upper part of the crown (Fig. 3). Mortality may occur from long periods of attack or from very severe initial attack on either mature trees (Fig. 4) or young trees (Fig. 5). However, trees may remain in a stagnant condition (Fig. 6) for an indefinite period.

Stem attack refers to aphids feeding on the main stem and/or at the base of branches. This attack is recognized by the white wax threads covering the feeding larvae and adults (Fig. 7). The salivary injections of the aphids result in the formation of enlarged annual rings of brittle, reddish-brown wood (Balch, 1952). This 'redwood' is apparent in cross sections of infested stems or branches (Fig. 8). Low aphid population levels on stems or branches usually cause recognizable redwood but moderate to high levels may cause prominent redwood

Photos by;

W.C. Parrott
S.G. Cochrane
D.G. Bryant

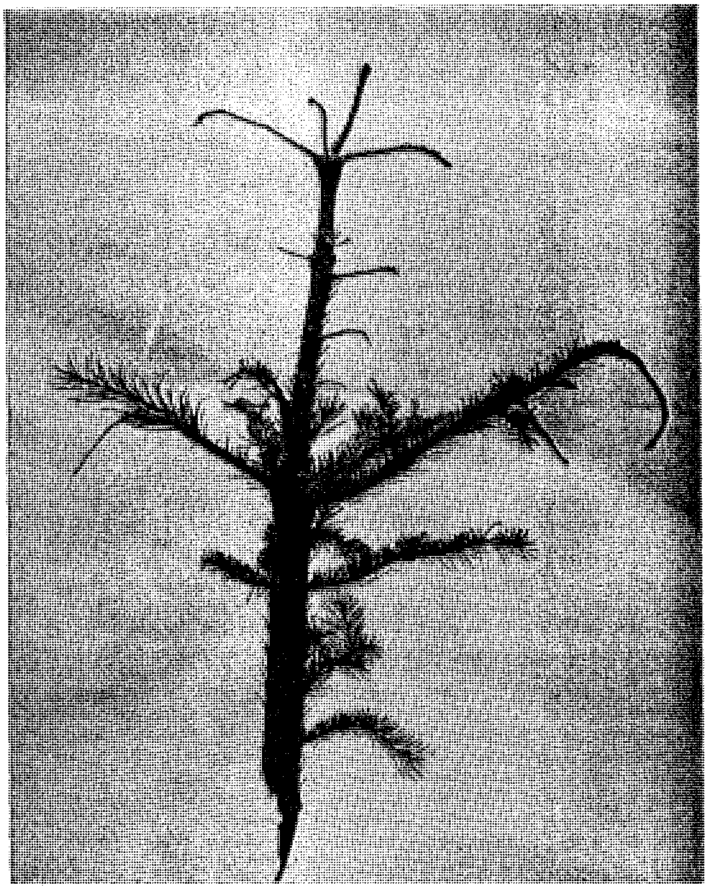


Fig. 2. Gout - swelling of nodes and twigs and inhibition of buds caused by aphid attack.

Fig. 3. Leader and branch mortality from prolonged attack.

Fig. 4. Mortality caused by medium to severe long-term gout.

Fig. 5. Mortality caused by severe gout on young balsam fir.

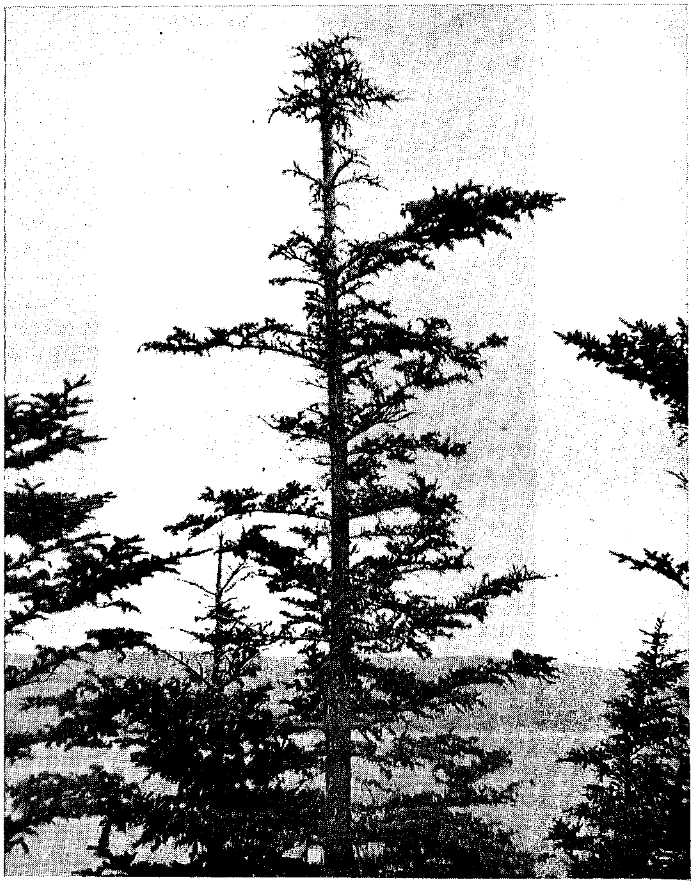


Fig. 6. Stagnated stand conditions caused by accumulated gout.

Fig. 7. Stem attack - recognized by white wax threads on main stem and at base of branches.

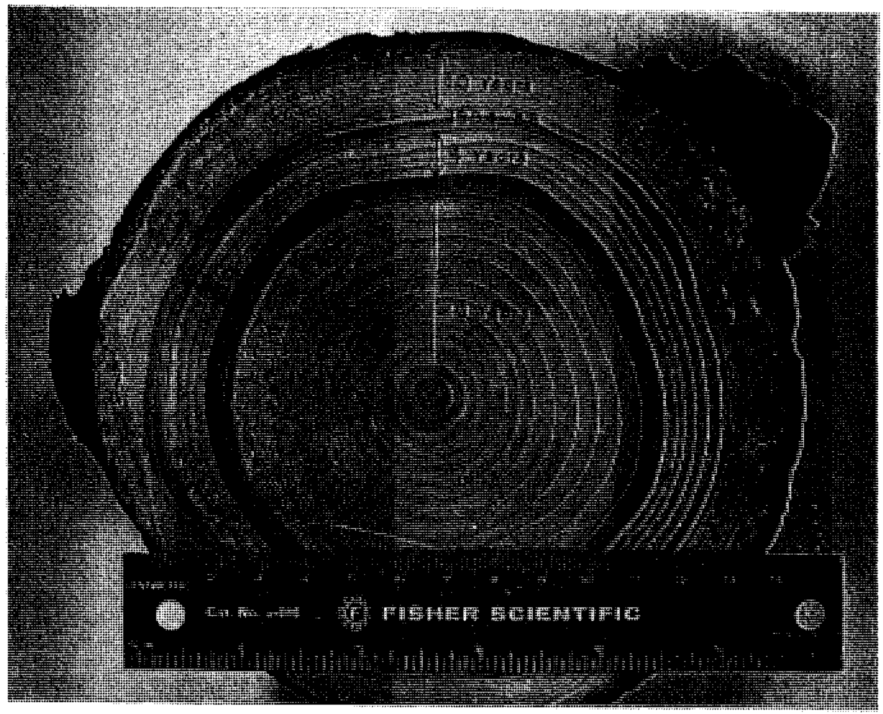


Fig. 8. Redwood - caused by aphid attack on the stem.

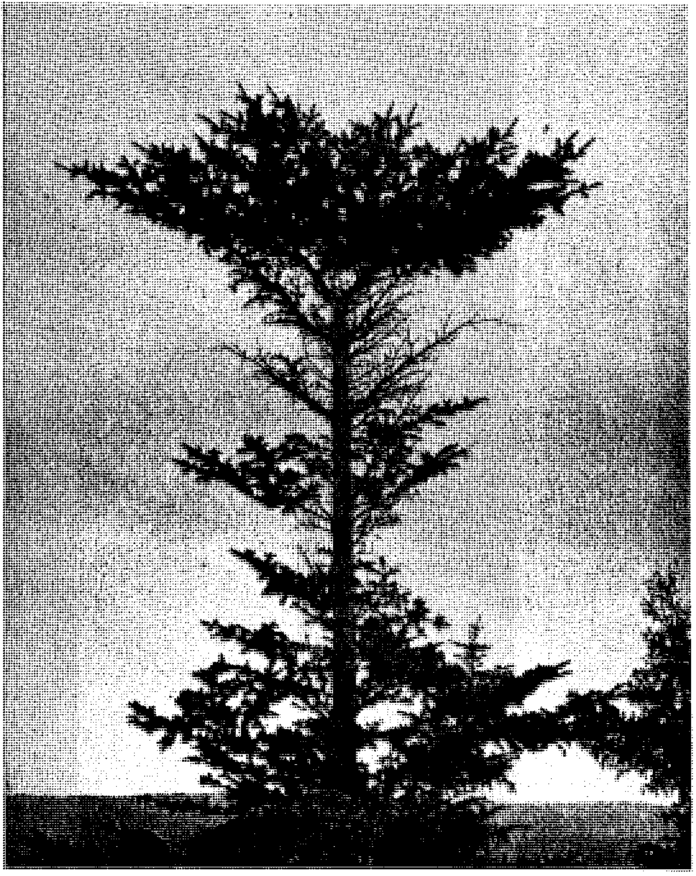


Fig. 9. Recovery - flat-top, little vertical and lateral growth.

and tree mortality in 1 to 3 years. Trees killed by stem attack are also characterized by red foliage which usually remains on the trees for at least one year.

Recovery is a tree reaction to gout and/or stem attack. Recovery from gout has several recognizable forms each with varying degrees of success: severely infested immature and mature trees may produce a well-defined 'flat-top' (Fig. 9) from which effective vertical growth rarely develops; lateral growth may occur following top-killing with or without successful vertical development (Figs. 10 and 11); vertical development may occur when a lateral or adventitious shoot replaces a damaged or dead leader. The latter condition is most common in immature (Fig. 12) or sapling (Fig. 13) trees. Trees may recover from several periods of stem attack as shown by the intermittent rings of redwood in Fig. 8. The success of any form of recovery depends upon the severity, duration and frequency of attack.

METHODS OF DETECTION AND APPRAISAL

Detection and appraisal surveys have been conducted since 1949 using a variety of methods to determine the occurrence and intensity of aphid damage throughout the Island. The types of plots, cruises, and classifications are described.

Detection Surveys

Intensive ground and aerial surveys have been conducted immediately outside the boundaries of known infestations and less intensively over all the predominately balsam fir areas on the Island. Gout, white wool and red foliage have been the symptoms used to identify the presence of the aphid in balsam fir stands. Results of surveys are mapped annually and boundary adjustments are recorded in annual reports.

Fig. 10. Recovery - good lateral development and some vertical development following top-killing.

Fig. 11. Recovery - good lateral development and no definite vertical development following top-killing.

Fig. 12. Good recovery in an immature tree.

Fig. 13. Good recovery on sapling balsam fir - subordinate lateral replacing killed leader on at least three occasions.

Damage Classifications

The first damage classification used was devised by the Forest Insect Laboratory, Fredericton, New Brunswick. In Newfoundland it is identified as the 1949 classification. Details follow:

Classification of Balsam Woolly Aphid Damage on Balsam Fir - 1949 (Fredericton, N.B.)

Class	Description
1	Uninfested
2A	New stem attack, light
2B	New stem attack, medium
2C	New stem attack, heavy
3A	Dead from stem attack red foliage
3B	Dead from stem attack, bare branches
4A	Gouty-distinct but light
4B	Gouty-some dying branches
4C	Gouty-some dead branches
5	Dead from gout

This system was modified in 1955 to include a classification of tree recovery recorded as P-poor; F-fair; or G-good.

In 1965, a new classification was designed in Newfoundland to provide a more detailed assessment of damage. Stand and plot descriptions, tree measurements and injury classification details are shown in Appendix "A". A detailed explanation of essential terminology and the classification follows:

Tree Divisions (Fig. 14)

Upper crown - upper vertical half, including the apex (apical two years' growth).

Lower crown - lower vertical half.

Bole - the portion of the stem between the root collar and the lower branches.

Tree Measurements

Dbh. - Tree diameter breast height to nearest 1/10 inch.

Hgt. - Total tree height.

Bole Hgt. - Height to lower branches.

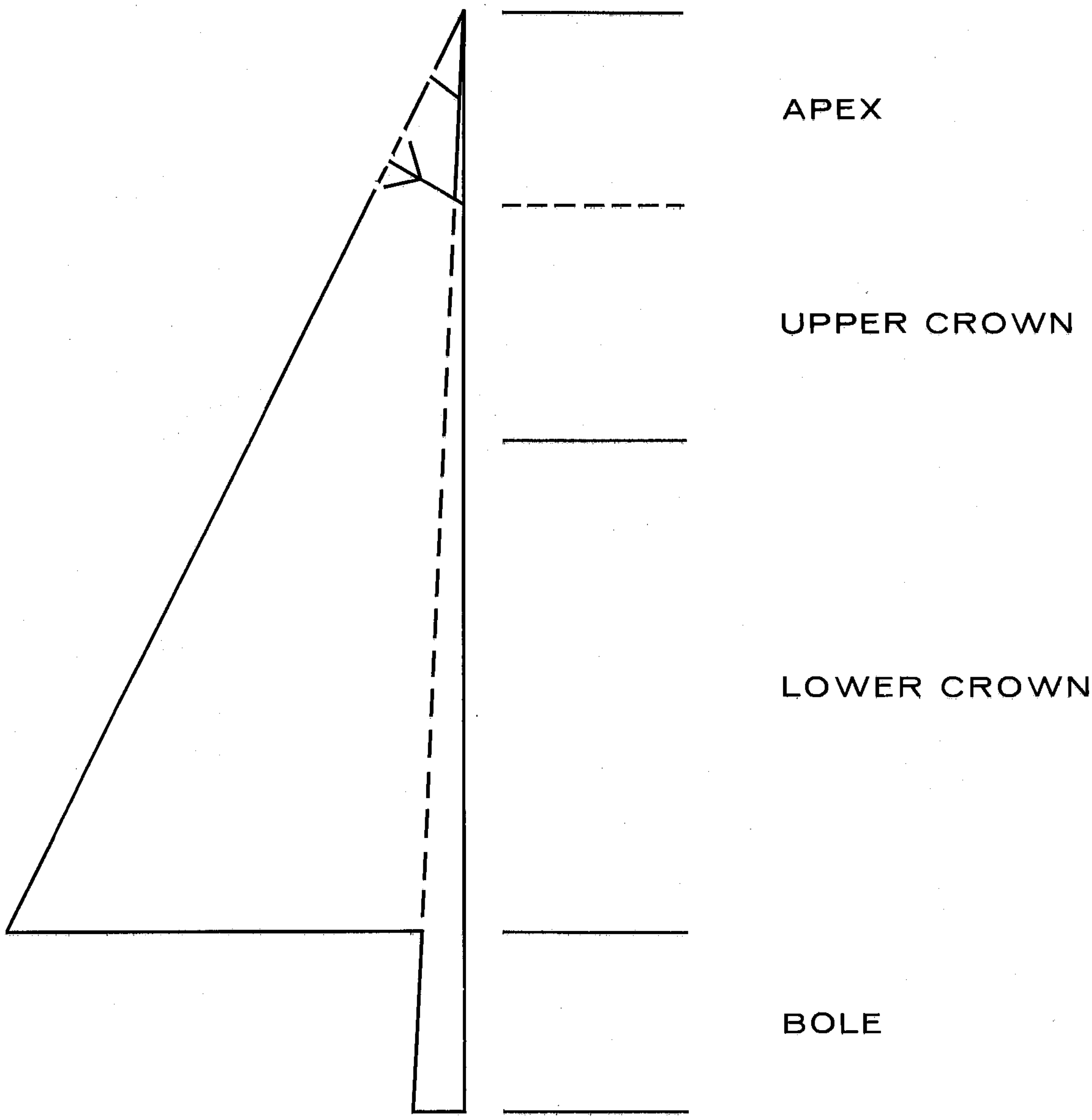
Crown Radius - Distance in feet from the bole to the outside of the crown. Radius estimated to the nearest foot.

Crown Class - Crown classes recorded as Dominant (D), Co-dominant (CD), Intermediate (I), or Suppressed (S).

Balsam Woolly Aphid Damage Classification - 1965

Tree division	Classification symbols
'Recovery'	F, G, Ft
Apex	Ef, Eb, Bf, Bb, A
Upper and lower crown	
Stem attack	O, L, M, H, U
Gout	O, La, Lb, M, Sa, Sb or numerals 1, 2, 3, 4, 5, 6
Bole	O, L, M, H

Fig. 14. Diagrammatic sketch of tree divisions used in balsam woolly aphid classification.


APEX
UPPER CROWN
LOWER CROWN
BOLE

Classification Terminology

Recovery

F	Fair recovery as indicated by the presence of normal epicormic shoots in moderate to severely damaged crowns or indications of a new leader developing (Fig. 15).
G	Good recovery as indicated by two or more years of new foliage production (Figs. 11, 12, 13).
Ft	Flat Top. This condition will be recorded when the tree has a definite flat top (Fig. 9).

Apex

Ef	Leader erect, foliated (Fig. 16).
Eb	Leader erect, bare (Fig. 17).
Bf	Leader bent, foliated (Fig. 18).
Bb	Leader bent, bare (Fig. 19).
A	Leader absent, broken off or not visible (Fig. 20).

Upper and Lower Crown

- Stem attack

Symbol	
O	No wool spots apparent.
L	Light infestation - up to ten wool spots per square inch of bark (Fig. 21).
M	Medium infestation - eleven to twenty wool spots per square inch of bark (Fig. 22).
H	Heavy infestation - over twenty wool spots per square inch of bark (Fig. 23).
U	Unrecorded - stem section not visible for assessment.

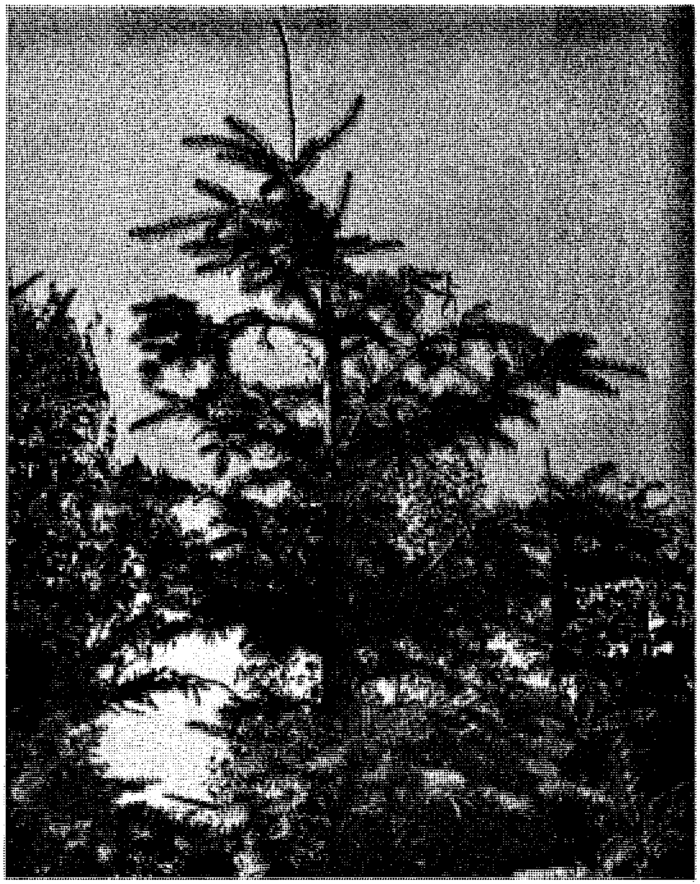


Fig. 15. Fair recovery on an immature tree.

Fig. 16. Leader erect, foliated.

Fig. 17. Leader erect, bare.

Fig. 18. Leader bent, foliated.

Fig. 19. Leader bent, bare.

Fig. 20. Dead top broken from mature tree - no leader replacement.

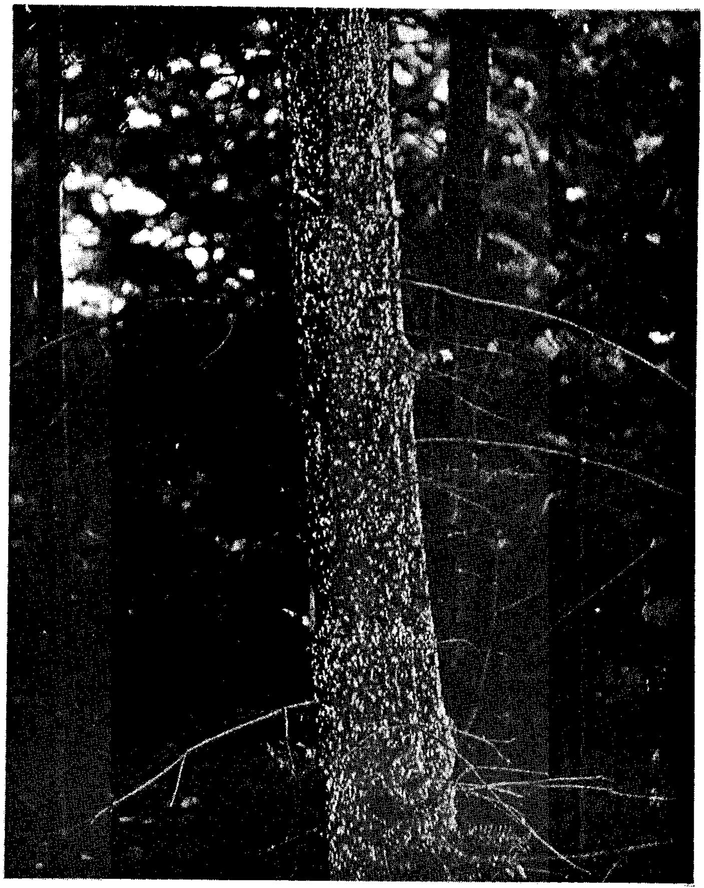


Fig. 21. Light stem attack.

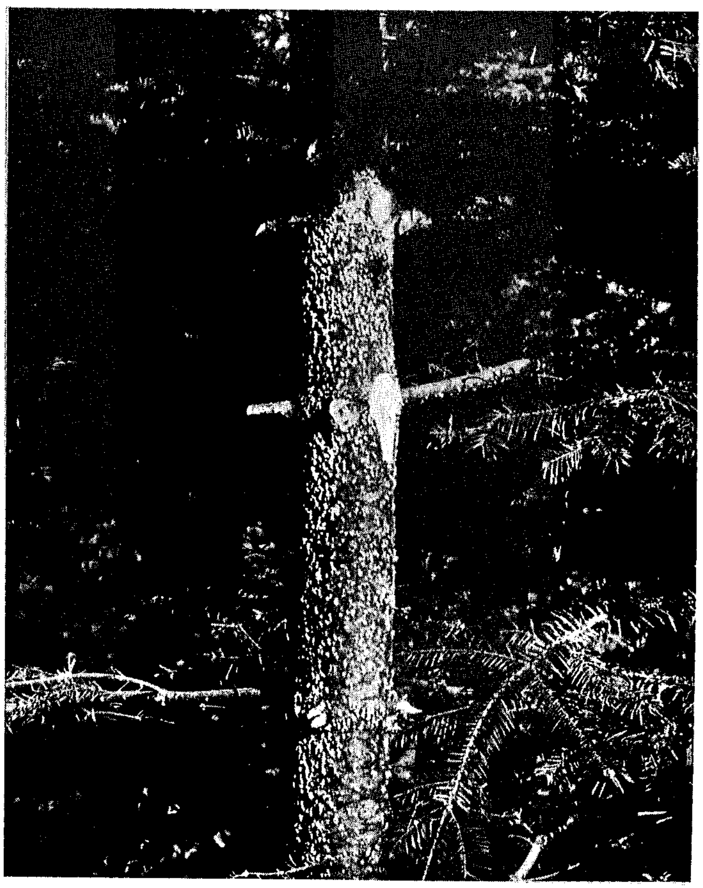


Fig. 22. Medium stem attack.

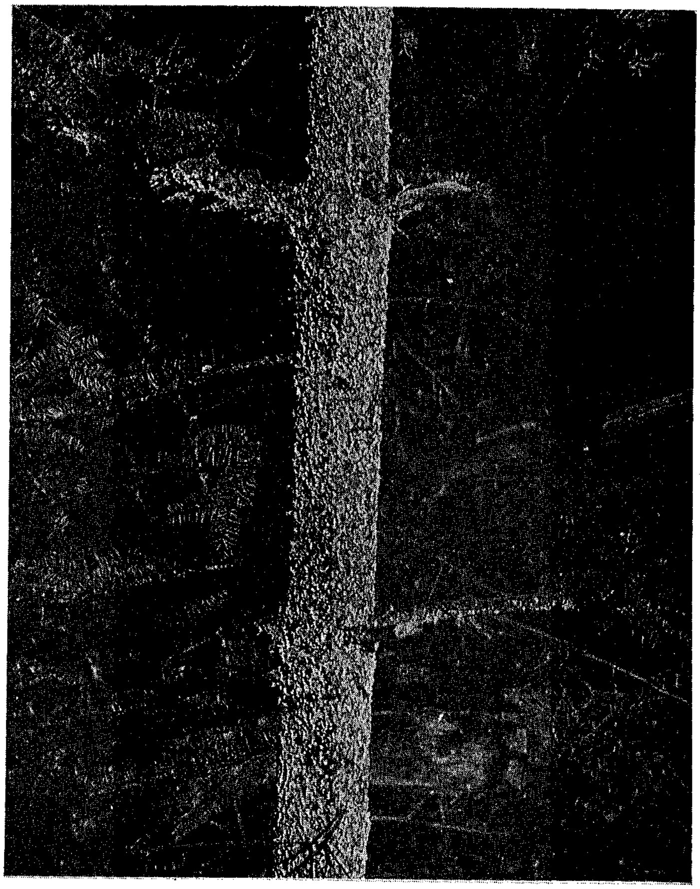


Fig. 23. Heavy stem attack.

- Gout

Symbol	Numeral	
O	1	Gout absent.
La	2	Swellings apparent on close examination (Figs. 24, 25).
Lb	3	Swellings distinct, stunting and distortion present (Fig. 26).
M	4	Node swellings and distortion distinct, some branch tips inhibited and foliage thin at the tips. No obvious mortality (Fig. 27).
Sa	5	Up to 12 inches of terminals and topmost laterals bare of needles or dead (Fig. 6).
Sb	6	Entire branches bare of needles or dead (Fig. 3).

Bole

See stem attack classification for 'Upper and Lower Crown'.

In using the classification the Forest Insect and Disease Survey has not attempted to equate recovery, stem attack and gout but each has been recorded individually. Damage assessment has been based primarily on gout as it is the most common symptom of aphid injury in Newfoundland.

Evaluation of gout damage in trees and stands is based on the average numerical gout classification of crowns and is categorized as follows:

Gout Evaluation in Trees or Stands

Range of Mean Numerical Damage Class	Functional Survey Class
$1 = \bar{X}$	Uninfested
$1 \leqslant \bar{X} \leqslant 2.6\dot{6}$	Light
$2.\dot{6}\dot{6} \leqslant \bar{X} \leqslant 4.3\dot{3}$	Medium
$4.\dot{3}3 \leqslant \bar{X} \leqslant 6.00$	Severe

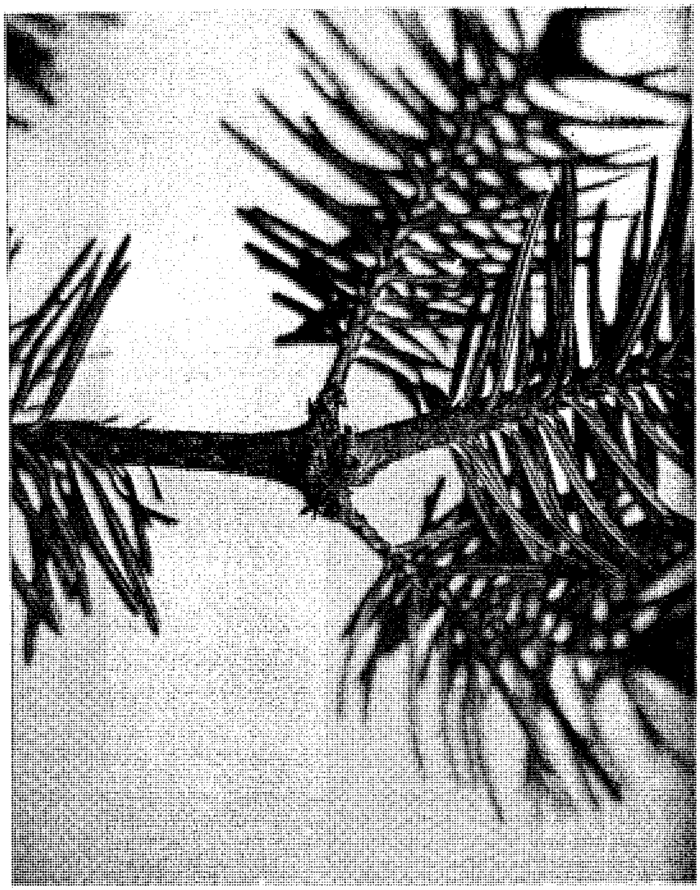


Fig. 24. Gout - (La, 2) front view.

Fig. 25. Gout - (La, 2) side view.

Fig. 26. Gout - (Lb, 3) side view showing distortion.

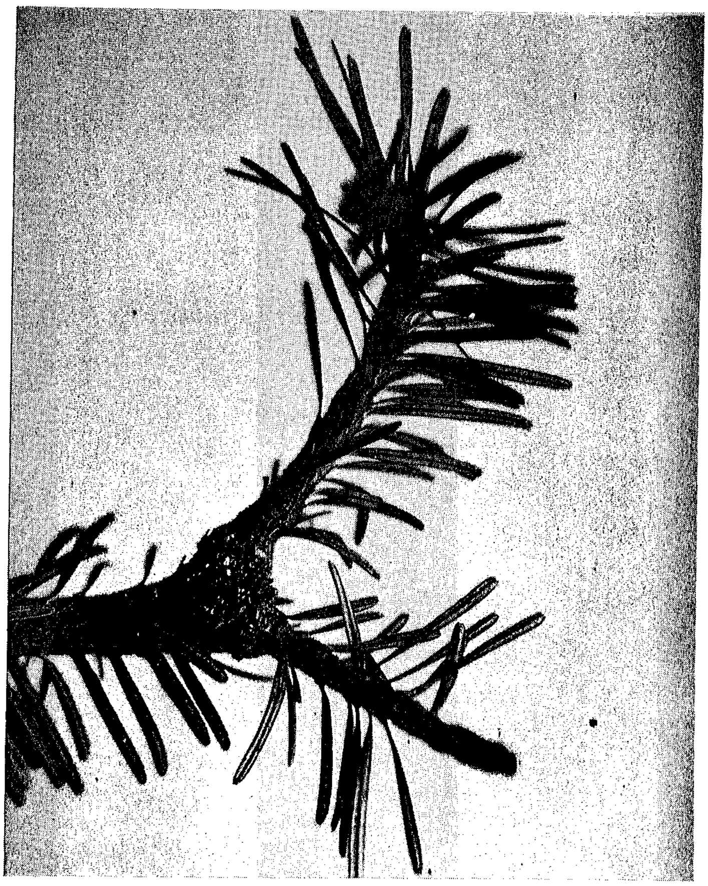


Fig. 27. Gout - (M, 4) side view showing tip inhibition, this foliage, swelling and distortion.

Plot and Cruise Methods for Damage Appraisal

Various plot and cruise surveys have been employed using the previously described classifications as they evolved and, together with annual aerial surveys, have provided pertinent data on dispersal and damage.

In 1949, 15 one-fifth acre plots were established in the St. Fintans - River Brook area on the west coast. These were laid out at 1,000 foot intervals along five cruise lines. Three additional plots were established in 1951. Aphid damage was classified by the 1949 method on all trees over 2-inch d.b.h. Continuous information was not collected from these plots because of logging operations and they were discontinued by 1953.

In 1955, a system of permanent 100-tree plots was initiated as follows:

Location	Year of Establishment	Remarks
South Branch	1955	continuing
North Branch	1955	continuing
Highlands	1955	continuing
Crabbs River	1955	continuing
Coal Brook	1955	cut 1961
Flat Bay Brook	1955	discontinued 1965
Stephenville Crossing	1956	cut 1963
Black Duck	1956	continuing
John's Beach	1955	cut 1963
Wild Cove	1955	continuing
Steady Brook	1959	continuing
Lomond	1959	continuing

Aphid damage was assessed on each tree annually. The 1955 classification was applied until it was replaced in 1965 with the new classification. Plots were discontinued as shown in the above 'Remarks'.

In 1956, aphid damage was assessed from several 10-tree roadside cruises in severely damaged stands along the Trans-Canada Highway from Port aux Basques to St. George's Bay. Damage was reassessed biennially to determine the progression of damage and the mortality accrued by mature and overmature stands.

Since 1965, aphid damage has been assessed along cruise lines in eight infested watersheds on the west coast. The 1965 classification was used on all fir trees over 2" d.b.h. along strips 8 feet wide by 22.3 to 144 chains long. Watersheds examined were Bottom Brook, Little Barachois Brook, Flat Bay Brook, Lower Flat Bay Brook, Fishels River, Crabbs River, Codroy Pond and Lower Humber River (Pasadena). All stands had a history of aphid attack for more than 10 years and cruises were performed to estimate the present status of injury and extent of mortality attributed to aphid damage.

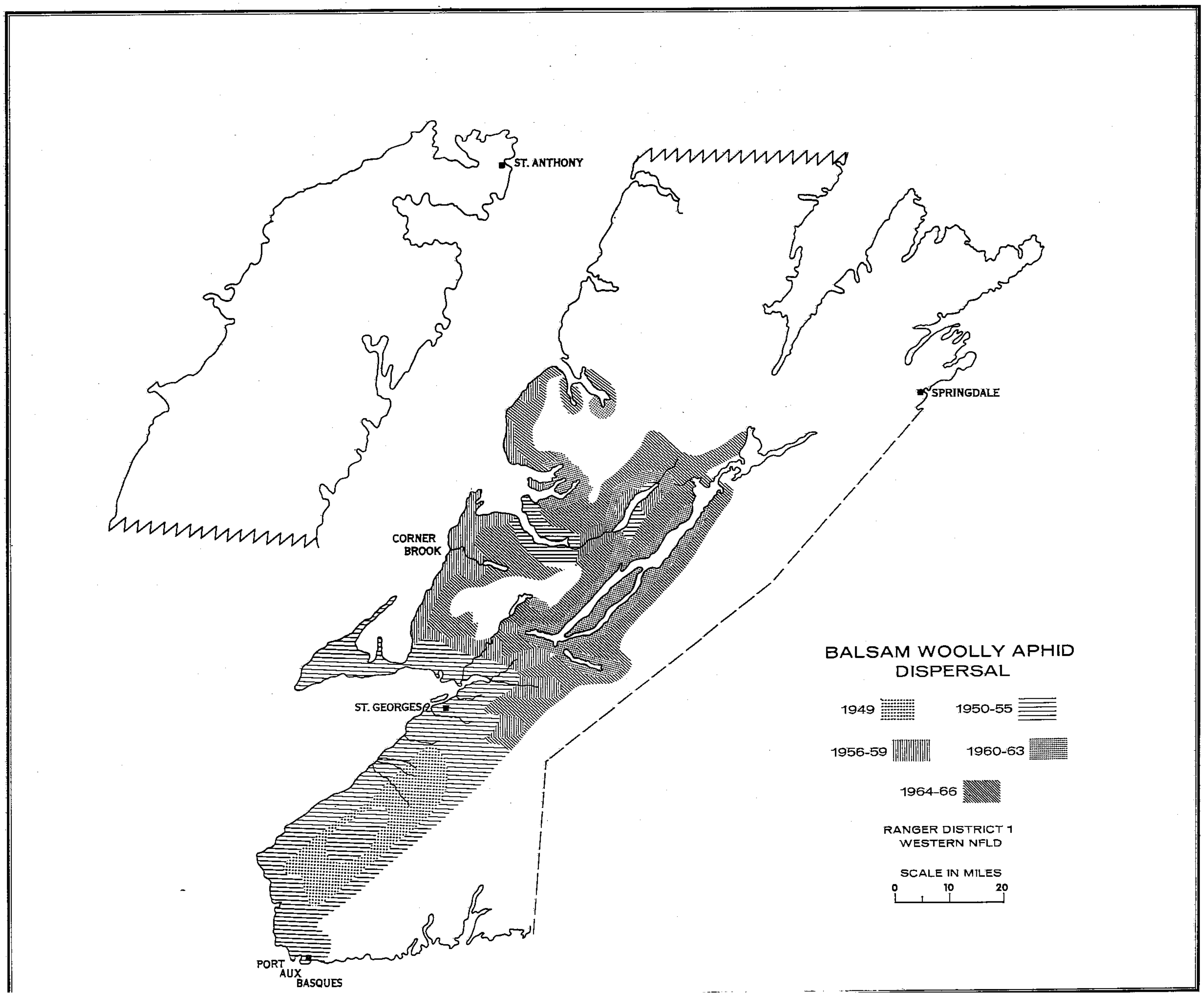
DISPERSAL PATTERN

The balsam woolly aphid has dispersed in an erratic pattern by a series of spot outbreaks that enlarged and coalesced to form irregular areas of infestation. The general direction of the infestation pattern has been from the southwest to the northeast throughout the Island. The continually expanding boundaries frequently enclosed extensive uninfested areas that were gradually invaded by the aphid. Information pertaining to the following description of dispersal pattern was obtained from unpublished Annual Ranger reports except where specific authority is indicated.

Western Newfoundland (Fig. 28)

When discovered in 1949 the aphid outbreak extended along the railway from Doyles to Robinsons with the most severe damage occurring in the Codroy Valley (Reeks et al., 1949).

Fig. 28. Dispersal pattern of balsam woolly aphid in western Newfoundland.


ST. ANTHONY
SPRINGDALE
CORNER
BROOK
ST. GEORGES
PORT
AUX
BASQUES
BALSAM WOOLLY APHID
DISPERSAL
1949
1950-55
1956-59
1960-63
1964-66
RANGER DISTRICT 1
WESTERN NFLD
SCALE IN MILES
0
10
20

By 1955, the infestation included the total coastal area from Port au Port Peninsula east to the western slope of the Long Range Mountains and south to Isle aux Morts. Smaller outbreaks were also found around the Humber Arm and along the shores of Deer Lake near South Brook and Nicholsville. No injury symptoms were observed in the intervening 600 square mile area between the northern boundary of the main outbreak and the smaller advance outbreaks in the north.

By 1959, the northern boundary of the main infestation, extending from Port au Port to the Long Range Mountains, expanded northeasterly about 8 miles, particularly up river valleys. The infestation also spread north along the coast to coalesce with the outbreak around the Humber Arm and up the Humber Valley to the Town of Deer Lake. Spot outbreaks were also reported at Middle Arm and North Arm and along the coast to Trout River.

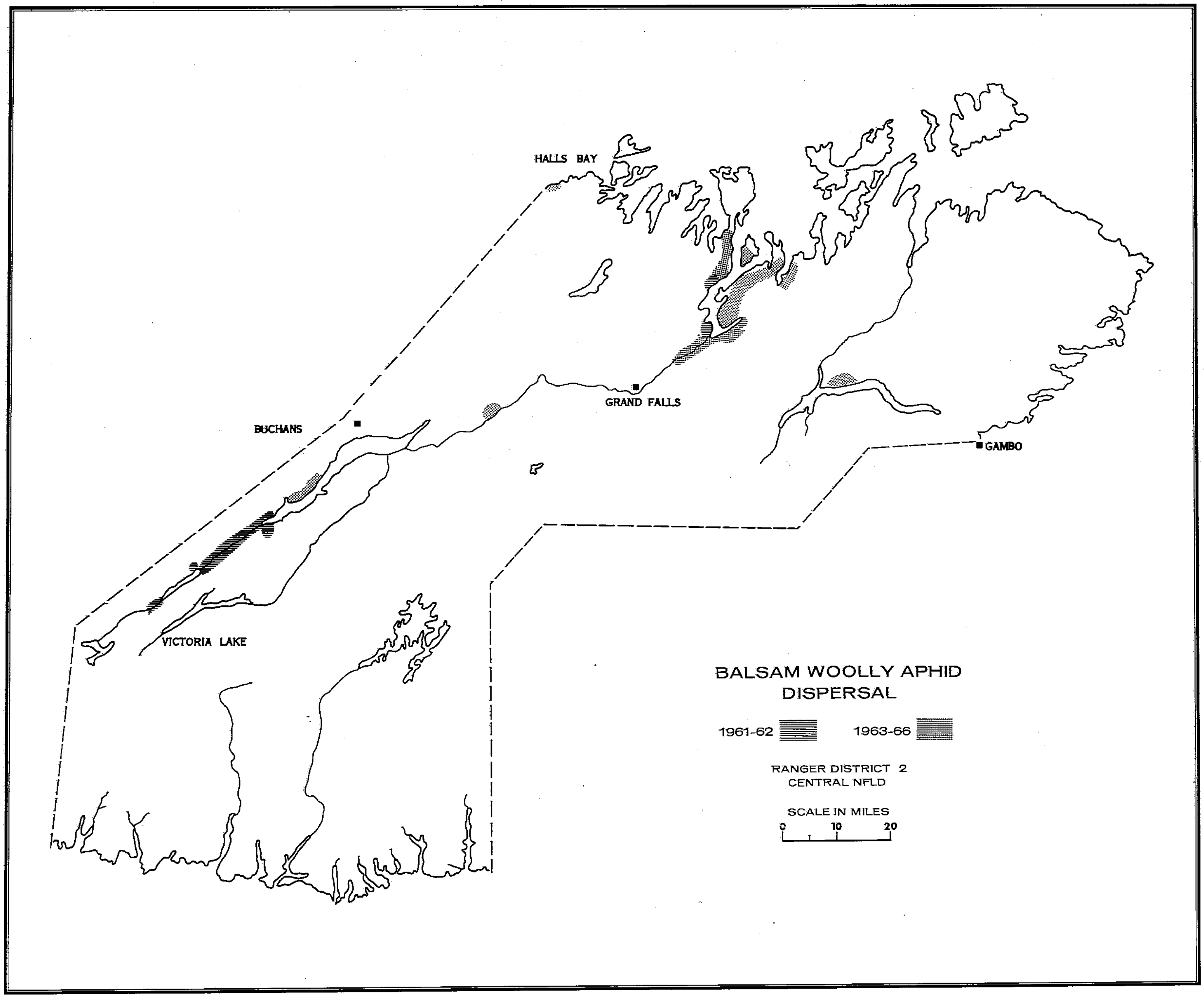
There was little change in the northern boundary of the main infestation by 1963 but the outbreaks around Deer Lake and Middle and North arms expanded. New outbreaks were found throughout the Little Grand Lake and Grand Lake watersheds, except for the area north of Hinds Brook on Grand Lake. There was also a new outbreak in the Bonne Bay area near Lomond but a large area between these boundaries remained uninfested.

By 1966, infestations had coalesced to cover an area of about 3,000 square miles, bounded on the east by the Long Range Mountains and extending north to Sandy Lake and Bonne Bay. A 300 square-mile forested area, south of Corner Brook, remained virtually uninfested.

Central Newfoundland (Fig. 29)

The first outbreak of the balsam woolly aphid in central Newfoundland was discovered at Norris Arm, Bay of Exploits, in 1961 and included about 300 acres. In 1962, a few scattered

Fig. 29. Dispersal pattern of balsam woolly aphid in central Newfoundland.


HALLS BAY
BUCHANS
GRAND FALLS
GAMBO
VICTORIA LAKE
BALSAM WOOLLY APHID
DISPERSAL
1961-62
1963-66
RANGER DISTRICT 2
CENTRAL NFLD
SCALE IN MILES
0
10
20

infested trees were discovered (throughout the Lloyds River watershed, extending from upper Lloyds Lake to the mouth of Shanadithit River on the northwest shore of Red Indian Lake and to Roebucks and Tulk's brooks on the south shore of the Lake.) There was little change in the boundaries of the infestation in central Newfoundland between 1962 and 1965. In 1965, new spot outbreaks were discovered along the north shore of Gander Lake and along the Badger-Buchans Road. The infestation at Exploits Bay had expanded to include about 100 square miles around the shoreline from Michael's Harbour to Point of Bay and a few infested trees were found on Thwart and Sivier Islands. Aphid conditions in central Newfoundland in 1966 were similar to 1965 except that a few infested trees were reported near Halls Bay on the boundary between the western and central districts.

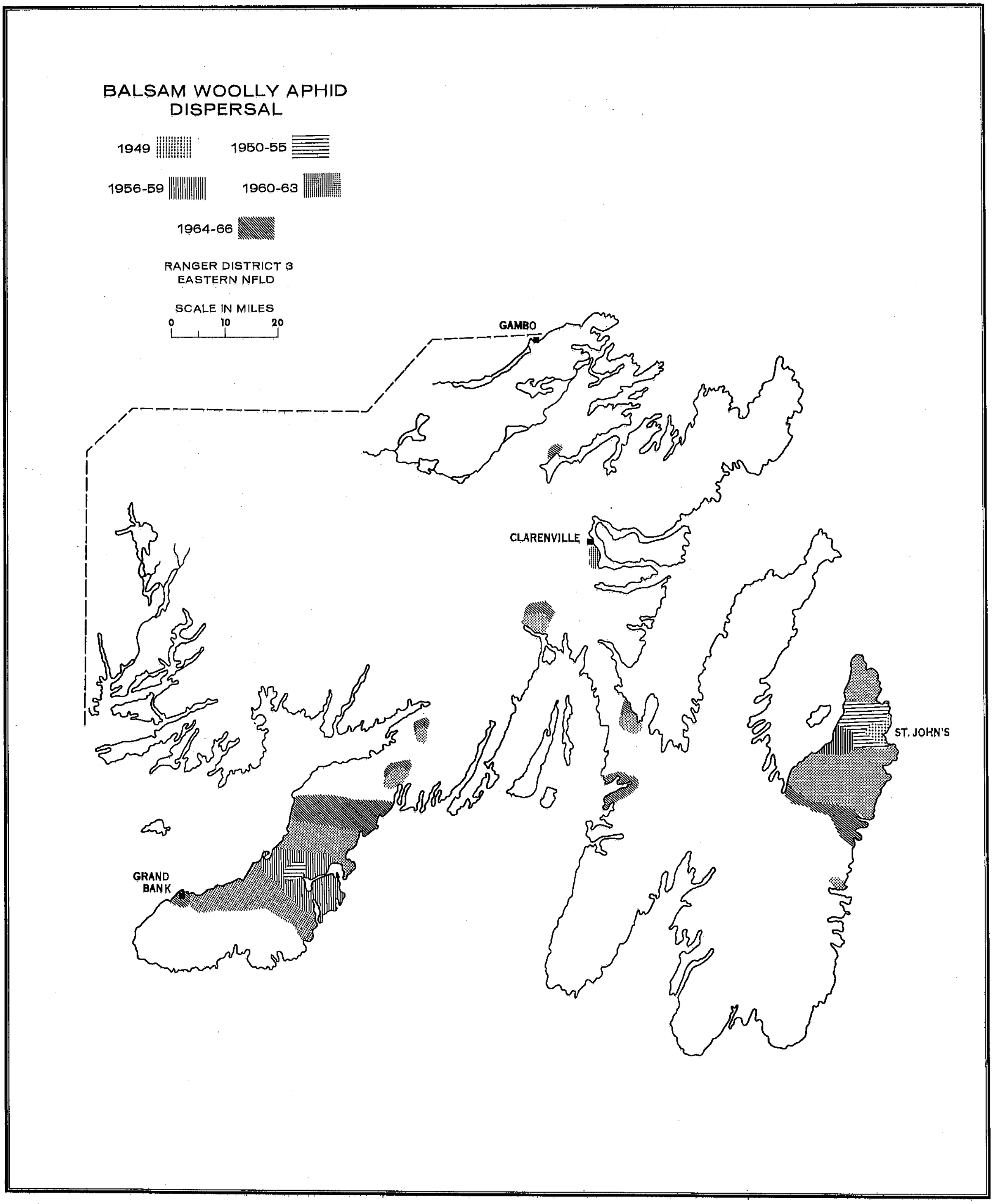
Eastern Newfoundland (Fig. 30)

There have been two main areas of infestations in eastern Newfoundland, one on the Avalon Peninsula and one on the Burin Peninsula. These are assumed to have been the source of the smaller spot infestations that now occur as far north as Terra Nova National Park.

The first outbreak was recorded at Bowring Park in St. John's in 1949. Infested trees were cut as they were discovered in the early years of the infestation and this treatment appears to have delayed the spread of the aphid as no siginificant advance was recorded until 1954 when scattered infested trees were found in several stands within a 15-mile radius of St. John's.

The first evidence of balsam woolly aphid on the Burin Peninsula was reported between Burin and Winterland in 1955. This infestation covered an area of about 50 square miles.

Fig. 30. Dispersal pattern of balsam woolly aphid in eastern Newfoundland.


BALSAM WOOLLY APHID
DISPERSAL
1949
1950-55
1956-59
1960-63
1964-66
RANGER DISTRICT 8
EASTERN NFLD
SCALE IN MILES
0 10 20
GAMBO
CLARENVILLE
ST. JOHN'S
GRAND BANK

There was a gradual extension of the boundaries of the infestations on both peninsulas from 1956 to 1963 but the increase was confined primarily to an enlargement of the original outbreaks. In 1963, spot outbreaks occurred at widely separated locations and for the first time north of the peninsulas near Swift Current and Deep Bight.

The only significant change in 1964 was the discovery of approximately 100 infested trees scattered throughout a 600-acre area in the Terra Nova National Park.

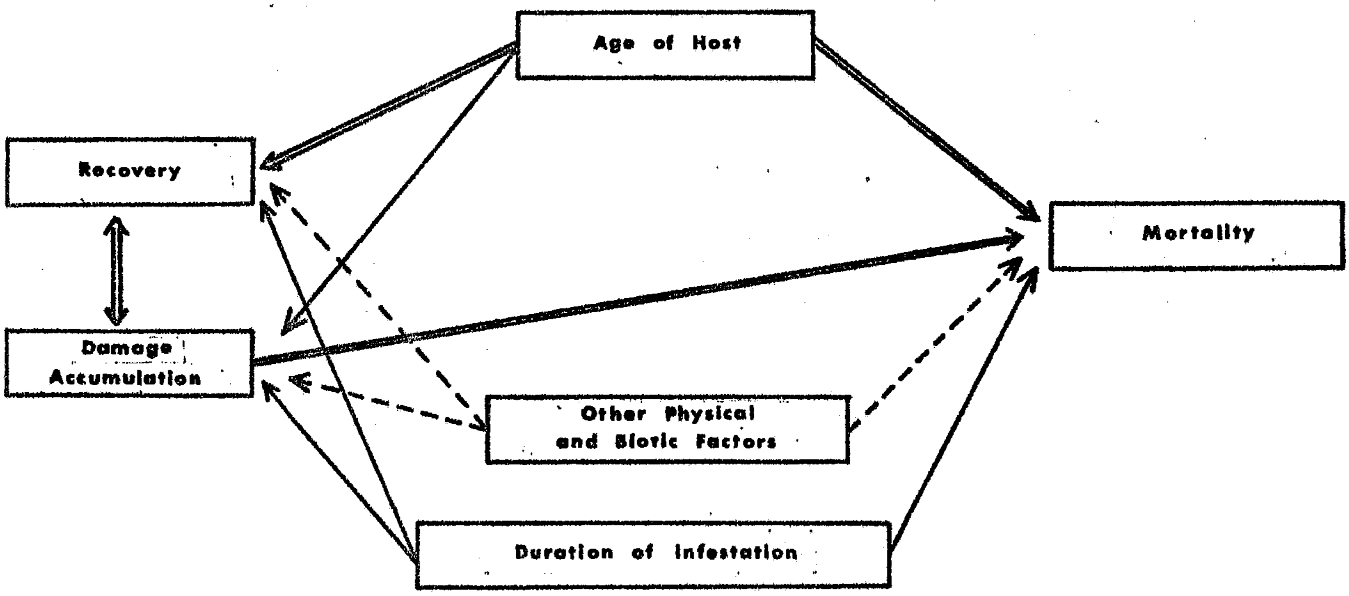
In 1965, a spot outbreak was found at Placentia on the Avalon Peninsula and minor extensions were recorded in the infestation boundaries on the Burin Peninsula, near Swift Current, Bellevue Beach and in the Terra Nova National Park. The total infested area in eastern Newfoundland was estimated at nearly 1,000 square miles. The status of the aphid remained unchanged in 1966.

DAMAGE PATTERN

Stem attack has caused significant damage only in small, scattered areas in Newfoundland, the most serious of which occurred near Robinsons, Stephenville Crossing, throughout the Lower Humber Valley, along the northeast shore of Deer Lake, and along the southeast shore of Grand Lake. Stem attack also occurs sporadically in trace amounts in many outbreaks and may contribute to more rapid tree mortality than would normally be associated with twig attack. However, twig attack is the prevalent form of attack in Newfoundland and Survey damage assessment data has been compiled primarily on gout symptoms.

Factors Affecting Damage Patterns

Damage pattern, as used in this study, is defined as the sequence of events related to aphid attack and subsequent damage influenced by physical and biotic factors that occur both spatially and temporally. The factors, site type and quality, tree height, stand type, density and composition, were examined by Balch (1952) but the evidence does not show their significance in relation to damage. The data collected in Newfoundland provides information on tree age and estimated age of infestation in merchantable stands. The following diagram presents the relationship of these factors in the damage pattern that leads to recovery or eventual mortality:



Effect of Duration of Infestation

Data was collected from various types of plots to study the effect of the duration of aphid attack on balsam fir stands in Newfoundland. Results show that aphid damage and associated tree mortality increase with the duration of infestations. Attacks less than 13 years old show a high proportion of undamaged or lightly damaged trees and limited mortality except where stem attack or stand disturbance occurred (Table I). Attacks older than 13 years show increasing amounts of damage and tree mortality except where recovery occurs. Therefore, it may be concluded that damage and tree mortality will increase with the duration of attack.

Effect of Host Age

The damage pattern in merchantable stands shows that the rate of damage accumulation and mortality increases with an increase in stand age (Fig. 31). This pattern progressed erratically and the rate of mortality was relatively low in the three plots in the 55 and 75 year age classes but in stands 90 years and older the damage class increased steadily and mortality rose sharply. The 100-year-old stand at Trout Brook, although recently infested, showed the same progression of damage and mortality exhibited by the other two older stands that had been attacked for a longer period. It appears certain that high mortality and rapid stand deterioration may be anticipated in stands approaching the 90-year age class.

Effect of Recovery

Recovery has been observed in aphid infested stands in Newfoundland for approximately 10 years. Various degrees may be recognized by host growth characteristics. These range from a virtually stagnated condition, as indicated by a flat top (Fig. 9), to effective recovery as expressed by an increase in vertical and lateral growth (Fig. 12) and distinctive refoliation (Fig. 11).

Survey records from 100-tree plots at South Brook and Crabbs River show the pattern of recovery exhibited by some stands on the west coast. Damage was classified as light to moderate in both plots in 1955, the year of plot establishment,

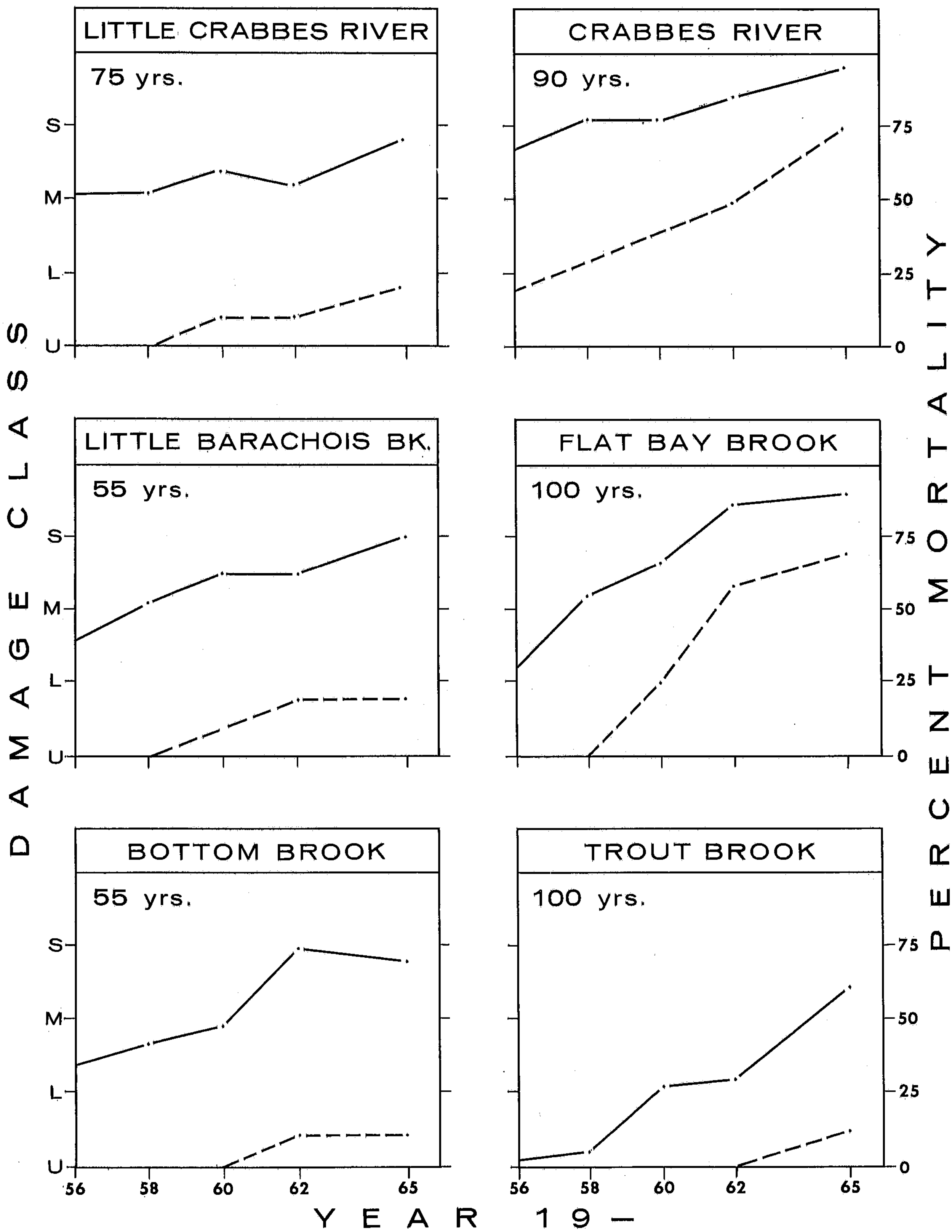
Table I. Current aphid conditions in merchantable balsam fir stands in western Newfoundland

Location	Type of survey	No. trees examined	Stand age	% Trees by damage class U	L	M	S	D	Estimated duration of outbreak in years	Remarks
Lomond	100-tree plot	100	50	30	70	0	0	0	5	
Black Duck	100-tree plot	100	65	11	83	6	0	0	6	
North Branch	100-tree plot	100	45	8	63	16	12	0	10	
Steady Brook	100-tree plot	100	45	0	2	9	82	7	12	Stem attack
Pasadena	22.3 chains	62	Uneven	89	11	0	0	0	12	
Codroy Pond	22.3 chains	200	Uneven	39	54	3	3	1	12	
Flat Bay	144.0 chains	987	Uneven	47	28	10	12	3	12	
Bottom Brook	44.6 chains	403	Uneven	41	35	7	14	3	12	
Trout Brook	roadside cruise	10	100+	0	20	20	50	10	12	Disturbed
Bottom Brook	roadside cruise	10	55	0	10	10	70	10	12	Disturbed
Southwest R.	roadside cruise	10	55	0	0	0	80	20	12	Disturbed
Little Barachois Brook	44.6 chains	519	Uneven	13	50	3	23	11	15	
Wild Cove	100-tree plot	100	40	0	6	20	54	20	15	Stem attack and recovery
Little Barachois Brook	roadside cruise	10	55	0	10	20	50	20	15	Disturbed
South Branch	100-tree plot	100	40	0	55	26	15	4	18	Recovery
Crabbs River	44.6 chains	232	Uneven	2	38	21	27	12	18	

Table I (Concluded)

Location	Type of survey	No. trees examined	Stand age	% Trees by damage class U	L	M	S	D	Estimated duration of outbreak in years	Remarks
Flat Bay Brook	22.3 chains	160	Uneven	1	27	21	36	15	18	
Little Crabbs R.	roadside cruise	10	75	0	10	20	50	20	18	Disturbed
Flat Bay Brook	roadside cruise	10	100+	0	0	10	20	70	18	Disturbed
Crabbs River	100-tree plot	100	40	0	37	23	38	2	20	Recovery
Highlands	100-tree plot	100	60	0	23	25	42	7	20	Recovery
Robinsons	roadside cruise	10	80	0	0	0	30	70	20	Disturbed
Crabbs River	roadside cruise	30	90	0	0	0	27	73	20	Disturbed

Fig. 31. Mean aphid damage class and percentage mortality in various age groups (roadside cruises).


LITTLE CRABBES RIVER
75 yrs.
CRABBES RIVER
90 yrs.
LITTLE BARACHOIS BK.
55 yrs.
FLAT BAY BROOK
100 yrs.
BOTTOM BROOK
55 yrs.
TROUT BROOK
100 yrs.
S
M
L
U
0
25
50
75
56
58
60
62
65
DAMAGE CLASS
PERCENT MORTALITY
YEAR 19—

and increased for the following six years as indicated in Fig. 32. At that time mortality had only reached 1% at Crabbs River and 2% at South Branch plots. However, many trees showed large areas of dead branches in the upper crown but since then have produced increasing amounts of new growth until the dead portions of the crowns have virtually disappeared except for residual dead tops which have been replaced by new leaders. There has not been any increase in tree mortality due to aphid damage since 1961.

The extent of recovery in infested stands is unknown as is the period that it remains an important factor in maintaining growth or reducing the rate of stand deterioration.

Damage Pattern in Recovery Trees

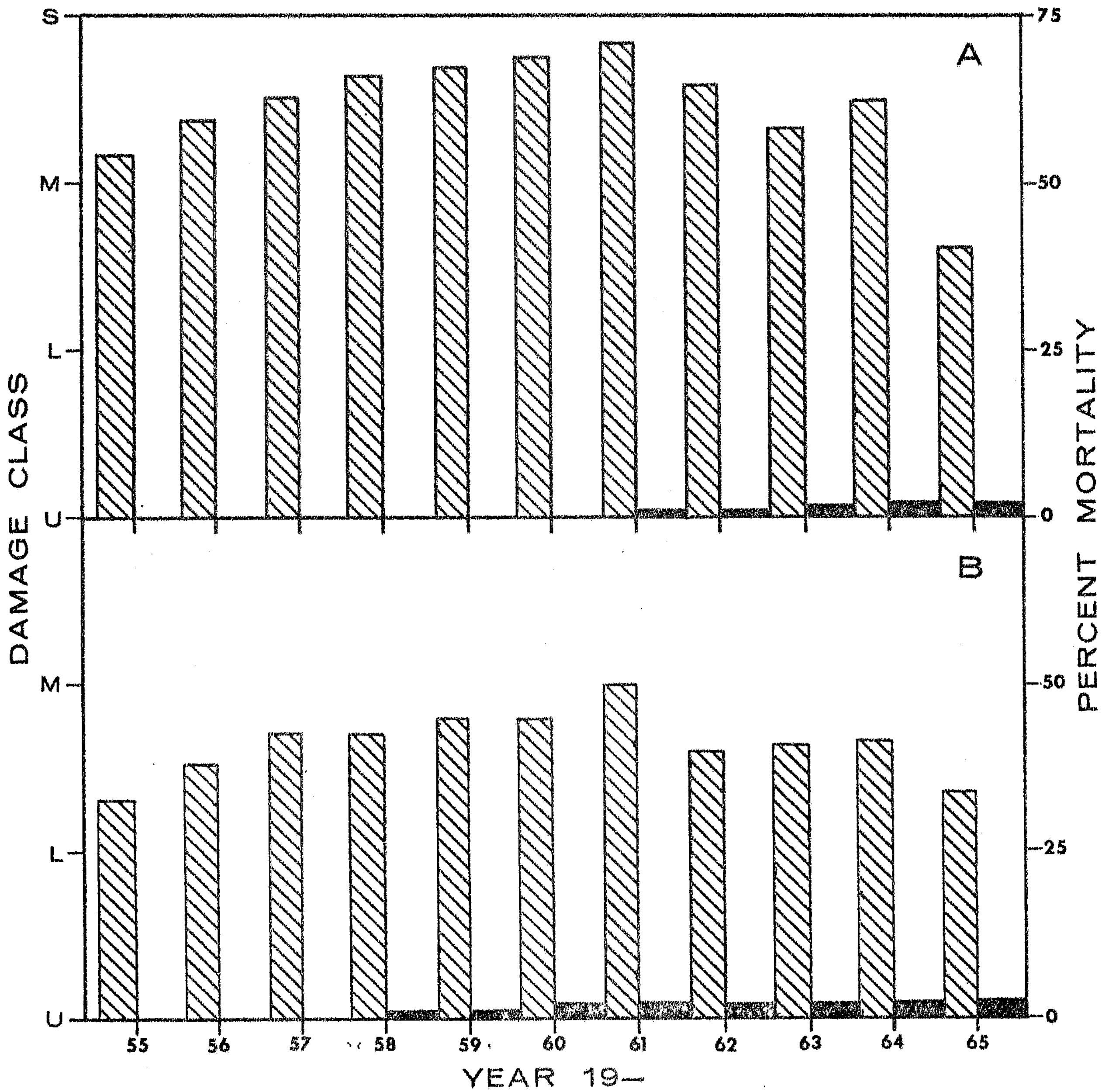
Damage pattern in recovery trees is caused by fluctuations in the rate of accumulation of damage inflicted by stem attack and twig attack. Four trees from the South Branch plot and two from the Crabbs River plot were cut at 4-foot intervals to study the effect of aphid attack on radial increment.

The pattern of redwood (Figs. 33, 34) indicates that stem attack occurred in both plots by 1943. All trees (Figs. 33 to 38) had been attacked by 1951 but only two trees (Figs. 34, 36) showed any appreciable amount of redwood.

Analysis of tree sections does not indicate the exact role of stem attack but Figs. 33 to 38 show that radial increment increases in proportion to the amount of redwood in the year of occurrence. However, growth is suppressed for varying periods following the more severe stem attack. Radial increment again increases following a period of suppression but not to equal the increment attained prior to appreciable redwood.

It is impossible to date twig attack by stem analysis or the distribution of gout throughout the crown but the former

Fig. 32. Mean aphid damage condition and percentage mortality in 100-tree plots at (A) Crabbs River and (B) South Branch for the period 1955-1965.



A
B
S
M
L
U
75
50
25
0
DAMAGE CLASS
PERCENT MORTALITY
55
56
57
58
59
60
61
62
63
64
65
YEAR 19—

symptom may be used to date bud, leader or branch mortality as indicated in Table II.

Table II. Bud and leader mortality of six trees selected from the two 100-tree aphid damage plots

Fig. No.	Tree No.	Location	Remarks
33	37	South Branch	1962 - top 2.5 ft. died
34	75	Crabbs River	1959 - top 3 ft. died
35	46	South Branch	1957 - top 3.5 ft. died
36	20	" "	1953 - Leader bud killed
37	44	" "	1953 - leader bud killed
38	57	Crabbs River	1951 - leader bud killed

The above data shows that twig attack was severe enough to cause leader-bud mortality in both plots by 1953 and top-killing at a later date, but it is probable that the initial twig attack was coincident with the stem attack in the 'nineteen-forties'. The most obvious effect of twig attack is the reduction in vertical growth caused by bud inhibition, leader or top-killing (Figs. 33 to 38) but pronounced vertical growth reduction began in all sample trees years before leaders or tops were killed (Table III). Vertical growth reduction began during 1946-50 for trees 37, 75 and 46 (Figs. 33, 34, 35) and during 1951-55 for trees 20, 44 and 57 (Figs. 36, 37, 38). The vertical growth reduction occurring prior to leader or top-killing may have been caused by loss of foliage and distortion, conditions that occur following moderate to severe twig attack.

Twig attack also causes a reduction in radial increment as illustrated in trees 44, 46 and 57, three trees that had insignificant amounts of redwood but exhibited obvious radial

Table III. The ratios, from six aphid attacked sample trees, of yearly radial, vertical and average growth in 5-year periods to the yearly growth during the 1936-1940 period ranked in order of the least average ratio during the last 15 years.

Tree	Stump age	Type of growth / Year 19--	36-40	41-45	46-50	51-55	56-60	61-65	Average 1951-65
37	50	Radial	1.000	0.890	0.710	0.510	0.180	0.280*	0.326
		Vertical	1.000	0.850	0.310	0.140	0.140	0.004*	0.095
		Average	1.000	0.870	0.510	0.325	0.160	0.142	0.209
75	52	Radial	1.000	0.980	0.990	0.610	0.290*	0.410	0.436
		Vertical	1.000	1.400	0.720	0.290	-0.220*	0.380	0.150
		Average	1.000	1.190	0.855	0.450	0.025	0.395	0.290
46	47	Radial	1.000	1.000	0.830	0.880	0.290*	0.470	0.546
		Vertical	1.000	1.260	0.730	0.350	0.140*	0.190	0.226
		Average	1.000	1.130	0.780	0.615	0.215	0.330	0.420
20	43	Radial	1.000	1.060	0.890	0.900*	0.430	0.640	0.656
		Vertical	1.000	1.010	0.900	0.460*	0.240	0.250	0.316
		Average	1.000	1.035	0.895	0.680	0.335	0.445	0.486
44	48	Radial	1.000	1.090	0.740	0.690*	0.330	0.350	0.456
		Vertical	1.000	0.800	0.800	0.570*	0.410	0.420	0.366
		Average	1.000	0.945	0.770	0.630	0.370	0.485	0.695
57	49	Radial	1.000	1.210	1.350	1.280*	0.740	1.040	1.020
		Vertical	1.000	1.570	1.660	0.840*	0.450	0.430	0.573
		Average	1.000	1.390	1.505	1.060	0.595	0.735	0.796

*Leader bud or top-killed

Fig. 33. Radial increment at 4-foot intervals, vertical growth in 5-year intervals and redwood pattern from tree #37 at South Branch.

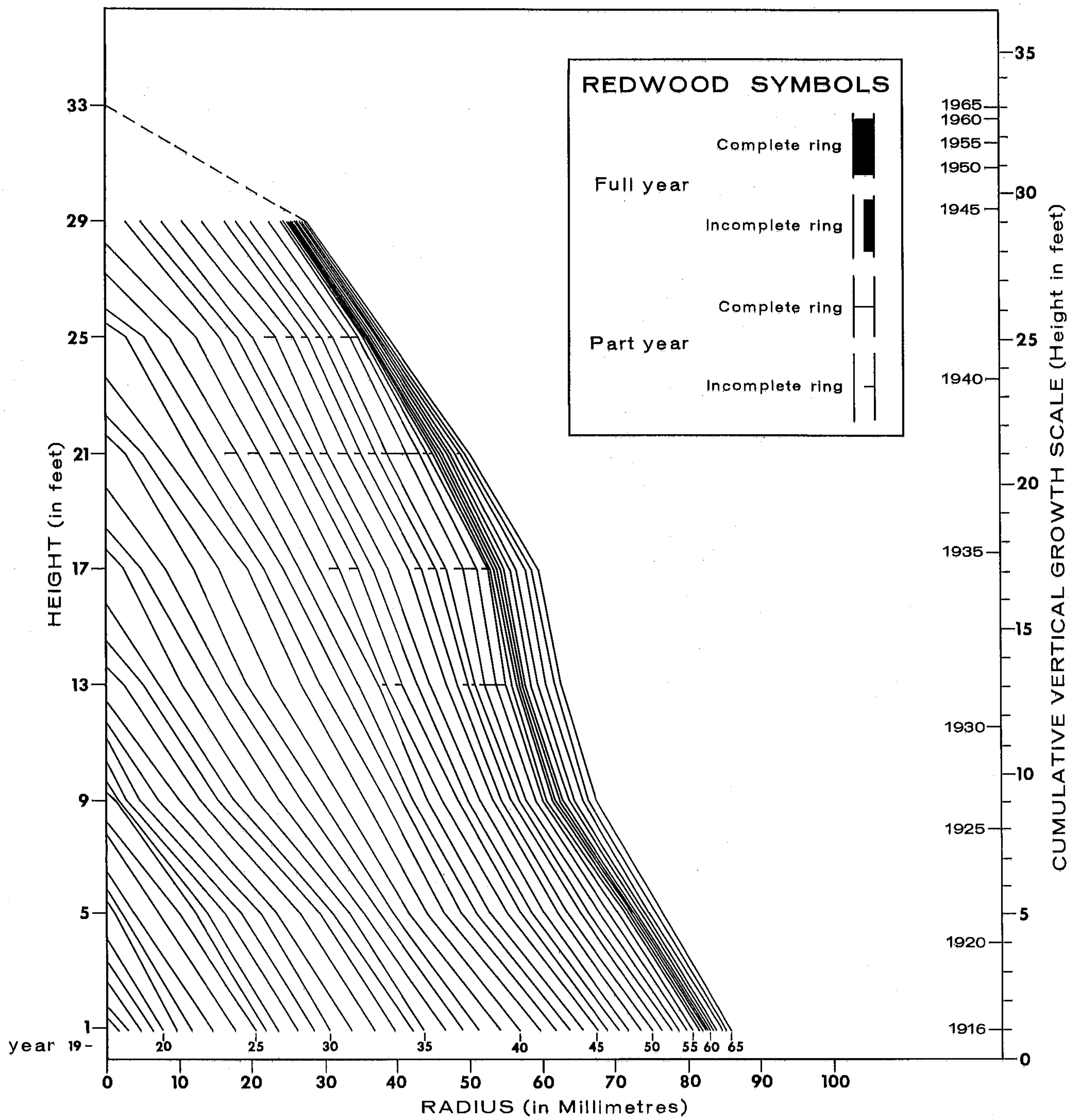
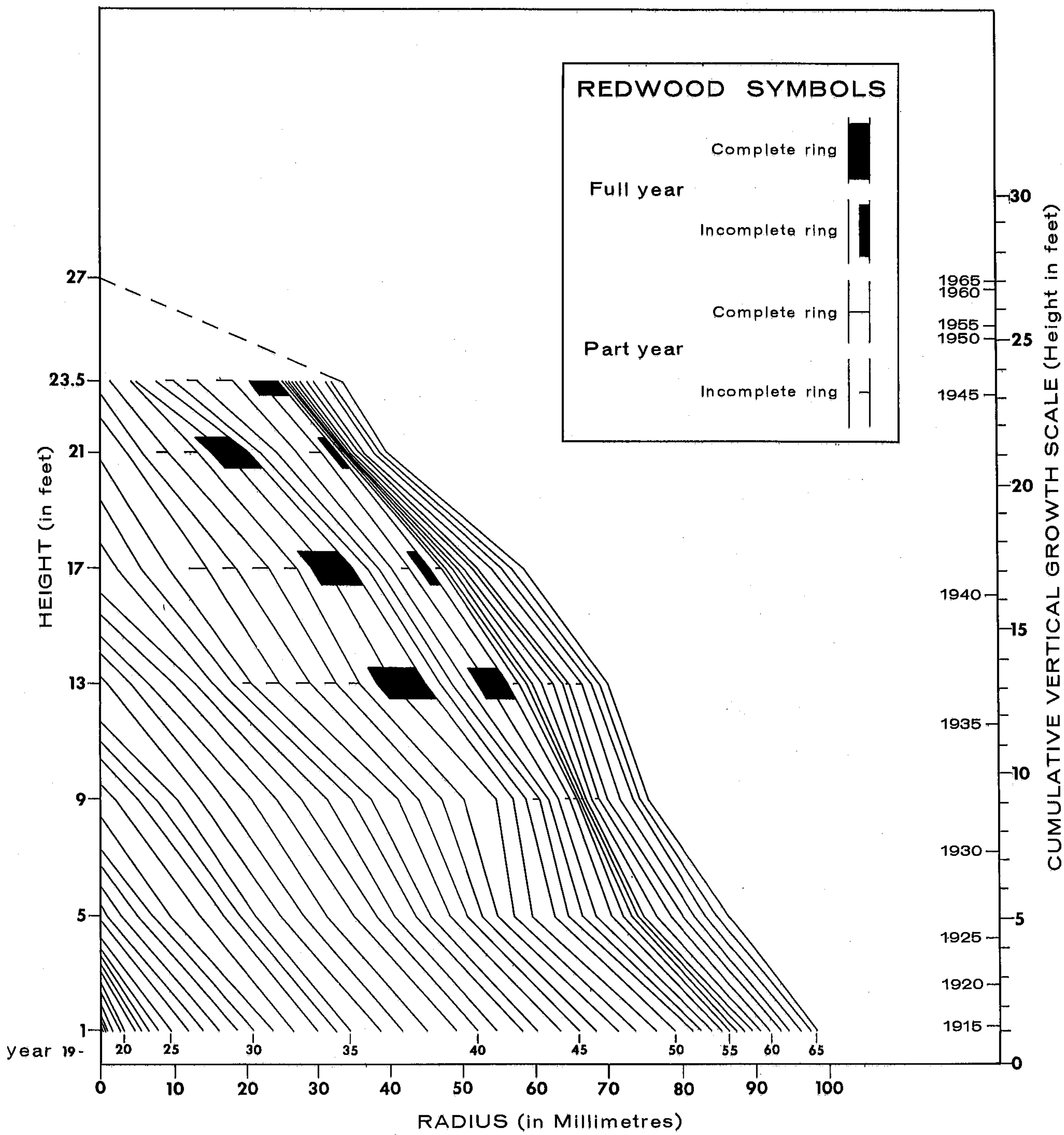

REDWOOD SYMBOLS
Full year
Complete ring
Incomplete ring
Part year
Complete ring
Incomplete ring
HEIGHT (in feet)
33
29
25
21
17
13
9
5
1
year 19-
20
25
30
35
40
45
50
55 60 65
0 10 20 30 40 50 60 70 80 90 100
RADIUS (in Millimetres)
CUMULATIVE VERTICAL GROWTH SCALE (Height in feet)
35
30
25
20
15
10
5
0
1965
1960
1955
1950
1945
1940
1935
1930
1925
1920
1916

Fig. 34. Radial increment at 4-foot intervals, vertical growth in 5-year intervals and redwood pattern from tree #75 at Crabbs River. (Reversed position of years 1960 and 1955 on vertical growth scale was caused by top-killing from twig attack.)



REDWOOD SYMBOLS
Full year
Complete ring
Incomplete ring
Part year
Complete ring
Incomplete ring
HEIGHT (in feet)
27
23.5
21
17
13
9
5
1
year 19-
20
25
30
35
40
45
50
55
60
65
0
10
20
30
40
50
60
70
80
90
100
RADIUS (in Millimetres)
CUMULATIVE VERTICAL GROWTH SCALE (Height in feet)
1965
1960
1955
1950
1945
1940
1935
1930
1925
1920
1915
30
25
20
15
10
5
0

Fig. 35. Radial increment at 4-foot intervals, vertical growth in 5-year intervals and redwood pattern from tree #46 at South Branch.

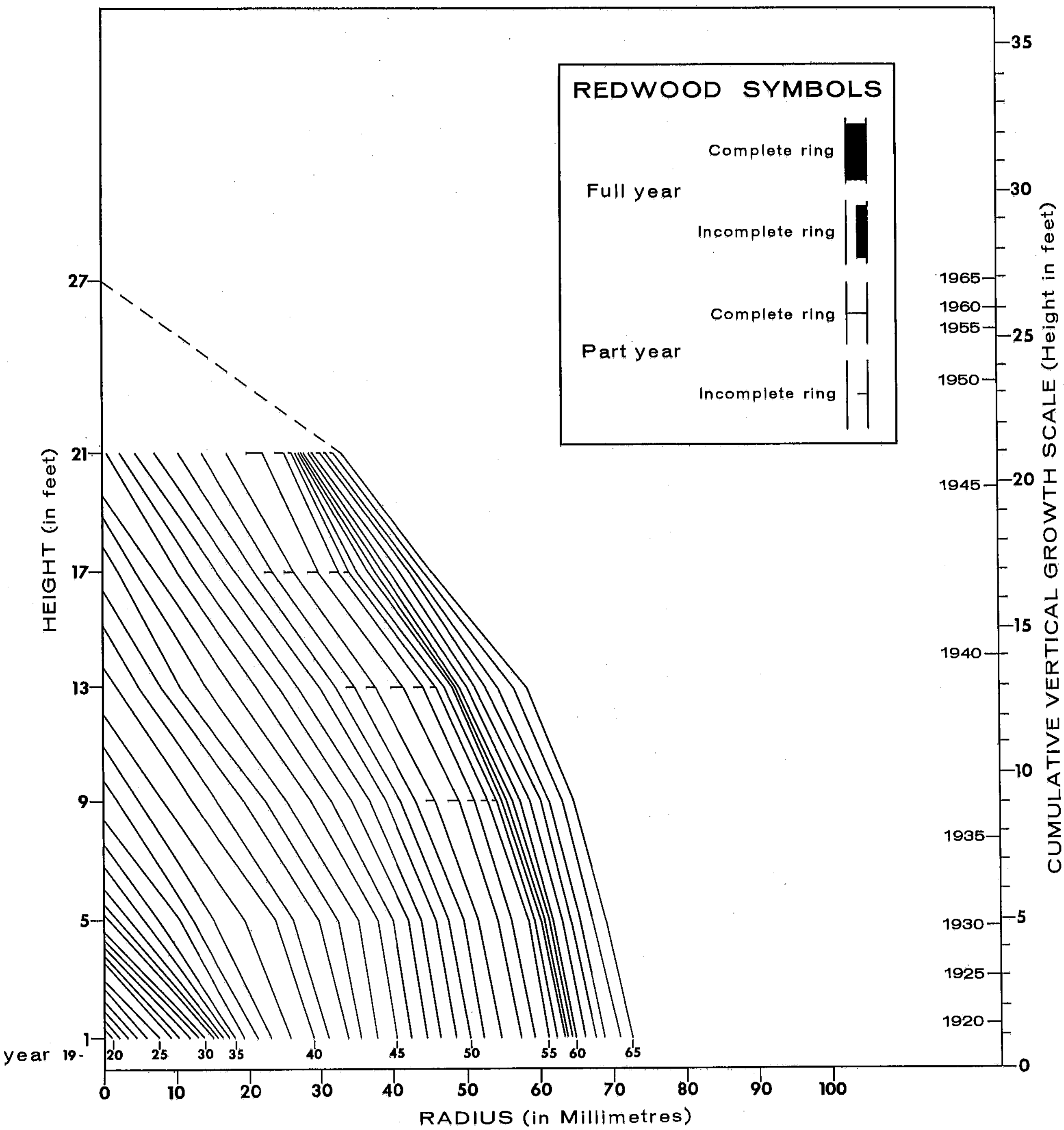
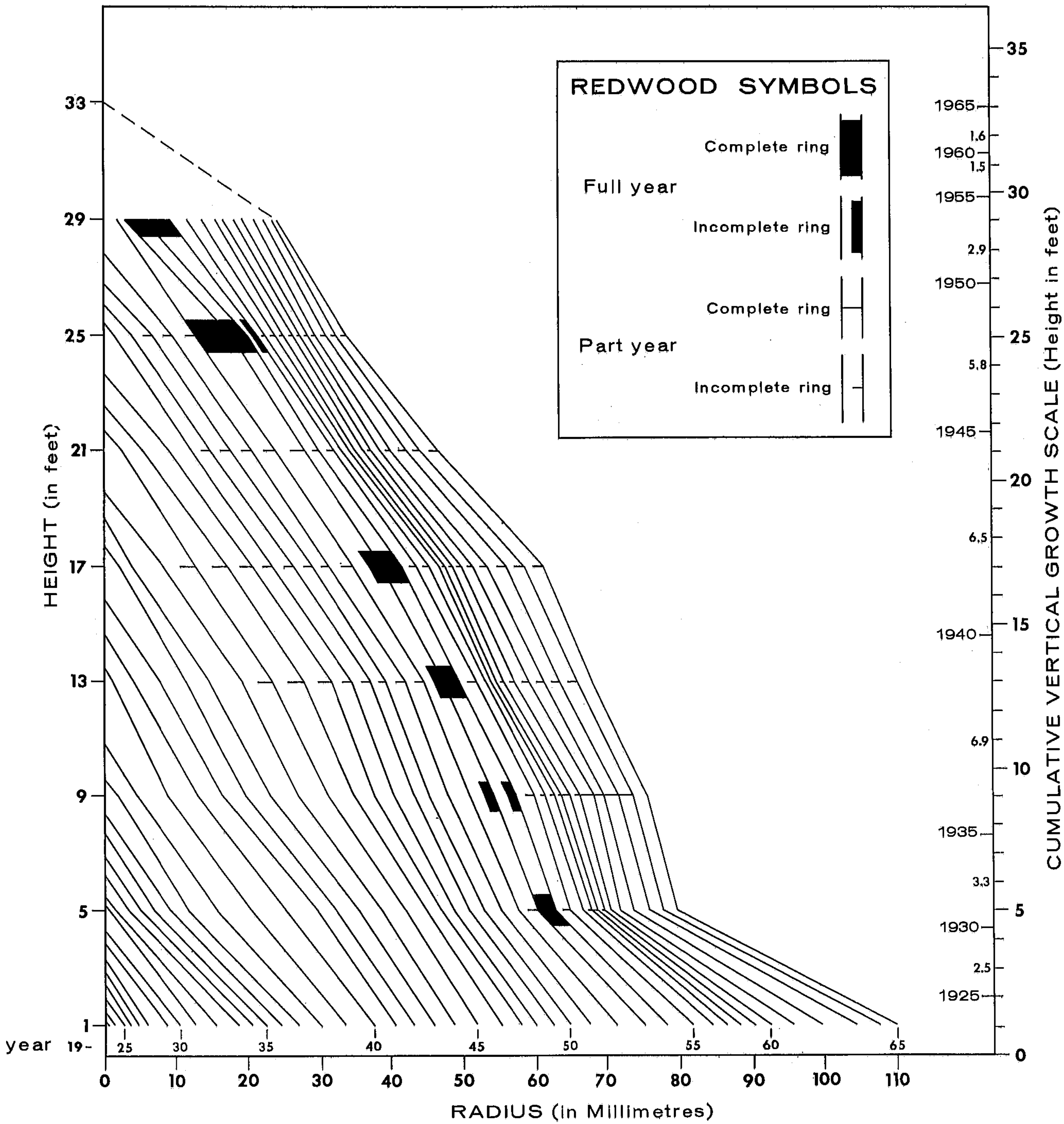
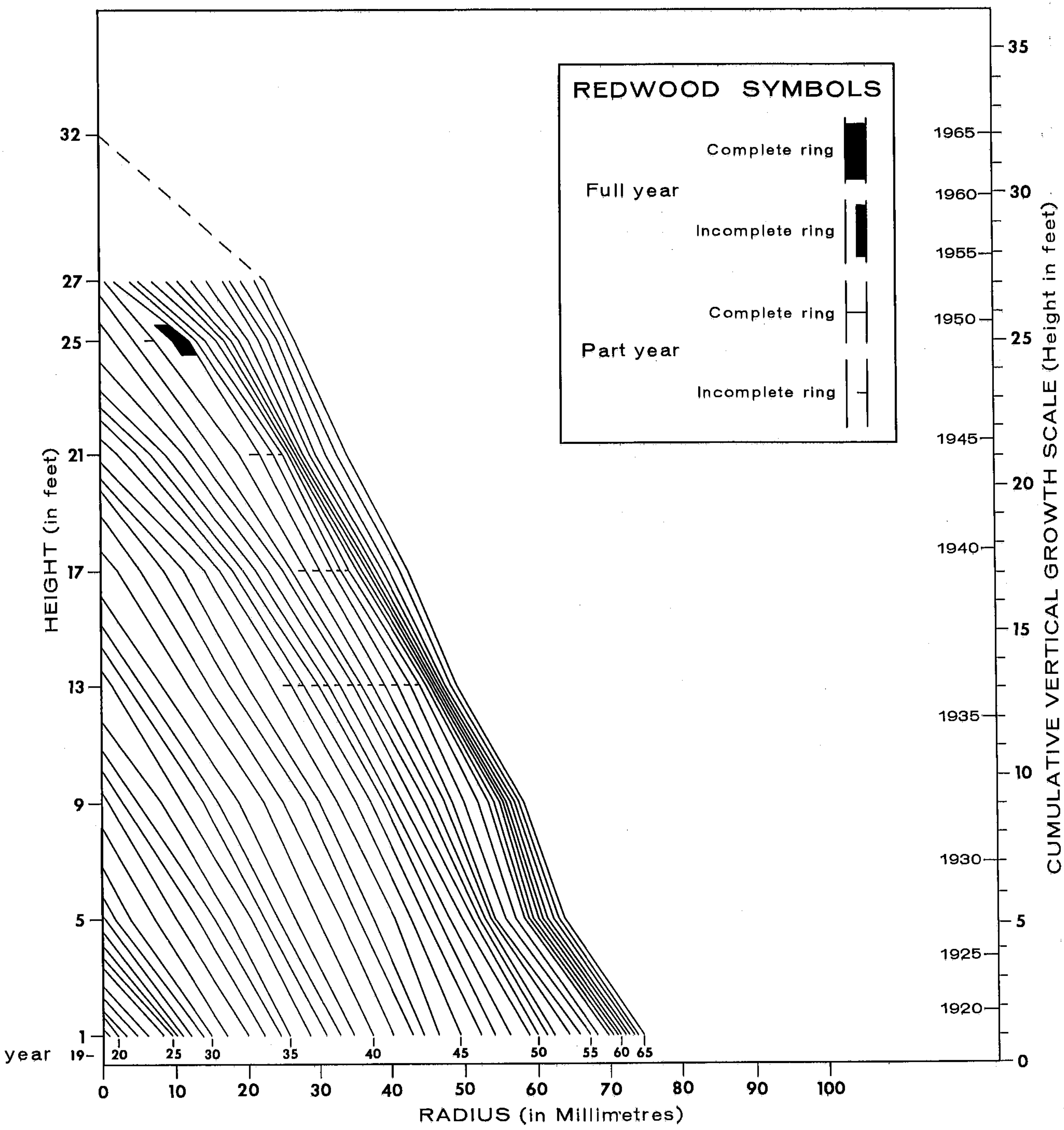

REDWOOD SYMBOLS
Full year
Complete ring
Incomplete ring
Part year
Complete ring
Incomplete ring
HEIGHT (in feet)
RADIUS (in Millimetres)
CUMULATIVE VERTICAL GROWTH SCALE (Height in feet)
year 19-
1965
1960
1955
1950
1945
1940
1935
1930
1925
1920

Fig. 36. Radial increment at 4-foot intervals, vertical growth in 5-year intervals and redwood pattern from tree #20 at South Branch.



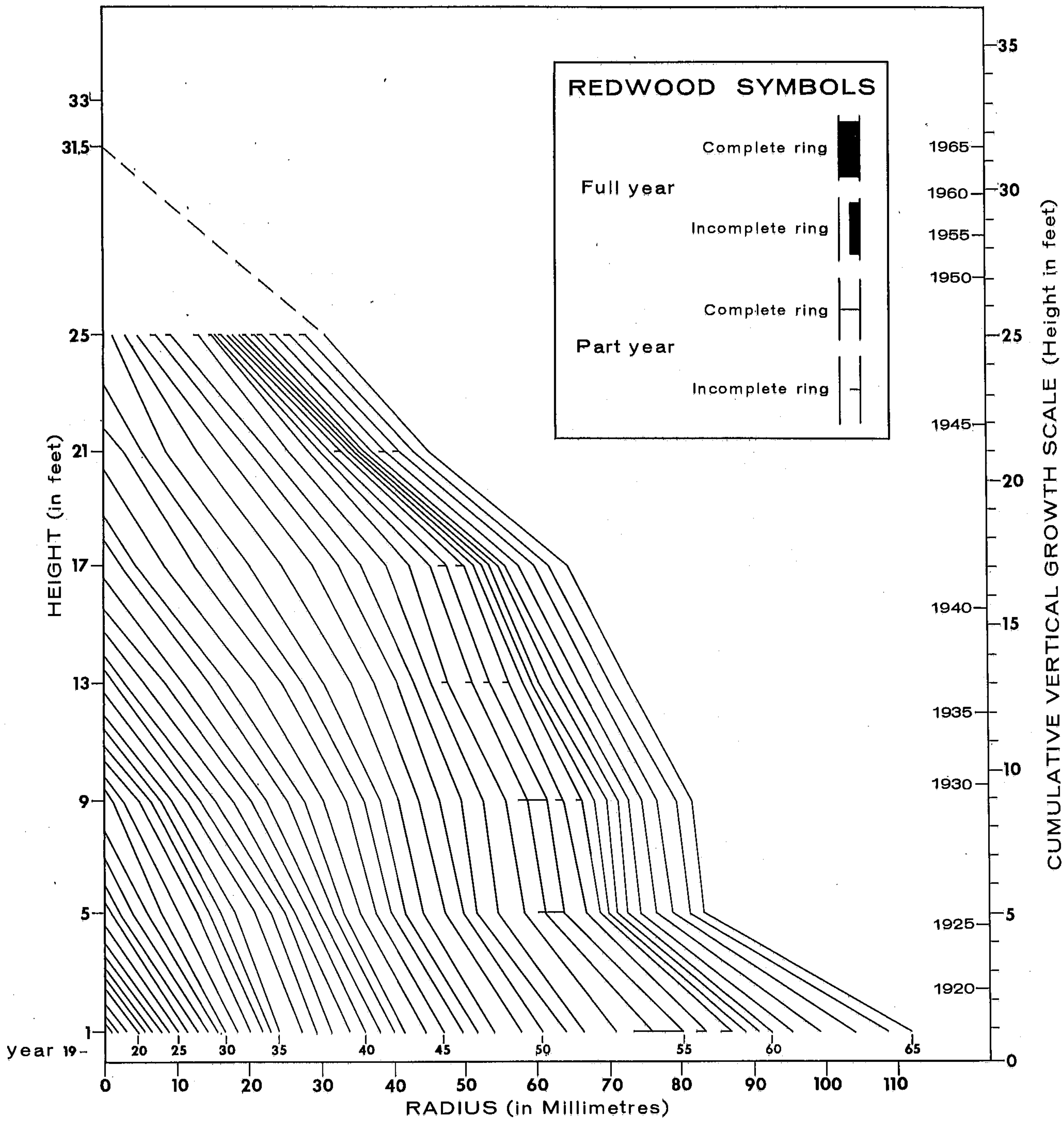
REDWOOD SYMBOLS
Full year
Complete ring
Incomplete ring
Part year
Complete ring
Incomplete ring
HEIGHT (in feet)
33
29
25
21
17
13
9
5
1
year 19-
25
30
35
40
45
50
55
60
65
0
10
20
30
40
50
60
70
80
90
100
110
RADIUS (in Millimetres)
CUMULATIVE VERTICAL GROWTH SCALE (Height in feet)
35
30
25
20
15
10
5
0
1965
1.6
1960
1.5
1955
2.9
1950
5.8
1945
6.5
1940
6.9
1935
3.3
1930
2.5
1925

Fig. 37. Radial increment at 4-foot intervals, vertical growth in 5-year intervals and redwood pattern from tree #44 at South Branch.



REDWOOD SYMBOLS
Full year
Complete ring
Incomplete ring
Part year
Complete ring
Incomplete ring
HEIGHT (in feet)
32
27
25
21
17
13
9
5
1
year 19–
20 25 30 35 40 45 50 55 60 65
0 10 20 30 40 50 60 70 80 90 100
RADIUS (in Millimetres)
CUMULATIVE VERTICAL GROWTH SCALE (Height in feet)
35 30 25 20 15 10 5 0
1965 1960 1955 1950 1945 1940 1935 1930 1925 1920

Fig. 38. Radial increment at 4-foot intervals, vertical growth in 5-year intervals and redwood pattern from tree #57 at Crabbs River.



REDWOOD SYMBOLS
Full year
Complete ring
Incomplete ring
Part year
Complete ring
Incomplete ring
HEIGHT (in feet)
33
31.5
25
21
17
13
9
5
1
year 19-
20
25
30
35
40
45
50
55
60
65
0
10
20
30
40
50
60
70
80
90
100
110
RADIUS (in Millimetres)
CUMULATIVE VERTICAL GROWTH SCALE (Height in feet)
35
30
25
20
15
10
5
0
1965
1960
1955
1950
1945
1940
1935
1930
1925
1920

suppression following aphid attack. The major factor contributing to reduction in radial increment by twig attack is probably due to the interference with transport by the production of redwood at the nodes. This results in a reduction in foliage leading to a loss in vigor. This is the same reaction as caused by stem attack (Balch, 1952) but the latter occurs primarily on the main stem rather than being concentrated at the branch nodes.

It is virtually impossible to assess the individual effects of stem attack and twig attack when they occur together other than the reduction in vertical growth from bud inhibition and leader or top-killing caused by twig attack.

SIGNIFICANCE OF THE APHID TO BALSAM FIR

Aerial and ground surveys have shown that the aphid was probably introduced in at least three different points on the Island: in the lower Codroy Valley on the west coast; near Marystown on the Burin Peninsula; and in Bowring Park on the Avalon Peninsula. They have also shown that the major progression of these infestations has been from south to north in series of spot outbreaks that have coalesced to cover large areas presently totalling about 4,000 square miles. It appears evident from the pattern of dispersal and the location of existing outbreaks that the aphid will eventually invade all balsam fir stands on the Island.

Surveys have not provided a realistic assessment of the magnitude of aphid damage but Table I presents a sample of present conditions throughout the infested mature stands of the west coast. Unfortunately, stands listed have been disturbed to varying degrees but the data shows that the severity of damage increases with the age of hosts and the duration of outbreaks. Data in Table I also shows that mortality has exceeded

70% in some overmature samples. There is no information on the extent of mortality but an increase can be anticipated in all infested mature and overmature stands.

Cull is another consideration in aphid infested stands. No records are available to determine the extent or to evaluate the association of this factor with aphid damage but results of preliminary investigations show that decayed volume in three aphid infested stands in western Newfoundland reached 45, 50 and 60% of the merchantable volume (Hudak, 1966). Observations indicate that cull is highest in severely infested mature and overmature stands. No cull was observed in the recovery stands investigated.

Data available on the extent of mortality and incidence of cull has been recorded only from west coast infestations but it is assumed that results would be equivalent where conditions are similar in the Central and Eastern districts.

Losses from mortality and cull are obviously serious. However, these losses can be minimized by timely salvage operations as demonstrated by the recent cutting program introduced by industry and the Provincial Government:

District	Agency	Locality	Salvage in cords	Period
	Bowater's	St.George's & west	400,000	1956-66
	Bowater's	Bottom Brook	33,000	1963-66
Western	Bowater's	Grand Lake	4,000	1965-66
	Bowater's	Deer Lake	15,000	1964-66
	Bowater's	Humber Valley	15,000	1960-66
	Dept. Mines Agr. & Res.	Bay of Exploits	600	1965-66
Central	Price (Nfld.)	Shanadithit River to Quakers Hat	15,000	Proposed 1967
	Bowater's	Kings Point	3,000	1965-66
Total			485,600	1956-67

Recent examination of the status of recovery in aphid infested stands indicates that immature trees may withstand severe attacks for several years and return to a reasonably vigorous condition. The extent of recovery in stands is as yet unknown but it is quite possible that recovery may be an important factor in the continuation of balsam fir as a merchantable species.

The Survey has not compiled any information on the incidence or degree of aphid damage to balsam fir regeneration. Seed production and stocking are adequate in most areas and observations in cut-over stands indicate that mortality and deformity are confined to scattered groups of trees. It was suggested (Carroll, 1966) that damage to balsam fir regeneration is less severe than originally anticipated.

The foregoing observations suggest that there are many aspects of the aphid problem that require further intensive study.

FIELDS FOR FURTHER STUDY

This paper has been concerned with information compiled by the Forest Insect and Disease Survey. Therefore, suggestions for further study arise primarily from Survey requirements.

The principal functions of the aphid survey are detection and damage appraisal. Further studies are required to improve methods of classification, to improve aerial scanning techniques, to examine the potential of aerial photogrammetry for aphid surveys, and to determine the role of the aphid in stand deterioration and its impact on the other components of the balsam fir community.

One of the major limitations to the application of aphid damage surveys has been the lack of a comprehensive inventory. The ideal inventory would include type maps that provide accurate information on stand composition, density, tree height and age, site type and associated volume tables. This information would then provide the basis for the Survey to interpret aphid damage in terms of stand and tree variables, to improve area assessment of aphid damage, to choose stands with specific characteristics for developing and improving sampling techniques and specialized research studies.

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APPENDIX 'A'

Balsam Woolly Aphid Ground Survey

Plot No. ____________ Location _________________________ District _________________________ Grid ____________ Date ______

Directions for locating stand ____

Reference point - bearing ____________________________ Stand age ____________ History ____________________________________

Remarks ____ Observer ______________________

TREE MEASUREMENTS						INJURY CLASSIFICATION									REMARKS
Tree			Bole	Crown		Recovery	Upper Crown			Lower Crown		Bole	Aphid	Killed	
Sp.	D.B.H.	Hgt.	Hgt.	Rad.	Class		Apex	Stem attack	Gout	Stem attack	Gout				