DECAY FOLLOWING PRUNING OF BALSAM FIR IN THE MARITIME PROVINCES OF CANADA

by

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B.S.F., The University of British Columbia, 1965

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN FORESTRY

Faculty of Forestry

We accept this thesis as conforming to the

required standard

THE UNIVERSITY OF BRITISH COLUMBIA

October, 1968

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ABSTRACT

As management of forests and parks intensifies, pruning of conifers becomes more common. Thus understanding the role of wounds as possible entry courts for decay fungi is vital. In order to study some aspects of this, three natural stands, one in New Brunswick and two in Nova Scotia, which had been pruned 4 to 7 years earlier by industrial or displaced workers, were examined. Five pruned and two unpruned balsam fir (Abies balsamea (L.) Mill.) trees from each stand were dissected; cultural isolations were taken from 207 knots where pruning had caused little or no apparent damage to the bole, and from 169 blazes resulting from less careful prunings. All 15 pruned trees, ranging in age from 23 to 42 years, had decay attributable to pruning which averaged 1.7% of the stem volume. This incidence and volume of decay exceeds that recorded in unpruned trees 40 to 60 years old in New Brunswick.

Axe blazes were the major entry court for decay-causing fungi: basidiomycetes were associated with 12% of the blazes and with 5% of the more carefully pruned knots. Neither stem nor butt decay was found in the unpruned trees.

In a further study, 7 branches on each of 30 balsam fir trees near Fredericton, N. B. were experimentally axe pruned; some carefully, some carelessly; both during tree dormancy and during wet and dry periods

of active growth. Thirty additional branches were saw pruned. At periods of 2 to 3 weeks, 5 to 7 months and 17 to 19 months after pruning, cultures were made in the field from 70 of the pruning wounds. Within 2 weeks of the latter period, the trees were dissected, measured and further cultures were made in the laboratory from the same 70 wounds.

Eighteen months after pruning, 28 of 30 trees had decay averaging 3.9% of stem volume and basidiomycetes were isolated from 22 (31%) of 70 wounds. In the controls butt decay only occurred in 4 of 10 trees.

These studies show: (1) that blazes into sapwood (careless pruning) were more frequently infected than those where little or no sapwood was exposed; (2) the incidence of infection was least in branches pruned during the dry period and about equal for those pruned in the wet-active and dormant periods; and (3) the successional pattern began with imperfect fungi and bacteria, and terminated with decay fungi.

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ACKNOWLEDGMENTS

W. R. Newell assisted with field work, culturing and compilation of results, Dr. M. K. Nobles identified cultures of *Stereum purpureum* and *Corticium laeve*, L. P. Magasi confirmed or corrected the identification of the major groups of the basidiomycetes, and Dr. R. S. Forbes offered valued criticism of the manuscript. The late Dr. J. E. Bier, Faculty of Forestry, University of British Columbia, guided the early stages of this study and gave encouragement and inspiration. Dr. A. Kozak suggested the analysis of variance which was used.

Gordon Allan Van Sickle

October 15, 1968

DECAY FOLLOWING PRUNING OF BALSAM FIR IN THE MARITIME PROVINCES OF CANADA

INTRODUCTION

In the Maritime Provinces numerous pruning projects have been initiated utilizing unemployed or displaced workers. The Nova Scotia Department of Lands and Forests is interested in managing vast areas of the Cape Breton plateau as a Christmas tree-pulpwood operation. Numerous areas are suited to this style of management for balsam fir [1], a native species, reproduces well on a variety of sites. Stands can then be pruned and thinned to 2500 to 3000 stems per acre, approximately 60% of which can later be cut for Christmas trees and the balance left for pulpwood. In the Maritimes, growing of Christmas trees is a small, but important industry which augments the annual income of many farmers. Annual export from the Region is about 4.0 million trees of which 2.5 million are from Nova Scotia, nearly 1.5 million from New Brunswick and less than 0.5 million

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[1] For botanical names of this and other trees referred to, see Appendix I.

from Prince Edward Island (McLeod, 1968). Regionally, balsam fir is one of the most important sources of pulpwood.

The removal of the lower whorls of branches by pruning facilitates easier movement in the stand, encourages formation of fuller-foliaged trees, increases lateral twig development, and provides a good bottom whorl of branches. Most areas, however, will not yield sizable quantities of well-shaped Christmas trees indefinitely and consideration should be given to a future yield of pulpwood (McLeod, 1968).

R. Mason (personal communication), contractor for pruning and thinning operations on Crowdis Mountain, Cape Breton Island, N.S., observed that nearly all the trees pruned in 1962 and cut in 1964 for the Christmas market had some butt rot, thus raising the question of cull in the remaining trees. Accordingly, a preliminary survey was made during September, 1965 of five randomly selected pruned balsam fir trees (Van Sickle, 1966). All contained noticeable firm decay. Basidiomycetes were isolated from 15 of 39 wounds where sapwood was exposed at the time of pruning and from 4 of 74 knots after careful pruning which exposed only the cut surface of the branch. Numerous problems evident in this study could not be overcome unless one was present at the time of pruning. It was not known, for example, if the association of a fungus with branch stubs resulted from several single-branch infections, or if it was an extension of heart rot established through broken tops or dead leaders. Uncertainty also existed whether decay entered through living or dead branches and before or after the branches were pruned. Questions of who did the pruning, using what tools, at what time of year and which year could seldom be answered as early

prunings were not well documented and were usually winter works programs rather than forest operations. Consequently, it was decided to experimentally prune a small number of trees to follow closely the infection process and to determine if incidence of decay-causing fungi is altered by more careful pruning or by timing the operation to coincide with certain weather conditions.

LITERATURE REVIEW

Incidence of Decay After Pruning

That benefits from pruning might be reduced or nullified by heart rot infections entering through pruning wounds has seldom been questioned. Andrews (1954) concluded that pruning protects ponderosa pine from decay by Polyporus anceps [2/] by eliminating recently dead branches, the principal infection avenues. Similarly, Baxter (1967) reported that small, much-weathered branch stubs provided infection courts for Fomes pini and suggested that early pruning would have reduced the probability of infection.

Andrews (1954) felt knots exposed by pruning were unimportant as entrance points for disease. Davidson and Redmond (1957) found branch stubs the most important infection courts for trunk decaying fungi in

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2/ For nomenclature for this and other fungi included in this paper, see Appendix II.

white spruce, while in red spruce, wounds were as important as branch stubs. Childs and Wright (1956) evaluated the practice of clubbing and sawing-off of dead and living branches of young Douglas fir and concluded that heart-rotting fungi often gain entrance through pruning wounds, but the average extent of decay was slight. Others working on a variety of coniferous hosts who agree that proper pruning caused no defects of any practical importance include Harris (1966), Henman (1963), Bauger and Orlund (1962), Finnis (1953) and Hawley and Clapp (1935).

In Britain, decay following pruning is attributed to pruning of large (2 in. + diameter) branches or to careless work, especially brashing (branch removal to facilitate access to stands), which leaves torn bark or long ragged stubs (Henman, 1963). Uncontrolled lopping of trees in India, resulted in injuries through which fungi entered (Bagchee and Bakshi, 1950). In central New York State, Risley and Silverborg (1958) found Stereum sanguinolentum causing extensive heart rot associated with wounds after branches, averaging 0.5 to 1 in. diameter, had been pruned. Five years after the Norway spruce trees were axe pruned, fruit bodies were abundant both on branch stubs and exposed sapwood. The resulting decay progressed rapidly and in some trees both heartwood and sapwood were decayed resulting in death. Sleeth (1938) and Spaulding and MacAloney (1935) also reported that S. sanguinolentum infected wounds and formed fruit bodies when 2 to 5 in. white pine branches were pruned. They concluded that young infected trees would be worthless before reaching a merchantable size and they cited a Swedish report of S. sanguinolentum entering blazes on Norway spruce and in less than two years causing decay that extended an average of 2 m from the wound.

Toole (1961) reported rot associated with 29% of the 1696 dead branches sampled in pruned hardwood trees, but Skilling (1958) found no indication that artificial pruning encouraged development of decay in sugar maple and white elm.

The work outlined above involves studies in all parts of the world on a variety of species, in different seasons, emphasizing attacks by different fungi under different climates, using different tools and for different reasons; hence, the difficulty in obtaining a concensus. None of these studies, however, concerned balsam fir, the wood of which is completely lacking in natural durability to decay (Bakuzis and Hansen, 1965). Considerable information, however, is available regarding natural wounds on balsam fir as entry courts for decay fungi. Early workers (Basham, Mook and Davidson, 1953; Spaulding and Hansborough, 1944; Kaufert, 1935 and McCallum, 1928) considered dead branches and stubs the most important infection courts of the destructive heart rot fungus, S. sanguinolentum, but this has not been verified. In artificial infection experiments, dead branches unlike living branches did not serve as points of entry for S. sanguinolentum (Davidson and Etheridge, 1963). Their further work showed this fungus becomes established in heartwood solely by way of injuries to living stems and branches. Since pruning wounds are a form of injury, they could easily be infection courts.

Season of Pruning

No agreement exists on the best season for pruning. Ralston and Lemien (1956) and Hawley and Clapp (1935) preferred dormant season

pruning, but chiefly for convenience in the work schedule. Roth (1939) stated wounds made during the growing season heal more rapidly than those made at other seasons of the year, but care is needed to avoid excessive bark stripping. Childs and Wright (1956) found much higher fungal infection from spring pruning than from autumn pruning. Henman (1963) reported European studies based on the incidence of fungal damage, which showed the only safe time for pruning to be the dormant season.

On the other hand, Roth (1939) reported the work of Swarbrick and Priestley in England who found "wounds made between April and September rapidly blocked the entry of decay; wounds made during September and October were blocked only partially and those made from October to May seldom were blocked until the following spring." Similarly, Davidson and Etheridge (1963) found infection highest in trees damaged in the winter and lowest in those injured in mid-summer.

Bauger and Orlund (1962), however, reporting on pruning performed in the autumn, winter and late spring, found no season to be less suitable than the others. Similarly, Lohrey (1963) found no significant differences in the time required for healing of wounds made throughout the year.

Etheridge (1965), the first to consider the requirements of the infecting organisms, determined that spores of S. sanguinolentum were produced from mid-April to mid-November, but infection of balsam fir occurred only during periods of rain and when mean daily temperatures were between 38 to 60 F. Susceptibility of summer produced injuries fell rapidly and irreversibly 24 hr after exposure (which agrees with Bakuzis

and Hansen, 1965, that aging of wounds increases resistance to infection), but winter produced injuries were still susceptible when thawing commenced early in April. Unfortunately, similar data are lacking for other fungal organisms or hosts.

EXPERIMENTAL AND SURVEY METHODS

Experimental Pruning, Acadia Forest Experiment Station

Study Area

In March, 1966 a detailed pruning study of balsam fir was started at the Acadia Forest Experiment Station, 13 miles east of Fredericton, New Brunswick. The study area lies within the Eastern Lowlands Section (A. 3) of the Acadian Forest Region (Rowe, 1959) which is "characterized by softwood stands of black spruce, red spruce and balsam fir or mixed woods in which these species are associated with white pine, red maple, sugar maple, yellow birch and white birch. The gently undulating plain is underlain by flat-bedded sandstones, shales and conglomerates. The surface tills are mostly of a clay loam or sandy loam texture and podzolic in soil profile development." Much of this area is in Canada Land Inventory class 5 (31 to 50 ft^3 mai). The stand chosen for study had an understory of fairly open-grown balsam fir with living crowns within two feet of the ground. The average age of the balsam fir at ground level was 39 years and the site index was 25 at 50 years. Many of the overstory hardwoods were girdled during winter of 1961.

Thirty-five balsam fir trees of good form and free of noticeable insect or disease damage were numerically tagged. On each tree, between 2 and 8 feet above the ground, seven branches were selected and lettered A to G inclusive. Generally only one branch per whorl was selected and the letter sequence and compass bearing of the first chosen branch on each tree was varied systematically so branches of the same notation were not always on the same side of the tree or at the same height. The trees were then randomly assigned to three groups of ten, one tree was designated as an extra in each group and two were left to be used as and if needed. Ten additional trees were designated as controls and received no treatment.

On March 10, 1966, a Stevenson weather screen containing a maximum-minimum thermometer and Fuess hygrothermograph was established in the stand and maintained until September 19, 1966.

(a) Dormant Pruning

On March 23, 1966, while the trees were still dormant, all 35 branches lettered A and 35 lettered B were pruned using a hand axe; A branches were carelessly pruned in such a manner that the bark and outer sapwood were wounded (Fig. 1), B branches were pruned as carefully as possible without leaving a protruding branch stub or significantly wounding the bole (Table 1). The status (living or dead) and the diameter of each pruned branch were recorded and basal 1-ft sections were labelled and taken to the laboratory. Within 24 hr each was split through its center and three small pieces of wood aseptically removed (Fig. 2) and placed on 2% malt agar slants to establish the presence or absence of fungi in the branches at time of pruning.

Unpruned branches in and near the whorls containing A and B were clipped 4 to 6 in. from the bole using hand pruning shears to reduce the

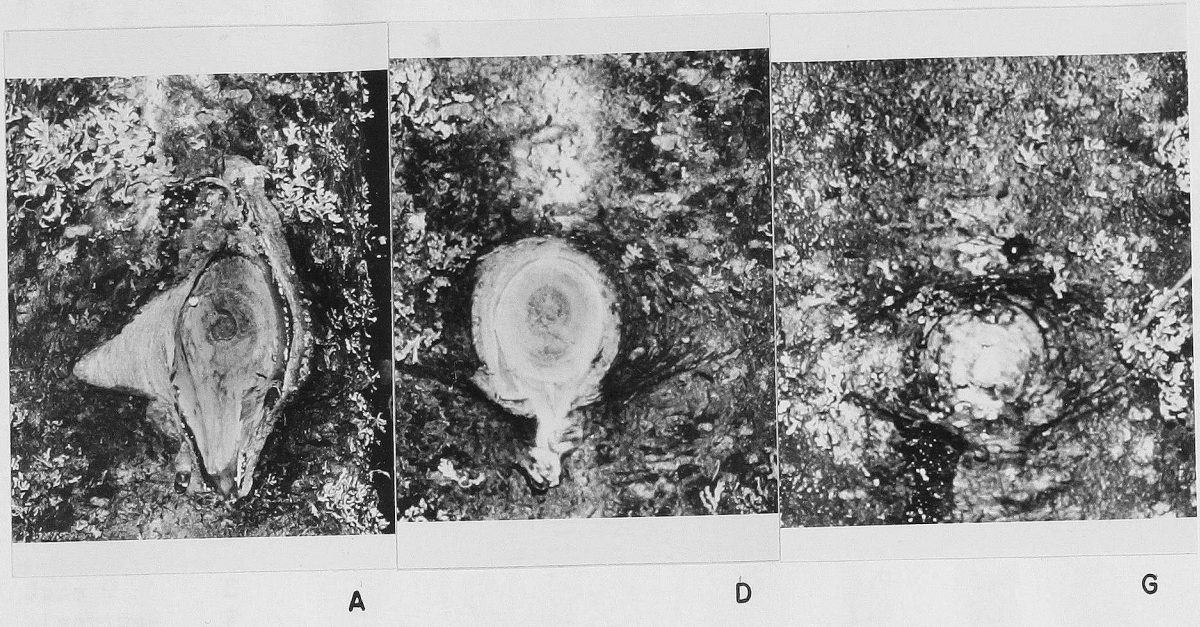

Figure 1. Typical wounds produced by pruning balsam fir branches. A. carelessly axe pruned, D. carefully axe pruned, G. saw pruned.

possibility of decay entry through these branches, but still provide a microclimate about the pruned branches similar to that around a fully pruned tree.

During the five days, March 21 to 25, centered about the day of dormant pruning, the mean daily temperature ranged from 36 to 40 F averaging 38 F, and measurable precipitation (.01 in. or more) was recorded on three days (Table 2). Balsam fir buds in this area normally flush about May 11 [3/].

3/ Forbes, R. S. (Unpubl. data, 1967) A phenological survey of the Maritime Provinces based on shoot growth measurements on balsam fir.

Table 1. Average branch diameter and wound size following pruning of 7 branches on each of 30 balsam fir trees.

Branch and date of pruning		Avg. pruned branch diameter (n=30) (in.)	Avg. size of pruning wound		
			Length (in.)	Width (in.)	Area ($in.^2$)
March 23 (dormant)	A	0.45	3.3	1.2	2.0[a]
	B	0.45	0.9	0.7	0.5[b]
July 4 (active-dry)	C	0.41	3.7	1.3	2.4[a]
	D	0.42	1.2	0.9	0.9[b]
June 9 (active-wet)	E	0.42	3.9	1.2	2.3[a]
	F	0.38	1.2	0.8	0.8[b]
	G	0.41	0.7	0.7	0.4[b]

[a] $\text{Area} = \frac{L \cdot W}{2}$

[b] $\text{Area} = \pi \left(\frac{L + W}{4}\right)^2 = \pi r^2$

(b) Active-wet Pruning

On June 9, 1966 following a period of moderate temperatures and high humidities and no change forecasted, branches lettered E were carelessly axe pruned, those lettered F were carefully axe pruned, and those lettered G (Fig. 1) were pruned using a hand saw to undercut and then cut from above to prevent tearing the bark when the branch fell. As in the dormant pruning, other branches near those pruned were clipped and basal sections of branches E, F and G were taken to the laboratory and cultured.

During the five days June 7 to 11, measurable precipitation was recorded on three days; for 76 hr the relative humidity exceeded 80%, averaging 78%, and the mean daily temperature ranged from 46 to 63 F, averaging 54 F (Table 2). Based on lateral shoot elongation, approximately

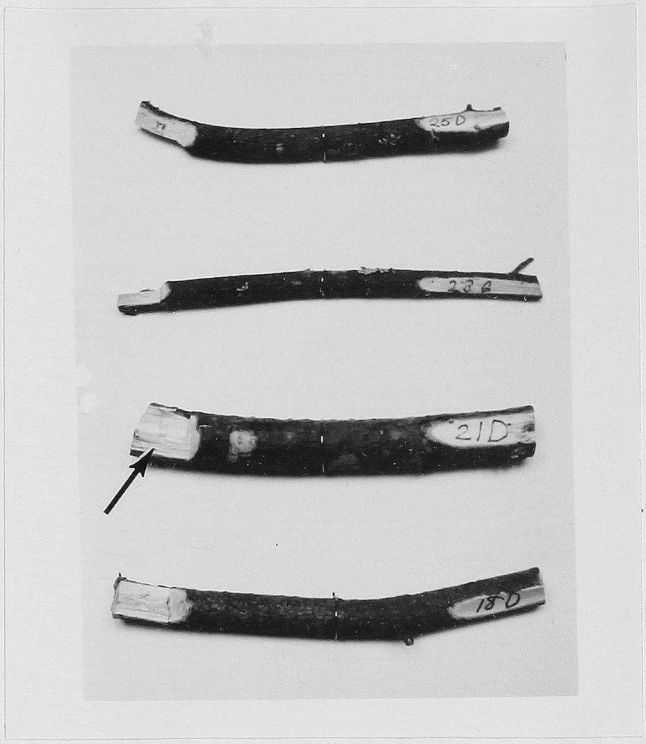

Figure 2. Basal section of pruned branches showing location of isolation attempts.

Table 2. Weather during 5 day period centred about day of pruning.

Type and date of pruning	Temperature (F) 5 day mean	Temperature (F) range	5 day mean relative humidity (%)	No. hr relative humidity > 80%	No. days ppt. >.01 in.
Dormant March 23	38	36-40	83	86	3
Active-wet June 9	54	46-63	78	76	3
Active-dry July 4	64	61-69	63	42	0

50% of the growth was completed by this date [4].

(c) Active-dry Pruning

On July 4, 1966 following a period of high temperatures and low humidities, and no change forecasted, branches lettered C were carelessly axe pruned and those lettered D were carefully axe pruned (Fig. 1). As before, sections of the pruned branches were cultured and the remaining branches from ground level to 8 to 10 ft were clipped 4 to 6 in. from the bole (Fig. 3).

During the five days, July 2 to 6, no measurable precipitation was recorded, and for 42 hr the relative humidity exceeded 80%, averaging 63% and the mean daily temperature ranged from 61 to 69 F, averaging 64 F (Table 2). July 4 coincided with the five year average date for completion of shoot elongation for balsam fir [5].

Tree Measurements and Fruit Body Survey

As an indication of the inoculum present for possible infection, samples of fruit bodies found on living or dead standing or fallen trees were collected June 23, 1966. These were dried and the identified specimens are deposited in the Mycological Herbarium at the Forest Research Laboratory, Fredericton, N.B.

On July 6, 1966 after all trees had been pruned the location of each was mapped and record made of: diameter at breast height, the aspect

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[4] Forbes. (Unpubl. data, 1967)

[5] Ibid.

Figure 3. Pruned balsam fir, trees 2 and 3. Unpruned branches to 10 ft were clipped 4 to 6 in. from the bole.

of each pruned branch with respect to cardinal compass points, the length and width to the nearest 0.1 in. and the height above ground level to nearest foot of each wound.

The 30 pruned and 10 control trees averaged 39 years at ground level, 3.1 in. dbh, 21.4 ft in height, and 1.1 ft per year in terminal

growth for the past 6 years. The live crowns (top of pruning) averaged 8.3 ft in height.

Seven branches were pruned from each of the 30 trees and 202 of the 210 total (96.2%) had green foliage when pruned. The diameters of pruned branches averaged 0.42 in. (s = 0.12), ranging from 0.2 to 0.8 in.

Field Culturing

Two to three weeks after each period of pruning, isolation attempts were made from the wounds on 10 randomly selected trees (Appendix III). Each wound was surface sterilized with 70% alcohol and allowed to dry before three small wood chips (one next to knot and one each above and below the knot) were removed and placed on 2% malt extract agar slants. Isolations were to be made using a sterilized increment hammer (Hubert, 1954), but because positioning the hammer and the variable size of the wood chip was a problem, narrow carpenter chisels were used.

On October 17,1966, 5 to 7 months after the branches were pruned, 10 wounds of each type, A to G inclusive, were surface sterilized and isolations made as before. Similarly, on October 17, 1967, 17 to 19 months after pruning, the last 10 wounds of each type were cultured in the same manner. The presence on the wound surfaces of fruit bodies or insect emergence holes was noted at this time.

After 20 to 27 days under laboratory conditions of light and temperature, all tubes were macroscopically examined and classified as containing: no growth (negative) bacteria, imperfect fungi (Fungi Imperfecti) or a mixture of two or more organisms. Cultures suspected of being

basidiomycetes were examined microscopically and when necessary sub-cultured to obtain pure cultures. Cultures of imperfect fungi were later examined microscopically and classified to form family and occasionally to form genus according to Barnett (1960). Basidiomycetes with distinctive characteristics (Stereum sanguinolentum and Amylostereum chailletii) were frequently identified using mounts prepared from the tube, but all others and the unidentified cultures were transferred to Petri plates and examined weekly for six weeks according to methods outlined by Nobles (1965).

Basidiomycetes were recognized by the presence of clamp connections, or in those that are simple septate the combination of fiber hyphae, chlamydospores, etc. It is generally accepted that basidiomycetes are the major wood decay fungi: with one exception (white spongy heart rot of sugar maple caused by Hypoxylon deustum), non-basidiomycetes are believed incapable of causing decay in living trees (Basham and Morawski, 1964; Wagner and Davidson, 1954). The assumption was made that basidiomycetes isolated from stained wood were capable of causing decay, and the basidiomycetes isolated and identified in this study are known in the literature to fulfil Koch's postulates.

Dissection of Pruned Trees

Within 15 days of the last field culturing, the 35 pruned and 10 control trees were felled at ground level and cut into 1-ft bolts to the living crown, or until no decay was noted on the cross section. If the stem diameter was not then less than 3 in., the tree was cut into 4-ft bolts until this limit was reached. The inside bark diameter of the transverse face of each section was measured to the nearest 0.1 in. as were the diameters of all defects on these faces. Wood noticeably softer than normal, healthy

heartwood was classified as unfirm decay. If the reduction in hardness was very slight, it was classified as firm decay. Tree volumes to living crowns and the volumes of firm and unfirm decay were calculated using Smalian's formula[6/]. Butt decays were traced to their uppermost limit and their volumes calculated separately.

Stump age was determined by ring count or in the few cases of hollow centres, the age at stump was estimated by adding to the number of rings countable, the average number of years required by 10 other trees in the plot to reach a radius corresponding to the radius of the rot column. Total tree height was also recorded as were any defects overlooked when the trees were selected.

All bolts containing pruning wounds from which isolations were attempted 3 to 15 days earlier were taken to the laboratory and dissected using a bandsaw. Each wound was sectioned vertically through the knot (branch base embedded in the wood of a tree trunk) and examined for evidence of decay or discoloration. Within 24 hr of dissection, three isolation attempts were made from the margin of the discolored zone, or from the 1966 growth ring if no discoloration was evident. Small superficial chips were removed with a flamed scalpel then a smaller chip was cut from the sapwood and transferred aseptically to a malt agar slant. Several knots of clipped, unpruned branches on each tree were also dissected and examined. Bolt sections were stored at 35 F for 20 to 25 days at which time the cultures

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6/ Volume in $ft^3 = \frac{B + b}{2} L$ where
B = area of large end of bolt, ft^2
b = area of small end of bolt, ft^2
L = length of bolt in ft

were examined and classified. All knots that yielded negative cultures or imperfect fungi, as well as several with basidiomycetes, were recultured as checks.

Survey of Pruned Balsam Fir and White Spruce

Cull Study

Three commercially thinned and pruned areas with fairly complete records were located in 1967: a balsam fir-white spruce stand in the Green River watershed, Restigouche County, N.B., and two balsam fir stands on Crowdis Mountain, Cape Breton Island, N.S. (Fig. 4).

In each area five pruned and two unpruned control balsam fir trees were randomly selected and cut at ground level. At the Green River site five pruned and two control white spruce trees were included. All trees were scaled and the percentage decay was estimated as previously outlined. The boles were transferred to the laboratory and stored at 35 F and within 1 to 7 weeks dissected using a bandsaw to radially section wounds and embedded branches. Record was made of branch diameter, status (living or dead) as judged by a macroscopic examination of growth rings and presence of bark inclusions, height of branch above base in 1-ft classes, wound size, and visible signs of decay or discoloration. Within 24 hr of dissection, three isolation attempts were made from the exposed faces as previously outlined. Cultures were stored and classified as before except only basidiomycetes were retained for identification.

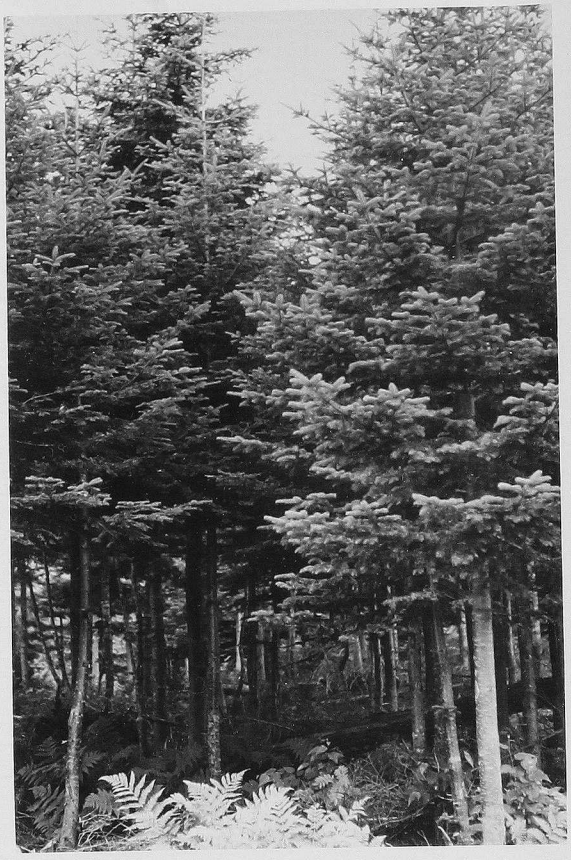

Figure 4. A natural 37-year-old balsam fir stand on Crowdis Mountain pruned and thinned in 1963 and being managed for Christmas trees and pulpwood.

Study Areas

Block 443 in the Green River watershed is crown land containing approximately 15 acres that was thinned and brashed, in August, 1960 by woods employees of Fraser Companies Limited. The area has a moderate slope

with a northeastern aspect. Both balsam fir and white spruce averaged 35 years of age at ground level. Rowe (1959) classified this area as Gaspe section (B. 2) of the Boreal Forest Region; characterized by "plateau-like highlands... which are a northeastward extension of the Appalachian Mountain system. The major forest cover types are dominated by conifers, although mixed conifer-hardwood stands are not uncommon. Balsam fir, black spruce and white spruce, often in combination with white birch form the characteristic cover types. Thin podzol profiles with rather heavy, but poorly-structured B horizons, are common in the well-drained position."

Crowdis Mountain, Cape Breton Island, N.S. is largely crown land currently leased and clear cut by Bowaters Mersey Paper Company Limited, but in 1969 it will be transferred to Nova Scotia Pulp Limited. Much of the area has heavy natural regeneration of balsam fir with 6,000 to 10,000 plus stems per acre. About 1,000 acres have been thinned and pruned with axes, saws and a pruning machette to approximately 2,500 to 3,000 stems per acre.

The Cape Breton plateau section (A .6) of the Acadian Forest Region as classified by Rowe (1959) "shows marked similarities to the Gaspe section. Balsam fir, white spruce, black spruce and white birch are the chief species, with the fir dominating. Shallow soils prevail and profile development under the cool-moist climatic conditions is to humus podzols, gleysols, and peats, according to drainage."

Two locations on the plateau were sampled; one was thinned and pruned by R. Mason, Springhill, N.S. during June, 1962, the other during September, 1963. The average age of balsam fir was 37 years and 24 years,

respectively. Both areas had a site index of 25 at 50 years and would be in Canada Land Inventory class 5 (31 to 50 ft^3 mai).

RESULTS

Experimental Pruning of Balsam Fir

Three balsam fir trees were deleted from the sample and replaced by predetermined alternates. Tree 28 was injured by a falling tree during winter 1966, a mycelial fan of Armillaria mellea was found at the base of tree 5 and tree 14 was cultured out of sequence. The remaining 10 trees in each group had not been visibly injured to influence the effects of pruning.

Butt decay was present in 1/3 of the pruned trees, but ended in the first 1-ft bolt and was not in contact with decay attributed to pruning. Cultures from the butts of three trees yielded A. mellea and one yielded S. sanguinolentum. Four control trees also contained measurable butt decay, but the average percent of volume decayed in the 14 trees was only 0.24%.

Macroscopically similar fruit bodies were observed in October, 1967 on wounds on seven trees; one sporophore (Fig. 5) was identified as Corticium laeve.

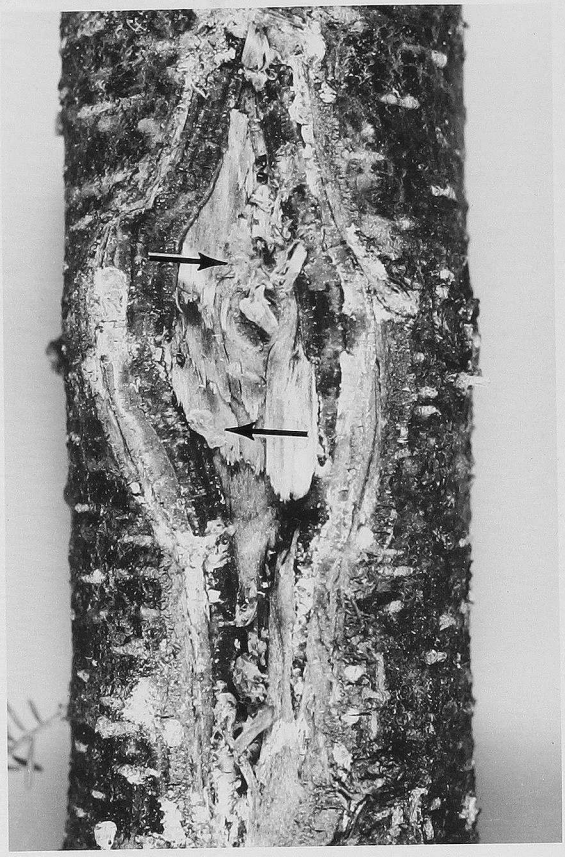

Figure 5. Corticium laeve fruit body on a wound resulting from branch pruning of this balsam fir tree less than 1½ years earlier.

Field Culturing

Of 420 isolations made at the time of pruning from the basal end of pruned branches, 402 (95.7%) were sterile, 16 (3.8%) yielded a variety of imperfect fungi, 3 contained bacteria and 1 from a dead branch, no. 10 B contained an unidentified nodose septate basidiomycete. As the cultures made in October, 1967 from 10 B yielded only bacteria and

an imperfect, it was felt that the decay fungus failed to enter the bole and there was no need to delete this branch from the sample.

Of 210 isolations made during each period, i.e. 2 to 3 weeks, 5 to 7 months, and 17 to 19 months after pruning; 1.4%, 6.6% and 19.5%, respectively contained basidiomycetes, 10.9%, 18.1% and 21.9%, respectively yielded moniliaceous imperfects, and 53.4%, 47.6% and 22.4%, respectively yielded dematiaceous imperfects (Fig. 6). Bacteria were present in 7.6%, 37.6% and 68.6% of the cultures. Less than 10% of cultures made at any one time contained Penicillum spp. Because a single tube frequently contained as many as three different organisms, totals often exceed 100%. In the total 630 field cultures made, Phialophora spp. (8.2%) were the most common moniliaceous fungi, Aureobasidium pullulans type IV (11.4%) and A. pullulans type III (7.8%) were the most common dematiaceous fungi. Types III and IV are as designated in the culture collection of the Faculty of Forestry, University of British Columbia, and are similar to those described by Barnett (1960) and Funk (1960). It is possible that the latter, typified by thick-walled resting spores, is simply a resting stage of the former in which blastospores are abundant. The resin-inhabiting fungus Retinocyclus abietis occurred in 4.0% of the cultures. Less frequently occurring imperfect fungi included Fusarium, Cephalosporium, Alternaria, Torula, Graphium and Trichocladium. Representative cultures have been retained in the stock culture collection at the Forest Research Laboratory, Fredericton, N.B.

One or more basidiomycetes were obtained in field cultures from 34 of the 210 wounds examined (Table 3). The proportion of branches containing basidiomycetes increased from .05 at 2 to 3 weeks to .31 at 17 to 19 months after pruning. Most decay-causing fungi were isolated from

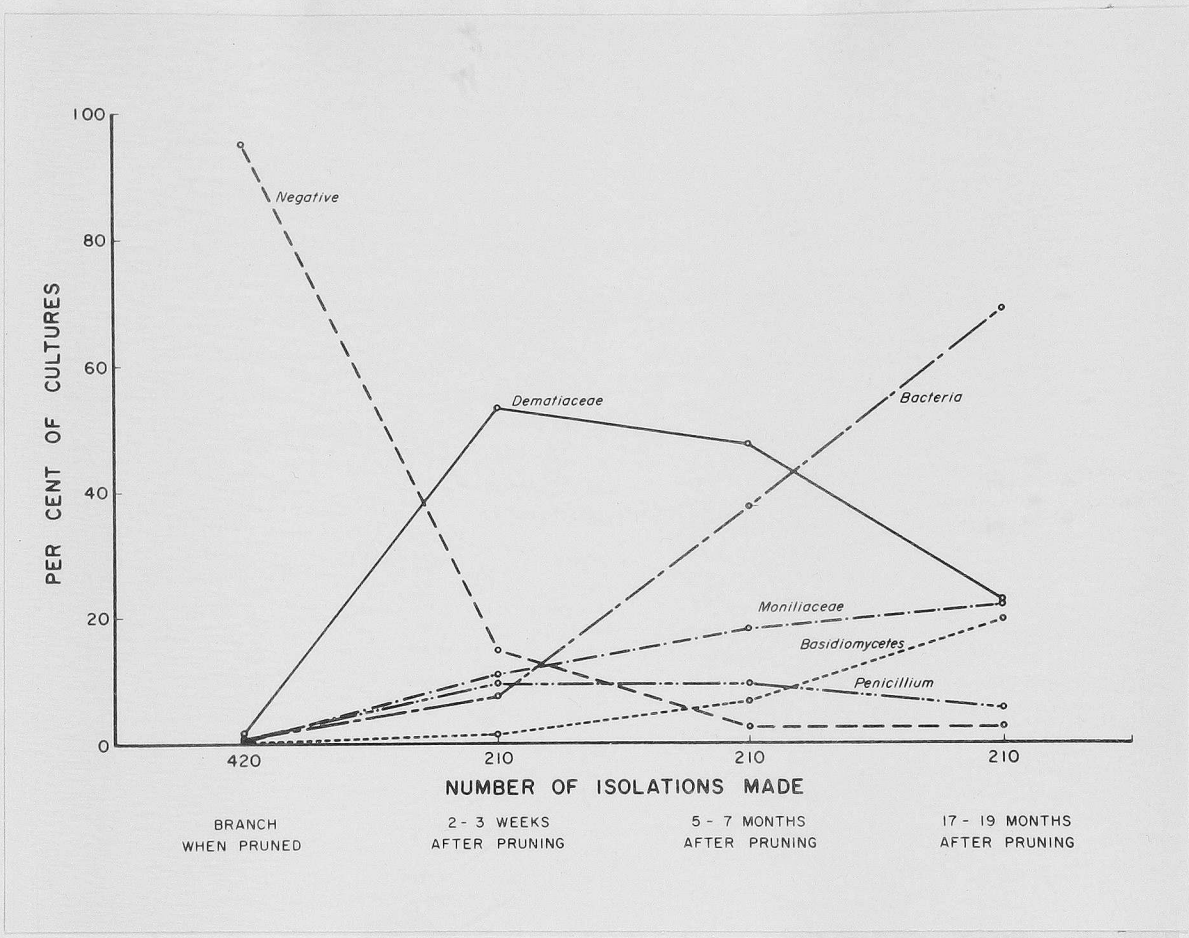

Figure 6. Cultural results at different times following pruning of balsam fir at Acadia Forest Experiment Station.

branches pruned during active growth in the wet period (.23), followed closely by those pruned during dormancy (.18) and were least (.08) for branches pruned during growth in the dry period (Fig. 7). Carelessly pruned branches consistently had a higher proportion (.24) of basidiomycetes than carefully pruned branches (.09). An analysis of variance (Keeping p. 219-227, 1962), indicated significant differences at the 5% level of

Table 3. Proportion of pruned balsam fir branches from which basidiomycetes were isolated in field cultures.

Type of isolation	Type and time of pruning: Dormancy Careless	Dormancy Carefully	Active-dry Careless	Active-dry Carefully	Active-wet Careless	Active-wet Carefully	Active-wet Sawn	Avg. time of isolation (excluding sawn)
(Pruning plus)								
2-3 weeks	0[a]	0	0	.1	.1	.1	0	.05
5-7 months	.1	.3	.1	0	.3	0	.1	.13
17-19 months	.6	.1	.2	.1	.8	.1	.3	.31
Avg. for type of pruning	.23	.13	.10	.07	.40	.07	.13	
Avg. for time of pruning	.18		.08		.23		-	

[a] proportion of 10 branches examined from which basidiomycetes were isolated.

probability between the occurrence of basidiomycete in carefully and carelessly axe-pruned branches and among the times of cultural isolation (Table 4). Saw pruning (Fig. 8), however, was not significantly different at the 5% level to careful axe pruning with respect to incidence of decay-causing fungi.

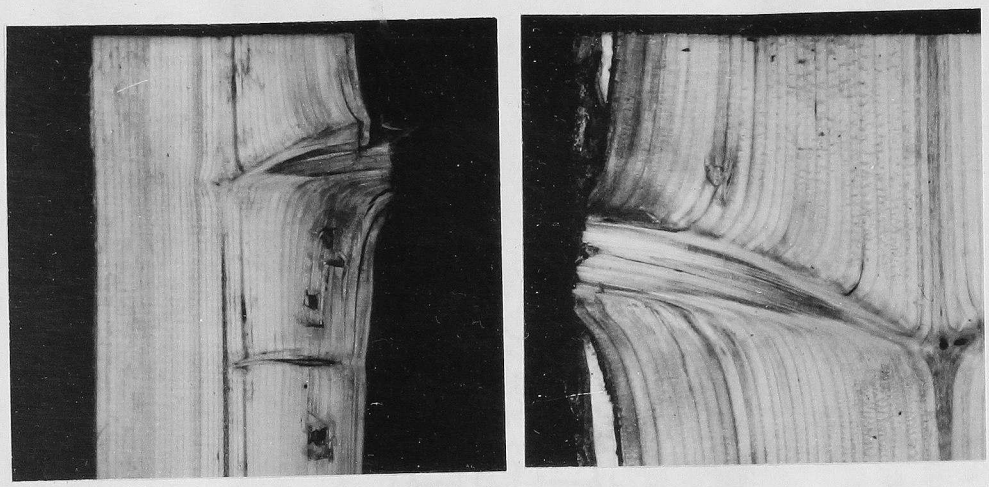

Figure 7. Radial stem section of knots carefully axe pruned during dormancy (left) and growth (right). Corticium laeve and Stereum purpureum were isolated from the branch on the right and left respectively.

Dissection of Pruned Trees and Laboratory Culturing

Measurable decay (Fig. 9) attributable to pruning occurred in 28 of 30 pruned trees. Butt decay, only, occurred in 4 of 10 unpruned control trees. The average volume decayed in the 28 trees was .02 ft^3 (3.9% of the stem volume) only 17 to 19 months after 7 branches on each tree were pruned. There was considerable variation (range .02% to 18.9%) in the amount of decay in trees, largely because of the action of different fungi. Most was firm decay with only 2 trees having a trace of unfirm decay. One or more basidiomycetes were isolated during field culturing from 22 (73%) of the pruned trees. Laboratory cultures made from the same branches as, and

Figure 8. Radial stem section of knot carefully saw pruned from which Stereum purpureum and basidiomycete 1 were isolated.

immediately following the October, 1967 field cultures provided similar relationships, but a higher overall proportion of basidiomycetes (Table 5).

During dissection of tree 17, branch E, numerous larval galleries were noted and one small larva with a single anal spine was identified as Sirex juvencus L., the woodwasp from which Stillwell (1966) isolated A. chailletii. The adult woodwasp is attracted to and oviposits in weakened and newly dead balsam fir (Stillwell, 1966) and apparently was attracted to the pruning wounds. Other larvae found (Family Melandryidae and Ichneumonidae) were those commonly parasitic on the woodwasp. Larval galleries were found in all but 1 of the 9 trees from which A. chailletii was isolated and of 16 knots or wounds from which this fungus was isolated,

Table 4. Analysis of variance for incidence of basidiomycetes following careful and careless axe pruning of balsam fir at three different times and from three different times of isolation.

Source of Variation	DF	MS	F	$F_{.05}$
Time of pruning (C)	2	.0351	1.63 N.S.[a]	4.10
Careful vs careless pruning (A vs A_1)	1	.1089	5.04 *	4.96
Time of isolation (T)	2	.1116	5.17 *	4.10
A * T	2	.0906	4.19 *	4.10
Error[b]	10	.0216		
Total	17			

[a] N.S. not significant. * significant at 0.05 probability level

[b] non-significant C * A and C * T interactions pooled to the error term.

insect galleries were found in 8 (Fig. 10). Had each branch been completely dissected, galleries might have been found in more branches, but sometimes the entry court could have been a different wound some distance from the point of isolation.

Basidiomycetes were isolated from all but 4 of the 30 pruned trees during field and laboratory culturing. When the amount of decay present in each tree was proportioned according to the total number of cultures of each basidiomycete obtained from that tree, it was estimated that A. chailletii was associated with approximately 46% of the decay

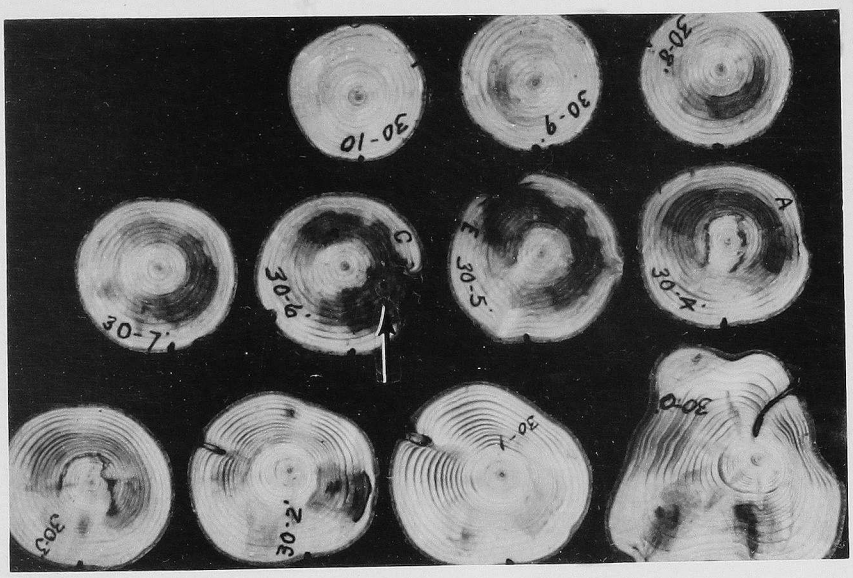

Figure 9. Transverse sections of tree no. 30 taken every foot from ground level to 10 ft. This 36-year-old balsam fir tree contained 17.5% of its volume as firm decay. Siricid larval galleries are evident (arrow) and the location of wounds A, C and E are noted. Aureobasidium pullulans was isolated from C 2 weeks after pruning, Peniophora sp. from E 5 months after pruning and Corticium laeve from A 17 months after pruning. Amylostereum chailletii was isolated in the laboratory from wound A.

Table 5. Proportion of basidiomycetes isolated during field and laboratory culturing of the same pruned balsam fir branches.

Type of isolation	Type and time of pruning							Avg. time of isolation (excluding sawn)
	Dormancy		Active-dry		Active-wet			
	Careless	Carefully	Careless	Carefully	Careless	Carefully	Sawn	
Field [a]	.6[b]	.1	.2	.1	.8	.1	.3	.31
Laboratory	.9	.2	.4	.4	.7	.2	.4	.47
Avg. of lab cultures for type of pruning	.55		.40		.45			

[a] field culture results repeated from Table 3.

[b] proportion of 10 branches examined from which basidiomycetes were isolated.

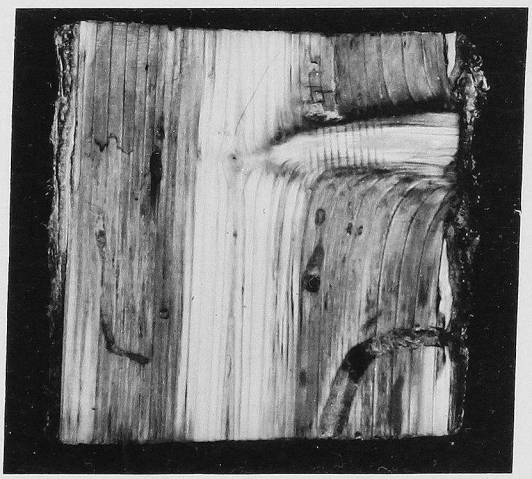

Figure 10. Radial stem section of knot and wound from which Amylostereum chailletii was isolated and sircid larvae taken.

present after pruning. C. laeve caused 21% of the decay followed by S. purpureum with 9%, Peniophora sp. 5%, and S. sanguinolentum 4% (Table 6). The balance was attributed to several unidentified basidiomycetes.

With but two exceptions, laboratory recultures yielded the same organisms as did the original laboratory isolation attempts. Cultures from 41 branches that had previously yielded bacteria and/or imperfect fungi again yielded bacteria and/or imperfects. Similarly, cultures from 4 branches again yielded basidiomycetes indicating retention of viability

Table 6. Number of pruning wounds, A-G, with basidiomycetes during field and laboratory culturing and proportion of decay associated with each fungus.

Basidiomycete	No. of knots or wounds which yielded basidiomycetes				Decay amount[a] associated with fungus (%)
	Field cultures at			Laboratory cultures	
	2-3 weeks	5-7 months	17-19 months	17-19 months	
White rots					
Amylostereum chailletii	1	1	-	14	46
Corticium laeve	-	1	9	7	21
Peniophora sp.	1	-	1	2	5
Stereum sanguinolentum	-	1	-	3	4
Stereum purpureum	-	-	4	6	9
basidiomycete 1	-	-	5	-	1
Brown rots					
basidiomycete 2	1	2	-	-	7
basidiomycete 3	-	1	-	-	2
unidentified[b]	-	3	3	-	5
Total	3[c]	9[c]	22[c]	32[c]	100

[a] amt. of decay per tree proportioned by no. of cultures of each basidiomycete
[b] includes groups 4-8 inclusive and mixed cultures
[c] of 70 knots and wounds examined

after 3 weeks cold storage. Only one branch from which bacteria were originally isolated yielded a basidiomycete, C. laeve, in the recultures. One branch from which S. purpureum was originally isolated yielded instead two bacterial and one sterile culture. However, the same basidiomycete was again isolated from each of these exceptions after a further 3 weeks storage.

A. chailletii was mainly isolated from branches pruned during the dry period of growth and during dormancy (Table 7). This might be expected

Table 7. Incidence of each basidiomycete isolated during field and laboratory culturing from branches pruned at three different times.

Basidiomycete	Time of pruning					
	Dormancy		Active-dry		Active-wet	
	No.	%	No.	%	No.	%
Amylostereum chailletii	5	7.8	10	15.6	1	1.6
Corticium laeve	7	10.9	-	-	5	7.8
Peniophora sp.	-	-	1	1.6	4	6.2
Stereum sanguinolentum	4	6.2	-	-	-	-
Stereum purpureum	1	1.6	-	-	8	12.6
basidiomycete 1	-	-	1	1.6	4	6.2
basidiomycete 2	2	3.1	-	-	2	3.1
basidiomycete 3	-	-	-	-	1	1.6
unidentified[a]	3	4.7	1	1.6	4	6.2
Total	22	34.3	13	20.4	29	45.3

[a] includes groups 4-8 inclusive and mixed cultures.

considering woodwasps are most active in dry warm weather. Many of the infections, however, apparently occurred earlier than the expected time of oviposition in mid-August and September (Stillwell, 1966). Peniophora sp. and S. purpureum were predominant in branches pruned during the wet period of growth. C. laeve occurred in dormant and active-wet pruned branches. Other basidiomycetes were not isolated frequently enough to determine trends.

In more than 90% of the sections examined a resin streak occurred in the annual ring corresponding to the year of pruning. However, it was seldom pronounced beyond the limits of the wound.

Based on chi-square tests of independence, the difference in incidence of basidiomycetes with increasing wound size (Table 8) was

Table 8. Incidence of balsam fir pruning wounds infected with basidiomycetes according to wound size.

Wound size ($in.^2$)	Number examined	Number[a] infected	Percentage infected
Small (0.1-1.0)	104	16	15
Medium (1.1-2.5)	69	21[b]	30
Large (2.6-5.5)	37	13	35
Totals and average	210	50	24

[a] Total of field and laboratory culture results.

[b] Differences between small and medium, and between small and large are significant at the 5% level of probability.

significant at the 5% level. Moreover, a significantly greater number of wounds with injured sapwood contained basidiomycetes than those wounds with uninjured sapwood. There was, however, no relation at the 5% level of significance between the occurrence of basidiomycetes and: pruned branch diameter (at least within the 0.3 to 0.6 in. range tested), branch status, compass orientation, height above the ground or dbh, total height, age or average terminal growth of the tree. Similarly, a scatter graph revealed no correlation between tree dbh and the amount of decay attributed to pruning. Nor was there a correlation between percent of the bole with decay and the number of infection courts. This may not be true were only one fungus considered, but no single basidiomycete occurred frequently enough to determine a relationship.

Fruit Body Survey

A variety of fruit bodies were present in the study area both on conifers and girdled hardwoods (Table 9). Five were species commonly known to attack coniferous trees, five occur only rarely on softwoods, and the balance are restricted to hardwoods. Also collected were three saprophytic fungi, Dasyscyphus agassizii, Aleurodiscus amorphus and Dermea balsamea; the last two occasionally act as weak parasites causing cankering and dieback of balsam fir (Conners, 1967).

Cull Survey of Pruned Trees

Balsam Fir

All five pruned trees examined in each area, Green River (A),

Table 9. Fruit bodies of wood-decay fungi collected from standing dead trees and slash near the site of the pruning study at Acadia Forest Experiment Station.

Host	Organism	Type of decay caused[a]
Balsam fir and black spruce	Polyporus abietinus	White rot of coniferous, or rarely, broad-leaved trees.
Balsam fir	Lenzites saepiaria	Brown rot of coniferous, or rarely, broad-leaved trees.
	Fomes pinicola	Brown rot of coniferous and broad-leaved trees.
	Fomes pini	Red ring rot of coniferous, and rarely broad-leaved trees.
	Stereum sanguinolentum	Brown heart rot of coniferous trees.
	Stereum purpureum	White rot of broad-leaved and coniferous trees.
Trembling aspen	Pleurotus ostreatus	White rot of broad-leaved, or rarely, coniferous trees.
	Polyporus pargamenus	White rot of broad-leaved, or rarely, coniferous trees.
	Polyporus dryophilus var. vulpinus	White rot of Populus spp.
	Polyporus dryophilus	White rot of broad-leaved trees.
	Stereum purpureum	White rot of broad-leaved and coniferous trees.
White birch	Fomes fomentarius	White rot of broad-leaved trees.
	Polyporus betulinus	Brown rot of Betula spp.
	Lenzites betulina	White rot of broad-leaved, or rarely, coniferous trees.
Red maple	Fomes connatus	White rot of broad-leaved trees, expecially Acer spp.

[a] from Nobles, 1948; 1965.

Table 10. Data on 5 balsam fir trees in each of 3 pruned stands.

Area	Date pruned	Avg. dbh (in.)	Avg. age at base (yr.)	Vol. of decay after pruning		Avg. pruned branch diameter (in.)	Avg. wound area ($in.^2$) $\frac{L.W}{2}$	Number examined and percentage infected with basidiomycetes			
				Avg./ tree (%)	Range (%)			Living branches (no.)	(%)	Wounds (no.)	(%)
Green River (A)	Aug./60	3.8	34	0.47	.02-2.08	.22	3.1	60	5.0	38	7.9
Crowdis Mt. (B)	June/62	3.4	37	1.66	.77-4.59	.32	2.3	70	4.3	73	8.2
Crowdis Mt. (C)	Sept./63	2.8	24	3.06	.33-4.25	.30	1.9	77	5.2	58	20.7
Avg.		3.3	32	1.73		.28	2.4		4.8		12.4

Crowdis Mountain (B) and Crowdis Mountain (C) contained measurable decay attributed to pruning. As also shown in Table 10, average volume of decay per tree and numbers of infection courts were least for trees pruned during August, intermediate in June and highest in September. This trend is supported by little evidence, but records from the weather station nearest each pruned stand reported only 3 days during August, 1960 with measurable precipitation and a mean temperature 36 to 60 F. Corresponding figures for June, 1962 and September, 1963 are 7 and 13 days respectively.

One or more decay-causing basidiomycetes (Table 11) were isolated from 9 of 15 trees. Each tree had an average of 8 dead (black) knots, 14 live (green) knots and 11 measurable wounds still evident as elliptical slashes on the bark (Fig. 11). No decay was noted in two unpruned trees in each area.

Table 11. Number of knots and wounds from which basidiomycetes were isolated in 5 balsam fir trees in each of 3 pruned stands.

Basidiomycete	Location of pruned stand		
	Green River (A)	Crowdis Mt. (B)	Crowdis Mt. (C)
Stereum sanguinolentum	1	8	10
Amylostereum chailletii	-	-	4
Polyporus abietinus	1	-	-
Peniophora sp.	-	1	-
unidentified	4	-	2
Total	6	9	16

Figure 11. Evidence of wound on balsam fir 4 years after pruning (left). Radial section of same wound from which Stereum sanguinolentum was isolated (right).

Of nearly 500 knots or wounds examined, discolored wood was associated with 8% of the dead knots, 12% of the live knots and 59% of the wounds. Decay-causing fungi were obtained in culture from 0, 4.8% and 12.0% of these injuries, respectively. As shown in Table 12, a larger proportion of cultures from discolored tissues contained basidiomycetes, imperfect fungi and bacteria, but fewer were sterile than from apparently normal wood.

White Spruce

Only five pruned and two unpruned white spruce were examined and the sample is too small for meaningful conclusions. Nevertheless,

Table 12. Frequency of isolation of different organisms in apparently normal and discolored wood associated with pruned branches of balsam fir.

Organism(s)	Cultures from Apparently normal wood (no. = 358)	Cultures from Discolored wood (no. = 135)
Basidiomycetes	0.8%	18.5%
Bacteria/Imperfects	34.1	60.0
Sterile	65.1	21.5

basidiomycetes were isolated from two of five pruned trees and measurable decay occurred in one of these trees (2.04% of volume), and one other (0.55%) from which no decay fungi were isolated. The trees averaged 35 years at stump height and 4.1 in. dbh. One of the 50 dead knots yielded Peniophora sp. in culture and S. sanguinolentum and Corticium laeve were isolated from 2 of the 42 wounds. Average wound size was 2.4 $in.^2$ and the average branch diameter at the time of pruning was .34 in.

DISCUSSION

Pruning of balsam fir trees should be done carefully or not at all if some of them are to be used for wood or pulp. Only $1\frac{1}{2}$ years after 7 branches were pruned on each of 30 trees, 28 trees had measurable decay averaging 3.9% of the stem volume, and during field culturing, wood decay

fungi were isolated from 31.4% of 70 wounds or knots. The latter percentage is probably an underestimate as there are several reasons why it is practically impossible to obtain cultures from all infections of wood-destroying fungi (Basham, Mook and Davidson, 1953). Davidson (1955) obtained successful cultures from only 36.6% of the butt decay examined in the Green River area.

Significant differences were present between the occurrence of basidiomycetes and careful and careless pruning and among the times of cultural isolation, but not among the times of pruning (Table 4). Careful saw pruning, however, was not better than careful axe pruning. Perhaps the rough surface of the sawn branch stub compared to the smooth axe pruned surfaces provided a niche more favorable for basidiospores. Infection was least in those branches pruned during the dry period possibly due to less favorable conditions for dispersal and germination of basidiospores, or the "higher temperatures may have reduced the chances of infection (of S. sanguinolemtum) by causing a temporary "breakdown" in the observed selectivity of balsam fir heartwood, thus favoring the colonization of the wound by competing fungi" (Davidson and Etheridge, 1963).

Numerous workers (Shigo, 1967; Etheridge, 1961 and Whitney, 1961) have considered the relative frequency of isolations of an organism from branches or wounds dead or exposed for known periods of time as an indication of the probable course of succession. Each worker found bacteria and non-decay fungi among the first organisms to invade and decay fungi the last. Similar trends were suggested by isolations made 2 to 3 weeks, 5 to 7 months, and 17 to 19 months following pruning of balsam fir (Fig. 6).

Initially 96% of the isolations were negative, but within 2 to 3 weeks this had dropped to 15% with dematiaceous imperfect fungi present in more than 50% of the isolation attempts. Only 1% of the cultures contained basidiomycetes. Five to seven months after the branches were pruned, the percentage containing bacteria rose sharply to 38. One year later the percentage of cultures containing bacteria and basidiomycetes had risen to 69 and 20, respectively. These results follow the expected pattern of succession, beginning with wood discoloration soon after the bark is ruptured and which is probably initiated by chemical changes, but enhanced by organisms. Siegle (1967) found fungi the main producers of the phenol oxidases which catalyze the discoloration process. Initial invasion by wood saprophytes, imperfect fungi and bacteria, induces a stain, a high pH, and a high moisture content. As the stain is destroyed, the pH and water content fall and the wood decay organisms dominate (Good, Basham and Kadzielawa, 1968 and Good and Spanis, 1958).

The continuing increase in incidence of bacteria suggests that basidiomycetes do not simply replace the bacteria and imperfect fungi, but rather exist with them. Either bacteria or imperfect fungi were isolated in immediate association with most of the basidiomycetes. This is not surprising as bacteria are considered pioneers in the wood decay process because of their ability to increase thiamine (many basidiomycetes require thiamine)content of the substrate (Fries, 1938). Bourchier [7] found

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[7] Bourchier, R. J. (Unpubl. rep., 1967). Wetwood and bacteria in balsam fir in the Maritime Provinces. Can., Dep. Forest. Rural Develop., Intern. Rep. M-21.

S. sanguinolentum mycelium produced in liquid shake cultures containing bacteria weighed about three times that produced in bacteria-free cultures. Even less is known of the role played by A. pullulans or many of the other imperfect fungi. Phialophora spp., the most commonly occurring moniliaceous fungi in this study, are capable of darkly staining red maple (Shigo, 1965), but little is known of their role in successional patterns or their effect upon wood properties. Numerous hyphae were observed to penetrate cell walls of a few wood sections which yielded cultures of Penicillium spp. or unidentified imperfect fungi. Merrill (1965) found weight loss and hyphal penetration by numerous common imperfect fungi in wood fiberboards. Obviously more work is required on the association of bacteria and imperfect fungi with the higher fungi.

Further work on succession should involve trap bolts or some means of limiting the period of possible infection. One of the greatest problems of successional studies based on frequency of occurrence of specific organisms is the uncertainty of infection time. It is not known, for example, whether the basidiomycete enters the wound at the same time as the primary invaders and simply grows slowly until the substrate is prepared or if indeed its entry is delayed. In this work the basidiomycetes could occur less frequently initially as suggested, or they could be more frequently isolated later simply because they have advanced further. Some basidiomycetes like S. sanguinolentum may only be primary invaders where the host is only susceptible to infection following summer produced injuries for about 24 hr (Etheridge, 1965), or up to 7 days with Fomes annosus (Cobb and Schmidt, 1964). Information regarding the infection process is lacking for the less aggressive basidiomycete invaders.

Research is needed on the effect of incipient and advanced decay on the yield and quality of pulp produced. Even before wood reaches the mill there may be much loss as incipient decay causes sinkage during water transport (Bakuzis and Hansen, 1965). In addition, shorter periods of yard storage may be required as pulpwood or chips may decompose faster following the introduction of fungi after pruning. Such general statements as "even small amounts of decay in balsam fir pulpwood cause serious reductions in yields and brightness of groundwood pulps" and "in the sulphite process decay affects the pulp produced more than for any other pulping process" (Glennis and Schwartz, 1952) have been made for North American wood species. Beath (1956) believes that for efficient operation of modern high speed paper machines decayed wood should make up less than 5% of wood used at any one time. These references, however, fail to account for differences between white rots and brown rots or to distinguish between incipient and advanced decay. In Sweden Björkman et al. (1964) found fungi that attack cellulose and lignin to approximately the same extent (S. sanguinolentum, Fomes pini), and present in a fairly advanced stage of development (firm dark rot), caused a 3-5% reduction in weight yield of sulphite pulp with mixtures of 10% by volume of decayed wood to corresponding sound spruce and pine wood. Pulp brightness was considerably lower, but the strength practically unchanged. Similar loss extimates are needed in Canada.

In the Maritime Provinces the future of Christmas tree-pulpwood management plans is uncertain. The projection of present decay rates and volumes is unreliable, but the consistency of decay in trees with only 7 pruned branches suggests that decay will be significant in balsam

fir trees after as many as 40 to 60 branches per tree have been pruned. This study reports the presence of more decay in younger trees than similar studies of unpruned trees[8/]. There was, however, considerable variation between areas. The average volume of decay per tree for Green River, Acadia Station, and the two Crowdis Mountain areas were respectively 0.5, 3.9, 1.7 and 3.1%. Similarly, basidiomycetes were associated with 6.1, 46.6, 6.3 and 11.8% of the pruned branches at these locations (Tables 5 and 10). The high incidence at Acadia and the variety of basidiomycetes isolated (Table 6) may stem from the open, mixed wood stand and the abundance of softwood and hardwood slash providing for a large basidiospore inoculum. Also, the open stand may be conducive to the build up of Sirex woodwasp populations, hence the abundance of A. chailletii in pruned trees. The percentage by volume of decay may vary in trees pruned $1\frac{1}{2}$ to 7 years ago because the initial rate of extension of a heart rot fungus in a tree may be much more rapid than that prevailing later and may stop almost completely after a relatively rapid initial advance (Wagener and Davidson, 1954). More is known, however, about the amounts of decay after a period of time than about annual rates of decay.

The low volume of decay in the Green River area may be due to many pruned branches being left with long stubs. Furthermore, no infection occurred at Acadia through branches clipped 4 to 6 in. from the bole, so clipping branches at a distance from the bole may reduce the incidence of decay, increase volume growth and provide a good lower whorl of branches

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8/ Smerlis, 1961; Davidson, A. G. (Unpubl. rep., 1951) A study of decay in balsam fir (Abies balsamea (L.) Mill.) in the Green River Watershed of New Brunswick.

for Christmas trees. This of course would only be suited to a Christmas tree-pulpwood operation for it would be many years before clear wood was formed.

Differences in amount of infection by trunk decay fungi could be due to factors associated with spore germination and infection (Davidson, 1955). Spore formation, liberation and dispersal might also be involved but virtually nothing is known of required conditions for even the most common and important of decay fungi. Were more known, it might be possible to prune when conditions were least favorable for the fungus. This study has indicated that hot dry periods may be best for pruning which agrees with recommendations for pruning plantations in Kenya (Griffen, 1967).

It is apparent that pruning of balsam fir, whether by axe or saw, is not to be recommended if discoloration and decay are to be avoided in a crop retained for a pulpwood harvest. Further research is needed on: (1) branch removal by clipping remote from the bole thereby reducing injuries which provide entry courts for decay fungi; (2) weather conditions favorable for basidiospore production, dispersal, germination and infection; (3) the role of bacteria and imperfect fungi in the discoloration and decay process; (4) the annual rate and total expected amount of decay following its entry into the stem; and (5) the effect of white and brown rots in varying amounts on final yield and quality of pulp. When this knowledge is at hand, pruning operations may be timed with conditions unfavorable to the initiation of discoloration and decay or at least to know what losses to expect in the end product.

REFERENCES 2/

Andrews, S. R. 1954. Effect of pruning on western red rot in young ponderosa pine in the southwest. J. Forest. 52: 33-38.

Anonymous. 1963. Native trees of Canada. Can., Dep. Forest., Bull. 61 Ottawa. 291 pp.

Bagchee, K. and B. K. Bakshi. 1950. Some fungi as wound parasites on Indian trees. Indian Forest. 76: 244-253.

Bakuzis, E. V. and H. L. Hansen. 1965. Balsam fir, a monographic review. Univ. Minnesota Press, Minneapolis. 445 pp.

Barnett, H. L. 1960. Illustrated genera of imperfect fungi. Burgess Publ. Co. Minneapolis. 225 pp.

Basham, J. T., P. V. Mook and A. G. Davidson. 1953. New information concerning balsam fir decays in eastern North America. Can. J. Bot. 31: 334-360.

_____ and Z. J. R. Morawski. 1964. Cull studies, the defects and associated basidiomycete fungi in the heartwood of living trees in the forests of Ontario. Can., Dep. Forest., Publ. 1072. Ottawa, 69 pp.

Bauger, E. and A. Orlund. 1962. A study of pruned trees of Sitka spruce, Abies grandis, western hemlock, Norway spruce, and Thuja plicata. (Eng. sum.) For. Res. Inst. West Norway. Publ. 36: 173-197.

Baxter, D. V. 1967. Disease in forest plantations: thief of time. Cranbrook Inst. Sci., Bull. 51. 251 pp.

Beath, L. R. 1956. The use of stained and rotten wood in the manufacture of newsprint. Forest. Chron. 32: 341-345.

Björkman, E. et al. 1964. The use of decayed wood from some conifers and broadleaf trees for chemical pulping purposes. Stud. Forest. Suecia, Stockholm. 66 pp.

2/ Abbreviations in accordance with American Standard for Periodical Title Abbreviations, 1963. Amer. Stand. Ass. N.Y. 19 pp.

Childs T. W. and E. Wright. 1956. Pruning and occurrence of heart rot in young Douglas fir. U. S. Dep. Agr. Pacific N. W. Forest Range Exp. Sta., Res. Note 132. 5 pp.

Cobb, F. W. and R. A. Schmidt. 1964. Duration of susceptibility of eastern white pine stumps to Fomes annosus. Phytopathology 54: 1216-1218.

Conners, I. L. 1967. An annotated index of plant diseases in Canada. Can., Dep. Agr., Publ. 1251. Ottawa. 381 pp.

Davidson, A. G. 1955. Decay of balsam fir (Abies balsamea (L.) Mill.) in the Maritime Provinces of Canada. Ph.D. Thesis, Univ. Toronto. 88 pp.

_____ and C. E. Brown. 1968. Disease cause code. Can., Dep. Forest. Rural Devlop. 164 pp.

_____ and D. E. Etheridge. 1963. Infection of balsam fir, Abies balsamea (L.) Mill. by Stereum sanguinolentum (Alb. and Schw. ex Fr.) Fr. Can. J. Bot. 41: 759-765.

_____ and D. R. Redmond. 1957. Decay of spruce in the Maritime Provinces. Forest. Chron. 33: 373-380.

Etheridge, D. E. 1965. Factors affecting infection of balsam fir by Stereum sanguinolentum. Proc. Can. Phytopathol. Soc. 31: 12.

_____. 1961. Factors affecting branch infection in aspen. Can. J. Bot. 39: 799-816.

Finnis, J. M. 1953. Experimental pruning of Douglas fir in British Columbia. Brit. Columbia Forest Serv., Res. Note 24. 26 pp.

Fries, N. 1938. Uber die Bedeutung von Weichsstoffen fur das Wachstum verschiedenes Pilze. Symbolae Bot. Upsaliensis 3: 1-188.

Funk, A. 1960. Descriptions of cultures of Fungi Imperfecti and Ascomycetes associated with forest damage in British Columbia. Can., Dep. Agr., Forest Biol. Div., Victoria. 17 pp.

Glennis, D. W. and H. Schwartz. 1952. Pulpwood decay: effect on yield and quality. Paper Ind. 34: 738-740.

Good, H. M., J. T. Basham and S. D. Kadzielawa. 1968. Respiratory activity of fungal association in zones of heart rot and stain in sugar maple. Can. J. Bot. 46: 27-36.

_____ and W. Spanis. 1958. Some factors affecting the germination of spores of Fomes igniarius var. populinus (Neuman) Campbell, and the significance of these factors in infection. Can. J. Bot. 36: 421-437.

Griffin, H. D. 1967. Further studies on Stereum sanguinolentum Alb. and Schw. ex Fries in Kenya forest plantations. (Abstr.) Forest. Abstr. 29: 851.

Harris, A. S. 1966. A test of pruning Sitka spruce in Alaska. U. S. Dep. Agr. Note NOR-13. 3 pp.

Hawley, R. C. and R. T. Clapp. 1935. Artificial pruning in coniferous plantations. Yale Univ., Sch. Forest. Bull. 39: 1-36.

Henman, D. W. 1963. Pruning conifers for the production of quality timber. Brit. Forest. Comm., Bull. 35. 55 pp.

Hubert, E. E. 1954. Isolations of fungi in the field using the Swedish increment hammer. J. Forest. 52: 131.

Kaufert, F. 1935. Heart rot of balsam fir in the Lake States, with special reference to forest management. Agr. Exp. Sta., Univ. Minnesota, Tech. Bull. 110.

Keeping, E. S. 1962. Introduction to statistical inference. Van Nostrand, Prunceton, N. J. 451 pp.

Lohrey, R. E. 1963. Healing time for pruning wounds in a red pine plantation. U. S. Dep. Agr., Res. Note LS - 24.

McCallum, A. W. 1928. Decay in balsam fir (Abies balsamea Mill.). Can., Dep. Agr., Bull. 104. Ottawa.

McLeod, J. W. 1968. Christmas tree management in the Maritime Provinces. Can., Dep. Forest. Rural Develop., Inform. Rep. M-X-15. 54 pp.

Merrill, W. 1965. Decay of wood and wood fiberboards by common fungi imperfecti. Holz. und Organismen Internationales Symp., Berlin. p. 69-76.

Nobles, M. K. 1965. Identification of cultures of wood-inhabiting hymenomycetes. Can. J. Bot. 43: 1097-1139.

_____. 1948. Studies in forest pathology. VI. Identification of cultures of wood-rotting fungi. Can. J. Res. 26: 281-431.

Ralston, R. A. and W. Lemien. 1956. Pruning pine plantations in Michigan. Michigan State Univ., Bull. 221. 27 pp.

Risley, J. H. and S. B. Silverborg. 1958. Stereum sanguinolentum on living Norway spruce following pruning. Phytopathology 48: 337-338.

Roth, E. R. 1939. The effect of pruning on the heartrot hazard in hardwoods. U. S. Dep. Agr. Mimeo. 9 pp.

Rowe, J. S. 1959. Forest regions of Canada. Can., Dep. N. Aff. Nat. Resources, Bull. 123. Ottawa. 71 pp.

Shigo, A. L. 1967. Successions of organisms in discoloration and decay of wood. Int. Rev. Forest Res. 2: 237-299.

_____. 1965. Decay and discoloration in sprout red maple. Phytopathology 55: 957-962.

Siegle, H. 1967. Microbiological and biochemical aspects of heartwood stain in Betula papyrifera Marsh. Can. J. Bot. 45: 147-154.

Skilling, D. D. 1958. Wound healing and defects following northern hardwood pruning. J. Forest. 56: 19-22.

Sleeth, B. 1938. Pruning wounds as an avenue of entrance for Stereum sanguinolentum in northern white pine plantations. U. S. Dep. Agr., Allegheny Forest Exp. Sta., Tech. Note 22: 1-3.

Smerilis, E. 1961. Pathological condition of immature balsam fir stands of Hylocomium - Oxalis type in the Laurentide Park, Quebec. Forest. Chron. 37: 109-115.

Spaulding, P. and J. R. Hansborough. 1944. Decay in balsam fir in New England and New York. U. S. Dep. Agr., Tech. Bull. 872

_____ and H. J. MacAloney. 1935. Stereum sanguinolentum, a dangerous fungus in pruning wounds on northern white pine. U. S. Dep. Agr., N. E. Forest Exp. Sta., Tech. Note 19. 2 pp.

Stillwell, M. A. 1966. Woodwasps (Siricidae) in conifers and the associated fungus, Stereum chailletii in eastern Canada. Forest Sci. 12: 121-128.

Toole, E. R. 1961. Rot entrance through dead branches of southern hardwoods. Forest Sci. 7: 218-226.

Van Sickle, G. A. 1966. Assessment of decay in pruned coniferous stands in Nova Scotia. Can., Dep. Forest. Rural Develop., Inform. Rep. M-X-4. 10 pp.

Wagner, W. W. and R. W. Davidson. 1954. Heart rots in living trees. Bot. Review 20: 61-134.

Whitney, R. D. 1961. Root wounds and associated root rots of white spruce. Forest. Chron. 37: 401-411.

APPENDIX I

Botanical and common names for tree species referred to in text.

Botanical Name[10/]	Common name
Abies balsamea (L.) Mill.	Balsam fir
Abies grandis (Dougl.) Lindl.	Grand fir
Picea abies (L.) Karst.	Norway spruce
Picea glauca (Moench) Voss	White spruce
Picea mariana (Mill.) BSP.	Black spruce
Picea rubens Sarg.	Red spruce
Picea sitchensis (Bong.) Carr.	Sitka spruce
Pinus ponderosa Laws.	Ponderosa pine
Pinus resinosa Ait.	Red pine
Pinus strobus L.	Eastern white pine
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Thuja plicata Donn	Western red cedar
Tsuga heterophylla (Raf.) Sarg.	Western hemlock
Acer rubrum L.	Red maple
Acer saccharum Marsh.	Sugar maple
Betula alleghaniensis Britt.	Yellow birch
Betula papyrifera Marsh.	White birch
Populus tremuloides Michx.	Trembling aspen
Ulmus americana L.	White elm

10/ Nomenclature in accordance with that used in Native Trees of Canada, Can., Dep. Forest. Bull. 61. 1963.

APPENDIX II

Botanical names 11/ for fungi referred to in text.

Aleurodiscus amorphus (Pers. ex Fr.) J. Schroet.

Amylostereum chailletii (Pers. ex Fr.) Boidin.

Armillaria mellea (Fr.) Kummer.

Aureobasidium pullulans (D By.) Arnaud

Corticium laeve Pers. ex Fr.

Dasycyphus agassizii (Berk. and Curt.) Sacc.

Dermea balsameae (Pk.) Seaver

Fomes annosus (Fr.) Karst.

Fomes connatus (Weinm.) Gill.

Fomes fomentarius (L. ex Fr.) Kichx

Fomes pini (Thore ex Pers.) Lloyd

Fomes pinicola (Sw. ex Fr.) Cke.

Hypoxylon deustum (Hoffm. ex Fr.) Grev.

Lenzites betulina (L. ex Fr.) Fr.

Lenzites saepiaria (Wulf. ex Fr.) Fr.

Pleurotus ostreatus (Jacq. ex Fr.) Kumm.

Polyporus abietinus Dicks. ex Fr.

Polyporus anceps Pk.

Polyporus betulinus Bull. ex Fr.

Polyporus dryophilus Berk.

Polyporus dryophilus var. vulpinus (Fr.) Overh.

11/ Nomenclature in accordance with that used by Davidson and Brown (1968). Disease cause code. Can., Dep. Forest. and Rural Devlp. 164 pp.

APPENDIX II (continued)

Polyporus pargamenus Fr.

Retinocyclus abietis (Crouan) Groves and Wells

Stereum purpureum (Pers. ex Fr.) Fr.

Stereum sanguinolentum (Alb. and Schw. ex Fr.) Fr.

APPENDIX III.

Schedule of pruning and culturing for 33 balsam fir trees at Acadia Forest Experiment Station, New Brunswick.

Pruning and branch stub cultures (2 isolates each branch)		Field cultures (3 isolates each knot) Time after pruning			Laboratory cultures (3 isolates each knot) All recultures November 23, 1967
		2-3 weeks	5-7 months	17-19 months	
		Tree nos.	Tree nos.	Tree nos.	
Dormant March 23, 1966	wound (A)	27,16,14,25, 21,15,13,26, 24,19,(32)	22,2,20,18, 5,7,23,4,9, 29,(31)	12,8,28,30, 17,3,6,1, 11,10,(33)	Group III October 23-31, 1967
	branch (B)	Group I April 6, 1966	Group II October 17, 1966	Group III October 17, 1967	
Active-dry July 4, 1966	wound (C)	Group III July 22, 1966	Group I October 17, 1966	Group II October 17, 1967	Group II October 23-31, 1967
	branch (D)				
Active-wet June 9, 1966	wound (E)	Group II June 28, 1966	Group III October 17, 1966	Group I October 17, 1967	Group I October 23-31, 1967
	branch (F)				
	branch (G) (saw)				

APPENDIX IV.

Related data for all wounds or knots from which basidiomycetes were isolated in 30 pruned balsam fir at Acadia Forest Experiment Station.

Tree no. & branch	Tree			% of volume with decay	Diameter of pruned branch (in.)	Wound Size			Compass orientation of wound	Height wound above ground (ft)	Field Cultures[c]	Lab cultures[c]	Insect galleries
	Age (years at stump)	dbh (in.)	Height (ft)			Length (in.)	Width (in.)	Area[b] ($in.^2$)					
1 - A[a]	48	2.8	17.4	17.22	0.7	7.3	1.5	5.5	N	6	FI, b	Ac,Sp,FI	-
- B					0.6	1.5	1.0	1.2	W	6	FI,b	Ac,FI,b	-
2 - C	33	2.0	15.6	1.16	0.4	2.0	1.0	1.0	E	7	Pl,FI	FI,b	-
- D					0.3	0.6	0.6	0.3	E	6	Bl,FI	FI	-
3 - A	35	1.8	13.8	9.69	0.2	3.5	0.8	1.4	S	4	FI,b	Ac	-
- E					0.4	4.5	1.0	2.2	N	5	Cl,FI, b	- - -	-
4 - B	45	2.2	15.0	14.83	0.5	1.0	0.7	0.6	W	5	B5,FI, b	- - -	-
- C					0.4	5.5	1.0	2.8	S	4	FI,b	Ac	+
- D					0.4	1.5	1.3	1.5	S	7	FI,b	Ac	+
6 - A	35	3.0	22.6	7.09	0.4	2.3	1.0	1.2	S	6	Cl,B5, b,FI	Ss,B5	-
- G					0.5	0.8	0.7	0.4	W	6	B2,FI	- - -	-
8 - A	47	2.6	19.3	2.07	0.4	5.0	1.2	3.0	W	7	Cl,b	Cl	-
- B					0.6	1.4	0.9	1.0	S	7	Cl,FI	Cl	-
9 - C	52	3.7	27.6	2.72	0.4	3.0	1.4	2.1	N	6	FI,b	Ac,b	+
- D					0.4	0.8	0.8	0.5	W	6	FI,b	Ac,b	+
- E					0.4	2.2	1.4	1.5	N	5	Pl,FI	- - -	-

APPENDIX IV. (continued)

Tree no. & branch	Tree Age	Tree dbh	Tree Height	% of volume with decay	Diameter of pruned branch	Wound Size Length	Wound Size Width	Wound Size Area[b]	Compass orientation of wound	Height wound above ground	Field Cultures[c]	Lab cultures[c]	Insect galleries
10 - A	46	4.9	29.7	0.33	0.4	3.2	1.5	2.4	E	4	Cl,b	Cl,FI, b	-
12 - A	52	2.7	20.2	18.88	0.4	2.0	1.0	1.0	E	6	Cl,FI, b	Ac,b	+
- D					0.4	0.6	1.0	0.5	N	4	Ac,FI	- - -	-
- E					0.4	3.5	1.0	1.8	W	4	B3,FI,b	- - -	-
15 - E	38	4.3	29.7	0.02	0.5	4.0	1.7	3.4	E	6	Cl,P2	Cl	-
16 - E	37	2.8	19.0	4.23	0.4	2.5	1.5	2.1	E	5	FI,b	Sp	-
- G					0.3	0.7	0.7	0.4	W	4	b,FI	Sp	-
17 - A	44	4.6	28.8	3.58	0.5	4.5	1.5	3.4	W	5	Cl,b, FI	Cl,Ss	-
18 - C	48	2.6	16.2	9.09	0.5	3.5	1.2	2.1	N	4	FI,b	Ac,b	+
- D					0.5	3.0	0.7	2.7	N	6	FI,b	Ac	-
19 - C	51	5.2	32.1	1.37	0.4	4.5	1.5	3.4	E	4	Ac,FI	- - -	-
- E					0.8	5.0	1.5	3.8	N	8	Sp,b	P2	-
- F					0.6	1.5	1.5	1.8	S	7	FI,b	Sp	-
- G					0.5	0.8	1.0	0.6	E	6	FI,b	Ac	-
21 - E	44	5.5	28.8	0.41	0.6	3.2	1.8	2.9	W	5	Cl,FI, b	Cl	-
22 - B	21	2.5	20.1	4.76	0.4	0.6	0.8	0.4	W	6	B2,b, FI	- - -	-
23 - C	26	2.7	20.1	0.92	0.4	3.0	1.0	1.5	W	7	B6,FI, b	FI,b	-
24 - E	36	2.7	20.9	0.47	0.4	7.0	1.0	3.5	E	6	B7,FI, b	Cl,FI, b	-

APPENDIX IV (continued)

Tree no. & branch	Tree Age	Tree dbh	Tree Height	% of volume with decay	Diameter of pruned branch	Wound Size Length	Wound Size Width	Wound Size Area[b]	Compass orientation of wound	Height wound above ground	Field cultures[c]	Lab cultures[c]	Insect galleries
25 - E	34	2.7	18.3	0.97	0.5	3.5	1.2	2.1	S	6	Sp,FI, b	Pl	-
- F					0.5	1.5	0.5	0.8	S	6	Sp,FI, b	Sp,b	-
- G					0.4	0.4	0.5	0.2	E	6	Bl,	Sp,b	-
26 - E	42	2.7	18.5	2.33	0.5	5.5	1.0	2.8	N	8	Sp,FI	Sp	-
- G					0.4	0.8	0.9	0.6	E	7	Bl,FI, b	Cl,b, FI	-
27 - E	29	2.3	18.0	0	0.2	0.7	0.9	0.3	N	3	B4,b, FI	b,FI	-
29 - B	50	3.3	23.4	9.26	0.4	1.7	0.7	1.1	W	7	B5,FI, b	- - -	-
- C					0.5	7.0	1.5	5.2	S	6	FI,b	Ac	+
- D					0.6	1.5	1.0	1.2	N	6	FI,b	Ac	+
30 - A	36	3.4	25.3	17.54	0.4	4.5	1.5	3.4	S	4	Cl,b	Ac,b,FI	-
- E					0.4	5.0	1.0	2.5	E	5	Pl,B8, FI,b	- - -	-
31 - A	28	2.0	14.5	2.47	0.5	3.5	1.0	1.7	W	3	B2,Ss, FI	- - -	-
- F					0.4	3.5	1.2	2.1	E	5	B2,FI	- - -	-
32 - E	32	2.5	17.5	0.20	0.5	5.0	1.0	2.5	W	7	Bl,FI, b	FI,b	-
- G					0.3	0.4	0.3	0.1	E	5	Bl,FI	FI,b	-
33 - A	28	2.5	18.3	2.94	0.5	3.0	1.0	1.5	W	4	FI,b	Ss,FI	-
Avg.	39.1	3.1	21.4	4.14	0.45	2.9	1.1	1.7		5.5			

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[a] Branches A (careless) B (careful) axe pruned March 23, 1966; C (careless) D (careful) July 4, 1966; E (careless) F (careful) G (sawn) June 9, 1966.

[b] Wounds A, C, E, diamond shaped, $A = \frac{L.W}{2}$; B, D, F, g more or less circular $A = \pi r^2$.

[c] Listed in order of decreasing number of cultures in each tree:

Ac = Amylostereum chailletii

Cl = Corticium laeve

Ss = Stereum sanguinolentum

Sp = Stereum purpureum

Bl, 2 ... = unidentified basidiomycete

Pl, 2= in Peniophora spp.

FI = Fungi Imperfecti

b = bacteria

--- = not cultured