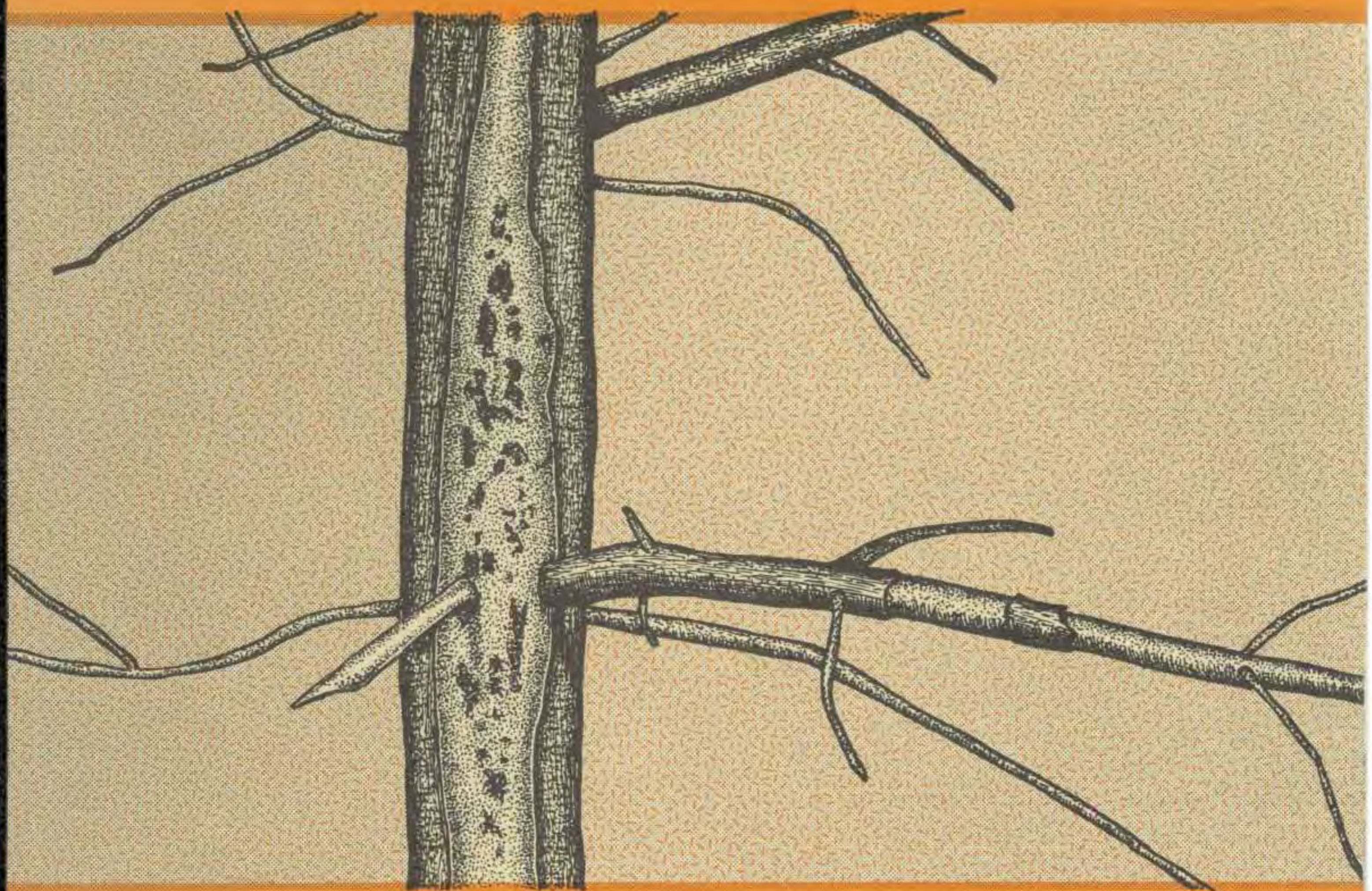

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ABSTRACT

Studies of the effect of Atropellis canker (*Atropellis piniphila* (Weir) Lohman and Cash) on the growth, mechanical and pulping properties of infected lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) were carried out in Alberta. The results obtained showed that the disease reduced the volume of infected trees up to 56.5%, and that infected trees gradually dropped out of their original crown classes.

The specific gravity of infected wood was almost double that of healthy wood, attributable to the high pitch content. The static mechanical properties of infected wood appeared to be unaffected, whereas the dynamic and some basic physical properties were lower than those of healthy wood.

Debarking of infected wood for pulping was difficult and 30% chip rejection occurred due to the high pitch content. Pulp yield loss caused by infection was 5-6% based on oven-dry extractive free wood; on oven-dry unextracted bases, it amounted to 11.9%. Pulp properties of infected wood were slightly lower than those of healthy wood except for the burst factor. Bleaching was very difficult.

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INTRODUCTION

Atropellis canker, caused by *Atropellis piniphila* (Weir) Lohman and Cash, is widespread on lodgepole pine (*Pinus contorta* Dougl.) in western Canada (8, 31). Disease incidence is highly variable (5, 26) and is greater in dense stands than in open ones, particularly in dry sites (17). Very high disease incidences were recorded in several stands in British Columbia (26) and Alberta (3, 10). From 78 to 100% of trees were infected and multiple stem cankers, sometimes 60 per tree, were common. Older cankers are usually covered by profuse resin flow and the cambium is killed in the infected areas, causing stem deformity. The cankers enlarge from year to year, mainly longitudinally (17). Circumferential spread of infection is very slow but may girdle small trees, while larger trees may also be girdled by several cankers at the same level (17). Re-examination of previously reported outbreaks in Alberta (30) demonstrated that up to 31% mortality may occur in severely infected stands. Survey results indicate rapid intensification of the disease.

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Over a 7-year period, a 10% increase in the number of infected trees was recorded in one stand (6), and the average number of cankers per tree increased from 3 to 5 during an 8-year period in another stand in Alberta (4).

The disease occurs primarily on lodgepole pine in British Columbia and Alberta, although it has been reported on other hosts: ponderosa pine (*P. ponderosa* Laws.) in British Columbia (25) and lodgepole pine-jack pine hybrid in Alberta (3). A line extending from Hazelton, B. C. eastward through Fort St. John to Edmonton constitutes the approximate northern limit of *A. piniphila* (8, 31), although the major host occurs well beyond this line.

The overall effects of the organism on tree growth, and the mechanical and pulping properties of infected wood have never been evaluated. A study was therefore conducted in Alberta in 1964, to determine these effects.

MATERIALS AND METHODS

To study the effect of varying degrees of infection on tree growth, three even-aged lodgepole pine stands were selected for sampling in the foothills of Alberta. The 65-year-old stand at Chungo Creek represented a wet site, as indicated by the continuous ground cover of mosses; site index of this stand was 50 ft (index age 50) (21). Over 80% of the trees were infected by *A. piniphila*, with an average number of eight cankers per tree. The second and third stands were 67 and 95 years old at Fallentimber Creek and Kananaskis, with site indexes of 45 and 40 ft, respectively. In the latter two, the high ground cover by *Arctostaphylos uva-ursi* (L.) Spreng. and *Calamagrostis rubescens* Buckl. indicated that they were dry sites. The average number of cankers per tree was five at Fallentimber Creek and two at Kananaskis.

Sampling for Growth Impact Determination

To minimize the effect of environmental differences, sample trees selected to represent similar site conditions were taken from an area of less than 50 acres in each case. Four infection classes were defined on the basis of the percentage of bark circumferences killed by one or more cankers at the same level (0-25, 26-50, 51-75, 76-100). Healthy trees of the stand served as controls. The following symptom classes, related to the infection classes, were used as a guide in the selection of standing sample trees.

0-25% - recent slight but noticeable pitch flow, scar usually not visible, crown healthy.

26-50% - visible canker, abundant pitch flow, crown healthy, canker usually just below the live crown.

51-75% - large visible canker, usually near top of tree or very large if below live crown - relatively less pitch flow than might be expected - crown deteriorating.

76-100%- tree dying, surface pitch dried, few live branches, needles very sparse and greenish yellow.

An attempt was made to sample twelve healthy and twelve infected trees in each of the four infection classes of a selected stand (60 trees). Each sample of 12 trees was to consist of 3 dominant, 3 codominant, 3 intermediate and 3 suppressed trees. However, due to difficulties to find the desired number of trees in the 76-100% infection class, at Chungo Creek only 3 dominant, 1 codominant, 2 intermediate and 3 suppressed trees and at Kananaskis, no dominant, 1 codominant, 3 intermediate and 2 suppressed trees were sampled. Hence a total of 171 trees were sampled in the three stands (Table I). The selected trees were felled and cut into 4-ft logs. Mensurational data were recorded for each log and Smalian's formula was used to calculate the cubic foot volume of the sample trees. The average volume of infected trees was compared to that of healthy ones and the volume differences

TABLE I. VOLUME LOSS CAUSED BY ATROPELLIS IN LODGEPOLE PINE STANDS

Location	Avg age	Infection Class: Healthy				1 - 25					26 - 50					51 - 75					76 - 100				
		No. of trees sampled	Average Dbh in	Average Hgt ft	Average Vol cu ft	No. of trees sampled	Average Dbh in	Average Hgt ft	Average Vol cu ft	Vol difference[1/] %	No. of trees sampled	Average Dbh in	Average Hgt ft	Average Vol cu ft	Vol difference %	No. of trees sampled	Average Dbh in	Average Hgt ft	Average Vol cu ft	Vol difference %	No. of trees sampled	Average Dbh in	Average Hgt ft	Average Vol cu ft	Vol difference %
Chungo Cr	65	12	6.5	45.8	5.4	12	6.1	43.8	4.9	9.3	12	5.2	42.1	3.5	35.2	12	4.4	40.3	2.4	55.6	9	4.8	41.3	2.5	53.7
Fallen-timber Cr	67	12	4.5	37.4	2.4	12	4.4	38.2	2.2	8.3	12	4.3	37.8	2.1	12.5	12	4.2	37.4	2.0	16.7	12	3.8	35.9	1.3	45.8
Kananaskis	95	12	4.8	34.0	2.3	12	4.6	35.0	2.2	4.4	12	4.3	34.5	2.0	13.1	12	4.0	31.8	1.4	39.1	6	3.5	32.0	1.0	56.5

[1/] Volume difference = $1 - \left(\frac{\text{Avg vol of infected trees}}{\text{Avg vol of healthy trees}} \right) \times 100$

were attributed to the effect of *Atropellis*.

The percentage of the circumference affected was measured at the center of the canker. If more than one canker was found at the same level, the killed areas were combined. The age of each atropellis canker was determined as described by Hopkins (17).

To study the pattern of radial growth of infected trees, six additional codominant and two intermediate trees were selected from the 95-year-old stand located in the Kananaskis Research Forest. The test sample included two codominants and two intermediates in the 76-100 and two codominants in the 26-50 infection classes. Two healthy codominant trees served as controls.

Detailed stem analyses were performed on the eight sample trees. The center of each internode was determined and a sample disk was taken to measure radial growth. The average radius method was used for ring width determination (12). Data were arranged for graphical analysis to study radial growth pattern on the basis of Duff and Nolan's type three sequence (16). Ring widths over year were punched on cards and a FORTRAN IV program was written for the IBM 360/50 computer to generate graphical stem analysis results on a Calcomp digital plotter.

Sampling for Wood Property Determinations and Pulping

Ten trees with large cankers were selected and cut in the stand at Kananaskis for the determination of specific gravity, pulp and pulping characteristics. The infected portion was removed from each stem and from these short bolts, the heavily black-stained wood was separated from the healthy part. Two specific gravity samples of ½ x ½ in were prepared for each of the two types of material from each tree and, using standard procedures, the appropriate specific gravity values were determined on an oven-dry basis (1).

An average representative sample of 20 lb was prepared for pulping from each of the remaining specimens of infected and healthy wood. Chemical analyses were conducted at the Western Forest Products Laboratory. The bark was removed by hand from both sets of samples and the chips were prepared with a Sumner experimental two-blade chipper[1/]. Table II shows the cooking schedule used for the 30 l. Weverk stainless-steel main digester and the stainless-steel precision digester studies.

Yield, brightness, burst, tear, screen rejects and bulk properties of pulps from infected and healthy wood were determined at different freeness levels and different permanganate numbers, using Standard Tappi procedures outlined in T 214 - ts-50. Bleaching studies were also conducted using small-scale laboratory techniques[2/].

Chemical analyses for the determination of Klason lignin (Tappi T 13-os-54), uronic anhydride (2) and extractive contents (Tappi T6 os-59) were carried out on the basis of indicated procedures. Glucose contents were determined on aliquots of the acidic filtrate from the Klason lignin determinations of the woods. The hydrolyzed sugars were reduced to alditols by borohydride and these reacted with acetic anhydride to form the corresponding alditol acetates. These derivatives were quantified by gas-liquid chromatography (27, 29).

[1/] The chips were prepared at the British Columbia Institute of Technology, Burnaby, B.C.

[2/] Bleaching studies were carried out by Dr. P.R. Thomas, Columbia Cellulose Co. Ltd. Technical Centre. Annacis Island, B.C.

TABLE II. PULPING CONDITIONS

	Main Digester	Precision digester	
		Non-extracted wood	Pre-extracted wood
Effective Alkali	16.5%	16.5%	16.5%
Sulphidity	23.5%	23.8%	23.8%
Time-to-max temperature	135 min.	135 min.	160 min.
Time-at-max temperature	85 min.	70, 85 and 100 min.	70 min.
Maximum temperature	171°C	171°C	172°C
Liquor-to-wood ratio			
(1) healthy	4 to 1	4.2 to 1	4.2 to 1
(2) infected		2.75 to 1	4.2 to 1
Maximum pressure	110-114 psi	———	———

RESULTS AND DISCUSSION

1. The Effect of *Atropellis* on Tree Growth

Relation of infection class to tree volume

Results of stand sampling are included in Table I. Volume differences between healthy and infected trees seem to be greatest in the 51-75 and 76-100% infection classes, reaching a maximum of 56.5%. The gradual decrease of average tree diameter and height from healthy to the higher infection classes indicates that the disease affected equally both component factors of volume. In the stand at Chungo Creek, the average number of cankers per tree was eight, compared to five and two in the other two stands, suggesting that, besides the rate of killing the bark, the number of cankers per tree has some influence on volume loss. Growth loss suggests that the separation of three infection classes (1-30, 31-60 and 61-100) would be sufficient to assess the effect of the disease.

Relation of infection class to radial growth

The effect of *Atropellis* on radial growth was studied on eight trees sampled in the Kananaskis stand (Table III). Most of the sample trees became infected by *A. piniphila* about 20 to 40 years ago and the majority of cankers were located on the lower two-fifths of the stem (Table III). Since the individual sequences of internodal cambial growth displayed similar characteristics, sequences of a 10-year period for both trees in an infection class were combined, averaged and plotted. Most of the sharp depressions on the graphs (Fig. 1) coincide with below-average precipitation during the growing season of the period (7). The average growth sequence of the two codominant trees in the 26-50% infection class was similar to that of the two healthy trees. The infected trees showed initial faster

TABLE III. DATA OF THE EIGHT TREES SAMPLED AT KANANASKIS FOR STEM ANALYSIS

Tree No.	Tree					Canker			
	Infection	Crown	D.B.H.	Hgt	Age	Age	Length	Bark circum-ference killed	Location above ground
	Class		in	ft	yr	yr	ft	%	ft
1	0	Co	5.5	52.4	90				
2	0	Co	6.5	47.8	97				
3	26-50	Co	7.6	58.6	97	40	3.3	40	16.0
4	26-50	Co	7.0	59.2	95	52	2.0	44	15.8
						38	1.7	34	21.4
5	76-100	Co	5.0	44.4	97	43	6.0	71	10.5
						20	4.0	79	18.5
						16	0.8	28	24.6
6	76-100	Co	7.0	52.5	88	25	4.3	76	25.0
						23	1.0	41	36.3
7	76-100	I	4.0	40.2	94	27	5.0	76	18.2
8	76-100	I	4.0	42.0	89	23	8.0	84	19.6

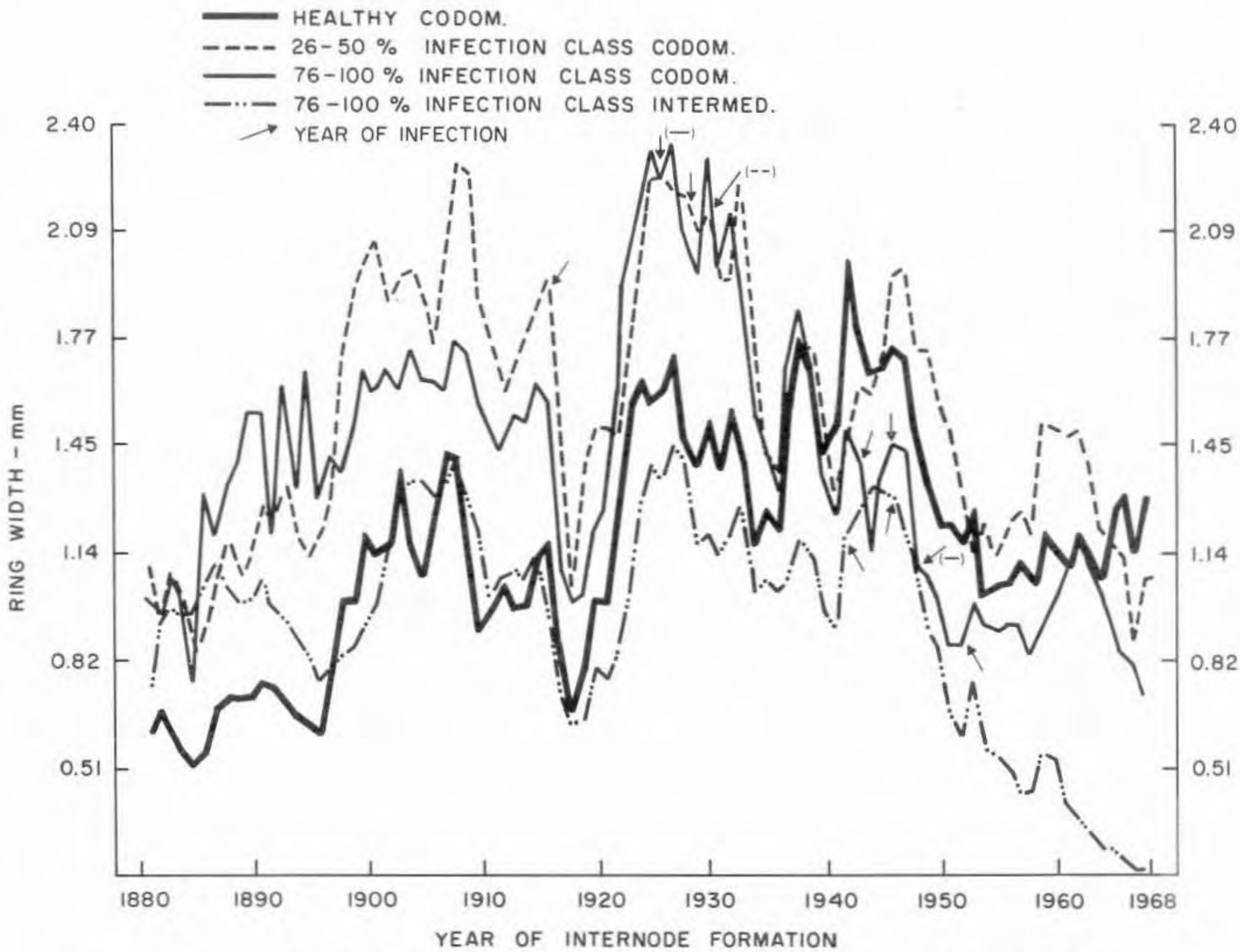

Fig. 1. Comparison of radial growth sequences of healthy and Atropellis infected lodgepole pine trees. Each graph represents the average radial growth sequence of two trees sampled in each infection class.

radial growth between 1883 and 1935 than the healthy trees. The 52-year-old canker of tree 4 and the 40-year-old canker of tree 3 (Table III) girdled 44 and 40% of the circumferences, respectively, but did not seriously affect the radial growth. The average initial radial growth rate of the two codominant trees in the 76-100% infection class was also faster than that of the healthy trees. Because of cankers, which girdled 79% (tree 5) and 76% (tree 6) of the circumferences, the radial growth rate started to decline 30-35 years ago, while the healthy trees exhibited a continued upward growth tendency. The two intermediate trees in the 76-100% infection class had been infected for 27 and 23 years and 76% (tree 7) and 84% (tree 8) of the circumferences were since girdled by cankers. The average growth rate of these trees dropped sharply after infection. The initially fast radial growth of the infected intermediate trees before 1900 suggests that they may have been dominant trees earlier. The limited data obtained during stem analysis (Table III) suggests that the circumferential extent or length of a canker was not directly correlated to canker age (compare trees 8 and 4).

2. Effect of *Atropellis* on Some General Physical and Mechanical Properties of Wood

When the fungus enters the wood, the major attack is on the parenchymatous elements which, in turn, are of relatively minor importance to strength properties, indicating that losses in strength would be very small and considerably less than those associated with decay (24).

Wangaard (32) and Panshin et al. (28) demonstrated that the mechanical behavior of wood can be predicted indirectly from specific gravity figures with acceptable accuracy for normal wood. The average specific gravity of 0.443 of healthy wood, based on oven-dry volume and oven-dry weight, was in close agreement with that of national averages for lodgepole pine (20). The specific gravity of the infected wood (0.715) was over 60% higher. The pitch and extractive contents were estimated to be approximately 38% from specific gravity figures based on infected wood. This value was 14.4% higher than that obtained by chemical extraction (18). The discrepancy can be explained by the nature and effectiveness of alcohol-benzene extraction.

The chemical analysis showed that the lignin and holocellulose content of infected wood was only 1.2% (18) and 4.3% lower, respectively, than that of normal wood based on extractive free wood, indicating that Atropellis might not affect the strength bearing constituent of wood. Therefore, it seems reasonable to assume the approximate validity of the relationship between extractive free wood specific gravity and mechanical properties.

Boyce (11), Knapp (23) and Colley (15) have studied the effect of sapstains on mechanical properties. From the specific gravity figures, holocellulose content and the results of the aforementioned studies, the infected wood is perhaps somewhat equal or higher in compression and in bending strengths when low to moderate static conditions are considered. In dynamic conditions, the reinforcing effect of excessive pitch content tends to reduce the elasticity and toughness of the infected wood (28).

The permeability and diffusibility would tend to decrease while the further decay resistance in service would be expected to increase for infected wood as a result of, and in relation to, the pitch content.

3. Effect of *Atropellis* on Pulping and Chemical Constitution of Infected Wood

The debarking and chipping characteristics of healthy and infected wood differed greatly. The infected wood samples, hard to debark even by hand, were almost impossible to debark by mechanical means without great wood volume loss. The chips obtained varied greatly in dimensions, with 30% rejection due almost entirely to oversize. The surfaces cut by the knives were rough and irregular, because of the high rigidity caused by excessive pitch content.

The effect on yield and pulp characteristics of healthy and infected lodgepole pine wood is given in Table IV for two freeness levels. That on yield and brightness is given in Table V for three permanganate numbers.

The yield differences between pulps of healthy and infected wood amounted to 5-6%, based on oven-dry extractive-free wood, depending on the permanganate number. When calculated on an oven-dry unextracted basis, the yield difference was almost double, i.e. 11.9%. Pulp from infected wood showed lower values in all properties, with the exception of burst factor, in comparison with those of pulp from healthy wood. The brightness of pulp from infected wood was nine points lower than that from healthy wood.

All pulp strength properties examined were well within the 95% confidence intervals of test results on pulps for healthy wood. The results of bleaching experiments indicated that approximately 50% more available chlorine is required for pulp from infected wood to reach a brightness of 87 compared to 92 for pulp from healthy wood. Other investigators studying wood infected by a variety of blue-stain and other organisms have also found that roughly similar additions of chlorine are required for bleaching (9, 13). The main difficulties in bleaching the pulp from infected wood are the pinkish-yellow color and the high pitch content.

To better understand the anatomical, physical, mechanical and pulping properties of Atropellis-infected lodgepole pine, its basic chemical constituents were compared to those of the extractive-free healthy wood.

TABLE IV. YIELD AND PULP PROPERTIES FROM HEALTHY AND ATROPELLIS-INFECTED LODGEPOLE PINE

Type of Wood Sample	Yield % (Wood)	Permanganate	Canadian Standard Freeness Level (ml)	Pulp properties				
				Burst Factor	Tear Factor	Breaking Length m	Screenings % (Wood)	Bulk cc/gm
Healthy	43.70 43.95[1]	19.14	500	92	100	13,200	1.07	1.45
Infected	32.05 42.00[2]	19.80	500	97	107	12,500	0.98	1.32
Healthy	-----	-----	300	99	100	13,500	----	1.40
Infected	-----	-----	300	102	98	13,300	----	1.30

[1] Yield corrected to permanganate number 19.8 using the expression, Yield (permanganate no. 20) = yield found (permanganate no. x) + 0.378 (20 - x) screened pulp.

[2] Yield calculated on an extractive - free basis. (The infected wood had an alcohol:benzene 1:2 extractive content of 23.6%).

TABLE V. YIELD AND BRIGHTNESS PROPERTIES OF HEALTHY AND ATROPELLIS-INFECTED LODGEPOLE PINE

Type of wood sample	Permanganate	Yield		Brightness	Time-at-max temp of 171° C (min)
		Total % (wood)	Extractive-free at permanganate no. 20 for pulp from infected wood		
Healthy	16.7	46.03	47.09[1/]	36.1	70
Infected	16.6	31.89	41.74	27.5	70
Healthy	13.6	44.92	46.63[1/]	----	85
Infected	15.3	31.68	41.47	----	85
Healthy	12.3	44.92	46.72[1/]	----	100
Infected	14.2	30.95	40.51	----	100

[1/] Yield of pulp from healthy wood was corrected to the same permanganate number as the pulp from infected wood to obtain meaningful differences.

The results of this study were published elsewhere (18). The holocellulose content of healthy wood was 68.7% compared to 64.4% of the infected wood.

The cellulose content in wood is known as the best indicator of its mechanical properties (24). Ifju (19) indicated, for example, that the tensile properties of Douglas-fir are mostly governed by cellulose content, whereas their crushing strength depends on lignin content. The existing small difference between holocellulose and lignin contents of infected and healthy wood seems to be in agreement with the previous results, i.e. the mechanical properties of infected wood are almost as good quality as healthy wood.

The high extractive content seems to be responsible for all difficulties such as dynamic resistance, chipping, pulping and bleaching of infected wood.

CONCLUSIONS

The application of the percentage of bark circumference killed by one or more Atropellis cankers as the basis for infection class separation appeared to be the right approach to determine the seriousness of the disease since the radial growth pattern of the infected trees (Fig. 1) did not appear to be related to canker age (Table III, trees 3 and 4). The use of three infection classes, 0-30, 31-60 and 61-100, in future work would be adequate.

The disease affected both height and diameter growth of severely infected trees (Table II). Volume reduction of infected trees up to 56.5% in the severe infection classes was observed, as was loss by increased mortality (30). Cankers that killed less than 50% of the circumference did not apparently affect radial growth; but tree growth, especially in the lower crown classes, was severely affected when 70+% of the bark circumference was killed. The suppressed growth of severely infected trees appears to lead to over topping. The combined influences are probably responsible for tree mortality (30).

The blue-black stain associated with the canker, like similar other sap stains, did not appreciably affect the quality of wood (11, 22). The proportion of stained wood depends on the number and dimensions of cankers per tree. Further research is needed to clarify the relationship between canker dimensions and volume of stained wood.

The specific gravity of infected wood was 1.61 times higher than that of healthy wood, due to the high extractive content. The static mechanical properties of infected wood appear to be unaffected, which can be explained by the negligible cellulose content reduction and the results of other investigators (11, 15, 23). Some of the basic physical properties such as diffusibility and permeability would be lower, due to the high pitch content. Frequently, small-size lodgepole pine trees are harvested for the manufacture of posts and poles: the critical ground line zones of these products should consist entirely of healthy wood. When preservation is considered, the low permeability of infected wood may cause problems. However, Cobb et al. (14) found that the mycelial growth of certain fungi was inhibited by volatile components of oleoresin. This effect is prolonged after the evaporation of these components by high concentration of phenols in resin soaked wood, which is inhibitory to fungus growth. The localized high pitch content may provide adequate protection to that location without any additional chemicals, but further research on this aspect is desirable.

In preparing the infected wood for pulping, debarking was difficult. Low quality chips were obtained and 30% chip rejection occurred, due to the high pitch content. However, in whole log chipping, this figure would be considerably reduced. The pulpability of infected wood was more difficult, as reflected by the higher permanganate number. Pulp properties of infected wood were slightly inferior to those of healthy wood, with the exception of the burst factor. Bleaching was very difficult and could be costly. The contents of all chemical constituents in the infected wood were lower in value, with the exception of uronic anhydride and extractives (18). Reduction of pulp yield due to *Atropellis* infection was 5-6% based on oven-dry extractive-free wood, and 11.9% when calculated on an oven-dry unextracted basis.

The major problem in the utilization of *Atropellis* infected lodgepole pine appeared to be the high pitch content and the stain. If the infected volume is less than 5% of the total volume, trees should be utilized for poles or posts. Based on personal observation, these products made from infected wood adequately withstand service requirements. Heavily infected stands could be harvested for the manufacture of chemical pulps with appropriate degree of blending (13). The pulp thus produced is suitable for the manufacture of corrugated medium or linerboard (23).

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