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ABSTRACT

Balsam fir trees killed by the eastern hemlock looper in Newfoundland were pulped and compared with pulps from living trees. Trees dead 3, 4, 5, and 6 years were used to prepare chemical and mechanical pulps in the laboratory and on a mill scale. In the laboratory chemical bisulphite and kraft pulps were prepared in sealed bombs in a controlled temperature oil bath. Chemical pulps were refined in a PFI mill. Mechanical pulps were prepared by refining presoaked chips in a 20 cm Bauer refiner. On a mill scale, chemical pulps were cooked in the high yield sulphite digester and groundwood pulps were produced on a Warren grinder. Pulps were compared for yield, strength and other properties. The dead trees yielded a lower amount and inferior quality pulp compared to pulps from living trees. Barking and chipping tests showed that losses were substantial for decayed wood. It is recommended that trees should be utilized within 4 years of death to minimize the increase in cost of manufacturing.

RÉSUMÉ

Des sapins baumiers de Terre-Neuve tués par l'arpenteuse de la pruche furent réduits en pâte et comparé avec la pâte venant d'arbres vivants. Les arbres morts depuis 3, 4, 5 et 6 ans furent utilisés dans la préparation de pâtes chimiques et mécaniques, en laboratoire et à l'usine. En laboratoire, les pâtes chimiques au bisulfite et au sulfate (Kraft) furent préparées en contenants scellés reposant dans un bain d'huile à température controlée. Les pâtes chimiques furent raffinées dans un moulin PFI. Les pâtes mécaniques furent préparées par raffinage de copeaux prétrempés dans un raffineur Bauer de 20 cm. Dans l'usine, les pâtes chimiques furent cuites dans le lessiveur au bisulfite à haut rendement et les pâtes mécaniques furent produites dans un broyeur Warren. Les pâtes furent comparées pour leur rendement, leur résistance et pour d'autres propriétés. Les arbres morts produisent une quantité moindre de pâte et de qualité inférieure comparé aux pâtes d'arbres vivants. Des essais d'écorcage et de mise en copeaux montrent que les pertes étaient substantielles pour le bois carié. Il est recommandé que les arbres morts devraient être utilisés durant les quatre années suivant leur mort pour minimiser l'augmentation des coûts d'usinage.

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ACKNOWLEDGEMENTS

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The authors are indebted to the late Dr. J.L. Keays, Research Scientist of the Canadian Forestry Service, Western Forest Products Laboratory, who provided technical advice throughout this study. The consultations with Dr. Harold Brownell, Research Scientist of the Canadian Forestry Service, Eastern Forest Products Laboratory and Mr. Harold Snow, Senior Research Engineer, Bowater Newfoundland Limited are gratefully acknowledged.

EFFECT OF SAPROT ON PULPING PROPERTIES OF

BALSAM FIR KILLED BY THE EASTERN HEMLOCK LOOPER

IN NEWFOUNDLAND

by

H.I. Hiscock[1], J. Hudak and J.P. Meades

INTRODUCTION

The eastern hemlock looper, Lambdina fiscellaria fiscellaria (Guen.), is native to Newfoundland and outbreaks of this insect occur in four to six year cycles with each outbreak lasting five to seven years. The larval stage of the looper thrives on balsam fir needles, and periodic attacks on the fir stands since 1912 have caused extensive defoliation and tree mortality.

The latest outbreak began in 1966 and it expanded at an alarming rate. The unprecedented magnitude of the outbreak prompted the two paper companies, Bowater Newfoundland Limited and Price (Nfld.) Pulp and Paper Mills Limited and the Government of Newfoundland to carry out an aerial spraying program. Areas in western and central Newfoundland were sprayed in 1968 and 1969 (Otvos, et al. 1971).

The outbreak began to decline in 1970 but the final result was that Newfoundland had an estimated twelve million cubic metres of dead balsam fir in various stages of decay.

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[1]Research Engineer, Bowater Newfoundland Limited.

The suitability of the dead trees for the manufacture of groundwood and chemical pulps was of major importance for the pulp and paper industry in Newfoundland. Bowater Newfoundland Limited requested and received a National Research Council grant under the Industrial Research Assistance Program to determine the pulping properties of wood in trees killed by the hemlock looper. The Canadian Forestry Service, Department of the Environment agreed to provide tree samples in which age, year of death, extent of decay, density, moisture content and chemical constituents were recorded.

This report documents the results of pulping tests and makes recommendations on the use of trees killed by the looper or that may be killed in future looper or other insect outbreaks that would cause the death of trees and lead to the same type of decay.

MATERIALS AND METHODS

Preparation of Samples

Trees for the laboratory tests of this study were provided by the Canadian Forestry Service from permanent sample plots at Serpentine Lake. These plots were established at the beginning of the looper outbreak to monitor the progress of defoliation, mortality and saprot and change in moisture content, and basic density (Hudak, Laflamme and Meades 1978). Tree mortality was indicated by the death of the inner bark at breast height. Trees dead for 3, 4, 5, and 6 years and containing average or greater than average penetration of saprot for the period since death were chosen. Living trees from the same area with comparable age and size were selected for control.

Trees were cut into 1.9 cm discs at 45° to the bolt. Discs were sawn into 1.3 cm wafers and these wafers were then hand chipped to give uniform chips of 1.9 cm x 1.3 cm x 0.3 cm which approximates the best chip size from the mill chippers. All knots and compression wood were discarded.

Each tree, both living and dead, was chipped into three separate samples; outer wood, inner wood, and mixture. The outer wood contained the saprot, the inner wood was sound and the mixture comprised both of these samples. This was accomplished by chipping wafers from one disc and keeping the inner and outer wood separate as indicated by discoloration caused by saprot. Wafers from each alternate disc were chipped and not separated. The whole tree was sectioned and chipped in this way (Fig. 1). The extractives, holocellulose and alpha cellulose contents of the samples were determined by the method of Erickson (1962) and Watson (1962) as modified by Hudak (1975).

Dead trees for mill scale trials were obtained from Bowater Newfoundland Limited timber stands in the Crabbes River watershed in western Newfoundland where the 1966 looper outbreak began. The stand was predominately mature and overmature and contained 98% balsam fir. Most of the trees were almost 100% defoliated in the first year of the outbreak, and were dead up to 6 years when used in this project. A seventeen cubic metre sample was taken from this area and although the selection was random, only standing trees were taken.

All other trees for this project were provided by Bowater Newfoundland Limited Woods Department.

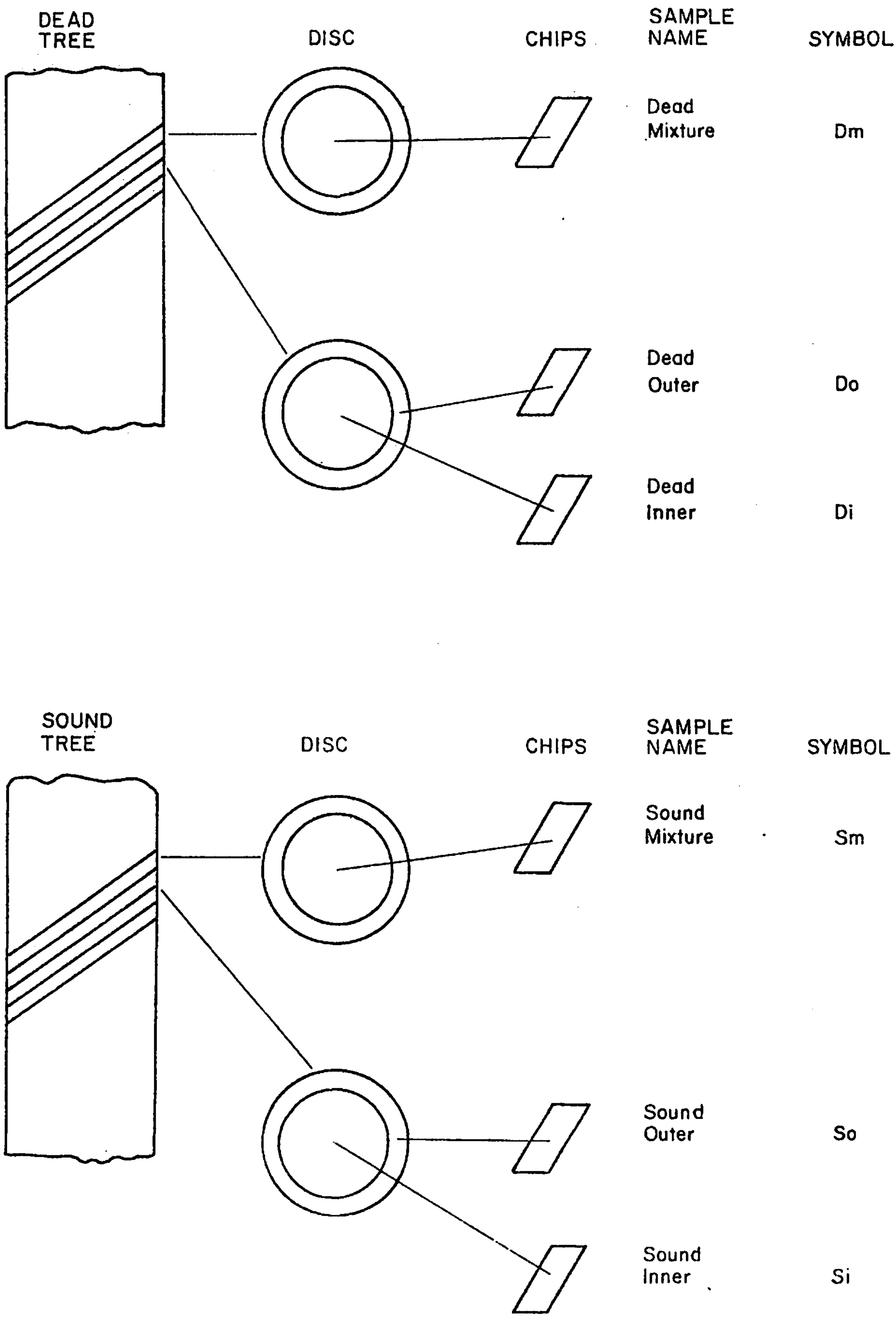

Figure 1. Preparation of samples for determining pulping properties of balsam fir killed by the hemlock looper.

Bisulphite Pulps - Laboratory Tests

Pulps were prepared by cooking air dried chips (moisture content 6-10%) in stainless steel sealed bombs of BK microdigester in a controlled temperature Teresso oil bath. The maximum temperature reached was 155°C. Cooking time was 5.5 h. The cooking liquor was sodium bisulphite with a total SO_2 of 4.0% and a pH of 4.5. The liquor to wood ratio was 4.5:1.0.

For each cook, six sealed bombs were used. Three bombs contained chips from decayed trees and three bombs contained chips from sound trees. Each bomb was charged with 55 g of chips and with an average moisture of 8% and at average yield of 65% produced approximately 32 g of oven dry bisulphite pulp. Two bombs, one containing decayed wood and one containing sound wood were used for determination of unscreened, total yield and the decayed and sound wood in the other bombs were assumed to have corresponding yields.

Pulp used for yield determination was discarded. Two bombs of decayed and two bombs of sound wood were then left for testing. Pulps used for testing were washed, disintegrated in a British standard disintegrator and then further refined in a PFI mill to approximately 300 CSF. A beater curve was produced for each sample (i.e. inner, outer, mixture) for each tree. Properties of replicate samples were extrapolated to 300 CSF using the beater curves. For this phase of the projects 18 decayed trees, and 11 sound trees were chipped and chemically pulped. Approximately 450 cooks were made. At first seven replicate samples were cooked and tested. Variations between samples from the same portion of the tree were small and hence, to allow more samples to be cooked, the number of replicates were reduced from seven to five and finally to three.

All tests performed were in accordance with the Technical Section standards of the Canadian Pulp and Paper Association (CPPA) or the Technical Association of the Pulp and Paper Industry (TAPPI).

The operation of the PFI mill was essentially as outlined in Tentative Standard C-7, CPPA, with the exception that 30.00 ± 0.25 g O.D. pulp was used instead of 24.00 ± 0.25 g.

The strength factor shown in this report is the multiple of burst factor, tear factor and 10^{-2}. This factor is not a CPPA or TAPPI standard, but it has been found useful at Bowater Newfoundland Limited in assessing pulp quality.

Bisulphite Pulps - Mill Test

Ten trees from the Bowater Newfoundland plot at Crabbes River were chipped in the mill chipper and then mechanically separated to remove large chips, knots, and dust. A sample from the good chips was cooked in a stainless steel perforated bomb which held the chips in a wire basket inside the bomb. The bomb was suspended by a stainless steel chain into the centre of a sulphite mill digester during a regular cook lasting approximately six hours. Sodium bisulphite was the cooking acid with pH of 4.5, a total SO_2 of 3.3%. Maximum temperature reached was 160°C. A bomb containing normal mill chips was cooked at the same time.

Cooked pulps were disintegrated in British Standard Disintegrator for 2000 revolutions and then refined for one min. in the PFI mill. Testing of samples was performed according to accepted standards.

Kraft Pulps - Laboratory Test

Kraft pulps were prepared from decayed trees dead for 4 years and from sound trees on a laboratory scale. Only wood mixture samples were cooked. The chips were cooked in stainless steel sealed bombs in a controlled temperature oil bath as used for bisulphite pulps. Cooking time was 7.5 h and the maximum temperature reached was 174°C. Ratio of cooking liquor to wood was 4.5:1. The cooking liquor was provided by Labrador Linerboard Mill and its properties are listed together with test results in Table 9.

Pulps produced were slushed in a British Standard Disintegrator but were not further refined. Physical properties were determined for the decayed and sound tree pulps.

Refiner Groundwood - Laboratory Test

The refiner groundwood trials were carried out on a laboratory scale with 20.3 cm Bauer disc refiner driven by a 10 H.P. motor. Plate clearance and screw feeder were hand operated.

Chip samples were soaked for 24 hours prior to refining. Chips were passed through the refiner until freeness was reduced to 100 ± 10 ml. Plate clearance was adjusted after each pass. Sound wood chips averaged 10 passes to obtain the desired freeness. Dead wood required approximately seven passes to obtain the same freeness. No attempt was made to measure power input into the stock.

After refining pulps were deshived on a Sommerville 0.015 cm cut plate and then tested by standard methods.

Refiner Groundwood - Mill Test

It was of interest to compare results from the Bauer 20 cm disc refiner to those from a mill test. Samples were shipped to Bauer Bros., Springfield, Mass. and a quantity of refiner groundwood samples were prepared using their 410 refiner.

Stone Groundwood - Mill Test

The major portion of a seventeen cubic metre sample taken from Bowater's test plot at Crabbes River was used in this trial.

A Warren grinder producing pit stock with a freeness in the range of 100-150 CSF at the time of the trial was chosen. The grinder magazine was filled to the top with normal wood supply and composite sampling began. As the mill supply wood dropped in the magazine, looper killed wood was added. A dye marker was inserted in a bolt in one of the decayed trees to indicate when these trees reached the stone. This procedure was repeated twice and composite sample of pulps from dead trees and normal mill supply trees were taken and tested. Samples for the four trials were taken over a period of approximately 10 hours. Pulps were screened on a 0.015 cm cut plate before testing.

Shive Content of Chemical Pulps

The shive test is a standard of the Technical Section, British Paper and Board Industry Federation. The shive content is the percentage rejects in 25 g of oven dry pulp screened on a 0.015 cm cut Sommerville plate.

In addition to the routine determination of shive content of chemical pulps tested for other properties the shive content at three different levels of freeness was determined for the outer wood samples from a tree dead for 4 and 6 years together with a control tree.

Linting Properties of Pulps

The International Printing Corporation (I.P.C.) uses a test procedure to assess the linting tendency of offset newsprint. This test is currently used by several European companies to control the linting quality of their offset newsprint. The Bowater Elphick Lint Test (BELT) is the Bowater version of the I.P.C. test. The BELT test consists of printing a paper sample in a Roto print R40/80 litho press. A disc section from the printed sample is then rubbed 50 times with a Patra Rub proofness tester and the number of fibres removed are counted with the aid of a microscope (X20 magnification) and grid.

Tests were conducted to compare hand sheets from decayed and sound trees and at different degrees of refining.

Debarking and Chipping Decayed Wood

The bolts from trees cut annually for saprot measurement and not used for pulping tests were marked with a red dye at either end and debarked in the Bowaters mill rotary drum barkers. The volume loss was computed from the diameters at middle before and after debarking. The test was repeated using larger diameter trees.

Also the sample of dead trees taken from the Bowater's plot at Crabbes River were debarked in the rotary drum and volume loss was determined.

A ten tree sample from the debarked wood from Crabbes River was chipped in the mill chipper. These chips were graded in a chip classifier and the percentage of distribution was determined.

Economic Value of Decayed Wood

The use of decayed wood in manufacturing newsprint results in increased cost per ton of paper. This increase is caused by higher wood costs resulting from handling and yield losses and by higher manufacturing costs incurred from the use of extra chemicals and power. The percentage of cost increase was estimated for using trees dead for 6 years but excluding any increase caused by losses during harvesting and transportation.

RESULTS AND DISCUSSION

Wood Characteristics

The properties of wood of sample trees are signified by the saprot content, basic density and moisture content (Tables 1 and 2) and by the extractives, holocellulose and alpha cellulose contents (Table 3). Trees were selected for average or greater rot penetration for a given period since death but the actual volume occupied by saprot varied among trees because of differences in the distribution of trees by diameter classes. Advanced rot did not occur until the fourth year (Hudak, Laflamme and Meades 1978) but due to variation one tree was without advanced rot among trees pulped in this group.

The basic density showed a gradual decrease with the increase in the number of years since death. The decrease in density of outer wood containing the rot was responsible for most of the decrease. It was estimated from a larger sample that the weighted average density of dead trees decreases about 5% in 5 years (Hudak, Laflamme and Meades 1978).

The moisture content on green weight basis varied from about 20% to 50% in dead trees and from about 48% to 64% in sound, living trees.

Among the chemical properties the extractives, holocellulose and alpha cellulose contents were determined. Results show that these properties did not change appreciably in the early years after the death of trees but in 6 years the extractives content increased to 5%, the holocellulose decreased to 67% and alpha cellulose decreased to 37%

Table 1.- Characteristics of hemlock looper killed balsam fir trees selected for pulping study.

Tree No.	Years since death	DBH (cm)	Age yr.	Saprot pen. (cm)		Saprot % merch. vol.		Basic density gr/cm^3			Moisture content % *
				Total	Advanced	Total	Advanced	Outer	Inner	Mixture	
LS 179	3	13.8	64	1.1	0.0	35.1	0.0	0.382	0.328	0.347	32.5
LS 232	3	15.5	75	1.0	0.0	27.5	0.0	0.391	0.346	0.360	34.4
LS 35	4	12.2	67	1.1	0.0	34.8	0.0	0.366	0.329	0.344	27.4
LS 218	4	12.2	-	1.6	0.8	55.6	22.8	0.297	0.312	0.302	30.1
LS 255	4	14.0	-	1.1	0.5	43.3	11.8	0.328	0.352	0.338	22.3
LS 305	4	13.7	69	1.3	0.3	38.2	6.9	0.363	0.338	0.349	24.5
LS 322	4	15.2	60	1.1	0.5	39.2	11.7	0.288	0.315	0.293	37.3
LS 802	4	13.7	70	1.5	0.3	41.1	8.7	0.331	0.329	0.330	23.8
LS 368	4	12.2	58	0.9	0.2	34.3	6.4	0.353	0.322	0.332	23.8
LS 398	4	12.2	70	1.2	0.2	40.7	3.0	0.426	0.349	0.389	19.3
LS 372	5	13.2	69	1.3	0.5	39.8	16.2	0.344	0.331	0.337	27.4
LS 397	5	13.5	62	1.3	0.7	29.1	7.7	0.305	0.311	0.310	22.5
LS 431	5	15.0	67	1.2	0.2	34.6	5.5	0.357	0.335	0.346	26.0
LS 697	5	11.7	67	1.0	0.3	36.1	11.9	0.406	0.374	0.391	50.9
LS 747	5	14.7	71	1.2	0.8	34.1	22.9	0.337	0.339	0.332	37.8
LS 793	5	14.2	72	1.7	0.6	49.2	22.0	0.318	0.309	0.313	33.5
LS 893	5	15.2	67	1.6	0.9	41.6	29.9	0.295	0.298	0.296	38.2
AM 706	6	15.2	48	2.2	1.0	56.1	26.4	0.284	0.316	0.297	-
AM 1470	6	12.2	45	1.9	0.3	56.9	12.9	0.301	0.291	0.300	-
AM 1685	6	15.5	61	1.5	0.4	37.1	11.4	0.272	0.289	0.291	-

*Green weight basis.

Table 2.- Characteristics of sound balsam fir trees selected for pulping study.

Tree No.	Years since death	DBH (cm)	Age yr.	Saprot pen. (cm) Total	Saprot pen. (cm) Advanced	Saprot % merch. vol. Total	Saprot % merch. vol. Advanced	Basic density gr/cm^3 Outer	Basic density gr/cm^3 Inner	Basic density gr/cm^3 Mixture	Moisture content % *
LS 2001	0	15.2	72	0.0	0.0	0.0	0.0	0.381	0.363	0.369	47.7
LS 2002	0	13.5	70	0.0	0.0	0.0	0.0	0.346	0.323	0.333	48.6
LS 2005	0	14.2	48	0.0	0.0	0.0	0.0	0.347	0.318	0.332	55.3
LS 2006	0	14.2	72	0.0	0.0	0.0	0.0	0.361	0.363	0.361	55.5
LS 2007	0	14.2	64	0.0	0.0	0.0	0.0	0.358	0.367	0.364	57.3
LS 2008	0	15.5	54	0.0	0.0	0.0	0.0	0.323	0.316	0.319	57.6
LS 2009	0	13.0	50	0.0	0.0	0.0	0.0	0.353	0.342	0.340	55.9
LS 2010	0	13.7	45	0.0	0.0	0.0	0.0	0.331	0.324	0.328	62.2
LS 2011	0	12.2	48	0.0	0.0	0.0	0.0	0.304	0.313	0.308	64.3
LS 2012	0	13.5	52	0.0	0.0	0.0	0.0	0.347	0.321	0.333	-
LS 2013	0	13.7	50	0.0	0.0	0.0	0.0	0.324	0.301	0.313	-
LS 2014	0	13.2	42	0.0	0.0	0.0	0.0	0.285	0.267	0.274	-
LSR-1	0	12.2	68	0.0	0.0	0.0	0.0	-	-	-	50.4
LSR-2	0	13.0	79	0.0	0.0	0.0	0.0	-	-	-	53.3

*Green weight basis.

Table 3. Chemical characteristics of hemlock looper killed balsam fir trees tested for their pulping properties.

Years since death	Outer wood: Extractives %	Outer wood: Holo-cellulose %	Outer wood: α - Cellulose %	Inner wood: Extractives %	Inner wood: Holo-cellulose %	Inner wood: α - Cellulose %	Mixed wood: Extractives %	Mixed wood: Holo-cellulose %	Mixed wood: α - Cellulose %
0 Control	2.3 ± 0.4*	73.8 ± 0.6	38.9 ± 0.5	2.7 ± 0.5	72.5 ± 0.4	39.0 ± 0.5	2.6 ± 0.2	73.3 ± 0.3	39.4 ± 0.5
3	2.5	69.7	42.8	3.6	70.6	41.0	3.2	71.3	40.4
4	3.5 ± 0.3	71.3 ± 1.1	42.5 ± 1.6	3.7 ± 0.3	72.7 ± 0.6	43.8 ± 0.6	4.0 ± 0.3	69.5 ± 1.1	40.5 ± 1.3
5	3.3 ± 0.7	70.3 ± 0.9	41.9 ± 1.6	3.8 ± 0.1	72.6 ± 0.8	43.3 ± 0.8	3.5 ± 0.2	71.7 ± 0.6	42.[illegible] ± 1.0
6	5.0	67.1	37.5	4.6	71.7	42.7	4.7	67.2	37.4

*Standard error.

in the outer decayed wood and to some extent in the mixed wood sample as well. Similar data were found for trees killed by the balsam woolly aphid (Hudak 1975).

The relatively constant alpha cellulose content in trees during the early years after death has a practical significance. It indicates that only the lower mulecular weight hemicelluloses were destroyed by the decay fungi and the higher molecular weight cellulose remained relatively intact (Cowling 1961). Furthermore the most important chemical factor affecting the yield and quality of chemical pulp is the alpha cellulose content of the wood (van Buijtenen 1969).

Bisulphite Pulp - Laboratory Test

Trees killed by the hemlock looper yielded a lower amount of inferior quality bisulphite pulp (Table 4). The total uncorrected yield from mixture wood samples decreased from 67.8% to 63.1% in 6 years after death. Similarly the burst factor decreased from 108.7 to 83.1, the tear factor decreased from 64.8 to 55.2 and the breaking length from 15.1 to 13.7. The optical properties of the pulp also deteriorated; the brightness decreased and the opacity decreased with the increase in years since death.

Losses in yield and quality of bisulphite pulp from the decayed outer portion of the wood was higher than that for mixed wood; the yield decreased to 60.9 in 6 years, the burst factor to 75.0 and the tear factor to 52.8.

The results for the inner wood also showed some decrease in pulp quality; burst factor decreased to 75 in 6 years. This decrease may have been caused by the imperfect separation of outer decayed wood from the inner sound wood. The separation was based on discoloration and decay fungi may have been present in some of the inner wood samples, especially in those from the upper portion of the stem.

Two other physical properties of the pulp from decayed wood require special mention. They are the refining properties and the shive content. Pulps from decayed wood refined to a lower freeness level more rapidly than pulps from sound wood. The shive content of chemical pulp from decayed wood was approximately five times as that for pulps from sound wood.

The higher shive content and more rapid refining are properties of pulp from decayed wood (Glennie and Schwartz, 1955; Shema 1955; Procter 1973). The higher shive content is probably caused by the uneven pulping of decayed wood and the faster refining is probably due to effect of decay on wood constituents. The samples contained mostly white rot which preferentially destroys the lignin. Brown, cubical rot which destroys the carbohydrate content was present only in negligible amounts (Hudak, Laflamme and Meades 1978).

An attempt was made to relate pulping properties with the amount of saprot by distributing the sample trees into five groups of increasing saprot content; group 1 was the control; it contained no

Table 4. Bisulphite pulping properties of sound balsam fir trees and trees killed by the hemlock looper.

Outer Wood

Parameter	Sound trees	Years since death: 3	4	5	6
Yield, %	67.4 ± 0.6*	65.8 -	64.4 ± 0.8	65.2 ± 0.8	60.9 ± 0.8
Hypo no.	19.4 ± 0.7	19.6 -	18.5 ± 0.4	17.2 ± 0.3	20.0 ± 1.7
CFS at 2 min. beating	360 ± 14	313 -	288 ± 29	261 ± 29	178 ± 42
Burst at 300 CFS	107.9 ± 2.8	89.0 -	89.3 ± 4.3	87.6 ± 3.1	75.0 ± 7.0
Tear at 300 CFS	66.9 ± 1.07	66.1 -	63.2 ± 2.7	62.4 ± 1.2	52.8 ± 0.3
Strength	72.1 ± 2.4	58.9 -	56.9 ± 4.5	54.7 ± 2.7	39.6 ± 3.6
Bulk	1.40 ± 0.03	1.48 -	1.47 ± 0.01	1.48 ± 0.02	1.42 ± 0.03
Breaking length (km)	14.8 ± 0.3	14.2 -	13.7 ± 0.5	13.1 ± 0.3	12.1 ± 1.3
Classification + 10	3.1 ± 1.4	2.7 -	2.2 ± 1.0	4.6 ± 1.1	- -
+ 14	38.0 ± 3.2	30.6 -	26.7 ± 3.9	47.4 ± 1.5	- -
+ 28	35.7 ± 2.7	38.2 -	43.6 ± 4.2	25.1 ± 1.7	- -
+100	14.0 ± 1.3	18.0 -	18.1 ± 1.2	13.6 ± 0.4	- -
-100	8.9 ± 0.6	10.9 -	10.5 ± 1.1	9.1 ± 1.0	- -
Brightness	50.9 ± 1.3	41.3 -	41.1 ± 1.7	41.9 ± 0.9	35.7 ± 0.5
Opacity	56.3 ± 1.4	63.4 -	64.4 ± 1.4	61.7 ± 2.4	62.4 ± 3.3
Color	61.8 ± 1.1	53.3 -	52.7 ± 1.7	53.9 ± 1.7	47.1 ± 0.7
Dominant wave length	580 ± 0.3	579 -	579 ± 0.3	579 ± 0.3	580 ± 0.0
% saturation	13.1 ± 0.5	15.8 -	15.9 ± 0.9	15.3 ± 0.6	18.8 ± 0.2
% shive	0.087 ± 0.04	- -	0.251 ± 0.08	0.55 ± 0.16	0.97 ± 0.14

*Standard error.

(Cont'd.)

Table 4. Bisulphite pulping properties of sound balsam fir trees and trees killed by the hemlock looper (Cont'd.).

Inner Wood

Parameter	Sound trees	Years since death: 3	4	5	6
Yield, %	68.1 ± 0.4*	67.4 -	68.2 ± 0.2	70.2 ± 0.8	68.9 ± 1.4
Hypo. no.	20.3 ± 0.4	19.9 -	20.8 ± 0.8	20.6 ± 0.8	20.8 ± 1.5
CFS at 2 min. beating	354 ± 15	330 -	372 ± 17	389 ± 16	384 ± 33
Burst at 300 CFS	108.0 ± 2.0	97.2 -	102.4 ± 2.52	103.9 ± 2.1	97.6 ± 2.1
Tear at 300 CFS	64.2 ± 0.6	63.2 -	61.7 ± 2.0	59.4 ± 1.0	56.7 ± 2.5
Strength	68.9 ± 1.2	61.4 -	63.1 ± 2.1	61.8 ± 2.0	55.4 ± 2.8
Bulk	1.37 ± 0.01	1.40 -	1.40 ± 0.01	1.39 ± 0.00	1.35 ± 0.01
Breaking length (km)	14.8 ± 0.2	14.6 -	14.4 ± 0.4	14.1 ± 0.2	14.3 ± 0.3
Classification + 10	0.8 ± 0.3	1.2 -	1.6 ± 0.6	1.2 ± 0.2	- -
+ 14	21.8 ± 4.0	23.4 -	25.2 ± 4.5	38.7 ± 3.1	- -
+ 28	47.9 ± 3.4	45.8 -	43.1 ± 5.0	34.7 ± 3.2	- -
+100	18.8 ± 1.5	20.1 -	18.1 ± 2.1	16.9 ± 1.8	- -
-100	10.7 ± 1.0	9.0 -	12.0 ± 1.3	8.4 ± 0.9	- -
Brightness	50.9 ± 1.0	48.1 -	46.1 ± 1.3	48.6 ± 1.3	44.7 ± 1.3
Opacity	54.3 ± 2.6	58.7 -	56.6 ± 1.3	53.5 ± 0.4	55.7 ± 2.2
Color	62.2 ± 0.8	58.7 -	59.6 ± 1.1	60.3 ± 1.2	54.0 ± 2.7
Dominant wave length	579 ± 0.3	579 -	580 ± 0.7	579 ± 0.6	580 ± 0.0
% saturation	13.7 ± 0.5	14.0 -	14.3 ± 0.5	14.4 ± 0.5	14.6 ± 0.5
% shive	0.075 ± 0.02	- -	0.16 ± 0.05	0.08 ± 0.01	0.58 ± 0.14

*Standard error.

(Cont'd.)

Table 4. Bisulphite pulping properties of sound balsam fir trees and trees killed by the hemlock looper (Concl'd.).

Mixed Wood

Parameter		Sound trees	Years since death: 3	4	5	6
Yield, %		67.8 ± 50.6*	65.5 -	66.1 ± 0.5	67.6 ± 0.4	63.1 ± 1.8
Hypo. no.		20.3 ± 0.5	19.9 -	19.3 ± 0.5	18.8 ± 0.4	19.3 ± 0.4
CFS at 2 min. beating		363 ± 15	396 -	298 ± 61	287 ± 35	256 ± 72
Burst at 300 CFS		108.7 ± 2.0	94.5 -	97.8 ± 2.7	96.3 ± 1.9	83.1 ± 3.6
Tear at 300 CFS		64.8 ± 0.6	65.3 -	63.3 ± 1.9	61.7 ± 1.1	55.2 ± 1.4
Strength		70.3 ± 4.2	61.6 -	61.9 ± 2.4	59.9 ± 2.1	46.0 ± 2.6
Bulk		1.39 ± 0.01	1.41 -	1.43 ± 0.01	1.42 ± 0.00	1.40 ± 0.03
Breaking length (km)		15.1 ± 0.2	13.7 -	14.1 ± 0.4	14.2 ± 0.2	13.7 ± 0.3
Classification	+ 10	1.5 ± 0.5	1.7 -	2.2 ± 0.9	1.5 ± 0.3	- -
	+ 14	30.9 ± 3.8	28.1 -	23.5 ± 3.9	41.1 ± 3.3	- -
	+ 28	40.4 ± 3.1	40.7 -	43.0 ± 4.7	31.1 ± 3.2	- -
	+100	17.7 ± 1.2	17.6 -	25.0 ± 5.4	16.4 ± 0.9	- -
	-100	9.5 ± 0.6	12.2 -	10.8 ± 1.0	9.9 ± 0.8	- -
Brightness		50.8 ± 1.2	44.4 -	42.5 ± 1.0	46.3 ± 1.1	39.1 ± 1.0
Opacity		54.1 ± 1.0	61.3 -	59.8 ± 1.0	57.4 ± 0.9	57.9 ± 3.1
Color		61.0 ± 1.5	55.0 -	55.0 ± 1.2	57.3 ± 0.9	49.3 ± 0.6
Dominant wave length		580 ± 0.3	579 -	580 ± 0.4	579 ± 0.2	579 ± 0.0
% saturation		13.7 ± 0.5	14.5 -	16.1 ± 0.5	15.1 ± 0.5	16.5 ± 0.4
% shive		0.08 ± 0.02	- -	0.15 ± 0.05	0.62 ± 0.28	0.55 ± 0.08

*Standard error.

rot and group five contained a total of about 55% including 21% advanced rot. Pulp yield from decayed outer wood decreased from 67.4% to 61.2% among the groups and the quality of the pulp also deteriorated; burst factor decreased from 107.9 to 85.9, tear factor from 66.9 to 61.5 and brightness from 50.9 to 43.0 (Table 5). Corresponding pulp yield and quality decreased to a lesser extent when mixture wood was tested; yield decreased from 67.9% to 63.1%,burst factor to 93.5, tear factor 63.3 and brightness to 46.2 (Table 6).

Results from laboratory test using composite samples from the Bowater sample plot at Crabbes River compare favourably to the grand average of data from mixture wood of trees provided by the Canadian Forestry Service from Serpentine Lake (Table 7).

Bisulphite Pulp - Mill Test

Accurate yield determinations cannot be made in mill tests. Therefore the yield was assumed to be mill average of 70% (Table 8). Also the pulps were tested at a higher freeness in an attempt to duplicate normal mill sulphite stock which averages 700 ml. It was difficult to produce pulp similar to the mill sulphite because of the difference in refining procedure. The pulps produced from decayed trees showed lower strength factor (Table 8).

Table 5. Yield and quality of bisulphite pulp from balsam fir killed by hemlock looper (Dead outer wood - Do sample)

Parameter	Groups* 1	2	3	4	5
Total saprot, % of merch. vol.	0.0	28.3	34.7	40.1	54.5
Advanced rot % of merch. vol.	0.0	3.9	7.1	14.2	21.0
Yield, % total	67.4	67.3	63.8	62.5	61.2
CSF @ 2 min. refining	360	264	285	214	183
Burst factor	107.9	92.9	100.2	90.6	85.9
Tear factor	66.9	67.6	68.6	64.8	61.5
Strength factor	72.1	62.3	68.7	58.7	52.8
Breaking length; km	14.80	14.58	14.27	14.05	13.05
Brightness (Elrepho)	50.9	43.5	48.2	44.0	43.0
Opacity	54.3	59.4	58.6	61.0	60.3

*Increasing amounts of saprot.

Table 6. Yield and quality of bisulphite pulp from balsam fir killed by hemlock looper (Dead mix wood - Dm sample)

Parameter	Groups* 1	2	3	4	5
Total saprot, % of merch. vol.	0.0	28.3	34.7	40.1	54.5
Advanced rot % of merch. vol.	0.0	3.9	7.1	14.2	21.0
Yield, % total	67.9	67.8	65.5	65.0	63.1
CSF @ 2 min. refining	363	298	256	255	202
Burst factor	108.6	104.3	101.6	98.8	93.5
Tear factor	64.7	66.7	68.5	64.0	63.3
Strength factor	70.3	69.6	69.6	63.2	59.2
Breaking length; km	15.10	14.98	14.38	14.19	14.28
Brightness (Elrepho)	50.8	48.7	49.1	48.5	46.2
Opacity (Elrepho)	54.1	55.5	58.9	59.2	58.0

*Increasing amounts of saprot.

Table 7. Comparison of bisulphite pulps from sound trees and from trees killed by the hemlock looper - laboratory test.

Parameter	Decayed wood sample from Bowaters test plot	Decayed mixture wood Dm	Sound mixture wood Sm
No. of trees	10	18	11
No. of trials	1	90	54
Freeness, CSF, ml	300	300	300
Yield % total	66.4	66.3	67.9
Burst factor	95.0	94.4	108.6
Tear factor	65.8	61.9	64.7
Strength factor	62.5	58.4	70.3
Bulk cc/gm	1.40	1.43	1.39
Breaking length km	13.85	14.00	15.10
Elrepho brightness	47.8	43.7	50.8
Elrepho opacity	53.9	58.6	54.1
Color - yC	59.4	55.1	61.0
Dominant wave length	578	579	580
% saturation	14.2	15.6	13.7

Table 8. Comparison of bisulphite pulps from sound trees and from trees killed by the hemlock looper - mill test.

Parameter	Decayed wood composite from Bowaters test plot	Sound wood mill supply	Average sulphite mill production
No. of trees	10	mill supply	-
No. of trials	3	3	-
Approximate % yield	70	70	70
Disintegration - rev.	2000	2000	-
Refining time - min.	1.0	1.0	-
Freeness, CSF, ml	713	725	700
Burst factor	67.1	68.4	64
Tear factor	69.6	73.1	83
Strength factor	46.7	50.0	53
Bulk cc/gm	1.74	1.69	1.74

Kraft Pulps - Laboratory Test

Trees used in this test were dead for 4 years and had an average incipient and advanced decay. Only wood mixture samples were pulped. Results showed a less than 2% loss in yield but a 19.5% lower burst factor and an 8.9% lower tear factor (Table 9). The greatest loss occurred in the burst factor, about twice the loss recorded for tear factor. The kraft process uses alkaline cooling liquor and is known to be more robust for pulping defective wood (Glennie and Schwartz 1955; Shema 1955 and Procter 1973). In comparison to the bisulphite method the use of decayed wood in the kraft process will cause more yield loss, but a smaller decrease in the quality of pulp.

Refiner Groundwood - Laboratory and Mill Tests

A comparison of refiner groundwood quality from the Bauer 20 cm disc refiner and that from the Bauer 410 refiner shows a considerable difference in the tear factor, but the factor and breaking length were surprisingly similar (Table 10). Pulps from decayed trees were inferior in quality and this loss in quality was more pronounced for the decayed outer wood than the mixed wood in the tree. The loss in burst factor and brightness for refiner mechanical pulp were similar to those for chemical pulps but tear factor difference between decayed and sound trees was much greater for mechanical pulps than for chemical pulps.

Similarly to chemical pulps decayed groundwood also required less refining than sound wood to reach the required freeness level.

Table 9. Properties of kraft pulp from sound balsam fir trees and from trees killed by the hemlock looper (sound mixture - Sm and decayed mixture - Dm samples).

Parameter	Decayed	Sound
No. of trees	2	1
No. of trials	2	2
Max. temp.° C	174	174
Effective alkali gm/ml	0.040	0.040
Active alkali gm/ml	0.046	0.046
Total titratable alkali	0.053	0.053
Sulphidity %	11.47	11.47
Yield % total	44.5	46.2
Refining time	0.0	0.0
CSF, ml	651	647
Burst factor	87.3	106.8
Tear factor	130.3	139.2
Strength factor	113.8	148.7
Breaking length k.m.	13.30	13.30
Bulk cc/gm	1.61	1.52

Table 10. Properties of refiner groundwood pulps from sound trees and from trees killed by the hemlock looper.

Parameter		Sound trees* mixed wood Sm	Sound trees** mixed wood Sm	Decayed trees* mixed wood Dm	Decayed trees* outer wood Do
No. of trees		3	-	6	6
No. of trials		8	-	10	10
Burst factor		24.9	22.7	21.6	19.2
Tear factor		56.6	81.7	53.0	45.5
Strength factor		14.1	18.6	11.4	8.9
Breaking length km		48.14	43.80	42.33	40.46
Bulk cc/gm		2.34	2.52	2.35	2.39
CSF, ml		98	100	105	100
Classification	+ 28	32.3		32.7	29.2
	+ 48	19.6		18.8	18.0
	+100	13.4		12.9	12.8
	+200	9.1		9.6	9.8
	-200	25.6		26.0	30.2
Screen rejects		8.2		10.1	8.9
Elrepho brightness		59.9		51.5	-
opacity		94.6		97.6	-
Color yC		71.3		63.2	-
% Saturation		11.1		12.2	-
Dominant wave length		578		578	-

*Bauer 20 cm disc refiner.
**Bauer #410 refiner.

Stone Groundwood - Mill Test

The quality of pulp produced on a grinder stone may vary considerably depending on stone condition, cutting rate, power and other factors. The grinder 3A was chosen for this test because the freeness was close to the average of 120 ml for Warren grinders. The quality of pulp produced from sound, normal wood supply on this grinder was slightly less than average. However, the quality of pulps produced from decayed wood was considerably less than the pulp from normal sound wood (Table 11). The burst factor, tear factor and breaking length decreased. Considering only wood mixture, the differences in quality are greater than the difference in quality for bisulphite pulps or refiner pulps. Similar results were obtained from pulping balsam fir trees damaged by the balsam woolly aphid (de Montmorency 1966).

Shive Content of Pulp from Decayed Trees

The shive content of chemical increased with the decay (Table 4). Sound wood pulp had an average shive content of 0.081% which is considered negligible, while decayed wood, outer and mixture, had an average shive content of 0.45% which is extremely high for 300 CSF. The mill production has an average of 0.40% shive at 700 CSF.

Shive has been considered to be the cause of several problems such as most of the breaks in both the press room and on the paper machine. Shive is also claimed to be the main cause of most linting problems. The shive from decayed pulps are particularly offensive because they are discolored and readily noticeable in the paper.

Table 11. Properties of stone groundwood pulp made in grinder 3A using normal wood supply and wood from trees killed by the hemlock looper.

Parameter		Decayed wood sample from Bowater test plot	Corner Brook Mill, normal wood supply
CSF, ml		139	127
Wet tensile stength		122	133
Elrepho brightness		58.2	61.6
Burst factor		11.1	13.3
Tear factor		40.8	45.9
Strength factor		4.5	6.1
Breaking length km		24.70	29.80
Bulk cc/gm		2.74	2.73
Classification	+ 28	13.2	12.8
	+ 48	18.5	19.8
	+100	19.0	20.7
	+200	14.1	15.4
	-200	35.2	31.3
Screen rejects %		1.43	1.50

Table 12. Shive content of chemical pulps from decayed trees killed by the hemlock looper.

	Percent Shive		
CSF, ml	Sound tree outer wood	Decayed tree dead 4 yrs. outer wood	Decayed tree dead 6 yrs. outer wood
450	0.231	1.552	1.560
350	0.080	0.130	0.432
250	0.027	0.059	0.291

Considerable effort has been expended by the industry to remove shive and refine it to an acceptable level. Pulps from the decayed outer wood from trees dead 4 and 6 years together with control were tested at different freeness levels (Table 12). The results show that pulps from decayed trees would have to be refined to a freeness below 250 CSF to achieve an acceptable shive level.

Linting Properties of Pulp from Decayed Trees

Preliminary tests included handsheets prepared from mill bisulphite pulp from sound balsam fir. The I.P.C. count on these handsheets at 300 CSF was 22. The test on decayed trees included handsheets at different refining (Table 13). Results showed that the I.P.C. count on handsheets from decayed wood was about 20% higher than that from sound trees. The data also show the decrease in I.P.C. count with an increase in refining. Although the roughness of the sulphite handsheet is high for satisfactory printing, it appears the results are consistent with the four levels of refining.

Debarking and Chipping Decayed Wood

Trees cut for annual assessment of saprot and not used for pulping were tested for volume loss during debarking in the mill drum debarker. Trees dead from 3 to 6 years were tested and volume loss increased from 5.2% to 11.1% for an average of 8.8% (Table 14). The test was repeated with trees from larger diameter classes and the volume loss increased from 6.1% to 8.1% in trees dead from 3 to 6 years respectively (Table 14). The loss increased with the amount of advanced

Table 13. Comparison of lint count on chemical pulp handsheets from living trees and from trees killed by the hemlock looper.

Refining time (min.)	I.P.C. lint count	
	Sound mixture wood	Dead mixture wood
1	31.5	35.0
2	25.5	32.2
3	20.0	25.8
4	12.2	15.8

Table 14. Percentage of volume loss in debarking balsam fir killed by the hemlock looper.

Years since death	Average D.B.H., cm	Saprot penetration, cm		Saprot % merch. vol.		Volume loss %
		Total	Advanced	Total	Advanced	
		Test no. 1, 1974				
3	11.4	1.16	0.0	40.0	0.0	5.2
4	14.5	1.32	0.38	35.5	11.1	7.9
5	13.0	1.29	0.51	38.1	15.6	9.1
6	15.0	1.70	0.55	46.8	18.3	11.1
Average	13.4					8.8
		Test no. 2, 1977				
3	19.1	1.22	0.0	30.6	0.0	6.1
4	19.1	1.55	0.81	38.3	20.8	4.5
5	18.5	2.03	1.42	39.3	26.7	7.3
6	21.6	2.06	1.04	40.1	22.5	8.1
Average	19.3					5.4

rot within each test. However, trees in the second test had more advanced decay but losses were lower than in the first test. This inconsistency may be caused by differences in the operating conditions of the debarker at different times.

The composite sample from the Bowater's sample plot at Crabbes River was also tested. The data from trees recovered from the debarker showed an average of 14% volume loss (Table 15). The average volume loss for sound trees was about 2-3%. However, these estimates are considered to be conservative because many of the bolts of smaller diameters disintegrated in the grinder.

A 10 tree sample from the debarked trees were chipped in the mill chipper and the chips were classified. The results in comparison to normal mill supply show that the fraction of good chips (2.5 cm) is smaller for decayed wood. The fraction of chips passing the 0.6 cm (1/4") was 6.8% for decayed wood and only 1.3% for sound wood.

Economic Value of Decayed Wood

The use of hemlock looper killed wood to produce newsprint would result in a cost increase per ton. This increase would be due to higher wood costs as a result of handling and yield losses and higher manufacturing costs incurred from bleaching, extra power for shive removal, and the use of extra chemical pulp to maintain strength. The increase in cost would depend on the extent of decay and/or the number of years dead. The increase cost per ton of newsprint as a result of using 100% killed wood dead 6 years is estimated at about 20% (Table 16).

Table 15. Debarking and chipping properties of normal wood supply and of wood from trees killed by the hemlock looper.

Parameter	Decayed wood	Normal mill supply
Classification		
1 - 1/4"	8.0	13.0
1"	11.8	15.7
3/4"	20.2	26.9
1/2"	30.1	25.4
1/4"	23.2	14.7
1/8"	5.8	1.2
Sawdust	1.0	0.1
% Distribution		
Good chips 1/2" - 1"	62.2	68.0
Defective on 1 - 1/4"	1.3	1.5
Passing 1/4"	6.8	1.3
Knots	1.0	0.4
Slivers	0.4	0.2
Volume loss on debarking %	14.0	2.0

This does not include increased logging costs. An increase in cost of this order would certainly make most mills in Canada noncompetitive and hence could not be tolerated. The increase in cost as a result of using trees dead three years or less would be substantially lower and probably in the order of 2%. Handling, yield, and strength losses would be negligible at the lower decay level and the extra cost would be mainly for bleach.

It is estimated that over 10% of wood used at the mills during the outbreak contained some decay. This was not necessarily hemlock looper killed wood, although it accounted for a major part. It is estimated that Bowater Newfoundland Limited and Price (Nfld.) Limited have salvaged about 15% of the 12 million m^3 killed during the outbreak. However, no estimate is available of the extra costs incurred from using this wood.

Table 16. Percentage increase in the cost per ton of newsprint caused by using hemlock looper killed trees dead for six years.

Parameter	Chemical pulp	Groundwood pulp
Cost increase by debarking @ 14% loss, %	10.9	10.9
Loss in chipping, %	0.8	0.0
Yield loss	2.4	0.0
Total increase in wood cost, %	14.1	10.9
Increase in cost per ton of newsprint based on 25% sulphite, 75% groundwood @ 1.15 cords/ton, newsprint, %	11.8	
Increase due to;		
Extra bleach	2.2	
Extra refining for shives	0.1	
Increase in chemical pulp content from 25 - 35%	5.6	
Total increase in cost per ton newsprint, %	19.7	

SUMMARY AND CONCLUSIONS

Balsam fir trees with a known history of defoliation and death caused by the eastern hemlock looper were sampled for saprot, moisture content, basic density and extractives, holocellulose and alpha cellulose content. Chemical and mechancial pulps from trees dead for 3, 4, 5 and 6 years were compared to pulps from sound trees. Wood losses during debarking and chipping and the economic value of decayed wood was also estimated.

Saprot content varied from about 30% of the merchantable volume in trees dead for 3 years to over 50% for trees dead for 6 years. Advanced rot reducing the hardness of the wood did not occur until the fourth year. Most of the advanced rot was a white rot type. The volume of brown cubical decay was negligible.

The basic density of dead trees decreased gradually with the number of years after death. The weighted average basic density decreased about 5% in 5 years.

The moisture content on green weight basis varied from about 48% to 64% in living control trees and from about 20% to 50% in dead trees.

The extractives, holocellulose and alpha cellulose contents did not change appreciably in the early years after death but in 6 years the extractives content increased from 3% to 5%, holocellulose content decreased from 72% to 67% and alpha cellulose from 40% to 37%.

The decayed, dead trees yielded a lower amount of inferior quality pulp. The yield of bisulphite pulp decreased from 67.8% to 63.1% in 6 years. Similarly the burst factor decreased from 108.7 to 83.1, and the tear factor decreased from 64.8 to 55.2. Also pulps from decayed trees had a higher shive content, higher linting count and opacity and lower brightness than pulps from sound trees. Loss in yield and quality was also recorded for kraft pulp, and for refiner mechanical and groundwood pulps. Mill scale tests also showed corresponding losses in pulp quality.

Wood losses in debarking dead trees varied from 5% to 14% and increased with number of year since death.

The increase in cost per ton of newsprint as a result of using 100% wood dead for 6 years is estimated at about 20%. This estimate does not include increased harvesting costs. Similarly the cost increase is estimated at about 2% for using trees dead for 3 years.

Although losses in quality of pulps from dead trees are substantial it is technically feasible to use in the production of bisulphite and kraft pulps trees dead for even 6 years. The limiting factor to the use of dead trees appears to be one of economics more than quality. Losses due to lower yield, inferior pulp quality and increased wood costs would be negligible during the first four years after death when advanced decay is at minimum and trees are firm enough to be harvested, transported and barked efficiently. Therefore it is recommended that stands killed by the hemlock looper should be salvaged within four years after death to minimize cost increases associated with utilization of damaged wood. Stands dead for a longer period of time may be utilized at an increase in cost of harvesting and manufacturing.

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