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Kraft pulp from budworm-infested Jack pine

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Abstract

This study evaluated the quality of kraft pulp from budworm-infested jack pine. The logs were classified as merchantable live, suspect, or merchantable dead. Raw materials were evaluated through visual inspection, analysis of the chemical composition, SilviScan measurement of the density, and measurement of the tracheid length. Unbleached pulps were then refined using a laboratory disk refiner. The mechanical and optical properties of handsheets made from the refined pulps were evaluated. Although budworm galleries may affect the physical integrity of the wood, they have no effect on pulp quality. Blue stain did not affect the handsheet brightness. The results indicate that merchantable dead jack pine trees are acceptable for kraft pulp production, with equivalent pulp yield.

Keywords: blue stain; insect infestation; jack pine; kraft pulping; maceration; SilviScan; small-diameter trees.

Introduction

The overpopulation of small-diameter trees in US National Forests not only increases the risk of fire, but also makes the trees prone to disease and insect infestation. Removing densely populated trees, including those infested by disease or insects, is necessary to restore forest health. High-value and large-volume utilization of these trees is the key to making their removal from the forest economically viable.

The largest single cost to pulp and paper mills is typically for quality wood fiber (Myers et al. 1997). Previous studies (Myers et al. 1999, 2003; Ahmed et al. 2000) conducted at the Forest Products Laboratory indicated that pulp produced from forest thinnings is acceptable for the commercial production of various grades of paper; these studies focused on healthy live trees. Insect-infested trees and dead trees have a potentially high value for pulp production, but they have low commercial value because their mechanical properties are unknown.

When our project was initiated, the jack pine in the Ottawa National Forest was infested with budworms, which carry blue stain fungi into the sapwood. Blue stain has been perceived to have a negative effect on the quality of wood pulp (Roberson 2000); i.e., more bleaching chemicals are required to obtain a desired pulp brightness. However, few studies have been carried out on the effects of blue stain on pulp properties. Most work on this subject has been on mechanical (Lougheed et al. 2003) or groundwood pulp production (Persson et al. 2002). Information on the potential for using budworm- and blue stain-infested logs for chemical pulp production is not available in the literature.

Jack pine (*Pinus banksiana Lamb*) can be readily pulped using the kraft process to produce writing paper, fine paper, tissue paper, and lightweight offset paper (Isenberg 1980). Literature on jack pine kraft pulping is limited (Hunt 1977; Einspahr et al. 1983; Hatton 1993, 2001; Lanouette et al. 1998) and all data were obtained from pulping of live trees. The objective of our study was to evaluate the potential for utilizing budworm-infested dead and living jack pine logs for the production of kraft pulp. This work has practical importance because infestation of jack pine by budworm is a recurring event in North America.

Experimental

Raw material and chip production

Logs were obtained from an overage stand of jack pine (*Pinus banksiana Lamb*) trees in the Ottawa National Forest in northern Michigan. The logs were classified by the Ranger District staff into four categories, based on their merchantability as lumber: (1) merchantable live, live healthy trees; (2) suspect, live trees with signs of being under stress; (3) merchantable dead, dead trees (bark starting to peel off) that retained merchantable quality; and (4) unmerchantable dead, dead trees that had deteriorated to the point of having no merchantable value. The first three classes of logs were used for our study.

A 4.9-m-long butt log was bucked from each tree on site and shipped to the Forest Products Laboratory. A 61-cm-long section from each end of each butt log was retained for the pulping study. A 2.5-cm-thick disk was cut from the top (toward the crown) 61-cm section. Three disks from each tree class (total of nine disks) were selected from 109 disks produced for SilviScan analysis of wood properties and measurement of tracheid length. The three disks selected represented the average, highest, and lowest ring count for each tree class. Logs were then hand-peeled to remove the bark and were chipped to 19-mm-long pieces in a four-knife commercial-sized chipper. The chips were screened to remove all particles greater than 38 mm and less than 6 mm in length. The thickness of the accepted chips ranged from 1 to 5 mm. Screened chips were thoroughly mixed in a large V-mixer, weighed into 4- or 5-kg samples, placed in polyethylene bags, and stored at 4°C until pulping. Three chip samples for each raw material were oven-dried to remove all moisture, and the average solids content was recorded.

Sample preparation and wood maceration

A Wiley mill was used to produce wood meal from the mixed wood chips for each class. The chemical composition of the samples was analyzed by the Analytical Chemistry and Microscopy Laboratory at the Forest Products Laboratory.

A strip was cut across the entire diameter of each of the nine disks selected, with the least differentiation in radius between the two radii from the pith to bark. After sanding, the nine strips were sent to the Tasmanian Forest Research Center [Commonwealth Scientific and Industrial Research Organization (CSIRO), Division of Forestry and Forest Products, Australia] for SilviScan analysis.

Another strip, cut parallel and adjacent to the strip for SilviScan analysis, was used to obtain the tracheid length for the selected section of each tree. The strip was evenly divided into five blocks along the radial direction; the blocks were labeled A–E from the pith to the bark. A 2-mm-thick (cross-radial direction) slice was cut from each block and reduced to matchstick size. A total of approximately 0.33 g was obtained for each sample. The matchstick-sized wood samples were macerated based on the method of Brisson, Gardner, and Peterson (Yeung 1998). The volumetric composition of the macerating solution was 1 part hydrogen peroxide (30% reagent solution), 4 parts deionized water, and 5 parts pure (100%) glacial acetic acid. All chemicals were obtained from commercial sources. Approximately 35 ml of macerating solution was added into a 40-ml vial to macerate approximately 0.33 g of wood sample. The vial was then capped and placed in an oven at 60°C. After 7 days, the sample appeared as a white-translucent material and the maceration solution became clear. The vial was then removed from the oven and allowed to cool to room temperature. The macerated sample was gently removed with a forceps and placed in a clean vial. The sample was mixed with deionized water for several minutes to separate any fiber bundles into individual fibers. The sample was then analyzed using a Kajaani FS-100 fiber analyzer to determine the tracheid length distribution. The same analyzer was used to determine the fiber length distribution of the refined pulps.

Kraft pulping

Kraft pulping experiments were conducted in a 23-l stainless steel batch digester. The cooking liquor had a sulfidity of 25%; active alkali of 16%, 17%, or 18% to produce pulps of kappa numbers 90, 60, and 30, respectively; and a cooking liquor/wood ratio of 5:1. Samples of 2 kg of wood chips, on an oven-dry (od) basis, were used in each cook. A screen basket that allows for free circulation of cooking liquor was filled with 100 g of od wood chips and placed in the middle of the digester for measurement of pulp yield. A vacuum of approximately 82 kPa was created in the digester. To improve penetration of the cooking liquor into the chips, the vacuum was held for at least 5 min before adding the cooking liquor. The cooking liquor was indirectly heated by steam in the jacket of the digester after being circulated from the bottom to the top of the digester for a few minutes. The circulation of liquor was continued at a rate of approximately 17 l min^{-1}. The steam condensate line was left slightly open to avoid condensate build-up in the steam jacket. The temperature of the digester was raised to 80°C in 10–15 min. The temperature was then raised to the cooking temperature of 170°C in 60 min. The cooking time was varied to obtain pulp kappa numbers of approximately 30, 60, and 90. The liquor was blown and the chips were mashed in situ with water at $>$80°C for 15 min. The washed chips were fiberized while still hot.

Pulp refining

Pulps were refined in a Sprout-Waldron (Springfield, IL, USA) 300-mm atmospheric laboratory refiner equipped with an auger feed. Plates were pattern C2976C, of 440-C alloy with no dams and a closed periphery. Pulp (od basis) was fed to the auger at 150 g min^{-1} via a constant-speed conveyor belt. The refining consistency was 15%. The 30-kappa pulps were refined in one pass using a plate clearance sufficiently tight to achieve the desired freeness. The 60- and 90-kappa pulps were refined in two passes, each at 15% consistency. For the first pass, plate clearance was adjusted to give a Canadian standard freeness (CSF) of 600–650 ml, depending on the final freeness desired. For the second pass, the clearance was adjusted to achieve the desired freeness. Target freeness values were 500 ± 25 and 400 ± 25 ml. The refining temperature was targeted to 100°C by preheating the pulp and was then maintained with boiling dilution water. Refined pulps were allowed to seep hot for a minimum of 1.5 h to remove latency before dewatering.

Results and discussion

Wood chemical and physical properties

Figure 1 shows a cross-section of a disk from a merchantable dead jack pine tree. Two features were characteristic of merchantable dead trees: (1) insect (budworm) galleries, found mainly in the outer diameter of the tree; and (2) blue stain, a general condition found mainly in all the dead trees and located in a zone of approximately one-quarter to half of the outer diameter of the tree. The number and size of insect galleries varied from tree to tree. Blue stain fungi were carried by budworms. The blue-stained insect trail was clearly evident in some cases.

No statistically significant differences in chemical composition were found in intact wood (without insect galleries) of merchantable dead trees compared with live or suspect trees (Table 1), indicating that the dead infested trees were chemically intact. The lignin content of all trees was approximately 3 percentage points higher than that reported by Hatton and Hunt (1990) and Einspahr et al. (1983).

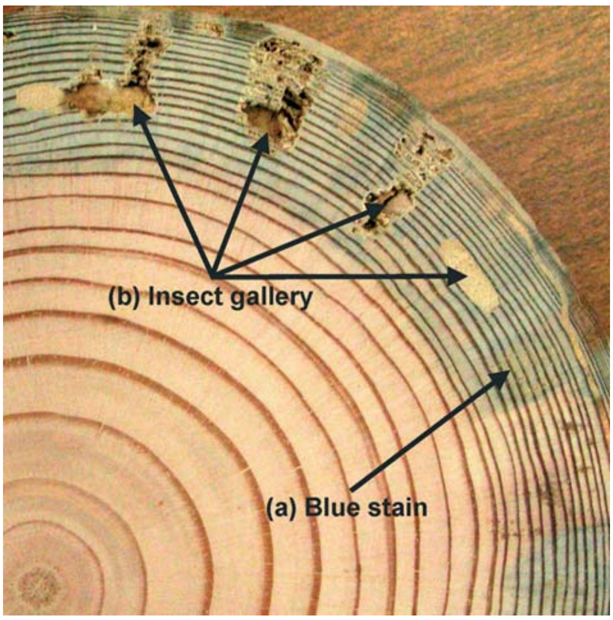

Figure 1 Budworm infestation and resultant blue stain in a cross-section of a merchantable dead jack pine tree.

Table 1 Chemical composition of the three tree classes.

Tree class	Component (%)									
	Lignin		Arabinan	Galactan	Rhamnan	Glucan	Xylan	Mannan	Total carbon	Total yield
	K	AS								
Live	30.92	0.72	1.42	2.80	0.12	40.31	6.20	10.51	61.4	93.1
Suspect	31.32	0.65	1.48	2.88	0.14	40.26	5.99	10.67	61.4	93.4
Dead	31.38	0.79	1.44	3.13	0.13	39.61	6.30	10.60	61.2	93.3

K, Klason; AS, acid-soluble.

SilviScan X-ray diffraction measurements gave the wood density profile for the strips tested, which provided information about the physical integrity of the trees. The strips tested did not contain any insect galleries (intact wood). Figure 2 compares the mean wood density profiles for three approximately 50-year-old trees from the three study classes. Statistical analysis showed significant differences between the live and dead trees, but these differences could have been the result of tree-to-tree variation. Statistical conclusions could not be drawn from one tree for each class. There were no abnormal trends in the mature wood region of the dead tree in which blue stain was observed in the density profile, indicating that the physical integrity of the blue-stained wood without insect galleries was not much different from that of the live tree. Very similar density profiles were also observed in a group of approximately 35-year-old trees.

Figure 3 shows the length-weighted mean tracheid length measured for wood strips from the same group of trees for which density profiles are shown in Figure 2. The mean tracheid length along the radial direction was essentially the same for the selected disks. The length-weighted mean tracheid length for the 51-year-old tree was approximately 2.6 mm, slightly shorter than the tracheid length of 3.2 mm reported by Einspahr et al. (1983). The tracheid length distribution along the radial direction was very similar for the selected disks. The distribution profiles for blocks A, C, and E shown in Figure 4 correspond to the data shown in Figure 3. Blue stain was visually observed in block E of the dead tree.

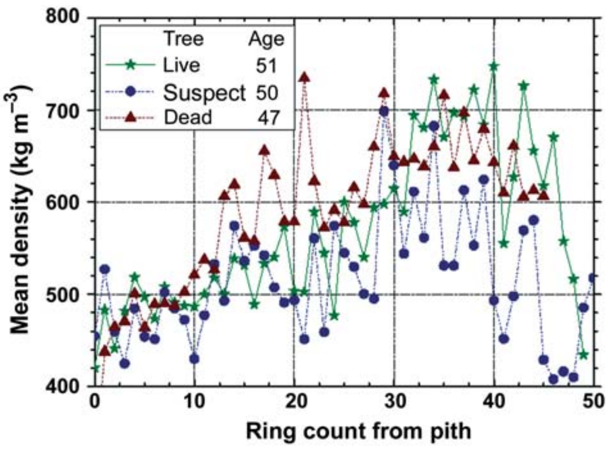

Figure 2 SilviScan density profile measured for wood strips from merchantable live, suspect, and merchantable dead trees.

Pulp yield

Chemical analysis suggested that pulp yields for the three classes of wood should be equal at a given kappa number. As shown in Figure 5, the pulp yield (unscreened) data for the three tree classes show good linear correlation to kappa number, with r^2 of 0.95. The pulp yields obtained were equivalent to those reported by Einspahr (1983) (43% at a kappa number of approx. 30) and 2 percentage points lower than values reported by Hatton (1993) (45% at a kappa number of ~30 and 54% at a kappa number of ~90). This was possibly due to the 3% higher lignin content of the wood used in our study compared to that used by Hatton (1993), as previously discussed. The results indicate that insect infestation had no significant impact on pulp yield because the insect galleries were often hollow (insects had eaten the wood) and so did not contribute to the weight of the log.

Pulp physical properties

Pulp fiber length, all fiber length are length weighted, decreased by approximately 10% (from 2.4 to 2.2 mm) through the refining process. All fiber lengths were length-weighted through the refining process, independent of pulp kappa number and tree class. Therefore, the reduction in fiber length was due to the refining process rather than to fiber weakening in the budworm-killed wood. The length of the unrefined pulp fiber (2.4 mm) is

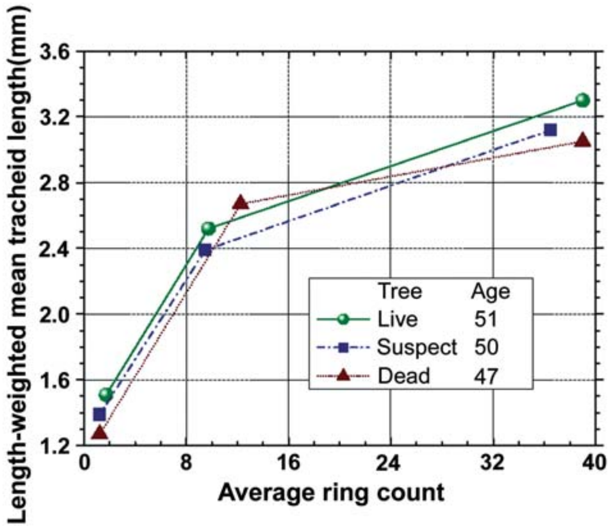

Figure 3 Radial profile of length-weighted mean tracheid length for merchantable live, suspect, and merchantable dead trees.

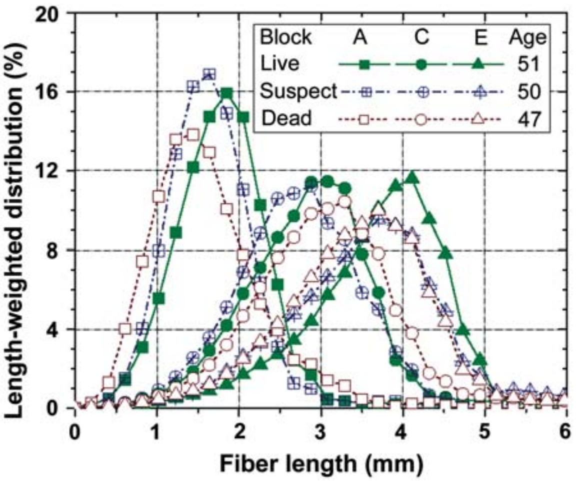

Figure 4 Tracheid length distribution in blocks from merchantable live, suspect, and merchantable dead trees.

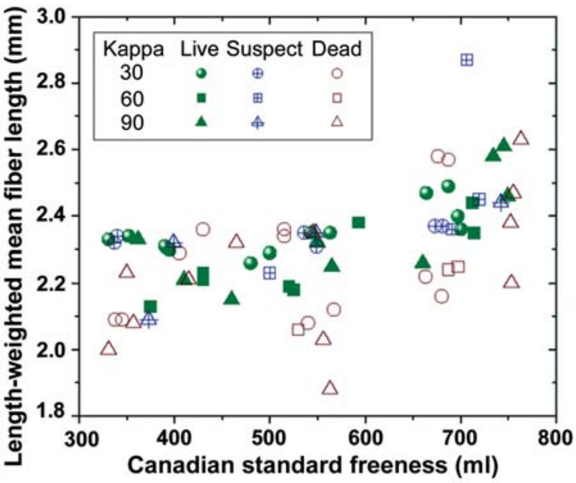

Figure 6 Effect of refining on the mean fiber length of pulp.

approximately the same as that reported by Einspahr et al. (1983) (2.25 mm). As shown in Figure 6, the decrease in fiber length occurred mainly in the early stage of the refining process. The large variation in fiber length in pulp from the dead tree was mainly due to variation in raw material. The mean fiber length in pulp from the dead tree was slightly lower than for pulp from the live trees. This difference in pulp fiber length could be due to the fact that the budworm galleries cut into the tracheids. A difference in pulp fiber length (Figure 6) was not observed in the tracheid length data (Figures 3 and 4) obtained from strips that did not contain insect galleries.

Handsheets made from the refined pulps were evaluated to study the effect of refining on mechanical properties. The conformability of the refined pulps was assessed by examining the relationship between hand sheet apparent density and pulp freeness. The results indicate that the relationship is independent of tree condition (live, suspect, or dead), but is slightly dependent on the kappa number; at a given freeness, pulp with a low kappa number produces a denser sheet than pulp with a high kappa number. The handsheet density data agree well with those reported by Hatton (1993) and Einspahr et al. (1983) (both studies used a PFI mill to refine pulp). The density values for sheets made from PFI-milled pulps were apparently approximately the same as for sheets made from disk-refined pulp at the same CSF level.

The stretch of a handsheet is directly related to the tensile energy absorption (TEA). The stretch values for handsheets prepared from the unrefined pulps were between 1.5% and 2.5%. The stretch increased to approximately 3.5–4.5% after refining. Furthermore, a rapid increase in stretch was obtained when pulp freeness (CSF) began to drop below 650 ml. The stretch reached an asymptotic value of approximately 4% when pulp freeness was reduced to ~525 ml. The stretch data agree with those reported by Hatton (1993). The data suggest that the stretch values of pulps with high kappa numbers fall into the low end of the stretch data range. However, no statistically significant differences were observed between the pulps from live and dead trees, as discussed later.

The relationships between burst index and tensile and tear indices were examined to study the effect of tree

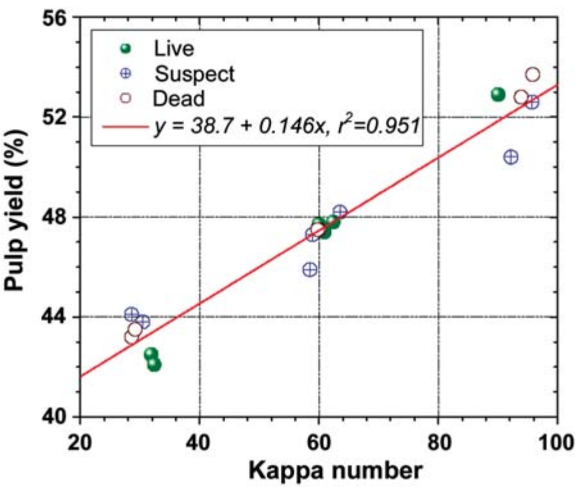

Figure 5 Pulp yield from merchantable live, suspect, and merchantable dead trees at kappa numbers of 30, 60, and 90.

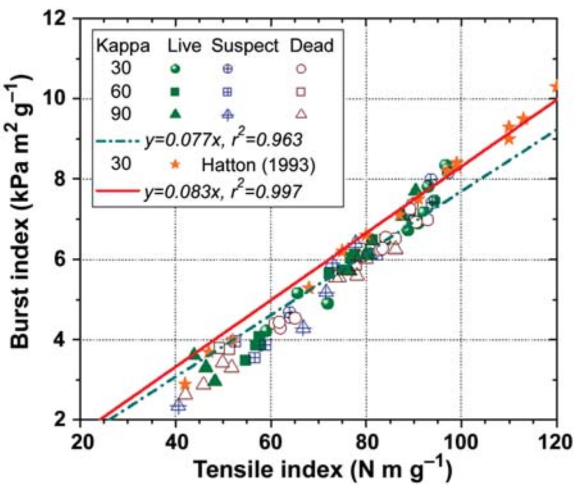

Figure 7 Effect of refining on the apparent density of handsheets. Correlation between burst and tensile indices of handsheets produced from merchantable live, suspect, and merchantable dead trees.

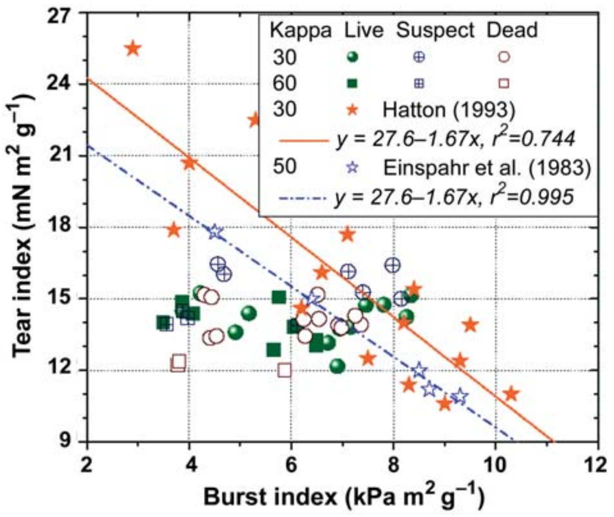

Figure 8 Effect of refining on the stretch of handsheets. Correlation between burst of tear indices of handsheets produced from merchantable live, suspect, and merchantable dead trees.

conditions on handsheet mechanical properties, as shown in Figures 7 and 8, respectively. The burst and tensile data for all handsheets fall into a universal line, independent of tree class. The slope of the line is only 7% less than that reported by Hatton (1993). In the work of Hatton (1993) and Einspahr et al. (1983) (no tensile data), PFI-milled pulps yielded sheets with greater burst and tensile strength than for pulps produced by the laboratory disk refiner in our study. These results agree with tensile data reported by Kerekes (2005). As shown in Figure 8, no correlation between burst and tear indices was evident from the data obtained in this study, which deviates from the traditional inverse linear correlation reported by Einspahr et al. (1983) and Hatton (1993). [Note that the burst index was used instead of tensile strength to compare results to the work of Einspahr et al. (1983), because tensile strength was not reported by these authors.] The constant tear index behavior (Figure 8) of sheets made from laboratory disk-refined pulps can be easily explained based on the slight reduction (only 10%, Figure 6) in mean fiber length of the pulps during refining, as discussed previously.

Pulp optical properties

Brightness is a concern for pulp made from wood infested with blue stain fungus. However, results indicate that the brightness of unbleached pulps made from the three tree classes at three kappa numbers was essentially the same, indicating that blue stain fungus has no effect on the brightness of unbleached pulp.

Conclusions

This study demonstrated the suitability of budworm-infested jack pine trees for kraft pulp production. The infested trees had two main features: insect galleries (often hollow) and blue stain in the sapwood. Analysis indicated that the differences in chemical composition were not significant between the intact wood (without insect galleries) of a dead tree with blue stain and the wood from a live or suspect tree. Furthermore, the density of a dead tree with blue stain was similar to that of a live or suspect tree of approximately the same age. The blue stain fungus infestation did not affect wood tracheid length, as evidenced by the comparison of radial profiles of tracheid length for dead and live trees. The mean fiber length in refined pulps made from dead trees showed relatively greater variation than the fiber length for live trees. These results indicate that blue stain fungus has no effect on wood chemical and physical properties.

The pulp yield for dead trees infested by insects and blue stain fungus was not different from that for live trees, except for bleachable grade pulp of kappa number 30, which could not be explained. This indicates that in the dead trees, neither the insect galleries, which were hollow for the most part, nor blue stain had an effect on pulp yield. No statistically significant differences were found in other handsheet properties (density, stretch, tensile strength, burst, tear, brightness, and opacity) among the three tree classes studied. Furthermore, blue stain fungus did not alter the behavior of pulp brightness during refining. Therefore, we conclude that merchantable dead jack pine trees killed by budworm are acceptable material for kraft pulp production.

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