

# Chapter 10

## Impact of the Mountain Pine Beetle on Pulp and Papermaking

Paul Watson

Pulp and Paper Research Institute of Canada  
3800 Westbrook Mall, Vancouver, British Columbia, V6S 2L9

---

### Abstract

The mountain pine beetle (*Dendroctonus ponderosae* Hopk. [Coleoptera: Scolytidae]) epidemic poses significant challenges to the pulp and paper industry. In this report, we summarize the current state of knowledge associated with the categories of attack stage (green, red, grey). Early-attacked lodgepole pine sapwood is blue stained and contains a high level of extractives. Grey stage wood exhibits low moisture content. As potentially the largest recipient of blue stained and dry wood, the pulp and paper industry must develop cost-effective utilization strategies to overcome the detrimental effects of these fibre sources. It is recognized that lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia*) killed by blue stain vectored by the mountain pine beetle will provide a significant volume of foreseeable fibre supplies. The long-term effects of dry (grey stage) lodgepole pine are of concern. We have identified the critical knowledge gaps and research needs.

### Résumé

L'épidémie de dendroctones du pin ponderosa (*Dendroctonus ponderosae* Hopk. [Coleoptera: Scolytidae]) pose de gros défis à l'industrie des pâtes et papiers. Le présent chapitre donne un aperçu de l'état actuel des connaissances associées aux divers stades d'infestation (vert, rouge et gris). L'aubier des pins tordus latifoliés en début d'attaque est bleui et contient des concentrations élevées de matières extractibles. Le bois au stade gris a une faible teneur en eau. À titre de plus grande acheteuse en puissance de bois bleui et de bois sec, l'industrie des pâtes et papiers doit élaborer des stratégies d'utilisation rentables pour compenser les effets néfastes de ces sources de fibres. Il est établi que les pins tordus latifoliés (*Pinus contorta* Dougl. ex Loud. var. *latifolia*) tués par les champignons agents du bleuissement transportés par le dendroctone du pin ponderosa fourniront un volume important et prévisible de fibres. On s'inquiète des effets à long terme de l'utilisation de pins tordus latifoliés secs (au stade gris) sur l'industrie. Les principales lacunes en matière de connaissances et les besoins les plus pressants en matière de recherche y sont signalés.

## Introduction

The mountain pine beetle (*Dendroctonus ponderosae* Hopk. [Coleoptera: Scolytidae]) epidemic poses significant challenges to the pulp and paper industry. Pulps prepared from interior British Columbia spruce, lodgepole pine and subalpine fir (SPF) chips command market premium status due to unparalleled kraft and mechanical pulp strength, and intrinsic brightness of mechanical pulps. Located at the end of the forest products value chain, and as a user of high quality sawmill residual chips prepared from the outside of the tree (composed largely of sapwood), as well as chips prepared from low quality roundwood, the pulp and paper industry will be significantly affected by the influx of low quality logs and blue stained sapwood available as a consequence of the mountain pine beetle epidemic. Lodgepole pines (*Pinus contorta* Dougl. ex Loud. var. *latifolia*) attacked by the mountain pine beetle begin to deteriorate before they are dead through the incursion of blue stain; following tree death and decay fungi incursion, moisture content reduces to below the fibre saturation point. Blue stain creates bleaching challenges for mechanical pulp manufacturers whereas dry wood is an undesirable fibre source for both kraft and mechanical pulp mills.

Pulp producers will likely be the largest recipients of blue stained wood from mountain pine beetle killed trees over the long term. Literature on the effects of mountain pine beetle associated blue stain on pulp quality is limited and the results are inconsistent (Troxell et al. 1980). Moreover, existing studies on the evaluation of mechanical and chemical pulping of blue stained wood suggests a wide variation in pulp quality. A majority of the literature suggests that trees that have been dead for up to two years can be used for kraft pulping without affecting pulp yield or paper properties, but to take full advantage of the blue stained resource, rapid removal and processing of this material is compulsory to minimize any possible low moisture content issues. The impact of mountain pine beetle-killed wood on wood chemistry and morphology as well as the appropriate pulping process for dry blue stained wood chips have yet to be fully determined. Given the somewhat forgiving nature of the complex processing required to manufacture kraft pulp in particular, the industry is also ideally situated to add value to such low quality fibre supply if the wood is well characterized in terms of moisture content, basic density and decay content, and is managed by careful metering and monitoring of the process. However, significant processing and product quality challenges still need to be addressed. Understanding the mechanisms of the problems associated with utilizing beetle-killed blue stained and dry wood will assist in developing cost-effective utilization strategies for the pulp and paper industry.

For the purposes of this discussion, lodgepole pine killed by blue stain vectored by the mountain pine beetle can be broadly categorized as early (green or red attack) and late (grey) stage. This classification is based on sapwood moisture content, the key factor that determines wood chip processability and, ultimately, pulp quality. The onset of wood decay is also considered to have occurred within late-attack stage wood.

## **The impact of early (green and red) attack wood on pulp and paper**

Green and red attack wood can be characterized as consisting of sapwood which has both high extractives and blue stain. Green and red attack sapwood, the source of sawmill residual wood chips, comprise significant levels of blue stain. The fungi cause a blue-grayish discolouration of the sapwood, generally thought not to cause structural damage to the wood. Blue staining fungi spread from the initial site of inoculation through the ray parenchyma. Hyphae then penetrate the tracheids through the pit membranes and travel from fibre to fibre. Any damage to tracheid walls can significantly impact pulp quality. Decay fungi are subsequently introduced which cause indiscriminant breakdown of the woody matrix.

The fungi cause substantial reduction in moisture content and disruption of moisture flow within the stem – a major cause of tree mortality. The standing tree dries further, to below the fibre saturation point, which creates significant technical challenges for wood utilization.

## **The effect of blue stain on pulp processing and production**

It is widely assumed that chips prepared from wood with moisture content above the fibre saturation point, regardless of the presence of blue stain, will maintain an acceptable size classification. Chipping studies completed in our (the Pulp and Paper Research Institute of Canada [Paprican]) laboratory have shown conclusively that blue stained wood gives a higher proportion of pinchips and fines, material unsuitable for the production of pulp. Pinchips can be metered back into the pulp chip stream (Watson and Hatton 1996) but fines are only suitable for burning to produce heat and energy.

British Columbia's interior chip supply consists of complex mixtures of spruce, lodgepole pine and subalpine fir (SPF). SPF chips are stored for up to four weeks prior to pulping, depending upon the season, in order to reduce the extractives content. Chip extractives content affects the time required for seasoning, the outdoor storage of chips that allows for hydrolysis and oxidation of extractives to prevent pitch (wood resin deposits), and paper machine friction problems (Back and Allen 2000). However, chip brightness loss and extractives reduction must both be considered. Mechanical pulp mills require bright wood hence storage is kept as short as possible. Kraft mills also prefer to keep chip storage times short – less than two weeks – particularly in the summer months.

Blue stain fungi present in mountain pine beetle infested lodgepole pine sawmill residual chips introduced to uninfested SPF chips will indiscriminantly inoculate clear chips within the pile.

## **The impact of blue stain on mechanical pulping and pulps**

Because of the presence of lignin, both unbleached and bleached mechanical pulps have a characteristic yellow color (yellowish tint) as represented by a high CIE yellow coordinate ( $b^*$ ) value. When bleached mechanical pulps are used along with bleached chemical pulps in high-grade papers, a blue dye has to be added to offset the yellow color (to lower the

CIE  $b^*$ ) and make the paper whiter. Very limited data on the bleaching of pulps made from blue stained logs/chips are available in the literature. Chemithermomechanical pulp (CTMP), made from chips containing blue stained lodgepole pine was reported to have an overall poorer response to sodium hydrosulphite bleaching, but a better response to alkaline hydrogen peroxide bleaching than the control, unstained CTMP (Lougheed et al. 2003). Unfortunately, in this study the species composition of the blue stained CTMP (96% pine and 4% spruce) was drastically different from that of the control pulp (61% pine, 37% spruce and 2% balsam fir). Therefore, it was not clear whether the different bleachability of the blue stained and the unstained CTMP was due to the effect of blue staining or to the difference in species composition.

Paprican has completed a preliminary series of thermomechanical pulping (TMP) and CTMP trials from blue stained and sound lodgepole pine samples. There was no well-defined relationship between refining energy, fibre properties, strength properties, or most surprisingly, optical properties of the TMP and CTMP pulps. It is evident that more research is required involving a larger number of samples where length of time since beetle infestation and the rate of deterioration after beetle infestation are well documented.

At a given freeness, the blue stained lodgepole pine sample had slightly lower scattering coefficient values than those from the sound sample when the comparison was made on either TMP or CTMP pulping processes (Fig. 1).

Chelated, freshly prepared blue stained TMP had an initial brightness of 54.9% ISO, very close to that of the control, unstained TMP (55.2% ISO). Blue stained lodgepole pine TMP

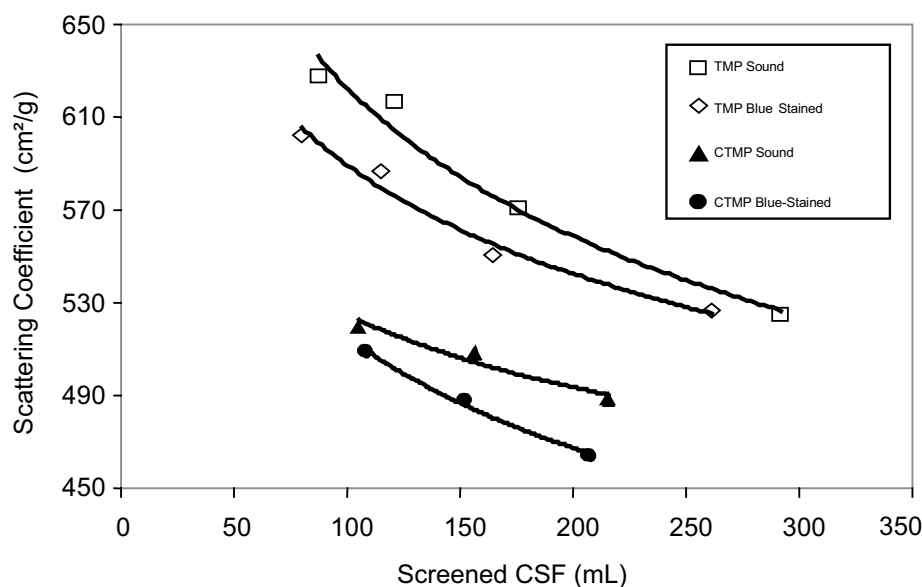


Figure 1. At a given freeness blue stained pine samples had lower scattering coefficient than those from sound pine samples for both TMP and CTMP pulping processes.

responded poorly to sodium hydrosulphite bleaching (a US\$7 differential to achieve 60% ISO brightness, Fig. 2), but responded as well as the sound lodgepole pine TMP to alkaline hydrogen peroxide bleaching at high peroxide charges (Fig. 3). The light-stability of the peroxide-bleached, blue stained TMP was identical to that of the peroxide-bleached, sound TMP.

The unbleached, blue stained pine TMP had a lower CIE  $b^*$  value than the unbleached, unstained pine TMP (Figure 4), indicating that it contained the blue stain. Interestingly, the hydrosulphite-bleached, blue stained pulps also had lower CIE  $b^*$  values than the unstained pulps bleached to the same brightness level. This suggested that most of the blue stain, if not all, remained with the blue stained pulp after hydrosulphite bleaching.

The poorer bleach response of the blue stained pine TMP means a higher hydrosulphite bleaching cost, but the lower CIE  $b^*$  of the bleached pulp may provide some downstream savings on blue dyes.

The difference in the CIE  $b^*$  between the peroxide-bleached, blue stained TMP and the peroxide-bleached, unstained TMP became progressively smaller as the charge of peroxide was increased (Fig. 5). This indicated that more blue stain was dissolved/removed from the blue stained pulp as the charge of alkaline hydrogen peroxide was increased. It is possible that the high concentration of caustic at a high alkaline peroxide charge facilitated the dissolution and removal of acids such as 2, 3-dihydroxybenzoic acids and ceratenolone. These acids, in the form of their ferric chelates, are thought to be responsible for the blue stain (Ayer et al. 1986, 1987).

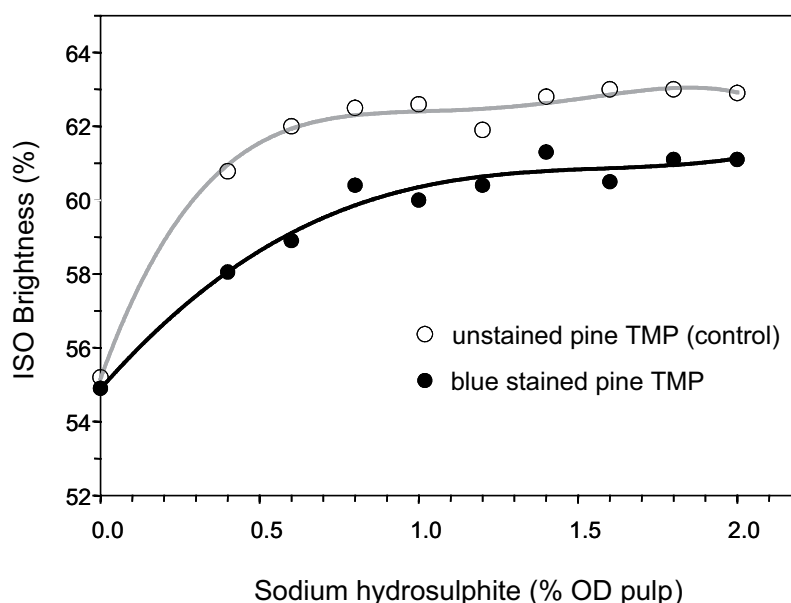


Figure 2. Brightness of the unstained and the blue stained TMP vs. charge of sodium hydrosulphite,  $\text{Na}_2\text{S}_2\text{O}_4$ .

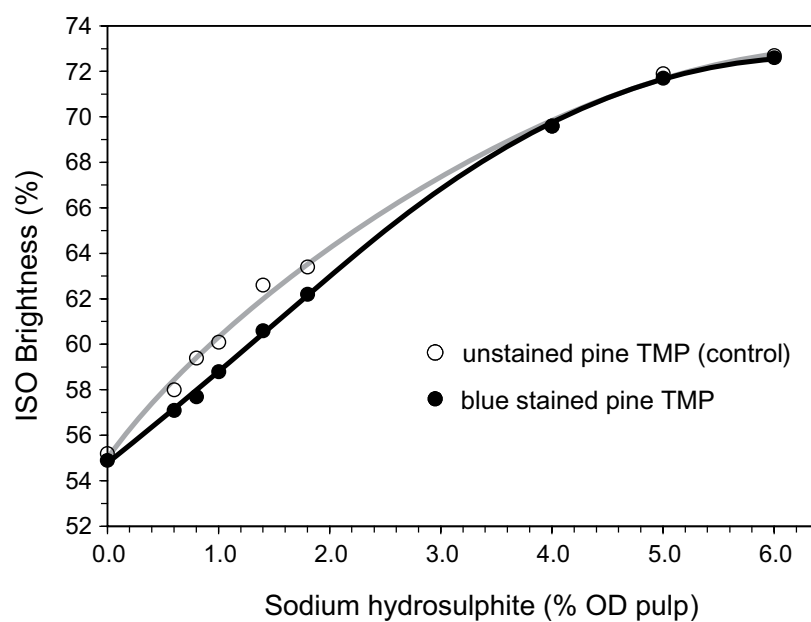


Figure 3. Brightness of the unstained and the blue stained TMP vs.  $\text{H}_2\text{O}_2$  charge;  $\text{NaOH}$  charge =  $\text{H}_2\text{O}_2$  charge.

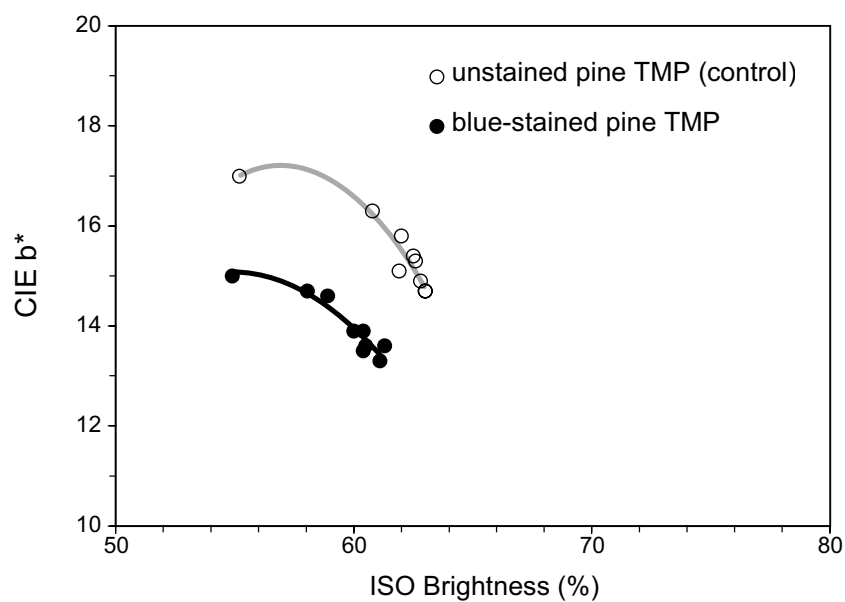


Figure 4. CIE  $b^*$  vs. ISO brightness of the unstained and the blue stained TMP during sodium hydrosulphite bleaching.

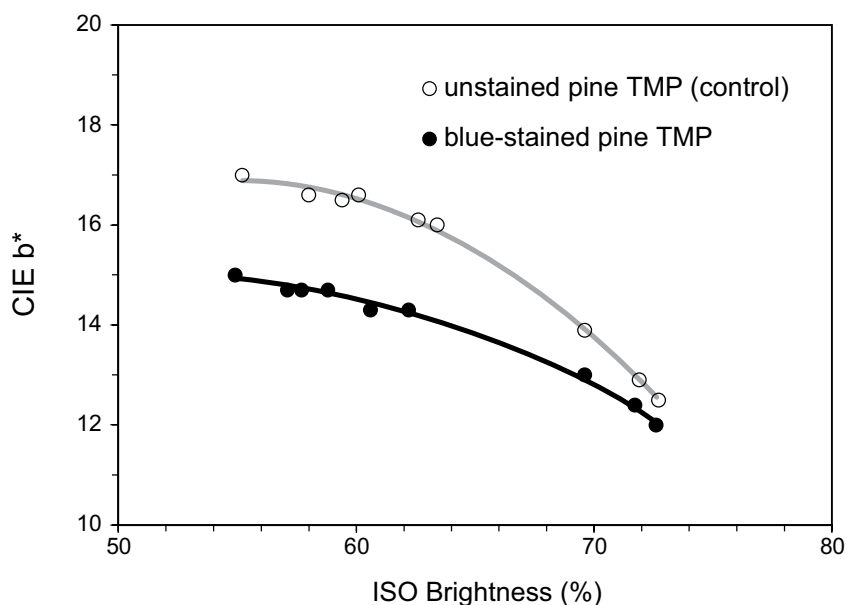


Figure 5. CIE  $b^*$  vs. ISO brightness of the unstained and the blue stained TMP during alkaline hydrogen peroxide bleaching.

The blue stained pine CTMP had a better response to alkaline hydrogen peroxide bleaching than the unstained pine CTMP, particularly at hydrogen peroxide charges of  $\geq 4.0\%$  (OD pulp) (Fig. 6). At such charges, the brightness of the bleached, blue stained pulp was  $\sim 2.0 - 3.0$  ISO points higher than that of the bleached, unstained pulp. To achieve the same brightness value, less bleaching chemicals were needed for the blue stained pulp than for the unstained pulp.

The unbleached, blue stained pine CTMP had a lower CIE  $b^*$  value than the unbleached, unstained CTMP, even though its initial brightness was slightly lower than that of the unstained pulp (Fig. 7). This indicated that the unbleached, blue stained pine CTMP contained the blue stain. A comparison of CIE  $b^*$  vs. ISO brightness of the peroxide-bleached, unstained and blue stained pulps showed that the difference in the CIE  $b^*$  between the two pulps became progressively smaller as the charge of peroxide used for the bleaching, and consequently the bleached brightness, was increased. This suggested increased removal of blue stain from the blue stained pulp. No significant difference in peroxide consumptions during bleaching of the two CTMP pulps was found.

Similar to the blue stained TMP, the blue stained CTMP did not respond to sodium hydrosulphite bleaching as well as the unstained pulp, but the hydrosulphite-bleached, blue stained pulp again had a lower CIE  $b^*$  than the bleached, unstained pulp (Table 1).

**Table 1.** ISO brightness and CIE b\* of the unstained and the blue stained pine CTMP bleached with various amounts of  $\text{H}_2\text{O}_2$  and NaOH, or with  $\text{Na}_2\text{S}_2\text{O}_4$

$\text{H}_2\text{O}_2$ / NaOH (% OD pulp)	$\text{Na}_2\text{S}_2\text{O}_4$ (% OD pulp)	Unstained CTMP		Blue stained CTMP	
		Brightness (%ISO)	CIE b*	Brightness (%ISO)	CIE b*
- / -	- / -	54.5 <sup>a</sup>	16.2 <sup>a</sup>	54.2 <sup>a</sup>	15.0 <sup>a</sup>
1.0 / 1.0		60.9	15.7	61.6	14.4
1.8 / 1.8		63.9	15.1	65.3	13.6
4.0 / 4.0		68.5	13.1	71.4	11.7
5.0 / 5.0		70.3	12.4	72.3	11.3
6.0 / 6.0		71.4	12.2	74.0	10.9
	1.0	61.8	14.4	61.0	13.0
	2.0	62.5	13.7	60.9	12.5

<sup>a</sup>value for unbleached pulp.

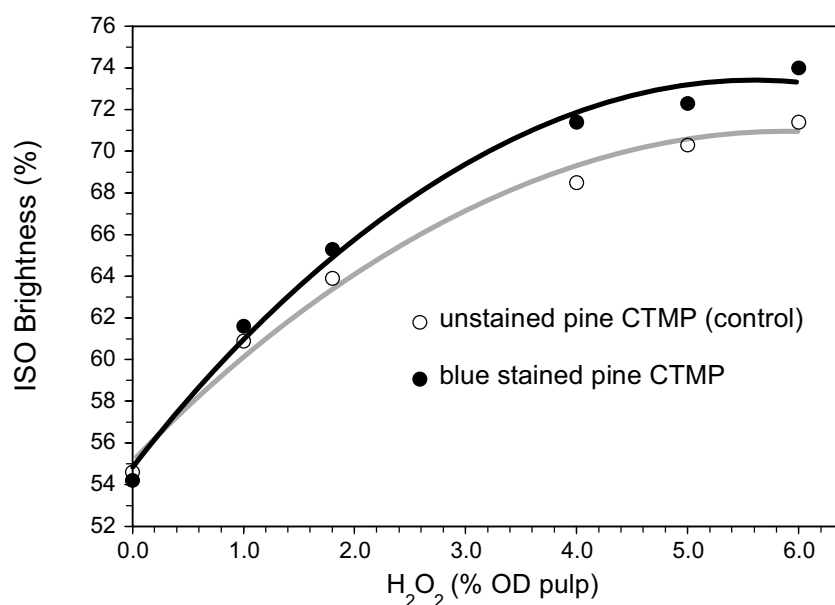


Figure 6. Brightness of the unstained and blue stained CTMP vs.  $\text{H}_2\text{O}_2$  charge; NaOH charge =  $\text{H}_2\text{O}_2$  charge.



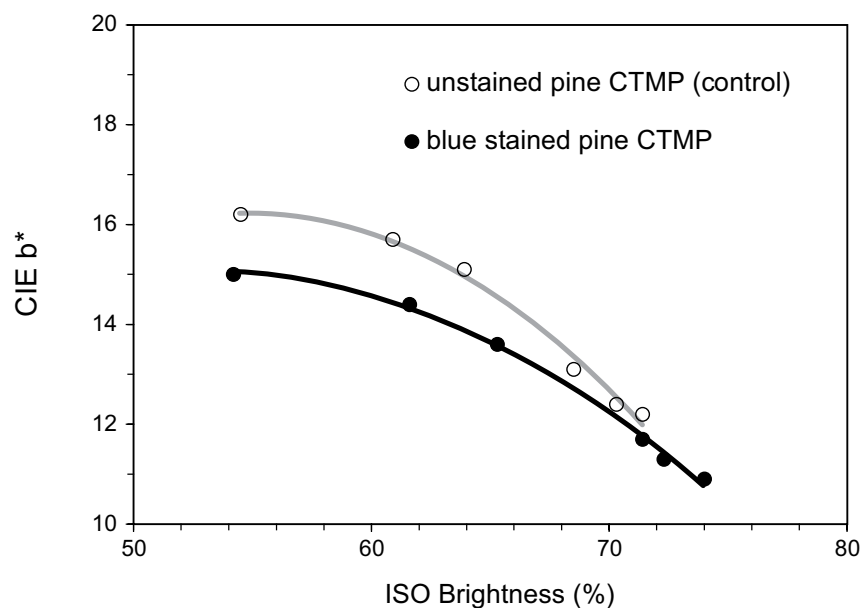


Figure 7. CIE b\* vs. ISO brightness of the unstained and the blue stained pine CTMP during alkaline hydrogen peroxide bleaching.

The light-stability of the peroxide-bleached, blue stained pine TMP was identical to that of the peroxide-bleached, unstained pine TMP. Interestingly, the light-stability of the peroxide-bleached, blue stained pine CTMP was slightly higher than that of the unstained pine CTMP bleached to the same initial brightness value.

### The impact of blue stain on kraft pulps

It is widely recognized that commercial kraft pulping processes can be forgiving of incoming wood chip quality. However, chip size distribution, incoming wood moisture content, wood density, fibre (tracheid) morphology and wood chemistry all play significant roles in the efficient production of high quality pulps for papermaking. Kraft pulping removes lignin to approximately 2%, creating a brown pulp, prior to entering the bleaching plant where residual lignin is removed. Although there are widely conflicting literature reports on the effect of blue stain (Woo et al. 2004), the general operational consensus, confirmed in the Paprican laboratory, is that kraft pulps prepared from blue stained chips which have a starting moisture content above the fibre saturation point, exhibit the same quality as those prepared from fresh lodgepole pine chips and are readily bleached to high final brightness. However, we have observed that currently infested trees had a significantly lower kraft pulp yield, and required more alkali to pulp to a given kappa number than those from late-stage beetle-infested trees. This difference can be attributed to the high extractives level of the chips which contributes to the dry weight (basic density) of the starting chips.

## Effect of elevated extractives on pulp and paper processing and production

Although extractives make up only a small percentage of the total chemical composition of wood, they play several significant roles on pulp and paper processing. Extractives can impact the pulping process by causing pulp colour reversion, and give rise to pitch deposits. Economic losses related to pitch problems in kraft mills have been estimated to account for as much as 1% – 2 % of sales (Back and Allen 2000).

The percentage of extractives in sound lodgepole pine varied from 1% – 2% in sapwood and 2% – 4% in the heartwood, corresponding to previous findings (Kim 1988; Shrimpton 1973; Lieu et al. 1979), which indicated that green lodgepole pine contained moderate amounts of extractives, ranging from 1% to 4%. Both Canadian Forests Products Ltd. (Canfor) and Paprican laboratories have determined that the extractives content of lodgepole pine sapwood chips was 1.2% in the grey stage, 7.7% in red attack, 5.4% in green attack, and 3.5% in healthy pine. Thomas (1985) has reported that black liquor tall oil content increased significantly with beetle attack and then decreased with time after attack .

A comprehensive analysis of the individual classes of extractives indicated that the relative proportion of extractives in the infested sapwood had also changed due to the beetle (fungal) infestation (Fig. 8). The results demonstrated a higher proportion of fatty and resin acids, and a lower proportion of sterols, steryl esters and triglycerides compared to sound sapwood. It is fair to conclude that a decrease in these extractives is a result of fungal invasion, such that fungi readily degrade triglycerides, steryl esters and sterols (Shrimpton 1973; Lieu et al. 1979). Wood triglycerides are the most readily degraded extractives component, which results in the liberation and accumulation of fatty acids (Higuchi 1985). Back and Allen (2000) also noted that an increased presence of resin and fatty acids in the sapwood may be due to early death of parenchyma cells.

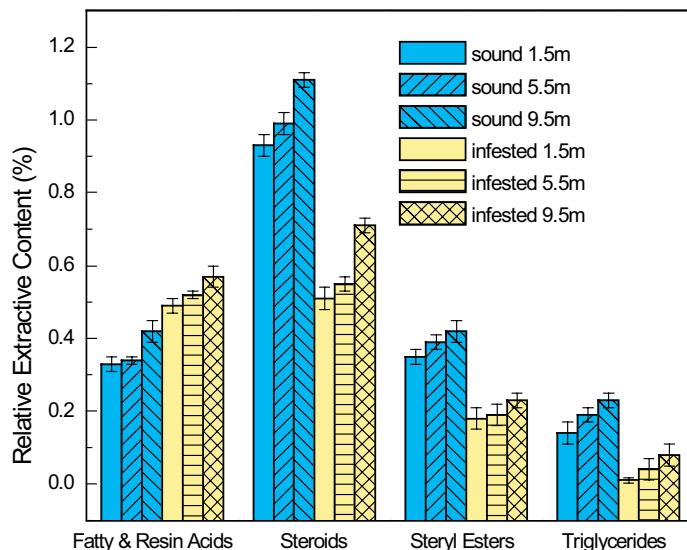


Figure 8. Relative proportion of individual classes of extractives in sound and infested lodgepole pine sapwood at different tree heights. Error bars indicate standard deviation.

During kraft pulping, extractives are either saponified, dissolved into the cooking liquor for subsequent recovery as tall oil, or unsaponified and hence discharged with the waste liquor. Alkali insoluble resin and fatty acids compose most of the unsaponified materials. Of the wood extractives found in pulp mill effluents, resin acids are widely regarded as the most toxic chemicals to aquatic organisms. As early as the 1930s, Ebeling (1931) found that 5mg/L of resin acids in pulp mill effluent killed perch in 40 hours. Leach and Thakore (1973) identified the toxic components of the resin acids in pulp mill effluent from 50% Douglas-fir and 50% western hemlock wood chips. They reported that three resin acid soaps in kraft pulpmill effluent (sodium isopimarate, sodium abietic, and sodium dehydroabietate), compounds also present in effluents from pine-containing pulping processes, caused over 80% of the toxicity to juvenile coho salmon. The toxicity of common resin acids to rainbow trout was 0.5-1.0mg/L during a 96h LC50 test.

As early infested lodgepole pine wood chips have 50%-120% more pitch than healthy pine trees, the discharge of high resin-acid-content effluent could compromise the effectiveness of kraft pulpmill secondary treatment systems. In addition, a problematic secondary treatment system lagoon foam has been reported by many operations. Paprican's preliminary research has confirmed that the foam is largely comprised of steryl esters, fatty alcohol esters, and triglycerides. Gas chromatography/mass spectral analysis suggests that the overall fingerprints are strikingly similar to those obtained from fresh lodgepole pine wood chips, with slight differences in the details likely caused by chemical or biological modification of the extractives. Further investigation is underway to determine if the high concentration of extractives found in the foam sample are, in fact, capable of creating foam.

In mechanical pulp and papermaking operations, extractives are more problematic as they are more readily retained within the pulp. Significant efforts are expended in these operations to ensure that the discharged whitewater is detoxified. Residual resin acids in the pulp can result in pitch accumulation on paper machines which contaminate the paper and can lead to more frequent paper breakage during manufacture.

Of more significant concern are changes to the friction characteristics of the sheet. Friction maintains traction between the paper web and rollers to prevent wandering and misregistration, thus playing a critical role in many web handling, web breaks and winding problems faced by the industry. For example, winding of low friction paper can cause interlayer movement below the paper roll surface, leading to defects such as crepe wrinkles. The coefficient of friction, while dependent on factors such as surface topography and strength, is also significantly influenced by chemistry. Extractives also play a major role. Fatty acids and glycerides on the paper surface generally contribute to a lower coefficient of friction and this effect increases with chain length, whereas the more polar resin acids increase the coefficient of friction. Operations utilizing fresh beetle-killed lodgepole pine have reported significant differences in paper machine runnability performance related to changes in the friction characteristics of their sheets. Research is required to determine the extent of the changes in chemical and morphological composition of these pulps and how they affect paper machine performance.

## The impact of grey stage wood on pulp and paper

The substantial reduction in moisture content of the sapwood is believed to be associated with the presence of blue stain in the sapwood (Reid 1961; Nebeker et al. 1993). The moisture content of logs from grey-stage beetle-killed lodgepole pine was frequently below 30% of oven dry weight (fibre saturation point) (Reid 1961; Giles 1986). It has been previously suggested (Nebeker et al. 1993) that the water stress may be due to the blockage of xylem tracheids by toxic fungal metabolites produced by the fungal hyphae, or by aspiration of tracheids when propagating hyphae penetrate cell walls. Either phenomenon may occur after fungal inoculation, but neither has been proven responsible for the loss in moisture content and subsequent tree death (Nebeker et al. 1993).

It has previously been suggested that the decline in density in infested (dead) trees is a function of time since death (Koch 1996). This decrease implies that the chemistry of the infested wood may be altered compared to that of sound wood.

We have confirmed the results of Lieu et al. (1979) who showed a decrease in lignin content in the sapwood following beetle infestation. As blue stain fungi are the primary colonizers in mountain pine beetle killed wood and are known not to degrade lignin, Scott et al. (1996) and Koch (1996) suggested that other decay fungi are likely present and associated with the incipient decay that often is difficult to detect. Therefore, the decrease in lignin content may be attributed to accompanying decay fungi, such as white-rot basidiomycetes which are known to degrade wood lignin.

Earlier studies (McGovern 1951; Lieu et al. 1979) demonstrated that holocellulose (cellulose and hemicellulose) content in sapwood of green lodgepole pine wood had slightly higher carbohydrate content than infested wood. This difference in carbohydrate content suggests that it is due to the removal (consumption) of low molecular, soluble carbohydrates by microorganisms in infested wood. A thorough evaluation of the specific carbohydrates indicated that the infested sapwood had a significant decrease in hemicellulose-derived sugars (Woo et al. 2003). This result is due to the fact that hemicellulose sugars are soluble, and the first material to be consumed by fungi during incipient growth on lignocellulosic material (Higuchi 1985; Zabel and Morrell 1992).

Most decay fungi generally maneuver through the wood by direct pit penetration, and with the removal of the pit membrane (through enzymatic digestion), the wood becomes more receptive to the movement of fluids. The changes induced by fungal pit degradation results in the infested wood's increased capacity to absorb and desorb liquids more readily than sound wood (Zabel and Morrell 1992) (Fig. 9).

Conclusions by Koch (1996), Flynn (1995), and Rice and D'Onofrio (1996) all support these findings, as they independently indicated that differences in permeability are generally due to differences in aspiration and the total amount of extractives. Resin deposition can vary substantially within the tree, and hydrophobic extractives in wood are known to impede water flow through the cells and to decrease permeability (Flynn 1995; Rice and D'Onofrio 1996; Vologdin et al. 1979).

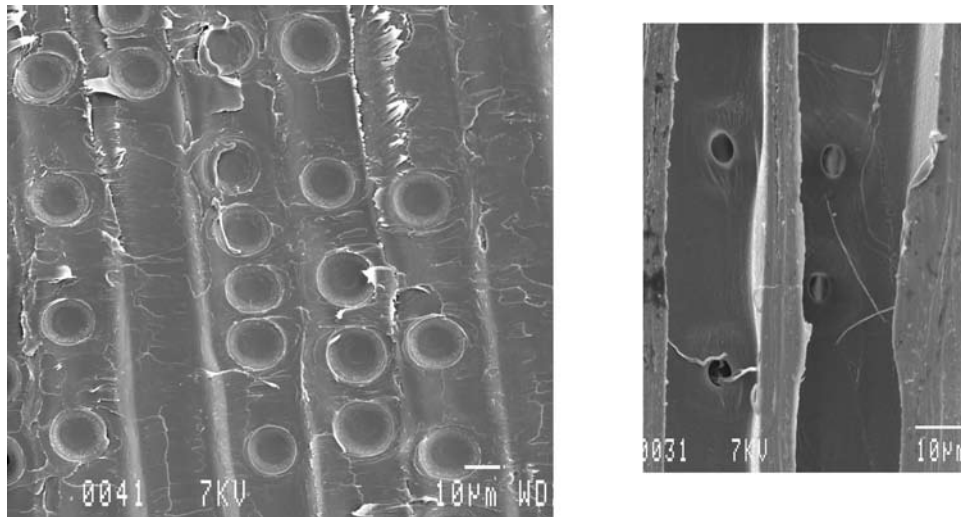


Figure 9. Scanning electron micrograph of aspirated pits in infested lodgepole pine heartwood at mid-bole height (600× magnification) and fungal hyphae in infested lodgepole pine sapwood at mid-bole height (1800× magnification).

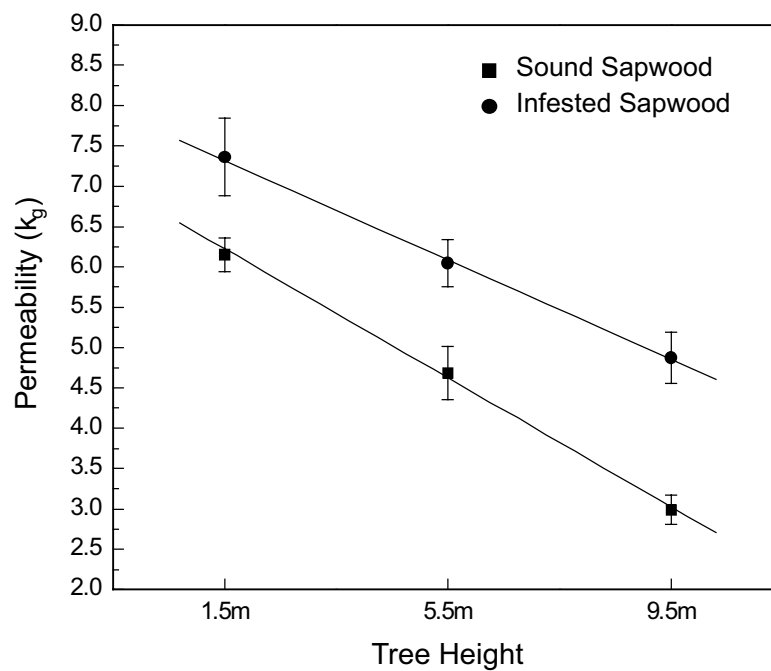


Figure 10. Longitudinal specific permeability of sound and infested lodgepole pine sapwood at different tree heights for a total of 18 samples. Error bars indicate 95% confidence interval.

## Kraft pulping

There are limited data available in the literature on kraft pulping of beetle-killed lodgepole pine. Thomas (1985) and McGovern (1951) reported a decrease in pulp yield and pulp quality with time after infestation whereas Lowery et al. (1977) reported no significant differences in pulp properties between sound and dead trees. The presence of sap rot decay in Alaskan white spruce was found to be an important indicator of pulping efficiency and resultant pulp quality. Log deterioration had mixed effects on paper properties, whereas the presence of sap rot increased the kappa number of the pulp and decreased the pulp yield (Scott et al. 1996).

The effects of time since beetle attack on wood characteristics, losses in debarking, and chip quality have been investigated by several researchers (Thomas 1985; Lowery et al. 1977; Dobie et al. 1978). Results obtained at Paprican confirm that the fine and pin chip contents increase with increasing time since beetle attack, whereas wood density decreased with time after attack and are attributed to the variation in wood moisture content; reduced moisture content will increase susceptibility to mechanical damage during the chipping process. The increased pin chip content in a kraft pulping digester will create liquor circulation problems, reduce pulp yield and cause pulping to become non-uniform (Hatton 1975). Paprican has recently completed a preliminary assessment of mountain pine beetle infested trees from the Williams Lake region.

The H-factor (an indicator of kraft cooking rate) vs. kappa number relationship is shown in Figure 11. It is evident that currently attacked, fresher wood chips were more difficult to pulp than the rest of the samples. Consequently, the pulp yields from currently attacked wood chips were significantly lower at a given kappa number than those from the other samples. These chips also consumed more alkali at a given kappa number as shown in Figure 12. The high pulp yield of the 1-year infested sample might be due to inherent yield variability for this species but is most likely due to the lower extractives level in this sample.

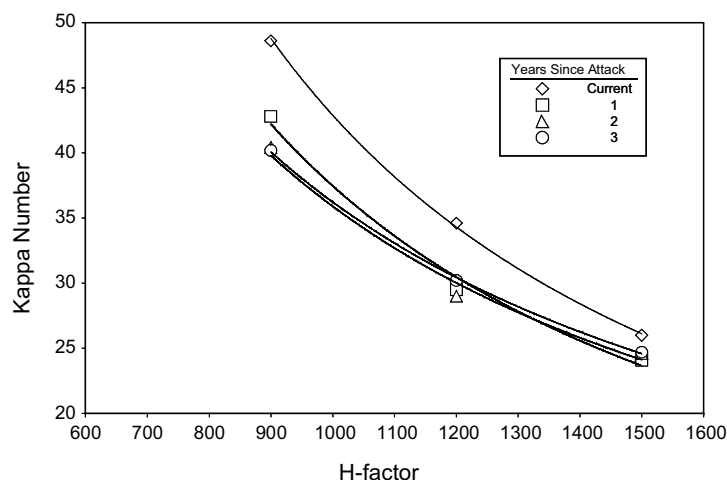


Figure 11. Kappa number/H-factor relationship indicates that currently attacked wood chips were more difficult to pulp to a given kappa number than the rest of the samples.

McGovern (1951) similarly observed that dead wood pulped more quickly. Many studies have indicated that as the wood deteriorates, there will be significant detrimental impact on pulp yield and quality. It is important to note that for laboratory kraft pulping, presteaming after chip impregnation is vastly superior to that of the conventional Kamyr continuous digesters found in the interior of British Columbia. The higher pin chip content and poor impregnation of dry chips leading to chip column hang-ups within the digester and liquor extraction screen plugging can significantly affect production.

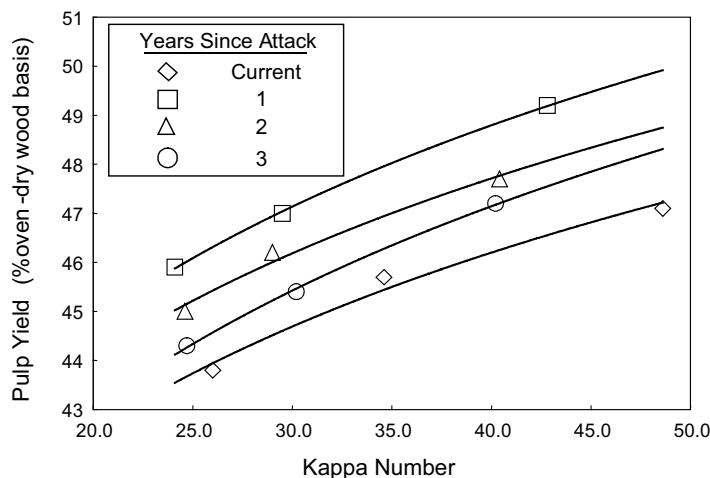


Figure 12. Pulp yield/kappa number relationships show that pulp yield of currently attacked wood was significantly lower at a given kappa number than in any of the other samples.

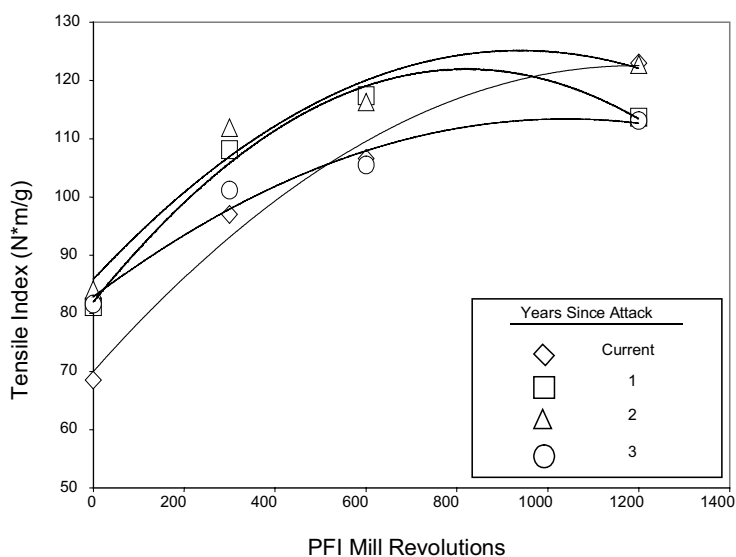


Figure 13. Tensile index/PFI revolutions shows the currently attacked sample had slightly lower tensile strength at lower beating levels than the other samples. However, the difference seems to disappear as the beating level increases.

Thomas (1985) has reported that beetle attack caused no significant differences in the bleachability of kraft pulps. However, he noted that beetle-attacked wood pulp showed poor pressing/drainage characteristics as well.

Figure 13 shows the tensile index as a function of PFI mill beating of unbleached kraft pulp at about 30 kappa number. Although pulp freeness was unaffected (Fig. 14), an unusual response to beating can be seen in the tensile strength properties (Fig. 13). Fully beaten, the current attack pulp produced a superior strength sheet whereas the 1- and 3-year sample exhibited a 10% tensile deficiency, which may, in fact, prove to be the norm for this wood source. The currently attacked sample responded more favourably to refining, creating a better bonded sheet.

### Thermomechanical pulping

While several authors (Hatton et al. 1984; Fereshtekhou et al. 1985; Dines et al. 1984) have investigated the properties of mechanical pulps produced from budworm-killed balsam fir, published literature on mechanical pulping of beetle-killed pine is scarce (Thomas 1985; Troxell et al. 1980). Thomas (1985) reported that there were no clear-cut relationships between strength characteristics and length of time since tree death in chemithermomechanical pulping of lodgepole pine; however, tear index usually decreased with increasing time since attack. Scott et al. (1996) have reported that more decayed Alaskan white spruce required the same or slightly less refining energy to achieve a certain level of freeness. A thermomechanical pulping study of beetle-killed ponderosa pine by Troxell et al. (1980) concluded that dead trees would be suitable for pulp and paper products. Paprican also conducted a preliminary thermomechanical pulping assessment of beetle infested trees from the Williams Lake region.

The data suggest that the 3-year infested sample required slightly less energy to achieve a given freeness than those from the other three samples investigated in this preliminary study. In general, there was no well-defined relationship between the specific refining energy requirement and the length of time since beetle infestation; this confirms our earlier results for refiner mechanical pulps from budworm-killed balsam fir that had been dead for 5 years (Hatton and Johal 1984). In contrast, other investigators have found that 2-year-dead balsam fir required 25% less energy than fresh balsam fir at a given freeness of 80 mL CSF (Canadian Standard Freeness) (Fereshtekhou et al. 1985). The Paprican study suggested that there was no relationship between chip moisture content and refining energy to a given freeness; one explanation for this could be that pre-steaming equalized the moisture content of the chips before refining. It has been reported by several other researchers that chip moisture content does not have any significant influence on energy consumption and pulp properties, except for shive content of TMP pulps, as long as the moisture content is kept above the fibre saturation point (Eriksen et al. 1981; Hartler 1986).



The tensile index of 3-year infested lodgepole pine samples was generally lower than that from current, 1-year and 2-year samples when the comparison was made at a given freeness (Table 2), a given refining energy, or a given sheet density (Fig. 14), respectively. The tear index at a given freeness from a 3-year lodgepole pine sample was significantly lower than that from current, 1-year and 2-year samples (Table 2).

The lower long-fibre fraction and lower average fibre length values of 3-year lodgepole pine samples are the main contributing factors for the lower tear strength. Surface and cross section images shown in Figure 15 indicate that 3-year sample pulps exhibited more uncollapsed fibres than those from current and 1-year samples, thus being a possible reason

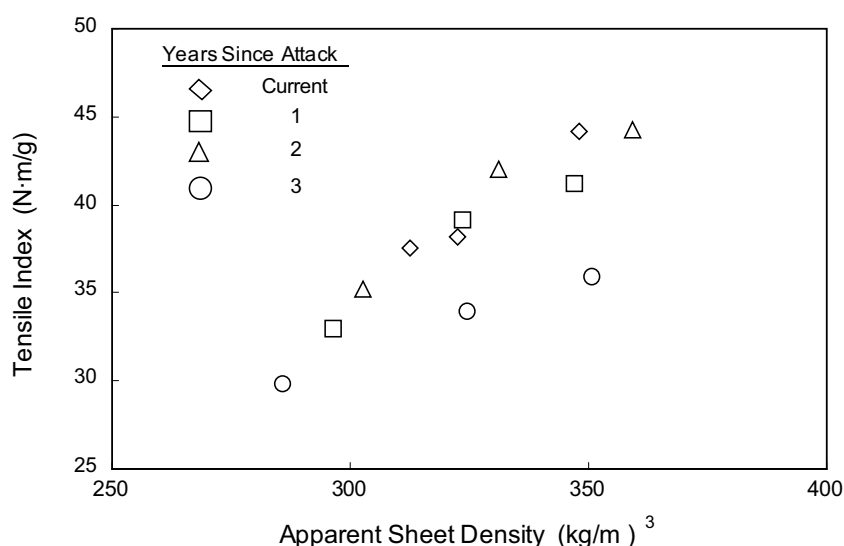


Figure 14. At a given specific refining energy, the tensile index of 3-year samples is significantly lower than those from current, 1-year, and 2-year samples.

**Table 2.** Properties of themomechanical pulps from beetle-attacked lodgepole pine at a constant freeness of 100 mL CSF.

Years Since Attack	Specific Refining Energy (MJ/kg)	R - 48 Fraction (%)	Fines (P-200) (%)	Length Weighted Fibre Length (mm)	Apparent Sheet Density (kg/m³)	Tensile Index (N·m/g)	Tear Index (mN·m²/g)	Sheffield Roughness (SU)	Brightness (%)	Scattering Coefficient (cm²/g)	ISO Opacity (%)
Current	11.3	57.8	28.2	1.84	337	43	8.9	239	56	634	96.3
1	11.9	57.6	27.0	1.69	339	41	8.3	239	56	620	96.2
2	11.3	58.8	26.3	1.74	342	43	8.2	244	56	598	96.2
3	11.0	56.2	26.7	1.57	334	35	7.4	226	49	609	98.1

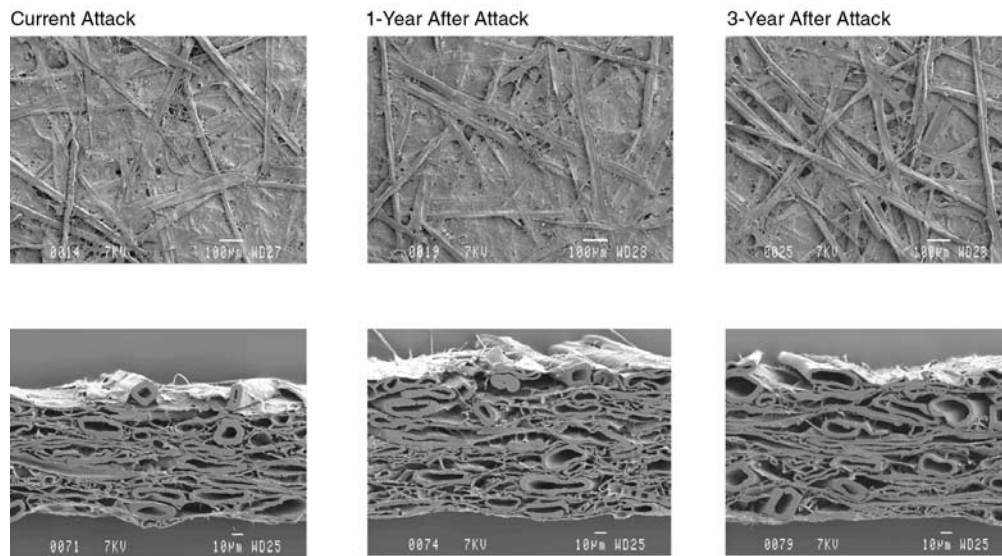


Figure 15: Surface and cross section images of TMP handsheets prepared from current, 1-year and 3-year beetle infested samples.

for strength differences compared to its counterparts. The loss in tensile and tear strengths have been confirmed by other investigators where strength properties from budworm-killed balsam fir were significantly lower for trees that had been dead for two or more years (Dines et al. 1984; Fereshtekhov et al. 1985). Chemithermomechanical pulps prepared from mountain pine beetle infested lodgepole pine wood samples indicated that tear index decreased with increasing time since infestation (Thomas 1985).

At a given freeness there is no clear-cut relationship between scattering coefficient and length of time since beetle infestation. The brightness of the 3-year sample was seven points lower than that of the current, 1-year, and 2-year samples. Thus, there would be a higher demand of bleaching chemicals for 3-year samples to restore the brightness to about the same level as that of pulps prepared from current, 1-year, and 2-year lodgepole pine samples. Other investigators have reported similar significant brightness losses for budworm-killed balsam fir and beetle infested lodgepole pine (Hatton et al. 1984; Fereshtekhou et al. 1985; Dines et al. 1984; Thomas 1985).

### **Summary of information gaps related to pulp and paper utilization of mountain pine beetle infested lodgepole pine**

The utilization of wood chips prepared from logs salvaged from insect infested stands is common practice for the pulp and paper industry, and there exist numerous publications on the topic. The potential of the current mountain pine beetle infestation to cause significant detrimental long term processing and product marketing challenges remains. Much of the published research suffers from poor sampling design and selection. Comprehensive

literature reviews and detailed consultations with Paprican's affected member company mills, which represent more than 5 million tonnes of SPF wood chip utilization, have highlighted the following technical information gaps:

1. Assessment of the pulping and pulp quality effects of increased lodgepole pine in SPF chip mixtures.
2. Quantification of the effects of blue stain in both kraft and mechanical pulping and pulp bleaching.
3. The development of a wood and fibre quality deterioration (shelf-life) model for infested lodgepole pine by location.
4. Development of portable and on-line rapid assessment devices to quantify blue stain content, moisture content and wood/fibre deterioration in standing trees, decked logs and wood chips.
5. Mechanical pulp pretreatment options for grey stage wood chips (chips below the fibre saturation point).
6. Quantification of kraft cooking of grey stage wood, including an evaluation of pretreatment options for continuous digesters and batch cooking processes.
7. Development of models to quantify blue stain inoculation and extractives losses in wood chip piles by season to maintain fibre quality and reduce pulp processing costs.
8. Quantification of the effect of early attack and grey stage lodgepole pine on tall oil production and quality.
9. Quantification and amelioration of the effect of early attack, high extractives content lodgepole pine on paper machine productivity for mechanical pulp grades.
10. Development of methods to minimize the foam propensity and toxic breakthrough events on secondary lagoons treating lodgepole pine extractives-rich effluents.

## References

- Ayer, W.A.; Browne, L.M.; Feng, M.C.; Orszanska, H.; Saeedi-Ghomi, H. 1986. The chemistry of the blue stain fungi. Part 1. Some metabolites of *Ceratocystis* species associated with mountain pine beetle infected lodgepole pine. *Canadian Journal of Chemistry* 64:904-909.
- Ayer, W.A.; Attah-Poku, S.K.; Browne, L.M.; Orszanska, H. 1987. The chemistry of the blue stain fungi. Part 3. Some metabolites of *Ceratocystis minor* (Hedgcock) Hunt. *Canadian Journal of Chemistry* 65:765-769.
- Back, E.L.; Allen, L.H. 2000. Pitch control, wood resin and deresination. Tappi Press. Atlanta, GA. Pages 1-83, 186-225, 307-324.
- Byrne T.; Woo K.; Uzunovic, A.; Watson, P. 2005. An annotated bibliography of the effect of bluestain on wood utilization with emphasis on mountain pine beetle vectored bluestain. Mountain Pine Beetle Initiative Working Paper 2005-4. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC.
- Dines, R. E.; Tombler, G. 1984. Mechanical and chemimechanical pulping of budworm-killed balsam fir. Preprints of the 70<sup>th</sup> Annual Meeting, Technical Section, Canadian Paperboard Packaging Association (CPPA), Montreal, QC. B11-B13.
- Dobie, J.; Wright, D.M. 1978. Lumber values from beetle-killed lodgepole pine. *Forest Products Journal* 28(6):44-47.
- Ebeling, G. 1931. Results of chemical and bioassay tests on pulp mill effluents. *Vom Wasser*, 5:192-200.
- Eriksen, J.T.; Hauan, S.; Gaure, K.; Mattans, A.L. 1981. Consequences of chip quality for process and pulp quality in TMP production. Proceedings of the International Mechanical Pulping Conference, Session: II, No. 1, Oslo, Norway.
- Fereshtekhou, S.; Neuman, R.D.; Sinclair, S.A. 1985. Thermomechanical pulp properties of spruce budworm-killed balsam fir. *Pulp and Paper Canada* 86(4):T100-T102.
- Flynn, K. 1995. A review of the permeability, fluid flow, and anatomy of spruce (*Picea* spp.). *Wood and Fiber Science* 27(3):278-284.
- Giles, D.R. 1986. Harvesting and processing of beetle killed pine. Harvesting and processing of beetle killed timber seminar proceedings. Prince George, B.C., Forintek Canada Corporation. 26 p.
- Hartler, N. 1986. Wood quality requirements in mechanical pulping. *Nordic Pulp Paper Research Journal* 1(1):4-10.
- Hatton, J.V. August 1975. WFPL chip quality analytical procedure: Effect of chipper, wood species and season on production of pin chips and fines. *Pulp and Paper Canada* 76(8).
- Hatton, J.V.; Johal, S.S. 1984. Effects of length of time since tree death on the mechanical pulping of budworm-killed balsam fir. *Journal of Pulp and Paper Science* 10(6):156-166.
- Higuchi, T. 1985. Biosynthesis and biodegradation of wood components. Orlando, Academic Press, Inc. Pages 43-50, 53-58, 441-464, 579-602.
- Kim, W. 1988. Chemical characterization of lodgepole pine in North America for use as industrial raw material. College of Forestry. University of Idaho. Moscow, ID. Pages 1-13, 15-164.

- Koch, P. 1996. Lodgepole pine in North America. Madison, Wisconsin, Forest Products Society. Pages 35-45, 213-318, 667-695, 927-940, 1029-1041.
- Leach, J.M.; Thakore, A.N. 1973. Identification of the constituents of Kraft pulping effluent that are toxic to juvenile Coho Salmon (*Onorhynchus kisutch*). Journal of the Fisheries Research Board of Canada 30(4):479-484.
- Lieu, P.J.; Kelsey, R.; Shafizadeh, F. 1979. Some chemical characteristics of green and dead lodgepole pine and western white pine. Ogden, UT. USDA Forest Service Intermountain Research Station, Research Notes RN 256. 8 p.
- Lougheed, M.; Dutton, B.; Huang, Q. 2003. Suitability of blue stained chips for the production of high yield market pulp. Pages 287-292 in Proceedings of the International Pulp and Paper Technical Association of Canada. June 2-5, 2003. Montréal, QC.
- Lowery, D.P.; Hillstrom, W.A.; Elert, E.E. 1977. Chipping and pulping dead trees of four rocky mountain timber species. USDA Forest Service Research Paper INT-193. Intermountain Forest and Range Experiment Station, Ogden, UT.
- McGovern, J.N. 1951. Pulping of lodgepole pine. USDA Forest Service, Madison, Wisconsin. 17 p.
- Nebeker, T.E.; Hodges, J.D.; Blanche, C.A. 1993. Host response to bark beetle and pathogen colonization. Pages 157-169 in T. D. Schowalter and G. M. Filip, eds. Beetle-pathogen interactions in conifer forests. New York, Harcourt Brace & Company, NY.
- Reid, R.W. 1961. Moisture changes in lodgepole pine before and after attack by mountain pine beetle. Forestry Chronicle 37(4):368-375.
- Rice, R.W.; D'Onofrio, M. 1996. Longitudinal gas permeability measurements from eastern white pine, red spruce, and balsam fir. Wood and Fiber Science 28(3):301-308.
- Scott, G.M.; Bormett, D.W.; Sutherland, N.R.; Abubakr, S.; Lowell, E. 1996. Pulpability of beetle-killed spruce. USDA Forest Service Research Paper FPL-RP-557.
- Shrimpton, D.M. 1973. Extractives associated with wound response of lodgepole pine attacked by the mountain pine beetle and associated with microorganisms. Canadian Journal of Botany 51:527-533.
- Thomas, P.R. 1985. Infestation by pine and spruce bark beetles in British Columbia and its effect on kraft and mechanical pulping. Proceedings, Harvesting and Processing of Beetle-Killed Timber, a seminar sponsored by Forintek Canada Corp., and Council of Forest Industries (COFI) for Northern Interior Lumber Sector. Special Publication No. SP-26.
- Troxell, H.E.; Tang, J.L.; Sampson, G.R.; Worth, H.E. 1980. Suitability of Beetle-Killed Pine in Colorado's front range for wood and fibre products. U.S. Forest Service Resource Bulletin, RM-2.
- Vologdin, A.I.; A.F. Razumova; Charuk, E.V. 1979. Importance of extractives for permeability of pine and spruce woods. Holztechnologie 20(2):67-69.
- Watson, P.; Hatton, J. 1996. Increasing the use of supplemental fibre sources in pulping. The Forestry Chronicle 72(5):501.
- Woo, K.; Watson, P.; Mansfield, S. 2003. The effects of mountain pine beetle and associated blue staining fungi on wood morphology and chemistry: Implications for wood and fiber quality. Wood and Fiber Science 37(1):112-126.
- Zabel, R.A.; Morrell, J.J. 1992. Wood microbiology: Decay and its prevention. New York, Academic Press, Inc. NY. Pages 22-261, 326-339.

