Wood moisture content variation in white spruce defoliated by spruce budworm

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Mature and over mature white spruce [*Picea glauca* (Moench) Voss] repeatedly defoliated by spruce budworm (*Choristoneura fumiferana* Clem.) in eastern Manitoba, were investigated for variation in moisture content (MC) which is known to influence pulping quality. In the fall of 1991, 100 trees in the Abitibi-Price Inc. Forest Management Licence area were selected randomly in two size classes and four defoliation classes. Heartwood and sapwood MC (% dry weight) was measured in 5-cm thick disks cut at 2.5 to 5.0 m intervals for small and large trees, respectively. Living trees with more sapwood than heartwood had a mean MC of 117%, and those with more heartwood than sapwood had a mean MC of 77%. Both of these groups contained sufficient overall moisture (> 45%) for pulping. The repeated defoliation did not affect the overall MC in live trees. Mean MC of trees killed by spruce budworm defoliation was 42% but this level varied with diameter and height above ground: > 45% in stems greater than 36 cm diameter inside bark, 30–60% in sections 17–36 cm, and < 45% in sections less than 17 cm. A minimum DBH of 30 cm is suggested as a criterion for accepting dead trees.

Key words: insect defoliation impact, wood moisture content, sapwood, heartwood, dead tree fibre, Manitoba

Les épinettes blanches [*Picea glauca* (Moench) Voss] mûres et surannées, défoliées à répétition par la tordeuse de l'épinette (*Choristoneura fumiferana* Clem.) dans l'est du Manitoba, ont été étudiées afin de connaître la variation du contenu en humidité (CH) lequel est reconnu comme ayant une influence sur la qualité de la mise en pâte. Au cours de l'automne de 1991, 100 arbres de la zone forestière sous la responsabilité d'Abitibi-Price ont été choisis au hasard selon deux classes de diamètre et quatre classes de défoliation. Le CH du bois de coeur et de l'aubier (en % de masse sèche) a été mesuré sur des disques de 5 cm d'épaisseur découpés selon des intervalles de 2.5 à 5 m pour les arbres respectivement de petites et de grandes dimensions. Les arbres vivants ayant plus de bois d'aubier que de bois de coeur avaient un CH moyen de 117%, et ceux avec plus de bois de coeur que de bois d'aubier avaient un CH de 77%. Les deux groupes contenaient suffisamment d'humidité de façon globale (>45%) pour la mise en pâte. La défoliation à répétition n'a pas affectée le CH total des arbres vivants. Le CH moyen des arbres tués par la défoliation de la tordeuse de l'épinette était de 42% mais ce niveau variait selon le diamètre et la hauteur au-dessus du sol: >45% pour les tiges de plus de 36 cm de diamètre sous écorce, 30–60% pour les sections de 17 à 36 cm, et <45% pour les sections de moins de 17 cm. Un diamètre minimal de 30 cm est suggéré en tant que critère d'acceptation des arbres morts.

Mots clés: impact de la défoliation par les insectes, contenu en humidité du bois, aubier, bois de coeur, fibre de bois mort, Manitoba

Introduction

From 1979 to 1991, areas up to 66,000 ha of white spruce [*Picea glauca* (Moench) Voss] and balsam fir [*Abies balsamea* (L.) Mill.] forest in eastern Manitoba (Lake Winnipeg East) were moderately to severely infested by spruce budworm [*Choristoneura fumiferana* (Clem.)] (Cerezke and Gates 1992; Moody and Cerezke 1985). The outbreak was first detected in the Abitibi-Price Inc. Forest Management License (Forest Management Unit 31) in 1979, increasing in size and intensity, and peaking in 1984; populations remained high throughout the decade (Knowles *et al.* 1992). Defoliation declined significantly since 1990. Salvage wood from insect, blowdown and fire damage comprised 29 and 40%, in 1989 and 1990 respectively, of the harvest volume³. The Abitibi-Price Inc. mill at Pine Falls, Manitoba currently requires a wood MC of approximately 45% to achieve desired product quality⁴. Preliminary observations in the field and at the mill suggested the MC of budworm-affected spruce was so low it affected pulp quality.

Moisture content (MC) of green eastern spruce (*Picea* spp.) averages 34% in the heartwood and 128% in the sapwood (Haygreen and Bowyer 1982). As trees age, overall MC generally declines with the declining proportion of sapwood. The impact of insect defoliation on wood MC has not been widely reported. Grammel *et al.* (1986) found that green sapwood of spruce that had lost 70% or more of its one- to three-year-old needles due to needle cast showed reduced MC while fir (*Abies* sp.) under similar conditions did not. Barnes and Sinclair (1983) reported significant differences in MC of balsam fir between sapwood and heartwood of healthy trees versus trees killed by spruce budworm; outer section MC (dry weight) decreased from 155% in healthy trees to 68% in trees dead for 12 months; inner section MC decreased from 125% in healthy to 109% in trees dead for 12 months.

Decreases or increases in MC can affect paper brightness, tear factor and processing (Binotto and Locke 1981). Lowery *et al.* (1977) reported that 30% more energy was needed to chip dead versus green Engelmann spruce (*Picea engelmannii* Parry). Moisture content is also an important factor in determining the liquor-to-wood ratio in the pulping digester (Parham 1983). It is more efficient to pulp water-swollen cell walls than those of drier wood because of easier penetration and saturation by the pulping liquor. As the wood dries, pits between the fibres close in, thus restricting free movement of pulping liquor. van Raalte (1983b) reported a one- to five-year

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increase in MC from about 42% to 65% wet weight (72% to 186% dry weight) of balsam fir associated with budworm kill. The implications of an increase in MC are greater deterioration due to decay, slower drying rates in piled wood resulting in further deterioration, and increased transportation and purchase costs because of heavier truck loads. In dead timber, MC influences decay rate, fire hazard, and wood loss during skidding and debarking (Basham 1980; Binotto and Locke 1981; Kiil 1968; van Raalte 1983a,b).

This study was initiated to determine the relationship between spruce MC and defoliation by spruce budworm, and to identify the trees expected to have low MC based on pulping requirements.

Methods

Study Area

The study area consisted of five white spruce and white spruce-aspen stands on the north side of Bird Lake, Manitoba (50°29'N, 95°17'W). This area had been heavily infested by spruce budworm and was scheduled to be salvaged during the winter of 1991–1992. All stands were Site Class 1 (Manitoba Natural Resources 1989) and predominantly mature and overmature. Fourteen plots were randomly selected from a grid of 400-m² plots within 72 ha. All spruce trees in each plot were sampled. Plots were selected consecutively until there were at least five trees in each defoliation-by-size category.

The sampling population consisted of standing trees, with a minimum diameter at breast height (DBH) of 10 cm, and a top diameter of 7.5 cm. Buffer zone and cull trees were excluded from the sampling population. Budworm-killed trees were included, although these were normally considered unmerchantable. Initially, trees were classed as “small” (DBH < 30 cm) or “large” (DBH ≥ 30 cm). Defoliation class was estimated according to crown defoliation and likelihood of survival:

Defoliation Class 1: dead trees.

Defoliation Class 2: severely defoliated, declining, not likely to recover.

Defoliation Class 3: severely defoliated, likely to recover.

Defoliation Class 4: lightly or not defoliated.

Dead trees (Class 1) were cut in August 1991 and the live trees were cut in September and October 1991. The trees were felled at an approximate butt height of 30 cm, delimbed and cut into pulp or sawlog lengths (2.54, 3.77, 5.08 m Tolerance level 1) (Canadian Standards Association 1986). A four- to five-cm thick disk was cut from the end of each log including the butt end. Tops above 7.5 cm diameter, and major stem defects were excluded from sampling. All disks were immediately placed in plastic bags and taken to the mill for weighing. Elapsed time between disk-cutting and weighing averaged four hours. On warm days (> 15°C), disks were carried in an electric cooler to reduce evaporation. One or two sapwood and heartwood samples were cut from each disk and weighed on a microbalance to ± 0.5 g if greater than 22 g, and ± 0.1 g if less than 22 g. Sapwood-heartwood borders were estimated visually by wet and dry appearance (dark-light) of wood. When the border could not be found, as in tree tops and some dead trees, the entire disk was weighed. After drying at 100°C for at least 40 hours, the samples were weighed again. Ninety percent of the

trees were sampled within one to eight days of felling, and all were sampled within 14 days. Sapwood, heartwood and outside bark diameters were measured to ± 0.1 cm. The disks were visually examined for incidence of stain or decay.

Analysis

The percent MC by dry weight of the sample blocks was calculated as follows (Parham 1983): $MC = (\text{wet weight} - \text{dry weight}) / \text{dry weight} \times 100$. The overall MC of each disk was calculated from the weighted means of the heartwood and sapwood subsamples and the heartwood:sapwood disk area ratios. The overall moisture of each tree (inside bark, merchantable portion) was calculated using Smalian's volume formula (Husch *et al.* 1972) and the weighted averages of the disk MCs.

Moisture content (Y) was compared according to defoliation class (D) and size class (S) using the following model:

$$Y_{ij} = D_i + S_j + DS_{ij} + E_{ij}$$

where error (E) is the variation among trees of the same defoliation-size class, i is any given defoliation class of 1, 2, 3 or 4, and j is any given size class, small or large.

Heartwood-to-sapwood volume ratio (H/S) was found to be a much better predictor of MC in living trees ($r^2 = 0.73$, $n = 74$ [(% MC)^{0.8} = 158.9 – 119.6 × (H/S)^{0.1}]) than DBH ($r^2 = 0.08$). The MC levels could generally be divided into well-defined groups at H/S=1. Therefore, delimitation based on size was changed from the arbitrary 30-cm DBH to a H:S ratio greater than or less than 1, which occurred on average at 23 cm DBH. The delineation between sapwood and heartwood was frequently unclear in dead trees, for which size delimitation was set at 23 cm DBH for analysis. Bartlett's test for homogeneity was used before conducting analysis of variance (Freese 1967). Data were grouped when differences between classes were insignificant.

Results

A total of 100 merchantable-size white spruce trees were harvested from the 14 plots. From these trees, 571 disks were cut for analysis. The numbers of trees per defoliation-size treatment combination were uneven. There were very few large Defoliation Class 2 trees in the study area, likely because most died soon after being severely defoliated in 1989 and 1990 and moved into Class 1.

The sample means and standard deviations in each defoliation-size treatment combination are shown in Table 1. The variances of the actual MCs were homogeneous ($P = 0.01$, Bartlett's test). The untransformed means were within 7 to 13% of the true treatment means [95% confidence interval (CI)]. The treatment means were analyzed and compared by two-way ANOVA (Tables 2 and 3).

Difference in the MCs in the defoliation classes by large and small trees are given (Fig. 1). All live trees had well over the minimum preferred 45% MC, regardless of size or defoliation class. There were no differences between defoliation classes in the live trees ($P = 0.09$; Bartlett's test $P = 0.02$) (Table 3), thus the live trees were grouped within size categories. Between size classes, those trees with more sapwood than heartwood (H/S < 1.0) averaged 117% MC (95% C.I. of 110 to 127%) while those with less sapwood than heartwood averaged 77% (95% CI of 73 to 82%) (Table 1). Differences between dead trees and all classes of live trees (pooled variance contrasts $P < 0.01$; Bartlett's test $P = 0.04$) are also provided (Fig. 1). The

Table 1. Moisture contents (MC) of defoliated trees

Defoliation class	Size class	Number of trees	% MC Mean	SD ¹
1 (Dead)	<23 cm DBH ²	17	44	17
	>23 cm DBH	10	37	12
2	≤1.0 H/S ³	8	119	24
	>1.0 H/S	9	79	13
3	≤1.0 H/S	13	124	17
	>1.0 H/S	26	79	14
4	≤1.0 H/S	1	105	0
	>1.0 H/S	17	80	16

¹SD = standard deviation.

²Heartwood/sapwood borders were not always distinct in the dead tree samples; the average DBH at which heartwood volume = sapwood volume in live trees was 23 cm.

³H/S ratio of heartwood volume to sapwood volume; 1.0 means 50% heartwood and 50% sapwood.

Table 2. Analysis of variance of moisture content (MC) in a two-way design for defoliation class (Def) and size of tree (Using SAS software, type III ANOVA)

Source	DF	ANOVA sum of squares	Mean square	F value	P > F
Def	3	53097.0	17699.00	63.79	0.0001
Size	1	5290.2	5290.22	19.07	0.0001
Def×Size	3	19682.7	6560.90	23.65	0.0001
Model	7	78070.0	11152.85	40.20	0.0001
Error	92	25526.9	277.47		
Corrected total	99	103596.9			

R-square	Coeff. of variation	Root mean squared error	mean
0.75	21.21	16.66	78.54

MCs of the dead trees were not different between size classes, so all dead trees were grouped together. The grouped MC of the dead class averaged 42%.

The MC in the bottom most logs of 14 of the 17 small dead trees was > 45%. Only one had > 45% MC in the first two pulp logs (5.0 m above ground), and none had > 40% above the second pulp log. In contrast, among the ten larger dead trees, > 23 cm DBH, three trees had < 32% MC even in the bottom most section, while six trees (all ≥ 32 cm DBH) had at least 44% MC up to 5 m above ground and in some as high as 15 m above ground.

Discussion

The purpose of this study was to help identify the quality of defoliated spruce timber for pulp processing. In terms of MC, the trees could be divided into three normally distributed groups: (1) dead trees (Defoliation Class 1), regardless of size; (2) live trees (Defoliation classes 2, 3 and 4) with heartwood volume less than sapwood volume; and (3) live trees with heartwood volume greater than sapwood volume. As long as the trees were still alive, the overall MC of all logs was well over the desired 45% minimum. Pulp and paper manufacturers should be concerned about the impacts of defoliation of which three are (1) the MC in dead trees; (2) the effect on MC of heartwood:sapwood volume ratio and the height of the log in the tree; and (3) the physical and biological interactions between wood MC and defoliation.

Table 3. Comparison of means of moisture content in defoliated living white spruce

Comparison	F	d.f.	F _{α=0.05}	Significance
Small vs. Large (H/S <1 vs. H/S >1)	1.660	5, 66	2.36	none
Def. Class 2 vs. 3 vs. 4 (H/S <1)	0.125	2, 22	3.44	none
Def Class 2 vs. 3 vs. 4 (H/S >1)	0.030	2, 44	3.21	none

Fig. 1. Comparison of moisture content of defoliated white spruce by size and defoliation class.

Dead Trees

In logs from dead trees, MC was over 45% provided that the inner bark diameter was greater than 36 cm, regardless of where this diameter occurred in the tree (Fig. 2). In logs less than 17 cm in diameter, the MC was nearly always less than 45%. In the logs between 17 and 36 cm in diameter, the MC was unpredictable, ranging from 30% to 60%. This variation was partly due to the skewed weight of the small trees; the bottom most logs of the small trees that fell into this diameter range had much higher MCs than the same diameter logs higher up from larger trees. Using the composite stem diagram (Fig. 2), the acceptability of logs in this size range can be assessed. Logs of diameter 17 to 36 cm (inner bark) from the base of dead trees will likely have at least 45% MC; the same size logs from upper sections of dead trees will likely have less than 45% MC.

Heartwood: Sapwood and Height Variation

Heartwood forms first in the lower tree stem resulting in lower wood MC near the ground. In live trees, the MC increases with height because of the decreasing proportion of heartwood to sapwood. In dead trees, the MC of the sapwood decreases with smaller diameter and greater height, so that the overall wood MC decreases with height (Barnes and Sinclair 1983).

Although overall MCs were acceptable, there were marked differences between sapwood MC and heartwood MC. Mean heartwood MC of all live trees was 46% vs. 144% in the sap-

Fig. 2. Moisture content of logs from dead white spruce, according to diameter and size of tree. (MC was determined by volume weighted mean of dry weight moisture content from 145 sections for 27 randomly selected trees.)

wood. There are wide variations between sapwood and heartwood MC in spruce (Haygreen and Bowyer 1982). The largest trees will tend to have the lowest overall MCs because the heartwood proportion generally increases with the size of the tree. Operationally, this means that concentrations of large diameter logs going into the mill will result in "pockets" of low moisture fibre. The proportion of sapwood varies with vigour, age, and tree size (Hazenberg and Yang 1991; Lassen and Okkonen 1969), and the amount of foliage on the tree (Coyea and Margolis 1992). In pulp made from healthy trees, differences between sapwood and heartwood MC are probably unimportant because the pulp process homogenizes the heartwood and sapwood fibres. However, if defoliation reduces sapwood volume and/or sapwood MC, then pulp quality may be affected, based on the proportion of sapwood in the harvested timber.

The small dead trees (< 23 cm DBH) had a higher average MC, 44%, than the larger dead trees, 37%. This moisture was concentrated almost entirely in the first 3-m section, whereas in the larger trees, the moisture was more uniformly distributed. Thus, it appears that stem sections to a diameter of approximately 36 cm of large white spruce, recently killed by spruce budworm, can be expected to contain enough moisture to meet the company's pulping requirements. Sections less than 17 cm in diameter from dead trees appear to be too dry unless they are the bottom most log in the tree.

Although the H/S ratio appears to be the best predictor of MC, it is unavailable to the field forester when deciding whether or not to accept a budworm-killed (Defoliation Class 1) white spruce tree. These data suggest that an appropriate tree size criterion is 30 cm DBH to ensure the dead trees have a minimum 45% MC to a height of 5 m. As a caution, however, Coyea and Margolis (1992) have shown DBH in balsam fir in Quebec to be less well correlated with foliage (leaf area) than various measures of sapwood area.

Moisture content of dead trees is strongly influenced by height. In budworm-killed balsam fir, MC ranged from about 50% to 150% over the length of the bole (Barnes and Sinclair 1983; Basham *et al.* 1974). Green heartwood MC in west coast species fluctuated with tree height while the sapwood MC remained fairly constant with height (Pong *et al.* 1986). The overall MC was < 45% in the sections above the height at which the diameter was < 30 cm in each of six trees and > 45% in the larger, lower sections. This indicates that the relationship of MC to height may be related to tree diameter. Although this observation could not be tested statistically, it may assist in selecting dead trees for harvest.

Physical and Biological Implications of MC Variation

Paper manufacturers are concerned about the possible effects of MC variation on volume and quality of fibre (Dolenko *et al.* 1981); however, the effects of a moisture decrease

alone in dead wood are difficult to assess. Following the death of the tree, MC changes at different rates in sapwood vs. heartwood, and is associated with both sapwood and heartwood decay rates, effecting volume losses from 1.5% annually to 18% in some studies (Basham and Morawski 1964; Binotto and Locke 1981; van Raalte 1983b). Further variations are associated with tree height, notably in the upper sections of some insect-defoliated trees where MC falls below the decay threshold (Hinds *et al.* 1965).

Although no degrading organisms were found to be closely associated with defoliation in this study, some levels of decay in individual trees may still render wood unusable. Assessing decay should be considered when MC is suspected to be varying due to defoliation.

Conclusion

Moisture content in all surviving defoliated trees was sufficient for the mill's normal papermaking process. Dead trees generally contained insufficient moisture with the notable exception of the lower portions of stems, depending upon height and size.

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