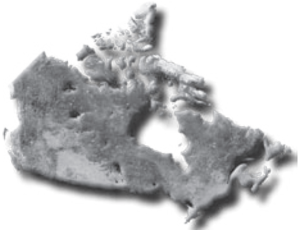

Rate of deterioration, degrade and fall of trees killed by mountain pine beetle: A synthesis of the literature and experiential knowledge

Kathy J. Lewis; Ian Hartley

Mountain Pine Beetle Initiative
Working Paper 2005–14

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2005

Abstract

This report is the first stage of a larger study to determine how factors that determine wood quality and quantity change with time-since-death, including the rate of tree fall. The type of wood products that can be manufactured from beetle-killed wood depends on these factors and on the technology used for production. The profitability of using the dead timber resource also depends on market conditions. This report however, is limited to the change in factors determining tree position (standing or down) and wood quantity and quality over time. The information presented in this report is a synthesis of over 90 published articles and responses from seven people with forestry and/or mill experience from the 1980s Caribou Plateau mountain pine beetle outbreak. In general, there is a rapid degrade of beetle-killed wood in the first one to two years post-mortality due to bluestain, reduced moisture content, and checking. Wood volume recovery from dead tree is very good, and almost the same as from green trees while the tree bark remains tight. Losses in volume up to this point are due to breakage during felling and handling. Recovery from trees with loose bark is significantly lower, but still high enough for many products. The literature and observations suggest that trees will fall to the ground before they reach the point where decay losses in standing trees are substantial. A table is provided that summarizes wood quality and quantity variables and their relationship with other variables such as time-since-death, tree size, and moisture regime.

Résumé

Ce rapport est la première étape d’une étude qui consiste à examiner comment les facteurs qui déterminent la qualité et la quantité du bois évoluent après la mort de l’arbre, en prenant notamment en compte le taux de chute des arbres. Le type de produits pouvant être fabriqués à partir des arbres tués par les scolytes dépend de ces facteurs et de la technologie utilisée pour la production. La viabilité économique de l’utilisation des arbres morts dépend également de l’état du marché. Ce rapport est néanmoins limité à l’évolution des facteurs déterminant la position de l’arbre (debout ou tombé) ainsi que la quantité et la qualité du bois durant son évolution. Les informations présentées dans ce rapport constituent la synthèse de plus de 90 articles scientifiques et des commentaires offerts par sept personnes qui ont travaillé dans le secteur de la foresterie et/ou des scieries lors de la flambée des dendroctones du pin des années 1980, sur le plateau Caribou. On observe en général une dégradation rapide du bois provenant des arbres tués par les scolytes au cours des deux premières années suivant la mort des arbres à cause du bleuissement, de la diminution du taux d’humidité et de la fissuration du bois. Le taux de récupération du bois provenant des arbres morts est très bon et se rapproche beaucoup du taux obtenu pour les arbres vivant tant que l’écorce reste en place. Les seules pertes en volume durant cette phase proviennent de cassures occasionnées lors de l’abatage ou de la manipulation. Le taux de récupération à partir des arbres dont l’écorce se détache est beaucoup faible mais reste suffisamment élevé pour de nombreux produits. Les études précédentes et les observations sur le terrain suggèrent que les arbres tombent sur le sol avant que leur bois ne soit trop dégradé. Les variables déterminant la quantité et la qualité du bois ainsi que les liens avec d’autres variables telles que le temps écoulé depuis la mort de l’arbre, la taille de l’arbre et le taux d’humidité sont rassemblés dans un même tableau.

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1.0 Introduction

The information presented in this report is a synthesis of over 90 published articles and responses from seven people with forestry and/or mill experience from the 1980s Caribou Plateau mountain pine beetle outbreak. The literature review focused on mountain pine beetle (mpb) and lodgepole pine, but also included papers on other conifer species and other agents of mortality (e.g., spruce budworm). Figure 1 shows a breakdown of references by subject area. Most of the research to date on issues surrounding "shelf-life" have been in the product value and recovery area, and much of this has been conducted in the United States. Most of the research on lodgepole pine and mountain pine beetle, in terms of product recovery, has been in Pacific Northwest and Intermountain region states, whereas research on southern pine beetle predominates in the southeastern states. There are a limited number of publications from research in British Columbia, and these are from the southern part of the province. In preparing this synthesis, we have relied most heavily on research involving lodgepole pine.

This report is the first stage of a larger study to determine how factors that determine wood quality and quantity change with time-since-death, including the rate of tree fall. The type of wood products that can be manufactured from beetle-killed wood depends on these factors and on the technology used for production. The technology used currently, or in the future, could be quite different from that used in the published studies. Utilization opportunities can change with technology, therefore the focus of this report is on factors of wood quality and quantity, although we have reviewed literature from the wood products industry.

Most of the research has focused on utilization of trees that have been dead for less than 5 years, and the general conclusion is that reduced moisture content, checking (related to moisture content) and bluestain are the most important factors involved in loss of product opportunities and quality. Decay of standing pine is slow (at least in the regions studied), and trees are more likely to fall over before significant losses of wood volume occur due to decay fungi. Once trees are on the ground, decay rates accelerate substantially.

Many of the studies considered the costs and benefits of utilizing dead wood, and it is very apparent that market conditions are paramount in determining value derived from dead wood products. Market analyses are beyond the scope of this report which focuses on the rate of change in wood properties, utilization opportunities for various wood products, and fall rate with respect to time-since-death.

The following sections present what is known about each of the above topics, and some projections of how those findings apply to the current outbreak. The current outbreak covers a large geographic area with highly variable climate. We used yearly climate normals from weather stations in the area to delineate five general climate regions for the shelf-life projections. Appendix one shows the regions.

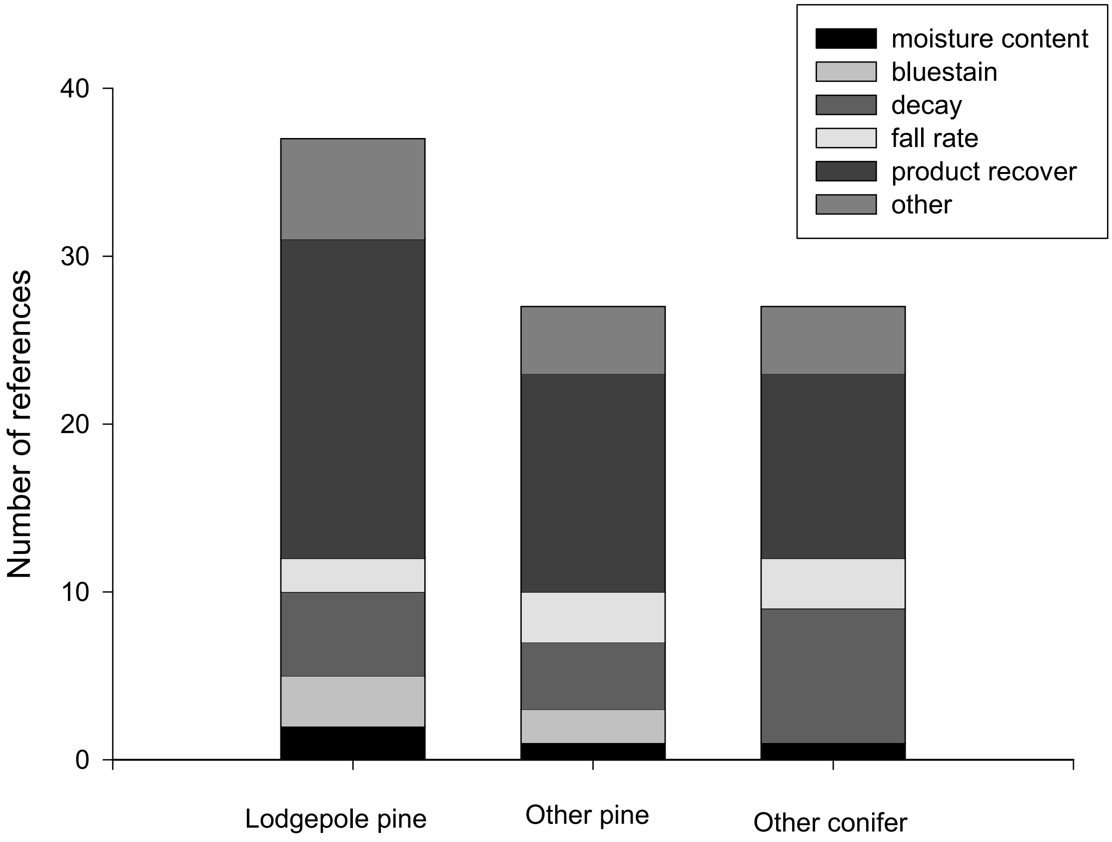

Figure 1. Number of references found by topic area and species.

2.0 Changes in Wood Quality with Time-Since-Death

2.1 Moisture Content

Three studies from British Columbia (B.C.) have examined the relationship between moisture content and time-since-death (tsd) in detail. Reid (1961) studied mountain pine beetle-killed trees one year after attack and found that moisture content (mc) decreased from 85% - 165% (oven-dry weight basis) in green trees to approximately 16% in dead trees, although this change in moisture content was limited to the sapwood. In live trees there was a horizontal gradient of decreasing moisture content from the outer to the inner sapwood that was not evident in dead trees (Figure 2). Vertically, moisture content varied in live trees, but no consistent patterns were identified.

Reid (1961) also measured moisture content of outer sapwood in trees that were: 1) successfully attacked in July; 2) successfully attacked in August; and 3) attacked during both flights but no brood produced. Figure 3 shows that trees attacked earlier in the season were the first to fall below the fibre saturation point (approximately 30%mc), which is when significant checking begins.

The second B.C. study, by Nielson (1986) in the Williams Lake area, found that moisture content decreased to 40% by the end of August following attack in July, then to fibre saturation point (fsp) within a year. They observed checking and splitting once the wood reached fsp.

Finally, Woo et al. (2003) also in the Williams Lake area (SBSdw biogeoclimatic subzone) performed a small study that involved one dead and one live tree, both of the same diameter. The dead tree had been dead for eight months. Sapwood moisture content was reduced by 85% in the dead tree relative to the live one, and by 7% in the heartwood. Moisture content did not vary with height.

These results are supported by studies from the United States. Lowery and Hearst (1978) found that there was no moisture content gradient in dead tree lumber, and further that lumber from dead trees (tsd ≤ 10 years) had approximately one half the moisture content as lumber from live timber. In eastern Oregon, Ince (1982) found that in trees ranging in tsd from recent to 10 years, the moisture content (mc) ranged from 4% to 52%, and that the mc for most trees was less than 20% (oven-dry basis).

Observations by Bob Hodgkinson, Regional Entomologist, Ministry of Forests Prince George Region, indicate that during the fall following attack, sapwood of trees attacked in the Vanderhoof area is still moist. Drying begins by winter and by the following fall the sapwood is very dry, with some checking evident. Other interviewees also noted that checking (a symptom of reduced moisture content) is evident after one year of attack. Checking in wetter areas was reported to be straighter than checking in dry areas.

The data available suggest that checking is significant once wood moisture content falls below fibre saturation point, but there is little information on whether or not checking worsens with time as dead trees experience wetting and drying cycles due to ambient conditions. McFarling

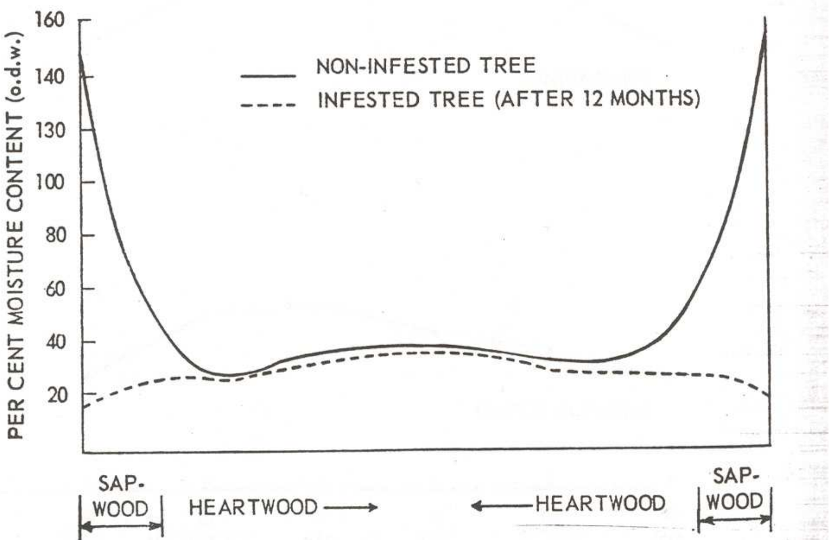

Figure 2. Horizontal variation in moisture content in attacked and unattacked lodgepole pine trees. From Reid (1961).

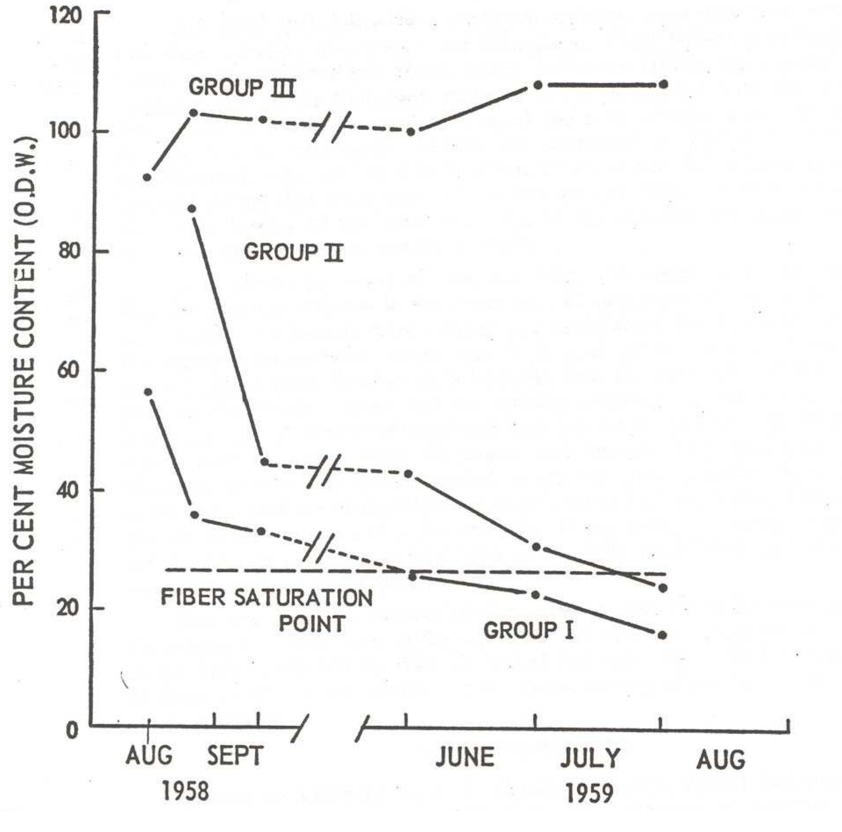

Figure 3. Seasonal moisture contents in the outer sapwood of successfully and unsuccessfully attacked lodgepole pine. Group I = successfully attacked in July, Group II in August, and Group III = unsuccessful attack. From Reid (1961).

and Byrne (2003) found that checking of blue-stained wood was no different from unstained wood when exposed to repeated wetting/drying cycles.

Moisture content and checking - projection for current outbreak

The rate of drying is not anticipated to be much different between what has been observed in southern B.C. and the U.S. Precipitation in the current outbreak area ranges from 400 mm to over 900 mm, compared to 413 mm in the Williams Lake area, 300 mm in eastern Oregon. This may contribute to a higher moisture content in the lower stem due to contact with the ground, as found by Tegethoff et al. (1977), who determined that long-butting was necessary in 76% of trees less than 5 years tsd, and in 94% of trees greater than 5 years tsd due to higher moisture contents and more decay. For most of the vertical length of the tree however, moisture content does not appear to be related to soil moisture.

Trees will have significantly reduced moisture content (to approximately 20%) by one year post-mortality, with checking beginning after one year. In cooler areas, checking may be delayed for up to 3 years due to slower drying rates (e.g., SBSwk, mk and mc) as determined by Fahey et al. (1986), and/or checking may be straighter-grained than in drier subzones (e.g., SBSdw). Once trees are dried to fsp, additional checking or worsening of checking will probably be limited.

2.2 Bluestain

In general, the onset of bluestain appears associated with the reduction in moisture content (Reid 1961), although bluestain is initiated before drying. Solheim (1995) found that bluestain was prevalent throughout the sapwood of trees from the Penticton area that were examined 7 weeks after attack. In a study from Oregon, Harvey (1979) tracked the spread of bluestain in trees that had been successfully attacked by mountain pine beetle in August. Trees were sampled through November of that year, and then in June the following year. Figure 4 shows the results of that study. By 9 to 10 months following attack, over 50% of the total volume, and almost 100% of the sapwood volume was stained. Smaller diameter trees have a lower ratio of sapwood to heartwood, therefore the percent of total wood stained in small trees is lower than in larger trees.

Fungi involved in the staining process were identified by Solheim (1995) in a study near Princeton. *Ophiostoma clavigerum* and *O. montium* were the most commonly isolated fungi in the bluestain group. *O. clavigerum* was not found as frequently as *O. montium*, but when the two were found together, *O. clavigerum* always preceded *O. montium* in terms of fungal penetration. In a larger study from southeastern B.C., Kim et al. (2005) found similar results with the above two fungi dominating those isolated from lodgepole pine attacked by mountain pine beetle. The prevalence of these two fungi, particularly *O. clavigerum* decreased with time-since-death, and the prevalence of other sap staining fungi increased with tsd. This is particularly true for fungi associated with ambrosia beetles. Further, according to one of the specialists interviewed, ambrosia beetles enter attacked trees the spring following the year of attack, if they are in the

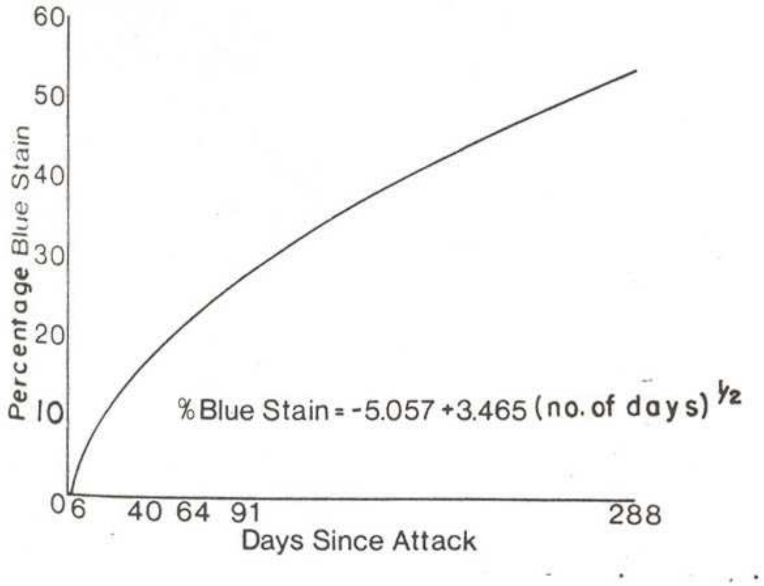

Figure 4. Predicted increase of blue stain volume in mountain pine beetle killed lodgepole pine in northeastern Oregon (Harvey 1979).

vicinity. After two years since death, ambrosia beetles won't attack even if they are around. Another interviewee noted that ambrosia beetles appear to be more prevalent in wetter areas.

In summary, staining of beetle-killed sapwood involves a succession of fungi, initiated by aggressive species carried in by the beetles, and continued by less aggressive, but more competitive species, including some fungi that are introduced by other insects such as ambrosia beetles and other wood borers. Bluestain is limited to the sapwood as the fungus feeds on materials found in living cells.

Bluestain – projection for current outbreak

There is no evidence to support that invasion of the sapwood by bluestain fungi will be at a different rate than observed in studies from southern B.C. and the United States. Therefore, throughout the central interior, beetle-killed trees will have to be harvested in the fall following attack to avoid substantial bluestain in the sapwood. Bluestain will continue to develop in sapwood of attacked trees as long as the moisture content remains above fsp.

3.0 Decay (volume loss)

3.1 Standing Wood

Published information on the rate of decay with time-since-death is limited to the Pacific Northwest and Intermountain regions for lodgepole pine, with very few studies from British Columbia. Results from the interviews suggest that in the region encompassed by the 1980s outbreak, decay of beetle-killed pine was not a factor in utilization of the wood until the trees fell over, then decay progressed rapidly. Most interviewees suggested that the rate of fall would precede the decay rate of standing trees. These opinions are supported by Harvey (1986) who studied decay of mountain pine beetle-killed trees in Oregon. Of 8000 cubic feet sampled, less than 1% volume was lost to advanced decay 11 years after tree death. Decay was observed in 13.7 of the sampled trees. In eastern Idaho, Tegethoff et al. (1977) studied the use of beetle-killed pine for power poles. They found that 60% of the pole-quality trees (in terms of size and form) had been dead for more than 5 years, and of those, 70% were sound (although some required long-butting to remove basal decay). Of poles from trees less than 5 years since death, 94% were sound. Butt rot was responsible for 50% of the cull volume in trees dead less than 5 years, and 63% in trees dead more than 5 years. Although defects, such as basal wounds, were frequently associated with decay, they were not reliable indicators of decay, suggesting that sap rot fungi (which require no wound for entry, but are restricted to dead trees) were active, and in fact a number of common sap rot fungi were identified based on production of sporocarps (conks). In a study of fungal diversity in mpb-killed trees in southeastern B.C., Woo et al. (2003) found that more basidiomycete fungi (decay fungi) were present in red and grey attacked trees than in green attacked. This study did not investigate loss of wood volume, and the presence or absence of advanced decay was not noted. However, the diversity of species, and frequency of isolation of decay fungi was relatively low, and increased with tsd, suggesting that basidiomycetes are relatively slow to invade, and decay progression is further slowed by the reduction in moisture content.

In a study of white pine lumber recovery following mortality, Snellgrove (1977) found that average yield for live timber logs was 34% but dropped to 22% when logs were from trees dead more than 7 years. Drying and checking, not decay, were the major causes of loss in recently killed trees (1-2 years) with sap rots and wood borers becoming more important in older dead material (Figure 5).

Several interviewees noted that as tsd increased, the likelihood of log breakage during felling and handling increased. One person (a mill manager) indicated that trees harvested 10 years after attack were producing grade 2 lumber and that the product was satisfactory, but that handling became an issue because of breakage. Snellgrove and Fahey (1977) found that log handling losses in white pine went from 4.5% of total volume to 6.7% by 2 years post-mortality, and up to 10.8% in 7 years post-mortality. This suggests that losses to decay were not substantial in these dry areas for up to a decade or more, but that the reduction in moisture content made the wood more brittle and likely to break on processing. An interviewee with knowledge of wetter stands in the eastern part of the 1980s Caribou Plateau outbreak stated that sap rot was an issue within 10 years in these wetter stands, whereas fall down was more important in the drier stands.

3.2 Downed Wood

Several of the people interviewed had observed that once trees fall, and are in contact with the ground, that decomposition proceeds very quickly. This is in contrast to published studies from the United States. A study of beetle-killed pine from central Oregon (mean precipitation 280 mm) found that bole wood density decreased significantly with decomposition age (Figure 6), but this was over a 60-year period. They also found that a minimum of 26 years residence time was required for 50% of the wood biomass to be decomposed (Busse 1994), and that decomposition was not evident in elevated boles. In a second study, by Brown et al. (1998) in Colorado, dendrochronology was used to date death of the downed trees. Lodgepole pine logs on the ground persisted for many decades with a majority of their volume intact (Figure 7). No difference in decomposition was observed on north versus south aspects.

We suspect that the difference between these published studies, and observations of sap rot in downed logs made during the interviews is due to different objectives. The purpose of the studies from the U.S. was to examine decomposition from an ecological perspective, as it related to coarse woody debris and nutrient cycling, whereas the interviewees were interested in utilization of the wood for various products. The latter purpose would be more sensitive to decay in the sapwood.

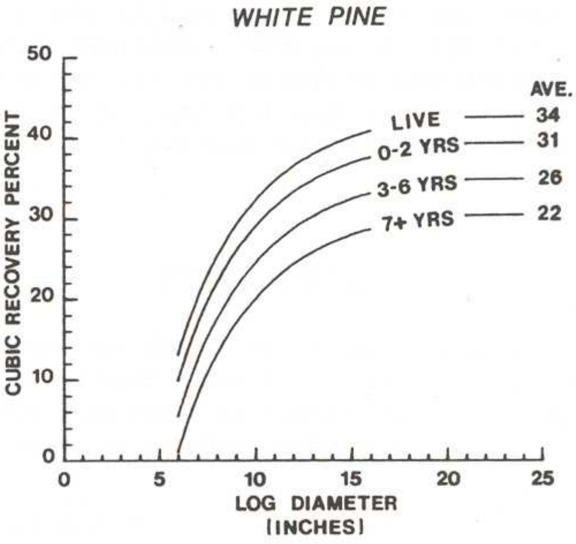

Figure 5. Relationship of lumber cubic volume recovery percent to log scaling diameter for western white pine (Snellgrove and Fahey 1977).

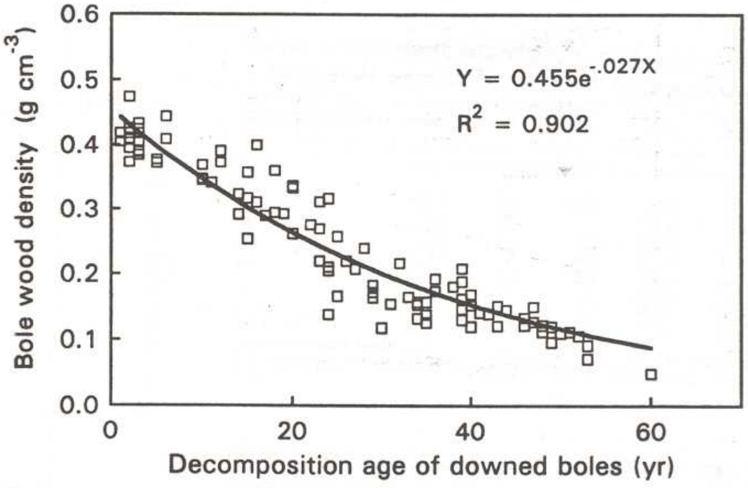

Figure 6. Single exponential decay curve for downed lodgepole pine bole wood (Busse 1994).

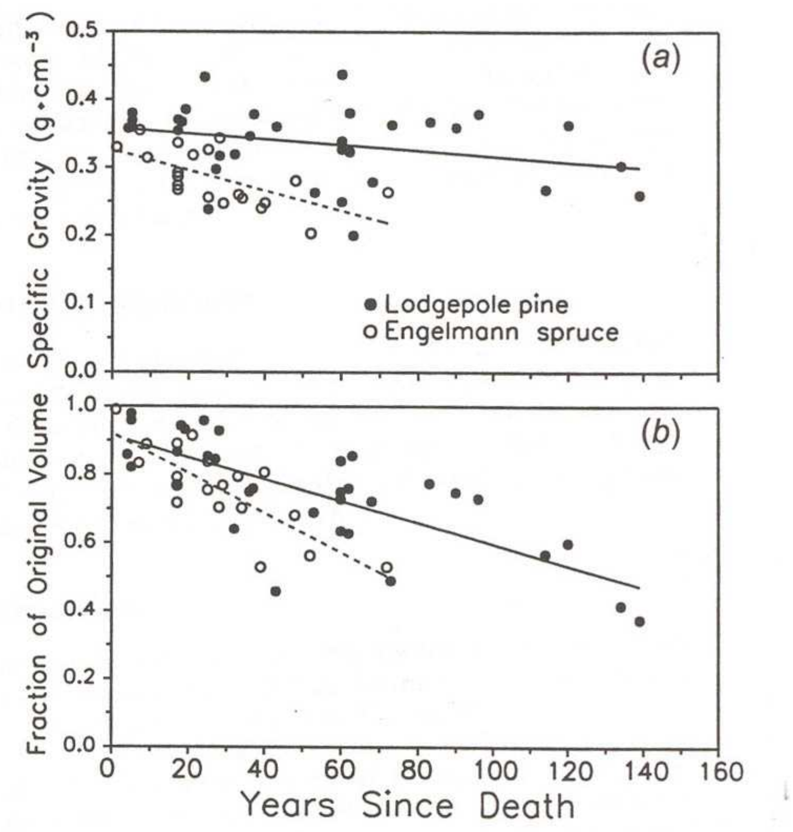

Figure 7. a) Specific gravity of wood remaining in cross-dated logs by years since tree death. b) Mean fraction of original wood volume in three cross sections used to determine specific gravities (Brown et al. 1998).

Decay – Projection for Current Outbreak

Volume loss due to decay depends on time-since-death, atmospheric moisture content, and tree size. Wetter areas will lose volume to sap rots more quickly, and we suggest that decay will start having an impact on standing trees and volume recovery by year 7 post-mortality. This estimate pertains to SBS mc1, mc2, mc3, wk variants. In drier regions (SBS dk, dw) it is expected that decay losses will not become important for 10 years or possibly longer.

Sap rots progress from the outside of the tree toward the centre, with the heartwood more resistant to decay. Therefore, in terms of percent total volume, large trees lose less volume to sap rots than small trees over the same period of tsd. This may offset the greater decay losses expected in richer sites and warmer areas (i.e., SBS wk), because these areas would also be the most productive and produce the largest trees. Dense stands of low volume trees will lose volume to decay the fastest, due in part to the small tree size, but also the greater likelihood of tree-fall scars leading to greater decay volumes prior to attack by the beetle.

4.0 Rate of Tree Fall

A study from the Williams Lake area found that the most common category of windthrown trees 15 to 20 years post-attack, were dead before falling, with 75% of the bark intact. Most of the fallen trees had broken off at the roots. Fall rates were determined as 0.04%/ha/year for live trees, and 1.43%/ha/year for dead trees over a 5.3 year period (Waterhouse and Armleder 2004). One interviewee said that soil moisture content is what drives the fall down rate, and that increased harvesting and edge did not affect the rate of fall. This person also noted that by year 15, most trees have fallen, and that most fall down occurred 10 to 18 years post-mortality. He has observed trees 5 years since death starting to fall in the Entiako area (SBSmc2, SBPSmc), and that less dense stands fall first. Another interviewee stated that in the Chilcotin area, stands with 30% of the attacked stems still standing were difficult to find 3 years ago. A third interviewee stated that in drier areas in the current outbreak, trees that are 6-7 years dead are still standing, and he predicted that trees may stand for 10 years.

Several interviewees noted that in stands with high levels of mortality, the soil moisture content had increased, presumably due to reduced transpiration. This would lead to a higher rate of tree fall due to faster butt rot development, than in areas where a lower proportion of trees were attacked.

Studies from Oregon found that trees killed by mpb began falling 3 years after death in thinned stands, and 5 years after death in unthinned stands (Mitchell and Preisler 1998). In thinned stands, 50% of the trees were down within 8 years, and 90% were down in 12 years. In the unthinned stands, 50% had fallen within 9 years, and 90% within 14 years. Most of these trees broke upon contact with the ground. The study also determined that small trees fell faster in the thinned stands, which is similar to results by Dahms (1949) with ponderosa pine.

Harvey (1986) also studied beetle-killed lodgepole pine in 1974 in Oregon. He found that only one tree fell in the first five years post-mortality, but by 1985, 25.3% of the trees had fallen. Variables that influenced fall rate of ponderosa pine in Oregon and northeastern California included climate, tree species, forest type, soil moisture and dbh (Keen 1955). In this study, 85% of snags were still standing after 5 years, but after this time, snags fell at an increasingly rapid rate. After 15 years, rate of fall decreased and the resistant snags stood for a long time. After 25 years, 10% of the snags were still standing. In Colorado, Schmid et al. (1985) found that ponderosa pine killed by mpb did not fall within 2 years of infestation. Thereafter trees fell at a rate of 3% to 5% per year, unless high winds occurred. Most of the fallen trees broke above ground.

Tree Fall – Projection for Current Outbreak

There are several variables that appear to influence the rate of tree fall. Soil moisture content appears to be one of the most important variables, therefore the rate of fall is expected to be greater in wetter subzones. In the SBSmc and wk variants it is anticipated that trees will begin to fall 3-5 years post-mortality, with the smaller trees falling first due to a smaller basal area. By 8 years post-mortality, it is estimated that 25% to 50% of the trees will have fallen, and by 15 years this number is expected to be around 90%. In drier areas trees are expected to remain standing for a slightly longer period of time. We estimate that 25% to 50% of the trees in dry subzones will have fallen within 10 years post-mortality.

Stands that have a high mortality rate are expected to experience a higher rate of tree fall due to increased soil moisture content leading to more rapid development of basal decay.

5.0 Wood Products and Time-Since-Death

There is a lack of consensus, among the literature and the interviewees, regarding the quality and utility of beetle-killed pine. Reasons for this lack of consensus include: 1) different technologies used to process the dead timber; 2) influence of market prices on the economics of processing and selling products from dead timber; 3) variation in the cost of the raw material; 4) extent of dead timber (i.e., in some cases the use of dead timber was economic because it could be mixed with a significant live component); and 5) lack of knowledge or understanding of actual properties of beetle-killed wood.

The literature, and the interviewees, all recognize that shelf-life varies with intended product, and that efficient use of dead timber must take this into consideration. The following section reviews literature and experiential knowledge around different products.

5.1 Solid Wood Products (Lumber, Veneer, Poles)

5.1.1 United States Studies

Woodfin (1979) studied lodgepole pine and other species from Wyoming and Montana that had been killed by mountain pine beetle a number of years ago (actual number unknown). Table 1 shows that there was a substantial lumber recovery potential from dead timber. Most of the losses were due to handling, checking, and grade reduction. Lumber grade yield as a percentage of total lumber for white pine is shown in Figure 8. In summary, for beetle-killed pine, there was an immediate reduction in recovery due to stain, which eliminated the No. 2 common and better lumber, value losses continue into the third and fourth year of mortality but at a slower rate that mainly reflects checking, wood borers and some sap rot. With stain graded as no-defect, the losses due to checking, wood borers and sap rot are evident but not significant factors until 4 or 5 years post-mortality.

According to Fahey (1980), the value loss at a random dimension mill is less than at a board mill because bluestain is not a grading factor for dimension lumber. At a stud mill, the value loss is further reduced. Fahey also determined that veneer was also a possible use for logs larger than 18 cm (7 in.). They used a 4-foot high speed lathe, and found that recovery was better than anticipated. It is not clear what the tsd was in this study.

Lemaster et al. (1983) studied beetle-killed lodgepole pine obtained from Wyoming. Raw material included beetle-killed trees with tight bark, beetle-killed trees with loose bark, and a control. Various products were evaluated. They found that beetle-killed timber maintained much of its physical integrity with minimal fibre degradation. Most of the losses were from drying on the stump. Dead trees with tight bark had little change in index values compared to live pine. Dead trees with loose bark were less suitable for many of the products tested (Table 2).

Table 1. Lumber recovery from lodgepole pine as a percentage of log volume (from Woodfin 1979).

		Percent of log volume	
Mill Location	Mill type	Live timber	Dead timber
Montana	Band mill	36	26
Wyoming	Band/scragg mill	48	47
Wyoming	Scragg mill	36	31

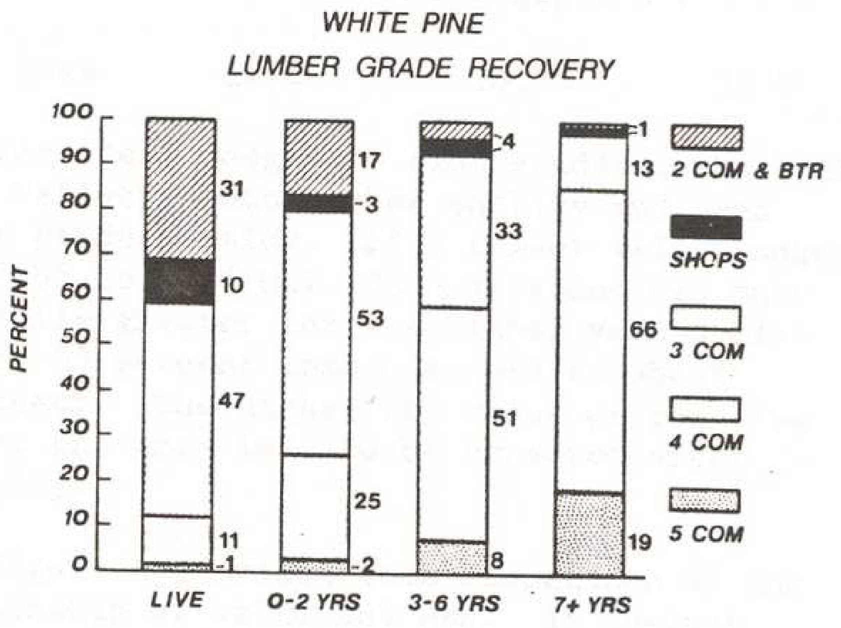

Figure 8. Lumber grade yield as a percentage of total lumber tally by condition of tree (Snellgrove and Fahey 1977). COMM& BTR = Common and Better

Table 2. Summary of average index values for 13 products by material class. Index values were based on evaluators (i.e., wood properties such as modulus of elasticity, freedom from checking, nail holding ability), as determined by the combined judgment of the investigators (from Lemaster et al. 1983).

Product	Live lodgepole pine	Dead lodgepole – tight bark	Dead lodgepole – loose bark
Yard lumber	100	91.0	88.3
Structural lumber	100	88.8	83.8
Mine timbers	100	103.5	98.9
Railroad ties	100	102.7	99.4
House logs	100	86.6	75.2
Utility poles	100	99.6	90
Construction poles	100	102.2	93.4
Corral poles	100	85	73.1
Fence posts	100	96.3	80.3
Fencing	100	85.6	78.6
Paneling (siding)	100	87.8	82.0
Pallets	100	87.6	84.9
Laminated beams and joists	100	96.1	89.4

Fahey et al. (1986) compiled several studies on changes in product recovery between live and dead lodgepole pine from the Pacific Northwest and Intermountain regions. The findings of these studies are summarized below.

Boards: Boards (1 inch) processed from live trees were graded No. 2 common and better. There was a major loss in volume of lumber recovered from older dead trees (> 3 years tsd) and a resultant increase in chip volumes (Figure 9). Most of the loss was due to checking, with some from stain as well (e.g., reduction in No. 2 common and better grade). In some cases, these defects could be removed in the edging process.

Dimension Lumber: At one mill in Wyoming, there was no difference in volume of lumber or chips from live and older dead trees (Table 3). At a second mill in Montana, there was a reduction in recovery from dead trees.

Studs: Stain is not a grading defect for studs and the length of splits is less restrictive for stud grade lumber. From a separate study in Oregon, the live and recently dead (1-2 years) samples were not different for any of the response variables analyzed, but the older dead was different (Table 4). Even with older dead, recovery was enhanced when mills salvaged either chips or smaller lumber (e.g., 2 x 2s).

Core Veneer: Core veneer is used for the centre layers in plywood. Knots and splits are the key factors for determining grade, and stain is not important. In Fahey et al. (1986), logs were in 8-foot segments and peeled on a 4-foot lathe. The volume of veneer recovered was based on green, untrimmed veneer. The older dead sample was significantly different than the live and recent dead samples (Figure 10). Changes in volume recovered were less than anticipated, particularly for recently dead pine. Older dead trees produced about 30% less veneer. Grade recovery for this core stock was not affected.

In a separate study from central Oregon, Snellgrove and Ernst (1983) examined recovery of dead lodgepole pine for core-stock veneer. They found that volume recovery for 1-year dead was not different from live trees, but 3-year dead recovery was approximately 30% less. Grade was not affected by tsd, but the percentage of random strip increased with increasing tsd. Layup losses were least for live trees and greatest for mixed live and dead material. The mixed loads were dried at schedules for green veneer, consequently the dead material was over-dried.

5.1.2 British Columbia Studies

Beetle-killed pine from southeastern B.C. was studied in 1978 by Dobie. Four quality classes were used: green top (1 year since attack), red top (trees with red foliage), grey tight bark (trees with no foliage, but tight bark), and grey loose bark. Trees from these categories were processed through a mill for dressed, dried lumber. Table 5 shows that there was no difference in lumber yields or grade recovery for the first three categories of dead wood.

Table 3. Average recovery (percent) by lumber grade from live and older dead (>3 years) lodgepole pine in dimension mills. To convert to fbm/m^3: 1bd ft/cu ft = 35.6 fbm/m^3.

Mill type	Location	Tree condition	Standard No. 2 or better	Utility or No. 3	Economy	Lumber recovery factor (bd ft/cu ft)
Chipping headrig	Montana	Live	81	9	10	5.7
		Older dead	34	47	19	5.7
Circular saw	Wyoming	Live	61	22	17	6.1
		Older dead	37	43	20	6.1

Table 4. Average recovery (percent) by lumber grade, from live, recent dead (1-2 years), and older dead (>3 years) lodgepole pine trees sawn in stud mills.

Location and tree condition	Stud	Short stud	Economy stud	Lumber recovery factor
Oregon				
Live	79	4	16	4.7
Recent dead	75	10	15	4.9
Older dead	75	10	15	4.5
Wyoming				
Live	85	8	7	5.4
Recent dead	68	9	23	5.2
Older dead	63	12	25	5.1

Table 5. Lumber recovery and grade yields from beetle-killed pine in B.C. (Dobie 1978).

	Yield		Grades (%)		
Quality group	% firmwood scale	% lumber cubic scale	#2 & better	#3	Economy
Green top	27	27	84	11	5
Red top	26	27	82	14	4
Grey, tight bark	25	27	77	17	6
Grey, loose bark	24	32	63	30	7

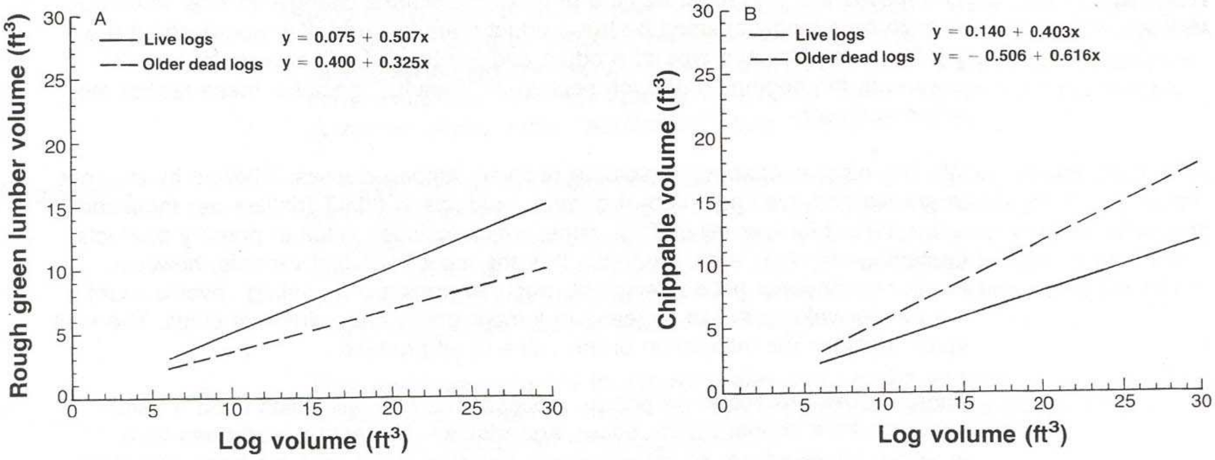

Figure 9. Estimates of the volume of lumber and chips for a mill in Montana producing boards from live and older dead lodgepole pine. A. Relationship of cubic feet of rough green lumber to cubic feet of gross log volume. B. Relationship of cubic feet of chippable volume to cubic feet of gross log volume (Fahey 1986).

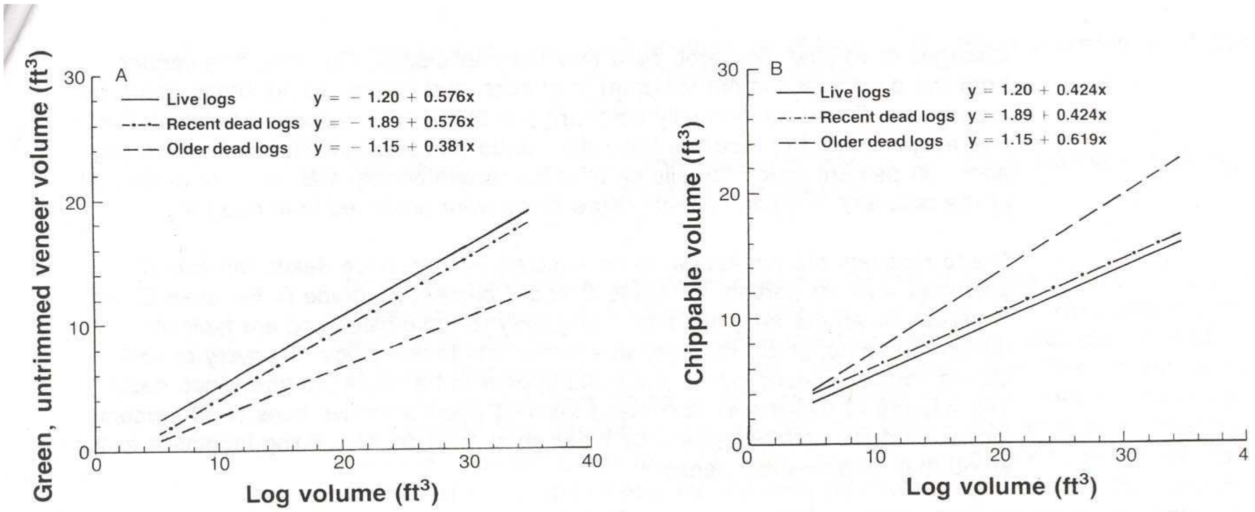

Figure 10. Estimates of the volume of veneer and chips for a mill in Oregon producing core veneer from live, recent dead, and older dead lodgepole pine. A. Relationship of cubic feet of green, untrimmed veneer to cubic feet of gross log volume. B. Relationship of cubic feet of green, untrimmed veneer to cubic feet of gross log volume (Fahey et al. 1986).

Operating costs for the first three groups were not different but were about 25% greater for the grey, loose bark category (presumably due to breakage).

A study of value recovery of beetle-killed trees on veneer processing has been completed for the current outbreak (Woodward 2005). In this study, the green attacked sapwood had 30% less moisture content than healthy sapwood, and moisture content has a significant effect on veneer recovery. Veneer recovery values were 47.3%, 44.0%, and 41.7% when processing 25%, 50%, and 75% mpb logs decked for 4-5 months. The veneer recovery improved to 50.3% when 25% mpb logs were processed within a week of arrival at the mill. The amount of random-width veneer ranged from 6.2% to 9.4% for mpb logs. Beetle-killed ribbons were rougher, but costs for drying were less. All of the above results refer to trees that were in the green attack stage ($\leq$ 1 year tsd).

5.2 Fibre Wood Products (pulp, oriented strand board, particle board)

Most of the past studies on fibre products and dead wood have been on chip production and pulping. Oriented strand board (OSB) and particle board are more recent products, and have not been well studied.

In a study of beetle-killed trees in southeastern B.C., Dobie and Wright (1978) found the moisture content of chips from grey dead trees was about half that of green attack or red trees. There was a slight increase in fines with deteriorating tree quality.

Thomas (1986) studied Kraft and mechanical pulping of beetle-killed trees in four categories of tsd (green attack, red, grey tight bark, grey loose bark). They made the following conclusions:

- material losses increased in the forest due to ageing of dead wood and breakage
- loss of pine good wood during debarking increased slowly with tsd until later grey stages when the rate of loss increases.
- chip fines increased with tsd
- wood moisture content and density decreased with tsd
- one percent caustic solubility increased slightly with tsd
- Kraft pulping alkali requirement did not change
- pulp viscosity was reduced for the longest dead trees
- Kraft pulp yield was reduced with increasing tsd
- black liquor tall oil content increased with beetle attack, then decreased with increasing tsd
- black liquor solids increased with tsd
- beetle attack caused no significant difference in bleachability of Kraft pulp
- Kraft pulp showed maximum strength in the green and red attack classes with reduce strength in the older grey stage.
- beetle-killed wood is likely to show poor pressing/drainage characteristics
- old attacked wood is susceptible to damage from mechanical action during pulping
- CTMP tear usually decreases with increased tsd
- CTMP shows poorer bleaching response with increased tsd

- effluent toxicity and pitch problems could increase for chemical and mechanical mills

Wood Products – Projections for the Current Outbreak

The economies around utilization of dead wood are dependent on the markets, current or developing technologies, and the ratio of dead to live trees in harvested stands. Some basic principles are:

1. Breakage during handling causes a significant proportion of lost volume. It is anticipated that breakage losses will increase sharply with the loss of moisture, then taper off as reduction in moisture content goes to zero. It is expected that greater losses to breakage can be expected from drier subzones.
2. Any product affected by stain (e.g., Japanese market boards) will be severely downgraded within the first year of attack.
3. Products not affected by stain will retain properties similar to green trees for 2 to 3 years, with moister regions maintaining properties longer.
4. Bark integrity may be a good indicator of wood quality as dead trees with tight bark frequently did not differ in recovery factors from live trees or recently dead trees. The effect of bark removal by woodpeckers on wood properties is not known.
5. Wood from trees that have loose bark (probably dead 4 years or more) is useful for both solid wood and fibre-based products, but recovery is lower.
6. Production of cants can result in grade enhancement by removal of outer checked wood.

6.0 Summary

In summary, the published and experiential information shows that there is a rapid degrade of beetle-killed wood in the first one to two years post-mortality, due to bluestain, reduced moisture content, and checking. Wood volume recovery from dead trees remains high, and is almost the same as from green trees as long as the tree bark remains tight. Losses in volume to this point in time are due to additional breakage during felling and handling. Recovery from trees with loose bark is significantly lower, but still adequate for many products. The literature and observations suggest that standing trees will fall to the ground before decay losses become substantial. Table 6 summarizes wood quality and quantity variables and their relationship with other variables such as time-since-death, tree size, and soil moisture regime.

Table 6. Summary of wood quality and quantity variables relative to time-since-death and other tree and environmental variables.

Property	Change from green condition	Time-since-death	Variables that can influence property
Moisture content – sapwood	Reduced <20%	Dry subzones[1] = 12 months Wet subzones[2] > 24 months	Time of attack – late in season, moisture content drops to fibre saturation pint (30% mc) within 2 months
Moisture content - heartwood	No change	N/A	N/A
Checking	Checking develops in standing trees	Dry subzones[1] = 12 months Wet subzones[2] > 24 months	Wet subzones – checking may be straighter Cooler subzones – onset of checking may be delayed
Bluestain	40% of sapwood 100% of sapwood	2 months 9 months	For large diameter trees, bluestain affects less overall volume than for smaller diameter trees
Decay - standing trees	Initiation of sap rot	Dry subzones[1] = 10 years Wet subzones[2] > 7 years	Tree diameter – large trees = less proportional loss Moisture content – dry wood limits fungal development, most decay will be at the base of the tree where it contacts the ground Stand density – increased density = increased decay
Tree fall	40% of infected trees down	Dry subzones[1] = 10 years Wet subzones[2] > 7 years	Wet subzones – expect 90% down within 15 years Tree diameter – increased diameter = decreased fall rate Soil moisture regime – increased mortality rate = increased soil moisture = increased fall rate Increased MPB tree fall – increased risk to wind throw of entire stand

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[1] Dry subzones include the SBS dw, dk, and regions I and II of Appendix
[2] Wet subzones include the SBS mc, wk, and regions III, IV and V of Appendix

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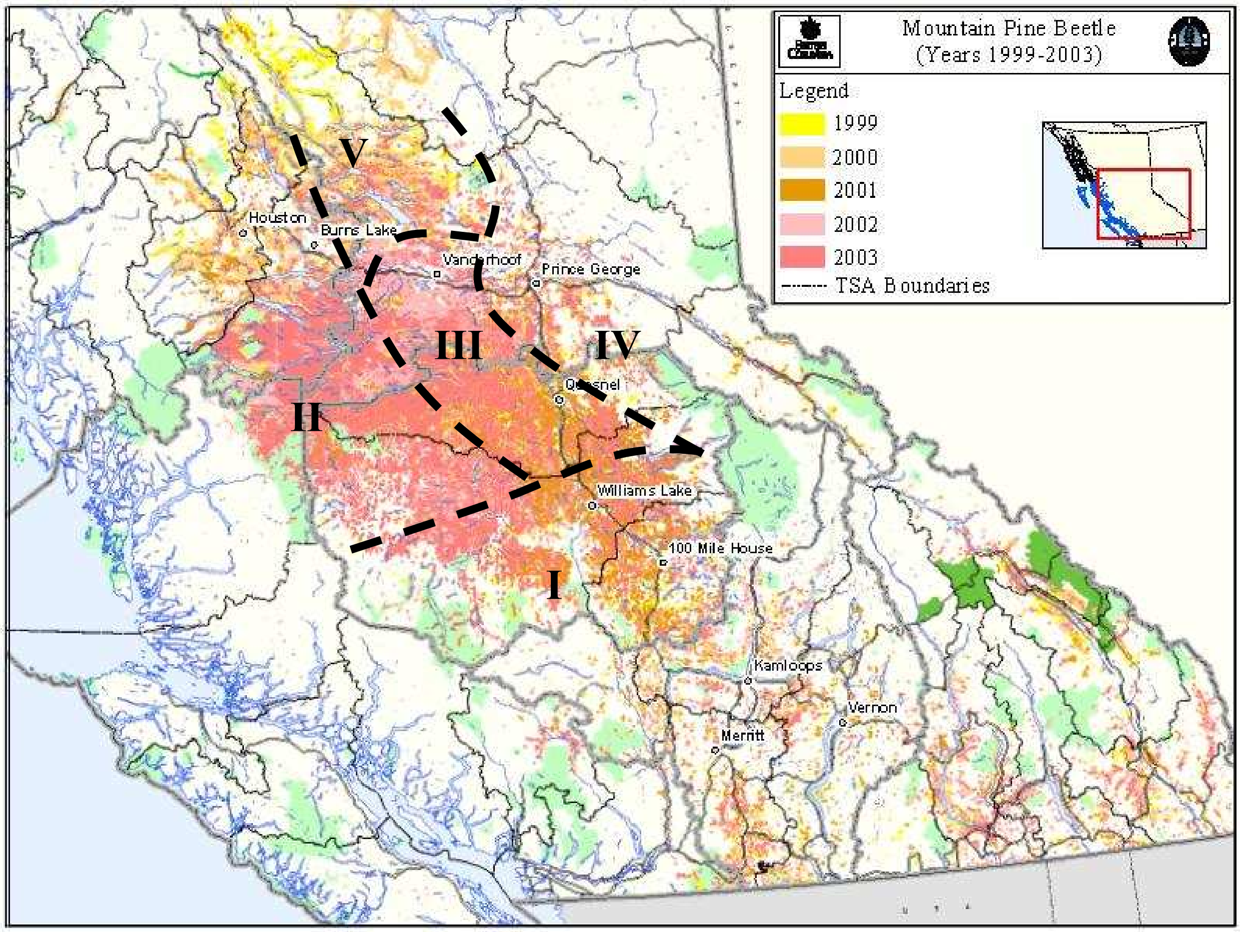
Appendix



Regions

I	warm, >4C; dry, <450mm precipitation
II	cold, <3.1C; dry, < 460mm
III	warm, >4.4C; wet, >500mm
IV	cold, <4C; wet, >600mm
V	cold, <3.1C; moist, 480 – 520mm

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