Discussion Paper

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Rate of deterioration, degrade, and fall of trees killed by mountain pine beetle

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Abstract

The information presented in this paper results from a review of published articles on deterioration of dead wood, and interviews of people with forestry and (or) mill experience from the 1980s Cariboo Plateau mountain pine beetle outbreak. The literature review focussed on mountain pine beetle (*Dendroctonus ponderosae*) and lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.), but also included papers on other conifer species. Most of the existing research has focussed on utilization of trees that have been dead for less than 5 years. The general conclusion was that reduced moisture content, checking (related to moisture content), and bluestain were the most important factors involved in loss of product opportunities and quality. Decay of standing pine was slow (at least in the regions studied), and trees were more likely to fall over before significant losses of wood volume due to decay fungi. Once trees were on the ground, decay rates accelerated substantially.

KEYWORDS: *bluestain, decay fungi, moisture content, mountain pine beetle, shelf-life, stand structure, wood products.*

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Introduction

The current mountain pine beetle epidemic, the largest outbreak ever recorded in North America, has spread over an area in excess of 7 million ha and can be traced back to 1993. Lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) is the most affected species, although the beetle (*Dendroctonus ponderosae*) also attacks ponderosa pine (*Pinus ponderosa* P. Laws. ex C. Laws.), western white pine (*Pinus monticola* Dougl. ex D. Don), and whitebark pine (*Pinus albicaulis* Engelm.) (Henigman *et al.* 1999). The previous largest outbreak in British Columbia occurred between 1969 and 1985 on the Cariboo Plateau. It affected 1.4 million ha of pine stands over a 4.8 million ha area (Rogers 2001), and significantly affected timber supply. Anecdotal evidence from foresters and mill operators who experienced the outbreak suggests that trees killed by mountain pine beetle (MPB) were harvested and utilized until 2004, although harvest of stands with 75% or more mortality ceased in the mid 1990s. Many small outbreaks have been recorded since 1959 by the former Forest Insect and Disease Survey (Natural Resources Canada [no date]).

The current outbreak extends over a much larger area, and includes many more forestry-dependent communities than previous outbreaks. It is anticipated that because of deterioration of dead trees over time, the current outbreak will seriously affect short- and intermediate-term timber supply, and therefore community stability (Government of British Columbia 2005). In addition, the outbreak will affect stand structure and dynamics, particularly in pine-dominated ecosystems, with consequent impacts on habitat and other non-timber forest resources. Despite serious past outbreaks, there is a lack of knowledge regarding the rate and process of wood degrade, decay, and fall-down, and variables that influence these changes over time. Such information is critical for strategic planning for timber flow, habitat, and fire hazard.

Several "shelf-life" studies have been initiated. Some information, primarily from United States wood products studies, can be used as a first estimate of changes in wood properties and vertical stand structure over time. This paper summarizes the existing literature and the experiential knowledge of foresters and mill operators from the Cariboo Plateau outbreak. It may help resource planners and managers in projections of "shelf-life" for the current outbreak.

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Although most of the present information focusses on wood products, our emphasis is on the change in properties of wood quality and quantity over time because numerous non-biological variables influence product manufacture. These variables include existing and developing technologies, market prices, and raw material and manufacturing costs. However, because much of the information was derived from wood products studies, we provide some limited observations and recommendations with regard to product manufacturing. For more detailed discussions of wood products from beetle-killed lodgepole pine see Byrne *et al.* (2005), Byrne and Uzunovic (2005), and Lum (2005).

Changes in Wood Quality with Time-Since-Death

Moisture Content and Wood Checking

Three studies from British Columbia examined in detail the relationship between moisture content (MC) and time-since-death (TSD). Reid (1961) studied beetle-killed lodgepole pine in the area of Invermere, B.C., and Banff, Alta., for 1 year after attack. He found that sapwood moisture content in green trees (85–165%, oven-dry weight basis) decreased to as low as 16% in dead trees. By the end of August following an attack in July, moisture content had decreased to 40%, then fell to fibre saturation point (FSP) within a year. In live trees, a horizontal gradient of decreasing MC exists from the outer to the inner sapwood, which was not evident in dead trees. Vertically, MC varied in live trees, but no consistent patterns were identified. Reid (1961) also measured MC of outer sapwood in trees that were successfully attacked in July, successfully attacked in August, and attacked during both flights but no brood were produced. The trees attacked earlier in the season were the first to fall below the FSP (approximately 30% MC), which is when significant checking begins. Trees attacked unsuccessfully experienced no notable decline in MC.

Woo *et al.* (2005) performed a small study that involved one dead and one live tree from the Williams Lake, B.C., area (Sub-Boreal Spruce [SBS]dw biogeoclimatic subzone). The dead tree had been dead for 8 months and had the same diameter as the live one. 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. Lodgepole pines sampled from four locations in southern and southeastern British Columbia showed significantly lower sapwood MC in dead red-stage trees than green-stage trees, and a slight further reduction in the dead grey-stage trees. Designation of green, red, or grey refers to the general colour of the crown of attacked trees. Mean sapwood MC of red-stage trees ranged from 19.8 to 26.9%, and were between 40 and 80% at the end of the first year following attack (Kim *et al.* 2005). Heartwood MC in the same study was significantly higher in green-stage trees compared to red- or grey-stage trees.

These results are supported by studies from the United States. Lowery and Hearst (1978) found that no MC gradient occurred in lumber from dead lodgepole and western white pines, and the lumber (TSD not determined, but up to a decade) had approximately one half the MC of lumber from live timber. In eastern Oregon, Ince (1982) found that in lodgepole pines ranging in time-since-death from recent to 10 years, the MC ranged from 4 to 52%, and that most trees had less than 20% (oven-dry basis).

Observations by Bob Hodgkinson (B.C. Ministry of Forests and Range, pers. comm., 2005) indicated that after an attack in the fall, tree sapwood in the Vanderhoof area of British Columbia was still moist. Drying began by winter and by the following fall, the sapwood was very dry with some checking evident. Preliminary results from a study located southwest of Vanderhoof also suggested that checking develops 1–3 years postmortality (K.J. Lewis, unpublished data, 2006, University of Northern British Columbia, Prince George, B.C.). Collectively, these observations were from locations further north and in a wetter climate than those of the other studies, which may explain the apparent slower rate of drying.

The data available suggest that checking becomes significant once MC falls below the FSP within 1 year following attack; however, little information exists on whether or not the number or depth of check increases with increasing TSD as dead trees experience wetting and drying due to ambient conditions. McFarling and Byrne (2003) found that checking of bluestained wood in service was no different from unstained wood when exposed to repeated wetting and drying cycles.

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Bluestain

The onset of bluestain appears associated with reduction in MC (Reid 1961) and is initiated before drying. Solheim (1995) found that bluestain was prevalent throughout the sapwood of trees from the Penticton, B.C. area 7 weeks after attack. In a study from Oregon, Harvey (1979) tracked the spread of bluestain in lodgepole pines that had been successfully attacked by MPB in August. Trees were sampled through November of that year, and then in June the following year. Nine to ten months following attack, over 50% of the total volume and almost 100% of the sapwood volume was stained. According to Harvey (1979), smaller diameter trees in even-aged stands have a lower ratio of sapwood to heartwood than larger diameter trees, therefore the percent of total wood stained in smaller trees is lower than in larger trees.

In a large study in southeastern British Columbia, Kim *et al.* (2005) found that *Ophiostoma clavigerum* and *Ophiostoma montium* were the dominant bluestain fungi isolated from MPB-attacked lodgepole pine. The prevalence of these two fungi, particularly *O. clavigerum*, decreased with TSD, and the prevalence of other sap-staining fungi increased with TSD. This was particularly true for fungi associated with ambrosia beetles. According to Bob Hodgkinson (B.C. Ministry of Forests and Range, pers. comm., 2005), if they are in the vicinity, ambrosia beetles enter MPB-attacked trees in spring the following year. After 2 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.

Changes in Wood Quantity with Time-Since-Death

Breakage and Decay in 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 suggested 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, and 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 lodgepole pines in Oregon. Of the 226 m^3 (8000 ft^3) 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 lodgepole 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 taken from trees dead less than 5 years, 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. This suggests that sap rot fungi, which require no wound for entry but are restricted to dead trees, were active. In fact, a number of common sap rot fungi were identified based on production of sporocarps (conks).

In a study of fungal diversity in mountain pine beetle-killed trees in southeastern British Columbia, Kim *et al.* (2005) found that more basidiomycete fungi (decay fungi) were present in red- and grey-attacked trees than in green-attacked trees. 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 decay fungi isolation was relatively low, but increased with TSD. This suggests that basidiomycetes are relatively slow to invade, and decay progression is further slowed by the reduction in MC.

In the 1980s outbreak, decay of beetle-killed pine was not a factor in utilization of the wood until the trees fell over, and then decay progressed rapidly.

The likelihood of log breakage when felling and handling of trees killed during the Cariboo Plateau outbreak increased with time since death.

In a study of white pine lumber recovery following mortality, Snellgrove and Fahey (1977) found that average yield for live timber logs was 34%, and yield 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.

According to experienced foresters and mill managers, the likelihood of log breakage when felling and handling of trees killed during the Cariboo Plateau outbreak increased with TSD. Trees harvested 10 years after attack produced grade 2 lumber and the product was satisfactory, but 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% with 2 years post-mortality, and up to 10.8% with 7 years post-mortality.

Decay in Downed Wood

Very little is known about decay in downed wood from a utilization perspective. Most of the research on decomposition of fallen trees has been done for nutrient cycling and habitat studies. For example, a study of beetle-killed lodgepole pine from central Oregon (mean annual precipitation 280 mm) found that bole wood density decreased significantly with TSD, but this was over a 60-year period (Busse 1994). Busse also found that a minimum of 26 years residence time was required for 50% of the wood biomass to decompose, and that decomposition was not evident in elevated boles. Brown *et al.* (1998) in Colorado found that lodgepole pine logs on the ground persisted for many decades with a majority of their volume intact. No difference in decomposition was observed on north versus south aspects.

Rate of Tree Fall

Published data and observations from the Cariboo Plateau outbreak suggest that soil moisture is an important factor in fall-down rate. Waterhouse and Armleder (2004) found that most 15–20 year post-attack, windthrown lodgepole pines were dead before falling, with 75% of the bark intact. Most of these had broken off at the roots. Fall rates were determined as 0.04%/(hectares per year) for live trees and 1.43%/(hectares per year) for dead trees over a 5.3-year period. Additional anecdotal observations suggest that most fall-down occurred 10–18 years post-mortality, and that in the Chilcotin area, stands with 30% of attacked stems still standing were difficult to find by 2002.

Studies from Oregon found that lodgepole pine 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 sooner in the thinned stands, which is similar to results by Dahms (1949) with ponderosa pine. Harvey (1986) found that only 1 of 427 trees fell in the first 5 post-mortality years, but after 10 years, 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 diameter at breast height (Keen 1955). In this study, 85% of snags were still standing after 5 years, but fell at an increasingly rapid rate after that. 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 3–5% per year, unless high winds occurred. Most of the fallen trees broke off above ground.

In 2005, we observed a very low rate (< 1 %) of fall-down for over 2500 trees surveyed in 32 plots (K.J. Lewis, unpublished data, 2006, University of Northern British Columbia, Prince George, B.C.). The trees were killed between 1999 and 2005 in the SBSdk and SBSmc biogeoclimatic subzones (dry cool and moist cold, respectively) between Vanderhoof and the Entiako Protected Area. Many trees were primarily small diameter, un-attacked trees that had lost position in the canopy during stand development.

Wood Products

Solid Wood

Woodfin (1979) studied lodgepole pine and other species from Wyoming and Montana that had been killed by MPB an unknown number of years ago. There was a substantial lumber recovery potential from dead timber. Most of the losses were due to handling, checking, and grade reduction. An immediate reduction in recovery was attributed to stain, which eliminated the grade 2 and better lumber. Value losses continued into the third and fourth year of mortality, but at a slower rate. This mainly reflected checking, and the presence of wood borers and some sap rot. With stain graded as no-defect, the losses due to checking, wood borers, and sap rot were evident but not significant factors until 4–5 years post-mortality.

According to Fahey (1980), the value loss of beetle-killed lodgepole pine 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). He 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 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. The authors developed an index based on important wood properties and the weighting of them for each product. Dead trees with tight bark had little change in index values compared to live ones. Dead trees with loose bark were less suitable for many of the products tested.

In 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-width veneer increased with increasing TSD. Veneer loss at the glue spreader was the lowest for live trees and the highest for mixed live and dead material. The mixed loads were dried at schedules for green veneer; consequently the dead material was over-dried, which negatively affected gluing and dimensional stability.

TABLE 1. Lumber recovery and grade yields from beetle-killed pine in British Columbia (Dobie 1978)

	Yield		Grades (%)		
Quality group	**% firmwood scale**	**% lumber cubic scale**	**#2 and 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

Beetle-killed lodgepole pine from southeastern British Columbia was studied by Dobie (1978). 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. There was little difference in lumber yields or grade recovery for the first three categories of dead wood (Table 1). Operating costs for the first three groups were similar, 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 in British Columbia (Woodward 2005). In this study, the green-attacked sapwood had 30% less MC than healthy sapwood, and MC had 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, respectively. 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 (< 1 year TSD).

Fibre Wood Products (Pulp, Oriented Strand Board, Particle Board)

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

TABLE 2. Change in properties of Kraft and mechanical pulp from trees killed by mountain pine beetle, with increasing time-since-death (Thomas 1986)

Property	Change with increasing TSD	Impact on pulp
Chip fines	Increase in proportion	Decreased uniformity of cooking in digester, wood waste
1% caustic solubility	Increased slightly	An increase in caustic requirements in pulping
Alkali requirement for Kraft pulp	No change	None
Pulp viscosity	Reduced in grey dead	An increase in degradation of fibres during pulping and bleaching process
Kraft pulp yield	Reduced	Loss in production
Black liquor solids	Increased	Loss in production for recovery-limited mills
Bleachability of Kraft pulp	No difference	None
Pressing and drainage	Poor	Decrease in efficiency of wet pressing
Damage from mechanical action during pulping	Increased in grey dead	Lower strength pulp
CTMP[a] tear	Decreased	Decreased strength
CTMP bleaching response	Decreased	A drop in brightness

[a] Chemical-thermo mechanical pulp

In a study of beetle-killed lodgepole pine in southeastern British Columbia, Dobie and Wright (1978) found the MC 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). During harvest and debarking, he reported greater material losses in the forest with increased TSD due to breakage. The loss of solid wood during debarking increased slowly with TSD until later grey stages when the rate of loss increased. The effects of increasing TSD on other pulp processes and quality as described by Thomas (1986) are listed in Table 2.

One study on composition board from beetle-killed lodgepole pine in Washington found that dead material could be used effectively in various types of composition board. Of the particles studied, hammermilled, ring-cut flakes, atmospheric and pressure-refined fibre produced the highest quality fibre. Drum-cut flakes were difficult to glue because of surface damage due to flaking dry wood. Dead trees were graded as recently dead (red) to old dead (no needles, twigs, or small branches). All grades were included in the study (Maloney *et al.* 1978).

Conclusions and Recommendations

In summary, the published and experiential information shows that there is a rapid degrade of beetle-killed wood in the first 1–2 years post-mortality due to bluestain, reduced MC, and checking. Wood volume recovery from dead trees with tight bark is almost the same as from green trees. 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 good 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.

"Shelf-life" depends upon the desired end-product and the technology available to accommodate changes in wood properties with TSD. From the literature and our observations, it is evident that standing dead trees located in dry ecosystems will not experience significant decay for many years (we estimate 15–20 years); however, basal decay develops within 4–7 years and may contribute to butt cull or fall-down. In terms of wood utilization, limiting factors are MC and checking. Bluestain affects only the appearance of the wood, and although this may be a significant problem with regard to Japanese markets (J-grade lumber), it does not negatively affect wood utilization. The MC problem develops within a few years of tree death. Therefore, to stretch out the short-term timber supply, the focus should be on products that can tolerate dry wood (e.g., log homes), and technologies that can increase cost: benefit ratios by using dry wood in existing products (e.g., pulp). Salvage opportunities may be longer than what is commonly thought; there is less of an immediate need to capture timber volume before it is "lost."

The moisture content problem develops within a few years of tree death; therefore, to stretch out the short-term timber supply, the focus should be on products that can tolerate dry wood, and technologies that can increase cost:benefit ratios by using dry wood in existing products.

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Test Your Knowledge . . .

Rate of deterioration , degrade, and fall of trees killed by mountain pine beetle

How well can you recall some of the main messages in the preceding discussion paper? Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. Within the first 3–5 years post-mortality, which of the following statements is most accurate?
   A) Volume losses due to sap rot are substantial, but percent volume recovery can be improved by long-butting
   B) Degrade of beetle-killed wood is due primarily to bluestain, reduction in moisture content, and subsequent checking
   C) Volume recovery from red-stage trees is significantly greater than volume recovery from grey-stage trees with tight bark

2. The focus of this article was on variables that influence utilization of wood for various products, not on the shelf-life for specific wood products. A number of factors are not directly related to the change in wood properties over time, and these can significantly affect the cost-effectiveness of manufacturing products from beetle-killed wood. Which of the following factors fall into that category?
   A) Demand for the wood product
   B) Technology used to manufacture the product
   C) Cost of raw material
   D) Biogeoclimatic zone as it relates to soil moisture regime

3. Different species of fungi are associated with mountain pine beetle-killed wood. Bluestain fungi are introduced by the mountain pine beetle and assist with causing mortality of the tree. Another fungus can be introduced by ambrosia beetles that (select the most accurate statement):
   A) Invade beetle-attacked trees during the first year of attack if they are in the vicinity
   B) Can continue to invade beetle-killed trees for several years after attack
   C) Invade beetle-attacked trees after the first year of attack if they are in the vicinity

ANSWERS

1. B 2. ALL BUT D 3. C