Research Report

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Evaluation of tree condition and tree safety assessment procedures in beetle-killed and fire-damaged lodgepole pine stands in central interior British Columbia

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Abstract

This study quantified characteristics related to tree condition and deterioration in stands affected by the mountain pine beetle (MPB, *Dendroctonus ponderosae*) or wildfire. The stands evaluated were representative of a range of conditions present in the Sub-Boreal Spruce (SBS) zone in central interior British Columbia. The primary objective of the study was to evaluate the application and utility of the assessment procedure and safety thresholds outlined in the provincial Wildlife/Danger Tree Assessment Course (WDTAC). Stands dominated by lodgepole pine (*Pinus contorta* var. *latifolia* Englem.) that were affected by MPB or by wildfire were assessed in the Fort St. James, Nadina, Quesnel, Prince George, and Vanderhoof forest districts. Fifty-eight fixed radius study plots were delineated and 536 individual tree assessments were made. Forty-five trees were also destructively sampled to reveal internal tree condition and stem shell thickness. Using the WDTAC procedures, 16 trees (approximately 3% of those visually sampled and approximately 36% of those destructively sampled) were assessed as "dangerous." Notably, none of the beetle-killed trees sampled had specific defects or decay and deterioration patterns directly attributable to the MPB. The WDTAC procedures effectively detected danger trees among MPB-affected and fire-damaged lodgepole pine trees; the procedures appeared to be accurate, reliable, and consistent. This study demonstrates that as beetle and/or wildfire salvage continues, and where an increased risk of wildfire occurrence exists, application and use of the WDTAC criteria will help facilitate safe work practices in these situations.

KEYWORDS: *danger trees, lodgepole pine, mountain pine beetle, Sub-Boreal Spruce zone, tree condition, tree damage, wildfire, worker safety.*

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Introduction

Standing dead and decaying trees are common components of all forest ecosystems. Deadwood in forests can contribute significantly to the structure and function of the ecosystem (Franklin et al. 1987; Clark et al. 1998; Tinker and Knight 2000) and is considered important habitat for a diversity of wildlife species (Hansen et al. 1991; Bunnell 1995; Keisker 2000; Fenger et al. 2006). The amount of standing deadwood in a forest depends on natural disturbance processes that affect its accumulation from tree mortality and breakage, such as impact by lightning, fire, wind, disease, or insects, as well as processes that affect its loss, such as decomposition, burning, and harvesting (Clark et al. 1998; Tinker and Knight 2001; Stone et al. 2002; Hawkes et al. 2005). Although standing dead trees may persist for many years before falling to the ground, damaged and defective trees are recognized as potential dangers for forest workers and recreation enthusiasts.

Concerns regarding dangerous trees in park and municipal settings and within forest firefighting and industrial forest harvesting and silviculture operations has led to the development of provincial danger tree assessment guidelines in British Columbia (Wildlife Tree Committee of British Columbia 2005). Endorsed by the Workers' Compensation Board of BC (WorkSafeBC), the Wildlife/Danger Tree Assessment Course (WDTAC) is the provincial standard for determining tree hazards and wildlife tree habitat values in forested parks and recreation areas, and for forest harvesting, silviculture, and roadside operations. The WDTAC was developed to promote the conservation of wildlife trees and associated stand-level biodiversity in a safe and operationally efficient manner (Manning et al. 2002). Using these procedures, specific assessment criteria and damage thresholds were developed to determine whether various tree defects are safe or dangerous for given work activities. In addition, tree species groupings (e.g., hemlock and true fir; cedar; pine, spruce, larch, Douglas-fir [*Pseudotsuga menziesii*], and broad-leaved deciduous) were built into this process to reflect species-specific differences in tree morphology and associated defect failure criteria and thresholds. Consequently, once identified trees have been assessed for a given work activity, the appropriate safe work procedures can be implemented based on a site-specific assessment. In the case of a tree assessed as dangerous, this would entail marking the tree for removal or installing a no-work zone of appropriate size and shape, before commencement of work activities (Wildlife Tree Committee of British Columbia 2005).

> *Despite a history of mountain pine beetle outbreaks in the province, little is known about the post-mortality rate of deterioration of beetle-killed lodgepole pine trees, or about factors that may influence the safety risk from falling beetle- or fire-damaged trees.*

Although these guidelines were created and field-tested by experts in occupational health and safety, logging, forest pathology, and forest and wildlife ecology, only a few studies to date have utilized the Wildlife Danger Tree Assessment (WDTA) process in a research context (Manning 2001; Rakochy and Hawkins 2006).

Lodgepole pine (*Pinus contorta* var. *latifolia* Englem.) is the most widespread tree species in British Columbia, and the predominate species on the province's central interior plateau. Wildfire and mountain pine beetle (MPB; *Dendroctonus ponderosae*) have historically been the primary stand replacement disturbance agents in this region (Roe and Amman 1970; Clark et al. 1998). Despite a history of MPB outbreaks in the province, little is known about the post-mortality rate of deterioration of beetle-killed lodgepole pine trees, or about factors that may influence the safety risk from falling beetle- or fire-damaged trees (Lewis and Hartley 2005).

The magnitude and intensity of the most recent MPB infestation in British Columbia has exacerbated the recruitment of large amounts of standing deadwood in these forests. Efforts to salvage marketable timber are still under way in many areas of the province; however, it is expected that large areas of residual unsalvaged pine will likely be retained (Eng 2004; Pederson 2004; Pousette 2005; BC Ministry of Forests and Range 2007). Part of the landscape, including those unsalvaged stands, will undergo future silviculture activities such as underplanting. Before our study, no empirical evaluation had been undertaken on the application, utility, and accuracy of the WDTA procedures in MPB-affected areas where road travel, salvage harvesting, and silviculture practices are planned.

The objectives of this project were to:

- evaluate the application and utility of the WDTA procedures in MPB-killed and fire-damaged stands; and
- quantify characteristics related to tree condition, including stem defects (scars, cracks), branch and foliar condition (needles and fine branches), and root soundness for these types of stands over a range of conditions in the Sub-Boreal Spruce (SBS) zone of central interior British Columbia.

Methods

Study location

The project study sites are located in the Moist Interior–Plateau Ecoregion (Natural Disturbance Type 1) from 53 to 55°N and from 122 to 126°W (Delong 2002; Figure 1). This area is ecologically classified as the SBS zone (Meidinger and Pojar 1991). The elevation ranges from 600 to 1800 m. The forests are broadly transitional between the true montane forests of Douglas-fir to the south, the drier, colder pine-spruce forest to the southwest, boreal forest to the north, and subalpine forest at higher elevations. The climate of the area is continental and is characterized by seasonal extremes of temperature—severe snowy winters, relatively warm, moist, and short summers, and moderate annual precipitation (Meidinger et al. 1991). Lodgepole pine and hybrid white spruce (*Picea glauca* × *engelmannii*) are the two most common tree species in this central interior plateau region.

The location's fire history indicates that hundreds of fires have burned over the last 20 years with wildfires as large as 12 000 ha and smaller than 2 ha recorded. The total area of MPB infestation is extensive in pine-leading as well as mixed coniferous–pine stands.

The beetle typically attacks stands over a number of successive years, often favouring the oldest and largest trees (Lewis 2006). The result is a landscape with a heterogeneous pattern of green, red, and grey-attacked trees (Figure 2). Beetle-killed stands that were attacked within the last 5 years are prevalent on the central interior

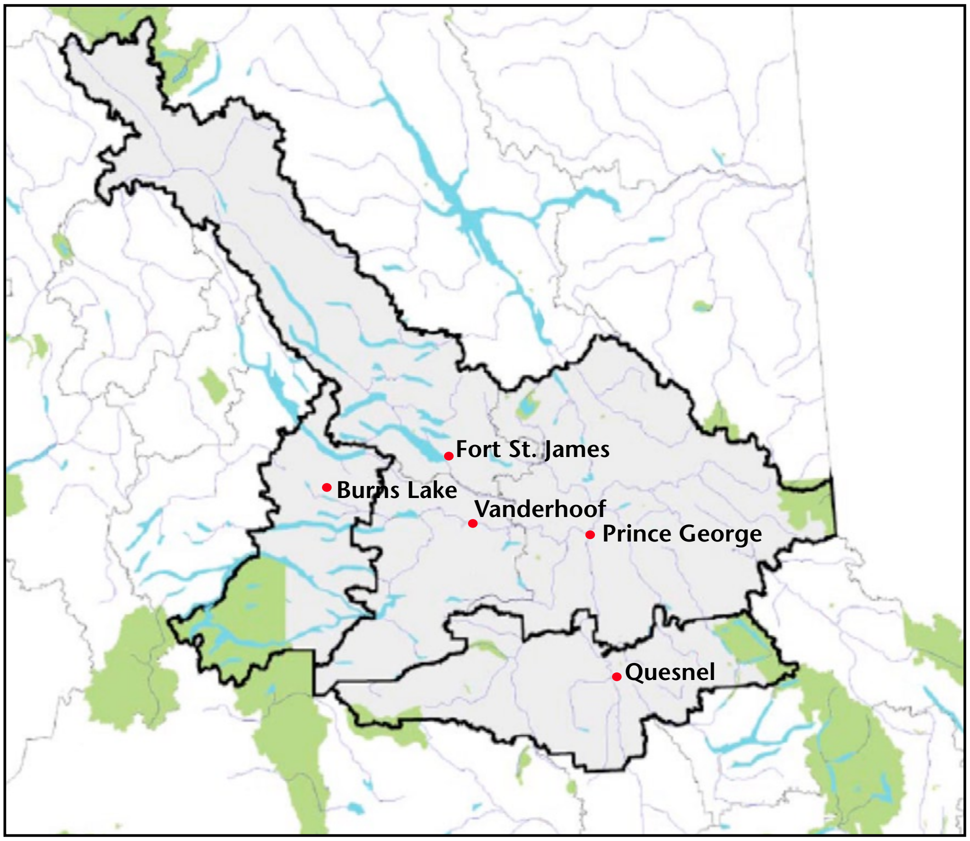

FIGURE 1. Study area in central interior British Columbia.

FIGURE 2. The beetle-affected landscape showing a mosaic of times since attack at the stand level.

landscape, whereas stands that were attacked over 10 years ago are less common. Similar to fire-damaged stands, MPB-affected stands represent large quantities of merchantable timber and often quickly become a priority for salvage-logging operations. Therefore, relatively few older attack sites with road access remain from previous MPB outbreaks. However, some trees attacked by MPB over 10 or as long as 20 years ago still remain standing in remnant areas around salvage block boundaries or within retained patches and riparian areas.

Site selection

To aid in the selection of MPB-affected sites, Forest Health Program and Mountain Pine Beetle Aerial Sketch Maps were obtained from Ministry of Forests and Range offices in the Fort St. James, Prince George, Quesnel, Vanderhoof, and Nadina forest districts. Additional information and maps were obtained from management staff of industrial land tenure holders that provided more specific information about the locations of MPB-infested stands and salvage-harvesting histories. As well, information was provided by Canadian Forest Service researchers that supported the inclusion of areas within Tweedsmuir Provincial Park (north side of Eutsuk Lake), which were attacked by MPB in the early to mid-1990s (Figure 3).

Candidate fire-damaged sites were determined using data and maps from the Vanderhoof Forest District and Prince George Regional District Fire Protection offices and were limited to those areas with reported fires of over 5 ha.

Experimental design

All sites selected were lodgepole pine-leading stands in the SBS zone and stratified by time since disturbance (Table 1; Figure 4). Time-since-disturbance categories, defined as the number of years since beetle infestation or years since fire occurrence, were 0–3 years, 3–5 years, and 10 or more years since the disturbance event. In a few cases, selected stands had canopy compositions slightly less than 70% pine, with hybrid white spruce, subalpine fir (*Abies lasiocarpa*), and trembling aspen (*Populus tremuloides*) making up the remainder.

The selected MPB-affected sites were also defined by variations in soil moisture regime, which for a pine-leading stand is most commonly dry or mesic. The selected stands ranged from Sub-Boreal Spruce dry warm (SBSdw1) to moist cool (SBSmc3) sites.

FIGURE 3. Outlined area of mountain pine beetle infestation in SBSmc2, north side of Eutsuk Lake, Tweedsmuir Provincial Park (Hawkes 1997).

TABLE 1. Description of beetle-affected study sites in the SBS biogeoclimatic zone of central interior British Columbia.

Time since attack (years)[a]	Forest district	Location[b]	Soil moisture[c]	BEC[d] subunit	UTM co-ordinates		Elevation (m)
0–3	Vanderhoof	611 Road	Dry	SBSdk	363000E	5936083N	919
0–3	Prince George	Blackwater FSR	Dry	SBSdw3	513700E	5482200N	820
0–3	Vanderhoof	Y & D Road	Mesic	SBSmc2	453778E	5951988N	958
3–5	Vanderhoof	South Woodcock	Dry	SBSdw2	464182E	5936261N	945
3–5	Quesnel	Batuni FSR	Mesic	SBSmc2	481508E	5899868N	912
3–5	Vanderhoof	Red Road	Mesic	SBSmc3	380629E	5933175N	930
10+	Quesnel	Dragon Mountain	Dry	SBSdw1	546930E	5845354N	1245
10+	Nadina	Eutsuk Lake	Mesic	SBSmc2	686513E	5905027N	897
20+	Fort St. James	Hat Lake FSR	Mesic	SBSmc3	405164E	6073022N	848

[a] Time-since-disturbance data taken from Ministry of Forests and Range Forest Health Program and Mountain Pine Beetle Aerial Sketch Maps and confirmed using visual indicators.

[b] Location = forest service road (FSR) access or nearest geographic feature.

[c] Soil moisture class determined using BC Ministry of Forests Forest District biogeoclimatic ecosystem classification mapped data.

[d] Biogeoclimatic ecosystem classification (BEC) data taken from BC Ministry of Forests and Range regional maps.

FIGURE 4. Beetle-affected pine-leading canopy, 0–3 years since disturbance (SBSdw3; Kilometre 10, Blackwater Forest Service Road, Prince George Forest District).

Fire-damaged study sites (i.e., from natural wildfires) were also categorized by build-up index values (obtained from BC Ministry of Forests Weather Data System, Prince George, BC) recorded during the 5-day period before the wildfire ignition date (Table 2). Build-up index is a numerical rating of combustibility and amount of fuel available for combustion in the subsurface layer located between forest litter and mineral soils. Selected fire stands included medium (build-up index = 40–70) and high (build-up index > 70) intensity fires on moist (SBSmc2) and dry sites (SBSdw2).

Data collection

Data were collected during September and October 2005 from 15 stands dominated by relatively uniform size and age class lodgepole pine. In each stand selected for analysis, a minimum of three randomly located fixed radius (5.64 m) plots was sampled. Tree condition and visual defect information were recorded for each plot using the provincial Wildlife/Danger Tree Assessment procedures (Wildlife Tree Committee of British Columbia 2005). Plot centres were determined by a randomly generated compass bearing and distance from a previous plot centre or a stand-edge starting point. Each tree (≥ 12 cm diameter at breast height [DBH]) that at least touched the perimeter of the plot was considered in-plot and was measured (described) according to the WDTA criteria.

For each tree within the fixed area plot, data recorded included: species; tree height (m) and DBH (cm); tree class; presence of wildlife habitat features (e.g., nest cavities, feeding signs); occurrence of tree defects

TABLE 2. Description of fire-damaged study sites in the Sub-Boreal Spruce (SBS) biogeoclimatic zone of central interior British Columbia.

Time since fire (years)[a]	Forest district	Location[b]	Fire Intensity[c]	BEC subunit[d]	UTM co-ordinates		Elevation(m)
0–3	Vanderhoof	Kenney Dam	Med	SBSdk	377610E	5948737N	777
0–3	Vanderhoof	Hay Lake	High	SBSmc3	412294E	5925572N	1057
3–5	Quesnel	Pantage Lake	Med	SBSdw2	499608E	5894881N	878
3–5	Vanderhoof	Gray Road	High	SBSmc3	401301E	5914086N	1100
10+	Nadina	Eutsuk Lake	Med	SBSmc2	683758E	5904718N	882
10+	Prince George	Meadow Lake	High	SBSdw2	463460E	5920581N	880

[a] Time-since-disturbance data based on wildfire ignition date from Forest Protection data.

[b] Location = forest access road or nearest geographic feature.

[c] Fire Intensity = average build-up index 5 days preceding ignition date; build-up index: Medium = 40–70; High = 70+; BC Ministry of Forests and Range Fire Weather System Data (Boyer 2005).

[d] Biogeoclimatic ecosystem classification (BEC) data taken from BC Ministry of Forests and Range regional maps.

such as broken tops, stem scars, stem cracks, and fungal conks; and root condition. When decay was evident, the type of decay was recorded (i.e., root disease, sap rot, and heart rot). Assessments of root condition were made by coring or probing at the root collar, and also at 50 cm away from the tree base along each major lateral root. All roots were assessed and percent of sound roots was recorded to quantify the overall proportion (%) of sound roots existing for each tree. All tree defects were described and rated according to the most common tree defect thresholds for forest harvesting activities (categorized as Level 3 disturbance) in accordance with WDTAC standards at that time (Wildlife Tree Committee of British Columbia 2005).

Additional information that was considered beyond the WDTA criteria (but relevant to specific tree conditions post-beetle attack or post-fire) was also recorded. Quantification of the amount (%) of intact bark present on the trunk at breast height (about 135 cm above ground), the percentage of needles and fine branches still present on the tree, and stand or microsite characteristics (e.g., wet depression, raised bench, or mound) were recorded to refine our understanding of the efficacy of the WDTA process for these stand types.

Destructive sampling

To determine potential correlations between visible external tree defects and internal tree condition (i.e., presence and extent of decay), destructive sampling was performed on a subsample of trees within MPB-affected and fire-damaged stands. All trees selected for destructive sampling had some type of visual defect (e.g., stem scar, stem crack, broken top). This provided an indication of how accurately the WDTAC procedures rate visible tree defects because these are the types of trees observable by persons conducting pre-work dangerous tree assessments, and/or by forest workers who may be in the vicinity of these types of trees. Previous studies (Manning 2001, 2007) have shown a significant correlation between the occurrences of visual stem defects and associated internal tree condition (i.e., wood decay). For this reason and also because of project budget limitations, it was decided not to destructively sample a random selection of trees that had no visible external defects. Internal tree decay characteristics (i.e., cross-sectional width of unsound and decayed stemwood) and measurements of stem shell thickness, as well as the longitudinal extent of decay in the tree bole, were recorded on trees with visual defects. Before trees were felled, a detailed tree assessment and estimate of average shell thickness was completed at four equally spaced positions on the tree stem at stump height (about 30 cm above ground), using a cordless drill and 5/16” auger bit. Estimated measures of average shell thickness were then verified by measurements taken on the stump cross-section after the tree was felled. Trees were felled at or below stump height, and then cut into 1 m long sections on either side of any visible defect or indicator of internal decay (i.e., using external indicators on the stems such as scars, cracks, or fungal conks, and internal indicators such as staining or brown rot that were visible upon sectioning). Root condition was not evaluated beyond the coring or probing procedure described above.

Data analysis

Comparison of overall tree sizes (± the standard error), tree defects, decay characteristics, and root condition was made across all treatments and replicates. Evaluation of mean differences over time-since-death versus moisture variation or build-up index for all assessment measures was completed using Kruskal-Wallis analysis of variance on ranks with Dunn's pairwise multiple comparison significance tests for unequal sample group sizes (Zar 1974). All statistical tests were conducted at the $\alpha = 0.05$ level of significance.

Results

Fifty-eight fixed radius study plots were established in nine MPB-affected and six fire-damaged stands. These included 36 plots established in MPB-killed stands and 22 plots in fire-damaged stands. A total of 536 individual tree assessments were made, which included 321 trees in MPB-killed stands and 215 trees in wildfire-damaged stands. Of this total, a subsample of 45 trees was destructively sampled (27 in MPB sites and 18 in fire-damaged stands).

Overall, 16 of 536 trees (3% of the total trees sampled) were rated as dangerous using the visual WDTA process (Wildlife Tree Committee of British Columbia 2005). All of these trees were subsequently confirmed as dangerous by destructive sampling (i.e., exhibited internal decay and low average shell thickness). Seven trees of the 16 rated as dangerous occurred in MPB-affected stands on moist (mesic) sites that had been infested by the beetle over 20 years ago. The other nine trees rated as dangerous occurred in wildfire-damaged stands and all of these had been affected by high-intensity fires (build-up index > 70). The most common tree defects observed (in order of occurrence) within MPB-affected stands were hazardous top, root damage/decay, and split trunk. In fire-damaged sites the most common tree defects were stem damage (i.e., from fire scarring), hazardous top, and root damage or failure (i.e., from burned out roots).

Comparison among mountain pine beetle treatments

Comparison of the mean tree size and decay characteristics for each MPB-affected study site revealed several significant differences ($p < 0.05$) across temporal treatments and moisture gradient replicates. The mean diameter (27.6 ±0.4 cm DBH) and height (22.2 ±0.3 m) of trees assessed in the oldest time-since-disturbance study sites (10+ years since disturbance) were significantly larger than more recently attacked stands ($p < 0.05$), which were found to be statistically similar to one another (0–3 and 3–5 years since disturbance; $p < 0.05$). The amount of intact bark recorded at breast height showed no noticeable difference between the two most recent treatments (99.9 ±0.1% vs. 95.5 ±1.5%); however, it was observed that over time (10+ years), a much smaller amount of bark (87.1 ±2.3%) is intact around the tree (Table 3).

TABLE 3. Time since beetle attack treatment: average tree size and decay characteristics (± SE, $n = 321$).

Time since disturbance treatment[b]	Tree measure and decay characteristics[a]											
	Diameter at breast height (cm)		Height (m)		Intact bark at breast height		Needles (% remaining)		Fine branches[c]		Root condition[d]	
0–3 years	26.0*a*	±0.4	19.2*a*	±0.3	99.9*a*	±0.1	42.0*a*	±2.8	1.2*a*	±0.0	92.0*a*	±1.2
3–5 years	26.1*a*	±0.3	18.3*a*	±0.3	95.5*a*	±1.5	11.8*b*	±1.8	2.0*b*	±0.1	90.8*ab*	±1.3
10+ years	27.6*b*	±0.4	22.2*b*	±0.3	87.1*b*	±2.3	4.2*c*	±0.9	2.4*c*	±0.1	82.3*b*	±2.4

[a] Analysis of variance on ranks of mean values with $p < 0.05$ used to test for significance (SigmaStat, version 3.1). Italic letters in common indicate no significant difference; different letters (*a* versus *b*) indicate a significant difference.

[b] Time since disturbance defines temporal treatment types. Number of years represents approximate time since MPB recorded in stands using both landscape history data and tree physical characteristic methods.

[c] Fine branches remaining in the tree canopy recorded in three percent categories (1 ≥ 25%; 2 = 24–1%; 3 = none remaining).

[d] Root condition represents the percentage of sound roots.

TABLE 4. Average tree size and decay characteristics (± SE) among destructively sampled beetle-affected trees.

	Tree measure and decay characteristics[a]											
	Diameter at breast height (cm)		Height (m)		Intact bark at breast height		Needles (% remaining)		Fine branches[b]		Root condition[c]	
Felled trees ($n = 27$)	27.5*a*	±0.8	23.4*a*	±0.6	83.8*a*	±4.2	7.2*a*	±2.4	2.5*a*	±0.1	71.5*a*	±5.7
Danger trees ($n = 7$) subsample	26.9*a*	±2.4	25.0*a*	±1.8	67.9*a*	±11.3	0.0*b*	±0.0	3.0*b*	±0.0	34.4*b*	±11.0

[a] Analysis of variance on ranks of mean values with $p < 0.05$ used to test for significance (SigmaStat, version 3.1). Italic letters in common indicate no significant difference; different italic letters (*a* versus *b*) indicate a significant difference.

[b] Fine branches remaining in the tree canopy recorded in three percent categories (1 ≥ 25%; 2 = 24–1%; 3 = none remaining).

[c] Root condition represents the percentage of sound roots.

Stands affected by MPB over 10 years ago showed the greatest amount of root damage or decay, which was significantly more than recently attacked stands (0–3 years). Mean root condition among stands affected by beetle 3–5 years ago (90.8 ±1.3% sound) did not appear significantly different than either the most recently attacked stands (92 ±1.2%) or the oldest time-since-disturbance stands (82.3 ±2.4%), although it was intermediate to both (Table 4).

Comparison of overall root condition among the MPB-affected trees assessed revealed a significant difference in the soundness of roots between moist and dry sites. Moist sites combined across all time-since-disturbance categories had significantly less root soundness than corresponding dry sites (82.5 ±1.52 vs. 93.6 ±0.96; $p < 0.05$, respectively).

Tree defects of stands affected by mountain pine beetle

Tree defects were observed on 35 MPB-killed trees (Figure 5), or approximately 11% (35/321) of the total MPB-affected sample population; however, as previously discussed, only seven trees (2%) were rated as dangerous using tree defect criteria for Level 3 disturbance activities.

The most common defects observed among MPB-affected trees (listed in order of occurrence) were hazardous tops, root inspection failure, dead limbs, and split trunk. The majority of the defects were recorded on trees (25/35 trees) at sites with the greatest time since disturbance (10+ years). The most common defect (among the 25 trees) observed in MPB-affected stands greater than 10 years after disturbance was root failure (i.e., damaged or decayed roots). In all other MPB site types and time-since-disturbance categories, hazardous top was the most prevalent (though not necessarily dangerous) defect observed.

Destructively sampled danger trees in mountain pine beetle stands

The MPB-killed trees rated as dangerous using the WDTA criteria, and which were confirmed as such by destructive sampling, all occurred on moist sites infested by pine beetle 22 or more years ago (Table 4). These trees ($n = 7$) had the following average characteristics: 26.9 ±2.4 cm in DBH and 25.0 ±1.8 m height; 67.9 ±11.3% bark intact at breast height; no needles or any fine branches remaining; and only 34.4 ±11.0% sound roots. Decay in these trees was extensive at the root collar and at the trunk base near the ground line.

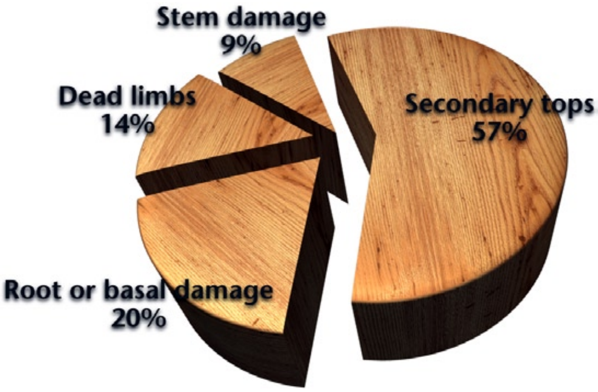

FIGURE 5. Summary (%) of defects observed on beetle-killed trees.

Five of the seven danger trees failed the root inspection, each with less than 50% sound roots; two of the inspected trees had no sound roots at all. Four danger trees also failed the stem wood condition assessment using minimum required shell thickness criteria. The average stemwood shell thickness in these trees was less than the required 30% of stem radius minimum shell thickness as per WDTA criteria (Wildlife Tree Committee of British Columbia 2005).

Comparison among fire treatments

Within fire-damaged study plots, 215 trees were assessed. Comparison of combined time-since-disturbance sample averages did not reveal any significant time-related damage or decay other than the percentage of fine branches remaining, which not surprisingly was greatest in most recent fires; however, comparison of fire site intensities combined across all sample sites revealed several significant differences. In addition to the diameter at breast height, the percentage of intact bark at breast height, percentage of remaining needles and fine branches, and percentage of root damage were all found to be significantly different ($p < 0.05$) between sites of medium- and high-intensity fires (Table 5).

Tree defects of fire-damaged stands

Tree defects were observed on 36 fire-damaged trees, or approximately 17% (36/215) of the total fire sample population. Nine of these trees (about 4% of the total fire sample) met or exceeded dangerous tree defect thresholds for Level 3 disturbance activities. The most common defects among the fire-damaged lodgepole pine trees (listed in order of occurrence) were stem damage, hazardous top, and root condition. Several individual fire-damaged trees had more than one dangerous defect (e.g., burned-out stem and root systems).

Destructively sampled danger trees in fire stands

The nine fire-damaged danger trees (as rated using the visual WDTA criteria and confirmed by destructive sampling) all occurred on moist sites affected by high-intensity fire. The only notable difference between the trees felled to enable destructive sampling ($n = 18$) and the subset determined as dangerous ($n = 9$) was the soundness of the lateral root system, which was significantly less for the danger trees (35.1 ±9.2% vs. 58.6 ±7.8%) (Table 6). Decay in these trees was extensive at the root collar and at the trunk base near ground level. Six of the nine danger trees had less than 30% sound roots; three trees failed the criteria of required shell thickness at stump height, with substantial fire burn damage to the stem wood (> 50% of stem cross-sectional area burned through).

Discussion

Planning for appropriate levels of forest retention in large-scale salvage operations where densities of standing dead or damaged trees occur requires a thorough assessment of worker safety considerations when workers may be exposed to residual standing dead trees. Standing deadwood is widely recognized

TABLE 5. Mean tree size and decay characteristics (± SE) of combined time-since-disturbance variable for fire intensities in fire-damaged stands.

	Tree measure and decay characteristics[a]											
Fire intensity[b]	Diameter at breast height (cm)		Height (m)		Intact bark at breast height		Needles (% remaining)		Fine branches[c]		Root condition[d]	
Medium build-up index (40–70)	25.5*a*	±0.3	19.7*a*	±0.3	92.9*a*	±1.5	11.7*a*	±1.7	2.0*a*	±0.1	93.0*a*	±1.3
High build-up index (> 70)	27.1*b*	±0.1	20.2*a*	±0.4	85.0*b*	±2.7	1.3*b*	±0.5	2.7*b*	±0.1	85.8*b*	±2.0

[a] Analysis of variance on ranks of mean values with $p < 0.05$ used to test for significance (SigmaStat, version 3.1). Italic letters in common indicate no significant difference; different italic letters (*a* versus *b*) indicate a significant difference.

[b] Build-up Index (BUI) variables determined using BC Ministry of Forests and Range Fire Weather System Data (Boyer 2005).

[c] Fine branches remaining in the tree canopy recorded in three percent categories (1 ≥ 25%; 2 = 24–1%; 3 = none remaining).

[d] Root condition represents the percentage of sound roots.

TABLE 6. Average tree size and decay characteristics (± SE) among destructively sampled fire-damaged trees.

	Tree measure and decay characteristics[a]											
	Diameter at breast height (cm)		Height (m)		Intact bark at breast height		Needles (% remaining)		Fine branches[b]		Root condition[c]	
Felled trees ($n = 18$)	24.9*a*	±0.7	18.2*a*	±0.9	71.4*a*	±8.0	5.0*a*	±2.2	2.7*a*	±0.1	58.6*a*	±7.8
Danger trees ($n = 9$) subsample	25.4*a*	±0.9	15.7*a*	±1.0	56.1*a*	±13.4	2.2*a*	±1.5	2.8*a*	±0.1	35.1*b*	±9.2

[a] Analysis of variance on ranks of mean values with $p < 0.05$ used to test for significance (SigmaStat, version 3.1). Italic letters in common indicate no significant difference; different italic letters (*a* versus *b*) indicate a significant difference.

[b] Indices of fine branches remaining (1, 2, and 3) correspond to ≥ 50%, 49–1%, and none remaining, respectively.

[c] Root condition represents the percentage of sound roots.

as a key habitat element for cavity-dwelling wildlife (Hansen et al. 1991; Bunnell 1995; Keisker 2000; Manning et al. 2002, 2005; Bunnell et al. 2004; Fenger et al. 2006). A greater understanding of MPB-affected and fire-damaged stands, and the efficacy of the WDTAC procedures, may help facilitate tree retention objectives in large-scale salvage operations in a safe manner.

Results of this study suggest that potentially dangerous tree defects are present in both MPB and fire-damaged stands. The number of danger trees in MPB-affected stands appears to vary with microsite characteristics (i.e., ground moisture, presence of hummocks or depressions) over time. In contrast, the absolute numbers of danger trees in fire-damaged areas depends primarily on the intensity of the previous fire disturbance.

The most common tree defects in MPB-affected stands were hazardous top, root damage/failure, and split trunk. In fire-damaged sites, the most common tree defects were stem damage (from fire scarring), hazardous tops, and root failure (i.e., burned-out roots), with the majority of these defects occurring at sites with high fire intensity. Notably, no specific tree defects or damage or decay patterns were observed among dangerous trees that could be directly attributable to the incidence of MPB.

Destructive sampling of a subset of trees that had visual defects confirmed the accuracy of the visual WDTA process. Of the trees assessed, approximately 2% of MPB-affected trees and 4% of fire-impacted trees were categorized as "dangerous" using the WDTAC criteria; these same trees were confirmed as dangerous through destructive sampling. Although tree defects in MPB-affected pine stands occurred on both dry and mesic sites, those defects rated as "dangerous" were predominantly found on moist site types over 22 years since disturbance. All danger trees observed in fire-damaged stands occurred at high intensity (build-up index > 70) fire sites.

Within both MPB-affected and fire-damaged stands, tree root condition represented the predominant structural weakness that exceeded minimum thresholds for safety (> 50% of major lateral roots damaged or unsound), thereby resulting in dangerous ratings for these trees. Comparison of danger tree root condition characteristics between MPB-affected and fire-damaged trees revealed similar levels of unsoundness of roots (34.4 ±11.0% vs. 35.1 ±9.2%), as seen on moist sites over 22 years since disturbance, and in areas subjected to high fire intensity disturbance, respectively.

Planning for appropriate levels of forest retention in large-scale salvage operations where densities of standing dead or damaged trees occur requires a thorough assessment of worker safety considerations when workers may be exposed to residual standing dead trees.

Quantification of the amount (%) of intact bark present on the trunk at breast height and the percentage of needles and fine branches still present on the tree indicated that more bark and needles or fine twigs are lost with the passage of time (especially after 10 years since death from beetle or wildfire), and also with increasing burn intensity. These results are supportive of the tree-class descriptors (e.g., class 4+) used in the WDTA process, which help determine overall tree danger.

All of the tree defects observed and rated in this study were for Level 3 disturbance work activities (i.e., includes most logging-related activities, such as tree falling, yarding, and use of heavy machinery). The defect failure criteria and hazard thresholds used to determine tree danger for Level 3 disturbance are more stringent than for other forestry work activities, such as tree planting, brushing, pruning, and road travel (on ballasted and compacted roads), which are categorized as Level 1 work activities (Wildlife Tree Committee of British Columbia 2005). Consequently, the risk of tree failure in beetle-killed and fire-damaged stands under these lower risk activities would likely be less.

This study showed similar proportions of danger trees (about 3% overall) as that found by Rakochy and Hawkins (about 5%, 2006) on dry sites of the Nadina Forest District, and also supports preliminary findings of Lewis and Hartley (2004). The relatively high fall-down rates of lodgepole pine after MPB attack predicted by researchers in other jurisdictions (e.g., Mitchell and Preisler 1998) were not corroborated by this study. However, our study results suggest that the risk of fall-down of MPB-affected trees is expected to increase after approximately 20 years, especially on moist sites.

Conclusions

This study revealed new information about the change in condition of MPB-killed and fire-damaged trees over time and under varying site conditions (i.e., soil moisture regime, fire burn intensity). The results reinforce the accuracy and reliability of the technical criteria, tree defect thresholds, and procedural standards currently used by the WDTAC to determine tree hazards and associated safe work practices for various forestry work activities in British Columbia (Wildlife Tree Committee of British Columbia 2005, 2008, 2009). Given the rate of large-scale salvage in many areas of central and southern interior British Columbia, combined with the beneficial practice of retaining standing dead trees as part of stand-level biodiversity (i.e., wildlife trees), dependable application of the WDTA procedures will become increasingly important. This study demonstrates that as beetle and/or wildfire salvage continues, and where an increased risk of wildfire occurrence exists, application and use of the WDTAC criteria in fire and MPB salvage operations will help facilitate safe work practices in these situations.

> *Our results reinforce the accuracy and reliability of the technical criteria, tree defect thresholds, and procedural standards currently used by the WDTAC to determine tree hazards and associated safe work practices for various forestry work activities in British Columbia.*

Limitations of the study and knowledge gaps

Although this study provided new information on the condition of MPB-killed trees over time and under different site conditions, the following limitations surround the application and interpretation of these results.

- The age distribution of MPB-killed trees in the 10+ years since disturbance sample was "patchy." Many of the trees in this age class were 10–12 years since disturbance, and others were 20+ years. No trees were sampled between 13–22 years since disturbance. To achieve a robust sample size, the data for this age class was pooled at 10+ years, which did not permit any statistical discrimination between years within this category (i.e., could not compare 12-year trees with 23-year trees).
- Because of the variable behaviour of most wildfires caused by on-site variations in fuel supply and type, topography, and changing weather conditions (wind or precipitation), variations in the burn intensity and resultant degree of tree damage will always occur on any fire regardless of the overall fire-intensity rating (build-up index) for that fire. Consequently, although the recommendations we provide here for high build-up index fires are valid, persons conducting danger tree assessments on all wildfires regardless of fire intensity should adhere to the accepted WDTAC standards and defect criteria

for wildland fire operations (see Wildlife Tree Committee of British Columbia 2005, 2009).

- Although 27 MPB-killed trees (27/321) were destructively sampled to assess wood condition, this effort was conducted mainly to determine the amount of sound stem wood (average stem thickness) adjacent to various external defects (e.g., stem scars, stem cracks, cavities, forked tops) visible on the tree. In many cases, the boles of MPB-killed trees on dry sites had ample sound stem shell wood and were, for the most part, dry and "decay free"; however, no direct correlations can be made about the "shelf life" of standing dead pine stems. At best, non-statistical inferences can be made concerning the degradative wood processes associated with wetter sites; that is, these processes likely reduce the merchantability of standing beetle-killed trees more rapidly than could be expected in drier pine stands of equivalent time since death. See Thrower et al. (2004) for a discussion of measurable tree characteristics related to the shelf life of MPB-killed lodgepole pine.
- The results and recommendations we provide are directly applicable to the SBS zone of British Columbia. We did not assess MPB-killed or fire-damaged stands in other biogeoclimatic zones.

Knowledge gaps

- A knowledge gap exists concerning the condition of MPB-killed trees between 13 and 22 years since disturbance, regardless of site moisture. Further research data should be collected for this cohort, especially in pine-leading stands on moist or wetter sites. Such information could confirm our conclusions about MPB-killed trees greater than 15 years since disturbance (i.e., the analyses in the current study pooled all MPB-killed pine >10 years since disturbance).
- Data on the condition of MPB-killed trees (both lodgepole pine and ponderosa pine) in other biogeoclimatic zones in the province should be collected, since the current study only involved lodgepole pine in the SBS zone.
- A cost analysis of conducting danger tree assessments in MPB-killed or fire-damaged stands was beyond the scope of this project; however, the operational efficiencies associated with the provincial WDTAC training standards (i.e., area stratification, level of disturbance category, and tree defect rating criteria and assessment procedures; Wildlife Tree Committee of British Columbia 2008, 2009) are well recognized. These standards have been employed in operational silviculture, harvesting, and fire protection scenarios in British Columbia since the early 1990s and are recognized internationally for their rigour and elegant simplicity of application in comparison to other standards of hazard tree assessment (Manning et al. 2002).

This study demonstrates that as beetle and wildfire salvage continues, and where an increased risk of wildfire occurrence exists, application and use of the WDTAC criteria in fire and MPB salvage operations will help facilitate safe work practices in these situations.

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Test Your Knowledge . . .

Evaluation of tree condition and tree safety assessment procedures in beetle-killed and fire-damaged lodgepole pine stands in central interior British Columbia

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

1. What are the most important factors to consider when trying to determine the hazard (i.e., likelihood of tree failure) of mountain pine beetle-killed trees?
   A) How long the tree has been dead
   B) Site conditions such as ground moisture and micro-topography
   C) Wind exposure
   D) a and b
   E) a and c

2. What are the most important factors to consider when trying to determine the hazard (i.e., likelihood of tree failure) of fire-killed trees?
   A) Intensity of the wildfire (i.e., how hot was the burn)
   B) Depth and condition of the anchoring soil layer
   C) Condition of the roots and lower stem
   D) All of the above

3. What are the most common tree defects that can result in a "dangerous" tree rating in MPB-killed or fire-damaged stands?
   A) Damaged root systems
   B) Large dead limbs
   C) Fungal conks
   D) Stem cracks

ANSWERS

1. D 2. D 3. A