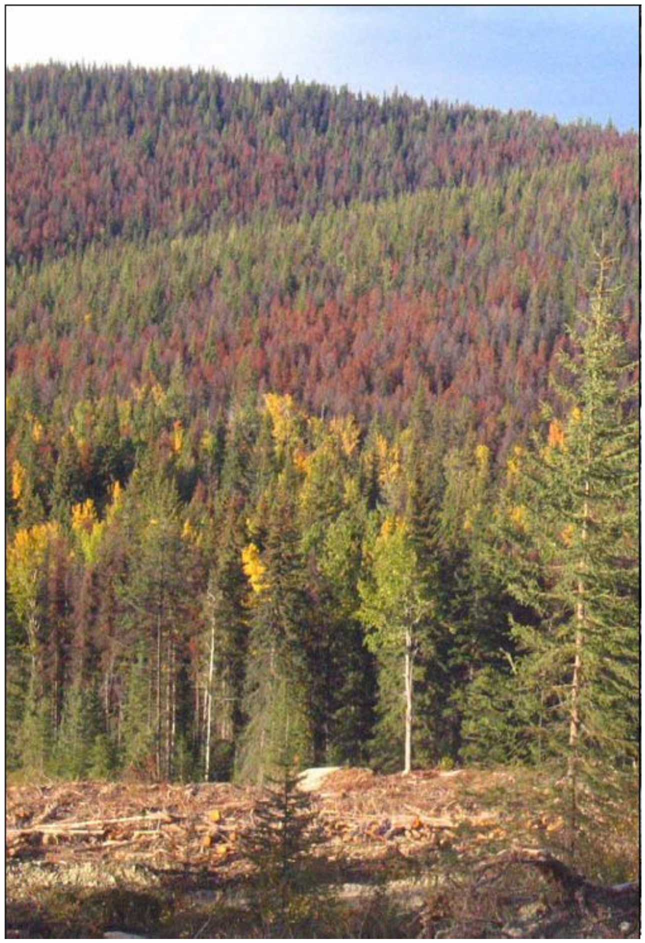
An Assessment of Tree Condition and Worker Safety Concerns in Mountain Pine Beetle-killed and Fire-damaged Lodgepole Pine Stands in Central Interior British Columbia



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EXECUTIVE SUMMARY

The objective of this study was to evaluate the effectiveness of the provincial *Wildlife/Danger Tree Assessment Course* (WDTAC) procedures in mountain pine beetle-killed (MPB, *Dendroctonus ponderosae*) and wildfire-damaged stands, and to quantify characteristics related to tree condition and deterioration for these types of stands over a range of conditions in the Sub-Boreal Spruce (SBS) zone in central interior British Columbia. Fifty-eight fixed-radius study plots were established in SBS mountain pine beetle-killed and fire-damaged stands in the Fort St. James, Nadina, Quesnel, Prince George and Vanderhoof Forest Districts. Thirty-six plots were located in MPB-killed stands which were stratified according to time-since-death (TSD) category (0-3 yrs, 3-5 yrs, 10+ yrs) and site moisture (dry or mesic). Twenty-two plots were located in fire-damaged stands. These were stratified according to the same TSD categories, as well as fire intensity (medium or high intensity as indicated by Build-up-Index (BUI) values for that fire).

In total, 536 individual tree assessments were conducted (321 in MPB sites and 215 in fire-damaged stands). Forty-five trees were destructively sampled (27 in MPB sites and 18 in fire stands) to determine actual internal tree condition and stem shell thickness, resulting in 16 confirmed danger trees.

Mountain Pine Beetle-killed Trees

The majority (80%) of MPB-killed trees were described as tree Class 3 (i.e., recently dead with some needles and fine twigs/branches remaining). There was an increasing proportion of Class 4 and Class 5 trees approximately five years time-since-death. While there will always be site-specific variations, it appears that many MPB-killed trees do not shed their fine twigs/branches nor begin to exfoliate their bark (i.e., they can still be categorized as Class 3), until five years or more after death.

In total, tree defects were observed on 35 MPB-killed trees (11% of the sample population). This proportion is comparable to other data collected in MPB-killed stands in B.C.

Root failure/decay was the most common defect observed in the 10+ yrs. TSD category. Not surprisingly, these stands showed the greatest amount of root system damage/decay compared to more recently attacked sites. However, moist sites consistently had greater root system damage across all TSD categories, compared to corresponding dry sites.

Only 7 (2% of sample population) MPB-killed trees were confirmed to be dangerous, both visually and after destructive sampling. **All these trees occurred in moist sites greater than 20 yrs. TSD**. The average tree class for these individuals was 4.2. They were **all rated dangerous because of root (or basal) condition failure**. On average, only 34% of roots were sound on these trees; this is significantly less than the 75% sound root requirement for Level 3 work activities, and also well below the 50% sound root requirement for Level 1 work activities (i.e., most silviculture activities including tree planting).

Notably, no MPB-killed trees were observed to have specific defects or decay/deterioration patterns directly attributable to pine beetle. In other words, the insect pathogen, while killing the tree, did not cause the occurrence of dangerous defects such as root failure. Root failure in MPB-killed stands, especially on moist/mesic sites, appears to be due to a long cycle of wetting and drying (i.e., rain and snowmelt) along with secondary mycological or bacterial agents. In most cases, root failure in these stands was not observed to be the result of primary fungal attack (e.g., *Armillaria* or *Heterobasidion* root disease center). To illustrate this effect somewhat colloquially, MPB-killed pine eventually rots away at the root collar/ground level, and either uproots or breaks off like an old, longstanding fence post. Thus, **it appears that beetle-killed pine, especially on drier sites, can easily remain standing with minimal hazard for at least 10-20 years after death.**

Windthrow

Windthrow in MPB-killed stands appears to be the result of **endemic windthrow factors** such as prevailing wind direction, topography, soil depth and condition, and proximity to edges and openings, rather than directly attributable to MPB-induced effects.

Fire Damaged Stands

The majority (66% overall) of the 215 fire-damaged trees were rated as tree Class 3. The relative abundance of Class 4 and Class 5 trees was similar for each TSD category, with greater numbers observed in high intensity fire stands (BUI >70).

The most common defects observed in fire-damaged lodgepole pine stands were stem damage (due to fire scarring), root system failure (burned out roots), and hazardous tops (secondary tops – these are not related to fire incidence). Comparison of combined TSD sample averages did not reveal significant time-related damage or decay other than the percent amount of fine branches remaining, which was greatest in most recent fires. Consequently, **how long ago the fire occurred did not seem to influence the degree of damage for the above defects**. However, significant differences in root/basal condition were revealed between **high intensity and medium intensity fires**. This is to be expected since higher intensity fires invariably do more burn damage to the roots and butt of affected trees.

In total, tree defects were observed on 36 fire-damaged trees (or 17% of the fire sample population). However, **only 9 fire-damaged trees (9/215 or 4% of the sample population) were actually rated as dangerous** (both visually and after destructive sampling). **These all occurred on high intensity wildfire sites**.

Reliabililty of the WDTAC Procedures

This study tested the reliability of WDTAC procedures in predominantly dead lodgepole pine leading stands affected by mountain pine beetle or by wildfire. By all accounts, the ability of the **WDTAC procedures to detect danger trees among MPB-impacted and fire-damaged lodgepole pine trees appeared to be accurate, reliable and consistent**. The WDTAC process was able to detect danger trees as well as changes in the extent of decay/deterioration in MPB-killed trees over time and between moist and dry sites. Trees assessed using the WDTAC visual assessment process (i.e., using external indicators) and detailed tree assessment criteria (i.e., stem drilling and root probing) were found to be dangerous in both mountain pine beetle and fire-damaged stands. Visual and detailed assessment ratings were confirmed by destructive sampling; however a few MPB-killed trees (n=3) which were visually rated as dangerous, actually proved to be safe upon destructive sampling. This suggests that the WDTAC process is actually somewhat conservative and will therefore accurately rate most tree defects.

All of the tree defects observed and rated in this study were for Level 3 disturbance work activities (i.e., includes most harvesting related activities). The defect failure criteria and hazard thresholds used to determine tree danger for Level 3 disturbance are “more strict” than for other work activities such as tree planting, brushing, pruning and road travel (on ballasted and compacted roads), which are categorized as Level 1 work activities (WTC 2005). Level 1 activities impart “less disturbance” to the ground and adjacent trees than Level 3 activities. Consequently, the risk of tree failure under these situations is less. Given the results of this study, it is likely that some of the trees which were rated “Dangerous” herein, would have actually been rated “Safe” at Level 1 disturbance.

In conclusion, the **tree defect criteria and failure/danger thresholds as defined in the current WDTAC standard** (WTC 2005) **are accurate and reliable**. Use of these criteria should be continued in

MPB- and fire-damaged stands in British Columbia, with a few recommendations as follows. **Note: the following recommendation only applies to older MPB-killed stands on moist or wetter sites**.

1. For general silviculture activities (except mechanical site prep.) in MPB-killed stands on moist sites (mh, mw, mm, mk, mc or wetter subzones), the WDTAC standards for Level 1 disturbance are adequate and should be followed **with this provision**:

   i) in stands **> 15 years time-since-death on moist or wetter sites ONLY**, either cease work activities when wind speeds exceed 20 km/h, or reassess the site to Level 3 disturbance.

Limitations of the Study

While this study provided new information on the condition of MPB-killed trees over time and under different site conditions, there are some limitations to which the results can be applied and interpreted. These are briefly described as follows.

1. The age distribution of MPB-killed trees in the 10+ yr. TSD sample was "patchy". Many of the trees in this age class were 10-12 yrs. TSD, while others were 20+ yrs. TSD. No trees were sampled between 13-22 yrs. TSD. Consequently, in order to achieve a robust sample size, the data for this age class was pooled at 10+ yrs., which did not permit any statistical discrimination between years within this category (i.e., could not compare 12 yrs. TSD trees with 23 yrs. TSD trees).
2. Because of the variable behavior of most wildfires caused by on-site variations in fuel supply and type, topography and changing weather conditions (wind), there will always be variations in the burn intensity and resultant degree of tree damage on any fire, regardless of the overall fire intensity rating (BUI) for that fire. Consequently, while recommendations provided in this study for high BUI fires are legitimate, 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 *Dangerous Tree Assessor's Course: Wildland Fire Safety Module* (2005), URL: http://www.for.gov.bc.ca/hfp/training/00016/index.htm).

3. While 27 MPB-killed trees (27/321) were destructively sampled in order to assess wood condition, this effort was conducted mainly to determine the amount of sound stem wood (AST) adjacent to various external defects (e.g., stem scars, stem cracks, cavities, forked tops). While 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", no direct correlations can be made to the "shelf-life" of standing dead pine stems. At best, non-statistical inferences can be made that the degradative wood qualities associated with wetter sites likely reduces the merchantability of standing beetle-killed dead trees more rapidly than could be expected on drier pine stands with equivalent time-since-death. A discussion of measurable tree characteristics related to the shelf-life of MPB-killed lodgepole pine is found in Thrower et al. (2004).

4. The results and recommendations provided in this study are directly applicable to the SBS zone of British Columbia. MPB-killed and fire-damaged stands in other BEC zones were not assessed.

Knowledge Gaps

1. Knowledge gap exists concerning the condition of MPB-killed trees between 13-22 years TSD, regardless of site moisture. Further research data should be collected for this TSD-cohort, especially in pine leading stands on moist or wetter sites. This information can be used to confirm the conclusions made about MPB-killed trees greater than 15 years TSD (i.e., the analyses in the current study pooled all MPB-killed pine $\geq$10 years TSD).

2. Data on the condition of MPB-killed trees in other biogeoclimatic zones in BC should be collected, since the current study only involved the SBS zone.

Acknowledgements

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INTRODUCTION

Standing dead and decaying trees are common components of all forest ecosystems. Deadwood in the forest contributes significantly to the structure and function of the ecosystem (Franklin *et al.* 1987; Clark *et al.* 1998; Tinker and Knight 2000), and is considered critical habitat for an abundance of wildlife species (Hansen *et al.* 1991; Bunnell 1995; Keisker 2000). 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 recreationists while in the woods.

Safety concerns regarding dangerous trees in municipal settings, provincial parks, and within forest fire-fighting and industrial forest harvesting and silviculture operations has led to the development of provincial danger tree assessment guidelines (WTC 2005). Endorsed by the Workers' Compensation Board of BC, Wildlife/Danger Tree Assessment (WDTA) is the standard used in British Columbia for determining tree hazards in forest harvesting, silviculture and roadside operations. The Wildlife/Danger Tree Assessor's Course (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., hemlocks and true firs; cedars; pines, spruce, larch and Douglas-fir (*Pseudotsuga* *menziesii*)) were built into this process to allow for differences in tree morphology in relation to defect failure criteria and thresholds. Consequently, once a particular tree(s) has been assessed for a given work activity, the appropriate safe work procedures can be implemented based on these assessments. Worker safety is ensured by assessing and marking danger trees for removal or installing no-work zones around dangerous trees, prior to commencement of work activities (WTC 2005).

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 WDTAC process in a research context (Manning 2001, Rakochy 2005).

Lodgepole pine (*Pinus contorta* var. *latifolia* Englem.) is the most widespread tree species in British Columbia and predominate species in the Central Interior Plateau. Wildfire and mountain pine beetle (*Dendroctonus ponderosae*) have historically been the primary stand replacement disturbance agents in this region (Roe and Amman 1970; Lotan *et al.* 1985; Bunnell 1995; Clark *et al*. 1998). Despite a history of mountain pine beetle outbreaks in British Columbia, 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 current magnitude and intensity of mountain pine beetle (MPB) infestation in BC has exacerbated the recruitment of large amounts of standing deadwood in these forests. Efforts to salvage marketable timber are underway; however, it is expected that large areas of residual unsalvaged pine will be retained (Pederson 2004; Pousette 2005). A portion of the landscape, including unsalvaged stands, will be candidates for future silviculture activities such as underplanting (Mitchell 2005). Whether the WDTAC procedures are sufficiently rigorous and responsive to the safety requirements (i.e., re dangerous trees) of Worker's Compensation Board regulations in MPB-impacted areas where road travel, salvage harvesting and silviculture practices are planned, is uncertain.

OBJECTIVES

The objective of this project is to:

- evaluate the effectiveness of the WDTAC procedures in mountain pine beetle-killed and fire-damaged stands, and to quantify characteristics related to tree condition and deterioration for these types of stands over a range of conditions in the Sub-Boreal Spruce (SBS) zone of central Interior British Columbia.

WDTAC criteria were used to assess MPB-killed trees on sites of varying moisture regime and time-since-death classes, as well as fire-damaged trees with varying burn intensities and time-since-death classes (see *Methods* section below). Validation of tree defect criteria and danger ratings thresholds as used in the WDTAC guidelines will afford greater confidence in the tree assessment procedures and safe work guidelines available to forestry practitioners in MPB-affected areas and fire-damaged pine stands in British Columbia.

STUDY AREA

The project study area is located in the Moist Interior - Plateau Ecoregion, situated between 53° - 55° N latitude and 122° - 126° W longitude (**Figure 1**). The area is ecologically classified as the Sub-Boreal Spruce (SBS) biogeoclimatic zone (Meidinger and Pojar 1991). The elevation range of this area is 600 – 1800m, most of which lies between 700 – 1200m. 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 sub-alpine 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 interior spruce (*Picea engelmannii* x *glauca*) are the two most common tree species in the Central Interior Plateau region.

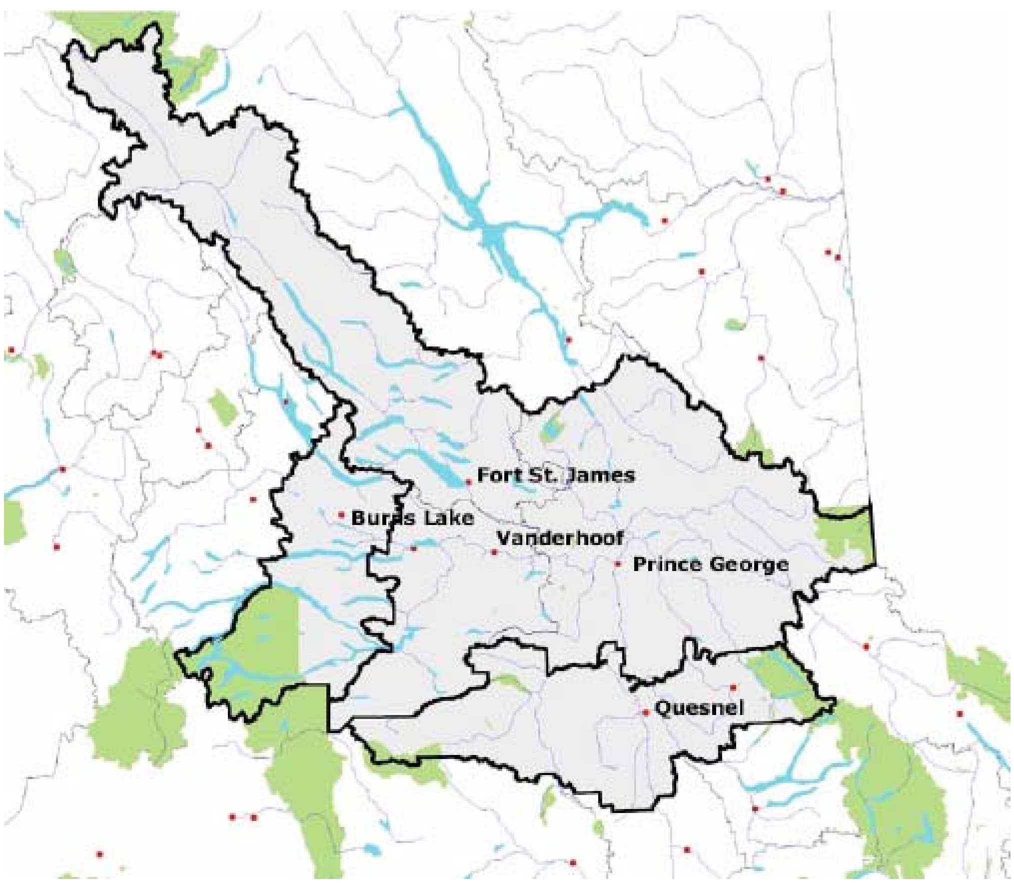

Figure 1. General study area in central interior British Columbia

The fire history of this area indicates that hundreds of fires have burned within the study area over the last 20 years. Fires large as 12,000 hectares and small as less than two hectares, have been recorded. Often, fire-damaged stands represent a large quantity of standing timber volume and are aggressively salvage-harvested to recover the value of standing timber, especially those stands with already-developed access.

The current level of mountain pine beetle infestation is extensive in pine-leading as well as mixed coniferous-pine stands throughout the study area (**Figure 2**).

Figure 2. MPB-impacted landscape with a mosaic of time-since-attack at the stand level

The beetle typically attacks stands over a number of successive years, often with the oldest and largest trees being hit first. The result is a landscape with a heterogeneous pattern of green, red and grey-attacked trees. Beetle-killed stands that were attacked within the last five years are prevalent on the central interior landscape, while stands that were attacked over 10 years ago are much less common. Similar to fire-damaged stands, MPB-impacted stands that represent large quantities of merchantable timber are quickly salvage-logged. Therefore, relatively few older attack sites with road access remain standing from previous MPB outbreaks. However, some trees that were attacked by MPB over ten or as long as 20 years ago, still remain standing in remnant areas around salvage block boundaries or within protected areas and riparian areas.

METHODS

Site Selection

To aid in the selection of MPB-impacted 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, obtained from management staff of industrial land tenure holders, provided more specific information regarding locations of MPB infested stands and salvage-harvesting history. In addition, information provided by the Canada Forest Service (CFS) supported the inclusion of areas within Tweedsmuir Provincial Park (north side of Eutsuk Lake), which were attacked by mountain pine beetle in the early to mid 1990s (**Figure 3**).

Figure 3. Outlined area of mountain pine beetle infestation in SBSmc2, north side of Eutsuk Lake, Tweedsmuir Provincial Park (CFS 1994)

Candidate fire-damaged sites were determined using data and maps from the Vanderhoof Forest District and Prince George Regional District Fire Protection Offices. Potential fire sites were limited to those fires reported over 5 hectares in area.

All candidate sites that were road accessible were visited on the ground to visually verify stand composition, infestation indicators of time since attack (see **Appendix A**) and occurrence of wildfire.

All sites selected were lodgepole pine-leading stands in the Sub-Boreal Spruce (SBS) biogeoclimatic zone (**Figure 4**). In a few cases, selected stands had canopy compositions less than 70% pine, with hybrid white spruce (*Picea engelmannii x glauca*), sub-alpine fir (*Abies lasiocarpa*) and trembling aspen (*Populus tremuloides*) making up the remainder.

Figure 4. MPB-impacted pine-leading canopy, TSD: 0-3 years. [Blackwater Rd.]

Study Treatment Strata

Study treatments were stratified by time-since-disturbance (TSD), which is defined as the number of years since beetle infestation or years since fire occurrence. TSD categories were 0-3 years, 3-5 years, and 10 or more years since disturbance event. MPB-impacted sites selected were also defined by variations in soil moisture regime, while wildfire-damaged sites were differentiated by differing Build-Up Indices (BUI). BUI is a numerical rating for the amount of fuel available for combustion in the sub-surface layer located between forest litter and mineral soil.

Table 1. Description of MPB-impacted study sites in the Sub-Boreal Spruce (SBS) biogeoclimatic zone of central interior British Columbia.

Time since MPB attack[1]	Forest District	Location[2]	Soil Moisture[3]	BEC[4] sub-unit	UTM Co-ordinates		Elevation (m)
0-3	Vanderhoof	611 Rd	Dry	SBSdk	363000E	5936083N	919
0-3	Prince George	Blackwater Rd	Dry	SBSdw3	513700E	5482200N	820
0-3	Vanderhoof	Y & D Rd	Mesic	SBSmc2	453778E	5951988N	958
3-5	Vanderhoof	S. Woodcock	Dry	SBSdw2	464182E	5936261N	945
3-5	Quesnel	Batuni Rd	Mesic	SBSmc2	481508E	5899868N	912
3-5	Vanderhoof	Red Rd	Mesic	SBSmc3	380629E	5933175N	930
10+	Quesnel	Dragon Mtn	Dry	SBSdw1	546930E	5845354N	1245
10+	Nadina	Eutsuk Lake	Mesic	SBSmc2	686513E	5905027N	897
20+	Fort St. James	Hat Lake Rd	Mesic	SBSmc3	405164E	6073022N	848

[1]Time since disturbance (TSD) data; taken from Ministry of Forests Forest Health Program and Mountain Pine Beetle Aerial Sketch Maps. Confirmed using visual indicators (see Appendix A).
[2]Location = forest access road or nearest geographic feature
[3]Soil moisture class determined using Ministry of Forests Forest District BEC mapped data
[4]Biogeoclimatic Ecosystem Classification (BEC) data taken from Ministry of Forests Regional maps

Soil moisture in pine-leading stands is most commonly dry or mesic. Lodgepole pine is generally not found leading on wetter sites. In an attempt to capture differences across the moisture regime in MPB-impacted pine stands, data was collected from three different SBS sub-unit replicates in each TSD category (**Table 1**). Stands ranged from Sub-Boreal Spruce dry warm (SBSdw1) to moist cool (SBSmc3) sites.

Figure 5. MPB-impacted mesic site with spruce advanced regeneration [Y&D Rd.]

The wildfire-damaged stands selected used the same three temporal (TSD) categories: 0-3 years; 3-5 years; and 10+ years since disturbance (**Table 2**). Fire-damaged study sites represented medium (40-70) and high (>70) BUI values, recorded during the five days prior to wildfire ignition. Selected fire stands included medium and high intensity fires on moist sites (SBSmc2), and medium and high intensity fires on dry sites (SBSdw2).

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

Time since fire[1]	Forest District	Location[2]	Fire Intensity[3]	BEC sub-unit	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 Lk.	Med	SBSdw2	499608E	5894881N	878
3-5	Vanderhoof	Gray Rd	High	SBSmc3	401301E	5914086N	1100
10+	Nadina	Eutsuk Lake	Med	SBSmc2	683758E	5904718N	882
10+	Prince George	Meadow Lk	High	SBSdw2	463460E	5920581N	880

[1]Time since disturbance (TSD) data; based on wildfire ignition date from Forest Protection Data (see **Appendix B**)
[2]Location = forest access road or nearest geographic feature
[3]Fire Intensity = average BUI[4] five days preceding ignition date; Med = 40-70; High = 70+; Ministry of Forests Fire Weather System Data (**Appendix C**)

Figure 6. Fire-damaged mesic site with spruce advanced regeneration [Hay Lake]

Data Collection Methods

Data were collected during September and October 2005, from 15 stands dominated by lodgepole pine. In each stand selected for study, a minimum of three randomly located fixed-radius plots; tree condition and defect data were collected using the provincial Wildlife/Danger Tree Assessment procedures (WTC 2005). Fixed plots were 5.64m radius ($100m^2$); the plot centre point was determined by a randomly generated compass bearing and distance from a previous plot centre or a stand-edge start-point. Each tree (≥ 12cm DBH) that at least touched the perimeter of the plot was considered in-plot, and was measured according to the assessment criteria.

Data recorded included tree class, wildlife habitat features (e.g., nest cavities, feeding sign), standard tree measures such as tree height and diameter at breast height (DBH), assessment of tree defects such as broken tops, stem scars, cracks or fungal conks, root condition, as well as notable stand or microsite characteristics (e.g., wet depression, raised bench; see field card **Appendix D**). All tree **defects were rated and compared to the defect thresholds used for Level 3 disturbance work activities**[a], as per the current WDTAC standards (WTC 2005). The type and location of visual tree defects, and stem and root condition were recorded for each tree within the fixed plot. Assessments of root condition were made at the root collar using a sharp probing tool, as well as at 50cm from the tree stem. Decay characteristic were also defined by percent amount of intact bark at breast height (~135 cm); percent needles (10%s) and fine branches remaining; and type, location and extent of actual decay present in the bole or roots. The amount of fine branches (that hold needle fascicles) remaining were classified as "1, 2 or 3", corresponding to ≥25% remaining, 24-1% remaining, and none remaining, respectively. Types of decay included root disease (RD), sap rot (SR) and heart rot (HR).

Destructive sampling was performed on a subsample of trees within MPB and fire-damaged stands. Internal tree decay characteristics and measurements of stem shell thickness as well as the longitudinal extent of decay in the tree bole, were recorded. Before trees were felled a detailed tree assessment and estimate of average shell thickness (AST) was completed. AST was estimated in the four cardinal directions at stump height using a hand drill and 5/16" auger bit. Estimated measures of shell thickness were then verified by actual shell thickness measurements taken on the stump cross-section after the tree was felled. Trees were felled at or below stump height (~30cm) and cut into 1m sections on either side of any visible internal decay (i.e., staining or brown rot).

[a] Level 3 disturbance activities include most forest harvesting activities (e.g., tree falling/harvesting, ground skidding, cable yarding), and use of heavy mechanized equipment (e.g., excavators, feller bunchers, mechanical site prep.). For more information on Level of Disturbance categories and associated work activities, consult the WTC website at http://www.for.gov.bc.ca/hfp/training/00016/index.htm .

Data Analysis

Comparison of overall means of tree size, tree defects and decay characteristics, and root condition was made across all treatments and replicates. Evaluation of mean differences over time-since-death versus moisture variation or BUI for all assessment measures was completed using Kruskal-Wallis analysis of variance (ANOVA) on ranks with Dunn's pair-wise multiple comparison significance tests for unequal sample group sizes (Zar 1974). All statistical tests were conducted at the 0.05 level of significance.

RESULTS

Fifty-eight fixed-radius study plots were established in MPB and fire-damaged stands. These included 36 plots in MPB-killed stands (4 plots in each of 9 MPB site types, see Table 1), and 22 plots in fire-damaged stands (4 plots in each of four fire-damaged site types, and 3 plots in each of two site types [Gray Rd and Pantage Lake], see Table 2). In total, **536 individual tree assessments were conducted** (321 in MPB sites and 215 in fire-damaged stands). Forty-five trees were destructively sampled (27 in MPB sites and 18 in fire stands), resulting in **16 confirmed danger trees in total**. Seven danger trees occurred in MPB-impacted stands --- these were **all infested over 20 years ago on moist sites**. Nine danger trees occurred in fire-damaged stands --- these were all found in areas which had **high intensity fires** (BUI >70). The most common tree defects in MPB-impacted stands were hazardous top (HT), root failure (RI), and split trunks (ST). In fire-damaged sites the most common tree defects were stem damage (SD, i.e., fire scarring), HT, and root failure (i.e., burned out roots).

Notably, **no tree was observed to have specific defects or decay patterns directly attributable to mountain pine beetle.**

MPB-IMPACTED TREES

A total of **321 trees were assessed in MPB-impacted study plots**. The combined average for all MPB-impacted trees from all time-since-death categories and replicate study sites, revealed the following mean tree characteristics (see **Table 3**): 26.6 ± 0.2cm DBH; 19.8 ± 0.2m height; 94.3 ± 0.9% bark intact at breast height (~135cm); 19.4 ± 1.5% fine needles present and between 1 and 24% fine branches remaining; and 88.5 ± 1.0% sound intact roots.

Table 3. Tree size and decay characteristics (±SE) averaged across each MPB-impacted study site for all individuals assessed (n=321).

MPB Sites	DBH[1] (cm)		Height (m)		Intact Bark @ BH		Needles (% remaining)		Fine Branches[2]		Root Condition[3]	
(0-3 yrs. TSD)												
611 Rd.	23.4	±0.4	17.9	±0.4	100	±0.0	20.3	±3.8	1.4	±0.1	94.4	±1.9
Blackwater Rd.	27.3	±0.8	21.4	±0.5	100	±0.0	43.7	±4.8	1.2	±0.1	93.7	±2.0
Y & D Rd.	27.3	±0.7	18.5	±0.3	99.7	±0.3	59.3	±3.4	1.1	±0.1	88.4	±2.2
(3-5 yrs. TSD)												
S. Woodcock	26.2	±0.7	15.1	±0.2	97.0	±1.4	17.6	±3.8	2.0	±0.1	94.2	±1.7
Batuni Rd.	26.2	±0.6	20.6	±0.7	89.7	±4.2	14.3	±3.2	2.0	±0.1	88.9	±2.5
Red Rd.	26.0	±0.6	19.5	±0.3	100	±0.0	2.7	±0.9	1.8	±0.1	88.9	±2.3
(10+ yrs. TSD)												
Dragon Mtn.	29.1	±0.7	19.8	±0.3	95.0	±2.3	9.7	±2.0	2.1	±0.1	92.0	±2.2
Eutsuk Lake	26.5	±0.7	22.4	±0.5	96.3	±1.6	0	±0.0	2.4	±0.1	86.4	±3.0
Hat Lake Rd. (23 yrs. TSD)	27.2	±0.7	24.3	±0.7	69.5	±5.2	2.7	±1.2	2.7	±0.1	67.8	±5.4
Overall average	26.6	±0.2	19.8	±0.2	94.3	±0.9	19.4	±1.5	1.9	±0.1	88.5	±1.0

Tree measure and decay characteristic

[1] Diameter at breast height (DBH) = equals the tree diameter measured at ~135 cm above ground level
[2] Fine branches remaining in the tree canopy recorded in three percent categories (1≥25%; 2=24-1%; 3=none remaining)
[3] Root condition represents the percent soundness of main lateral roots

Comparison of the mean tree size and decay characteristics for each MPB-impacted study site revealed several **significant differences (*p*<0.05) across temporal treatments and moisture gradient replicates** (**Table 4**). The mean diameter (27.6 ± 0.4cm DBH) and height (22.2 ± 0.3m) of trees assessed in the **oldest time-since-disturbance study sites (10+ysd) were significantly larger than more recently attacked stands** (p<0.05), which were found to be statistically similar to one another (0-3ysd and 3-5ysd; p>0.05). The amount of intact bark recorded at breast height (~135 cm) 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 significantly smaller amount of bark (87.1 ± 2.3%) is intact around the tree.

Table 4. Time since mountain pine beetle attack treatment: Average tree size and decay characteristics (±SE, n=321)

TSD treatment[1]	Tree measure and decay characteristics											
	DBH (cm)		Height (m)		Intact Bark @ BH		Needles (% remaining)		Fine Branches		Root Condition	
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

[1] Time-since-disturbance (TSD) defines temporal treatment types. Number of years represents approximate time since mountain pine beetle recorded in stands. Analysis of variance (ANOVA) on ranks of mean values with $p<0.05$ used to test for significance (SigmaStat, version 3.1). Small characters in common indicate no significant difference, where different characters (*a* versus *b*) indicate a significant difference.

Both the percent amount of needles and fine branches remaining in the beetle-killed tree canopy, showed significant differences among all TSD treatment categories. Not surprisingly, the greatest amounts of needles were found in stands impacted by mountain pine beetle within the last 3 years (42.0 ± 2.8%). This was found to be significantly greater than stands impacted 3-5 years ago (11.8 ± 1.8%), which in turn was significantly greater than stands impacted by the beetle over ten year ago (4.2 ± 0.9%). The average amount of fine branches remaining, recorded in three different percent categories (1 ≥ 25%; 2 = 24-1%; 3 = none remaining) was significantly less between each of the three treatments, with the majority of fine branches lost 3-5 years after beetle attack.

Stands impacted by mountain pine beetle over ten years ago showed the greatest amount of root damage/decay[2], which was significantly more than recently attacked stands (0-3 yrs). Mean root condition among stands impacted 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 TSD stands (82.3 ± 2.4%), although it was intermediate to both.

A closer look at mean root condition between dry and moist sites revealed significant differences in the soundness of roots among all MPB-impacted treatments. **Moist sites impacted by MPB across all TSD categories, all had significantly less root soundness than corresponding dry sites** ($p<0.05$).

[2] Based on observations of tree root systems and surrounding site conditions (i.e., moisture, microtopography, evidence of windthrow, presence and condition of upturned root wads, presence of fungal sporophores), it is likely that "root decay" in many of the MPB-killed stands visited may be due to a long cycle of wetting/drying along with secondary mycological and bacterial agents, but not primary fungal disease (i.e., failure because of endemic root disease such as *Armillaria* or *Heterobasidium* spp.).

Tree Class

Each of the 321 MPB-impacted trees assessed was assigned a tree class rating based on the 9 category system for conifers (WTC 2005). The majority (80 %) of the MPB-killed sample trees were rated as Class 3 (recently dead; most fine branches/twigs and some needles remaining, most bark present and still tight). An increasing proportion of Class 4 (no needles and no fine branches) and Class 5 (no limbs, bark loose and some bark missing) trees was observed in stands impacted by beetle **after five years since disturbance** (**Figure 7**).

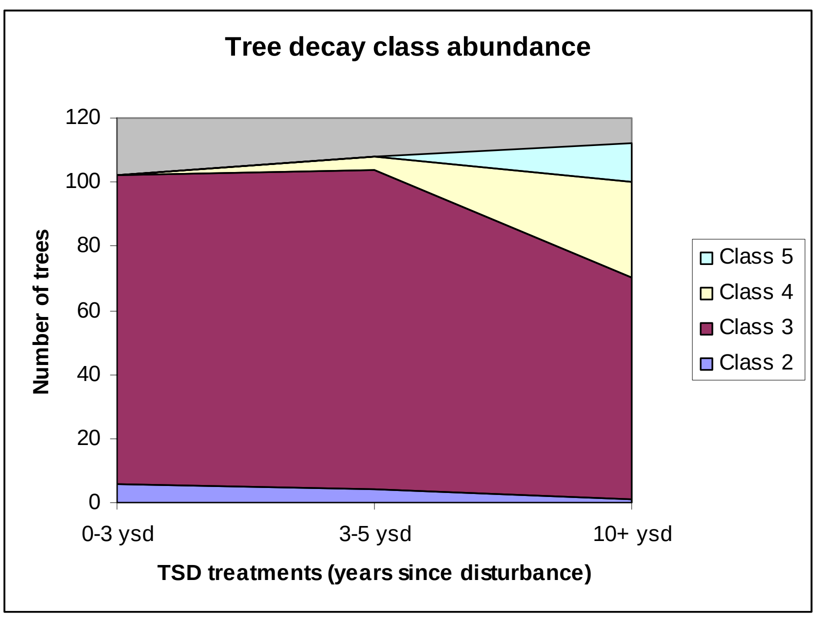

Figure 7. Tree decay class abundance (n=321) in MPB-impacted stands

Destructive Sampling

Among the 321 MPB-impacted trees assessed, 27 trees were felled and destructively sampled. Ten trees (~3%) were rated as dangerous prior to felling using visual WDTAC criteria for Level 3 disturbance. However, destructive sampling of these trees resulted in only 7 trees actually confirmed dangerous. Therefore, three trees deemed unsafe using detailed assessment indicators for shell thickness (i.e., drilling to estimate average shell thickness), actually had sufficient sound shell thickness[3] as confirmed by destructive sampling (**Figure 8**).

[3] Required shell thickness (RST) is calculated as tree radius x 0.30. Measured average actual shell thickness (AST) must be greater than RST in order to meet acceptable limits for bole columnar strength (WTC 2005).

Figure 8. Destructively sampled MPB-killed trees. For comparison, tree at left has ample sound stemwood. Tree at right has extensive heartrot in the stem near ground level; note there is virtually no sound stemwood shell. The 3 areas outlined in black are the only sound sections of stemwood in the tree stem at this position.

The average size and decay characteristics of destructively sampled MPB-killed trees were larger overall and had greater amounts of decay than the average tree assessed. Average characteristics for destructively sampled MPB trees (n=27) were as follows (**Table 5**):

3.7 mean decay class; 27.5 ± 0.8cm DBH and 23.4 ± 0.6m height; bark remaining at breast height was 83.8 ± 4.2%; the amount of needles and fine branches still attached to the tree was 7.2 ± 2.4% and 2.5 ± 0.1%, respectively; 71.5 ± 5.7% of the main lateral roots were sound.

Table 5. Average tree size and decay characteristics (±SE) among destructively sampled MPB-impacted trees

	Tree measure and decay characteristic											
	DBH (cm)		Height (m)		Intact Bark @ BH		Needles (%remaining)		Fine Branches		Root Condition	
n=27 Felled Trees	27.5	±0.8	23.4	±0.6	83.8	±4.2	7.2	±2.4	2.5	±0.1	71.5	±5.7
Subsample of 7 Danger Trees	26.9	±2.4	25.0	±1.8	67.9	±11.3	0.0	±0.0	3.0	±0.0	34.4	±11.0

Destructively Sampled Danger Trees

The seven danger trees confirmed by destructive sampling in MPB sites **all occurred on moist sites impacted by beetle 20 or more years ago** (**Table 5**). These trees (n=7) had the following average characteristics: decay class 4.2; 26.9 ± 2.4cm DBH and 25.0 ± 1.8m height; 67.9 ± 11.3% bark intact at breast height; no needles nor any fine branches remaining; and **only 34.4 ± 11.0% of sound roots**. **Decay in these trees was extensive at the root collar and at the trunk base near the ground line** (see **Figure 9**, bottom photo).

Five of the seven danger trees failed the root inspection, each with less than 50% sound roots, of which two trees were determined to have no sound roots at all. Four danger trees also failed the stem wood condition assessment using minimum RST criteria. The average shell thickness in these trees was less than the required RST minimum. Two of those trees also failed the root inspection.

Overall Tree Defects Observed in MPB-killed Sites

Tree defects were observed on 35 MPB-killed trees (**Figure 10**), or approximately **11% (35/321) of the total MPB-impacted sample population**. However, **only 7 trees (2%) were rated dangerous** using tree defect criteria for Level 3 disturbance activities.

The most common defects observed among MPB-impacted trees, listed in order of occurrence, were hazardous tops (HT, **Figure 9** at right)[4], root failure (RI), dead limbs (DL) and split trunk (ST, **Figure 9** at left). The majority of the defects were recorded on trees (25/35 trees) at sites with the longest TSD (10+ years). The **most common defect** (among the 25 trees) observed in **MPB-impacted stands >10 years TSD was root failure** (RI). In all other MPB site types and TSD categories, hazardous top (HT) was the most prevalent defect observed.

[4] The term "hazardous top" (HT) is a defect descriptor label for trees having live or dead secondary tops in the form of spikes, forks or multiple leaders. Whether this condition is actually "dangerous" depends on the condition of the top, the proximity of the tree to the work area, and the type of work activity occurring within reach of the tree. Detailed information on danger rating criteria for "hazardous tops" and other tree defects can be found on the WTC website at http://www.for.gov.bc.ca/hfp/training/00016/index.htm .

Figure 9. Lodgepole pine dangerous defects (upper left and right): split trunk, hazardous top; (bottom): extensive root and basal decay at ground interface (23 yrs. TSD after mountain pine beetle, moist site)

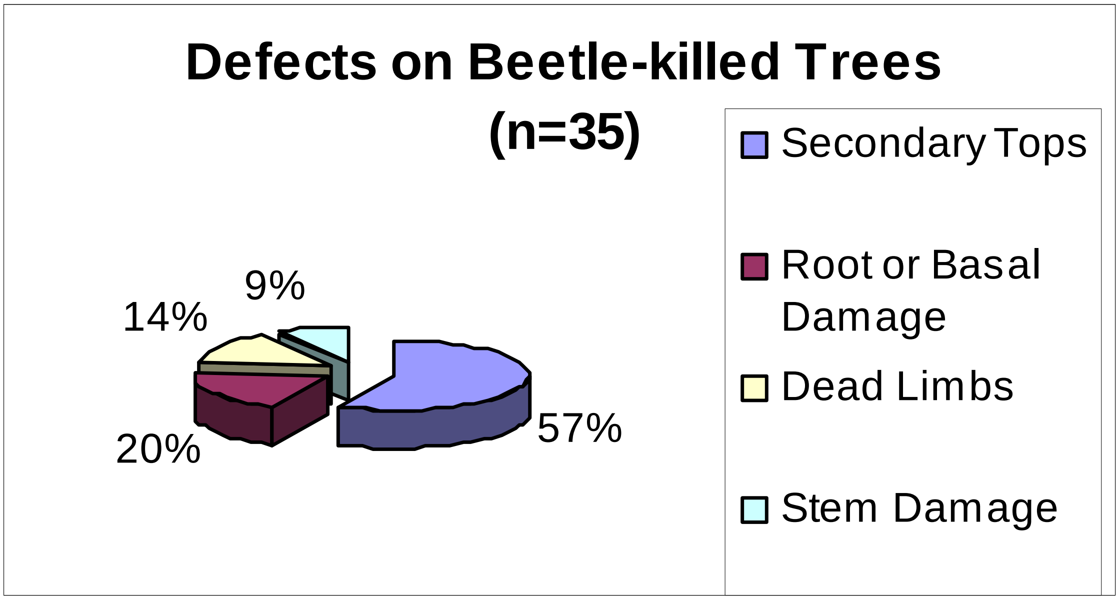

Figure 10. Summary (%) of defects observed on mountain pine beetle-killed trees (n=35)

FIRE-DAMAGED TREES

A total of **215 trees were assessed within fire-damaged study plots**. The combined average tree size and structural characteristics from **all time-since-disturbance fire study sites** showed the following average characteristics (**Table 6**): 26.3 ± 0.2cm DBH and 19.9 ± 0.2m height; 89.0 ± 1.5% bark intact at breast height; 6.5 ± 0.9% fine needles and between 1 and 24% fine branches remaining; and 89.4 ± 1.2% sound roots.

Table 6. Mean tree size and decay characteristics (±SE) for all individuals (n=215) and fire-damaged study sites.

Fire Sites	Tree measure and decay characteristics[1]											
	DBH (cm)		Height (m)		Intact Bark @ BH		Needles (% remaining)		Fine Branches[2]		Root Condition	
Kenney Dam	24.4 [a]	±0.5	18.3 [a]	±0.3	92.1 [b]	±2.3	14.8 [c]	±2.8	1.2 [a]	±0.1	95.0 [c]	±1.8
Hay Lake	26.8 [b]	±0.7	18.3 [a]	±0.4	80.3 [a]	±5.6	0.9 [a]	±0.5	2.7 [b]	±0.1	82.1 [a]	±4.4
0-3 TSD average	25.6 [a]	±0.4	18.3 [a]	±0.2	86.5 [a]	±3.0	8.2 [a]	±1.7	1.9 [a]	±0.1	88.8 [a]	±2.4
Pantage Lake	26.7 [b]	±0.6	22.0 [b]	±0.5	95.5 [b]	±2.8	6.7 [b]	±2.4	2.7 [b]	±0.1	93.6 [bc]	±2.3
Gray Rd.	27.1 [b]	±0.6	21.6 [b]	±0.4	82.6 [a]	±5.1	3.1 [b]	±1.3	2.8 [b]	±0.1	87.2 [a]	±3.3
3-5 TSD average	26.9 [a]	±0.4	21.8 [c]	±0.3	89.0 [a]	±3.0	4.9 [a]	±1.4	2.7 [b]	±0.1	90.4 [a]	±2.1
Meadow Lake	25.4 [a]	±0.5	19.0 [a]	±0.3	91.2 [b]	±2.6	13.0 [c]	±3.1	2.1 [b]	±0.1	90.3 [b]	±2.4
Eutsuk Lake	27.2 [b]	±0.6	20.5 [b]	±0.5	91.6 [b]	±2.9	0 [a]	±0.0	2.6 [b]	±0.1	88.0 [ab]	±2.5
10+ TSD average	26.3 [a]	±0.4	19.8 [b]	±0.3	91.4 [a]	±1.7	6.4 [a]	±1.7	2.4 [b]	±0.1	89.1 [a]	±1.7
Overall average	26.3	±0.2	19.9	±0.2	89.0	±1.5	6.5	±0.9	2.3	±0.1	89.4	±1.2

[1] Tree measure and decay characteristics based on WDTAC procedures with addition of TSD decay factors (see Appendix A).
[2] Fine branches remaining in the tree canopy recorded in three percent categories (1≥25%; 2=24-1%; 3=none remaining).
Analysis of variance (ANOVA) on ranks of mean values with $p<0.05$ used to test for significance (SigmaStat, version 3.1). Small characters in common indicate no significant difference.

Comparison of the mean tree size and decay characteristics between each fire-damaged study site revealed some significant differences among treatment types (**Table 6**). Although differences were recorded among mean tree diameter and height, fire-related damage or decay differences were most notable. The amount of intact bark, percent remaining needles and fine branches, as well as root condition, all appeared **significantly different between high intensity (Hay Lake) and medium intensity (Kenney Dam) fires** within the most recent time since disturbance treatment (p<0.05). Similarly, intact bark (3-5 ysd), proportion of needles remaining (10+ ysd), and root condition (3-5 ysd) all showed statistical differences between study sites of the **later TSD treatments** (3-5 and 10+ years since disturbance). **However, comparison of combined TSD sample averages did not reveal any significant time-related damage/decay** other than the percent amount of fine branches remaining, which was greatest in most recent fires.

Tree Class

The majority (66% overall) of the 215 fire-damaged trees were rated as tree Class 3 (recently dead with fine branches/twigs remaining; 80% Class 3 in 0-3 yrs. TSD and 65% Class 3 in 3-5 yrs. TSD). The relative abundance of Class 4 (no fine branches) and Class 5 trees (no limbs, bark loose and some missing) was similar for each TSD category, with greater numbers observed in high intensity fire stands. In high intensity fires, Class 4 and 5 trees combined represented up to 45% of all trees sampled.

Destructive Sampling

Eighteen trees were felled and destructively sampled out of 215 fire-damaged trees. **Fifty percent (9/18) of these were visually rated as dangerous**; this was confirmed by destructive sampling. These nine trees all failed for obvious root and stem damage that was beyond the corresponding WDTAC safe tree criteria/thresholds for Level 3 disturbance (**Figure 11**).

Figure 11. Clockwise from top left: Burned-out roots/butt, split trunk, burned stem, and hazardous top; all considered dangerous trees at a high BUI fire site. [Hay Lake]

The average size and characteristics of destructively sampled trees (n=18) were smaller overall and had greater amounts of damage than the average assessed fire-damaged tree. Average destructively sampled tree characteristics (n=18) were: 24.9 ± 0.7cm DBH and 18.2 ± 0.9m height; 71.4 ± 8.0% bark remaining at breast height; 5.0 ± 2.2% needles still attached to the tree; and 2.7 ± 0.1% fine branches remaining in the canopy. On average, 58.6 ± 7.8% of the main roots were sound (**Table 7**). Average characteristics for the subsample (n=9) of danger trees was: decay class 4.8, 25.4 ± 0.9cm DBH and 15.7 ± 1.0m height; 56.1 ± 13.4% bark intact at breast height; 2.2 ± 1.5% needles and 2.8 ± 0.1% fine branches remaining; **only 35.1 ± 9.2% of roots were sound** (Table 7).

Table 7. Average tree size and decay characteristics (±SE) among destructively sampled fire-damaged trees

	Tree measure and decay characteristic											
	DBH (cm)		Height (m)		Intact Bark @ BH		Needles (% remaining)		Fine Branches		Root Condition	
n=18 Felled Trees	24.9	±0.7	18.2	±0.9	71.4	±8.0	5.0	±2.2	2.7	±0.1	58.6	±7.8
Subsample of 9 Danger Trees	25.4	±0.9	15.7	±1.0	56.1	±13.4	2.2	±1.5	2.8	±0.1	35.1	±9.2

Destructively Sampled Danger Trees

All nine destructively sampled fire-damaged danger trees were assessed on **moist sites impacted by high intensity fires** [Hay Lake and Gray Road]. Six of the nine trees failed the detailed root inspection. Using ">50% unsound roots" as the threshold for root failure in fire-stands, each of the main lateral roots was inspected and considered unsound if >50% of the root was burned through or penetrable (i.e., wood is soft or spongy). **These nine trees all had 30% or less sound roots** (i.e., more than 70% of the root system was unsound). Three of these trees also failed the criteria of required shell thickness at stump height (30cm above ground). These trees all had substantial fire burn damage to their stem wood (>50% of stem cross-sectional area burned through). One still-standing tree had <20% sound stem wood cross-section remaining (**Figure 12**). Calculated required shell thickness (RST = radius X 0.30) was found to be greater than the actual average shell thickness (AST<RST) for these three danger trees.

Overall Tree Defects Observed in Fire-damaged Sites

Tree defects were observed on 36 fire-damaged trees, or approximately **17% (36/215) of the total fire sample population**. However, **only 9 trees (4%) actually met or exceeded dangerous tree defect thresholds for Level 3 disturbance activities**; these were **due primarily to the extent and severity of structural burn damage**. The most common defects among the fire-damaged lodgepole pine trees, listed in order of occurrence, were stem damage (SD), hazardous tops (HT) and root condition (RI). The majority of these defects were recorded at sites with greatest BUI. Accordingly, **stem damage (SD) due to fire scarring was the most common defect among the 25 trees observed in stands impacted by high intensity fire** (**Figure 12**). Several individual fire-damaged trees had more than one dangerous defect (e.g., burned out stem and root system).

Figure 12. Burned out roots and significant stem damage on a high intensity fire site

DISCUSSION

The presence of forest structure in the form of standing deadwood (i.e., wildlife trees) is widely recognized as an essential habitat element for cavity-dwelling wildlife (Hansen *et al.* 1991; Bunnell 1995; Keisker 2000; Manning *et al.* 2002; Bunnell *et al.* 2004). Maintenance of high standards of worker safety is an uncompromised priority in today's highly mechanized forest industry. Consequently, the Wildlife/Danger Tree Assessor's Course (WDTAC) was developed in order to facilitate the retention of wildlife trees in forestry operations, in a safe and operationally efficient manner (WTC 2005). These objectives will become increasingly important in many areas of central and southern British Columbia as beetle salvage continues, and where reforestation and in many cases, underplanting of residual standing dead pine stands, will occur.

Although the rate of breakage and/or fall down for lodgepole pine stands impacted by mountain pine beetle is not yet well studied, potential safety concerns for workers conducting various forestry activities (e.g., salvage, silviculture) in these stands over time, have been raised (Rakochy 2005). This is especially relevant in locations where high densities of standing dead pine may remain unharvested, but require restoration activities such as underplanting, or where road access through areas of standing dead trees will occur. The results of this current study have 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). In addition, these results reinforce the technical criteria and defect thresholds currently used by the WDTAC to determine tree hazards and associated safe work practices. These factors are discussed below.

MPB-killed Sites

The mean diameter and height of beetle-killed trees was significantly larger in the oldest time-since-disturbance (TSD 10+ yrs.) sites, compared to the more recently attacked stands. The reason for this is uncertain, but may reflect changes in the size and age class demographics of pine in the central interior over the past 10-20 years.

The **majority (80%) of MPB-killed trees were described as tree Class 3** (i.e., recently dead with some needles and fine twigs/branches remaining). There was an increasing proportion of Class 4 and Class 5 trees approximately five years TSD. While there will always be site-specific variations, it appears that many MPB-killed trees do not shed their fine twigs/branches nor begin to exfoliate their bark (i.e., they can be categorized as Class 3), until five years or more after death.

In total, tree defects were observed on 35 MPB-killed trees (11% of the sample population). This proportion is comparable to the 9% proportion observed by Rakochy (2005), in one of the few other studies of tree defects in MPB-killed stands in British Columbia.

Root failure/decay was the most common defect observed in the 10+ yrs. TSD category. Not surprisingly, these stands showed the greatest amount of root system damage/decay compared to more recently attacked sites. However, **moist sites consistently had greater root system damage across all TSD categories, compared to corresponding dry sites**. This finding is supported by Lewis and Hartley (2005) who suggested that increased soil moisture content would increase decay rates and root instability. Remarkably, even at the oldest moist MPB-killed site visited (23 yrs. TSD, SBSmc3, Hat Lake Rd. location), some dead trees which were situated on dry raised microsites, were still standing and had sound roots. In Oregon, Agee (1981) reported that 15% of fire- or beetle-killed lodgepole pine were still standing 10 years after being killed.

For the more recent TSD categories, hazardous top defects (i.e., secondary tops including forks, multiple tops or single leaders) were more common than root system defects. Rakochy (2005) also found a similar incidence (~51%) of hazardous top defects in beetle-killed pine stands <10 yrs. TSD. Manning (2001) documented hazardous top condition as the most common defect in lodgepole pine; however, he assigned a "medium mean failure potential rating" to this condition, noting the relative stability of such tops until the tree advances beyond Class 4.

Only 7 (2% of sample population) MPB-killed trees were confirmed to be dangerous, both visually and after destructive sampling. **All these trees occurred in moist sites greater than 20 yrs. TSD**. The average tree class for these individuals was 4.2. They were **all rated dangerous because of root condition failure**. On average, only 34% of roots were sound on these trees; this is significantly less than the 75% sound root requirement for Level 3 work activities, and also well below the 50% sound root requirement for Level 1 work activities (i.e., most silviculture activities including tree planting).

Notably, no MPB-killed trees were observed to have specific defects or decay/deterioration patterns directly attributable to pine beetle. In other words, the insect pathogen, while killing the tree, did not cause the occurrence of dangerous defects such as root failure. Root failure in MPB-killed stands, especially on moist/mesic sites, appears to be due to a long cycle of wetting and drying (i.e., rain and snowmelt) along with secondary mycological or bacterial agents. In most cases, root failure in these stands was not observed to be the result of primary fungal attack (e.g., *Armillaria* or *Heterobasidion* root disease center). To illustrate this effect somewhat colloquially, MPB-killed pine eventually rots away at the root collar/ground level, and either uproots or breaks off like an old, longstanding fence post.

Thus, **it appears that beetle-killed pine, especially on drier sites, can easily remain standing with minimal hazard for at least 10-20 years after death**.

Windthrow

Although a moderate to high level of windthrow was observed in a majority of visited stands, this study does not support previous findings that suggest significant amounts (>50%) of MPB-impacted trees will fall between 9 and 14 years after mountain pine beetle attack (Mitchell and Preisler 1998). Many fallen trees were observed in the understorey, however, the fall-down rate of beetle-killed lodgepole pine *per se* was not revealed. Due to shallow rooting, lodepole pine trees are susceptible to windthrow. Typically, lodegpole pine-leading stands have considerable amounts of coarse woody debris in the understorey (Tinker and Knight 2000). Even within stands with the greatest time since death by beetle (up to 20+ years), fallen trees in the understorey were not attributed definitively to MPB impacts. Rakochy (2005) found one MPB-impacted tree that had fallen on a dry site affected by mountain pine beetle 7 years prior. However, the tree had apparently been knocked down by an adjacent tree that had succumbed to a windthrow event.

Consequently, windthrow in MPB-killed stands appears to be the result of **endemic windthrow factors** such as prevailing wind direction, topography, soil depth and condition, and proximity to edges and openings, rather than directly attributable to MPB-induced effects.

Fire-damaged Sites

The **majority (66% overall) of the 215 fire-damaged trees were rated as tree Class 3**. The relative abundance of Class 4 and Class 5 trees was similar for each TSD category, with greater numbers observed in high intensity fire stands (BUI >70).

The most common defects observed in fire-damaged lodgepole pine stands were stem damage (due to fire scarring, **Figure 13**), root system failure (burned out roots), and hazardous tops (secondary tops – these are not related to fire incidence). Comparison of combined TSD sample averages **did not reveal significant time-related damage or decay** other than the percent amount of fine branches remaining, which was greatest in most recent fires. Consequently, how long ago the fire occurred did not seem to influence the degree of damage for the above defects. However, **significant differences in root/basal condition were revealed between high intensity and medium intensity fires**. This is to be expected since higher intensity fires invariably do more burn damage to the roots and butt of affected trees.

In total, **tree defects were observed on 36 fire-damaged trees** (or 17% of the fire sample population). However, **only 9 fire-damaged trees** (9/215 or 4% of the sample population) were **actually rated as dangerous** (both visually and after destructive sampling). **These all occurred on high intensity wildfire sites**.

Figure 13. Extensive basal tree burn damage, typical of high intensity fires. Note complete loss of organic duff layer. (Photo: courtesy BC MoFR, Protection Branch)

Reliabililty of the WDTAC Procedures

This study tested the reliability of WDTAC procedures in predominantly dead lodgepole pine leading stands affected by mountain pine beetle or by wildfire. By all accounts, the ability of the **WDTAC procedures to detect danger trees among MPB-impacted and fire-damaged lodgepole pine trees appeared to be accurate, reliable and consistent**. The WDTAC process was able to detect danger trees as well as changes in the extent of decay/deterioration in MPB-killed trees over time and between moist and dry sites. Trees assessed using the WDTAC visual assessment process (i.e., using external indicators) and detailed tree assessment criteria (i.e., stem drilling and root probing) were found to be dangerous in both mountain pine beetle and fire-damaged stands. Visual and detailed assessment ratings were confirmed by destructive sampling; however a few MPB-killed trees (n=3) which were visually rated as dangerous, actually proved to be safe upon destructive sampling. This suggests that the WDTAC process is actually somewhat conservative and will therefore accurately rate most tree defects.

All of the tree defects observed and rated in this study were for Level 3 disturbance work activities (i.e., includes most harvesting related activities). The defect failure criteria and hazard thresholds used to determine tree danger for Level 3 disturbance are "more strict" than for other work activities such as tree planting, brushing, pruning and road travel (on ballasted and compacted roads), which are categorized as Level 1 work activities (WTC 2005). Level 1 activities impart "less disturbance" to the ground and adjacent trees than Level 3 activities. Consequently, the risk of tree failure under these situations is less.

Given the results of this study, **it is likely that some of the trees which were rated "*Dangerous*" herein, would have actually been rated "*Safe*" at Level 1 disturbance**.

CONCLUSIONS

The results of this current study have 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). In addition, these results reinforce the technical criteria and defect thresholds currently used by the WDTAC to determine tree hazards and associated safe work practices for various forestry activities. Use of these criteria should be continued in MPB-killed and fire-damaged stands in British Columbia, with a few recommendations for older MPB-killed stands on moist or wetter sites (see *Recommendations* below).

LIMITATIONS OF THE STUDY

While this study provided new information on the condition of MPB-killed trees over time and under different site conditions, there are some limitations to which the results can be applied and interpreted. These are briefly described as follows.

1. The age distribution of MPB-killed trees in the 10+ yr. TSD sample was "patchy". Many of the trees in this age class were 10-12 yrs. TSD, while others were 20+ yrs. TSD. No trees were sampled between 13-22 yrs. TSD. Consequently, in order to achieve a robust sample size, the data for this age class was pooled at 10+ yrs., which did not permit any statistical discrimination between years within this category (i.e., could not compare 12 yrs. TSD trees with 23 yrs. TSD trees).

2. Because of the variable behavior of most wildfires caused by on-site variations in fuel supply and type, topography and changing weather conditions (wind), there will always be variations in the burn intensity and resultant degree of tree damage on any fire, regardless of the overall fire intensity rating (BUI) for that fire. Consequently, while recommendations provided in this study for high BUI fires are legitimate, 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 *Dangerous Tree Assessor's Course: Wildland Fire Safety Module* (2005), URL: http://www.for.gov.bc.ca/hfp/training/00016/index.htm).

3. While 27 MPB-killed trees (27/321) were destructively sampled in order to assess wood condition, this effort was conducted mainly to determine the amount of sound stem wood (AST) adjacent to various external defects (e.g., stem scars, stem cracks, cavities, forked tops). While 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", no direct correlations can be made to the "shelf-life" of standing dead pine stems. At best, non-statistical inferences can be made that the degradative wood qualities associated with wetter sites likely reduces the merchantability of standing beetle-killed dead trees more rapidly than could be expected on drier pine stands with equivalent time-since-death. A discussion of measurable tree characteristics related to the shelf-life of MPB-killed lodgepole pine is found in Thrower et al. (2004).

4. The results and recommendations provided in this study are directly applicable to the SBS zone of British Columbia. MPB-killed and fire-damaged stands in other BEC zones were not assessed.

RECOMMENDATIONS

Based on the above results and discussion, the following guidelines are recommended for conducting forestry operations in stands impacted by mountain pine beetle or wildfire in the SBS zone of British Columbia.

1. For silviculture activities (except mechanical site prep.) in MPB-killed stands on dry sites (dh, dw, dc and dk subzones), the WDTAC standards for Level 1 disturbance are adequate and should be followed.

2. For general silviculture activities (except mechanical site prep.) in MPB-killed stands on moist sites (mh, mw, mm, mk, mc or wetter subzones), the WDTAC standards for Level 1 disturbance are adequate and should be followed **with this provision**:

    i) based on the incidence of dangerous trees in the 10+ yrs. TSD cohort, **for stands > 15 years TSD on moist or wetter sites ONLY**, either cease work activities when wind speeds exceed 20 km/h, or reassess the site to Level 3 disturbance.

    How to Recognize These Types of Potentially Dangerous Trees

    Most of the standing dead trees from this age cohort and site moisture regime will be categorized as class 5 (no limbs, bark loose and some bark missing); however some trees may still appear as class 4 (no fine twigs, only coarse limbs remaining, bark loosening and starting to fall off). Watch for evidence of decay (rotting) or other **damage to the tree stem at the tree-ground interface**. Also watch for severe damage to the main lateral roots (which may not even if present after 15 years TSD), and trees which have started to lean significantly (15%+) as a result of basal or root system damage (refer to **Figure 9** (bottom photo) for an illustration of severe basal rot and associated tree lean in a dead pine 23 years TSD on a moist site).

3. For silviculture activities (except mechanical site prep.) in fire-damaged stands, regardless of the subzone location, time-since-death, or fire burn intensity, the WDTAC standards for Level 1 disturbance are adequate and should be followed, with particular heed to the following factors:

    i) for high intensity burn sites (BUI >70[b]), a thorough site assessment overview should be conducted by a qualified person as part of the pre-work field inspection[c] in order to determine the general type and extent of fire damage to standing trees, including:

    - damage to the anchoring soil layer
    - degree of root burn
    - burn damage at the tree base and to the lower portion of the tree stem.

4. During **danger tree field inspections**, the assessor should focus on the "**bottom end of the tree**" (roots, ground level interface, tree butt). This is especially true for **high intensity wildfire sites**, and in MPB-killed stands which are **>15 years old on moist or wetter sites**.

   Note: as part of due diligence, the assessor should still visually inspect the tree for overhead hazards in the stem and crown (e.g., stem scars, split trunk, forked or multiple tops, large dead limbs) based on the defect criteria for the intended level of disturbance (work activity).

Knowledge Gaps

5. A knowledge gap exists concerning the condition of MPB-killed trees between 13-22 years TSD, regardless of site moisture. Further research data should be collected for this TSD-cohort, especially in pine leading stands on moist or wetter sites. This information can be used to confirm the conclusions made about MPB-killed trees greater than 15 years TSD (i.e., the analyses in the current study pooled all MPB-killed pine ≥10 years TSD).

6. Data on the condition of MPB-killed trees in other biogeoclimatic zones in BC should be collected, since the current study only involved the SBS zone.

[b] High intensity fires (BUI >70) are typically characterized by burning of the organic duff layer down to exposed mineral soil. Tree roots will be exposed and wholly or partially burned through. In many cases, the lower portions of tree stems will be badly fire scarred and damaged (Figure 12).

[c] Fire history information, including BUI values for a particular fire, should be gathered where available, as part of "office pre-planning" prior to conducting danger tree assessment field work on a given fire site. This type of information will facilitate the site assessment component of the field inspection by giving the assessor qualifying data concerning the fire intensity, and therefore provide a "heads- up" as to the likely type of tree damage to expect on-site.

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APPENDIX A. TREE CHARACTERISTICS RELATED TO TIME SINCE DEATH

The guidelines to estimate years since death in this project are[1]

Years Since Death	Characteristics
0-1 yr	red attack – no needle loss.
3–5 yrs	red attack – ranges from some to almost all needles lost.
8+ yrs	grey attack – all small branches lost, many trees falling.

[1]Adapted from: J.S.Thrower *et al.* 2004. Sample plan to measure tree characteristics related to shelf life of mountain pine beetle-killed lodgepole pine trees in British Columbia. 17pp.

Other researchers have given guidelines to estimate time since death as:

Tegethoff et al. (1977) noted for southeastern Idaho:

Years Since Death	Characteristics
1–3 yrs	Needles bright orange to straw-colored to grey. Some foliage lost
3–5 yrs	No needles. Most small twigs supporting needle fascicles lost
5+ yrs	No small twigs. Bark peeling

Cole and Amman (1969) noted for western Wyoming:

Years Since Death	Characteristics
0-1 yr	Needles bright orange to straw-colored
2 yrs	Needles dull orange. Most foliage retained
3 yrs	Needles dull orange to grey. Most foliage lost
4 yrs	No needles. Most small twigs supporting needle fascicles lost
5+ yrs	Bark peeling

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APPENDIX B. MINISTRY OF FORESTS AND RANGE FOREST PROTECTION DATA

Fire location, dates and size statistics recorded for fires in the BC central interior plateau

Location	Point ID[1]	Fire Year	Ignition Date	Fire Size (ha)	UTM Co-ordinates		Elevation (m)
Kenney Dam	1016	2004	June 24	10300	377610E	5948737N	777
Hay Lake	1019	2004	August 8	369	412294E	5925572N	1057
Pantage Lk.	986	2002	June 14	8	499608E	5894881N	878
Gray Rd.	974	2002	June 19	250	401301E	5914086N	1100
Eutsuk Lake	PB[2]	1995	September 20	~650	683758E	5904718N	882
Meadow Lk.	571	1994	July 27	5	463460E	5920581N	880

[1]Point identification number corresponds to mapped fire data, Prince George Forest District forest fire database
[2]Prescribed control burn (PB); Tweedsmuir Park MPB Control Burn; BC Parks Report by Embers Research Services Ltd. November 1995.

APPENDIX C. MINISTRY OF FORESTS FOREST FIRE WEATHER SYSTEM DATA

Hay Lake Fire – Bounded days for Vanderhoof

Date	Temp.[1]	RH[2]	Wind Dir.[3]	Wind Sp.	Precip.	FFMC[4]	DMC[5]	DC[6]	ISI[7]	BUI[8]	FWI[9]
2004/08/17	28.0	40	0	2	0.0	90.7	57	552	5.3	91	19.3
2004/08/18	26.9	42	0	12	0.0	90.7	61	559	8.6	95	27.8
2004/08/19	26.6	38	0	8	0.0	90.8	64	567	7.4	100	25.6
2004/08/20	22.1	51	0	22	1.0	86.0	67	574	7.4	103	26.0
2004/08/21	19.6	51	0	18	0.0	86.9	69	581	6.7	106	24.5

Kenney Dam Fire – Bounded days for Fort St. James

Date	Temp.	RH	Wind Dir.	Wind Sp.	Precip.	FFMC	DMC	DC	ISI	BUI	FWI
2004/06/20	27.1	37	73	8	0.0	92.7	39	324	9.3	60	23.2
2004/06/21	27.8	36	12	6	0.0	92.7	44	332	8.4	66	22.6
2004/06/22	26.5	41	87	7	0.0	91.9	48	340	8.0	71	22.7
2004/06/23	28.4	31	320	10	0.0	92.3	54	349	9.8	77	27.4
2004/06/24	25.8	49	338	9	0.0	90.5	57	357	7.3	82	22.8

Gray Road Fire – Bounded days for Vanderhoof

Date	Temp.	RH	Wind Dir.	Wind Sp.	Precip.	FFMC	DMC	DC	ISI	BUI	FWI
2002/06/15	24.4	34	270	1	0.0	92.8	45	352	6.8	69	17.1
2002/06/16	17.7	55	0	4	0.0	89.2	47	359	4.8	71	16.7
2002/06/17	17.5	63	270	2	0.0	93.1	53	358	5.0	78	16.0
2002/06/18	16.0	51	315	9	0.3	90.3	56	364	3.9	85	12.5
2002/06/19	16.3	61	270	2	0.0	91.0	61	370	4.1	87	13.8

Pantage Lake – Bounded days for Chilako

Date	Temp.	RH	Wind Dir.	Wind Sp.	Precip.	FFMC	DMC	DC	ISI	BUI	FWI
2002/06/09	24.4	26	135	4	0.0	87.9	24	134	3.8	33	8.4
2002/06/10	25.6	21	90	4	0.0	93.0	30	142	7.8	39	16.3
2002/06/11	25.0	28	315	8	0.0	93.0	35	150	9.7	44	20.4
2002/06/12	27.0	21	135	1	1.0	94.1	40	158	8.1	49	18.9
2002/06/13	29.1	24	90	4	0.0	94.1	46	167	9.5	55	22.5

Meadow Lake Fire – Bounded days for Chilako

Date	Temp.	RH	Wind Dir.	Wind Sp.	Precip.	FFMC	DMC	DC	ISI	BUI	FWI
1994/07/22	27.7	13	90	5	0.0	96.0	45	315	12.7	66	30.0
1994/07/23	29.9	17	50	5	0.0	96.0	51	324	12.8	73	31.7
1994/07/24	28.6	34	0	4	0.0	94.0	55	332	9.2	78	26.3
1994/07/25	24.1	49	0	6	0.0	90.7	58	340	6.5	82	20.9
1994/07/26	22.4	52	270	9	1.0	85.3	61	348	3.5	85	13.4

Eutsuk Lake Fire – Bounded days for Grassy Plain

Date	Temp.	RH	Wind Dir.	Wind Sp.	Precip.	FFMC	DMC	DC	ISI	BUI	FWI
1995/09/16	16.7	48	0	9	0.0	86.2	30	558	4.4	72	19.2
1995/09/17	17.8	40	45	4	0.0	86.8	31	563	5.7	74	16.3
1995/09/18	18.3	40	50	4	20.0	87.0	33	568	4.5	32	1.6
1995/09/19	6.5	55	90	2	1.0	31.0	12	571	3.6	34	3.5
1995/09/20	12.8	40	180	7	0.0	53.0	13	575	3.4	38	6.8

[1]**Temp.** – Temperature recorded at 1300hrs.
[2]**RH** - Relative Humidity - a numerical measure of air moisture saturation.
[3]**WindDir. -** Wind Direction from origin in degrees (0º = North)
[4]**FFMC** - Fine Fuel Moisture Code. A numerical rating of the moisture content of litter and other cured fine fuels. This code is an indicator of the relative ease of ignition and flammability of fine fuel.
[5]**DMC** - Duff Moisture Code. A numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. This code gives an indication of fuel consumption in moderate duff layers and medium-size woody material.
[6]**DC** - Drought Code. A numerical rating of the average moisture content of deep, compact, organic layers. This code is a useful indicator of seasonal drought effects on forest fuels, and and index of the amount of smouldering in deep duff layers and large logs.
[7]**ISI** - Initial Spread Index. A numerical rating of the expected rate of fire spread. It combines the effects of wind and FFMC on rate of spread, without the influence of variable quantities of fuel.
[8]**BUI** - Build Up Index. A numerical rating of the total amount of fuel available for combustion that combines DMC and DC.
[9]**FWI** - Fire Weather Index. A numerical rating of fire intensity that combines ISI and BUI. **It is suitable as a general index of fire danger**.

APPENDIX D. FIELD DATA CARD

Wildlife/Danger Tree Assessment - MPB Stands

Assessor's Name: [illegible]		Date: D/M/Y	[illegible]
District: [illegible]	Location: YSD Rd.	Location features: [illegible] lots of damage	Elevation: 850
BECsub-zone: SBSdk	Moisture: 3=wet 2=mesic 1=dry: 2	UTM Coordinates: 453820E, 5952004N	
Aspect (degrees): –	Slope (%):	Micro-topography: [illegible]	Secondary insect attack (Y=1; N=0): –

2

Tree #	Tree Class	DBH (cm)	DSH (cm)	Tree Height (m)	Habitat: Wildlife value (1-3)	Wildlife use	Tree lean (%): 1=<10, 2=10-20, 3=21-30, 4=>30	Dangerous Defects (Y=1, N=0): HT	DL	ST	SD	SB	TL	R	Stump condition grnd. level: AST measure 1	AST measure 2	AST measure 3	AST measure 4	Damaged roots (1-4)	RST (radius x 0.3)	Average Sound Thickness	Stand Characteristics: Crown closure	Percent pine (%)	Number of stems (5.64m): <21 cm DBH	21-32 cm DBH	>32 cm DBH	Decay Characteristics: Intact bark at BH (%)	Needles remaining (10%'s)	Fine branches remaining (1-3)	Type of decay (AD, SA, HR)	Location of decay (legend 2=lower third, 3=mid third, 4=upper third)
1	3	21.5	25.5	16.5	1	–	1	–	–	–	–	–	–	–						0	0						100	95	1	–	–
2	3	29.1	33	20.5	1		1	–	–	–	–	–	–	–						0	0	20	[illegible]	6	7	1	[illegible]	80	1		
3	3	32.5	35	20.0	1		1	–	–	–	–	–	–	–						0	0							60	1		
4	3	31.5	35	20	1	[illegible]	1	–	–	–	–	–	–	–						0	0						[illegible]	60	1		
5	3	25	28	7.5	1	[illegible]	1	–	–	–	–	–	–	–						0	0	Tree Species	Pl	[illegible]	7		1	10	1		
6	3	22.5	25	15.0	1	[illegible]	1	–	–	–	–	–	–	–						0	0		Sx					75	1		
7	3	24.5	26	19	1	[illegible]	1	–	–	–	–	–	–							0	0		At				[illegible]	90	1		
8	3	31.0	34	18.5	1	WPhases	1	–	–	–	–	–	–	–						0	0		Act				90	90	1		
9	3	26.5	31	7.5	1		1	–	–	–	–	–	–	–						0	0		Bw						1		
10						[illegible]														0	0		Ba								
11																				0	0										
12																				0	0										
13																				0	0										
14																				0	0										
15																				0	0										