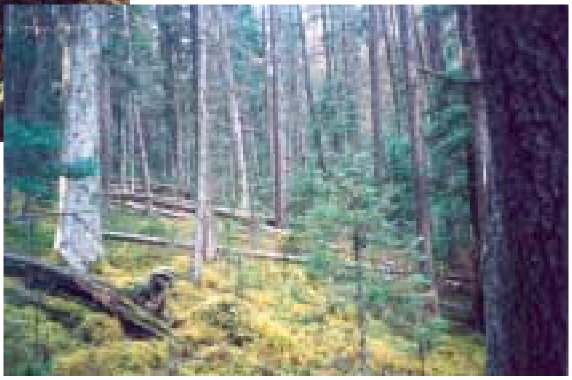
Mountain pine beetles (*Dendroctonus ponderosae*) and old-growth forest characteristics in the Moist Interior Plateau, Vanderhoof Forest District



Research Report

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EXECUTIVE SUMMARY

The Moist Interior Plateau Natural Disturbance Unit (NDU) in the Vanderhoof Forest District is in the centre of the largest mountain pine beetle (*Dendroctonus ponderosae* Hopk.) epidemic ever recorded in North American history. In order to salvage infested timber, Allowable Annual Cuts have been increased substantially over long term sustainable harvest levels. However, mountain pine beetles are native to British Columbia and are an integral element of lodgepole pine (*Pinus contorta* var *latifolia* Engelm) stand dynamics. As both the beetle infestation and timber salvaging efforts spread, options for conserving old forests are rapidly declining.

This report focuses on defining the structural characteristics of old-growth forests in the Moist Interior Plateau NDU with an emphasis on maintaining old-growth characteristics across a landscape heavily affected by the beetle epidemic. The study includes data from 29 sites between 80 and 230 years old located across two biogeoclimatic (BEC) zones and five variants. Such a broad range of BEC units was included in order to be relevant to the NDU system proposed for the region.

Old-growth forests in British Columbia are generally identified using forest cover age-classes. However, age-class does not necessarily identify the functional and structural attributes of old growth. Although age-classes are derived from photo interpretation where old-growth associated attributes are an important estimator of stand age, they are often inaccurate. In this study, half of the stands were incorrectly classified, with the age of most stands over-estimated in the forest inventory data. When mapped age-classes were assessed, they did not provide a suitable surrogate for successional stage. The recently retrofit and updated Vegetation Resources Inventory may provide more accurate inventory estimates and should be used in database assessments.

Sampled stands had a range of impacts from the current mountain pine beetle infestation, so data were analysed using three beetle impact scenarios:

1) In the *Before Beetle* scenario, data were assessed as if there had been no MPB outbreak, and sample trees that had been killed by the beetles were ‘resurrected’ and analysed as if still living.
2) In the *Current Mortality* scenario, stand structural data were assessed as sampled in the field. At the time of sampling, stands were undergoing various stages of beetle infestation and the degree to which the MPB had already impacted a stand was largely linked to the stand’s location and not to inherent stand susceptibility characteristics. Thus, current levels of mortality did not reflect the condition of stands expected once the beetle attack passes.
3) In the *Predicted Mortality* scenario, we estimated stand structural characteristics following the beetle outbreak using predicted mortality rates. A conservative mortality estimate and a high mortality estimate were used to predict the loss of live lodgepole pine, by size classes due to the MPB.

The *Before Beetle* scenario was used to determine baseline old growth conditions in the Moist Interior Plateau NDU as though there was no beetle epidemic. Principal Components Analysis (PCA) was used to develop multiple structural attribute thresholds for an Old Growth Index based on suites of stand-level old-growth characteristics. The PCA analysis was first conducted using all sites grouped together. However, site productivity was found to have a large influence on stand structure, and the data were stratified into Higher and Lower productivity groups using a calculated site index threshold of 17. Separate Old Growth Indices were produced for Higher and Lower productivity sites because Higher productivity sites were found to have significantly higher densities of large trees and snags, and lower densities of small trees.

Site productivity was still found to be the largest source of variation within data from both the Higher and Lower productivity groups, although stand age was also important in driving stand structural characteristics. Large structural attributes, which are important functional elements of old growth, developed more rapidly on Higher productivity sites, and were most abundant on older, Higher productivity sites.

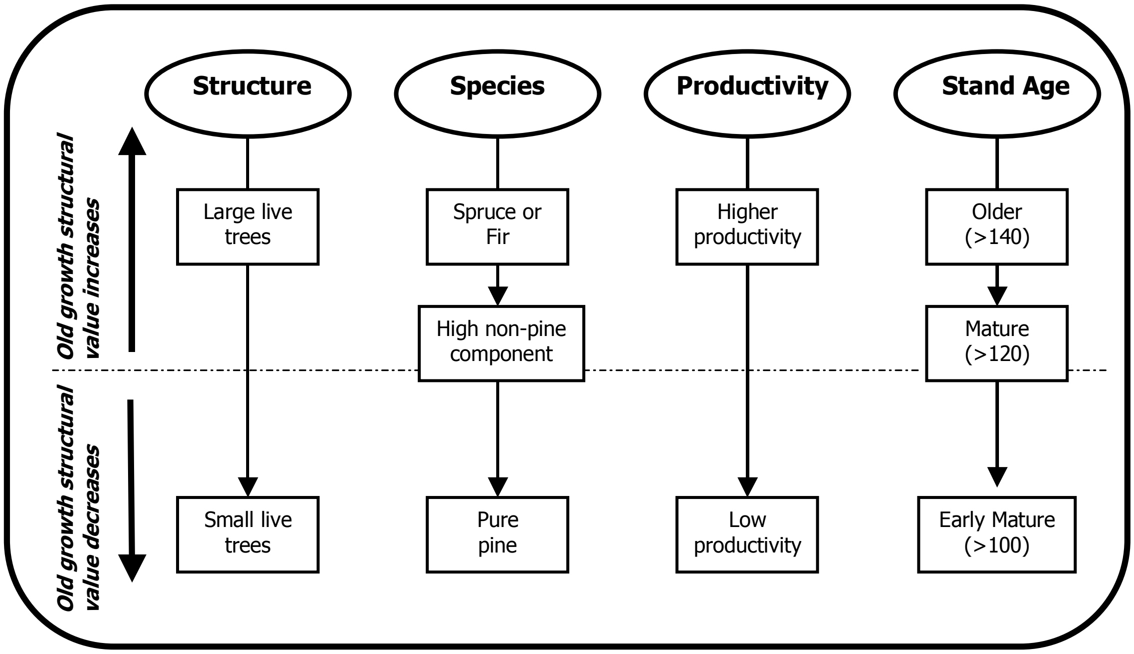
We propose using the Old Growth Indices developed here to guide old growth reserve selection at the stand level. The thresholds provided in the Old Growth Indices indicate the structural value of potential old growth reserves. While it is likely that many beetle-affected stands will not meet the criteria presented due to high mortality, the thresholds can be used as benchmarks for comparing potential candidate areas, and can be used to evaluate and monitor whether old forest attributes are being retained at stand and landscape-levels.

When the Old Growth Index was applied to stand data from each of the beetle mortality scenarios, we found that old-growth scores from stands with high scores prior to beetle infestation were reduced in the *Predicted Mortality* scenarios by the impacts of the MPB as large diameter live pines were killed off. The old-growthness of younger, dense stands with low old growth scores increased in some cases as the beetles thinned the stands and increased the density of medium-sized snags. In the *Predicted Mortality* scenarios, the highest scores were still found at older Higher productivity sites where large diameter live spruce and subalpine fir were abundant.

Our *Predicted Mortality* scenarios show an expected loss of lodgepole pine trees over 27.5 cm dbh from beetle-infested stands. As the larger pine component is killed off, the contribution of spruce and subalpine fir to old-growth habitat is expected to increase considerably. These analyses suggest that the best stands for old growth conservation in the Moist Interior Plateau are on Higher productivity sites with high densities of large diameter, older, live spruce and fir trees that exceed the thresholds, by size class, presented in our Old Growth Index. Stands with these features should be preferentially selected for old growth reserves because they are likely to retain more old growth attributes in the short term (following beetle kill) and will provide a source for future large trees, snags and CWD over the next rotation.

Defining old-growth characteristics in the Moist Interior Plateau is increasingly complex due to the current MPB outbreak and several factors apply to the biological value of a potential old growth reserve including stand structure, species composition, site productivity and stand age. The figure below shows the characteristics that are likely to provide the most valuable old growth habitat, given the current beetle situation. For example, older stands (>140) with a high component of large, live spruce and/ or fir on higher productivity sites are likely to provide the most unique old growth habitat values, while younger pure pine stands on low productivity sites will not. Similarly, mature stands over 120 years old on high productivity sites are likely to provide more old growth attributes than older stands on lower productivity sites.

Site characteristics and likely old forest structural value



Higher productivity sites reflect the most efficient allocation of old growth reserves for biodiversity because large diameter structures develop more rapidly on these site types so they are likely to recover old forest characteristics sooner than Lower productivity sites. Old forest recruitment sites (future old growth) should also be preferentially allocated to Higher productivity sites because old growth structures will develop more quickly there. With the magnitude of the current MPB outbreak and the subsequent salvage efforts, it will be important to re-establish old forest dynamics over the next rotation period. The larger-sized stand structures on higher productivity sites will help to bridge the habitat gap between the current outbreak and recovery across the landscape.

Managing for old growth requires planning on multiple time scales. In the short term, the most efficient biological strategy is to maintain stands with large live trees. In the mid and long term, it is important to plan for future (recruitment) old growth that will develop the characteristics required for old growth habitat over the next rotation. Maintaining a medium term old growth supply is important to ensure that as current old growth reserves are no longer adequate (due to insect or disease outbreaks, fire or other disturbance), new areas are rapidly available as replacements.

Stand structure thresholds are provided separately for Higher and Lower productivity sites. In the proportion of the landbase where Lower productivity sites are selected for old growth management, the Old Growth Index thresholds can be used to ensure that maximum biodiversity values are being conserved.

Old growth planning in the Vanderhoof Forest District is currently following an aspatial approach. However, stand and landscape level considerations should be taken into account to ensure that high structural value sites, with large diameter live trees, are maintained across the landbase. It is also important that old-growth reserves be located throughout the landscape and not just placed in areas where beetle impacts have already been high.

Developing landscape level old-growth plans is beyond the scope of this project. However, based on the research we have conducted, we recommend the following approach as a general strategy for old growth biodiversity conservation in the Moist Interior Plateau:

1) Stratify stands based on estimated site productivity.
2) Further stratify stands by age-class group: younger (< age-class 5); early mature (age-class 6-7); mature (age-class 7); and old (age-class 8).
3) Identify stands where spruce and fir comprise an estimated 15%, 30%, 50%, and 70% of the canopy.
4) Use the gradients in the figure above and the thresholds in the Old Growth Index to select a range of stands that comprises the highest biological value.
5) Use adaptive management to monitor and revise old growth reserves with short, medium and long term old growth supply in mind.

ACKNOWLEDGEMENTS

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Thanks also to Kendra Wood and Steve Ogle for their insightful assistance in the field. Linda Sheffield, Natasha Schorb and Joanne Siderius analyzed tree cores and Corey Bird and Joanne Siderius diligently entered data.

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INTRODUCTION

The Moist Interior Plateau Natural Disturbance Unit (NDU) in the Vanderhoof Forest District is in the midst of the largest mountain pine beetle (*Dendroctonus ponderosae* Hopk.) epidemic ever recorded in North American history (BC Ministry of Forests 2003a). The Council of Forest Industries (COFI) estimates that the current outbreak has infested 173.5 million cubic meters of lodgepole pine (COFI 2003). This figure is more than double the yearly Allowable Annual Cut (AAC) for the entire province of British Columbia. In 2003, the beetle infestation was estimated to have increased by 60% over 2002 levels (COFI 2003), infesting an additional 4.2 million hectares (BC Ministry of Forests 2003b). As the beetle spreads, efforts to harvest affected timber have increased through considerably elevated AAC levels. In June 2002, the AAC for the Prince George Timber Supply Area was increased by 24% above the long term sustainable harvest level in response to the beetle epidemic (BC Ministry of Forests 2002).

Mountain pine beetles are native to British Columbia and are an integral element of lodgepole pine (*Pinus contorta* var *latifolia* Engelm) stand dynamics (Samman and Logan 2000). As a host specific species, the beetles preferentially attack older lodgepole pine and Ponderosa pine (*Pinus ponderosa* Dougl. ex. P & C Laws.), as well as western white pine (*Pinus monticola* Dougl. ex D. Don). As both the beetle infestation and timber salvaging efforts spread, options for maintaining and recruiting old forests are rapidly declining. This report focuses on defining the structural characteristics of old-growth forests in the Moist Interior Plateau NDU with an emphasis on maintaining and recruiting old-growth characteristics across a landscape heavily affected by the beetle epidemic.

Old-growth forests are unique ecosystems that provide habitat assemblages, microclimates and stand structures important for biodiversity. Species associated with old forests tend to rely on habitats such as large diameter snags and trees or an abundance of coarse woody debris (Bunnell and Kremsater 1991, Marcot 1997, MacKinnon 1998). In general, these structural attributes are not readily available in younger, managed forests and are not easily or quickly created (Bunnell and Kremsater 1991). In order to inventory, manage and conserve old-growth forests, definitions that adequately describe key attributes are necessary.

Various terms are used to name forests that have been free from stand-replacing disturbance for a relatively long period of time. These include old growth, old seral, old forest, over-mature, decadent, and climax forest. We use the term old-growth forest most often in this report because it is commonly used in scientific and popular literature.

Conceptual definitions of old-growth forests range from simplified descriptions based solely on forest cover age estimates (see Province of BC1995) to definitions that follow broad principles of forest stand development (e.g. Oliver and Larson 1996) or definitions based on stand structural attributes (e.g. Spies and Franklin 1988). In general, old-growth forests contain trees that are older and larger than the expected patterns for the species, are associated with abundant large dead and down woody debris, and are relatively old for a given ecosystem.

Age-based definitions are the simplest approach to describing old growth. In theory, age-based definitions allow managers and planners to identify old growth using existing forest inventory data without the expense of field sampling. Although age is an essential component, defining old growth without an assessment of structure may fail to identify the most biologically important areas of older forest.

Using population dynamics, old growth definitions are based on stages of stand development and a number of different conceptual models have been presented to describe these stages. Oliver and Larson (1996) divide stand development following major disturbances into four phases: stand initiation, stem exclusion, understory re-initiation, and old growth. Franklin et al. (2002) use eight: disturbance and legacy creation, cohort establishment, canopy closure, biomass accumulation/competitive exclusion, maturation, vertical diversification, horizontal diversification, and pioneer cohort loss. According to Oliver and Larson, true old growth is not reached until all trees that invaded following a stand-replacing disturbance have been replaced through small-scale processes by a new cohort of trees.

Several authors have endorsed the use of old growth definitions based on multiple structural attributes because it is the structure that provides unique habitat values and ecosystem functions that confer special importance to old-growth (Spies and Franklin 1988; Franklin and Spies 1991; Marcot et al. 1991; Kneeshaw and Burton 1998; Wells et al. 1998). Attributes used in old-growth definitions include: large old trees, a multi-layered canopy, numerous large snags and logs, a diverse tree community, old age of some trees, canopy gaps, hummocky micro-topography, complex structure, wider tree spacing, and increased understory production (from Kneeshaw and Burton 1998; see also Franklin and Spies 1991; Holt and Steeger 1998). Quantitative approaches to defining old-growth tend to focus on these structural elements since they are easily measured, are often linked to biodiversity values, and have the potential for manipulation through forest management (Wells et al. 1998).

Regardless of the definition used, the old-growth stage of forest development is specific to the ecosystem in question. Characteristics of old growth in moist, temperate regions will differ significantly from those in cooler, drier climates. In addition, old growth structure varies at a regional scale on the basis of natural disturbance patterns, species composition, climate, ecosystem type, and site productivity. Ecosystems with frequent stand replacing disturbances generally lack the longevity of large, 'majestic' or 'cathedral-like' trees often associated with old growth in ecosystems that may exist for thousands of years without stand replacing disturbances (e.g. coastal British Columbia (Lertzman et al. 2002), wet Interior Cedar Hemlock forests (Holt and MacKillop 2002a; Arsenault and Gower 2000). In these forests, with higher disturbance rates, there is rarely sufficient time for stand development stages to progress beyond Oliver and Larson's (1996) understory re-initiation phase or past Franklin et al.'s (2002) maturation stage. These factors necessitate an ecosystem-specific perspective on old growth that emphasizes stands that are relatively old, contain structural attributes associated with older forests, and provide valuable and unique habitats that are typically absent in younger, more common stands.

With the current beetle epidemic in the Moist Interior Plateau, options for conserving old-growth forests are limited and even more complex. Mountain pine beetles tend to favour older stands with large diameter pine trees – the same stand types that generally fulfill requirements for old-growth status. Thus, stand-level changes following the MPB outbreak are integral to determining the most appropriate old growth site types. Good longer term management for old growth in the Moist Interior Plateau require an assessment of predicted stand structure *following* the beetle outbreak.

The goals of this project are:

1) to describe old-growth structural characteristics in mixed lodgepole pine and spruce stands in the Moist Interior Plateau NDU in the Vanderhoof Forest District;
2) to determine which structural elements of old forest remain in mountain pine beetle infested stands;
3) to develop strategies for retaining old-growth features within landscapes heavily impacted by mountain pine beetles.

In this report, old-growth forests are assessed under three scenarios:

1) The *Before Beetle* scenario examines stand structure under the assumption that there was no beetle outbreak. Pines killed by the MPB were resurrected and analysed as if still living.
2) The *Current Mortality* scenario uses stand structural data as sampled in the field. At the time of sampling, stands were undergoing various stages of beetle infestation and the degree to which the MPB had already impacted a stand was largely linked to the stand's location and not to inherent stand susceptibility characteristics. Thus, current levels of mortality do not reflect the expected condition of stands once the beetle attack has passed.
3) The *Predicted Mortality* scenario is based on predicted stand structure following the beetle outbreak and is based on estimated mortality levels, stratified by size class.

Limitations

This report represents the culmination of a relatively limited field sample (29 stands), separated over two field seasons. The attributes chosen for measurement include those most commonly cited as important structural features associated with old-growth forest as well as standard descriptors of forest parameters (e.g. density of trees by size class). Attributes that are relatively quick to assess consistently were specifically chosen, while those that are generally inconsistent or time consuming to obtain (including measures of vertical or horizontal heterogeneity and the age of all trees) were not included. In past projects, we have sampled a single biogeoclimatic (BEC) variant and within each variant, we have stratified the data by site series or groups of site series (e.g. Holt and MacKillop 2002a,b). This project addresses five BEC variants with numerous site series in order to be relevant to the landscape level Natural Disturbance Units proposed by DeLong (2002). Due to the small sample size, site stratification by BEC was not possible.

STUDY AREA[1]

The study area includes forests in the Sub-Boreal Spruce and Sub-Boreal Pine and Spruce biogeoclimatic (BEC) zones in the Moist Interior Plateau Natural Disturbance Unit (DeLong 2002) of the Vanderhoof Forest District. NDU's are planning units that combine BEC variants based on expected patterns of natural disturbance and stand development. They were developed in the Prince George Forest Region to provide more refined landscape units than the Natural Disturbance Types (NDT) outlined in the Biodiversity Guidebook (Province of BC 1995). Describing old growth characteristics for a Natural Disturbance Unit that includes a variety of biogeoclimatic variants was deemed ecologically reasonable because of the relatively low ecological variation across variants and the hypothesised unifying feature of similar natural disturbance processes and successional dynamics (C. DeLong pers comm.).

The Moist Interior Plateau NDU occupies the gently rolling terrain of the Fraser Plateau and the Fraser Basin Ecoregions and corresponds to the Sub Boreal Spruce BEC zone (dk, dw2, dw3, mc2, mc3, mk1, mw, wk3a, dw1, mh, and wk1 variants) with small portions of the SBPS (mc and dc variants). It is found over a wide geographic range from 53° - 55° N latitude and 122° - 125° W longitude and from 600 – 1200m in elevation. The climate is continental, and is characterized by seasonal extremes of temperature, severe, snowy winters, relatively warm, moist, and short summers, and moderate annual precipitation (Meidinger and Pojar 1991). Mean annual temperature for most of the area ranges from 0.6 to 3.7°C; average temperatures are below 0°C for 4-5 months of the year, and above 10°C for 2-5 months. Mean annual precipitation data from long-term stations ranges from 481 – 727 mm, with up to half falling as snow.

Upland coniferous forests dominate the Moist Interior Plateau landscape. Hybrid white spruce (*Picea engelmannii* Parry ex Engelm x *glauca* (Moench) Voss) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt. are the dominant climax tree species, but lodgepole pine (*Pinus contorta* var *latifolia* Engelm) is the most prevalent species in the unit and is common in mature forests throughout the unit. Both lodgepole pine and trembling aspen (*Populous tremuloides* Michx.) are pioneers in seral stands. Paper birch (*Betula papyrifera* Marsh.) is another pioneer tree found most often on moist, rich sites. Douglas fir (*Pseudotstuga menziesii* (Mirb.) Franco), is usually a long-lived seral species occurring most abundantly on dry and warm sites in the southeastern part of the NDU and in the northern portion near Fraser lake. Black spruce (*Picea mariana* (P. Mill.) P.S.B) also occurs in climax upland forests in combination with lodgepole pine.

Historically, fire and mountain pine beetle are the key stand-replacing disturbance agents operating in the SBS. Under recent natural conditions, the natural disturbance rate[2] for the zone is estimated at 0.75 - 1.25 percent [3] of the total forested area per year (DeLong 1998), with an average site disturbance

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[1] Description adapted from DeLong 2002 with the author's permission.

[2] All disturbance rates are for stand replacing wildfire except where noted.

[3] All estimates quoted are for period of the period of 1911-30 as these were deemed to more accurately reflect the true natural disturbance rate.

frequency of between 80 and 125 years (Andison 1996, DeLong 1998, Wong et al. 2002). Prior to forest harvesting and fire suppression, stand ages over 200 years may have been rare, but relatively large patches (>100 ha) of older forest (140+ years) could be found scattered across the landscape and their position would have moved around over time (Andison 1996, DeLong and Tanner 1996). Table 1 shows estimated distributions of stand ages (time since disturbance) for the Moist Interior Plateau (DeLong 2002).

Table 1. Expected time since disturbance for the Moist Interior Plateau.

Stand Replacement Disturbance Cycle[a]	Time since disturbance distribution[b] (% of total forest area)				Disturbance type (% of disturbance area)[c]	
	>250 yrs	>140 yrs	>100 yrs	<40 yrs	Stand Replacement	Gap Replacement[d]
100	6 - 12	17 - 33	28 - 49	25 - 50	98	2

[a] Disturbance cycles are the inverse of disturbance rate (% of total forested area/yr) x 100. Disturbance rates were derived using methodology outlined in DeLong (1998) and generalized for the NDU.
[b] This is the range in percent of the total forested area within the NDU, that has not had a stand replacing event for the specified time period, estimated to be present at any one time. Estimates were determined as per DeLong (2002).
[c] Based on expert opinion.
[d] Disturbance openings caused by death of individual trees or small groups of trees. Gaps generally < 1ha in size and removing <40% of the basal area of a stand.

Large wildfires (> 1000 ha) historically dominated the landscape and were regenerated quickly by dense lodgepole pine and/or trembling aspen resulting in large patches of relatively even-aged forests. Studies in the 1930s to 1950s indicate that approximately 3-15 percent of burn areas were left as remnant patches during wildfires (DeLong and Tanner 1996). These forest remnants maintain structural attributes very similar to old forests (DeLong and Kessler 2000) and are distributed throughout all landscape positions including flat lodgepole pine stands (DeLong and Tanner 1996). Scattered remnant trees are uncommon outside of these patches where DeLong and Tanner (1996) found an average of 0.26 snags and 0.75 live trees per ha. More live remnant trees are likely to occur in areas with a higher component of Douglas-fir due to this species' increased ability to survive fire, but this has not been tested. Our ability to sample remnants was very low in this study.

METHODS

Field sampling

A total of 29 stands were sampled in October 2002 and October 2003. The first year of sampling focused on stands where mortality from mountain pine beetles was absent. In the second year, stands with a range of MPB mortality levels were targeted. In 2002, 80 stands were randomly selected from all lodgepole pine leading polygons in the Vanderhoof Forest District and a subset of 14 of these was selected for sampling. The goal was to sample mixed lodgepole pine and interior spruce stands evenly distributed between 80 years old and the oldest possible stand ages (i.e. 200+ years). In 2003, sites were selected using GPS coordinates obtained from a helicopter flight over infested areas of the Vanderhoof District, and were targeted at stands over 120 years old.

Stands were located in the SBSdk, SBSdw3, SBSmc2, SBSmc3 and SBPSmc BEC variants (DeLong et al. 1993). A total of 11 site series / variant combinations ranging from submesic, poor sites to slightly wetter than mesic and medium soil nutrient regimes were sampled. Three plots were sampled in each polygon. Plots were located at least 30 m from an edge and 100 m apart using randomly determined bearings. A nested plot design was used with an inner radius of 11.28m (0.04ha) and an outer radius of 17.84 m (0.1 ha). Trees and snags 7.5 cm dbh and greater were measured in the inner plot, while a diameter limit of 20 cm was set for the outer plot. Within each plot, the following attributes were measured on live and dead trees: species; dbh; pathogen indicators (forks, scars, conks, frost cracks, dead/broken tops, mistletoe, large rotten branches; as per Province of BC 1998); arboreal lichen abundance (as per Armleder et al. 1992); Wildlife Tree Class (as per Province of BC 1998); Wildlife Tree Type (as per Keisker 2000) and presence of mountain pine beetle attack.

Tree cores and heights were taken for a minimum of two live trees per species[4] from the largest size classes present. Live conifer saplings were tallied by species within the 11.28m radius plot. Although present on many sites, broadleaf saplings were not tallied. Coarse woody debris (CWD) was measured along two perpendicular transects intersecting at plot centre. In 2002, modified 15 m transects were used, but in 2003 the standard 24 m transects were employed (as per VRI; BC Ministry of Sustainable Resource Management 2003). For each piece, the following measurements were taken: species (where evident); diameter at point of intersection with the transect; estimated piece length; decay class (as per Province of BC 1998); and Wildlife Tree Type (as per Keisker 2000). CWD volume was calculated for each plot using the formula described in Van Wagner (1982) and Marshall and Bugnot (1991):

$$V = \frac{\pi^2 \Sigma d^2}{8L}$$

Where V is volume in m^3/ha, d is diameter (cm) of each piece of woody debris, and L is the length (m) of the transect. The number of CWD pieces per hectare (SPH) was estimated using the following formula:

$$SPH = \frac{10000\pi}{2L} * \sum\left(\frac{1}{l_{ij}}\right)$$

Where L is the transect length and l_{ij} is the estimated length of each piece.

Ecological data were collected for each plot, including BEC zone and site series (as per DeLong et al. 1993), slope, aspect, mesoslope position and surface topography. Soil moisture regime (SMR), soil nutrient regime (SNR), LFH thickness, Humus Form, soil horizons, rooting depth and coarse fragment content were assessed using shallow soil pits.

Data analysis

Beetle impact scenarios

Stratification by time since beetle attack would have provided the most useful information on old-growth stand structure over the short, medium and long term. However, this was not possible given the sample size, and instead data were analysed under three different beetle impact scenarios to assess pre-infestation stand structure, mid-attack structure and post-beetle attack.

The ***'Before Beetle'*** scenario was used to assess old-growth characteristics and stand dynamics as if there had been no MPB epidemic. During field sampling, the presence of beetles on live and dead trees was noted during field sampling through bark assessments and, where necessary, by examining the cambial region for MPB galleries. Beetle-killed trees were then 'resurrected' and considered alive in subsequent analyses. This was possible since all snags assessed as beetle-kill were either Wildlife Tree Decay Class 3 or 4 (as per Province of BC 1998) and their characteristics had changed very little since beetle attack.

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[4] The largest healthy trees (free of obvious defects or pathogens) were sampled where possible. Where trees with obvious damage were cored, heights were not taken and age data was not used to determine site index.

In the ***'Current Mortality'*** scenario stands were assessed based on their actual mortality status. However, at the time of sampling, stands were undergoing various stages of beetle infestation and the degree to which the MPB had already impacted a stand was largely linked to the stand's location and not to any inherent stand susceptibility characteristics. From maps showing the estimated beetle spread it is clear that some areas (particularly the southwest portion of the District) have had elevated beetle activity, while in other areas (such as northern portions of the District), the beetle is yet to spread. While current beetle impacts had little to do with the long term impacts of MPB on old-growth, they are shown in this report to provide data on beetle infestations 'in progress'.

The '***Predicted Mortality'*** scenario involved analyzing stand data as if the beetles had 'come and gone' from a stand. Because old-growth management inherently follows long time scales, the predicted impact of the MPB following the epidemic is essential for determining old growth conservation areas. Two variations of the *Predicted Mortality* scenario were used, based on two levels of beetle mortality. The first takes a conservative approach and assumes more moderate pine mortality that increases with tree size. The second variation assumes a high level of mortality at all size classes. In both scenarios, trees greater than 32.5 cm dbh are not expected to survive. We expect that in most cases mortality at a given site will fall between the two estimates. Estimated mortality levels by size class are shown in Table 1.

Predicted Mortality levels were determined by assessing stand data collected by Natural Resources Canada's Pacific Forestry Centre in the nearby Tweedsmuir Park (B. Hawkes[5], pers comm.) and by examining mortality levels in stands collected through this project where MPB activity was obvious, but live MPB activity was minimal (i.e. the beetles have primarily come and gone).

The *Predicted Mortality* scenarios were compared to data from the *Before Beetle* conditions and were used to develop recommendations for selecting old growth sites that maintain some of the pre-epidemic old-growth characteristics. The scenarios presented here reflect a crude means of modeling the effects of MPB on stand dynamics and should be interpreted with caution.

Table 2. Mortality rates for the Conservative and High Predicted Mortality scenarios.

*DBH size class**	*Predicted Mortality – Conservative Estimate*	*Predicted Mortality – High Estimate*
10	30%	50%
15	60%	75%
20	75%	90%
25	90%	95%
30	95%	100%
35	100%	100%
40	100%	100%
45	100%	100%
50+	100%	100%

* midpoint of 5 cm dbh classes. The 50+ class includes all trees 47.5 cm dbh and greater

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[5] Dr. Brad Hawkes, Fire Researcher, Pacific Forestry Centre, Victoria, BC.

Stand Age and Site Productivity

Tree ages were determined from tree core samples. Where all of the largest diameter pine trees were beetle-killed, cores were extracted from dead trees. An effort was made to core trees as close to the pith as possible. Where the pith was not included in the sample, concentric ring overlays were used to estimate the number of missing years. Site productivity was measured using site index (SI), which is defined as the ‘average height that free growing, undamaged top height trees of a given species can achieve in 50 years growth above breast height’ (BC Ministry of Forests 1999). The SI and estimated years to breast height (YTBH) for lodgepole pine and spruce in each plot and each stand were calculated with height and age data in the Site Tools (version 3.2) computer program (BC Ministry of Forests 2001). YTBH for spruce was generally over-estimated because many of the spruce sampled were from lower canopy strata and had experienced suppression. To compensate for this discrepancy, an average of 10 years was used for growth to breast height for spruce trees. Calculations were not available for site index or YTBH for subalpine fir, so the 10 year YTBH average was also applied.

Mean, maximum and veteran ages (were applicable) were calculated for each site. Maximum ages reflect the time since the most recent stand-replacing disturbance, while mean ages were calculated to provide cross-referencing with inventory age data and for use in management applications. Veteran trees are those that survived the most recent stand-replacing disturbance and are defined as being at least 40 years older than the remainder of the trees and comprising less than 6% of the stand’s crown closure (BC Ministry of Sustainable Resource Management 2003).

Veteran trees were present in one plot from each of four stands (Table 3). Veteran ages were not included in the mean ages that were compared to age-classes from the Forest Cover inventory since they represent a Forest Cover layer other than the main canopy (BC Ministry of Sustainable Resource Management 2003).

References to age-classes in this study reflect measured values and not mapped estimates unless otherwise stated.

Site Stratification

Data were stratified by site productivity to account for differences in forest attributes. A calculated site index threshold of 17 was used to separate sites into Higher and Lower productivity groups (G. Nigh[6], pers comm.). Stratification was deemed necessary after preliminary PCA and stand structural assessments showed significant increases in large-sized structures with increasing site index. No patterns were found between site productivity and BEC variant, however, several BEC zones, variants and site series combinations were included in this study and, as such, sample sizes were too low to detect differences.

Stand structure: site characteristics

Stand-level attribute development patterns were summarized by age-class and site productivity grouping to assess changes over time. Variables assessed include species composition by density (sph) and basal area; density and basal area of live and dead trees by size class, density of trees with pathogen indicators (scars, conks, forks, dead tops, etc.); densities of Wildlife Tree Types (Keisker 2000), sapling densities by species, CWD volume and density by size class and decay class. The total stems per hectare and the total basal area were also calculated for each stand.

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[6] G. Nigh, Leader, Strategic Analysis, BC Ministry of Forests, Victoria, BC.

Stand structure: changes with the MPB

For each age-class, diameter distributions by species, stem size class and mortality status were graphed for the *Before Beetle*, *Current Mortality*, and *Predicted Mortality* scenarios. Stands in age-classes 5 and 6 (80-120 years old) were grouped together. These graphs highlight the changes in live tree species composition and stem size class distribution expected due to the beetle infestation. This is important for old growth management in that it shows the presence (or absence) of larger trees, which are usually associated with older forests, as well as the smaller stems that would be recruited into the canopy following a beetle infestation. Two sets of graphs are provided: one for Higher productivity sites, and another for Lower productivity sites.

An Old Growth Index:

Old Growth Indices were developed for both Higher and Lower productivity sites using Principal Components Analysis (PCA). PCA analysis was based on data from the *Before Beetle* scenario in order to develop an Old Growth Index reflective of undisturbed old forests in the Moist Interior Plateau NDU. Data from the *Predicted Mortality* scenario were then compared to the PCA data to assess the applicability of thresholds to beetle infested stands.

PCA uses a correlation matrix of variables to find indices (principal components) that capture variation in different dimensions of the data. Each PCA axis is orthogonal (uncorrelated) with the others. PCA1 describes the maximum variation within the data and therefore explains the major patterns expressed in the data. PCA2 is orthogonal to PCA1 and captures the next largest amount of variation in the data, and so on (Tabachnik and Fidell 1996). PCA provides insight into stand development trends, although the results are hypotheses that require testing. Plot rather than stand data were used in the analysis, since pseudo-replication is less of an issue with exploratory data analysis (V. Lemay[7] and G. Bradfield[8] pers. comm. 1999).

Although PCA does not actually look for clusters in the data, PCA was used to explore whether any natural groupings occurred among the plots sampled and to examine whether suites of attributes could be found that describe similarities between plots that are related to ‘old growth’. Relationships between input variables for each plot are assessed using a correlation matrix and are shown in a component matrix table (Table 6 and Table 7). Scores on the component matrix of greater than 0.71 reflect an excellent correlation between a variable and a PCA axis. Scores of 0.63, 0.55, and 0.45 are considered ‘very good’, ‘good’ and ‘fair’, respectively. Scores of 0.32 are ‘poor’ and are at the lower limits of interpretability (Tabachnik and Fidell 1996).

The analysis was first conducted using variables related to attribute size, decay class, and wildlife habitat values. Variables that had low correlations with all other variables in the dataset were then excluded. Different models, containing different attribute sets were run using Systat 8.0 (SPSS Inc.1998). The final model chosen was (i) that which explained most variation in the data, (ii) where the attributes associated with the main axes (PCA1 and PCA2) could be linked to expected patterns of old growth development (based on theory and literature review of important old-growth attributes), and iii) where the largest number of variables were included. The first principal component axis (PCA1) was graphed against the age of plots to assess how stand age relates to PCA ordination.

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[7] V. Lemay, Professor of Biometrics, Faculty of Forestry, University of British Columbia

[8] G. Bradfield, Professor of Botany, Department of Botany, University of British Columbia

RESULTS

A total of 29 sites and 84 plots were sampled in the Vanderhoof Forest District. Ten of the 29 sites sampled were in the SBSdk, five were in the SBSdw3, eight were in the SBSmc3, and three were in each of the SBSmc2 and SBPSmc. Study sites ranged from flat to 35 percent slope with an average of 9%, and in aspect from north (2 degrees) to south (180 degrees; Appendix 1).

The following results are separated on the basis of the three beetle impact scenarios: *Before Beetle*, *Current Mortality*, and *Predicted Mortality*.

The Before Beetle Scenario

Stand age

When beetle mortality was excluded, the mean stand age of the sampled sites ranged from 80 years at Kluskus[9] to 223 years at Entiako, a very low productivity (SI = 8.6) SBPS site in the Van Tine drainage. The oldest tree sampled was a 310 year old spruce at the Johnny site that showed signs of considerable suppression in the earliest 150 years of the tree ring record. Since all other trees sampled at Johnny were less than 160 years old, it is likely that this old tree was a small tree that survived a stand-replacing event 160 years ago. Veteran trees were also present at Cork in plot 2 where they were 90 years older than the remaining stand, and at the Noon site where they were 40 years older. At Kluskus, plot 3 was located within a small island remnant (DeLong and Kessler 2000) dominated by a small number of larger, older trees. The remaining two plots were half the age of the remnant plot and contained numerous small diameter, young trees (Table 3).

Stand top heights (dominant and codominant strata) ranged from 19.2 m at the Noon site, to 36.9 m at Blue. Site index (SI50) measures for lodgepole pine ranged from 9 at Entiako to a maximum of 20 at Johnny. These values reflect overall low productivity in the study area, considering a site index of 22 is considered 'good' productivity (BC Ministry of Forests 1999). A significant correlation (R = 0.464; p = <0.001) was observed between measured SI and the estimated SI from Forest Cover maps, although there was considerable variation between estimated and measured values (Figure 1).

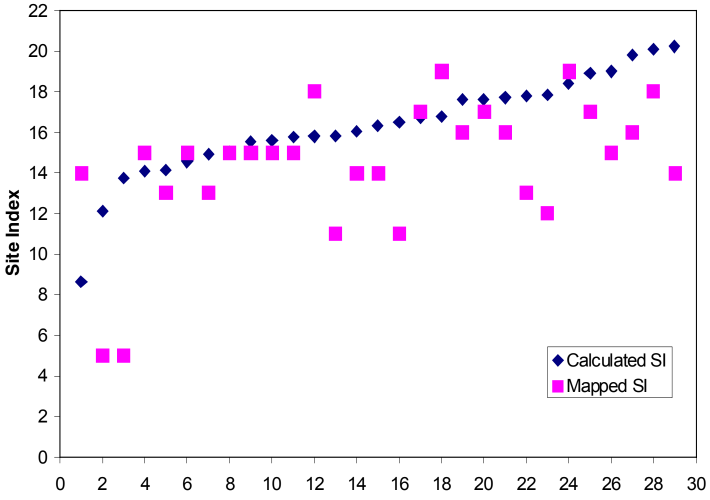

Figure 1. Mapped and calculated site index values for sites sampled.

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[9] Note: All sites are referred to by a name to make it easier to cross-reference information in the text and to improve overall readability.

Mapped forest cover age-classes[10] differed from mean ages calculated using tree ring data on 16 of 29 sites (55%) with forest cover data overestimating stand age on 10 sites (34%) and underestimating on six (21%). However, estimates were within 10 years of the correct age class on five of the sites where forest cover data overestimated ages, and within 10 years on one of the sites were age was underestimated[11]. The greatest error was for sites that contained a small number of veteran trees where stand age was substantially overestimated. This information is shown to provide a preliminary analysis of the reliability of locating old-growth reserves solely on forest cover age data. New Vegetation Resource Inventory (VRI) data were released after the first season of field sampling. VRI data are an improved retrofit of forest cover data and are likely more accurate than the older data used here (J. Lecuyer pers comm.).

Table 3. Stand age and site index.

Site Name	*Mean Age**	*Maximum Age*	*Veteran Age***	*Top Height*	*Site Index*	*Productivity Group*	*Mapped Forest Cover Age-class*
Kluskus	80	81	177	24.1	13.7	Low	9
Noon	88	102	144	19.2	12.1	Low	9
Cork	90	99	188	29.5	17.7	High	8
Sob Lk	93	99	…	23.1	15.8	Low	5
Knews	111	119	…	28.0	17.8	High	7
Cheslatta	115	143	…	28.3	18.9	High	7
Holy	122	146	…	33.1	16.3	Low	8
Marilla	124	137	…	25.9	16.0	Low	7
Naught	126	134	…	31.9	17.6	High	7
Johnny	129	165	310	32.7	20.2	High	8
Hunt	130	138	…	31.8	19.0	High	8
Pink	133	147	…	31.6	16.8	Low	8
Cold	136	155	…	28.2	15.8	Low	6
Cross	137	151	…	31.2	17.9	High	7
Done	137	156	…	29.6	15.5	Low	7
Goshawk	137	151	…	33.1	17.6	High	8
For	140	148	…	35.2	17.0	High	8
Cicuta	145	149	…	27.9	16.5	Low	7
Bobtail	148	150	…	24.2	15.0	Low	6
Tatuk	156	173	…	31.1	15.6	Low	8
Blue	158	179	…	36.9	20.1	High	7
Van Tine	160	178	…	27.8	14.1	Low	7
Gold	161	164	…	24.8	14.1	Low	8
Lucas	164	242	…	27.3	15.8	Low	8
Red	165	178	…	26.7	14.6	Low	8
Binta	178	187	…	35.0	19.8	High	8
Chutanli	181	188	…	24.6	14.9	Low	8
Frank	189	197	…	32.9	18.4	High	7
Entiako	223	232	…	24.8	8.6	Low	8

* Mean age of the leading species.

** Plot 3 at Kluskus was an island remnant and is much older than the other two sample plots. Plots 2 at both Noon and Cork had lodgepole pine trees with signs of surviving a stand replacing fire and Plot 2 at Johnny had a small, but old spruce.

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[10] Forest cover age-classes are as follows: 1 = 0-20; 2 = 21-40; 3 = 41-60; 4=61-80; 5=81-100; 6=101-120; 7=121-140; 8=141-250; 9=251+.

[11] 10 years may be an acceptable level of error due to missed rings, estimated age to breast height, and time between sampling and updating forest cover data.

The sites named Kluskus and Noon were mapped as age-class 9 (>250 years old), but tree core evidence suggested that they were age-class 5 (80-100 years old) with veteran trees. Both sites have low calculated site indices (12 and 13). One of the plots at Kluskus (plot 3) was a remnant patch that had escaped the most recent stand-replacing fire[12]. No other remnant patches were observed while walking through the stand. Veteran trees were also observed at the Noon, Cork and Johnny sites, although their densities were low (under 25 stems per hectare). In other stands, there was generally very little difference observed between the mean and maximum ages in a stand. This suggests that most stands are comprised of an even-aged overstory.

Table 4. Accuracy of Forest Cover inventory data Age-classes.

	Number of Stands	*Percentage of Stands*
Forest Cover is accurate	13	45%
Forest Cover is accurate to within 10 years	19	66%
Forest Cover over-estimates	10	34%
Forest Cover under-estimates	6	21%
TOTAL mis-labeled	16	44-55%*

*The range reflects potentially acceptable errors of within 10 years of the estimated age-class

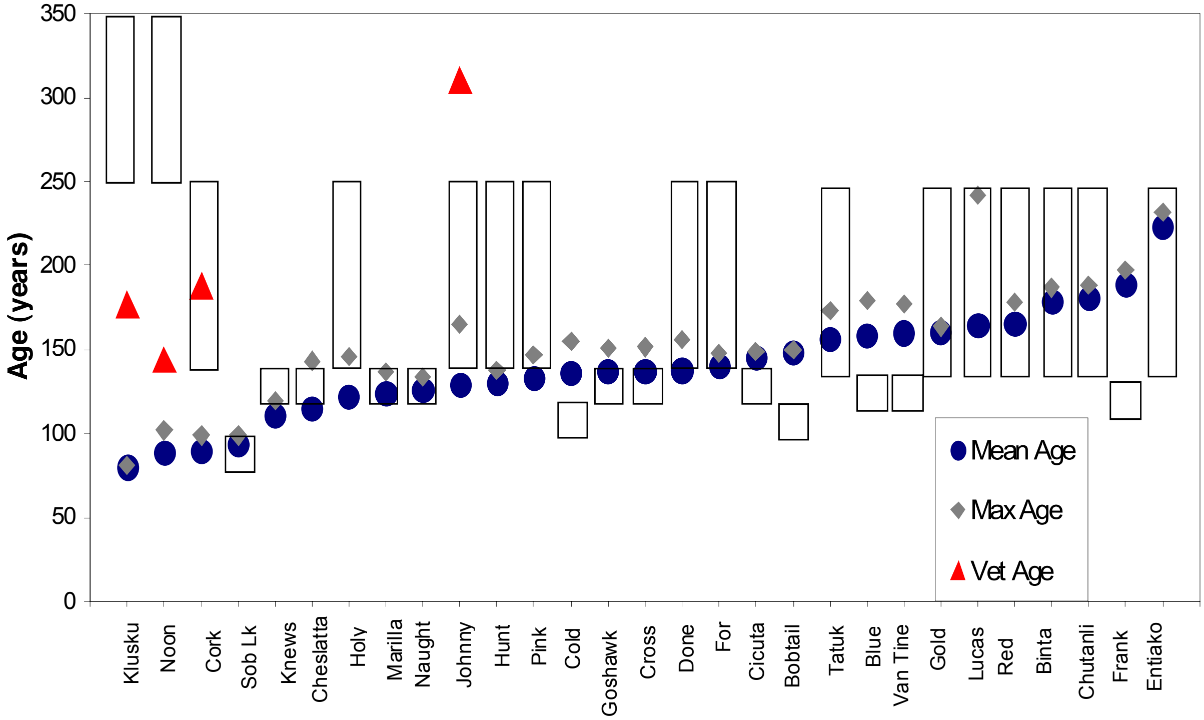

Figure 2. Mean, maximum and veteran ages as measured from tree cores. Rectangular boxes represent forest cover age-classes.

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[12] Based on basal scars and age data.

Stand characteristics

The range of stand characteristics on a site-by-site basis is presented in Appendix 2 and Appendix 3. Summaries are provided for sapling densities, live and dead tree diameters, CWD, tree pathogens, and functional Wildlife Tree Types (Keisker 2000). Wide variation was observed across all sites and all variables.

Few of the attributes measured were significantly correlated with stand age, although trends with age were observed when stands were stratified by site index, particularly for Higher productivity sites. Figure 3 shows that the densities of trees 32.5-42.5 cm dbh increases by age-class and productivity group. Other examples of trends with age such as the basal area of large trees and snags, as well as total CWD volume, and mean tree and snag diameters are shown in Appendix 4. For Low sites, many attributes followed a U-shaped or inverted U-shaped development pattern with age (see Appendix 4). This is largely an artifact of small sample sizes since the site index for Lower productivity stands was highest for age-class 7 stands (121-140 years old). The patterns presented in Appendix 4 are important for understanding stand dynamics in this system, particularly since they highlight the importance of stand productivity on increasing densities of large-diameter trees, snags and CWD.

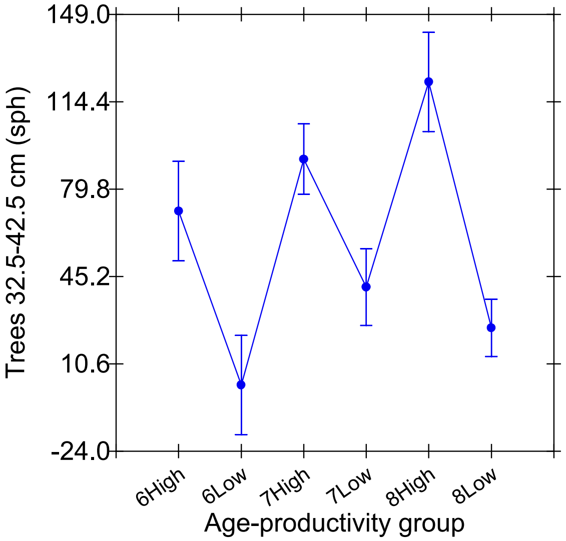

Figure 3. Relationship between the density of trees 32.5-42.5 cm dbh and age/productivity groups.

PCA: An Old Growth Index using Before Beetle data

In this study, we used PCA on the *Before Beetle* scenario data to separate plots into groups with high and low structural value. Plot data were originally analysed with both Higher and Lower productivity sites combined. However, two sources of variation were clearly evident. The first, which was reflected in PCA1, was highly correlated with site index ($R = 0.731$; $p < 0.001$) and accounted for 42.5% of the variation in the data. The second, reflected in PCA2, was moderately correlated with stand age ($R = 0.464$; $p < 0.001$) and accounted for 12% of the variation in the data. The strong link between PCA1 and site index was a key factor in site stratification by productivity.

When data were stratified by site productivity (using a site index threshold of 17), the same patterns resulted: PCA1 was significantly correlated with productivity for both the Higher and Lower productivity groups and PCA2 was significantly correlated with stand age (Table 5; Appendix 6). In both the Higher and Lower productivity analyses, PCA1 also reflected an axis of large structural attributes. However, PCA2 was most related to different attributes for Higher and Lower productivity groups, with PCA2 on

Higher productivity sites correlated with the density of larger diameter snags (17.5+ cm dbh) and on Lower sites correlated with the density of snags 17.5-27.5 cm dbh, but not smaller or larger snags.

Table 5. Correlations between PCA, site index and stand age

	All Sites		*Higher Productivity*		*Lower Productivity*	
	R	p	R	p	R	p
PCA1 vs. Site Index	0.731	<0.001	0.438	0.008	0.544	<0.001
PCA2 vs. Stand Age	0.464	<0.001	0.415	0.012	0.436	0.002

It was evident that PCA1 reflected densities and diameters of large trees on both Higher and Lower productivity sites, but PCA1 scores were compared to site index values and stand ages to determine the driving forces behind differences in PCA1 scores. A regression of stand age, site productivity, aspect and percent pine on PCA1 showed that only stand age and site productivity were significant for both productivity groups (model not shown). Correlations between age, productivity and PCA resulted in moderate but significant relationships between PCA1 and site index and between PCA2 and stand age. Stronger correlations were found for Lower productivity sites and for the combined dataset (Table 5; Appendix 6). The link between site index and PCA1 suggests that site productivity forms the major source of variation in the data, even with stratification on the basis of site index, and that stand age is a secondary factor in determining stand structure in the Moist Interior Plateau NDU.

We recognize that PCA1 is primarily a reflection of site productivity and that it is not surprising that large structures increase with productivity. However, when we have done similar analyses for old growth assessment projects in the ICHmw2, ICHdw, MSdk, ICHwk1, ESSFdk, and Boreal Foothills Natural Disturbance Unit (Holt et al. 1999, Holt et al. 2001, Holt and MacKillop 2002a, Holt and MacKillop 2002b, MacKillop and Holt 2003) we have found site productivity to be an important determinant of stand structure, but age has played a more significant causal role in the distribution of large structural attributes. While age is an important determinant of old growth, from a functional perspective, it is the large structures (large trees, snags and CWD) that provide the unique and important habitats required for old-growth biodiversity conservation. Therefore, because site productivity primarily responsible for determining large structures in the Moist Interior Plateau, we feel that PCA1 is a biologically justifiable surrogate for determining old-growth characteristics on both Higher and Lowerer productivity sites.

PCA: Higher productivity sites

Using *Before Beetle* data for Higher productivity sites, PCA1 explained 32% of the variation in the data and was primarily associated with mean tree diameters and the density of live trees 32.5-42.5 cm dbh. The density of live trees greater than 42.5 cm dbh, the mean tree diameter and the density of trees under 22.5 cm dbh were also well correlated with PCA1, although the density of trees under 22.5 cm dbh showed a negative correlation with PCA1 (Table 6). Thus, PCA1 was interpreted to reflect an axis of large sized trees. PCA2 explained only 17.6% of the variation in the data and reflected the density of snags 17.5-27.5 cm dbh and greater than 27.5 cm dbh. The volume of CWD pieces greater than 30 cm in diameter was uncorrelated with both PCA1 and PCA2, but showed a correlation of –0.850 with PCA3 which suggests a third source of variation in the data. However, PCA3 only explained 15% of the data and is not addressed in this study.

PCA: Lower productivity sites

Using *Before Beetle* data on Lower productivity sites, PCA1 accounted for 34.9% of the variation in the data and was primarily associated with mean tree and snag diameters, the density of trees under 22.5 cm dbh and the density of trees 32.5-42.5 cm dbh. As with Higher productivity sites, the density of trees under 22.5 cm dbh was negatively correlated with PCA1. PCA2 explained 16.5% of the variation in the data and was related to the density of snags 17.5-27.5 cm dbh, and less so to the density of trees in the

22.5-32.5 cm dbh and 42.5+ cm dbh size classes, and CWD under 20 cm diameter. The relationship between stand-level attributes and PCA axes is shown in Table 7. Subsequent PCA axes (PCA3, PCA4, etc) reflected a smaller portion of the variation in the data and are not shown here.

Table 6. PCA component matrix showing the association between attributes and PCA axes for Higher productivity sites

	PCA1	*PCA2*
Density Snags <17.5 cm dbh	-0.565	0.474
Density Snags 17.5-27.5 cm dbh	0.82	0.767
Density Snags 27.5+ cm dbh	0.306	0.804
Density Live Trees <22.5 cm dbh	-0.763	0.219
Density Live Trees 22.5-32.5 cm dbh	-0.300	0.158
Density Live Trees 32.5-42.5 cm dbh	0.838	-0.078
Density Live Trees 42.5+ cm dbh	0.763	-0.030
Mean Tree dbh	0.895	-0.118
Mean Snag dbh	0.648	0.401
CWD Volume <20 cm	-0.423	0.475
CWD Volume 20-30 cm	0.255	0.404
CWD Volume 30+ cm	0.026	0.126

Table 7. PCA component matrix showing the association between attributes and PCA axes on Lower productivity sites

	PCA1	*PCA2*
Density Snags <17.5 cm dbh	-0.646	0.323
Density Snags 17.5-27.5 cm dbh	0.186	0.796
Density Snags 27.5+ cm dbh	0.447	0.383
Density Live Trees <22.5 cm dbh	-0.860	0.015
Density Live Trees 22.5-32.5 cm dbh	0.378	0.580
Density Live Trees 32.5-42.5 cm dbh	0.747	-0.285
Density Live Trees 42.5+ cm dbh	0.538	-0.520
Mean Tree dbh	0.915	-0.046
Mean Snag dbh	0.882	0.092
CWD Volume <20 cm	-0.017	0.521
CWD Volume 20-30 cm	0.422	0.353
CWD Volume 30+ cm	0.085	-0.042

PCA: Thresholds for an Old Growth Index

Interpretation is key to the success of PCA, and the attributes correlated with PCA1 are commonly associated with old-growth forests (based on the literature). The separation of stands into Higher and Lower productivity groups allowed for the development of two separate thresholds using PCA to develop an Old Growth Index. We have used PCA1 = 0 as an initial split between sites that are have 'Low Old Growth structural value' and sites that have potentially 'High Old Growth structural value' because splitting the data at PCA1 = 0 has a statistical basis in that plots with a positive score are positively correlated with PCA1 and its associated variables. Stand age is significantly correlated with PCA2, so we have used this axis to develop age-based thresholds. This interpretation combines expected patterns of attribute abundance with a recognition that older sites may have inherent value for old-growth conservation. With that said, not all old sites are classed as 'High' quality old growth on the basis of their stand structural characteristics.

Thresholds for the Old Growth Index were calculated using the midpoint between the mean of each group plus or minus its standard error of the mean. Attributes were not included in the index of old-growthness when a) there was an overlap between group means, plus or minus one standard error, b) there was no biologically meaningful pattern for the variable, or c) the attribute followed an inverted-u or u-shaped development curve. PCA2 was used to determine age thresholds for the Old Growth Index because it was this axis that was significantly correlated with stand age. Thresholds are shown in Table 8. An Old Growth Index is presented with the *Predicted Mortality* scenarios, where the effects of the current MPB outbreak are factored into a subset of the thresholds in Table 8. Many of the thresholds in Table 8 are complimentary; for example thresholds are provided for basal area and density where possible to provide flexibility for managers. Summary statistics for PCA groupings (High and Low Old Growth structure) are provided for both Higher and Lower productivity groups in Appendix 5.

Table 8. Old Growth thresholds for Higher and Lower productivity sites

	Threshold for HIGHER productivity sites	*Threshold for LOWER productivity sites*
Density of Trees <22.5 cm dbh	< 468	< 1034
Density of Trees 22.5-32.5 cm dbh*	< 227	> 222
Density of Trees 32.5-42.5 cm dbh	> 88	> 26
Density of Trees 42.5+ cm dbh	> 16	> 3
Total Tree Density	< 811	< 1297
BA of Trees <22.5 cm dbh	< 8.4	< 18.7
BA of Trees 22.5-32.50 cm dbh	< 13.1	> 11.3
BA of Trees 32.5-42.5 cm dbh	> 9.2	> 2.6
BA of Trees 42.5+ cm dbh	> 2.7	> 0.5
Density of Saplings	> 31.8	no threshold
Maximum Tree DBH	> 45.6	> 34.3
Mean Tree DBH	> 24.9	> 20.5
Mean Snag DBH	> 21.2	> 15.6
Density of Snags <17.5 cm dbh	< 90	< 275
Density of Snags 17.5-27.5 cm dbh	no threshold	no threshold
Density of Snags 27.5+ cm dbh	> 23	> 5
Total Snag Density	< 177	< 338
Total Snag BA	> 5.6	< 5.0
BA Snags <17.5 cm dbh	< 1.1	< 3.1
BA Snags 17.5-27.5 cm dbh	no threshold	no threshold
BA Snags 27.5+ cm dbh	no threshold	> 0.4
Density of Snags WTC 3-4	< 155	< 322
Density of Snags >20 cm dbh WTC 5-8	no threshold	> 2
CWD Volume <20 cm	< 10.4	no threshold
CWD Volume 20-30 cm	no threshold	> 6.7
Total CWD Volume	no threshold	> 22.1
Total CWD Density	< 537	< 875
CWD Density <20 cm	< 449	< 824
CWD Density 20-30 cm	> 72	> 49
CWD Density 30+ cm	no threshold	no threshold
CWD Volume >20 cm DC 1-2	> 13.5	> 7.3
Maximum Stand Age**	> 152	> 151
Mean Stand Age**	> 144	> 144

* for Higher productivity sites, the threshold is <; for Lower productivity sites the threshold is >
** based on PCA2

The Current Mortality Scenario

The previous discussion centred on estimated stand structure prior to the current MPB outbreak. When actual mortality levels from field sampled data were assessed, 20 of the 29 sites sampled contained beetle infested trees (Table 9), with impacts from the infestations ranging from moderate ‘green attack’ to virtually 100% pine mortality within individual plots. The levels of current MPB impacts are expected to change at all sites as the beetle infestation continues; sites with a currently Low impact may have virtually all lodgepole pine trees killed by beetles over the duration of the current outbreak. Susceptibility is generally considered to be a factor of tree size, stand density, and stand age (Mata et al. 2003), but in the stands sampled here, high mortality was observed in all stand types, with trees as small as 10 cm dbh attacked by the beetles. In general, where stands were heavily impacted by beetles, pine trees over 22.5 rarely survived (Figure 4).

Table 9. Current beetle impacts – live attack and beetle kill.

Site Name	*Total Pl alive Before Beetle*	*% Pl current attack - Live*	*% Pl Dead - MPB*	*Total % MPB*	*Current MPB Impact*
Kluskus	1527	0	0	0	Low
Noon	1643	0	0	0	Low
Cork	120	0	0	0	Low
Sob Lk	2083	0	0	0	Low
Knews	615	0.5	95.4	95.9	High
Cheslatta	512	0.7	48.5	49.2	Moderate
Holy	288	18.3	8.7	27.0	Low
Marilla	510	11.4	49.0	60.5	Moderate
Naught	418	0	0	0	Low
Johnny	162	0	78.4	78.4	High
Hunt	410	16.3	0.8	17.1	Low
Pink	785	15.5	29.3	44.8	Moderate
Cold	800	0	0	0	Low
Goshawk	408	43.3	9.0	52.2	Moderate
Cross	153	10.9	0	10.9	Low
Done	110	54.5	3.0	57.6	Moderate
For	778	3.0	0	3.0	Low
Cicuta	958	4.3	74.8	79.1	High
Bobtail	1005	0	0	0	Low
Tatuk	250	26.0	36.0	62.0	Moderate
Blue	285	59.6	0	59.6	Moderate
Van Tine	750	0.9	42.7	43.6	Moderate
Gold	1197	0	0	0	Low
Lucas	227	1.5	85.3	86.8	High
Red	817	0	0	0	Low
Binta	327	6.1	7.1	13.3	Low
Chutanli	1115	57.4	14.8	72.2	High
Frank	683	2.9	0	2.9	Low
Entiako	813	1.0	75.0	76.0	High

Under endemic conditions, lodgepole pine mortality is estimated to average less than 2% per year; under outbreak conditions, mortality levels are estimated at 80% or more over 5-7 years in even-aged, homogeneous lodgepole pine stands (Samman and Logan 2000). Mortality by species and size class at four stands from this study is shown in Figure 4. The rates of mortality are extremely high and survival was very rare among pine trees over 22.5 cm dbh (in the 25 and greater classes). Given such high mortality rates, the Conservative and High *Predicted Mortality* scenarios used here and in data from the Pacific Forestry Centre (Hawkes[13], unpublished) were justified (B. Riel[14], pers comm.).

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[13] Dr. Brad Hawkes, Fire Researcher, Pacific Forestry Centre, Victoria, BC.

[14] Bill Riel, Mountain Pine Beetle modeler, Pacific Forestry Centre, Victoria, BC.

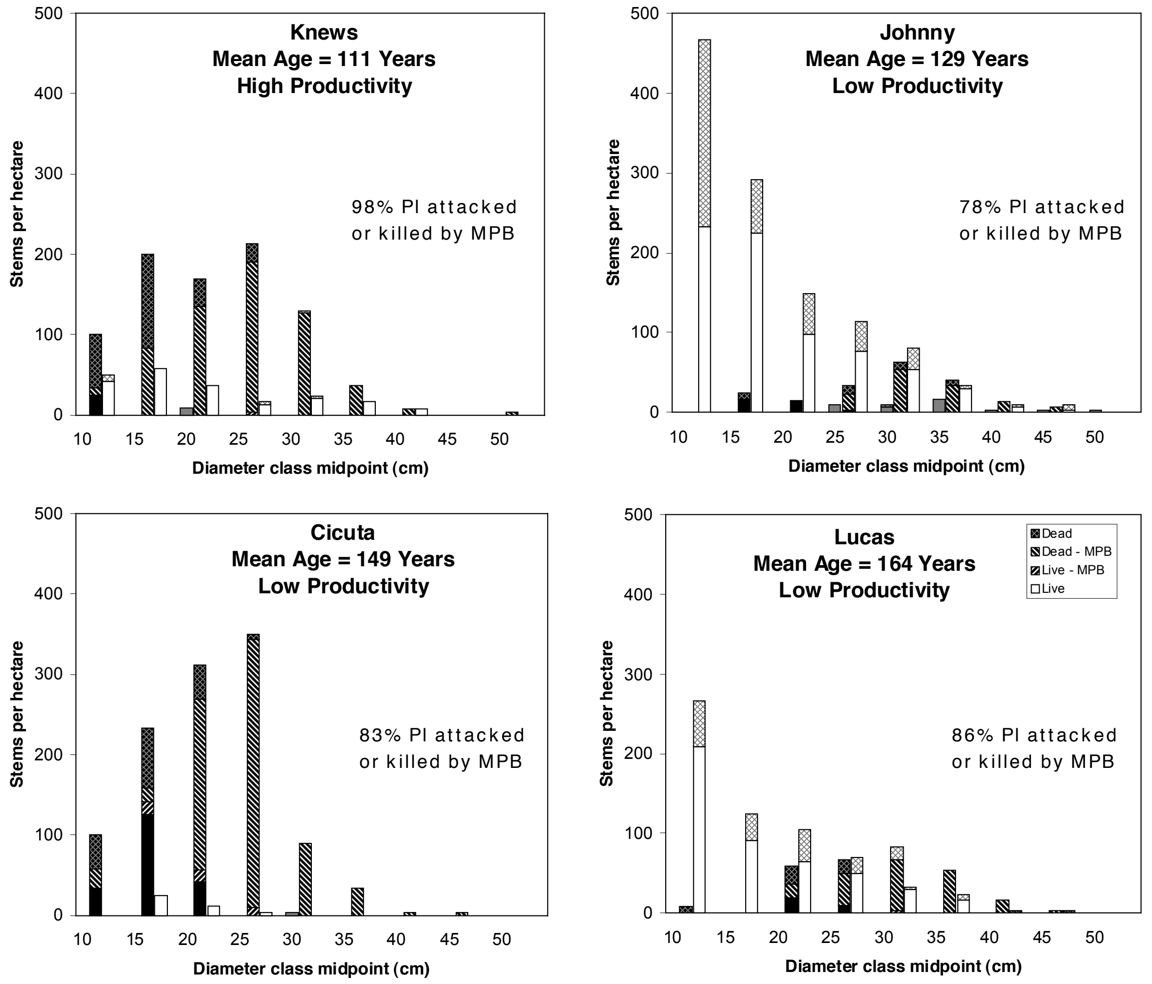


Figure 4. Actual live and dead stem distributions by species and size class for four stands sampled in the current study where the beetles have already flown to new sites. Live and dead lodgepole pine trees are shown in black, spruce trees in white, deciduous in light grey, and subalpine-fir in dark grey.

The Predicted Mortality Scenario

Stand structure: comparing pre and post beetle stand dynamics

The current MPB outbreak is causing major changes to stand structure across the Moist Interior Plateau NDU. With extreme beetle pressures, mortality rates among lodgepole pine are often over 90%, with larger trees (over 25 cm dbh) having virtually non-existent survival probabilities (Figure 4). Stand structure prior to the beetle infestation, in current conditions, and under two predicted scenarios is compared for Higher and Lower productivity sites using diameter distributions in Figure 5 and Figure 6.

According to Smith et al. (1997) even-aged stands, where the majority of a stand has established following a major stand-replacing disturbance, have diameter distributions that approximate the normal, bell-shaped curve. Old-growth stands are expected to be uneven-aged with an approximate reverse-J diameter distribution (Kneeshaw and Burton 1998) that reflects establishment through autogenic processes such as gap-phase replacement. Uneven-aged stands can be classified as ‘balanced, where steady establishment of understory trees replaces death of overstory trees, or more commonly, ‘irregular’ where small, even-aged sub-cohorts develop in response to episodic small-scale disturbances. Balanced uneven-aged stands have a reverse-J shaped curve while irregular uneven-aged stands display various ‘humps’ along the diameter curve (Smith et al. 1997). These patterns are stronger in pure species stands or mixes where all species have similar height and diameter growth.

In the *Before Beetle* scenario, even-aged lodgepole pine cohorts (approximately normal distributions, shown in solid black bars) are evident in all age-classes. The development of uneven-aged spruce and subalpine-fir cohorts is evident as stands age, with an increasingly reverse-J pattern for older stands. This pattern is more pronounced for Higher productivity sites where stand development appears to be progressing at a more rapid rate than Lower productivity sites. Younger Lower productivity stands show particularly slow development patterns with a ‘truncated’ bell-curve for the even-aged pine component, which generally indicates that stands are still experiencing stem-exclusion processes. If stand growth were to continue, a normal diameter distribution would develop.

Other differences between age-classes and productivity groups were evident in the *Before Beetle* data. On Higher productivity sites, we found a considerable increase in stems in the 25 – 35 cm dbh midpoint classes as stand ages increased. Stems in the 45 cm dbh class and larger were rare in all age-classes, but especially so in stands under 120 years old and virtually no snags over 27.5 cm dbh were measured in the younger stands. A distinct increase in the presence of subalpine fir was also evident in age-class 8 stands. On Lower productivity sites there was an increase in total stems per hectare from age-class 7 to age-class 8, particularly among stems in the 15 – 25 cm dbh midpoint classes. On younger Lower productivity sites, live and dead trees over 27.5 cm were rare. Densities of snags under 22.5 cm dbh were greatest on the older sites, and lowest on younger stands.

Mortality and species composition change dramatically in the *Predicted Mortality* scenarios. Even in the conservative estimate, where mortality rates may be under-estimated, live trees over 30 cm dbh are limited to species other than pine. With the virtual removal of the pine component from post-beetle stands, spruce and subalpine-fir are predicted to take on considerable importance in stands following MPB infestations (presuming no fire). Stands with numerous large diameter spruce and subalpine-fir are expected to be particularly important in maintaining large live structure across the landscape. Higher productivity sites develop large diameter trees more rapidly, so will likely provide immediate old-growth structure as well as ‘recruitment’ old growth faster.

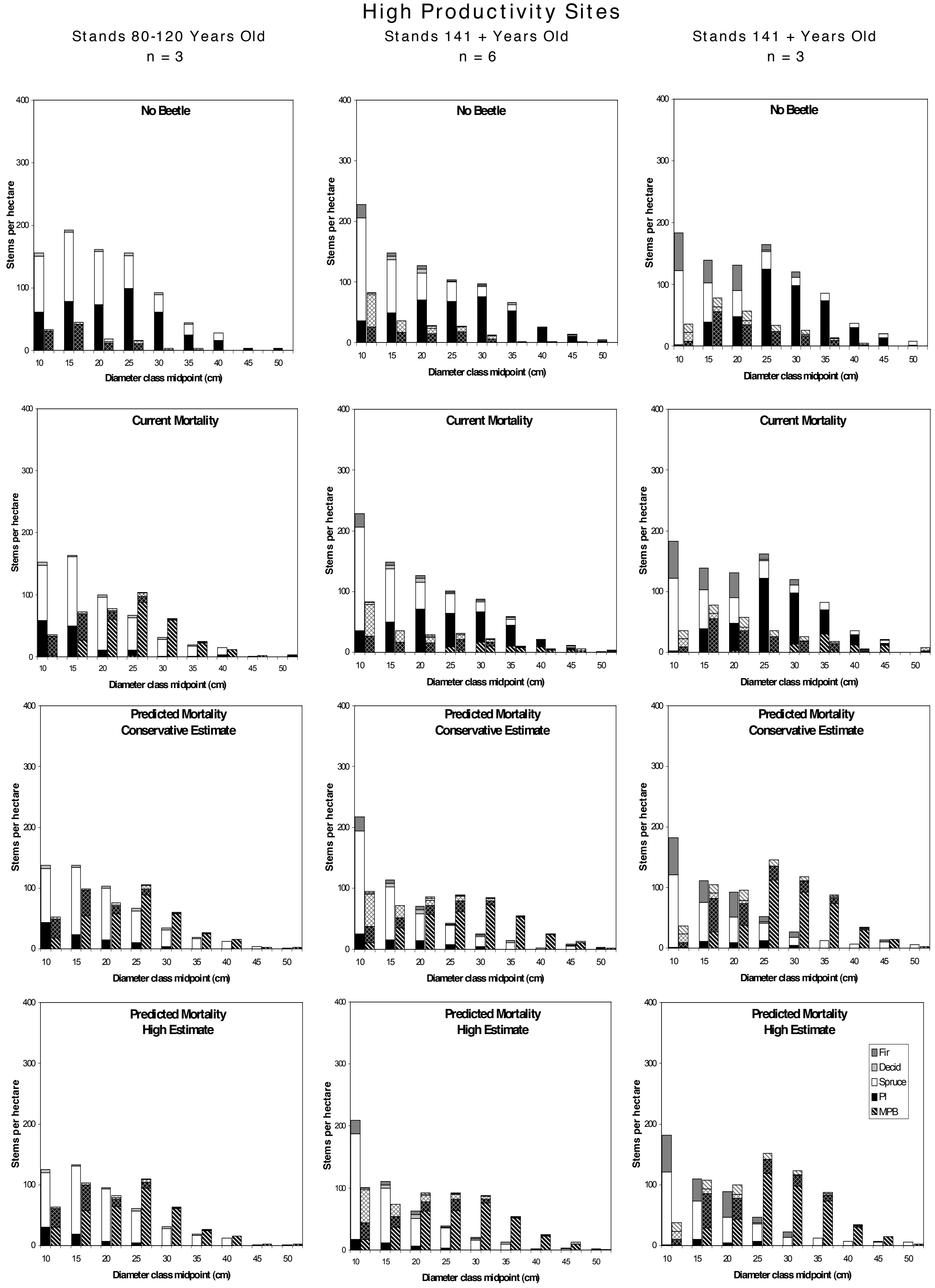
Changes in live tree composition are greatest in the mid size classes. Table 10 and Table 11 show densities of live trees (all species) by size class prior to the beetle outbreak and under the conservative *Predicted Mortality* estimate. On Higher productivity sites, densities of trees greater than 32.5 cm dbh decline dramatically following the MPB infestation. On Lower productivity sites, trees over 32.5 cm dbh were relatively low on average in the *Before Beetles* scenario, but become more so after the beetles.

Table 10. Live species composition before and after MPB infestation on Higher productivity sites

	Trees<22.5		*Trees 22.5-32.5*		*Trees 32.5-42.5*		*Trees 42.5+*	
	Before Beetles	Conservative Mortality	*Before Beetles*	Conservative Mortality	*Before Beetles*	Conservative Mortality	*Before Beetles*	Conservative Mortality
Stands 80-120	508	377	248	101	71	31	7	4
Stands 121-140	503	401	201	68	92	16	18	11
Stands 141+	453	387	284	80	122	19	29	19

Table 11. Live species composition before and after MPB infestation on Lower productivity sites

	Trees<22.5		*Trees 22.5-32.5*		*Trees 32.5-42.5*		*Trees 42.5+*	
	Before Beetles	Conservative Mortality	*Before Beetles*	Conservative Mortality	*Before Beetles*	Conservative Mortality	*Before Beetles*	Conservative Mortality
Stands 80-120	2206	1338	71	12	2	1	1	0
Stands 121-140	584	365	213	78	41	14	10	6
Stands 141+	1065	670	267	78	25	7	1	0


High Productivity Sites

Stands 80-120 Years Old
n = 3

Stands 141 + Years Old
n = 6

Stands 141 + Years Old
n = 3

Figure 5. Changes in mortality levels by stem size class for stands 80-120, 121-140 and 141+ years old on Higher productivity sites under 4 scenarios: No Beetles; *Current Mortality* (as sampled); *Predicted Mortality* – Conservative Estimate; *Predicted Mortality* – High Estimate. Live trees are shown as solid bars and dead trees are shown as thatched bars. Live current MPB attack is shown as thatched bars in the same column as other live trees.

Low Productivity Sites

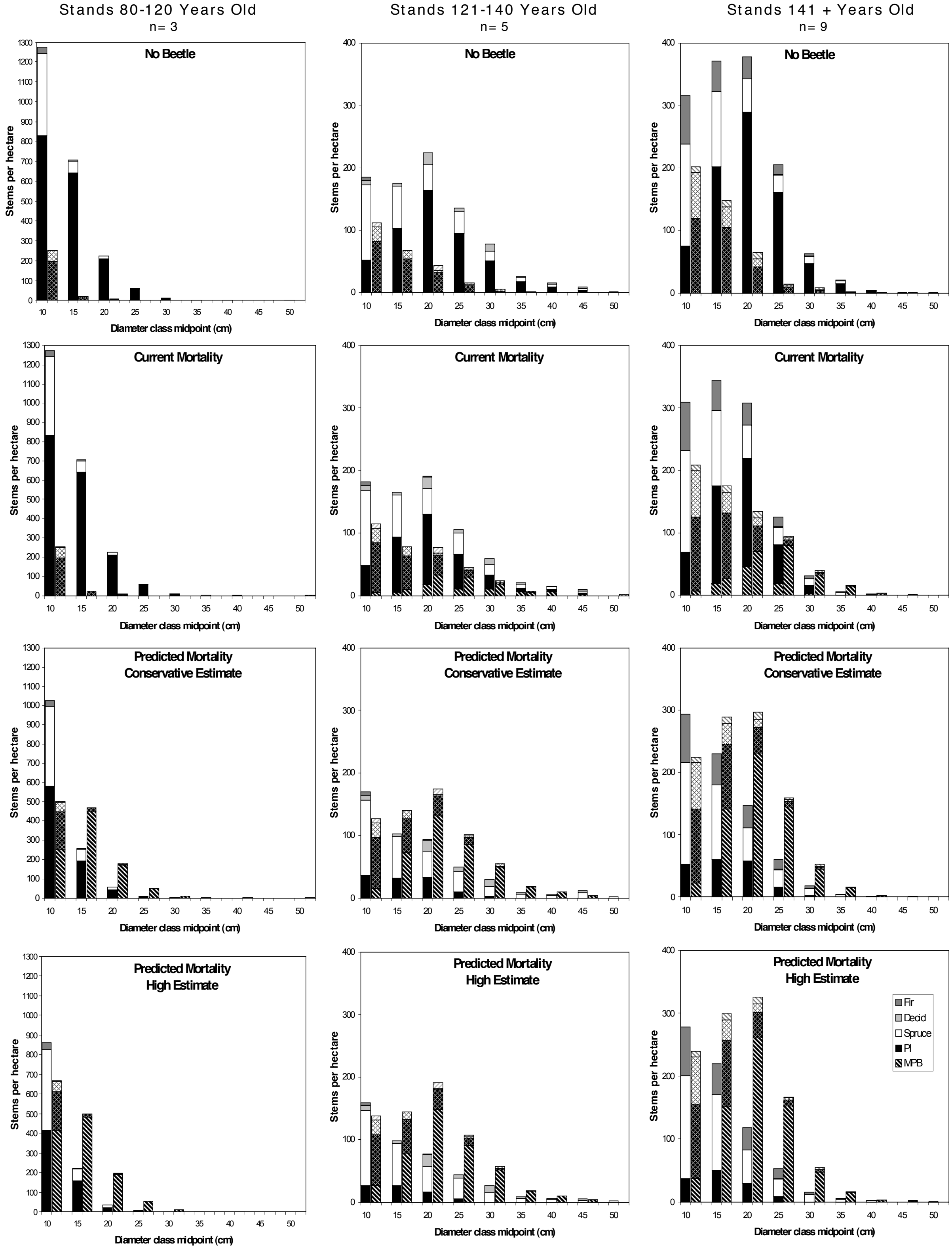


Figure 6. Changes in mortality levels by stem size class for stands 80-120, 121-140 and 141+ years old on Lower productivity sites under 4 scenarios: No Beetles; *Current Mortality* (as sampled); *Predicted Mortality* – Conservative Estimate; *Predicted Mortality* – High Estimate. Live trees are shown as solid bars and dead trees are shown as thatched bars. Live current MPB attack is shown as thatched bars in the same column as other live trees.

An Old Growth Index

Several approaches have been used to create Old Growth Indices. Scoring systems have been used in ecosystems across North America. Spies and Franklin (1988) first developed an index of old-growthness using Discriminant Function Analyses with a broad range of forest attributes from Douglas-fir forests in the Pacific Northwest. In 1992, Mehl used arbitrarily set thresholds for select variables to score forests. More recently, Kneeshaw and Burton (1998) multiplied attributes by their component loading scores in PCA to develop a continuous index for the SBSmc2. Holt et al. (e.g. 1999, 2002a,b) developed a scorecard approach for several ICH variants using PCA to separate the data, but did not use component loading scores because they were found to change dramatically with the addition or removal of variables. Harrison and DeLong (2000) used Discriminant Functions to determine age-based old-growth scores for the ICH wk3 and mm variants as well as the ESSF wk2 and mm. Stewart et al. (2003) used a weighted scoring system based on expert-developed thresholds in Nova Scotia, and Morgantini and Kansas (2003) built an Old Growth Index out of a series of ANOVAs looking at stand structure and stand age-class.

We used PCA in developing our index of old-growthness because it was less affected by assumptions of multivariate normality than other methods and its derivation was not explicitly linked to measures of stand age. The index uses thresholds for ‘High’ and ‘Low’ old-growth structural values in a scorecard format to rank older forests (see Table 12 and Table 13.). Although based on *Before Beetle* data, we have added maximum or minimum thresholds to our Index to account for the effects of MPB mortality.

Using the *Before Beetle* scenario, for both Higher and Lower productivity sites, PCA1 represented an index of large structural attributes (see above). Large live trees are an important functional element of old-growth stand structure and are becoming increasingly rare with the current MPB outbreak. Based on PCA1, site index is the primary driver of stand variation in the Moist Interior Plateau NDU, with stand age creating a secondary influence (as shown using regression analysis). While not specifically linked to age, PCA1 shows the range of structural attributes found on both Higher and Lower productivity sites and was used to develop Old Growth Indices based on structural attributes. This range of structure is particularly important for old-growth conservation because of the current loss of large diameter pine trees. While PCA1 is largely related to site productivity, age remains an important element in determining old-growth structure in the Moist Interior Plateau NDU.

The scorecard is a tool for managers to use in systematically evaluating stand-level structural attributes associated with old-growth forests. The use of multiple attributes ensures that stands are evaluated using suites of variables and are not rejected as ‘old growth’ on the basis of any single parameter. The scorecard approach also allows managers to identify particular attributes (such as abundant snags or CWD) within a stand in order to incorporate these variables into their broader management goals. The scorecard can be used as follows:

1) Use a random POC and random bearings to locate at least three plots that cover the variation within the stand (in the field or in the office).
2) Sample the attributes presented in the scorecard using nested plots – we used a 0.04ha main plot (11.28m radius) for trees over 7.5 cm dbh and a 0.1ha large plot (17.84m radius) for trees and snags >20cm dbh. At each plot, select a random bearing and run two coarse woody debris transects at 90 degrees to one another. Core a minimum of two trees of each species from the largest size class and a minimum of three trees per plot.
3) Compile tree, snag, age and CWD data and fill in the scorecard with data from the stand. Record the appropriate value for each attribute based on the thresholds provided. If the attribute fails to meet the threshold for ‘high’ old-growth structure, record a 0 for ‘low’ structure. If it meets or exceeds the threshold, record a 1.
4) Calculate the sum of all attribute scores to obtain the total score then divide this by the maximum possible score. The percentage of the maximum old-growth score is the index value for a stand.
5) Compare results with other stands, including the index value, individual attribute scores, and the costs and benefits of landscape level parameters.

Sample scorecards with site data for the *Before Beetle* and *Predicted Mortality* scenarios are presented in Appendix 7. For stands with moderate to high pre-infestation old-growth ratings, the beetles reduced overall beetle scores. However, for stands with low old-growth scores, beetles increased scores for some stands by reducing the density of smaller diameter trees and adding larger diameter snags that were previously missing.

Table 12. Old Growth scorecard for Higher productivity sites in the Moist Interior Plateau NDU.

Old Growth Scorecard for HIGHER productivity sites in the Moist Interior Plateau Natural Disturbance Unit (Site Index >17)

Stand Name ___________Map Sheet_________ Polygon _________________ Map Age _________

BEC variant _______ Site Series______ Slope ____ Aspect _____ Site Index ______ Size (ha) ______

Structural Attribute	Measured Value		Threshold for High Structure	Minimum or Maximum Threshold	Attribute Score: Low = 0 High = 1
Density Live Trees <22.5 cm dbh		<	468 sph		
Density Live Trees 22.5-32.5 cm dbh		<	227 sph	>50	
Density Live Trees 32.5-42.5 cm dbh***		>	88 sph		
Density Live Trees 42.5+ cm dbh***		>	16 sph		
Total Live Tree Density		<	811	>340	
Mean Tree dbh		>	24.9 cm		
Mean Snag dbh		>	21.2 cm	<30.7	
Density Snags <17.5 cm dbh		<	90 sph		
Density Snags 27.5+ cm dbh		>	23 sph	<80	
Total Snag Density		<	177 sph		
CWD Density <20 cm		<	449		
CWD Density 20-30 cm		>	72		
Maximum Age*		>	152 years		
Mean Age*		>	144 years		

Landscape Considerations / Notes	***TOTAL SCORE:*** **/13**
	% of MAXIMUM SCORE:

* Based on a separation in the data using PCA2. Use mean or maximum age, but not both.
** Maximum score = 13
*** Do not include pine trees if assessing a pre-beetle stand.

Table 13. Old Growth scorecard for Lower productivity sites in the Moist Interior Plateau NDU.

Old Growth Scorecard for LOWER productivity sites in the Moist Interior Plateau Natural Disturbance Unit (Site Index <17)

Stand Name ___________Map Sheet_________ Polygon ________________ Map Age _________

BEC variant _______ Site Series______ Slope ____ Aspect _____ Site Index ______ Size (ha) ______

Structural Attribute	**Measured Value**		**Threshold for High Structure**	**Minimum or Maximum Threshold**	**Attribute Score: Low = 0 High = 1**
Density Live Trees <22.5 cm dbh		<	1034 sph	>135	
Density Live Trees 22.5-32.5 cm dbh		>	222sph		
Density Live Trees 32.5-42.5 cm dbh***		>	26 sph		
Density Live Trees 42.5+ cm dbh***		>	3 sph		
Total Live Tree Density		<	1297 sph	>395	
Mean Tree dbh		>	20.5 cm		
Mean Snag dbh		>	15.6 cm	<26.8	
Density Snags <17.5 cm dbh		<	275 sph		
Density Snags 27.5+ cm dbh		>	5 sph	<5	
Total Snag Density		<	338 sph		
CWD Density <20 cm		<	824 sph		
CWD Density 20-30 cm		<	49 sph		
Maximum Age*		>	151 years		
Mean Age*		>	144 years		

Landscape Considerations / Notes	***TOTAL SCORE:*** /
	% of MAXIMUM SCORE:

* Based on a separation in the data using PCA2. Use mean or maximum age, but not both.

**Maximum score = 23

*** Do not include pine trees if assessing a pre-beetle stand.

Limitations of the Index

The thresholds developed here pertain to stand level values. Old forest assessments should also contain information regarding the landscape context in order for a full evaluation to be made. Additional considerations include: the size of the patch, position in relation to other old growth management areas within the landscape unit and with adjacent landscape units, connectivity potential of the patch, state of the surrounding forest cover matrix (an old growth reserve buffered by surrounding forest may have higher short term value than one surrounded by clearcuts, powerlines or housing), and other special management zone or biodiversity values in the landscape. It is also important that old-growth reserves be located throughout the landscape and not just placed in areas where beetle impacts have already been high.

DISCUSSION

Old growth management requirements are currently in flux within British Columbia. In the Moist Interior Plateau, licensees are expected to reserve between 12 and 17% of the landbase as old forest (percent varies by BEC variant; C. DeLong, pers comm.). Allocation of these percentages is to be done aspatially. But from the perspective of biodiversity, what types of stands are best suited to meeting the old forest and recruitment requirements? What forest characteristics should be prioritized?

The current mountain pine beetle outbreak in the Moist Interior Plateau creates several challenges for locating old forest reserves across the landscape. Old growth areas should contain habitats and ecological process that are unique to later successional stages. With pine leading stands, the ideal candidate old growth sites from a purely structural perspective may also be those most susceptible and at risk of beetle attack. As salvage and sanitation harvesting are planned and implemented, it is important to maintain old forest attributes and to plan for future old growth across the landscape.

In this report we analysed forest data under three Beetle Impact scenarios: the *Before Beetle* scenario where beetle-killed trees were resurrected and analysed as if still living; the *Current Mortality* scenario where data were summarized as they were collected in the field; and the *Predicted Mortality* scenario where mortality levels, by tree size class, were estimated based on actual beetle-kill data (Hawkes, unpublished; data from this project).

The *Before Beetle* scenario was used to determine the types of old-growth structures that develop in the Moist Interior Plateau NDU in the absence of beetle disturbance. This baseline data was then compared to projected stand structures following the beetle epidemic, based on a) a conservative mortality estimate b) a higher but likely realistic mortality estimate. The comparisons are intended to provide guidance on the types of structures to retain in old forest reserves, and to evaluate the potential for beetle-infested stands as old growth reserves. This approach assumes that pre-beetle disturbance structure provides 'better' old growth habitat than post-beetle structure within a given stand.

Stand development in the Moist Interior Plateau

Mountain pine beetles are native to British Columbia. As a major factor in forest dynamics, the beetles "play a critical role in the development, senescence, and rebirth of Western forests" (Samman and Logan 2000). Although larger than any outbreak recorded in North America, the current outbreak is the result of "natural beetle population cycles, continuous mild winters, and an abundance of uniformly mature pine stands"[15]. Major stand changes are caused by the MPB, changes that alter a stand's old-growth characteristics over multiple time scales.

Under a generalized model for stand development in the Moist Interior Plateau, stand replacing fires initiate stand development. Heat from the fire opens serotinous lodgepole pine cones, releasing

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[15] Ministry of Water, Air and Land Protection: http://wlapwww.gov.bc.ca/bcparks/conserve/pine_beetle/pine_beetle.htm

numerous seeds and an even-aged pine stand establishes, often with a minor spruce or subalpine fir component. After the establishment of the initial cohort, pine regeneration is sparse and shade tolerant species such as spruce and subalpine fir generally dominate the understory. As time progresses, the 'normal' process of stand development and vegetation succession are such that mean tree size increases and overall tree density decreases as smaller trees are lost through competition induced mortality (DeLong and Kessler 2000). In this study, we also found that densities of subalpine fir, and to a lesser extent spruce, increased considerably in older stands (140 years+; Figure 5 and Figure 6).

The relationship between ecological complexity and age is not linear, but in most systems the structural and functional attributes most important to wildlife tend to develop as forests age (Tyrell and Crow 1994). Large diameter trees, snags and CWD are generally linked to old growth structural and functional definitions because their densities generally increase with stand age due to the basic length of time required for growth. From a conservation perspective, locating old forest reserves in stands with densities of large trees is likely to provide the highest quality old-growth habitat.

Susceptibility to MPB attack

Susceptibility to MPB attack is key to predicting the potential impacts of beetle infestations on an old growth management area over time. In general, susceptibility to MPB is related to tree size (dbh), stand density, and stand age, as well as current growth rates and crown competition factors (Mata et al. 2003). Typically, susceptible stands are greater than 80 years old with a mean dbh of 20 cm or greater including a substantial number of trees with a dbh over 25 cm dbh, and a total stem density of between 750-1500 sph (Whitehead et al. 2001). Large trees are generally attacked first because their visual size is attractive to the beetles, which require large spaces for brood development (Whitehead et al. 2001). Larger trees also usually have slower growth rates, which may lead to the release of "some physiologically susceptible signal" that attracts the beetles (Mata et al. 2003).

Research in other areas has suggested that mixed-species stands suffer lower beetle-induced mortality than pure lodgepole pine stands (Goyer et al. 1998). In the stands sampled here, there appears to be no difference in attack and mortality levels for relatively homogeneous stands or mixed-species stands (see Figure 4). The primary difference, however, is that mixed stands retain more live stems after the pines are killed by MPB.

Although the MPB has been heavily studied, stand dynamics both during and after an outbreak are less understood and the MPB appears to infest different ecosystems in a variety of ways. Data from the Pacific Forestry Centre for the SBPS zone in the Cariboo Forest Region suggests that pine mortality rates are quite low (close to 30%) whereas in the SBS in the Tweedsmuir Park area the beetle has had a much more devastating effect with mortality rates as high as 100% (Hawkes, pers comm.). The stands in the Cariboo Region were multi-sized, and presumably multi-aged, and have had beetles pass through multiple times with either fire or beetle disturbance recorded at approximately 40 year intervals (Vera 2003). However, the multi-sized nature of these stands leaves a range of susceptible trees and it seems that only the larger pines are attacked.

Data from the more even-sized and even-aged stands in Tweedsmuir Park, and from the current study, suggest that trees of all sizes are susceptible to MPB mortality during outbreak conditions in these even-aged stands. Although stands younger than 80 years old were not sampled in the current study, small diameter pine stands were observed to have heavy beetle mortality (personal observations), and trees as small as 10 cm dbh were both attacked and killed in sample plots. Such high mortality rates across size classes highlight the importance of non-pine species in maintaining stand structure after a beetle outbreak.

Stand dynamics following an outbreak

Following a mountain pine beetle attack, the natural course of stand development is either towards replacement through wildfire or continuation through successional stages. Where fires occur, they generally take place within 15 years of an outbreak (Samman and Logan 2000). The degree to which stands are affected by beetle mortality may influence their susceptibility to intense crown fires. During the 1988 fire season in Yellowstone National Park, stands that had previously suffered with low to moderate mortality from beetles had fewer high intensity crown fires than uninfested stands, whereas stands with over 50% mortality from beetles over the previous 5-17 years burned more intensely. This is likely because intermediate mortality reduced the continuity of crown fuels (Turner et al. 1999). Where fires do burn, they may help perpetuate lodgepole pine dominance across the landscape by opening serotinous pine cones and enabling re-establishment of this shade intolerant species. According to Samman and Logan (2002), “Beetle outbreaks are subsequent fires are often stand-replacing events critical to maintaining lodgepole pine over much of its distribution.”

Where fire does not occur, beetle-induced mortality results in more open stands, which increases light in the understory and promotes the development of multi-layered, uneven-aged stands. This may hasten succession to species other than pine, and may also result in release of understory lodgepole pine (Wright et al. 2000). Although growth rates are lower in smaller openings, lodgepole pine has been found to regenerate and infill small gaps (Tesch 1981, Coates 2000). Romme et al. (1986) found that lodgepole pine productivity recovered 5-15 years after a mountain pine beetle attack. Although they were unsure if the total volume prior to the outbreak could be recovered through release of smaller pines, their study highlights the differences between beetle attack and fire in that considerable stand structure may remain after the beetles have flown. This is particularly true where high densities of spruce or fir are present across a range of sizes.

There are many differences between the effects of fire and MPB. Fires tend to favour regeneration of shade intolerants including lodgepole pine and deciduous species. In contrast, shade tolerant species such as spruce and subalpine fir are often the largest beneficiaries of a MPB outbreak, with establishment of new individuals and release of existing trees. In a large outbreak such as that in the Moist Interior Plateau, promotion of spruce and subalpine fir is expected in previously mixed pine stands.

There are also many differences between the effects of MPB and salvage operations, particularly in the context of old forest conservation. Salvage operations can “undermine many of the ecosystem benefits of natural disturbance” (Lindenmayer et al. 2004). They negate successional processes and, as with fire, tend to favour early seral species. Prior to the current MPB outbreak, harvesting was increasingly the largest disturbance within the Moist Interior Plateau. Although not a perfect match, the harvesting methods used more closely resemble disturbances from fire than insect. Beetles and fire are considered to be the prevailing historic disturbance agents, but as salvage efforts target beetle-affected stands, an increasing proportion of the landscape is experiencing large stand-replacing disturbance, with minimal areas undergoing successional processes following smaller scale ‘insect-type’ disturbances (Stadt 2001). From an old-growth perspective, salvage, and other harvest operations, reduce the density of old forest structures and habitats across the landscape. These ‘biological legacies’ of natural disturbance can be important for many reasons including facilitating species recovery and restoring nutrient levels (Lindenmayer et al. 2004).

Stands affected by MPB have both beneficial and detrimental impacts on wildlife species and favour some species over others. Some habitat elements, such as woodpecker feeding substrates and CWD levels in streams, ‘improve’ after a beetle outbreak, while others, such as hiding cover for ungulates and older tree habitats critical for some species, can be diminished (Samman and Logan 2000), particularly if beetle infestations are followed by salvage operations. Even if old-growth conditions ‘improve’ for some species, the effect is often temporary and long term habitat supply must be considered at stand and landscape scales. For example, while large, old pine snags are in abundant supply following an outbreak, unless management activities plan for their replacement over time, they will become rare.

Age and relative old growthness in the Moist Interior Plateau

Fire return intervals in the Moist Interior Plateau are short enough that post-fire initiated trees dominate most stands and the role of autogenic processes and post initiation partial disturbances is small in these relatively young stands. Research in other ecosystems has shown that it generally takes centuries to develop ‘majestic’ attributes, such as large trees, snags and CWD that are typically associated with old growth. This is largely because it can take hundreds of years for trees to grow to large sizes and for old-growth processes such as gap-based regeneration and overstory tree senescence to dominate stand dynamics.

The Biodiversity Guidebook set 140 years as a threshold for old forest in the BEC variants found in the Moist Interior Plateau (Province of BC 1995). A similar mean age threshold of 144 years was found using *Before Beetle* data for both Higher and Lower productivity sites in the Old Growth Index developed here. When Forest Cover age-class estimates were compared to measured age-classes, the Forest Cover data were only correct 45% of the time, and estimates were both over (34%) and under (21%) actual values. Although age-classes are derived from photo interpretation where old-growth associated attributes are an important estimator of stand age, mapped age-classes were not accurate predictors of successional stage or ‘old-growthness’.

Historically, large patches of forest over 140 years old are expected to have occurred across the landscape, but stands over 250 years old were historically rare in the Moist Interior Plateau portion of the SBS and SBPS (Andison 1996, DeLong and Tanner 1996). In this study, the oldest sample tree found was 242 years old, although a 310 year old veteran tree was found. Of the 29 stands sampled, 13 were 140+ years old, including four over 175 years old. Similarly, the largest tree measured in this study was a 59.8 cm dbh hybrid spruce (at Cross, a SBSdk, site series 01) and only 11 trees[16] at six stands were over 50 cm dbh (five hybrid spruce, three Douglas-fir and three lodgepole pine). In contrast, trees over 100 cm dbh were common and trees over 200 cm dbh were found at several sites in an old growth study in the ICHwk1 (Holt and MacKillop 2002a).

Holt et al. (1999, 2002b) found old growth attributes were generally abundant in stands over 250 years old in the ICHmw2 and over 200 in the ESSFdk. In SBSmc stands in northwestern British Columbia, Kneeshaw and Burton (1998) found that most stands over 200 years old showed considerable old-growth characteristics including gap-phase processes and high levels of dead biomass. Although the stands sampled here do not resemble ‘typical’ old-growth forests such as the extensively studied coastal stands in the Pacific Northwest (Spies and Franklin 1991; Lertzman 1992, Halpern and Spies 1995), relatively old forests (>150 years old) were historically present in the Moist Interior Plateau SBS, are still found, and are likely to contain important biological attributes that are particularly worthy of conservation.

Remnant patches – where canopy trees have survived the most recent fire – may provide important old-growth habitat and should be considered when defining old growth in the Moist Interior Plateau. DeLong and Kessler found that most remnants are less than two ha in size and typically contain large diameter trees, snags and CWD that are absent or rare in the surrounding younger forests. When compared to old stands (>140 years old), remnant patches had slightly lower densities of trees over 25 cm dbh, higher total stem densities (>7.5 cm dbh), and more nesting cavities in live and dead trees. The higher overall density in remnant sites is related to pulses of lodgepole pine regeneration in remnant patches. Post disturbance pine regeneration contributes to multi-aged stands with a range of tree sizes. Our ability to sample remnant patches in this study was very weak given their relatively low frequency on the landscape and their small size; however, it is generally believed that small remnants patches provide old-growth structure within larger areas of young and mature forest. The current MPB outbreak may increase the number of remnant forest types across the landscape, particularly in areas reserved from harvesting.

An Old Growth Index

The scoring system developed in this paper does not differentially weight attributes. Instead, the scorecard method allows managers and researchers to determine the importance of individual measured attributes and thresholds based on their management goals. Given that live lodgepole pine trees over 22.5 cm dbh are becoming rare due to the MPB, when assessing stands with current or expected beetle impacts, the species and densities of live trees >22.5 cm dbh may require increased attention. The

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[16] A total of 6921 trees (>7.5cm dbh) were sampled.

threshold values in the Old Growth Index provide minimum values and should not be considered in isolation as ‘absolute’ values. Sites with attributes that exceed the thresholds developed here, particularly for large live spruce and fir trees, may contain higher biodiversity value and should be prioritized as old growth reserves.

In testing the Index (Appendix 7), we found that stands that had moderate or high old-growth scores using data from the *Before Beetle* scenario generally had reduced scores using the *Predicted Mortality* scenarios. However, for stands with low *Before Beetle* old-growth scores, assessments of the *Predicted Mortality* scenarios actually showed improvements in old-growth scores. This is likely because stands with low pre-beetle old-growth scores had high densities of small diameter trees and few snags. The MPB is predicted to thin these younger stands and to add snags in larger diameter classes and may actually accelerate some old-growth features in these high-density young stands.

The highest old-growth score was found at Blue, a Higher productivity site (site index = 20.1) where large diameter trees were relatively abundant. Although Blue received high scores for all attributes using the *Before Beetle* data, when large diameter pines were removed, the score dropped in half from 13 to 6, with high structural value scores remaining only for CWD attributes, mean live tree diameters, densities of trees <22.5 and >42.5 cm dbh, and snag densities <17.5 cm dbh. The lowest score was found for Entiako, a very old, but low productivity site (site index = 8.6) where small diameter tree densities were high. Using the *Before Beetle* scenario, the only high structural value score was gained for stand age. However, when mortality was predicted, the old-growth score increased from 1 to 3, with the site meeting thresholds for the density of snags over 27.5 cm dbh and for the mean snag diameter. These examples show that while old-growth values change with beetle impacts, the Old Growth Index developed here can still be used to assess the potential habitat and conservation values of potential old forest sites. In particular, the Blue site, while losing much of its old forest value due to beetle impacts, is predicted to maintain large diameter spruce trees, which makes it a more valuable candidate old growth area than stands with no large diameter spruce or fir trees.

Rather than develop thresholds based on total stand mortality or susceptibility, we propose using the Old Growth Index developed here to guide old growth reserve selection. The thresholds provided in the Old Growth index indicate the structural value of potential old growth reserves. While it is likely that many beetle affected stands will not meet the criteria presented due to high mortality, the thresholds can be used as benchmarks for comparing potential candidate areas, and can be used to evaluate and monitor whether old forest attributes are being retained at stand and landscape-levels.

CONCLUSIONS

In developing the Old Growth Indices, it was very apparent that site productivity is an important gradient in determining stand structure present currently and into the future. Stratifying the data and performing two separate PCA analyses increased the discriminatory power of the Old Growth Index and allowed us to identify structural thresholds for different site types. Stratification also illustrated the differences in old-growth features between Higher and Lower productivity groups. Although increases were found with age, typical old growth structure was highest where site productivity was relatively high (greater than 17). In particular, increased densities of large diameter trees and snags were evident on Higher productivity sites when comparisons were made between similar age-classes (Appendix 4, Figure 5 and Figure 6). This suggests that retaining Higher productivity sites as old-growth reserves will maximize old forest conservation values across the landscape.

Defining old-growth characteristics in the Moist Interior Plateau is increasingly complex due to the current MPB outbreak and several factors apply to the biological value of a potential old growth reserve including stand structure, species composition, site productivity and stand age. Figure 7 below shows the characteristics that are likely to provide the most valuable old growth habitat, given the current beetle situation. For example, older stands (>140) with a high component of large, live spruce and/ or fir on higher productivity sites are likely to provide the most unique old growth habitat values, while younger pure pine stands on low productivity sites will not. Similarly, mature stands over 120 years old on Higher productivity sites are likely to provide more old growth attributes than older stands on lower productivity sites.

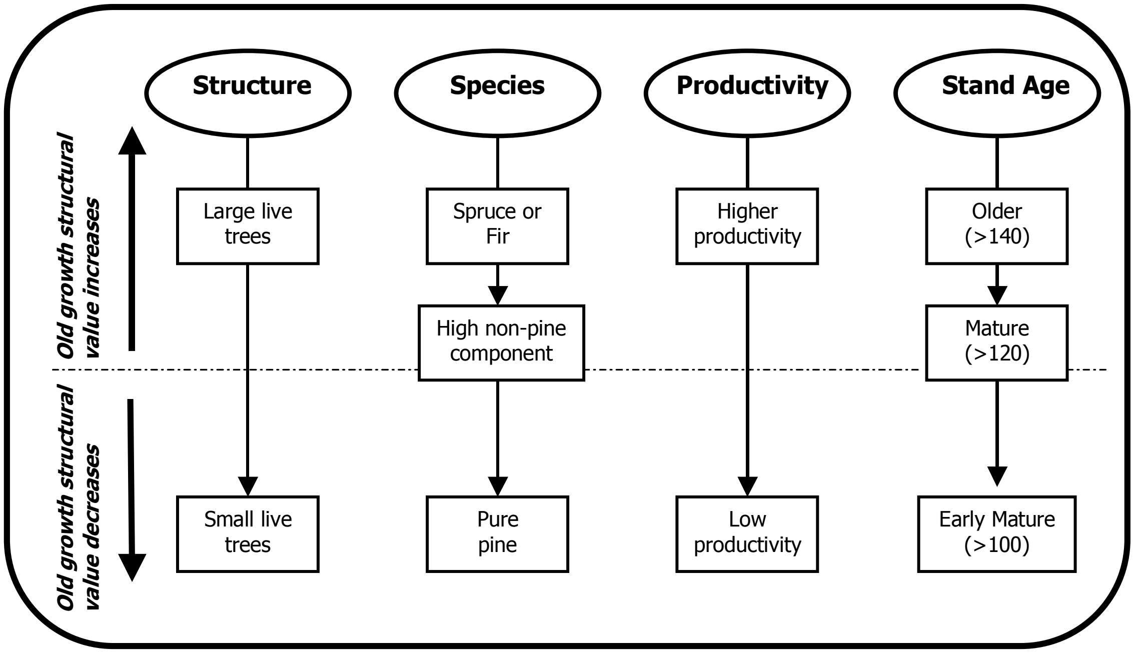

Figure 7. Site characteristics and likely old forest structural value.

Selecting Higher productivity sites as old forest reserves will increase the habitat types associated with old growth in the short term, bridging the gap between pre-beetle infestation conditions and stand recovery in the future. Maintaining large diameter live spruce and fir trees will ensure some old forest features are available as the large diameter pines die and then fall to the ground. Higher productivity sites will also provide the most efficient recruitment old growth sites because, as the analyses in this report show, stand development is more rapid on higher productivity sites. Thus, large diameter trees are expected to develop faster where Higher productivity younger sites are conserved as future old growth.

Current species composition is also of particular importance to old growth definitions and old forest location in the Moist Interior Plateau. Because most large lodgepole pines are expected to perish, stands with a high spruce or fir component in larger diameter classes are likely to retain more large living trees than purely or predominantly pine stands. Species other than pine will also provide a future source of large diameter snags and CWD to be added to stands later on in succession.

Since beetles attack larger trees, infestations will increase habitats and structure related to large dead trees in the short term. Preliminary results from the PCA analysis explored in this report suggest that large snags are correlated with stand age and are an important element of old-growth forests in the Moist Interior Plateau NDU. In mixed species stands, pine snags will be created amidst living non-pine trees. These large snags will provide important old-growth associated habitat where there is no salvage logging. Whether old growth reserves have been impacted by beetles already or are expected to be in the future, stands with a mix of large diameter pine and spruce trees are more likely to maintain unique old-growth habitats over the long term.

The species composition among small stems is also important since release of advanced regeneration and intermediate or suppressed trees will play a key role in determining the future stand. Wright et al. (2000) studied release in 11 tree species in northern interior British Columbia and found that although less shade tolerant species (including lodgepole pine) showed a time lag in response to release, the effects of prior suppression disappear over time during release. Of those conifer species commonly found in the Moist Interior Plateau, lodgepole pine is the least shade tolerant, followed by hybrid spruce, black spruce and subalpine fir. Shade tolerance and response to release will factor into the development of a stand following beetle-induced mortality.

The best sites for old forest retention are on Higher productivity sites, and have densities of large diameter, older spruce and fir trees that exceed the thresholds, by size class, presented in our Old Growth Index. Although sapling thresholds were not developed because there were no patterns between sapling densities and old-growthness, advance regeneration should also be assessed and valued, particularly on old forest recruitment sites.

The scenarios and analyses presented in this report assume that no catastrophic weather event will halt the current epidemic. Extreme cold temperatures, such as a sudden cold snap (-25 degrees or colder) in the early fall or late spring, or a prolonged period of –40 degrees during winter are required to cause significant mortality to the beetles (BC Ministry of Forests 2003a). While such events have yet to occur, extreme weather has contributed to the termination of past beetle epidemics, such as the outbreak in the Quesnel area in the 1980s, and are expected to impact the current outbreak at some point. Therefore, it would be prudent to select old forest reserve sites that have already had beetle impacts, as well as sites where the MPB is yet to spread. Established old forest recruitment sites in areas with no beetles will also increase preparedness for natural losses to old growth reserves now and in the future. These strategies will ensure the broadest range of habitats are conserved, and will maintain options into the future. Identifying stands with minimal or no current beetle impact as old forest reserves should also be in keeping with the Chief Forester’s directive on salvage priorities. According to scenarios developed by the Chief Forester, the impacts of the current MPB outbreak will be less severe if: harvesting targets more severely infested timber; harvesting focuses on lodgepole pine rather than other species; and if infested stands are regenerated immediately following harvest (BC Ministry of Forests 2003b).

The analyses presented here focus on stand-level old forest attributes and have particular relevance in describing old-growth characteristics and providing guidance in choosing between candidate old-growth reserve areas. However, landscape level attributes play are equally, if not more, important. Conservation biology theory emphasizes both scales of conservation, and places considerable importance on maintaining patch sizes and connectivity across the landscape.

The Moist Interior Plateau covers a very large area in central British Columbia and includes numerous variants of the SBS zone as well as variants in the SBPS. In this study, sites were sampled in the SBSdk, SBSdw3, SBSmc2, SBSmc3, and SBPSmc (DeLong et al. 1993). The full range of stand ages (78-234 years old) was included in each of the BEC units. The variants sampled differ from one another on the basis of mean annual and seasonal temperatures as well as species composition, but the overall sample size is too low to determine if BEC unit was a significant covariate. It is important that old forest reserves be spread across the range of BEC units present in the Moist Interior Plateau.

Developing landscape level old-growth plans is beyond the scope of this project. However, based on the research we have conducted, we recommend the following approach as a general strategy for old growth biodiversity conservation in the Moist Interior Plateau:

1) Stratify stands based on estimated site productivity.
2) Further stratify stands by age-class group: younger (< age-class 5); early mature (age-class 6-7); mature (age-class 7); and old (age-class 8).
3) Identify stands where spruce and fir comprise an estimated 15%, 30%, 50%, and 70% of the canopy.
4) Use the gradients in the figure above and the thresholds in the Old Growth Index to select a range of stands that comprises the highest biological value.
5) Use adaptive management to monitor and revise old growth reserves with short, medium and long term old growth supply in mind.

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Appendix 1. Sample polygons

Site Name	*Site Number*	*Map Sheet*	*Polygon Number*	*Polygon Label*	*BEC*	*Site Series*	*Aspect*	*Slope*	*Measured Age Class*	*Mapped Age Class*	*Sample Year*
Binta	27	93F096	536	Pl(S) 8317-16	SBSmc2	01	N	16-28	8	8	2003
Blue	22	93F086	515	PlS 7316-18	SBSdk	01(06)	S	5-15	8	7	2003
Bobtail	3	93G062	356	Pl 5337-15	SBSdw3	05	N	0-6	8	6	2002
Cheslatta	23	93F065	488	Pl(S) 7314-17	SBSdk	05	SE	10-18	6	7	2003
Chutanli	30	93F038	297	Pl(S) 8314-13	SBSmc3	05	NW	3	8	8	2003
Cicuta	31	93F055	218	Pl(S) 7316-11	SBSdk	05(01)	S-SE	0-3	8	7	2003
Cold	13	93F089	574	Pl(S)6336-15	SBSdw3	05(01)	S-W	6-10	7	6	2002
Cork	7	93F090	572	PlAtS 8315-16	SBSdw3	01	N	4-13	5	8	2002
Cross	12	93F076	236	PlAtS 7315-12	SBSdk	01(05)	S-NW	2-24	7	7	2002
Done	14	93F089	264	PlS(At)8314-15	SBSdk	01/05	N/A	2-4	7	8	2002
Entiako	29	93F024	405	PlS 8315-13	SBPSmc	03	NW	6-8	8	8	2003
For	8	93F075	504	Pl(S) 8316-17	SBSdk	05(01)	NW-SW	8-26	8	8	2002
Frank	11	93F095	159	PlS 7316-19	SBSmc2	01	W	5-15	8	7	2002
Gold	6	93F059	679	Pl 8316-15	SBSmc3	04(05/01)	N	2-5	8	8	2002
Goshawk	19	93F097	408	Pl(S) 7317-16	SBSmc2	01	E-SE	8-19	7	7	2003
Holy	4	93F066	109	Ew PlAtS 8315-14	SBSmc3	01(04)	SE	1-22	7	8	2002
Hunt	21	93F086	356	Pl(S) 8314-15	SBSdk	05(01)	NE-SE	5-10	7	8	2003
Johnny	24	93F014	330	PlS(At) 8314-13	SBPSmc	05(01)	S	4-18	7	8	2003
Kluskus	2	93F079	442	Pl 9237-5	SBSmc3	05(04)	W	4-9	4	9	2002
Knews	20	93F045	509	Pl 7316-13	SBSdk	05(01)	E-SE	9-15	6	7	2003
Lucas	28	93F055	270	SPl 8315-11	SBSdk	05(01)	NE-E	9-11	8	8	2003
Marilla	18	93F066	569	Pl(S) 7317-14	SBSdk	01(05)	N-SW	12-25	7	7	2003
Noon	5	93F069	256	Pl 9215-5	SBSmc3	04(05/01)	N	0-7	5	9	2002
Naught	9	93K018	260	PlS 7315-17	SBSdw3	04(05/01)	S-SW	3-4	7	7	2002
Pink	32	93F057	537	Pl 8416-19	SBSmc3	01(03)	N-NE	7-35	7	8	2003
Red	10	93F047	147	PlS 8317-15	SBSmc3	01	NE	2-7	8	8	2002
Sob Lk	1	93G072	510	Pl 5336-18	SBSdw3	01	W-N	7-8	5	5	2002
Tatuk	26	93F059	443	PlS 8315-15	SBSmc3	03(02)	S-SE	10-18	8	8	2003
Van Tine	25	93F024	385	PlS(B) 7316-13	SBPSmc	03	NW-N	5-8	8	7	2003

** Sites 15-17 were sampled in a pilot study by the Ministry of Forests in Prince George, but were not included in this report due to discrepancies between sampling protocols.*

Appendix 2. Species composition by basal area (BA) and stem density (SPH).

Prior to the beetle infestation, lodgepole pine was the leading species, by basal area, on all sites except two where hybrid spruce dominated. However, when all stems over 7.5 cm dbh were tallied, spruce was the most abundant species at five sites. Total basal area ranged from 21.5 m^2 at the Tatuk site to 49.7 m^2 at Frank. Total stem density (sph) was highest at Sob Lk and lowest at Tatuk, although densities were also low at Hunt, Blue and Done. Low basal area and stem densities at Tatuk reflect a relatively dry and open stand. The Table below provides a summary of species composition by stem density and basal area.

					Lodgepole pine (%)		*Hybrid spruce (%)*		*Black Spruce (%)*		*Fir*** (%)*		*Deciduous**** (%)*	
Site Name	Actual Leading Species*	# Tree Species**	Total BA (m^2)	Total Density (SPH)	BA	SPH	BA	SPH	BA	SPH	BA	SPH	BA	SPH
Kluskus	Pl	4	33.0	2203	78.0	69.3	6.1	5.3	15.8	25.4	…	…	…	…
Noon	Pl	3	29.2	2005	87.4	82.0	8.8	12.2	…	…	3.8	5.8	…	…
Cork	Sx	3	34.9	1065	12.9	11.3	79.8	83.6	…	…	…	…	7.3	5.2
Sob Lk	Pl	4	34.8	2632	88.0	79.2	1.9	2.3	9.7	18.4	0.4	0.1	…	…
Knews	Pl	4	36.6	817	81.0	75.3	18.4	23.7	…	…	…	…	0.6	1.0
Cheslatta	Pl	2	25.6	618	81.8	82.7	18.2	17.3	…	…	…	…	…	…
Holy	Pl	3	32.3	803	45.5	35.8	25.5	41.1	…	…	…	…	29.0	23.1
Marilla	Pl	4	23.7	750	75.8	66.4	23.0	31.6	…	…	0.7	1.6	0.5	0.4
Naught	Pl	3	25.7	665	79.1	62.9	8.5	32.1	…	…	12.3	5.0	…	…
Johnny	Sx	3	36.4	932	28.5	17.4	62.2	78.0	…	…	…	…	9.3	4.7
Hunt	Pl	3	36.4	543	85.8	75.5	12.6	22.4	…	…	1.2	2.1	0.4	0.0
Pink	Pl	4	37.1	1072	75.3	73.3	23.2	23.8	…	…	0.3	1.6	1.2	1.4
Cold	Pl	4	28.7	1032	81.1	77.5	10.3	7.6	7.8	13.7	…	…	0.8	1.1
Goshawk	Pl	4	32.9	713	77.5	57.2	12.0	14.5	…	…	9.6	27.3	0.9	0.9
Cross	Pl	3	27.1	823	44.2	18.6	43.8	72.7	…	…	2.5	0.0	9.6	8.7
Done	Pl	4	26.2	583	47.5	18.9	42.9	72.9	…	…	…	…	9.6	8.3
For	Pl	4	37.1	1210	79.7	64.3	16.5	31.3	3.3	4.1	0.5	0.3	…	…
Cicuta	Pl	3	40.2	1002	97.2	95.7	2.3	4.0	…	…	…	…	0.5	0.3
Bobtail	Pl	3	33.5	1100	94.6	91.4	3.1	5.2	2.3	3.5	…	…	…	…
Tatuk	Pl	3	21.5	520	55.3	48.1	41.1	49.4	…	…	…	…	3.5	2.6
Blue	Pl	4	37.2	545	70.2	52.3	28.4	45.9	…	…	0.6	0.6	0.8	1.2
Van Tine	Pl	4	47.5	1767	60.3	42.5	5.9	7.5	13.5	14.0	20.3	36.1	…	…
Gold	Pl	3	34.7	1520	83.5	78.7	0.6	0.0	15.4	21.3	0.6	0.0	…	…
Lucas	Pl	3	27.1	688	53.3	32.9	46.7	67.1	…	…	…	…	…	…
Red	Pl	4	48.1	1798	54.7	45.4	29.5	36.6	…	…	14.9	17.6	0.9	0.4
Binta	Pl	3	39.2	850	57.8	38.4	11.1	7.5	…	…	31.1	54.1	…	…
Chutanli	Pl	4	46.3	1925	66.7	57.9	3.4	3.1	16.4	29.4	13.5	9.6	…	…
Frank	Pl	3	49.7	1272	75.4	53.7	24.2	45.6	…	…	0.4	0.7	…	…
Entiako	Pl	3	39.4	1905	54.3	42.7	…	…	23.4	31.3	22.3	26.0	…	…

*based on actual basal area as measured in the field

** Includes saplings.

*** Subalpine fir in all sites except Naught where Douglas-fir was present.

**** Includes *Salix sp*, black cottonwood, paper birch, and trembling aspen

Appendix 3. Stand Structural attribute summaries by site – *Before Beetle* scenario

Under the *Before Beetle* scenario, sapling densities varied considerably by species, but hybrid spruce saplings were found at all sites except the Van Tine site where subalpine fir dominated the understory, and the Entiako site where hybrid spruce was absent in all size classes, but black spruce was abundant. Although generally shade intolerant, lodgepole pine saplings (Wright et al. 2000) were found at 18 sites, although they were very rare in 13 of these stands. Where present, pine saplings were either suppressed in the understory, or growing in gaps. Black spruce saplings were generally abundant where present, but were found on few sites (see Table 1). Saplings were not tallied for deciduous species.

Table 1. Density of saplings, by species.

Site Name	*Subalpine fir*	*Lodgepole pine*	*Black spruce*	*Hybrid spruce*	*Total Saplings*
Sob Lk	0	8	742	308	1058
Kluskus	8	508	1208	42	1767
Bobtail	0	108	183	25	317
Holy	0	200	0	225	425
Noon	17	125	0	433	575
Gold	0	0	375	75	450
Cork	0	0	0	792	792
For	42	17	25	542	625
Naught	8	733	0	400	1142
Red	25	0	0	92	117
Frank	58	0	0	300	358
Cross	0	158	0	1625	1783
Cold	0	33	875	167	1075
Done	8	117	0	908	1033
Marilla	8	217	0	458	683
Goshawk	875	0	0	83	958
Knews	125	192	0	567	883
Hunt	600	625	0	142	1367
Blue	92	0	0	592	683
Cheslatta	0	1033	0	192	1225
Johnny	0	0	0	458	458
Van Tine	2075	0	17	0	2092
Tatuk	0	25	0	133	158
Binta	608	0	0	17	625
Lucas	33	33	0	975	1042
Entiako	825	0	433	0	1258
Chutanli	1125	0	0	300	1425
Cicuta	0	17	0	42	58
Pink	100	517	0	125	742

Prior to the beetle outbreak, live stem diameters varied considerably across sites and were highly correlated with site productivity (Table 2). The largest diameter trees were hybrid spruce trees found at Cross and Binta, although the highest mean diameter was found at Blue. Hybrid spruce were also the largest snags in the dataset, with the overall largest diameter snags found at Lucas and Johnny, and the highest mean at Blue and Lucas. Standard deviations of the mean diameters were generally low with the highest variation at Done, a wide-spaced age-class 8 stand, and the lowest at the younger Sob Lk and Noon sites where the lowest mean tree and snag diameters were observed.

Table 2. Mean and maximum diameters of live trees and snags (cm).

Site	*Trees*			*Snags*		
Name	Mean	Std	Max	Mean	Std	Max
Kluskus	15.3	5.6	48.7	11.4	3.6	19.3
Noon	13.6	4.5	28.4	9.7	2.4	19.8
Cork	22.1	8.2	48.5	22.3	5.6	36.8
Sob Lk	13.1	4.2	26.8	9.7	1.9	15.1
Knews	25.2	6.8	52.9	19.9	5.5	32.3
Cheslatta	24.2	9.6	45.6	12.1	7.3	34.2
Holy	23.1	8.3	46.2	18.9	5.4	32.4
Marilla	21.7	6.3	37.2	18.7	8.0	36.8
Naught	25.1	10.1	57.5	20.8	5.9	28.3
Johnny	25.9	7.8	47.0	23.0	8.7	46.1
Hunt	29.9	8.4	48.5	19.6	N/A	29.8
Pink	21.9	5.7	44.7	13.6	4.3	24.2
Cold	20.2	6.4	39.2	13.9	5.3	28.2
Goshawk	25.7	9.1	49.3	20.9	5.9	34.0
Cross	22.5	9.9	59.8	23.0	16.4	43.9
Done	25.4	11.3	47.7	21.2	7.8	34.0
For	21.5	6.1	42.6	18.9	6.2	39.9
Cicuta	23.8	4.7	43.0	15.9	4.7	23.7
Bobtail	20.8	4.5	31.9	14.3	4.0	31.0
Tatuk	24.0	7.3	50.8	20.5	4.5	29.0
Blue	30.8	9.1	49.2	25.5	7.3	38.7
Van Tine	19.7	6.5	36.3	15.1	5.2	35.8
Gold	18.1	5.1	30.8	13.5	3.9	23.6
Lucas	24.1	9.1	42.5	25.1	7.1	46.2
Red	19.7	5.7	33.5	14.2	4.5	26.9
Binta	25.5	9.4	58.4	23.1	7.6	40.5
Chutanli	18.6	5.5	30.5	17.2	6.6	28.8
Frank	23.6	8.0	51.3	17.6	6.0	31.2
Entiako	17.1	5.7	32.7	12.2	4.2	32.0

CWD densities ranged from 90 pieces per hectare at Naught to 2307 pieces per hectare at Red (Table 3), although six sites contained higher CWD Volumes than Red, including Tatuk with the highest CWD volume (and the lowest stand BA and stem density) with 53.4 m3. Both Red and Tatuk had high volumes in the smallest size class (<20 cm dbh), although four of the remaining sites with high volumes had large concentrations in the 20-30 cm class, 37% of the volume at Cork had a diameter greater than 30 cm. Pieces over 30 cm in diameter were rare at all other sites and were only found on nine of 29 sites.

Table 3. CWD density and volume, by size class.

Site Name	*Number of pieces*	*Volume (m^3)*	*Volume pieces <20*	*Volume pieces 20-30 cm*	*Volume pieces 30+ cm*
Kluskus	1648	27.6	25.6	2.0	…
Noon	528	31.4	14.4	16.9	…
Cork	562	48.9	7.5	23.3	18.2
Sob Lk	509	13.6	8.8	4.8	…
Knews	290	7.4	5.3	2.0	…
Cheslatta	326	7.4	5.1	2.2	…
Holy	377	20.7	10.4	10.3	…
Marilla	466	17.2	6.9	10.3	…
Naught	90	3.2	3.2	…	…
Johnny	494	30.4	8.0	17.0	5.4
Hunt	168	3.7	1.4	2.2	…
Pink	918	16.7	14.2	2.5	…
Cold	603	7.4	7.4	…	…
Goshawk	841	28.4	11.3	10.0	7.1
Cross	705	47.0	19.9	23.0	4.0
Done	226	7.2	5.0	2.2	…
For	822	24.9	20.2	4.7	…
Cicuta	859	30.8	18.7	12.1	…
Bobtail	998	19.6	19.6	…	…
Tatuk	1494	53.4	35.3	15.6	2.5
Blue	299	23.8	6.7	14.2	2.9
Van Tine	739	28.4	10.9	17.5	…
Gold	1081	21.1	21.1	…	…
Lucas	695	36.8	10.2	21.8	4.9
Red	2307	33.6	28.2	5.4	…
Binta	750	36.3	18.1	15.2	3.0
Chutanli	1102	44.0	24.1	19.9	…
Frank	959	19.0	17.2	1.7	…
Entiako	941	15.3	10.6	2.2	2.5

Scars were by far the most common pathogen indicator found in this study and some sites, such as Frank, Marilla, Goshawk, Pink, Knews, and Gold had scars on over 30% of the trees that would have been alive prior to the beetle outbreak (Table 4). Cicuta, Sob Lk, Kluskus, Done and Bobtail had scars on over one quarter of the trees. Most of these scars were due to cankers and tree fall scars, although extensive scarring was observed on large pines at Done and Blue. Forked, broken and dead tops were reasonably rare among stand sampled here and, although an important indicator of old-growth in the ICH (Holt et al. 1999, Holt and MacKillop 2002a), they do not appear to have any relation to old-growth characteristics in this system.

Table 4. Density of live trees with pathogen indicators prior to the beetle outbreak.

Site Name	*Total stem density*	*% with pathogen indicators*	*% with forked tops*	*% with scars*	*% with dead or broken tops*
Kluskus	2203	40	8	28	8
Noon	2005	30	5	22	4
Cork	1065	18	5	12	2
Sob Lk	2632	42	8	28	8
Knews	817	42	7	33	2
Cheslatta	618	28	4	18	11
Holy	803	29	2	22	4
Marilla	750	48	5	42	9
Not	665	26	13	6	8
Johnny	932	18	3	8	8
Hunt	543	25	10	8	7
Pink	1072	46	2	34	7
Cold	1032	25	1	15	7
Goshawk	713	46	12	39	6
Cross	823	18	3	13	3
Done	583	29	…	26	1
For	1210	28	4	14	8
Cicuta	1002	39	6	29	5
Bobtail	1100	48	15	25	13
Tatuk	520	40	6	10	18
Blue	545	25	5	16	4
Van Tine	1767	23	6	13	5
Gold	1520	45	6	31	12
Lucas	688	19	3	13	…
Red	1798	35	3	24	9
Binta	850	31	6	19	6
Chutanli	1925	30	7	15	8
Frank	1272	52	4	48	5
Entiako	1905	32	7	19	7

Keisker (2002) developed the 10-category Wildlife Tree Type and associated 6-category CWD Type classification system for northern British Columbia to describe and group stand structures on the basis of functional habitat types. While WLTT 9, presence of live insects beneath or on the bark of trees and snags, was by far the most abundant WLTT due to the MPB, other WLTT were relatively rare. Elevated runways on CWD (CWDT5) were the most abundant and frequently encountered wildlife tree/CWD type in this study. Cavities and cavity substrates (WWTT1-3) were the next most common WLTT in the study, followed by brooms, mistletoe and other hiding substrates (WLTT7; Table 5). Loose or furrowed bark (WLTT6) and hunting or resting perches (WLTT8) were also common. CWDT1-3 were rare in the study area, and WLTT 4, 5, and 10 were absent.

Table 5. Density (sph) of wildlife tree types on trees and snags, and on CWD (as per Keisker 2002).

Site Name	*Trees & Snags CWDT 1+3*	*Trees & Snags WLTT1-3*	*Trees & Snags WLTT6*	*Trees & Snags WLTT7*	*Trees & Snags WLTT8*	*CWDT1-3**	*CWDT4*	*CWDT5*	*CWDT6*
Kluskus	…	…	…	108	…	…	…	126	…
Noon	…	…	…	…	…	10	…	55	…
Cork	12	7	8	25	3	23	…	179	39
Sob Lk	…	…	…	17	17	10	…	105	…
Knews	…	…	…	3	…	…	…	24	…
Cheslatta	…	…	3	…	…	…	…	…	…
Holy	…	30	18	30	5	…	52	136	…
Marilla	7	25	…	12	…	…	…	60	26
Not	15	3	13	…	18	…	…	46	…
Johnny	…	10	…	…	…	…	6	137	31
Hunt	…	12	7	…	…	…	22	6	…
Pink	…	22	3	38	…	…	11	284	…
Cold	…	12	12	17	20	…	30	153	…
Goshawk	…	17	3	…	3	…	…	114	…
Cross	…	35	17	…	…	…	62	487	41
Done	3	40	…	8	…	…	8	79	…
For	…	7	3	28	38	…	23	252	12
Cicuta	…	…	…	…	27	…	47	844	113
Bobtail	3	3	20	3	60	…	17	316	…
Tatuk	…	28	…	98	20	…	…	…	…
Blue	…	17	23	…	10	…	…	…	…
Van Tine	…	7	8	17	…	…	…	189	…
Gold	…	…	…	8	98	…	…	615	…
Lucas	…	7	…	15	3	…	…	695	…
Red	…	3	8	…	112	…	19	886	…
Binta	…	23	12	3	8	…	7	454	…
Chutanli	…	…	…	25	…	…	…	830	272
Frank	…	43	3	…	…	…	…	348	…
Entiako	…	3	…	40	…	…	…	…	…

* See Table 4 in this section for total CWD densities.

Appendix 4. Changes in tree, snag and CWD attributes with stand age and site productivity.

Data	*Age-Class 5-6*		*Age-Class 7*		*Age-Class 8*		*Pattern*
	Low Site Index	*High Site Index*	*Low Site Index*	*High Site Index*	*Low Site Index*	*High Site Index*	
Sample Size	3	3	5	6	9	3	
Site Index	13.9	18.1	16.1	18.2	14.4	19.4	Low AC7 sites have higher SI than other Low sites
BA Snag <20 cm dbh	2.27	1.27	2.79	1.69	5.24	2.42	Increases with Productivity and Age
BA Snags 20-30 cm dbh	0.00	1.15	1.36	2.36	1.84	3.59	Increases with Productivity and Age; Absent in Low AC5-6 sites
BA Snags 30+ cm dbh	0.00	0.31	0.47	1.13	0.39	2.69	Increases with Productivity and Age; Absent in Low AC5-6 sites
Density snags <20 cm dbh	281	86	207	135	392	142	High sites increase with age; Low sites highest in AC8
Density snags 20-30 cm dbh	0	27	33	50	43	77	Increases with Productivity and Age; Absent in Low AC5-6 sites
Density snags 30+ cm dbh	0	3	6	11	4	30	Increases with Productivity and Age; Absent in Low AC5-6 sites
Density of all Snags	281	116	246	195	439	249	Increases with Productivity and Age; highest in Low productivity AC8
Density live trees <20 cm dbh	2133	422	455	438	875	397	U-shaped pattern with Age on Low productivity sites; slight inverse-U pattern on High sites
Density live trees 20-30 cm dbh	139	286	311	223	438	284	High productivity sites have slight U-shaped pattern; Low sites increase with age
Density live trees 30-40 cm dbh	7	110	67	128	43	167	High productivity sites increase with Age; Low productivity sites highest in AC7 (inverse-U pattern), but generally low
Density live trees 40+ cm dbh	1	16	15	26	3	41	High productivity sites increase with Age; Low productivity sites highest in AC7 (inverse-U pattern), but generally low
Density of all live trees	2280	833	848	814	1358	889	U-shaped pattern for Low productivity sites
Maximum DBH	34.6	49.0	43.0	50.8	36.9	53.0	Increases with Productivity; Low productivity sites are inverse-U: highest in AC7; High sites increase with age
Mean DBH	14.0	23.8	22.5	25.1	20.7	26.6	Increases with Productivity; Low productivity sites are inverse-U: highest in AC7; High sites increase with age
Mean Snag DBH	10.2	18.1	17.2	21.0	16.4	22.1	Increases with Productivity; Low productivity sites are inverse-U: highest in AC7; High sites increase with age
Density live trees with pathogen indicators	858	238	303	215	464	352	Highest in young, Low productivity sites
CWD Volume <20 cm	16.3	6.0	8.8	10.7	19.9	14.0	Increases with Age on High productivity sites; U-shaped in Low productivity sites
CWD Volume 20-30 cm	7.9	9.2	5.1	9.5	10.5	10.4	U-shaped pattern for Low productivity sites

Data	Age-Class 5-6		Age-Class 7		Age-Class 8		Pattern
	Low Site Index	High Site Index	Low Site Index	High Site Index	Low Site Index	High Site Index	
CWD Volume 30+cm	0.0	6.1	0.0	2.8	1.1	2.0	Increases with Productivity, but decreases with age on High productivity sites; absent at AC5-6 and AC7 Low productivity sites
CWD Total Volume	24.2	21.2	13.8	22.9	31.4	26.4	Increases with Age on High productivity sites; U-shaped in Low productivity sites
CWD Vol DC1-2	2.1	1.8	9.8	14.3	19.5	16.6	Increases with Age
CWD Vol DC3	3.8	6.8	3.3	5.2	8.1	6.8	Highest in old, Low productivity sites
CWD Vol DC4-5	18.2	12.6	0.7	3.4	3.9	2.9	Decreases with Age
CWD SPH<20 cm	828	318	487	450	1047	601	Same as Vol
CWD SPH 20-30 cm	67	63	31	59	86	66	Same as Vol
CWD SPH 30+ cm	0	12	0	10	2	3	Same as Vol
Total CWD SPH	895	393	518	520	1135	670	Same as Vol
BA Live trees <20 cm	28.13	8.06	10.14	7.77	19.66	8.43	U-shaped pattern with Age
BA Live trees 20-30 cm	5.73	14.49	15.32	12.99	20.94	17.88	Same as SPH
BA Live trees 30-40 cm	0.56	10.22	6.46	12.36	4.04	17.60	Same as SPH
BA Live trees 40+ cm	0.21	2.35	2.29	4.65	0.44	6.86	Same as SPH
Total BA Live trees	34.63	35.11	34.20	37.78	45.07	50.77	Increases with Productivity and Age
Mean Stand Age	86	105	131	133	167	175	High productivity AC5-6 stands are older than Low productivity AC5-66 sites
Maximum Stand Age	94	121	148	148	184	188	High productivity AC5-6 stands are older than Low productivity AC5-6 sites
Density WTC 3-4	272	104	219	175	423	218	Increases with Age on High productivity sites; U-shaped in Low productivity sites
Density WTC5-6	3	9	21	17	15	27	Increases with Age on High productivity sites; inverse-U in Low productivity sites
Density WTC7-8	6	3	5	3	1	4	Decreases with Age on Low productivity sites
CWD SPH DC1-2	63	88	306	236	671	264	Increases with Age
CWD SPH DC3	304	183	169	169	319	156	High productivity sites decrease with Age; Low productivity sites are U-shaped
CWD SPH DC4-5	527	122	43	115	145	249	Highest on older High productivity sites and young Low productivity sites
Saplings	45	39	32	42	31	22	Lowest on Highly productive old sites
PCA1	-1.4142	0.4036	0.0131	0.7150	-0.5295	1.0286	Highest on older High productivity sites; AC7 sites are highest for Low productivity sites
PCA2	-2.9918	-1.8078	-1.5179	-0.9144	6.5621	1.8079	Increases with Age; highest on Low productivity AC8 sites and lowest on Low productivity AC5-6 sites

Appendix 5. Summary statistics, by stand structural attribute, for High and Low Old Growth Structure on Higher and Lower productivity sites, based on PCA analysis using the *Before Beetle* Scenario

	Higher Productivity								*Lower Productivity*							
	Low Old Growth Structure				High Old Growth Structure				Low Old Growth Structure				High Old Growth Structure			
	Mean	SE	Min	Max	Mean	SE	Min	Max	Mean	SE	Min	Max	Mean	SE	Min	Max
Density of Trees <22.5 cm dbh	736	114.1	205	2160	273	41.1	0	535	1613	142.0	730	3455	513	83.0	135	1645
Density of Trees 22.5-32.5 cm dbh	276	29.3	40	450	184	23.2	50	450	164	22.7	0	420	269	33.1	100	600
Density of Trees 32.5-42.5 cm dbh	53	7.2	0	110	129	13.0	40	260	3	1.3	0	20	59	10.0	0	160
Density of Trees 42.5+ cm dbh	7	1.6	0	20	28	4.4	0	70	0	0.0	0	0	10	3.9	0	70
Total Tree Density	1071	100.6	565	2230	615	35.9	340	865	1780	130.6	900	3455	850	95.2	395	1925
Total Tree BA	41.0	2.1	23.8	62.6	39.2	2.5	23.9	56.2	41.4	2.1	27.2	68.3	37.3	3.0	23.6	66.8
BA of Trees <22.5 cm dbh	13.2	1.6	4.8	30.0	4.4	0.7	0.0	9.3	26.7	1.3	14.1	39.4	10.2	1.8	3.2	32.2
BA of Trees 22.5-32.50 cm dbh	15.4	1.6	2.2	23.0	11.2	1.3	2.7	25.3	8.3	1.2	0.0	21.9	14.9	1.8	6.3	33.7
BA of Trees 32.5-42.5 cm dbh	5.5	0.7	0.0	11.0	13.4	1.3	4.0	26.2	0.3	0.1	0.0	1.9	5.9	1.0	0.0	16.9
BA of Trees 42.5+ cm dbh	1.2	0.3	0.0	4.4	4.7	0.7	0.0	10.7	0.0	0.0	0.0	0.0	1.6	0.6	0.0	11.2
Density of Saplings	25	4.0	1	63	42	7.3	2	120	38	7.1	0	124	29	6.2	1	96
Density of Trees and Snags with WLTT1_8	38	9.4	0	135	30	7.5	0	105	67	11.8	0	180	63	12.2	0	190
Maximum Tree DBH	43.1	1.7	26.8	59.8	47.5	1.1	39.2	58.4	29.2	0.7	21.6	36.6	40.1	1.5	30.5	51.7
Mean Tree DBH	22.3	0.7	14.0	25.9	27.7	0.9	23.0	33.9	17.1	0.6	11.6	21.5	23.9	0.7	18.0	32.0
Mean Snag DBH	18.5	1.1	10.2	28.8	23.6	0.7	17.4	30.7	12.3	0.4	8.5	16.1	19.2	0.9	14.0	26.8
Density of Snags <17.5 cm dbh	178	49.5	0	800	42	11.1	0	200	433	47.2	50	775	133	32.2	0	450
Density of Snags 17.5-27.5 cm dbh	56	11.8	0	190	67	15.2	0	235	48	11.6	0	185	62	10.5	0	140
Density of Snags 27.5+ cm dbh	16	6.9	0	90	30	6.2	0	80	2	1.2	0	20	10	3.0	0	40
Total Snag Density	250	61.1	0	1080	139	26.4	35	410	484	51.3	50	870	204	40.0	25	540
Total Snag BA	4.5	0.7	0.7	10.9	7.2	1.4	1.5	22.3	5.8	0.8	0.0	13.4	4.3	0.8	0.4	12.9
BA Snags <17.5 cm dbh	2.0	0.5	0.0	7.5	0.5	0.1	0.0	2.3	4.5	0.5	0.6	8.5	1.8	0.5	0.0	6.1
BA Snags 17.5-27.5 cm dbh	2.2	0.5	0.0	6.9	2.5	0.5	0.0	7.7	1.5	0.4	0.0	5.9	2.2	0.4	0.0	5.2
BA Snags 27.5+ cm dbh	1.5	0.6	0.0	7.9	2.5	0.5	0.0	6.4	0.1	0.1	0.0	1.3	0.8	0.2	0.0	3.2
Density of Snags WTC 3-4	225	60.9	0	1080	121	25.4	35	390	464	51.3	50	870	191	40.8	0	515
Density of Snags WTC 5-6	20	5.1	0	65	15	4.2	0	60	18	5.7	0	100	12	3.6	0	50
Density of Snags WTC 7-8	6	3.0	0	45	3	2.8	0	50	2	1.4	0	25	2	1.1	0	20
Density of Snags >20 cm dbh WTC 5-8	6	3.1	0	50	5	2.0	0	25	1	0.6	0	10	5	2.0	0	30
CWD Volume <20 cm	14.1	2.0	0.0	28.4	7.3	1.3	0.0	18.5	15.5	2.1	0.0	38.8	15.3	2.8	0.0	47.8

	Higher Productivity								*Lower Productivity*							
	Low Old Growth Structure				High Old Growth Structure				Low Old Growth Structure				High Old Growth Structure			
	Mean	SE	Min	Max	Mean	SE	Min	Max	Mean	SE	Min	Max	Mean	SE	Min	Max
CWD Volume 20-30 cm	8.9	2.2	0.0	28.1	13.2	2.4	0.0	34.5	3.3	1.6	0.0	32.9	11.1	2.6	0.0	33.7
CWD Volume 30+ cm	3.7	3.1	0.0	54.5	3.9	1.5	0.0	21.3	0.3	0.3	0.0	7.5	0.4	0.4	0.0	7.6
Total CWD Volume	26.6	4.6	5.3	81.0	24.4	3.9	0.0	47.2	19.1	2.6	0.0	51.5	26.8	4.3	0.0	58.6
Total CWD Density	793	112.1	204	1976	333	60.6	0	1095	1030	137.1	0	2459	736	122.7	0	2123
CWD Density <20 cm	726	114.6	0	1976	236	50.3	0	911	998	134.4	0	2394	665	119.4	0	2103
CWD Density 20-30 cm	57	13.5	0	197	89	15.4	0	199	31	13.6	0	262	70	16.4	0	237
CWD Density 30+ cm	10	6.9	0	104	8	4.6	0	82	1	0.9	0	22	1	0.7	0	14
CWD Volume >20 cm DC 1-2	9.0	2.8	0.0	30.3	18.7	3.3	0.0	36.0	2.6	1.4	0.0	22.2	13.5	2.9	0.0	29.3
CWD Volume >20 cm DC 3	6.8	2.7	0.0	29.4	11.7	3.3	0.0	42.2	2.4	1.7	0.0	30.3	4.8	2.2	0.0	26.2
CWD Volume >20 cm DC 4-5	10.8	3.4	0.0	42.8	10.6	2.7	0.0	36.1	3.0	1.7	0.0	28.0	5.1	2.4	0.0	30.4
Maximum Stand Age	140	8.0	78	197	153	5.2	119	197	147	8.8	80	232	157	6.4	117	243
Mean Stand Age	135	8.1	72	196	143	4.6	113	185	142	8.8	76	229	147	4.7	111	191
Maximum Stand Age*	136	5.7	78	197	167	5.4	140	197	133	5.6	80	177	171	7.0	111	243
Mean Stand Age*	130	5.6	72	196	158	5.2	131	185	127	5.4	76	173	162	6.3	103	229

* based on PCA2

Appendix 6. Relationships between PCA, stand age and site index for Higher and Lower productivity sites.

HIGHER PRODUCTIVITY SITES:

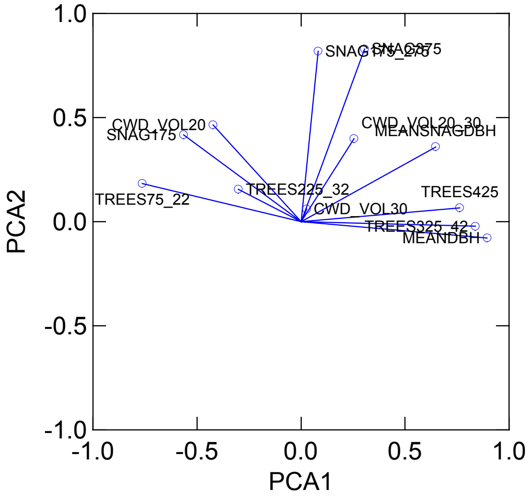

Figure 1. Component loadings for Higher productivity sites showing the association between input variables and PCA axes.

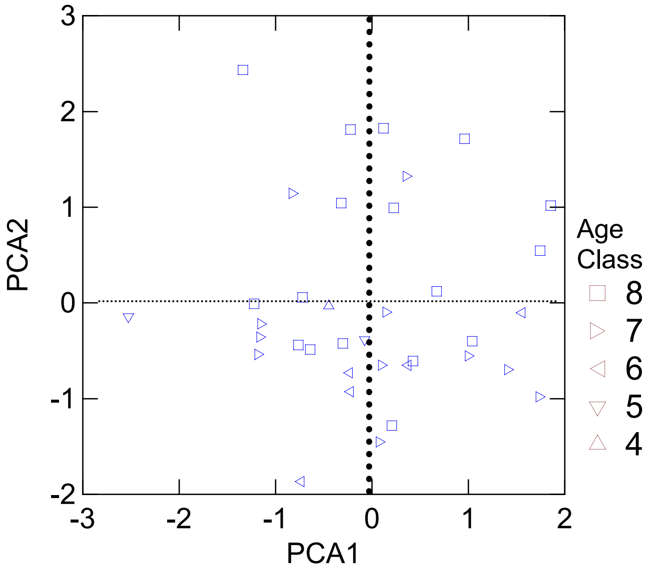

Figure 2. Relationship between PCA1 and PCA2 for Higher productivity sites, marked by the age of each plot

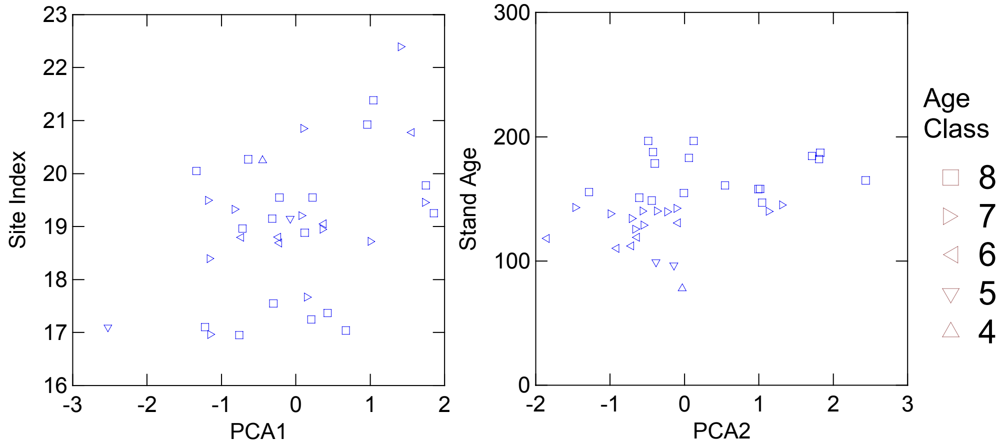

Figure 3. Relationship between PCA, stand age and site index for Higher productivity sites

LOWER PRODUCTIVITY SITES

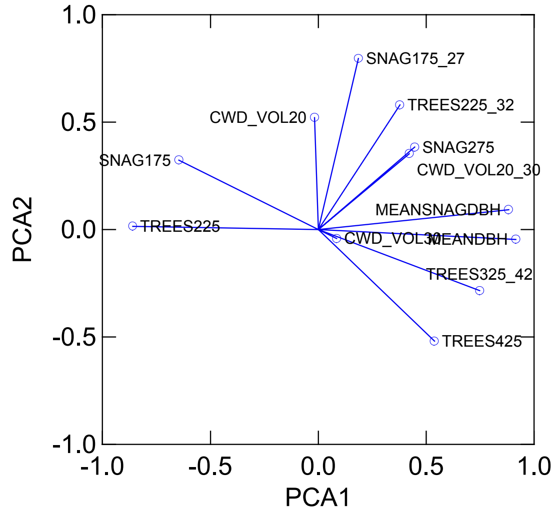

Figure 4. Component loadings for Lower productivity sites showing the association between input variables and PCA axes

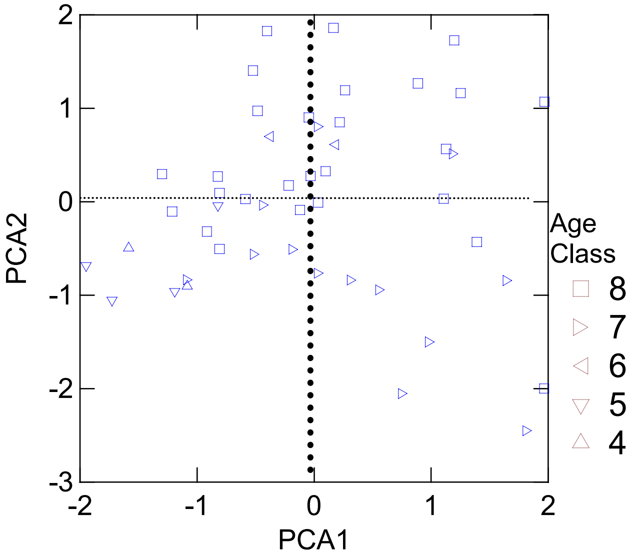

Figure 5. Relationship between PCA1 and PCA2 for Lower productivity sites, marked by the age of each plot

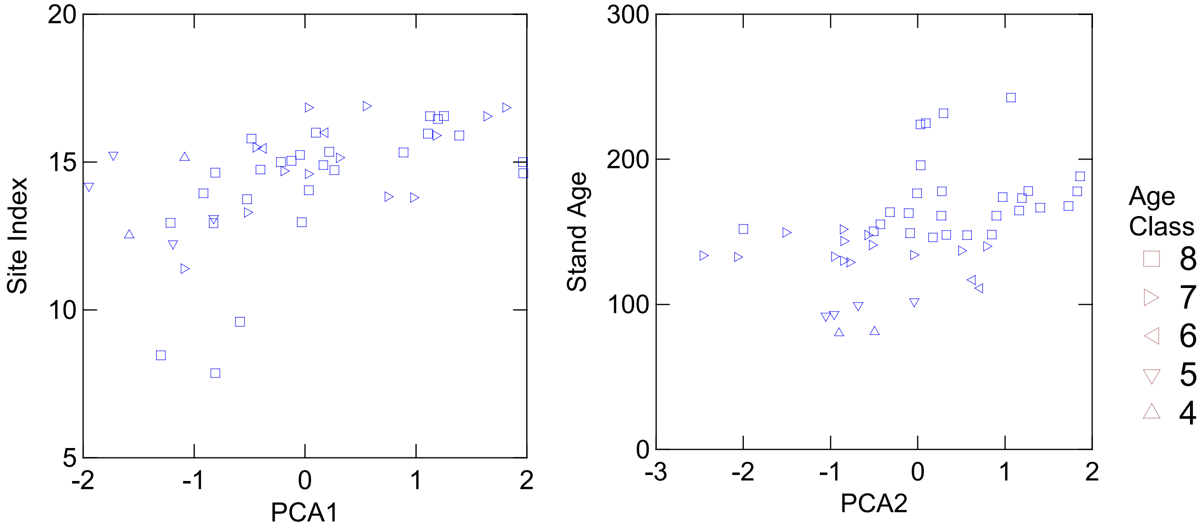

Figure 6. Relationship between PCA, stand age and site index for Lower productivity sites

Appendix 7. Scorecards for sample sites.

Table 1. Old Growth score for ‘Blue’, a Higher productivity older site – *Before Beetle* scenario

Old Growth Scorecard for HIGHER productivity sites in the Moist Interior Plateau Natural Disturbance Unit (Site Index >17)

Stand Name BLUE **Map Sheet** F086 **Polygon** PI(S) 8314-15 **Map Age** AC8

BEC variant SBSdk **Site Series** 01/06 **Slope** 5% **Aspect** 180 **Site Index** 20.1 **Size (ha)** 15ha

Structural Attribute	Measured Value		Threshold for High Structure	Minimum or Maximum Threshold	Attribute Score: Low = 0 High = 1
Density Live Trees <22.5 cm dbh	**188**	<	468 sph		1
Density Live Trees 22.5-32.5 cm dbh	**150**	<	227 sph	>50	1
Density Live Trees 32.5-42.5 cm dbh***	**150**	>	88 sph		1
Density Live Trees 42.5+ cm dbh***	**57**	>	16 sph		1
Total Live Tree Density	**545**	<	811	>340	1
Mean Tree dbh	**30.8**	>	24.9 cm		1
Mean Snag dbh	**25.5**	>	21.2 cm	<30.7	1
Density Snags <17.5 cm dbh	**50**	<	90 sph		1
Density Snags 27.5+ cm dbh	**57**	>	23 sph	<80	1
Total Snag Density	**168**	<	177 sph		1
CWD Density <20 cm	**214**	<	449		1
CWD Density 20-30 cm	**82**	>	72		1
Maximum Age*	**166**	>	152 years		1
Mean Age*		>	144 years		

Landscape Considerations / Notes	***TOTAL SCORE:*** 13 /13
	% of MAXIMUM SCORE: *100%*

Table 2. Old Growth score for ‘Blue’ – *Predicted Mortality* scenario, Conservative Estimate

Old Growth Scorecard for HIGHER productivity sites in the Moist Interior Plateau Natural Disturbance Unit (Site Index >17)

Stand Name BLUE **Map Sheet** F086 **Polygon** PI(S) 8314-15 **Map Age** AC8

BEC variant SBSdk **Site Series** 01/06 **Slope** 5% **Aspect** 180 **Site Index** 20.1 **Size (ha)** 15ha

Structural Attribute	Measured Value		Threshold for High Structure	Minimum or Maximum Threshold	Attribute Score: Low = 0 High = 1
Density Live Trees <22.5 cm dbh	175	<	468 sph		1
Density Live Trees 22.5-32.5 cm dbh	42	<	227 sph	>50	0
Density Live Trees 32.5-42.5 cm dbh***	33	>	88 sph		0
Density Live Trees 42.5+ cm dbh***	23	>	16 sph		1
Total Live Tree Density	273	<	811	>340	0
Mean Tree dbh	26.0	>	24.9 cm		1
Mean Snag dbh	31.2	>	21.2 cm	<30.7	0
Density Snags <17.5 cm dbh	56	<	90 sph		1
Density Snags 27.5+ cm dbh	273	>	23 sph	<80	0
Total Snag Density	441	<	177 sph		0
CWD Density <20 cm	214	<	449		1
CWD Density 20-30 cm	82	>	72		1
Maximum Age*	150	>	152 years		0
Mean Age*		>	144 years		

Landscape Considerations / Notes	***TOTAL SCORE:*** 6 /13
	% of MAXIMUM SCORE: 46%

Table 3. Old Growth Score for Entiako, a Lower productivity, old site – *Before Beetle* scenario.

Old Growth Scorecard for LOWER productivity sites in the Moist Interior Plateau Natural Disturbance Unit (Site Index >17)

Stand Name Entiako **Map Sheet** F024 **Polygon** PIS 8315-13 **Map Age** AC8

BEC variant SBPSmc **Site Series** 03 **Slope** 8% **Aspect** 340 **Site Index** 8.6 **Size (ha)** 25 ha

Structural Attribute	**Measured Value**		**Threshold for High Structure**	**Minimum or Maximum Threshold**	**Attribute Score: Low = 0 High = 1**
Density Live Trees <22.5 cm dbh	**1715**	<	1034 sph	>135	**0**
Density Live Trees 22.5-32.5 cm dbh	**187**	>	222sph		**0**
Density Live Trees 32.5-42.5 cm dbh***	**3**	>	26 sph		**0**
Density Live Trees 42.5+ cm dbh***	**0**	>	3 sph		**0**
Total Live Tree Density	**1905**	<	1297 sph	>395	**0**
Mean Tree dbh	**17.1**	>	20.5 cm		**0**
Mean Snag dbh	**12.1**	>	15.6 cm	<26.8	**0**
Density Snags <17.5 cm dbh	**633**	<	275 sph		**0**
Density Snags 27.5+ cm dbh	**3**	>	5 sph	<5	**0**
Total Snag Density	**700**	<	338 sph		**0**
CWD Density <20 cm	**917**	<	824 sph		**0**
CWD Density 20-30 cm	**16**	<	49 sph		**0**
Maximum Age*	**227**	>	151 years		**1**
Mean Age*		>	144 years		

Landscape Considerations / Notes

TOTAL SCORE: **1 /13**

% of MAXIMUM SCORE: ***8%***

Table 4. Old Growth Score for ‘Entiako’ – *Predicted Mortality* scenario, Conservative Estimate

Old Growth Scorecard for LOWER productivity sites in the Moist Interior Plateau Natural Disturbance Unit (Site Index >17)

Stand Name Entiako **Map Sheet** F024 **Polygon** PIS 8315-13 **Map Age** AC8

BEC variant SBPSmc **Site Series** 03 **Slope** 8% **Aspect** 340 **Site Index** 8.6 **Size (ha)** 25 ha

Structural Attribute	Measured Value		Threshold for High Structure	Minimum or Maximum Threshold	Attribute Score: Low = 0 High = 1
Density Live Trees <22.5 cm dbh	1237	<	1034 sph	>135	0
Density Live Trees 22.5-32.5 cm dbh	90	>	222sph		0
Density Live Trees 32.5-42.5 cm dbh***	0	>	26 sph		0
Density Live Trees 42.5+ cm dbh***	0	>	3 sph		0
Total Live Tree Density	1327	<	1297 sph	>395	0
Mean Tree dbh	15.2	>	20.5 cm		0
Mean Snag dbh	16.7	>	15.6 cm	<26.8	1
Density Snags <17.5 cm dbh	903	<	275 sph		0
Density Snags 27.5+ cm dbh	23	>	5 sph	<5	1
Total Snag Density	1279	<	338 sph		0
CWD Density <20 cm	917	<	824 sph		0
CWD Density 20-30 cm	16	>	49 sph		0
Maximum Age*	225	>	151 years		1
Mean Age*		<	144 years		

Landscape Considerations / Notes

TOTAL SCORE:

3 /13

% of MAXIMUM SCORE: ***23%***