Current State of Knowledge Regarding Secondary Structure in Mountain Pine Beetle Impacted Landscapes

MPB Impacted Stands Assessment Project

January 2012

K. David Coates[1*] and Donald L. Sachs[2]

[1]Ministry of Forests, Lands and Natural Resource Operations, Bag 6000, Smithers, BC, V0J 2N0, Canada.

[2]111 View St., Nelson, BC, V1L 2V8, Canada

[*]Corresponding Author: E-mail: dave.coates@gov.bc.ca; phone: (250) 847-6386; FAX: (250) 847-6353

Abstract

Within the different ecological zones impacted by the mountain pine beetle (MPB), we have focused on determining the proportion of each zone considered to be in poor condition and hence likely to recover slowly from a timber supply perspective, especially in the short- to mid-term. We did this by setting different threshold levels for the abundance of secondary structure – understory stocking and/or basal area of surviving residual trees – in post beetle attack stands. Understanding the extent of poorly stocked conditions is the first step in developing a recovery strategy and in properly projecting future yield expectations for MPB impacted landscapes.

Unlike a regeneration or free growing survey after logging there are no simple and clear standards for assessing if a MPB impacted stand is in good condition. Because of uncertainty in future performance we provided a range of threshold levels of post-beetle conditions (2-10 m^2 ha^{-1} of sub-canopy and canopy secondary structure and 400-1600 stems ha^{-1} of understory) and associated proportions of each ecological unit meeting or exceeding these thresholds by pre-beetle pine composition. In this way, the problem can be bracketed and it is possible to see how changing thresholds affects the extent of the problem. We then selected what we think are key thresholds for sub-canopy and canopy secondary structure (4 and 6 m^2 ha^{-1}) and understory stocking (800 and 1600 stems ha^{-1}) as potential critical thresholds for success. These values are based on earlier model simulations by SORTIE-ND and TASS. MPB damaged stands exceeding these thresholds would be expected to recover fairly well whereas stands below these thresholds are expected to recover poorly.

Our major conclusions for pine leading stands (greater than 50% pine) are:

1. Generalizations about secondary structure abundance based solely on the pre-beetle dominance of merchantable pine are crude at best. In reality, understory, sub-canopy and canopy secondary structure post-beetle can vary widely at any level of pine dominance.
2. MPB-impacted stands in the ESSF and ICH zones pose few problems for future timber supply recovery. These ecological units have high levels of residual secondary structure basal area and represent a small management risk. In fact, our analysis suggests some 92% of the ESSF and 100% of ICH zone sites impacted by MPB currently exceed 10 m^2 ha^{-1} of secondary structure basal area.
3. MPB-impacted stands in the SBS zone pose the greatest risk for future timber supply. As much as 31% of pine-leading stands may fall below the 6 m^2 ha^{-1} threshold in the SBS zone. The next greatest risk is in the IDF zone where some 20% of pine-leading stands may fall below the 6 m^2 ha^{-1} threshold. The risk reduces to 13-14% of the area in the MS and SBPS zones and then falls to 9% in the BWBS zone. Sample sizes were very low in the BWBS zone and results may be unreliable.
4. Combining residual secondary structure basal area thresholds with understory stocking thresholds will give a slightly more refined estimate of the proportion of area at greatest risk for future timber supply. Even if a site does not meet the minimum basal area threshold it may well exceed a minimum stocking threshold thus reducing the overall proportion of an ecological zone at risk for future timber supply, especially in the long-term. This proved to be the case. For example, including a 1600 stems ha^{-1} thresholds with the 6 m^2 ha^{-1} threshold reduced the area at risk in the SBS zone from 31 to 25%.
5. A simple basal area threshold, however, may adequately capture the proportion of area at risk in each ecological unit.
6. Threshold values need to be confirmed through model simulations and monitoring programs.

Introduction – Phase 1 - State of knowledge regarding secondary structure

The mountain pine beetle (MPB, *Dendroctonus ponderosae* Hopkins) is currently in the outbreak phase of an infestation cycle throughout much of its range in British Columbia. The epidemic is resulting in variable levels of damage from near complete mortality of all canopy trees in older lodgepole pine stands, to partial mortality in other pine stands and in mixed stands. The composition and abundance of trees surviving the epidemic (secondary structure) is also highly variable. It consists of varying combinations of species and densities of both understory and overstory trees. Extensive areas of MPB impacted forests will remain un-harvested and it is these stands that are the focus of this assessment. The broad objective of the assessment is to gain a better understanding of the future growth potential of MPB affected, un-harvested stands.

An analysis recently completed by Forest Analysis and Inventory Branch indicates that between 2 and 3 million hectares of the Timber Harvesting Land Base over 60 years in age and containing more than 50% pine would likely not be harvested or rehabilitated. The question that follows from this finding is "what is the future for these forests?" The broad objective of the MPB Impacted Stands Assessment Project is to characterize the future growth potential of these stands if left to naturally develop. The project has six phases, listed below, and this report presents results from phase 1. Results for the subsequent phases will be reported elsewhere.

Phases of the MPB Impacted Stands Assessment Project:

1. Assess the current state of knowledge and information regarding secondary structure by impacted biogeoclimatic zones.

2. Developing a first approximation of what the stand growth potential could be following MPB attack based on existing information and professional experience.

3. Identify areas where critical information required to define future stand growth of attacked stands is missing or weak and develop a project plan to address.

4. Collect required critical information to improve growth predictions.

5. Develop more refined stand growth trajectories for impacted stands based on improved information.

6. Monitor actual stand growth relative to expectations.

Methods – Phase 1 - State of knowledge regarding secondary structure

The MPB epidemic has been killing swaths of lodgepole pine in the interior forests of British Columbia since the late 1990s. The term *secondary structure* was coined as a way to describe the abundance, composition or distribution of trees that remain alive in stands impacted by the MPB epidemic (Coates et al. 2006). Secondary structure can be broken into two main components: understory and overstory trees. Understory trees include seedlings and saplings and can include smaller lodgepole pine trees that survive the epidemic. Overstory trees that survive the beetle epidemic are typically of non-host species (e.g., interior spruce, subalpine fir, Douglas-fir, or broadleaf species). Phase 1 of the project has focused on summarizing existing plot data from pine stands throughout the range of the current MPB epidemic in order to characterize secondary structure (Table 1).

Criteria for plots and trees to be included in the analysis

Only plots from stands that were considered to be at least 60 years old were included in the analysis. Plots had to be from one of the following six biogeoclimatic zones: the Boreal White and black Spruce, the Engelmann Spruce-Subalpine Fir (ESSF), the Interior Cedar-Hemlock (ICH), the Interior Douglas Fir (IDF), the Montane Spruce (MS), the Sub-Boreal Pine Spruce (SBPS), and the Sub-Boreal Spruce (SBS) zones.

Overstory lodgepole pine can and will survive through the current epidemic; however, numbers will be highly variable and unpredictable. In this analysis, sub-canopy and canopy lodgepole pine trees, 12.5 cm DBH and greater, were not considered to be secondary structure even if they were alive in the source plot data. The only pine trees that could contribute to secondary structure composition or abundance were seedlings, saplings, and sub-canopy trees that were less than 12.5 cm DBH. This may be a conservative estimate; some larger sub-canopy and canopy pine trees will survive the MPB attack. We use this approach to reduce the risk of over-estimating secondary structure and to provide a clear representation of the non-pine secondary structure present in the understory, sub-canopy, and canopy layers.

Data sources used in the analysis

The individual data sources used in our analysis were collated from individual studies established at different times relative to the mountain pine beetle attack (Table 1). These studies and plots were established before the current epidemic hit, during the current epidemic, or after the worst of the current epidemic had passed. Information on the individual studies and the methods used in data collection can be found in Coates et al. 2006, 2009; Nigh et al. 2008; Vyse et al. 2009; and Pousette 2010. All VRI data was obtained from the Forest Analysis and Inventory Branch. All individual data sources were carefully checked for overlap and duplicate plots deleted.

Table 1. Data sources and number of plots used in this analysis.

source	>= 30% Pl		>= 50% Pl	
	(# plots)	(% ot total)	(# plots)	(% ot total)
Burton	155	3.6	151	3.9
Cariboo	818	19.0	813	21.3
Cichowski	56	1.3	56	1.5
Coates	53	1.2	48	1.3
Delong	18	0.4	18	0.5
Hawkes	79	1.8	72	1.9
Nigh	539	12.5	538	14.1
Pousette	881	20.5	745	19.5
Rakochy	303	7.0	303	7.9
VRI	893	20.7	658	17.2
Vyse	512	11.9	421	11.0
Total	4307	100.0	3823	100.0

Specific information about data sources used in this analysis:

VRI data:

Regeneration was measured in three height classes: 0.1 -0 .3m, 0.3 – 1.3m, > 1.3 m. All trees < 4.0 cm DBH are in the small tree class. Trees > 4 cm DBH are broken down by species, size class and whether live or dead. Stems ha^{-1} and basal area ha^{-1} of live and dead trees were provided in VRI data summary tables.

Pousette data:

These plots are from the Hawkins data sets used in the original study (Coates et al. 2006). The majority of these were in the Coates data, but there are some additional Hawkins plots and Pousette did much work to clean up the data.

Vyse data:

512 plots in 167 sample stands in the southern interior, mostly in the Kamloops Forest District. BEC zones included ESSF, IDF, MS, SBPS, and SBS. Small seedlings measured (< 10 cm tall), as well as established seedlings 0.1 – 1.3 m tall. Saplings (1.3 m tall and < 7.5 cm DBH) and poles (7.5 cm – 15.0 cm DBH) were counted by diameter class. Canopy trees (> 15.0 cm DBH) were measured with prism plots so only basal area was recorded.

Nigh data:

Data from 18 sample stands, all from the MS zone were used in this analysis. Most stands had 40 0.1 ha subplots, but a few stands had missing subplots. A total of 707 subplots were included. All trees > 10 m height were considered canopy trees and DBH was recorded. Smaller trees were considered to be regeneration and were broken down into 5 classes:

- class 1: height < 0.1 m
- class 2: height between 0.1 and 0.3 m
- class 3: height between 0.3 and 1.0 m
- class 4: height between 1.0 and 2.0 m
- class 5: height between 2.0 and 10.0 m

Therefore, classes 1-3 were compatible with all other data sets. Classes 4 and 5 were not compatible as there were no DBH measurements on saplings and poles. Species specific height vs. DBH curves from SORTIE-ND were used to generate DBH for these trees, and they were apportioned to size classes used in this analysis.

We were able to summarize the plot information from the individual data sources (see above) into different tree layers that were then used in the current analysis:

- Established seedlings (10 cm to < 1.3 m height)
- Saplings (1.3 m tall to 7.5 cm DBH)
- Poles (7.5 – 12.5 cm DBH)
- Canopy tree class 1 (12.5 – 17.5 cm DBH)
- Canopy tree class 2 (17.5 – 22.5 cm DBH)
- Canopy tree class 3 (> 22.5 cm DBH)

Datasets compiled for the current analysis

In the broadest dataset, individual sample plots needed to contain 30% or more of their overstory basal area ($m^2\ ha^{-1}$) in lodgepole pine pre-epidemic. The basal area of the overstory was calculated based on merchantability limit of 12.5 cm DBH for lodgepole pine and 17.5 cm DBH for other species. Dead pine trees from individual plots were included in the pine proportion calculation to give an estimate of the original stand structure before beetle attack. A total of 4307 plots contained 30% or more lodgepole pine in the overstory using these criteria. At a minimum of 50% lodgepole pine in the overstory, then 3823 plots are in this reduced dataset (Tables 1 and 2).

Three further datasets were compiled based on different pine canopy class proportions (Table 3):

- at least 30% pine, but less than 50% (30-50% pine)
- at least 50% pine, but less than 70% (50-70% pine)
- at least 70% pine (70-100% pine)

Table 2. Number and percent of plots by BEC zone with >=50% canopy lodgepole pine prior to the MPB attack.

BEC Zone	>= 50% canopy pine	
	(# plots)	(% ot total)
SBS	1698	44.4
MS	1031	27.0
SBPS	428	11.2
IDF	390	10.2
ESSF	206	5.4
ICH	48	1.2
BWBS	22	0.4
Total	3823	100

Table 3. Number and percent of plots by BEC zone with 30-50%, 50-70% and 70-100% canopy lodgepole pine prior to the MPB attack.

BEC zone	Percent canopy lodgepole pine			
Frequency Row Pct	30-50%	50-70%	70-100%	Total
SBS	11.9 229	19.2 370	68.9 1328	1927
MS	6.4 71	12 132	81.6 899	1102
SBPS	3.6 16	17.6 78	78.8 350	444
IDF	14.3 65	21.8 99	64 291	455
ESSF	27.2 77	25.1 71	47.7 135	283
ICH	28.4 19	29.9 20	41.8 28	67
BWBS	24.1 7	34.5 10	41.4 12	29
Total	484	780	3043	4307

Results – Secondary structure in MPB impacted biogeoclimatic zones

The information provided in the tables and figures of this report parse out the proportion of plots in different BEC units that meet specific criteria based on pre- and post-beetle stand structure. Pre-beetle stand structure was based on the percent of canopy pine in each plot prior to beetle attack (Tables 2 and 3). Post-beetle secondary structure represents the seedlings, saplings, sub-canopy, and canopy trees that have survived the beetle epidemic. Here, we report information for conifer species only as broadleaved species were very minor components of the data sources and, generally, not actively managed for on the site types examined.

Differences in secondary structure among 30-50%, 50-70% and 70-100% lodgepole pine stands

Our first objective was to look for differences in secondary structure among the three broad percent of canopy pine categories (Tables 4-6). These three tables provide basic information on abundance of conifer seedlings (Table 4), conifer seedlings and saplings combined (Table 5), and basal area of all conifers greater than 7.5 cm DBH (Table 6) in the three broad percent of canopy pine categories in each BEC zone. The information provided in each table can be further summarized in different ways. For example, if you want to know what proportion of plots in a BEC unit have a minimum of 800 stems ha^{-1} of seedling and saplings you simply add together the 0-400 and 400-800 stems ha^{-1} categories in Table 5.

As might be expected, plots with 30-50% pine pre-beetle generally had more abundant understory stocking post-beetle than plots with 70-100% pine (Tables 4-5). For example, in the SBS zone 43.2% of plots in 30-50% pine had 1,600 stems ha^{-1} or more conifer seedlings and saplings compared to 26.8% of plots in 70-100% pine (Table 5). Conifer understory stocking was higher in more mixed stands with the exception of the SBPS and IDF zones, where there were little differences in conifer understory stocking by pine overstory component.

One would expect a greater basal area of secondary structure post-beetle in more mixed species stands than in pine dominated stands and this was usually the case, although differences were not always large (Table 6). The differences were most pronounced in the SBS and MS zones and least pronounced in the SBPS, ESSF, ICH, and BWBS zones (Table 6). In the SBS zone, 85.6% of plots in 30-50% pine stands had 10 m^2 ha^{-1} or more of secondary structure basal area post-beetle attack compared to 45.6% of plots in 70-100% pine stands (Table 6). In general, one would expect the recovery of 30-50% pine stands to be excellent in the MS, IDF, ESSF, and ICH zones since 97% plus of plots had 10 m^2 ha^{-1} or more of secondary structure basal area after beetle attack. Up to 15% of plots in 30-50% pine stands in other ecological zones had less than 10 m^2 ha^{-1} of secondary structure basal area (Table 6). In contrast, in the ESSF, ICH and BWBS zones greater than 90% of plots in 70-100% pine stands had 10 m^2 ha^{-1} or more of secondary structure basal area after beetle attack, dropping to 45-76% in the SBS, MS, SBPS, and IDF zones (Table 6).

In general, it is correct to say 30-50% pine stands are in better shape post-beetle, especially in the SBS, MS, and IDF ecological units, however, there were not substantial differences in post-beetle secondary structure basal area by pre-beetle pine composition in the SBPS, ESSF, ICH, and BWBS zones. Differences were more pronounced in understory stocking based on pre-beetle pine composition.

Secondary structure in stands with 50% or more lodgepole pine

Tables 7-9 summarize understory stocking and secondary structure basal area for stands with 50% or more lodgepole pine pre-beetle attack (pine leading) in the same groupings as presented in Tables 4-6. Pine leading stands in the ESSF zone had the highest stocking of seedlings and saplings exceeding 1,600 stems ha^{-1} post-beetle whereas the SBS, MS and BWBS zones had the lowest conifer understory densities (Table 7 and 8).   In the SBS and MS zones some 27-30% of plots had combined conifer seedlings and saplings densities that exceeded 1,600 stems ha^{-1} compared to 44-49% of plots with less than 400 stems ha^{-1} (Table 8). The SBS zone (50.5%) had the lowest proportion of plots in pine leading stands with 10 m^2 ha^{-1} or more of secondary structure basal area after beetle attack (Table 9). This compares to 91.7% and 100%, respectively for the ESSF and ICH zones (Table 9).

Another way of presenting results for pine leading stand is to examine the percent of plots in each ecological zone that meet threshold levels of conifer understory densities or threshold levels of secondary structure basal area post-beetle attack (Fig. 1-3). The values represented by each bar in each figure can be calculated from data presented in tables 7-9 (e.g., bar values in figure 1 are from data in table 7). Figures 1-3 show clear differences among the BEC zones in conifer seedling (Fig. 1), conifer seedling and sapling (Fig. 2), and secondary structure basal area (Fig. 3) thresholds. Remember that these graphs portray the proportion of plots with understory stocking or secondary structure basal areas equal to or below specific thresholds (e.g., 800 stems ha^{-1} or 6 m^2 ha^{-1}) and as such, graphs with shorter bars represent ecological zones with better understory stocking or higher secondary structure basal areas. Understory stocking is clearly poorest in the SBS, MS, and BWBS zones compared to the ESSF, IDF, and ICH zones, with the SBPS zone being intermediate (Figs. 1 and 2). In terms of secondary structure basal area, the SBS zone is the poorest closely followed by the IDF zone and then either the MS or SBPS zones (Fig. 3). The ESSF, ICH and BWBS zones have the highest levels of post-beetle secondary structure basal area.

Specific criteria for post-beetle timber supply recovery in pine leading stands

So far we have provided summary data by pre-beetle pine composition and general categories of secondary structure post-beetle. In terms of timber supply recovery post-beetle it will be different combinations of understory stocking and/or residual secondary structure basal area that will result in conditions with a reasonable chance of recovery. Conversely, when both understory stocking and secondary structure basal area are below certain key thresholds, stand recovery may be a long and slow process without management intervention. In this section, from a timber supply perspective, we explore the proportions of each ecological zone that fall below (deemed to be in poor condition) or above (deemed to be in good condition) specific threshold levels of post-beetle understory stocking, secondary structure basal area, or combinations of the two. It is important to state here that minimum threshold levels for stand recovery based on understory stocking or residual secondary structure basal area are difficult to establish, hence we provide information for a reasonable range of conditions. If the reader prefers a different threshold than we present, the values can likely be calculated from the summary data presented in Tables 4-9. Threshold levels need to be confirmed by simulation modelling which is another component of the overall MPB Impacted Stands Assessment Project.

First, we looked at different thresholds of secondary structure basal area of sub-canopy and canopy trees (all conifers >7.5 cm DBH) when understory stocking (density of seedlings and saplings) was marginal (minimums of 800 or 1,600 stems ha^{-1}) across MPB impacted stands in the different ecological zones (Tables 10-11). The assumption is that understory stocking is poor and stand recovery primarily depends on the abundance of surviving sub-canopy and canopy trees. If, for example, you set 6 m^2 ha^{-1} of secondary structure basal area after beetle attack as a minimum threshold for good recovery, you can tell from these tables what proportion of each BEC zone does not make this threshold. For example, 25.3% of all SBS zone plots had less than 6 m^2 ha^{-1} of secondary structure basal area and an understory of 1,600 stems ha^{-1} or less and could be considered in poor condition using these threshold values (n=430 of 1698 total SBS plots, Tables 10 and 3). If the minimum understory density threshold is reduced to 800 stems ha^{-1}, then 20.7% of all SBS plots meet this threshold for understory conditions and had less than 6 m^2 ha^{-1} of secondary structure basal area (n=351 of 1698 total SBS plots, Tables 11 and 3). Or, in other words, about 5% of MPB impacted stands moved out of poor conditions by reducing the understory threshold from 1,600 to 800 stems ha^{-1} in the SBS zone at a threshold of 6 m^2 ha^{-1} of secondary structure basal area after beetle attack. This type of description of each BEC zone can be generated by selecting different secondary structure basal area thresholds in Tables 10 and 11.

Tables 10 and 11 clearly demonstrate that even when understory stocking is poor in the ESSF and ICH zones the abundance of surviving sub-canopy and canopy trees is high suggesting recovery in these two ecological zones areas should be reasonable regardless of understory conditions.

Second, we summarize the proportion of plots below threshold secondary structure basal areas (4, 6, 8 and 10 m^2 ha^{-1}) by the five different understory density classes (Table 12-13). These tables can be used to examine 'good' or 'poor' conditions depending on the threshold level selected for secondary structure basal area and understory stocking post-beetle attack. If, for example a threshold of 4 m^2 ha^{-1} or less of secondary structure basal area is selected and then combined with low understory stocking of 0 to 400 stems ha^{-1}, then some 12% of all SBS plots meet these criteria and may be considered to have a 'poor' chance of recovery due to low residual secondary structure basal area and understory stocking (n=204 of 1698 total SBS plots, Tables 12 and 3). In contrast, using the same basal area threshold (4 m^2 ha^{-1} or less), but looking for plots with a well stocked understory of 1,600 or more stems ha^{-1}, some 5.6% of SBS plots meet this criteria and may have a 'good' probability of recovery due to a robust understory (n=95 of 1698 total SBS plots, Tables 12 and 3). Exactly the same information can be extracted for basal area thresholds of 6, 8 and 10 m^2/ ha^{-1} (Tables 12-13).

Tables 14-15 are the mirror images of Tables 12-13 in that they present the proportion of plots above the threshold secondary structure basal areas of 4, 6, 8 and 10 m^2 ha^{-1} by the five different understory density classes. Understory conditions are far less important here since the overstory secondary structure basal area threshold is a fixed level of basal area or higher. The tables do, however, provide an indication of the proportion of a BEC zone that might be in very good condition, that is exceeding the selected basal area threshold with a well stocked understory of 1,600 stems ha^{-1} or higher. For example, at a threshold basal area of more than 6 m^2 ha^{-1}, some 22.2% of plots in the SBS zone also have high understory stocking (1,600 stem ha^{-1} +, n=377 of 1698 total SBS plots, Tables 14 and 3).

At this point in time, it is not clear at what specific post-beetle threshold conditions we can expect good recovery in the mid- or long-term for timber supply and the threshold will likely vary depending on the time frames for recovery. Modelling of the different secondary structure basal area and understory conditions described here should help inform decisions around threshold levels for recovery.

Third, returning to the earlier objective of looking for differences in secondary structure among the three broad percent of canopy pine categories (30-50%, 50-70, and 70-100% pine), we have summarized the proportion of plots above or below 6 m^2 ha^{-1} of secondary structure basal area and above or below 1,600 stems ha^{-1} of understory (Tables 16-17). These mutually exclusive threshold categories provide an indication of how residual stand conditions post-beetle may vary in stands with different pre-beetle pine composition. Interestingly, the proportion of plots above or below 6 m^2 ha^{-1} of secondary structure basal area or above or below 1,600 stems ha^{-1} of understory within each BEC zone were often fairly similar regardless of pre-beetle pine composition. Clearly, some exceptions existed, especially at low basal area and understory stocking where the proportion of plots meeting this condition (<=6 m^2 ha^{-1} and <=1,600 stems ha^{-1}) in 70-100% SBS, MS, and IDF zones were much higher than in other pre-beetle compositions. In general, however, pre-beetle pine composition does not appear to be an overly useful indicator of post-beetle conditions.

Lastly, we provide a summary table using less that 4 and 6 m^2 ha^{-1} of secondary structure basal area and less that 800 and 1,600 stems ha^{-1} of understory density as critical thresholds that need to be exceeded for a reasonable expectation of future recovery of MPB impacted stands. Based on preliminary model results it appears these thresholds may be especially important for mid-term timber supply.

The proportion of each BEC unit with less than 4 m^2 ha^{-1} of post-beetle secondary structure basal area varied from 0 to 22% increasing to a maximum of 31% with a less than <6 m^2 ha^{-1} threshold (Table 18). The SBS, MS, SBPS, and IDF zones had the greatest proportion of plots with low post-beetle secondary structure basal area. The ESSF ad ICH zones have higher levels of post-beetle secondary structure basal area and the BWBS zone is somewhat intermediate, but with very low sample sizes making interpretations difficult.

Combining the secondary structure basal area thresholds with understory stocking thresholds may give a slightly more refined estimated of the proportion of area, based on proportion of plots, in each BEC zone that could be considered in poor condition. For example, some 18.3% of SBS plots had less than 4 m^2 ha^{-1} of post-beetle secondary structure basal area and less than 1,600 stems ha^{-1} of understory (Table 18). At less than 6 m^2 ha^{-1} of post-beetle secondary structure basal area and less than 1,600 stems ha^{-1} of understory the proportion of plots meeting this standard in the SBS decreased to 25.3% from 31.1% based on the basal area criteria only (Table 18). Understory conditions, however, will change over time with ingress of natural regeneration and may be less important than post-beetle secondary structure basal area for overall stand recovery, especially in the mid-term.

Discussion – State of knowledge regarding secondary structure

The magnitude of the impact by the mountain pine beetle (MPB) can be highly variable from stand to stand. Obviously, pine dominated stands will be more affected than stands with mixed species composition where pine is a minor component.

There are two pathways for recovery of MPB attacked stands. First, impacted stands can be salvage logged, usually by clearcutting with retention, followed by planting or natural regeneration. Salvage logging prescriptions follow standard practices with outcomes as predictable as conventional non-salvage logging from a timber supply perspective. Second, and the focus of our analysis, is the recovery of unmanaged natural stands. This is a much more complicated issue for projection of future stand development compared to a salvage logging and planting scenario. Here, we discuss the factors that will influence the recovery of unmanaged stands.

Virtually all canopy lodgepole pine trees will be killed by MPB attack in heavily impacted stands, but non-host tree species will survive and small diameter pine may also survive. We use the term *secondary structure* to describe the abundance of surviving trees post-MPB attack. The amount of secondary structure within MPB impacted stands is a key element for the future sustainability of many forest resources and values (hydrological recovery period, timber supply, wildlife habitat, range conditions, carbon storage, species diversity, viewscapes, and tourism) in MPB impacted landscapes. In order to access the impact of the epidemic on any of the resources or values a good understanding of the abundance and structural composition of secondary structure post-attack is required. We have compiled plot data from throughout the epidemic area in BC. Our focus is on timber supply recovery of impacted stands without any management intervention. The information summarized here is also of great utility for decisions around other resources and values in these forests.

The information from this analysis can be used to estimate the proportion of area in each biogeoclimatic unit (BEC) that meets different threshold levels of secondary structure abundance. We use simple metrics of total conifer understory density (stems ha^{-1}) and total conifer sub-canopy and canopy basal area (m^2 ha^{-1}) of secondary structure in post-MPB impacted stands. Our analysis does not inform how that secondary structure is spatially distributed at the stand or landscape scales nor the species acceptability or condition, however, the incidence of physical damage and forest health problems in secondary structure was found to be low by Lewis (2011). It is worth remembering that these stands are natural stands composed of native species much like all unmanaged stand in BC. The issue for projecting the future growth potential of individual stands or landscapes is to gain a better understanding how different combinations of understory and overstory stocking will translate into future growth. Lewis (2011) found strong release in growth of secondary structure with the magnitude of response related to the proportion of overstory killed. Another component of the MPB Impacted Stand Assessment Project is to model future growth responses of impacted stands.

One might expect understory stocking and secondary structure basal area to increase as pine basal area decreases. In general, this trend was observed in the data but it was not strong or consistent among the ecological zones. Generalizations about secondary structure abundance based solely on the pre-beetle dominance of merchantable pine are crude at best. In reality, understory, sub-canopy and canopy secondary structure post-beetle can vary widely at any level of pine dominance, requiring site-specific field data for a precise estimate of secondary structure abundance.

In this analysis we were especially interested in identifying the extent of each ecological zone that, immediately post-beetle, had low abundance of secondary structure and might be considered to be in poor condition – low understory stocking, low basal area of living residual trees – and hence likely to recover slowly from a timber supply perspective, especially in the short- to mid-term. Understanding the extent of poorly stocked conditions is the first step in developing a recovery strategy and in properly projecting future yield expectations for MPB-impacted landscapes. Because of uncertainty in future performance we have provided a range of threshold levels of post-beetle conditions and associated proportions of each ecological unit meeting these thresholds. In this way, we can bracket the problem and see how small changes in selected thresholds affect the extent of the problem. We have also presented data in a way that allows the reader to calculate their own thresholds should they wish.

Unlike a regeneration or free growing survey after logging there are no simple and clear standards for assessing whether a MPB-impacted stand is in good condition. We have selected thresholds of 4 and 6 m^2 ha^{-1} of sub-canopy and canopy secondary structure as potential critical thresholds for success (Table 18). These values are based on earlier model simulations by SORTIE-ND and TASS. MPB damaged stands exceeding these thresholds would be expected to recover fairly well whereas stands below these thresholds are expected to recover poorly.

MPB-impacted stands in the ESSF and ICH zones pose few problems based on these thresholds. These ecological units have high levels of residual secondary structure basal area and represent a small management risk. In fact, our analysis suggests some 92% of the ESSF and 100% of ICH zone sites impacted by MPB currently exceed 10 m^2 ha^{-1} of secondary structure basal area.

The SBS zone poses the greatest risk for future timber supply. As much as 31% of pine-leading stands may fall below the 6 m^2 ha^{-1} threshold in the SBS zone. The next greatest risk is in the IDF zone where some 20% of pine-leading stands may fall below the 6 m^2 ha^{-1} threshold (Table 18). The risk reduces to 13-14% of the area in the MS and SBPS zones and then falls to 9% in the BWBS zone (Table 18). Sample sizes were very low in the BWBS zone and results may be unreliable (Table 3).

Combining residual secondary structure basal area thresholds with understory stocking thresholds may give a slightly more refined estimate of the proportion of area in each BEC zone that could be considered at greatest risk for future timber supply. Even if a site does not meet the minimum basal area threshold it may well exceed a minimum stocking threshold thus reducing the overall proportion of an ecological zone at risk for future timber supply. This proved to be the case, but the impact of including understory thresholds of 800 and 1600 stems ha^{-1} was small (area reduction of 2-5%, mostly 1-2%, Table 18). This suggests a simple basal area threshold may adequately capture the proportion of area at risk.

In summary, we believe thresholds such as those presented in Table 18 provide the clearest picture of the proportion of the pine-leading land base within each BEC unit that is at risk for future timber supply. Threshold values need to be confirmed through model simulations and monitoring programs.

Acknowledgements

The following individual contributed to the overall direction of project: Albert Nussbaum, Graham Hawkins, John Pousette, Susanna Laaksonen-Craig, Pat Martin, Atmo Prasad, Barry Snowdon, Terry Chow, Xioping Yuan, Jim Goudie, and Sam Otukol.

References

Bergerud, W. 2002. The Effect of the Silviculture Survey Parameters on the Free-Growing Decision Probabilities and Projected Volume at Rotation. Res. Br., B.C. Min. For., Victoria, B.C. Land Manage. Handb. No. 50. http://www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh50.htm

Coates, K.D., C. DeLong, P.J. Burton, and D.L. Sachs. 2006. Abundance of secondary structure in lodgepole pine stands affected by the mountain pine beetle. Report for the Chief Forester, 17 pp. http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/stewardship/

Coates, K.D., T. Glover, and B. Henderson. 2009. Abundance of secondary structure in lodgepole pine stands affected by the mountain pine beetle in the Cariboo-Chilcotin. Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, MPB working paper 2009-20. 47 pp. http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/31195.pdf

Lewis, K.J. 2011. Forest health and mortality of advance regeneration following canopy tree mortality caused by the mountain pine beetle. Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, MPB Working Paper 2010-03. 26 pp. http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/32213.pdf

Nigh G.D., J.A. Antos, and R. Parish. 2008. Density and distribution of advance regeneration in mountain pine beetle killed lodgepole pine stands of the Montane Spruce zone of southern British Columbia. Can. J. For. Res. 38:2826-2836.

Pousette, J. 2010. Secondary stand structure and its timber supply implications for mountain pine beetle attacked forests on the Nechako Plateau of British Columbia. Masters Thesis – Univ. of Northern B.C., 198 pp.

Vyse, A., C. Ferguson, D.J. Huggard, J. Roach, and B. Zimonick. 2009. Regeneration beneath lodgepole pine dominated stands attacked or threatened by the mountain pine beetle in the south central Interior, British Columbia. For. Ecol. Manage. 258(1):S36-S43.

BEC zone	Pl 30-50% Conifer seedlings stems ha^{-1}					Pl 50-70% Conifer seedlings stems ha^{-1}					Pl 70+% Conifer seedlings stems ha^{-1}				
% of plots / Samples	0-400	401-800	801-1200	1201-1600	1600+	0-400	401-800	801-1200	1201-1600	1600+	0-400	401-800	801-1200	1201-1600	1600+
SBS	51.1	9.2	4.4	3.5	31.9	49.7	10.5	7.8	5.1	26.8	63.8	11	6.6	2.5	16.2
	117	21	10	8	73	184	39	29	19	99	847	146	87	33	215
MS	56.3	14.1	4.2	4.2	21.1	47	13.6	6.1	3	30.3	69.9	8	3.7	3.1	15.4
	40	10	3	3	15	62	18	8	4	40	628	72	33	28	138
SBPS	93.8	6.3	0	0	0	53.8	10.3	9	5.1	21.8	53.1	9.4	8.3	4.6	24.6
	15	1	0	0	0	42	8	7	4	17	186	33	29	16	86
IDF	63.1	4.6	6.2	4.6	21.5	49.5	10.1	7.1	3	30.3	52.2	6.9	6.5	3.1	31.3
	41	3	4	3	14	49	10	7	3	30	152	20	19	9	91
ESSF	16.9	7.8	6.5	5.2	63.6	14.1	15.5	7	5.6	57.7	38.5	6.7	4.4	5.2	45.2
	13	6	5	4	49	10	11	5	4	41	52	9	6	7	61
ICH	26.3	15.8	15.8	0	42.1	25	15	0	0	60	57.1	10.7	0	10.7	21.4
	5	3	3	0	8	5	3	0	0	12	16	3	0	3	6
BWBS	71.4	28.6	0	0	0	70	0	0	0	30	66.7	16.7	16.7	0	0
	5	2	0	0	0	7	0	0	0	3	8	2	2	0	0
Total	236	46	25	18	159	359	89	56	34	242	1889	285	176	96	597

Table 4. Percent of plots (top) and sample size (bottom) of total conifer seedling (10 cm to 1.3 m tall) by BEC zone, percent canopy lodgepole pine, and density class. Density classes are 0-400, 401-800, 801-1200, 1201-1600, and greater than 1600 stems ha^{-1}. For example, in >70% pine stands, in the ESSF zone, 38.5% of plots (n=52) had less than 400 stems ha^{-1} and 45.2% of plots (n=61) exceeded stems ha^{-1} of total conifer seedlings.

	Pl 30-50%					**Pl 50-70%**					**Pl 70+%**				
BEC zone	**Conifer seedlings+saplings stems ha^{-1}**					**Conifer seedlings+saplings stems ha^{-1}**					**Conifer seedlings+saplings stems ha^{-1}**				
% of plots **Samples**	**0-400**	**401-800**	**801-1200**	**1201-1600**	**1600+**	**0-400**	**401-800**	**801-1200**	**1201-1600**	**1600+**	**0-400**	**401-800**	**801-1200**	**1201-1600**	**1600+**
SBS	36.2	7.9	6.6	6.1	43.2	30.3	10.8	10.3	6.2	42.4	48.3	12.7	7.2	5	26.8
	83	18	15	14	99	112	40	38	23	157	641	169	96	66	356
MS	42.3	8.5	9.9	4.2	35.2	29.5	12.9	6.8	8.3	42.4	51.4	11.9	6.7	5.9	24.1
	30	6	7	3	25	39	17	9	11	56	462	107	60	53	217
SBPS	81.3	12.5	0	0	6.3	29.5	12.8	5.1	10.3	42.3	34.6	10	6.9	6	42.6
	13	2	0	0	1	23	10	4	8	33	121	35	24	21	149
IDF	35.4	7.7	6.2	6.2	44.6	19.2	6.1	10.1	9.1	55.6	29.6	9.3	8.6	7.2	45.4
	23	5	4	4	29	19	6	10	9	55	86	27	25	21	132
ESSF	9.1	3.9	5.2	3.9	77.9	11.3	9.9	4.2	5.6	69	29.6	8.1	3	4.4	54.8
	7	3	4	3	60	8	7	3	4	49	40	11	4	6	74
ICH	15.8	10.5	5.3	0	68.4	20	10	5	0	65	53.6	10.7	3.6	3.6	28.6
	3	2	1	0	13	4	2	1	0	13	15	3	1	1	8
BWBS	57.1	14.3	14.3	14.3	0	60	10	0	0	30	58.3	16.7	8.3	8.3	8.3
	4	1	1	1	0	6	1	0	0	3	7	2	1	1	1
Total	163	37	32	25	227	211	83	65	55	366	1372	354	211	169	937

Table 5. Percent of plots (top) and sample size (bottom) of total conifer seedling and sapling density (10 cm tall to 7.5 cm DBH) by BEC zone, percent canopy lodgepole pine, and density class. Density classes are 0-400, 401-800, 801-1200, 1201-1600, and greater than 1600 stems ha^{-1}. For example, in >70% pine stands, in the ESSF zone 29.6% of plots (n=40) had less than 400 stems ha^{-1} and 54.8% of plots (n=74) exceeded 1600 stems ha^{-1} of total conifer seedlings and saplings.

	Pl 30-50%						Pl 50-70%						Pl 70+%					
BEC zone	Basal Area m^2 ha^{-1} – all conifers > 7.5 cm dbh						Basal Area m^2 ha^{-1} – all conifers > 7.5 cm dbh						Basal Area m^2 ha^{-1} – all conifers > 7.5 cm dbh					
% of plots Samples	0-2	2-4	4-6	6-8	8-10	10+	0-2	2-4	4-6	6-8	8-10	10+	0-2	2-4	4-6	6-8	8-10	10+
SBS	1.3	1.7	3.9	2.6	4.8	85.6	2.2	2.4	5.4	9.7	11.9	68.4	16.5	10.2	10.3	9.4	8.1	45.6
	3	4	9	6	11	196	8	9	20	36	44	253	219	135	137	125	107	605
MS	0	0	0	2.8	0	97.2	0	0	3	5.3	3.8	87.9	11.2	2	2.3	4.4	3.7	76.3
	0	0	0	2	0	69	0	0	4	7	5	116	101	18	21	40	33	686
SBPS	6.3	0	0	12.5	12.5	68.8	1.3	0	9	19.2	1.3	69.2	3.4	4	6	9.1	6.6	70.9
	1	0	0	2	2	11	1	0	7	15	1	54	12	14	21	32	23	248
IDF	1.5	0	0	0	1.5	96.9	1	5.1	3	1	4	85.9	10.3	7.9	5.5	6.5	6.2	63.6
	1	0	0	0	1	63	1	5	3	1	4	85	30	23	16	19	18	185
ESSF	0	0	1.3	0	1.3	97.4	1.4	0	2.8	0	0	95.8	0	2.2	1.5	3	3.7	89.6
	0	0	1	0	1	75	1	0	2	0	0	68	0	3	2	4	5	121
ICH	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	100
	0	0	0	0	0	19	0	0	0	0	0	20	0	0	0	0	0	28
BWBS	0	0	0	0	14.3	85.7	0	0	10	0	10	80	8.3	0	0	0	0	91.7
	0	0	0	0	1	6	0	0	1	0	1	8	1	0	0	0	0	11
Total	5	4	10	10	16	439	11	14	37	59	55	604	363	193	197	220	186	1884

Table 6. Percent of plots (top) and sample size (bottom) of total live conifer basal area (all trees with a diameter at DBH) by BEC zone, percent canopy lodgepole pine, and basal area class. Basal area classes are 0-2, 2-4, 4-6, 6-8, 8-10 and greater than 10 m^2 ha^{-1}. For example, in >70% pine stands, in the SBS zone 16.8% of plots (n=223) had less than 2 m^2 ha^{-1} and 44.7% of plots (n=594) exceeded 10 m^2 ha^{-1} of total live conifer basal area.

Pl >= 50%						
BEC zone	Conifer seedlings stems ha^{-1}					
% of plots Samples	0-400	401-800	801-1200	1201-1600	1600+	Total
SBS	60.7 1031	10.9 185	6.8 116	3.1 52	18.5 314	1698
MS	66.9 690	8.7 90	4 41	3.1 32	17.3 178	1031
SBPS	53.3 228	9.6 41	8.4 36	4.7 20	24.1 103	428
IDF	51.5 201	7.7 30	6.7 26	3.1 12	31 121	390
ESSF	30.1 62	9.7 20	5.3 11	5.3 11	49.5 102	206
ICH	43.8 21	12.5 6	0 0	6.3 3	37.5 18	48
BWBS	68.2 15	9.1 2	9.1 2	0 0	13.6 3	22
Total	2248	374	232	130	839	3823

Table 7. Percent of plots (top) and sample size (bottom) of total conifer seedling (10 cm to 1.3 m tall) in stands with greater than 50% canopy lodgepole pine by BEC zone and density class. Density classes are 0-400, 401-800, 801-1200, 1201-1600, and greater than 1600 stems ha^{-1}. For example, in the ESSF zone, 30.1% of plots (n=62) had less than 400 stems ha^{-1} and 49.5% of plots (n=102) exceeded 1600 stems ha^{-1}.

	Pl >= 50%					
BEC zone	**Conifer seedlings+saplings stems ha^{-1}**					
% of plots **Samples**	**0-400**	**401-800**	**801-1200**	**1201-1600**	**1600+**	**Total**
SBS	44.3 753	12.3 209	7.9 134	5.2 89	30.2 513	1698
MS	48.6 501	12 124	6.7 69	6.2 64	26.5 273	1031
SBPS	33.6 144	10.5 45	6.5 28	6.8 29	42.5 182	428
IDF	26.9 105	8.5 33	9 35	7.7 30	47.9 187	390
ESSF	23.3 48	8.7 18	3.4 7	4.9 10	59.7 123	206
ICH	39.6 19	10.4 5	4.2 2	2.1 1	43.8 21	48
BWBS	59.1 13	13.6 3	4.5 1	4.5 1	18.2 4	22
Total	1583	437	276	224	1303	3823

Table 8. Percent of plots (top) and sample size (bottom) of total conifer seedling and sapling density (10 cm tall to 7.5 cm DBH) in stands with greater than 50% canopy lodgepole pine by BEC zone and density class. Density classes are 0-400, 401-800, 801-1200, 1201-1600, and greater than stems ha^{-1}. For example, in the ESSF zone 23.3% of plots (n=48) had less than 400 stems/ha and 59.7% of plots (n=123) exceeded 1600 stems ha^{-1}.

Pl >= 50%							
BEC zone	**Basal Area m^2 ha^{-1} – all conifers > 7.5 cm dbh**						
% of plots Samples	**0-2**	**2-4**	**4-6**	**6-8**	**8-10**	**10+**	**Total**
SBS	13.4	8.5	9.2	9.5	8.9	50.5	
	227	144	157	161	151	858	1698
MS	9.8	1.7	2.4	4.6	3.7	77.8	
	101	18	25	47	38	802	1031
SBPS	3	3.3	6.5	11	5.6	70.6	
	13	14	28	47	24	302	428
IDF	7.9	7.2	4.9	5.1	5.6	69.2	
	31	28	19	20	22	270	390
ESSF	0.5	1.5	1.9	1.9	2.4	91.7	
	1	3	4	4	5	189	206
ICH	0	0	0	0	0	100	
	0	0	0	0	0	48	48
BWBS	4.5	0	4.5	0	4.5	86.4	
	1	0	1	0	1	19	22
Total	374	207	234	279	241	2488	3823

Table 9. Percent of plots (top) and sample size (bottom) of total live conifer basal area (all trees with a diameter at DBH) in stands with greater than 50% canopy lodgepole pine by BEC zone and basal area class. Basal area classes are 0-2, 2-4, 4-6, 6-8, 8-10 and greater than 10 m^2 ha^{-1}. For example in the SBS zone 13.4% of plots (n=227) had less than 2 m^2 ha^{-1} and 50.5% of plots (n=858) exceeded 10 m^2 ha^{-1}.

Pl >= 50% and seedlings+saplings <= 1600 stems ha^{-1}							
BEC zone	**Basal Area m^2 ha^{-1} – all conifers > 7.5 cm dbh**						
% of plots Samples	**2**	**4**	**6**	**8**	**10**	**10+**	**Total**
SBS	11.1	18.3	25.3	31.7	36.7	33.1	
	188	310	430	539	623	562	1185
MS	9.2	11.0	12.5	16.3	18.7	54.8	
	95	113	129	168	193	565	758
SBPS	2.8	5.6	9.3	15.0	16.6	40.9	
	12	24	40	64	71	175	246
IDF	7.9	10.8	14.4	16.7	19.7	32.3	
	31	42	56	65	77	126	203
ESSF	0.5	1.5	2.4	2.4	2.9	37.4	
	1	3	5	5	6	77	83
ICH	0.0	0	0	0	0	56.3	
	0	0	0	0	0	27	27
BWBS	4.5	4.5	9.1	9.1	9.1	72.7	
	1	1	2	2	2	16	18
Total	328	493	662	843	972	1548	2520

Table 10. Cumulative percent of plots (top) and sample size (bottom) in stands with greater than 50% canopy lodgepole pine by BEC zone with 1600 or less stems/ha of seedling and sapling (10 cm tall to 7.5 cm DBH) and basal area of large secondary structure trees less than 2, 4, 6, 8, and 10 m^2 ha^{-1}, and greater than 10 m^2 ha^{-1}. For example in the SBS zone 25.3% of plots (n=430) with at least 1600 stems ha^{-1} of seedlings and saplings had less than 6 m^2 ha^{-1} basal area and 33.1% of plots (n=562) with 1600 or less sph of seedlings and saplings exceeded 10 m^2 ha^{-1} basal area.

Pl >= 50% and seedlings+saplings <= 800 stems ha^{-1}							
BEC zone	Basal Area m^2 ha^{-1} – all conifers > 7.5 cm dbh						
% of plots Samples	2	4	6	8	10	10+	Total
SBS	9.2 156	14.7 249	20.7 351	25.8 438	30.4 516	26.3 446	962
MS	8.4 87	9.9 102	11.1 114	14.4 148	16.4 169	44.2 456	625
SBPS	2.6 11	4.7 20	7.5 32	11.7 50	13.1 56	31.1 133	189
IDF	7.4 29	10.3 40	12.6 49	13.8 54	15.6 61	19.7 77	138
ESSF	0.5 1	1.5 3	2.4 5	2.4 5	2.9 6	29.1 60	66
ICH	0.0 0	0.0 0	0.0 0	0.0 0	0.0 0	50.0 24	24
BWBS	4.5 1	4.5 1	9.1 2	9.1 2	9.1 2	63.6 14	16
Total	285	415	553	697	810	1210	2020

Table 11. Cumulative percent of plots (top) and sample size (bottom) in stands with greater than 50% canopy lodgepole pine by BEC zone with 800 or less stems/ha of seedling and sapling (10 cm tall to 7.5 cm DBH) and basal area of large secondary structure trees less than 2, 4, 6, 8, and 10 m^2 ha^{-1}, and greater than m^2 ha^{-1}. For example in the SBS zone 20.7% of plots (n=351) with 800 or less stems ha^{-1} of seedlings and saplings had less than 6 m^2 ha^{-1} basal area and 26.3% of plots (n=446) with 800 or less stems ha^{-1} of seedlings and saplings exceeded 10 m^2 ha^{-1} basal area.

	Pl >= 50% and BA <= 4 m^2 ha^{-1} (all conifers > 7.5 cm dbh)					Pl >= 50% and BA <= 6 m^2 ha^{-1} (all conifers > 7.5 cm dbh)				
zone	**Conifer seedlings+saplings stems ha^{-1}**					**Conifer seedlings+saplings stems ha^{-1}**				
% of plots Samples	**0-400**	**401-800**	**801-1200**	**1201-1600**	**1600+**	**0-400**	**401-800**	**801-1200**	**1201-1600**	**1600+**
SBS	12.0	2.7	2.7	0.9	5.6	16.7	3.9	3.2	1.5	8.0
	204	45	46	15	95	284	67	54	25	136
MS	8.1	1.7	0.6	0.5	1.3	8.8	2.2	1.0	0.5	2.2
	84	18	6	5	13	91	23	10	5	23
SBPS	4.0	0.7	0.5	0.5	4.4	6.1	1.4	0.7	1.2	7.2
	17	3	2	2	19	26	6	3	5	31
IDF	7.7	2.6	0.0	0.5	5.9	9.5	3.1	0.8	1.0	8.7
	30	10	0	2	23	37	12	3	4	34
ESSF	1.0	0.5	0.0	0.0	0.5	1.5	1.0	0.0	0.0	1.5
	2	1	0	0	1	3	2	0	0	3
ICH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0	0	0	0	0	0	0	0	0	0
BWBS	4.5	0.0	0.0	0.0	0.0	9.1	0.0	0.0	0.0	0.0
	1	0	0	0	0	2	0	0	0	0

1

Table 12. Percent of plots (top) and sample size (bottom) in stands with greater than 50% canopy lodgepole pine by BEC zone with <= 4 and 6 m^2 ha^{-1} of secondary structure basal area and varying levels of understory stocking of seedlings and saplings. Percent of plots is based on the sample size presented here being divided by total sample size for each respective BEC zone presented in Table 3.

	Pl >= 50% and BA <= 8 m^2 ha^{-1}					Pl >= 50% and BA <= 10 m^2 ha^{-1}				
zone	Conifer seedlings+saplings stems ha^{-1}					Conifer seedlings+saplings stems ha^{-1}				
% of plots Samples	0-400	401-800	801-1200	1201-1600	1600+	0-400	401-800	801-1200	1201-1600	1600+
SBS	20.8 353	5.0 85	3.7 62	2.3 39	11.8 200	24.4 414	6.0 102	3.8 65	2.5 42	14.2 241
MS	11.5 119	2.8 29	1.4 14	0.6 6	3.4 35	13.4 138	3.0 31	1.6 16	0.8 8	4.5 46
SBPS	9.1 39	2.6 11	0.9 4	2.3 10	11.9 51	9.8 42	3.3 14	1.2 5	2.3 10	16.6 71
IDF	10.8 42	3.1 12	1.3 5	1.5 6	11.0 43	12.1 47	3.6 14	1.8 7	2.3 9	14.1 55
ESSF	1.5 3	1.0 2	0.0 0	0.0 0	3.9 8	1.9 4	1.0 2	0.0 0	0.0 0	5.8 12
ICH	0.0 0	0.0 0	0.0 0	0.0 0	0.0 0	0.0 0	0.0 0	0.0 0	0.0 0	0.0 0
BWBS	9.1 2	0.0 0	0.0 0	0.0 0	0.0 0	9.1 2	0.0 0	0.0 0	0.0 0	4.5 1

Table 13. Percent of plots (top) and sample size (bottom) in stands with greater than 50% canopy lodgepole pine by BEC zone with <= 8 and 10 m^2 ha^{-1} of secondary structure basal area and varying levels of understory stocking of seedlings and saplings. Percent of plots is based on the sample size presented here being divided by total sample size for each respective BEC zone presented in Table 3.

	Pl >= 50% and BA > 4 m^2 ha^{-1} (all conifers > 7.5 cm dbh)					Pl >= 50% and BA > 6 m^2 ha^{-1} (all conifers > 7.5 cm dbh)				
zone	**Conifer seedlings+saplings stems ha^{-1}**					**Conifer seedlings+saplings stems ha^{-1}**				
% of plots Samples	**0-400**	**401-800**	**801-1200**	**1201-1600**	**1600+**	**0-400**	**401-800**	**801-1200**	**1201-1600**	**1600+**
SBS	32.3	9.7	5.2	4.4	24.6	27.6	8.4	4.7	3.8	22.2
	549	164	88	74	418	469	142	80	64	377
MS	40.4	10.3	6.1	5.7	25.2	39.8	9.8	5.7	5.7	24.2
	417	106	63	59	260	410	101	59	59	250
SBPS	29.7	9.8	6.1	6.3	38.1	27.6	9.1	5.8	5.6	35.3
	127	42	26	27	163	118	39	25	24	151
IDF	19.2	5.9	9.0	7.2	42.1	17.4	5.4	8.2	6.7	39.2
	75	23	35	28	164	68	21	32	26	153
ESSF	22.3	8.3	3.4	4.9	59.2	21.8	7.8	3.4	4.9	58.3
	46	17	7	10	122	45	16	7	10	120
ICH	39.6	10.4	4.2	2.1	43.8	39.6	10.4	4.2	2.1	43.8
	19	5	2	1	21	19	5	2	1	21
BWBS	54.5	13.6	4.5	4.5	18.2	50.0	13.6	4.5	4.5	18.2
	12	3	1	1	4	11	3	1	1	4

Table 14. Percent of plots (top) and sample size (bottom) in stands with greater than 50% canopy lodgepole pine by BEC zone with > 4 and 6 m^2 ha^{-1} of secondary structure basal area and varying levels of understory stocking of seedlings and saplings. Percent of plots is based on the sample size presented here being divided by total sample size for each respective BEC zone presented in Table 3.

	Pl >= 50% and BA > 8 m^2 ha^{-1} (all conifers > 7.5 cm dbh)					Pl >= 50% and BA >10 m^2 ha^{-1} (all conifers > 7.5 cm dbh)				
zone	**Conifer seedlings+saplings stems ha^{-1}**					**Conifer seedlings+saplings stems ha^{-1}**				
% of plots Samples	**0-400**	**401-800**	**801-1200**	**1201-1600**	**1600+**	**0-400**	**401-800**	**801-1200**	**1201-1600**	**1600+**
SBS	23.6	7.3	4.2	2.9	18.4	20.0	6.3	4.1	2.8	16.0
	400	124	72	50	313	339	107	69	47	272
MS	37.1	9.2	5.3	5.6	23.1	35.2	9.0	5.1	5.4	22.0
	382	95	55	58	238	363	93	53	56	227
SBPS	24.5	7.9	5.6	4.4	30.6	23.8	7.2	5.4	4.4	25.9
	105	34	24	19	131	102	31	23	19	111
IDF	16.2	5.4	7.7	6.2	36.9	14.9	4.9	7.2	5.4	33.8
	63	21	30	24	144	58	19	28	21	132
ESSF	21.8	7.8	3.4	4.9	55.8	21.4	7.8	3.4	4.9	53.9
	45	16	7	10	115	44	16	7	10	111
ICH	39.6	10.4	4.2	2.1	43.8	39.6	10.4	4.2	2.1	43.8
	19	5	2	1	21	19	5	2	1	21
BWBS	50.0	13.6	4.5	4.5	18.2	50.0	13.6	4.5	4.5	13.6
	11	3	1	1	4	11	3	1	1	3

1

Table 15. Percent of plots (top) and sample size (bottom) in stands with greater than 50% canopy lodgepole pine by BEC zone with > 8 and 10 m^2 ha^{-1} of secondary structure basal area and varying levels of understory stocking of seedlings and saplings. Percent of plots is based on the sample size presented here being divided by total sample size for each respective BEC zone presented in Table 3.

BEC zone	Seedlings+saplings <= 1600 stems ha^{-1} and BA <= 6 m^2 ha^{-1}			Seedlings+saplings <= 1600 stems ha^{-1} and BA > 6 m^2 ha^{-1}		
	% Pl in overstory			% Pl in overstory		
% of plots Samples	30-50%	50-70%	70-100%	30-50%	50-70%	70-100%
SBS	6.6 15	7.8 29	30.2 401	50.2 115	49.7 184	43.0 571
MS	0.0 0	3.0 4	13.9 125	64.8 46	54.5 72	62.0 557
SBPS	6.3 1	11.5 9	8.9 31	87.5 14	46.2 36	48.6 170
IDF	1.5 1	4.0 4	17.9 52	53.8 35	40.4 40	36.8 107
ESSF	0.0 0	2.8 2	2.2 3	22.1 17	28.2 20	43.0 58
ICH	0.0 0	0.0 0	0.0 0	31.6 6	35.0 7	71.4 20
BWBS	0.0 0	10.0 1	8.3 1	100.0 7	60.0 6	83.3 10
Total	17	49	613	240	365	1493

Table 16. Percent of plots (top) and sample size (bottom) in stands with different combinations of post-beetle secondary structure basal area and understory conditions by BEC zone and pre-beetle attack percent canopy lodgepole pine. Percent of plots is based on the sample size presented here being divided by total sample size for each respective BEC zone presented in Table 3.

	Seedlings+saplings > 1600 stems ha^{-1} and BA <= 6 m^2 ha^{-1}			Seedlings+saplings > 1600 stems ha^{-1} and BA > 6 m^2 ha^{-1}		
BEC zone	**% Pl in overstory**			**% Pl in overstory**		
% of plots **Samples**	**30-50%**	**50-70%**	**70-100%**	**30-50%**	**50-70%**	**70-100%**
SBS	1.3 3	3.5 13	9.3 123	41.9 96	38.9 144	17.5 233
MS	0.0 0	1.5 2	2.3 21	35.2 25	40.9 54	21.8 196
SBPS	0.0 0	3.8 3	8.0 28	6.3 1	38.5 30	34.6 121
IDF	0.0 0	7.1 7	9.3 27	44.6 29	48.5 48	36.1 105
ESSF	1.3 1	1.4 1	1.5 2	76.6 59	67.6 48	53.3 72
ICH	0.0 0	0.0 0	0.0 0	68.4 13	65.0 13	28.6 8
BWBS	0.0 0	0.0 0	0.0 0	0.0 0	30.0 3	8.3 1
Total	4	26	201	223	340	736

Table 17. Percent of plots (top) and sample size (bottom) in stands with different combinations of post-beetle secondary structure basal area and understory conditions by BEC zone and pre-beetle attack percent canopy lodgepole pine. Percent of plots is based on the sample size presented here being divided by total sample size for each respective BEC zone presented in Table 3.

BEC zone	< = 4 m^2 ha^{-1}	< = 6 m^2 ha^{-1}	< = 4 m^2 ha^{-1} < 800 stems ha^{-1}	< = 4 m^2 ha^{-1} < 1600 stems ha^{-1}	< = 6 m^2 ha^{-1} < 800 stems ha^{-1}	< = 6 m^2 ha^{-1} < 1600 stems ha^{-1}
SBS	21.9	31.1	14.7	18.3	20.6	25.3
MS	11.5	13.9	9.8	10.9	11.0	12.5
SBPS	6.3	12.8	4.8	5.7	7.5	9.4
IDF	15.1	20.0	10.3	10.8	12.6	14.4
ESSF	2.0	3.9	1.5	1.5	3.5	3.5
ICH	0.0	0.0	0.0	0.0	0.0	0.0
BWBS	4.5	9.0	4.5	4.5	9.1	9.1

Table 18. Percent of plots with greater than 50% canopy lodgepole pine by BEC zone that could be considered to have a low chance of recovery, from a timber supply perspective, in the mid- to long-term. Different combinations of threshold levels are presented for secondary structure basal area (all conifers > 7.5 cm dbh) and understory seedling and sapling density (all conifers <= 7.5 cm dbh). The percent of plots based on different threshold levels than presented in this table for secondary structure basal area and understory seedling and sapling density can be calculated from earlier tables in this report.

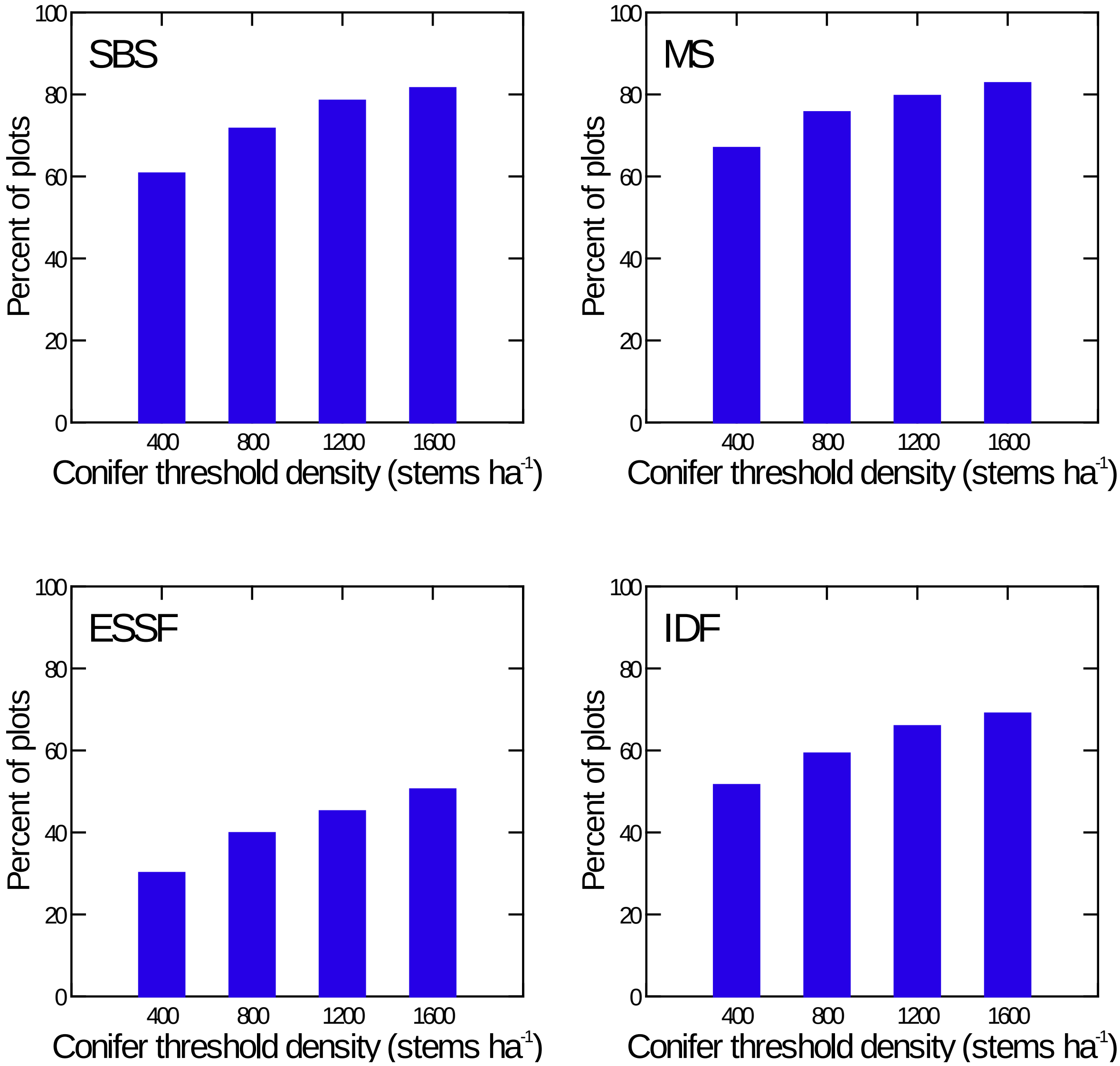

Figure 1. Percentage of plots (at least 50% Pl overstory) in each BEC zone with total conifer seedlings (< 1.3 m tall) less than or equal to 400, 800, 800, 1200, 1600 stems ha^{-1}.

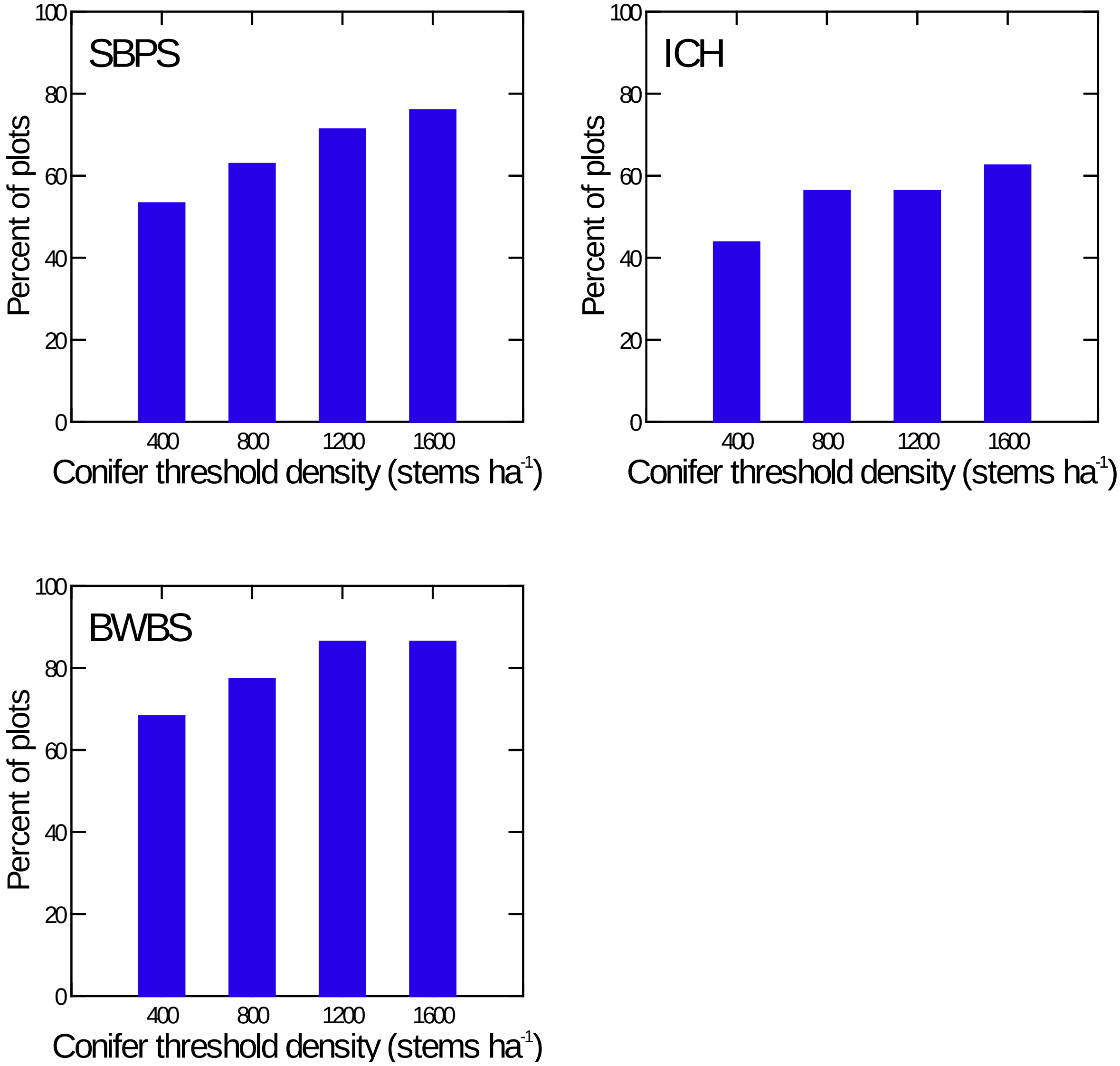

Figure 1 continued. Percentage of plots (at least 50% Pl overstory) in each BEC zone with total conifer seedlings (< 1.3 m tall) less than or equal to 400, 800, 800, 1200, 1600 stems ha^{-1}.

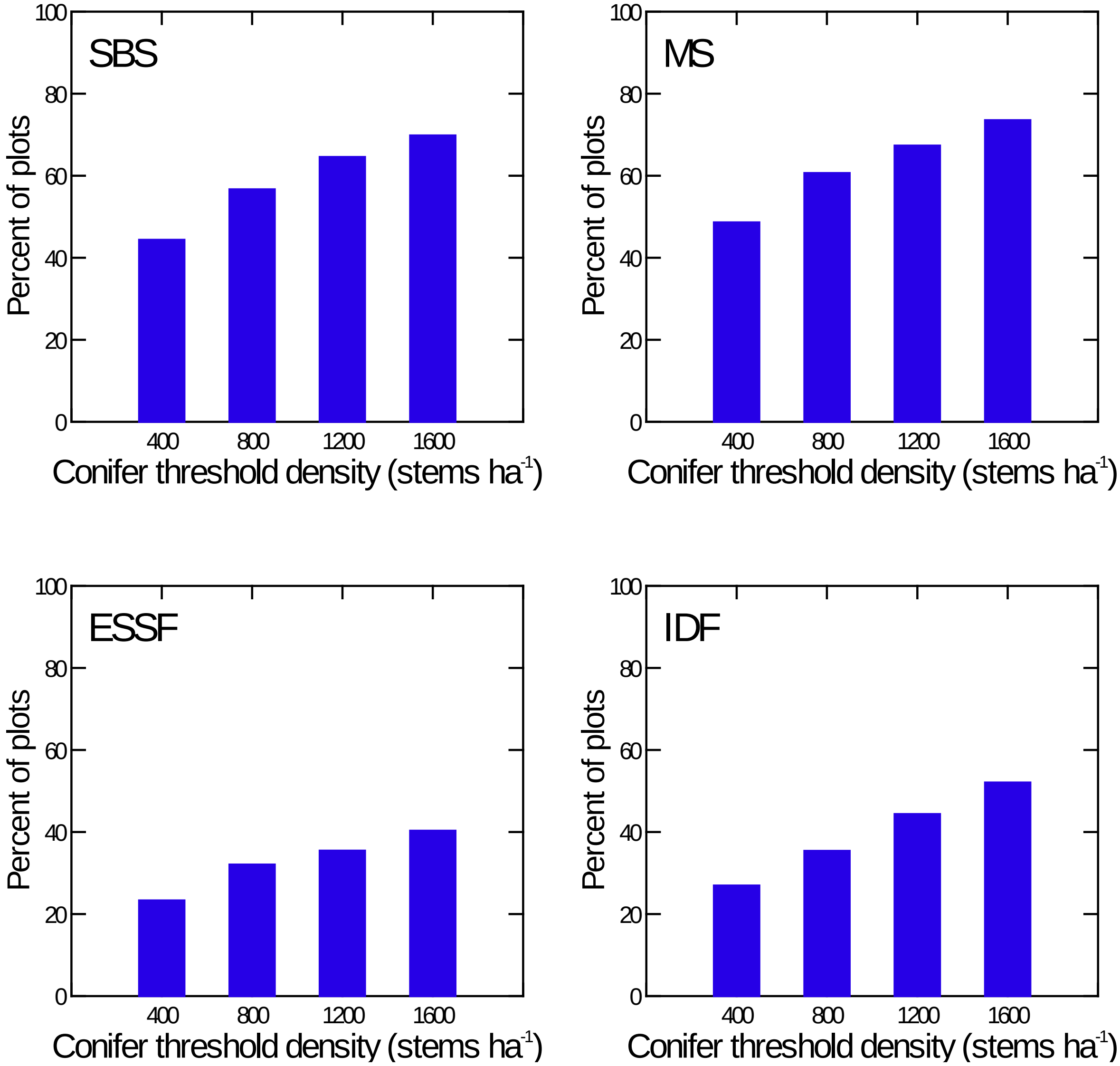

Figure 2. Percentage of plots (at least 50% Pl overstory) in each BEC zone with total conifer seedlings (< 1.3 m tall) + saplings (>1.3 m tall and < 7.5 cm dbh) less than or equal to 400, 800, 1200 and 1600 stems ha^{-1}.

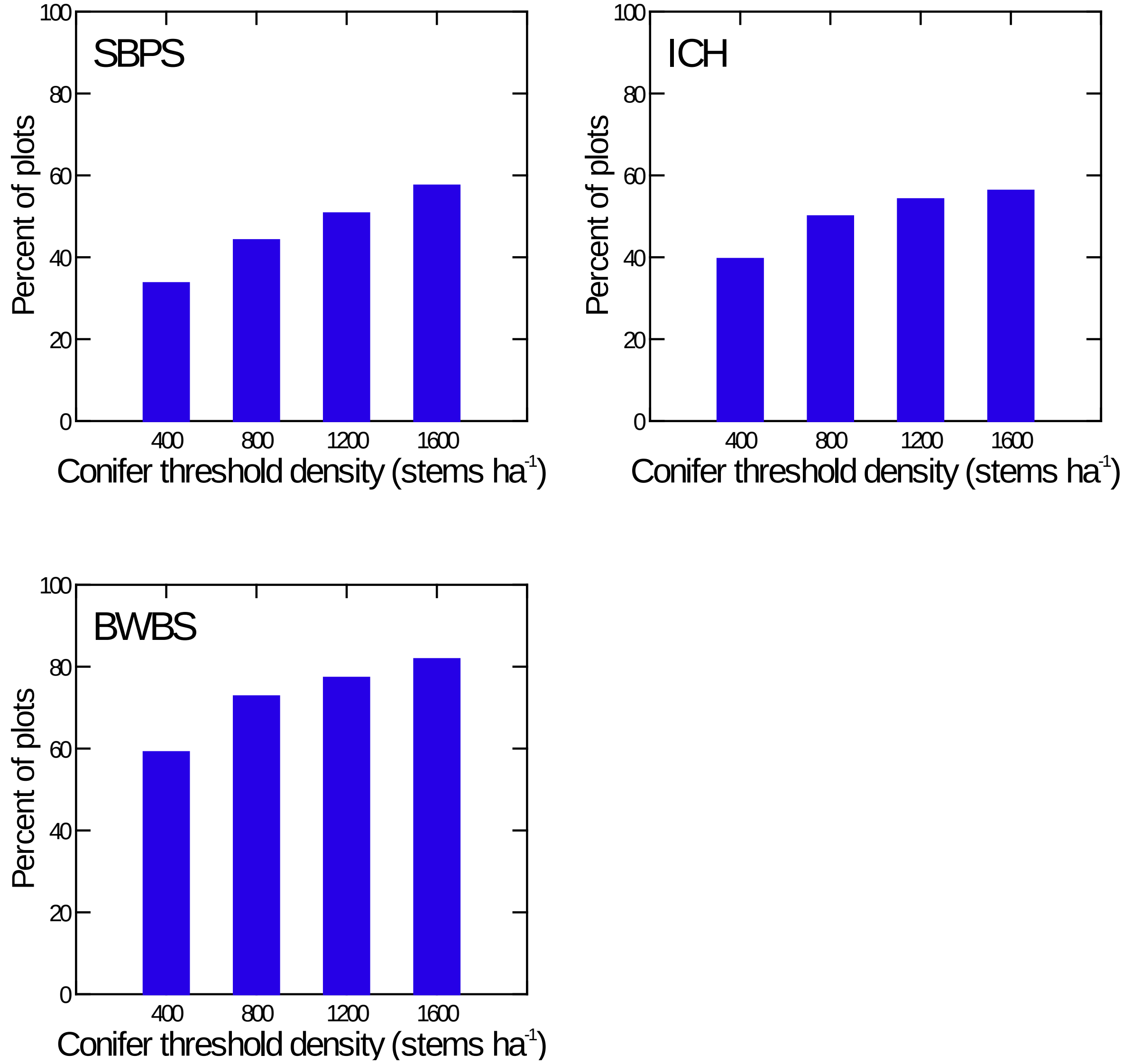

Figure 2 continued. Percentage of plots (at least 50% Pl overstory) in each BEC zone with total conifer seedlings (< 1.3 m tall) + saplings (>1.3 m tall and < 7.5 cm dbh) less than or equal to 400, 800, 1200 and 1600 stems ha^{-1}.

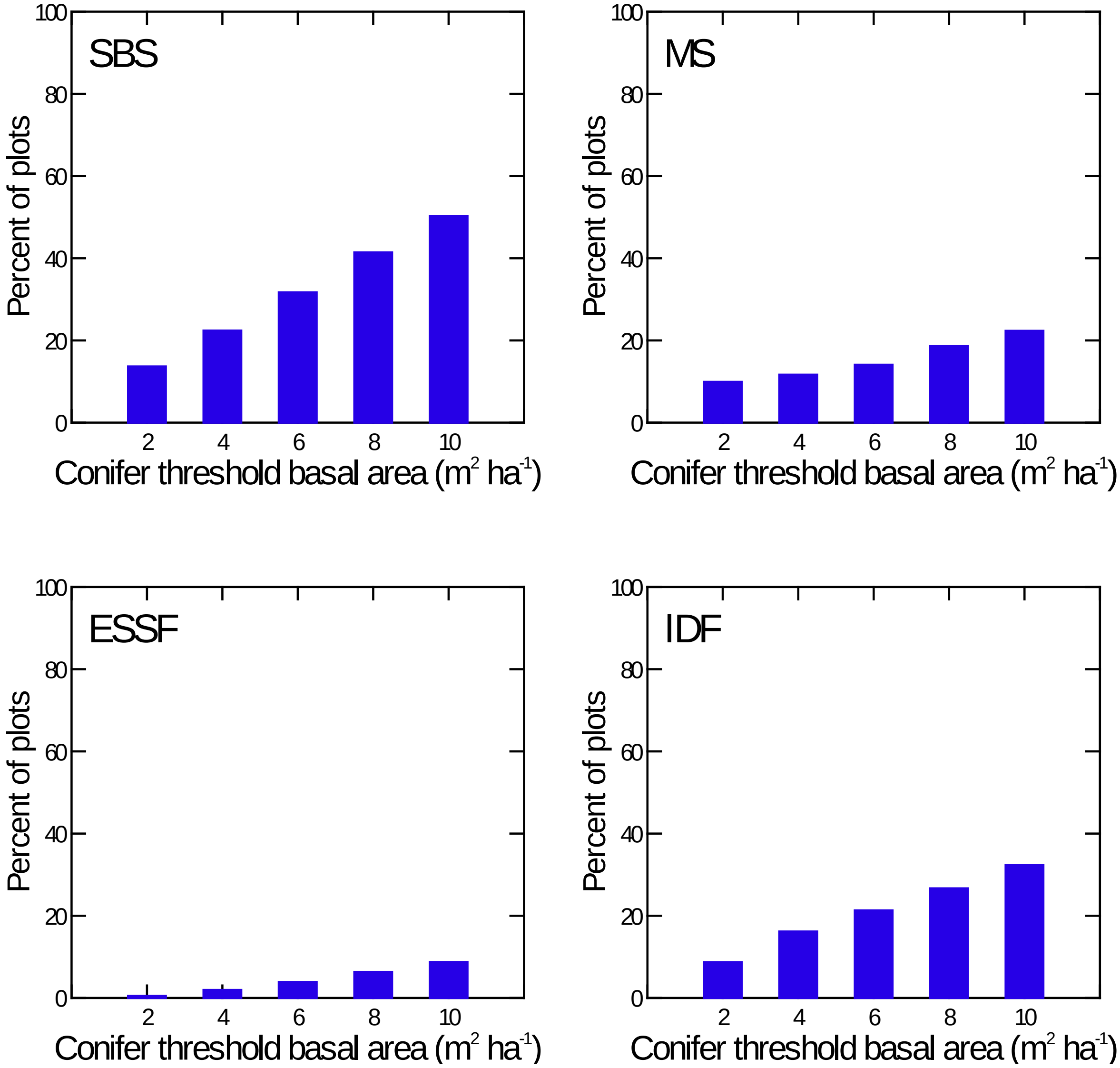

Figure 3. Percentage of plots (at least 50% Pl overstory) in each BEC zone with basal area of secondary structure (total non merchantable conifers) less than or equal to 2,4,6,8 and 10 m^2 ha^{-1}.

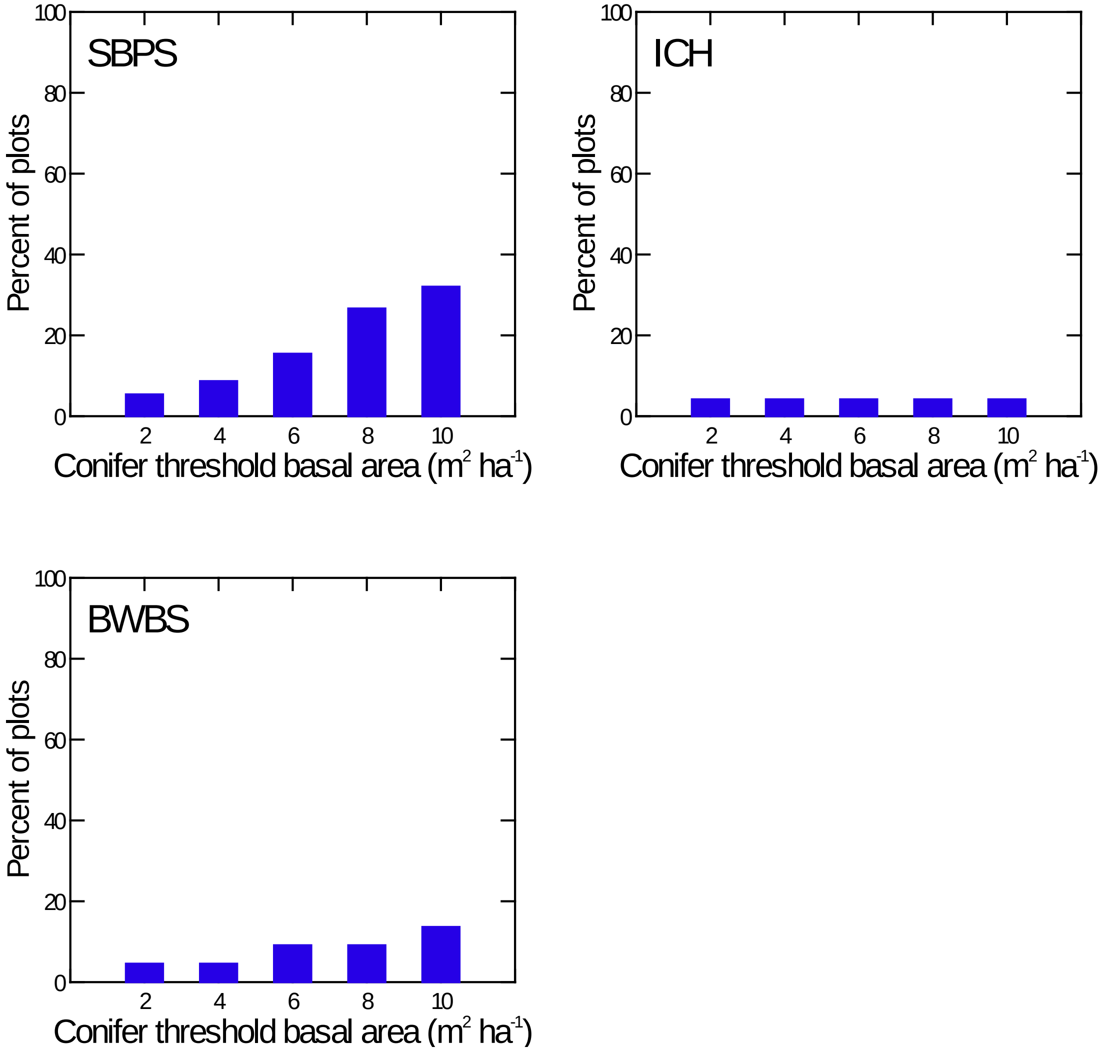

Figure 3 continued. Percentage of plots (at least 50% Pl overstory) in each BEC zone with basal area of secondary structure (total non merchantable conifers) less than or equal to 2,4,6,8 and 10 m^2 ha^{-1}. Note that in the ICH 100% of plots had more than 10 m^2 ha^{-1} of basal area.