Range of Variation in Structural Attributes of Harvested Stands in the Babine Watershed: Refining Current Indicators

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Abstract

Structural attributes of forests provide habitat for a wide range of organisms. Most natural disturbances leave some structural attributes in the newly-regenerating stand. This study compares structural legacies in managed stands with those in natural stands. Structural legacies in terms of live and dead standing stems and downed dead wood were measured in 30 plots in 8 sites that had been harvested between 1992 and 2000. Results were compared to equivalent data collected previously in young stands originating from natural disturbance (wildfire, beetle attack and windthrow) within the same general area. In the first decade after the disturbance, timber harvest generally left fewer standing stems, particularly snags, than natural disturbances. Proportions of snags, large live trees and long downed logs in harvested areas were low compared with naturally-disturbed stands of the same age.

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Keywords: snags, coarse woody debris, large live trees, stand structure, natural disturbance, young seral, wildlife tree patch

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Introduction

Structural attributes of old forests, including downed wood, large live trees, dead and decaying trees, and patches of shrubby vegetation, provide critical habitats for a variety of mammals, birds, invertebrates, plants and lichens (Rosenvald, P. and A. Lõhmus. 2008, Bunnell et al. 2003, Price and Hochachka 2001, Schoonmaker and McKee 1988). Most natural disturbances leave some structural attributes in the newly-regenerating stand (Hansen et al. 1991, Franklin et al. 2000). Legislation (e.g., Forest and Range Practices Act) and land-use plans (e.g., Sustainable Resource Management Plans, Landscape Unit Plans, Forest Stewardship Plans) prescribe retention of wildlife tree patches — with a variety of structural features — in young managed stands. However, high uncertainty about the threshold amount of structure needed to maintain biodiversity currently limits the usefulness of wildlife tree patches as an indicator of sustainability. A risk assessment undertaken by the Babine Watershed Monitoring Trust (www.babinetrust.ca) highlighted resolution of this uncertainty as a top priority within the Central Interior of BC.

In 2006, a study conducted by the BWMT provided information on the quantity and attributes of structural elements remaining on site during up to 50 years following natural disturbances (Lloyd et al., 2007). The intent of this project is to provide similar information on structure remaining following managed disturbance (timber harvesting) within the same study area, as a basis for direct comparisons between residual structure present after wildfire, bark beetle attack, windthrow and timber harvest. By reducing uncertainty surrounding the amounts of residual structure present, it will also enable a more accurate assessment of risk associated with current levels of retention during timber harvest.

Methods

Study area

The study area includes the SBSmc2 and ESSFmc subzones of the Northern Interior Forest Region, in the Babine River Watershed of the Skeena-Stikine Forest District. The Babine Watershed is the focus of a series of special management requirements, in which forestry activities are expected to protect high-value salmon, grizzly bear, biodiversity and wilderness resources (see www.babinetrust.ca). Sampling for this project was limited to cutblocks within the Nichyeskwa and Nilkitkwa watersheds due to funding constraints.

Study design

This project is intended to complement the previous study of residual structure following natural disturbance (Lloyd et al., 2007), focussing primarily on managed disturbances at the stand scale.

At the disturbance scale, we used existing Forest Cover mapping to identify cutblocks within the study area and classify them according to size and extent. Aggregate cutblocks, usually resulting from timber salvage following bark beetle attack, were treated as a single opening as long as the constituent openings were contiguous. These were compared to the size and extent of natural disturbances caused by wildfire and beetle attack in the northern part of the Bulkley TSA. Within a subsample of cutblocks, we used recent (2003) orthophotography to distinguish between cutover and reserve areas within each cutblock. All timber harvest used the clearcut or clearcut-with-reserves system; we did not identify any instances of partial cutting within the study area.

At the stand scale, we stratified all cutblocks according to biogeoclimatic subzone and year of harvest, with 1998-2007 including blocks that were harvested since the Forest Practices Code came into effect, and 1978-1997 including only pre-Code blocks. Within each subzone/harvest date combination, we randomly selected two cutblocks for detailed study (excluding those with particularly difficult access) for a total of 8 study blocks. All blocks were harvested between 1992 and 2000.

Within each study cutblock, we located three plots randomly within the cutover area and, where possible, one plot within the reserve (Table 1). Data collection followed the protocol outlined in Lloyd *et al*, 2007 and included standing live trees over 7.5cm dbh that were considered to have been present at the time of the disturbance; standing dead trees over 7.5cm dbh; and downed dead wood (CWD) over 7.5cm diameter. We also recorded crown closure and % disturbed soil within each plot.

We analysed data using descriptive statistics, averaging values across plots to provide and estimate of residual structure for each site. We compared the results to data from naturally-disturbed sites in the same area (Lloyd et al., 2007).

We calculated the percent of natural stand structure based on this study and Lloyd et al., 2007. We used the results to estimate risk to biodiversity associated with current strategies based on risk curves included in the Babine Watershed Monitoring Trust's Knowledge Base.

Table 1 Characteristics of cutblocks used to estimate structural legacies following timber harvest

Disturbance					Number of plots		
Location	Type[1]	Year of harvest	Age class[2]	BGC subzone	cutover area	reserve area	Total
Nichyeskwa 455 rd Block 1	clearcut	1994	2	SBSmc2	3	0	3
Nichyeskwa 455 rd Block 2	CCR	1998	1	ESSFmc	3	1	4
Nichyeskwa 455 rd Block 3	CCR	1999	1	ESSFmc	3	1	4
Upper Van Fire Block 1	CCR	1995	2	ESSFmc	3	1	4
Upper Van Fire Block 2	CCR	1995	2	ESSFmc	3	1	4
Nilkitkwa 459 rd Block D	CCR	2000	1	SBSmc2	3	1	4
Nilkitkwa 459 rd Block C	clearcut	1998	1	SBSmc2	3	0	3
Nilkitkwa 468 rd Block 1	CC(R)	1992	2	SBSmc2	3	1	4
Total					24	6	30

[1] clearcut = clearcut without reserves; CCR = clearcut with reserves
[2] 1 = harvest 1998-2007; 2 = harvest 1978-1997

Results

Disturbance scale: size and severity of disturbances

Disturbance size

We identified 336 openings (cutblocks or cutblock aggregates) within the study area, all of which had been harvested since 1965 and most since 1990. The size of cutblocks, including aggregate cutblocks, ranged from less than 1 ha to 1163 ha. Most were between 10 and 100ha., and 9 cutblocks out of 336 exceeded 100 ha. Table 2 shows a comparison between cutblock sizes and the extent of natural disturbances (fire and beetle attack) in the same general area (from Lloyd et al., 2007; data for windthrow were not available but it is likely that major wind-initiated disturbances have not occurred in the study area within recent decades).

Table 2 Size distribution of harvested cutblocks and natural disturbances in and around the study area

area (ha.)	disturbance agent (no. of polygons)					
	fire[1]	beetles[2]				harvest[3]
		MPB	SB	BBB	total	
<10	2	1833	95	21	1949	127
10-100	11	16	48	4	68	200
100-1000	3	1	7	6	14	8
>1000	2	0	1	4	5	1

[1] fires with unsalvaged areas; Bulkley TSA within 93M mapsheet; disturbed since 1956
[2] Bulkley TSA within 93M mapsheet; moderate-severely disturbed since 1975
[3] Bulkley TSA within Babine Watershed; disturbed since 1965

Due to limited data quality and availability, it is not possible to make direct comparisons between the numbers of polygons disturbed; however, the data show a clear trend towards a relatively large number of small disturbances, with a much smaller number of extensive disturbances. This is true of wildfires, beetle attacks and timber harvesting; we did not locate any instances of catastrophic windthrow in the study area that was unsalvaged and not associated with harvesting operations.

Remnant patches (reserves) within disturbances

Six of our eight study blocks included undisturbed (reserve) areas within the cutover area, with the reserve accounting for 4-13% of the total area (Table 3). To be comparable with natural disturbances, we did not include external reserves. There were no instances of partial canopy removal within a cutblock, although Machine Free Zones around small streams within cutblocks had residual understory trees and undisturbed soil.

Table 3 Area and disturbance severity within study blocks

Location	Total area (ha.)	Reserve area (ha.)	Reserve area (%)
Nichyeskwa 455 rd Block 1	21.5	0	0
Nichyeskwa 455 rd Block 2	29.6	1.2	4
Nichyeskwa 455 rd Block 3	45.3	4.1	9
Upper Van Fire Block 1	32.6	4.2	13
Upper Van Fire Block 2	29.9	1.5	5
Nilkitkwa 459 rd Block D	37.1	1.9	5
Nilkitkwa 459 rd Block C	22.5	0	0
Nilkitkwa 468 rd Block 1	20.0	0.8	4

Three of the four post-code blocks meet or exceed the stand structure targets set by the Bulkley Higher Level Plan within the block. Nilkitkwa 459 rd Block C is the exception, with a target of 5% (additional area may have been included outside the block).

In terms of comparative disturbance-scale severity, these cutblocks rank between wildfires <100ha in area, which left no undisturbed remnant patches but did include partially-disturbed areas, and beetle attacks, in which residual canopy cover was always >5% and appeared to be intact in up to 18% of the total disturbance area (Lloyd et al., 2007).

Stand scale – structure within cutblocks

For each cutblock, remnant structure was calculated as the weighted mean of structure within reserves and structure within the cutover area. The following results therefore represent the entire cutblock, not only the harvested area. Comparisons are made with similar data from natural disturbances (wildfire, beetle attack and windthrow) within the same study area, as described in Lloyd et al., 2007.

Differences between cutblocks

Neither subzone, age class, nor the presence of internal reserves had significant influence on the overall numbers of standing live stems or the total volume of CWD; however, standing dead stems (snags) were found only in blocks with reserves (Figure 1). Snags were significantly more abundant in the ESSFmc than in the SBSmc2. This result is likely because the two blocks without reserves were both in the SBSmc2, whereas all four blocks in the ESSFmc had internal reserves (even though these were not legally required prior to the introduction of the Forest Practices Code).

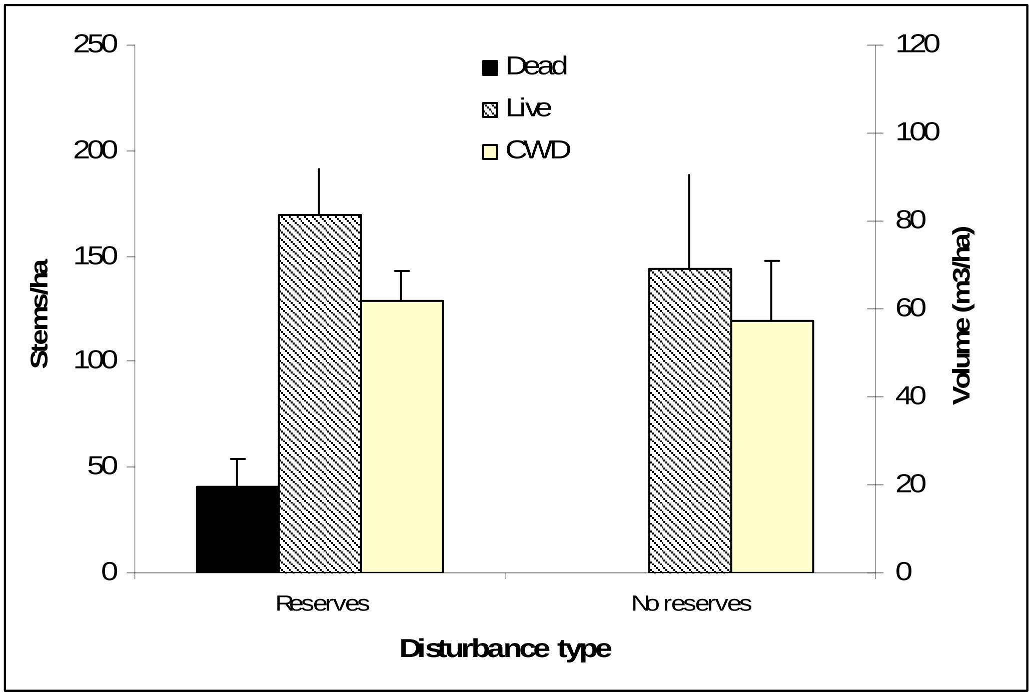

Figure 1 Mean numbers of standing live and dead stems, and mean volume of downed dead wood in cutblocks with and without reserves (bars are standard error)

Comparisons among disturbance types

In the first decade after the disturbance, timber harvest left fewer standing stems overall than either wildfire, beetle attack or windthrow. In particular, there were considerably fewer standing dead stems (snags) after timber harvest than after any of the three natural disturbances ($F_{1,12} = 59.9$, $p < 0.001$, post-hoc orthogonal contrasts). Timber harvest retained more standing live stems than wildfire, but fewer than beetles or wind (Figure 2a). CWD volumes were lowest in harvested sites (Figure 2b) but not significantly different from beetle attack or wildfire.

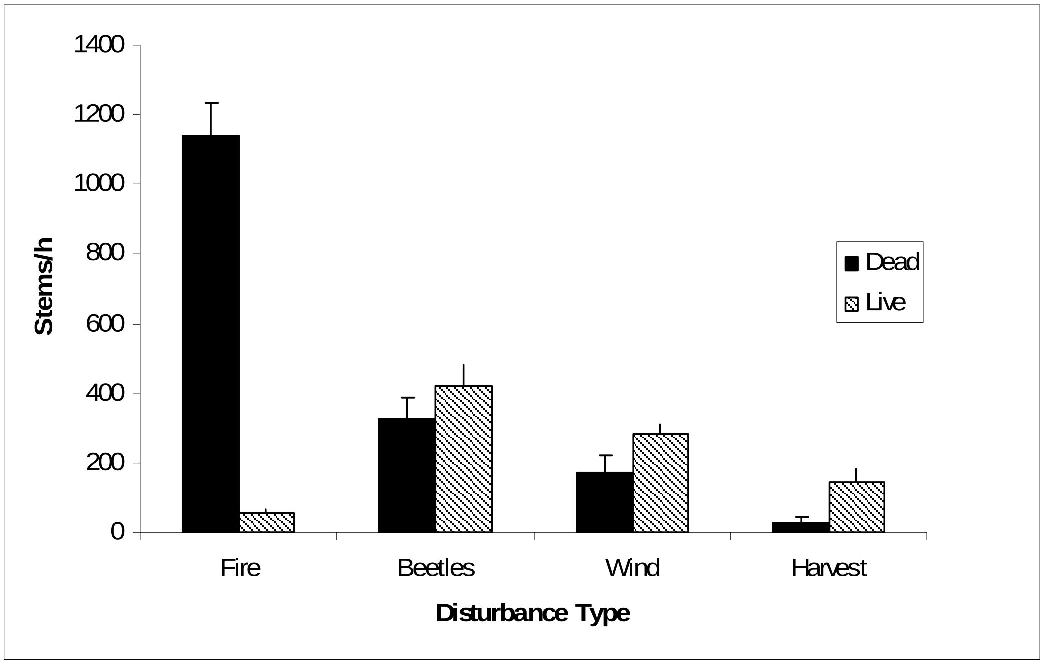

Figure 2a Number of standing dead and live trees remaining within the first decade after disturbance by beetles, fire, wind and timber harvest (bars are standard error; live trees: $F_{3,12} = 9.7$, $p = 0.002$; dead standing: $F_{3,12} = 46.5$; $p < 0.0001$; $n = 16$)

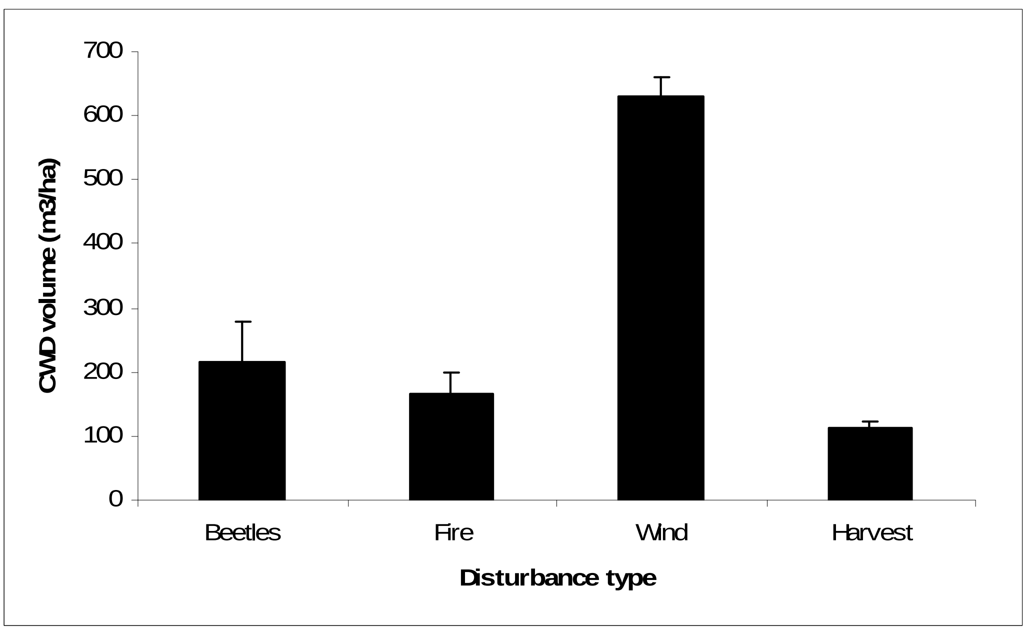

Figure 2b. Volume of CWD present within the first decade after disturbance by beetles, fire, wind and timber harvest (bars are standard error; downed wood: $F_{3,12} = 20.59$, $p < 0.0001$).

Figure 3 shows the relative patchiness (as mean coefficient of variation between plots within each stand) of standing live and dead stems following timber harvest and natural disturbances. In harvested sites, patchiness in live stems is intermediate between fire, wind and beetle attack, generally reflecting the distribution of residual small stems across the cutover area as well as the higher concentration of live stems in reserve areas. Patchiness of dead stems, however, is highest following timber harvest; standing dead stems were never found outside reserve areas, except for stubbed snags (those cut at 3-5m above the ground).

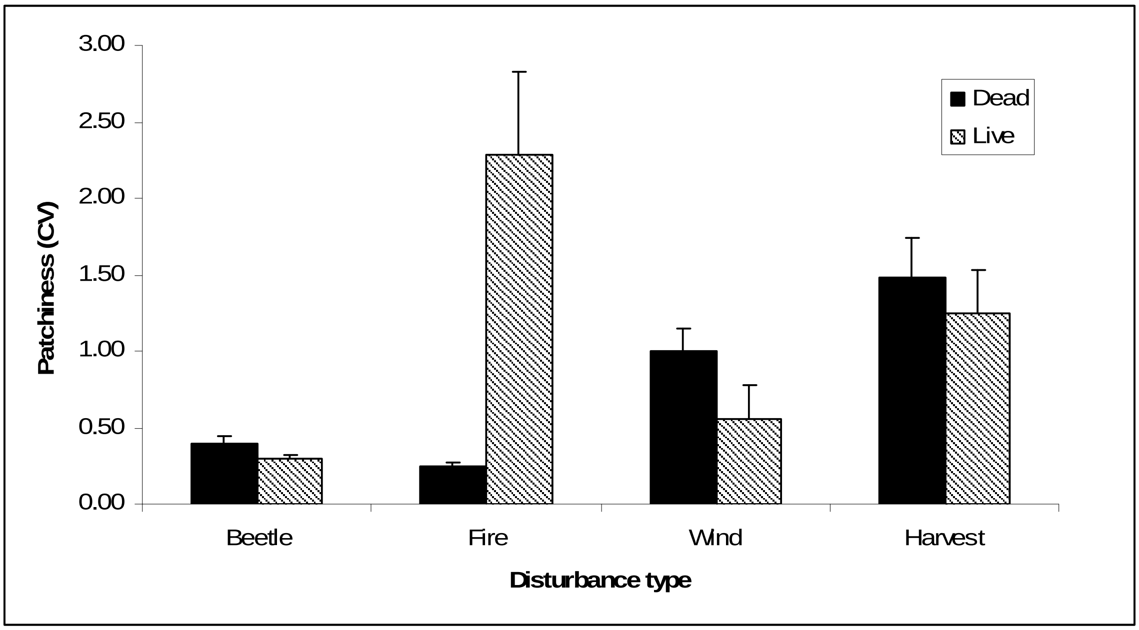

Figure 3. Patchiness (coefficient of variation of number of stems among plots within sites, averaged across sites; bars are standard errors) in dead and live standing structure after disturbance by beetles, fire, wind and timber harvest.

Patchiness in distribution of structural elements following timber harvest is of particular interest because it demonstrates the contribution made to post-harvest stand structure by the inclusion of reserves.

Diameter and length class distribution

Diameter-class distribution of standing trees in harvested stands differed considerably from that in naturally-disturbed stands. The diameter class distribution of live trees remaining in the first decade after timber harvest followed an exaggerated version of the inverse-J distribution remaining after beetle attack and wind, with almost all the remaining trees in the smallest diameter class (Figure 4). The diameter class distribution of standing dead trees followed a sigmoidal distribution, with most snags in the two smallest diameter classes. Harvested stands had significantly fewer large live or dead trees (>17.5 cm dbh) than naturally-disturbed stands (snags: $F_{1,12} = 50.9$, $p < 0.001$; live trees: $F_{1,12} = 7.2$, $p = 0.02$; post-hoc orthogonal contrasts).

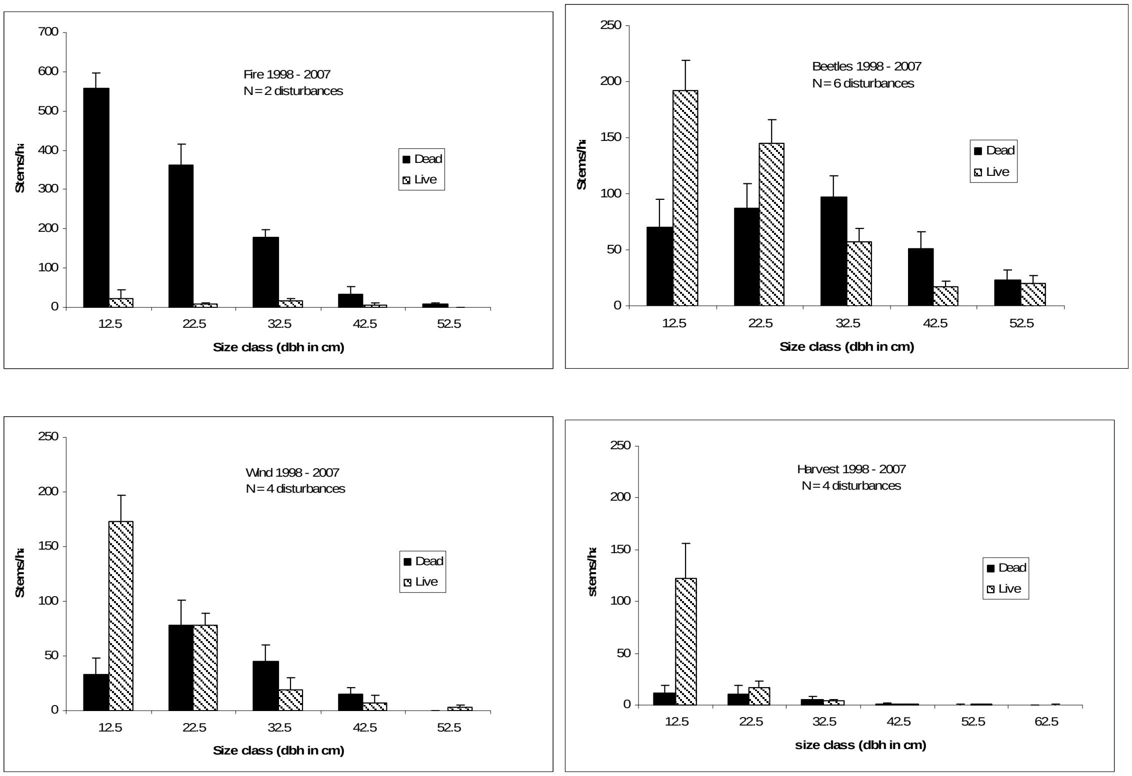

Figure 4 Diameter-class distribution of standing live and dead trees in the first decade after fire, beetle attack, wind and timber harvest. (Y-axis for fire is a different scale; bars are standard errors).

Among harvested stands, standing live and dead stems other than live trees of the smallest diameter class (i.e. > 17.5 cm dbh) occurred only in cutblocks with reserves (Figure 5). In particular, "functional" snags (>20cm dbh; BC MoF, 2005) and large live trees were limited to reserve areas and, overall, occurred at a much lower density in harvested areas than in any type of natural disturbance (Table 4).

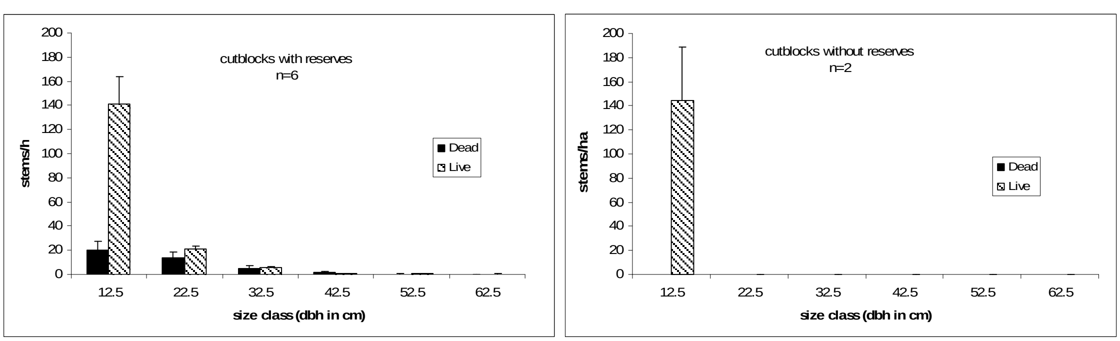

Figure 5 Diameter class distribution of live and dead stems in cutblocks with and without reserves. (Bars are standard error.)

Table 4 Mean abundance of "functional" snags and large live trees in the first decade following disturbance by fire, beetles, wind and timber harvest

size class	functional snags (stems/ha)				large live trees (stems/ha)			
(cm)	Fire	Beetles	Wind	Harvest	Fire	Beetles	Wind	Harvest
17.5-27.5	362	87	78	11	10	145	78	17
27.5-37.5	180	97	45	5	17	57	19	4
37.5-47.5	32	51	15	1	6	17	7	1
47.5-57.5	7	23	0	0	0	20	3	1
Total	581	258	138	17	33	239	107	23

For downed dead wood, no differences were apparent in diameter class distribution or in decay class distribution between harvested sites and natural disturbances. There were also no detectable differences in harvested stands over time, although since all cutblocks in the area had been harvested over a single 10-year period, differences may not have had time to develop.

Piece length, however, was markedly different between downed logs in harvested stands and downed logs in naturally-disturbed stands (Figure 6). Logs were much shorter in harvested stands (chi-squared test, P<0.001), with 13% of the total volume consisting of pieces over 10m long, compared with 50-79% of the total in naturally-disturbed stands (Table 5).

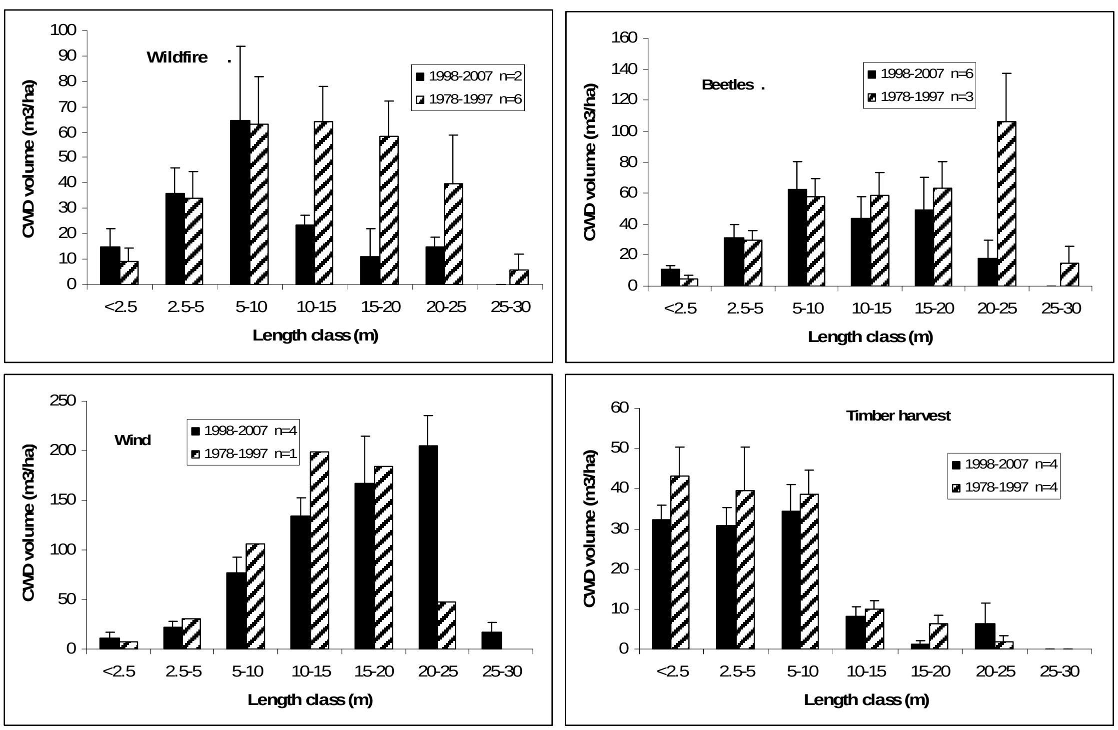

Figure 6 Length class distribution of downed dead logs following disturbance by fire, beetles, wind and timber harvest. (Bars are standard error.)

Table 5 Piece length distribution of downed dead wood in the first two decades following disturbance by fire, beetles, wind and timber harvest

length class	% of total downed log volume			
	Fire	Wind	Beetles	Harvest
<5m	21%	6%	14%	58%
5-10m	29%	15%	22%	29%
>10m	50%	79%	64%	13%

Discussion

Summary of results

This study estimates the structural legacies following timber harvest in the Babine watershed, and enables a comparison with RONV for the same attributes following natural disturbances (fire, beetle attack and wind) in the same general area.

Overall, timber harvesting left fewer standing stems than fire, beetle attack or windthrow. In particular, timber harvesting retained significantly fewer snags than any form of natural disturbance, and no snags were retained in cutblocks without reserve areas. The abundance of “functional” snags (>20cm dbh) was much lower after timber harvest than after natural disturbance. Residual live stems were less abundant after timber harvest than after beetle attack or windthrow, but more abundant than after wildfire; however, nearly all the residual live trees encountered after timber harvest were in the smallest diameter class, and cutblocks without reserves did not include any large (>20cm dbh) live trees at all. Figure 2a presents an estimate of the range of variability for standing live and dead trees following wildfire, beetle attack, windthrow and timber harvest.

Downed dead wood was somewhat less abundant after timber harvest than after any form of natural disturbance, although differences were statistically significant only with windthrow. Diameter class distribution and decay class distribution were comparable between all forms of disturbance, but timber harvesting resulted in much shorter pieces than any form of natural disturbance. Figure 2b presents an estimate of the range of variability for downed dead wood volumes following wildfire, beetle attack, windthrow and timber harvest.

No analysis of the change in structural attributes over time following timber harvest was possible, as all cutblocks were harvested within a 10-year period and differences between cutblocks harvested in the Babine River watershed before and after the introduction of the Forest Practices Code were not detectable. However, a previous analysis of changing stand structure in five decades following wildfire (Lloyd et al, 2007) showed that the volume of CWD increased as the number of standing snags decreased. This recruitment of CWD from the fall of standing snags cannot occur following timber harvest because there are no snags remaining except within reserves. Analysis of wildfire sites also shows a continuing input of relatively sound wood from snag fall lasting for at least 50 years after the original disturbance, resulting in the presence of relatively sound CWD across the disturbed area for several decades after the fire. As CWD recruitment from snag fall cannot occur in harvested areas, only well-decayed CWD will be present after 30-35 years (based on rate of decay since snag fall documented in Delong et al, 2005).

Patterns of remnants within disturbances

Most cutblocks in the study area were between 10 and 100ha in size, with a few that were considerably larger and one that exceeded 1000ha. This is comparable to the pattern of natural disturbances, most of which were less than 100ha but which did occasionally exceed 1000ha. However, it is possible that in an uncontrolled natural environment (without fire suppression or beetle control), large disturbances might be more common than is presently the case.

Remnant patches (internal reserves) were present in six out of eight study blocks, accounting for 4-14% of the total block area. Wildfires of similar extent (less than 100ha.) generally lacked undisturbed remnant patches, but included partially-disturbed areas and structural legacies in disturbed areas (snags and, later, large volumes of sound CWD) that were absent from cutover areas. Harvested sites lacked areas of partial canopy removal, but included Machine-Free Zones around small streams where little or no soil disturbance occurred and where relatively high numbers of small precommercial understory trees remained intact. Patchiness (as coefficient of variation) was higher in areas disturbed by wildfire or timber harvest than by beetle attack or windthrow.

Beetle-disturbed sites in the study area had a more even distribution of structural legacies, including snags and large live trees that in harvested stands were limited to reserve areas. This is likely a result of forest characteristics in the study area, where stands generally include a mix of susceptible and non-susceptible tree species and age/size classes (unlike, for example, the uniform pine stands further east where nearly all trees are vulnerable to MPB attack). This remnant pattern is likely more closely approximated by partial cutting than by clearcutting, but the former appears not to have been used in the study area.

Implications of cutblock size

At present, most cutblocks are 10-100ha in size and our estimates of stand-level retention are derived from cutblocks of about 20-50ha. At current levels of retention, it is probable that second- and third-pass harvesting will increase the mean opening size (by aggregation of cutblocks) without increasing the mean number of snags, large live trees or volumes of CWD. The aggregate openings may contain stands of different ages, but the difference is likely to be a matter of decades, which is insufficient time for snags, large live trees and large logs to develop. In our previous study (Lloyd et al., 2007, Table 5), we showed that extensive fires in the area have left undisturbed or partially disturbed areas that account for up to 40% of the total. If harvesting continues, and mean opening size increases, the discrepancy between structure in natural and managed stands is likely to increase unless retention levels are increased to better reflect the higher retention in large natural disturbances.

Risk assessment

This survey shows that structural legacies following clearcut logging (with or without reserves) do not fall within the RONV of structural legacies following natural disturbance, especially as regards “functional” snags and large live trees (Table 6). Clearcut timber harvest follows the distribution pattern of wildfires (clumped) as far as large live trees are concerned, but the low numbers and limited distribution of snags is unlike any natural disturbance. CWD volume and attributes present a lesser issue in the first two decades following harvest, but are expected to deviate markedly from that left by natural disturbance within three or four decades after harvest unless provision is made for CWD recruitment from standing stems at the time of harvest.

Table 6. Percent of natural structure retained in managed stands in the first decade after disturbance, calculated using mean values in each case. Large standing trees are those > 17.5 cm dbh; long CWD are those > 10m.

Disturbance	Live	Dead	CWD	Large live	Large dead	Long CWD
Fire	262	3	68	69	3	32
Beetles	33	9	52	9	7	14
Wind	51	17	18	21	13	4

The risk curve included in the stand structure section of the Knowledge Base shows a sigmoidal increase in risk to biodiversity related to the % of natural amount of structure retained (Figure 7). Based on this curve, current levels of retention within cutblocks poses a high risk to biodiversity (i.e. are below 30% of natural levels), particularly in relation to snags (small or large). Amounts of large live trees (> 17.5 cm dbh) and long CWD pose moderate risk when compared with fire (the most prevalent natural disturbance in the area).

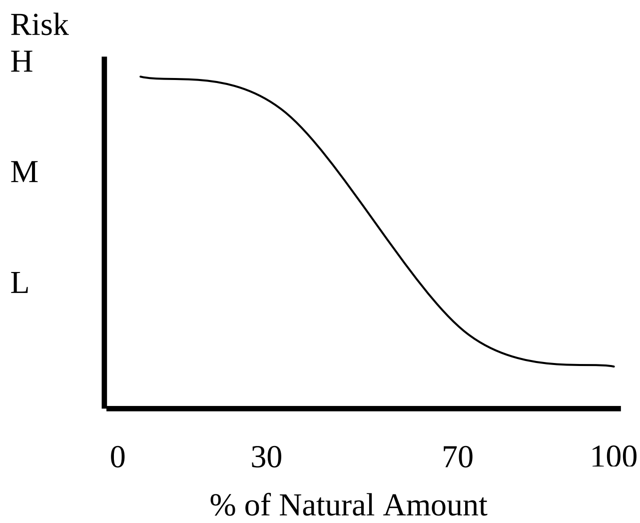

Figure 7 Risk curve for stand structure from BWMT Knowledge Base.

A finding of high risk requires consideration of other questions. First, stand level retention is only one of several strategies designed to maintain biodiversity. The first task is to examine the landscape context. If sufficient levels of forest are retained within the landscape, stand-level retention is less crucial. BWMT is currently investigating seral stage patterns over the landscape. The results from that project should be used to inform any conclusions based on this study.

Patterns of stand-level structure vary not only with seral stage but also with stand origin. This study shows that structural legacies will be very different in stands originating from timber harvest and in those originating from natural disturbance. An assessment of risk based on seral stage patterns must therefore consider disturbance type as well as seral stage.

The current MPB disturbance is changing the landscape context, decreasing the amount of old forest, but increasing snags. This disturbance could change optimum retention from snags (currently at highest risk) to live trees.

Unfortunately, very little work anywhere has investigated the interaction between stand-level and landscape-level retention. A recent meta-analysis of the benefits of stand-level retention clearly concludes that many organisms benefit from retention (Rosenvald and Lõhmus 2008), but does not examine trade-offs among scale. A meta-analysis of studies of forest birds (Huggard 2006) concludes that retention of 15 – 20% should maintain abundances of many forest-dwelling birds that are less sensitive to harvesting; that somewhat sensitive species benefit from 40% within-stand retention, and that landscape-level reserves are necessary to maintain the most sensitive species and intact forest bird communities. In addition, community similarity to uncut forest drops sharply at retention below 12%.

Another avenue of consideration would re-examine the risk curves in the Knowledge Base to determine if there is any new evidence to improve the hypothesis. The Knowledge Base will be updated this year; the BWMT should ensure that the stand-level curves are considered.

Finally, it is important to consider the importance of the stand-level objective. An objective to "lifeboat" species requires higher levels of retention than an objective to increase the rate of recovery of old forest structure. Discussion with the Community Resources Board should clarify this point.

Management suggestions

It is not possible for commercial timber harvesting to approach levels of structural elements found after natural disturbance, because harvesting removes much of the biomass of the original stand from the site. However, to approach more closely the natural levels and distribution, the following priorities are recommended:

1. Increase the number and size of standing live trees across the cutover area.
At present, live and dead standing stems are concentrated in reserve areas, with residual structure in the cutover area limited to CWD and small live trees. Natural distribution patterns demonstrate an increased number and a more uniform distribution either of all standing stems or of dead standing stems; however, retention of standing snags is operationally difficult due to safety considerations. Live standing stems are not a safety concern, and may be expected to mature into standing snags and/or into CWD over the life of the new stand.

Based on natural disturbance patterns, increased retention of standing stems is increasingly important in larger cutblocks. This is true regardless of whether the cutblock is even-aged or formed by aggregation of two or more cutblocks of different ages. The Chief Forester recently recommended that retention levels be increased in large openings resulting from MPB salvage (Snetsinger, 2005), and it is recommended that similar measures be adopted in aggregate clearcuts even when part of the opening consists of a developing stand several decades old, because the structural features whose absence poses the highest risk to biodiversity (snags, large live trees, long CWD) will not have had time to develop.

2. Increase the size of downed dead logs across the cutover area.
At present, CWD is present across the cutblocks in volumes comparable to natural disturbance but generally in smaller, shorter pieces and without provision for further recruitment except in reserves. Since it is probably not feasible to retain standing snags in the cutover area, CWD recruitment is likely to be delayed until residual live trees mature, die and fall. Priority should therefore be given to retaining CWD in such a way that it will persist and continue to function for as long as possible, to buffer the "trough" in supply that is almost certain to occur between decay of existing CWD and recruitment of new CWD from maturing trees in the new stand. Large logs decay more slowly than small ones (Maser and Trappe, 1984; Harmon et al., 1986), fulfil more functions (Maser

et al., 1979; Hayes and Cross, 1987; Torgersen and Bull, 1995) and are more likely to maintain a connected network of travel routes than small, short pieces. Maintaining vertical distribution (layering) may also slow decay by reducing or delaying the log's contact with the ground.

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