WESTERN FOREST PRODUCTS, ADAPTIVE MANAGEMENT PROGRAM

Habitat Structure Monitoring – Summary of 2007 Updates

FIRS numbers 6649005, 6654011, and 6658004

David Huggard, Dec. 18, 2007

1) The main field work of the habitat structure monitoring project in 2007 involved monitoring 22 operational harvest blocks. The blocks were divided between the former tenures of Weyerhaeuser/Cascadia, CanFor and Western Forest Products, to identify current weak points in retention for future operational improvement and to establish a baseline to measure progress in the future. The monitoring also updates changes in practices in former Weyerhaeuser/Cascadia operations since previous operational surveys from 1999 (first year of VR implementation) to 2003. Measuring operational progress is ultimately the test that adaptive management is working. This work is summarized in detail in the report "Habitat Structure Monitoring in Operational Cut-blocks, 2007", prepared by David Huggard. The summary of that report is attached as section 1 below.

2) A second component of field work completed 5-year re-measurements of habitat structure in 4 sites in CWHwh (Haida Gwai'i). One of the important contributions of the re-measurements is to follow the fate of individually-tagged trees and snags over time. This provides local information for both VR and uncut stands on growth and mortality rates of live trees, and fall and decay rates of snags, which is much needed for projecting deadwood resources. In conjunction with an FSP project to Fred Bunnell, Laurie Kremsater and David Huggard, all the tagged tree information was thoroughly re-analyzed to estimate growth, mortality, decay and fall rates by species, ecosystem, harvest treatment and edge distance in patches. The summary of results is provided as an update of section 3.12 of the main report on habitat structure monitoring[1] and is attached as section 2 below. Complete results are summarized in an update of Appendix 11 of the main report.

3) A separate field study investigated unexpected declines in the amount of soft CWD in some sites that were re-measured after 5 years. A summary of this work, which was undertaken by Strategic Forest Management Inc., was provided by Jeff Sandford of WFP, and is also attached below. It will be included as part of the section on the 5-year re-measurements in future updates of the main report.

4) Some data gaps from previously-surveyed sites were filled in. This information will be included in future updates of the main report.

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[1] Huggard, David J. 2006. Habitat monitoring 1999 to 2006 – Summary and data report. Available from Jeff Sandford at WFP, Campbell River, BC.

1. Habitat Structure Monitoring in Operational Cut-blocks, 2007 - Summary

Full results are in a separate report.

Western Forest Products (WFP) monitored habitat structure in 22 operational cut-blocks in 2007, continuing the program of MacMillan-Bloedel, Weyerhaeuser and Cascadia Forest Products (MB/W/C). The monitoring included blocks in the former tenures of Cascadia, CanFor and WFP. Most sites were group or mixed retention in CWHxm (with similar results for the two systems), or group retention in CWHvm. Retention of 50 habitat elements in the operational blocks was compared to levels in benchmark sites in uncut forest. Interpreting results as operational progress in a simple adaptive management loop is difficult, because there have been many changes in ownership, tenures and markets in the past few years. However, the results provide a baseline for looking at trends in the future, and suggest several weak points in habitat retention that could be a focus for operational improvement:

- Retaining some of the largest trees in CWHxm blocks.
- Retaining higher densities of large trees in CWHvm in the former CanFor and WFP operations.
- In WFP operations, retaining some very large snags, even if these are relatively well-decayed and short veterans from a previous stand.
- For all tenures, maintaining mid-size to moderately large snags in CWHxm.
- In CWHvm, where snag retention was higher, emphasizing important rare features, like big hollow snags.
- Continuing to try to retain tall snags in CWHxm, which have declined in the former MB/W/C tenure. In CWHvm, there was some improvement in retention of this element in MB/W/C operations, but they were rare in CanFor and WFP blocks.
- CWD was generally retained or created at high levels, except for soft wood in CWHvm in general, and in CWHxm in WFP operations, a sign of considerable ground disturbance during harvesting in these sites.

Many of these specific habitat elements are associated with higher productivity mesic sites, and may be missed if there is too much reliance on anchoring patches on wetlands or rock outcrops. Ensuring that some retention patches are located in productive mesic sites should be a priority.

One mixed VR block in CWHvm harvested by CanFor had high overall retention levels and especially high levels of several important habitat elements. If this block is typical, CanFor's mixed system would be a good complement to the group VR systems in this ecosystem.

The one dispersed retention block monitored in 2007 had few live trees and no snags recorded, possibly reflecting problems with the sub-sampling scheme in a patchy dispersed block, or high initial windthrow. Assuming the low habitat element levels in this one block are an anomaly, this system should not be neglected as a management tool.

Continuing the monitoring of operational blocks will start to show trends in retention with the current ownership, tenure and markets. Recommendations for the structure monitoring include:

- Continued random selection of operational blocks, but intentionally sampling distinctly different systems (e.g., group VR versus CanFor's mixed approach in CWHvm)
- Establishing benchmarks that are appropriate for comparing to operational blocks in CanFor's and WFP's former tenures, ideally by measuring pre-harvest levels of habitat elements in operational blocks. This is a priority for monitoring in 2008.

- Increasing the number of dispersed blocks monitored, to allow conclusions about how this system is currently being implemented. We may also have to consider how to monitor harvest blocks that are intermediate between the former MB/W/C dispersed and patch VR systems (e.g., patchy partial retention, or clumps of ~0.1ha).

2. Individually tagged trees after 5 years: Growth, mortality, fall and decay rates – Summary (2007 update of main report section 3.12.2)

Full results are reported in a separate document, an update of Appendix 11 of the main report.

An extensive analysis was undertaken of trees and snags that were individually tagged in the first post-harvest monitoring sessions and included in plots re-measured 5 years later. The analysis used the information on individual stems to calculate rates of diameter growth, mortality and mortality mode (standing versus fallen) of live trees, and fall and decay rates for different classes of snags. Growth, mortality and snag fall rates were compared between dispersed and group+mixed VR for Douglas-fir in CWHxm. With many more tagged trees in group+mixed VR, effects of dbh, tree species and ecosystem groupings on all these parameters were examined, as were any additional effects of distance from the edge of retention patches.

This information is a critical resource for long-term projection modeling of habitat structures, especially snags and CWD, in VR stands. Relatively little good information is otherwise available to support this modeling for VR stands and for the local ecosystem types. Some of the results also have more direct implications for VR management. Because of their importance for projection modeling, the methods and results are presented in detail in Appendix 11.

The main findings include:

<u>Live tree growth</u>

- Measured diameter growth was generally low, but only differed between VR and uncut sites for hemlocks (higher in uncut).
- Growth rates of cedars increased with dbh, and were higher in the CWHmm+dm and CWHwh than in other subzones, while other species showed less effect of dbh and ecosystem.
- Diameter growth of larger Douglas-fir in CWHxm were 3-4 times as high in dispersed VR as in group+mixed VR, with highest rates in 80cm dbh trees in dispersed VR.
- Growth rates were slightly higher 0-10m into retention patches compared to further into the patch. This may reflect true edge effects from removing adjacent trees, but it may also reflect anchoring many patches on wetlands or outcrops that lower growth rates near the patch centres.

<u>Tree mortality</u>

- Mortality rates for retained Douglas-fir trees decreased with dbh, while cedar and hemlock showed little difference in mortality among small or large trees. Deciduous trees and true fits had very high mortality rates at larger sizes, possibly because they are prone to windthrow, but this is based on a small number of samples.
- Mortality was considerably higher in VR blocks than in uncut forest in most cases.
- Mortality rates of Douglas-fir in CWHxm were higher in dispersed VR than group+mixed VR for smaller trees, but lower for larger trees.
- Mortality was moderately higher 0-10m into retention patches, decreasing with distance into the patch.
- Douglas-fir trees that died in VR blocks – particularly large trees – were much less likely to remain standing than in uncut forest, which reduces how much the extra mortality in VR stands contributes to snag supply. Moderate-sized hemlocks and cedars in drier ecosystems were least likely to remain standing, which is unfortunate since these are the main potential source of snags useful to many wildlife species.

Snag fall

- Fall rates of snags generally did not differ between VR stands and uncut forest, and there was relatively little difference in fall rates among the species.
- Fall rates usually declined with increasing snag diameter. Because decay rates did not change consistently with diameter, large snags are more likely to remain standing long enough to become well-decayed snags.
- Fall rates were somewhat higher for class 6+ (soft) snags, but there was no consistent increase in fall rates from class 3 to class 5.
- There were no apparent edge effects on fall rates of snags, except somewhat elevated fall rates of recent (class 3) snags near edges, as expected from their higher susceptibility to windthrow.

Snag decay

- Decay rates of snags were higher in VR than in uncut forest in a few cases, but the pattern was inconsistent. Decay rates also showed inconsistent relationships with dbh.
- Douglas-fir snags typically decayed more slowly than other species, including red-cedar.
- There were no consistent edge effects on decay rates.

General relationships with dbh

- Averaged across species, ecosystems and treatments, growth and mortality rates increased slightly with tree dbh, snag fall rates decreased in inverse proportion to dbh (doubling dbh halved fall rates), and snag decay showed no relationship with dbh.

3. CWD Data Audits – Summary (provided by Jeff Sandford)

Analysis of the 2006 CWD data indicated an unexpected decline in the amount of CWD in some areas from 2001 to 2006. Data from 30 sites was well within predicted ranges. Further analysis and was performed on the data from 11 of the 41 sites where these differences were the largest to attempt to understand where these differences were occurring and why. Field checking was performed at 3 of these sites. A complete summary of this work was completed by Strategic Forest Management Inc.

There was on average about a 25% reduction in the number of pieces of CWD counted at the 11 sites where differences were largest. Field checking verified that this was likely the result of one or more of the following factors:

1. **Missed Wood** (largest proportion) – due to measurement error. Field checks revealed many pieces of CWD are now obscured by humus and/or dense vegetation (Figures 1 and 2). Some of the species that make re-location difficult are Deer Fern, Sword Fern and taller, woody species such as Salmonberry and Huckleberry or Blueberry. Some CWD had developed a thick mat of moss on top that made it difficult to differentiate between the wood and soil. Hand digging was required to locate many of these pieces.

Figures 1 and 2. CWD obscured by humus and Deer Fern.

Lessons learned from this investigation have provided us with the knowledge and understanding of how to minimize the amount of missed pieces in future assessments.

2. **Gone/Decayed Wood** - some pieces had decayed to decay class 5 and a discretionary call in the field was made as to determine whether to include these pieces or not.
3. **Moved/Out Wood** – missed by transect if transect line not in exactly the same location as previous assessment. Transect lines must be carefully re-established to sample the same areas that we sampled in previous assessments. Machine traffic, salvage operations, shake cutting, and firewood removal can all have a significant effect on year-to-year assessments of CWD. Machinery had shattered wood near one transect that resulted in it not being counted.
4. **Natural Site Disturbance** – windfall resulted in some pieces becoming buried or moved.
5. **Small Wood** – "shrinking" below minimum size limit no longer counted due to decay and/or bark falling off.

6. **Data Management and Methods**– there was one instance where data from field cards was not transferred to the handheld data collector. There was also some confusion at one site about whether to include live or dead roots from upturned root wads.

Re-locating CWD in disturbed areas after five year of coastal vegetation and regeneration is difficult and requires trained and experienced personnel. Extra care and attention must be taken to ensure both accuracy and integrity of data. While some fluctuations in CWD in the short term are unavoidable and anticipated, this variability can likely be a reduced in future assessments by ensuring that the work is performed by personnel with a high level of experience with this type of assessment who are familiar with both the detailed methodology that must be followed and the source of where difficulties may be encountered. “CWD Field Cards” have been created for future assessments. These should help reduce the frequency of collecting CWD data that doesn’t get entered into either the handheld or database. These cards contain all the information necessary for someone to enter this data after the field season is over if required.

WESTERN FOREST PRODUCTS

ADAPTIVE MANAGEMENT PROGRAM

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Prepared by: David Huggard

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Summary

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1. Introduction

The program to monitor habitat structure as part of a larger adaptive management framework was initiated by MacMillan-Bloedel in 1999 and continued by Weyerhaeuser, Cascadia and Western Forest Products (WFP). The adaptive management program is intended to ensure that monitoring results improve operational practices. The monitoring is designed to allow several comparisons that can help guide practices, including comparisons of variable retention (VR) types (dispersed, group, mixed) and retention levels, comparisons with benchmark sites to identify weak points in retention, and evaluating edge effects to help design retention patches. An important part of the adaptive management framework is measuring trends over time, to test that the monitoring results and other guidance are actually being incorporated, and that operational practices are improving. This is a basic hallmark of successful adaptive management.

Most of WFP's habitat structure monitoring in 2007 focussed on operational VR blocks. However, many larger changes make it difficult to interpret these results as indicating how much progress has occurred since the initial operational monitoring from 1999 to 2003. Most obviously, the original MacMillan-Bloedel tenure has undergone three changes of ownership, including current amalgamation with two other companies as WFP. Each of those companies had different specific ecological objectives, and different practices intended to meet those objectives. Since 2003, there have been substantial changes in operating areas, markets, operational contractors, and the larger ecological context (e.g., less emphasis on MacMillan-Bloedel's original zoning and more smaller Old-Growth Management Areas). Changes in stand-level retention over time are more likely to reflect these larger factors than any ongoing adaptive management of practices. Although this report does examine retention of some habitat elements identified as priorities in the past, the main emphasis is on identifying current weak points for future improvements, and establishing a baseline to measure operational progress in the future.

Two comparisons are useful for guiding retention of habitat elements. First, comparing levels of habitat elements in VR blocks to levels in benchmark sites shows what percentages of natural levels are being retained in harvest units. Greater retention is more likely to meet ecological objectives of VR, including supporting species that use particular habitat elements, "life-boating" species, and accelerating structural development in the regenerating stand. However, greater retention of habitat elements generally means greater overall retention levels, which has an obvious economic cost. The second comparison is therefore the percent retention of particular habitat elements compared to the overall retention level. This has the most practical use, pointing out elements that are being retained most poorly at a given overall retention level, which provides a focus for future operational improvements. For example, if 20% overall retention retains 40% of small trees but only 10% of big old snags, the snags should clearly be a priority for improving retention. These weakest elements would be emphasized in future monitoring of operational progress.

2. Methods

2.1. Field methods

Field methods are described in detail in the main report on habitat structure monitoring (Huggard 2006). In brief, group and mixed VR sites are surveyed using transects across the edge of retention patches, extending 50m into the harvested matrix and 50m into the patch (or less if the patch is small). Two transects are used per patch, and three patches surveyed per block (unless there are less than 3 patches in the block). Six of these 100m-long transects are used in uncut mature stands, which are used as benchmark comparisons for the VR sites. Species, diameter at breast height (dbh), decay class (following Thomas et al. 1979), descriptors of form, and height (of some stems) are recorded for trees 12.5-30cm dbh in a 5m-wide transect and for larger trees and all snags in a 10m-wide transect. Coarse woody debris (CWD) volume is measured using the central transect and perpendicular transects every 10m as intercept transects, following van Wagner (1968), with diameter at point of interception, decay class (following Thomas et al. 1979), height above ground and length class recorded for each log. Canopy closure, cover, height and dominant species of shrubs and herbs, moss cover and depth, litter cover and type, and mineral soil exposure are recorded in subplots every 10m along the main transect.

The transects were designed for retention patches greater than ~0.25ha. In several blocks in CanFor's and WFP's former tenures, there were only one or two patches large enough to sample (Jeff Sandford, *pers. comm.*) The data summary accounts for the total percent area in retention, but if much of the retained area is in very small patches, the summary may overestimate retention of habitat elements that are difficult to retain in small patches (e.g., snags).

Operational blocks were monitored in 1999 (blocks harvested in 1998, the initial year of VR implementation), 2000, 2001, 2003 and 2007 (blocks harvested in 2006). Monitoring in the initial years tended to be in blocks considered good examples of VR practices. Later monitoring chose a more random sample of operational blocks. Operational monitoring from 1999-2003 included dispersed, group and mixed retention in the range of ecosystem types in the former tenure of MB/W/C, as summarized in the main report (Huggard 2006). Monitoring in 2007 focussed on group and mixed VR in the CWHxm and CWHvm ecosystems, including 8 group or mixed VR blocks harvested in 2006 or early 2007 by Cascadia, 5 by Western Forest Products and 7 by CanFor. An additional dispersed VR block harvested by CanFor in CWHmm, and a Cascadia block in the MH zone[1] were also monitored. The 9 Cascadia blocks monitored post-harvest in 2007 were also surveyed pre-harvest in 2004. All operational blocks were compared to a set of uncut mature benchmark sites monitored between 2001 and 2005 by Weyerhaeuser. The 30 benchmark sites in CWHxm are mainly in mature second-growth, the dominant age class in that subzone, while the 37 benchmark sites in CWHvm are mainly in old forest.

2.2. Data summary

Fluctuations in retention levels of various habitat elements from 2000-2003 were reported in the main report. It is unclear how much of that year-to-year variation reflected market changes, chance differences as different harvest areas were accessed and true changes in practices. For this report, the results from 2000-2003 operational blocks were

[1] The MH block was originally classified as CWHvm2, but it was re-classified as MH in 2007, as supported by the fact that all trees are yellow cedar, mountain hemlock or amabilis fir.

therefore combined. Results from 1999 were kept separately to represent the initial implementation of VR. Results from 2007 are reported separately for each of the former companies. This allows an examination of operational progress within the MB/W/C tenure, and initial values for future examinations of progress in the other 2 operations.

Initial inspection of results showed no obvious large differences between group and mixed retention blocks in CWHxm. The two retention types in CWHxm were combined as "group+mixed" VR. In CWHvm in 2007, there was only one (CanFor) block labelled as mixed retention, and results were quite different from group retention in the same ecosystem. Group and mixed retention were therefore kept separate in CWHvm. The one dispersed VR block surveyed in 2007, from CWHmm, was also summarized separately, along with 1999-2003 results from dispersed retention in CWHmm and CWHxm. The one MH block is not summarized here, because there is little benchmark data for comparison. One WFP block could not be surveyed in 2007 because it was too steep.

Results for each habitat element are expressed as a percentage of the level of that element in uncut benchmark sites in each subzone. Although these is a large sample of benchmark sites in the two subzones, the comparison should be treated with some caution because there is variation between areas within a subzone. In particular, the benchmark sites are scattered through MB/W/C's former tenure, but may be less representative of pre-harvest conditions for blocks in CanFor or WFP's former tenures. The concern is greatest for patchy and/or species-specific elements, such as "large cedar snags." For 8 Cascadia blocks monitored in CWHxm and CWHvm in 2007, results can also be expressed directly as the percent retention of elements measured before harvest in 2004. A comparison of percentage of mature levels and percentage of pre-harvest levels for these 8 blocks provides a test of how representative the mature benchmark sites are of pre-harvest conditions in the operational blocks.

Results were tabulated for 50 habitat elements for the four combinations of BEC subzone and VR type monitored in 2007 (CWHxm group+mixed, dispersed; CWHvm group, mixed), along with results from the same subzones and VR types from the 1999-2003 operational monitoring. Graphs and more detailed interpretations are provided for 17 main habitat elements, including ones that were most challenging to retain in the past, for group+mixed VR in CWHxm and group VR in CWHvm, where >1 operational site was surveyed in each company's former tenure in 2007. Results for other subzones monitored in 1999-2003, but not in 2007, are in the main report (Huggard 2006).

3. Results

3.1. Benchmarks versus pre-treatment

For most of the habitat elements in the MB/W/C tenure monitored in 2007, percent retention relative to benchmark sites is very similar to percent retention relative to the pre-harvest levels. In other words, the benchmark and pre-harvest conditions were similar. Exceptions were more small snags in the pre-harvest stands than in the benchmarks in CWHxh (and therefore, lower percent retention of small snags relative to the pre-harvest values), more soft CWD in the pre-harvest stands in CWHxh and less total CWD pre-harvest in CWHvm. The similarity of the pre-harvest and benchmark values for most elements supports using the benchmarks to indicate pre-harvest levels in other stands. However, the benchmarks may be less representative for CanFor and WFP stands that are away from the Weyerhaeuser benchmark sites.

3.2. Trends in percent retention by area

The recorded retention levels for operational group VR are based on the percent of the block area in retention patches. For the MB/W/C blocks, retention area declined in CWHxm from 16.6% in 1999 to 13.0% in 2000-2003, then increased to 20.3% in 2007. In CWHvm, retention increased from 12.7% to 21.3% to 23.9%. The retention levels in CanFor and WFP blocks were lower, 13.7% and 13.9%, respectively, in CWHxm, and 15.6% and 19.2% in CWHvm. All else being equal, habitat elements associated with the patches – particularly live trees and snags – should follow a similar pattern. However, selective retention could increase or decrease some elements from these levels, management practices in the patches – such as snag-falling for safety around edges – could alter the levels, and “extra” retention scattered in the harvested matrix could increase levels of some elements above these recorded retention levels.

3.3. Main comparisons over time – group+mixed VR in CWHxm; group VR in CWHvm

Results for trends over time in group+mixed VR in CWHxm and group VR in CWHvm, and comparisons of recent blocks in the three former tenures are in the following sections, for live trees, snags, CWD and cover layers. An important part of the monitoring is to identify weak points – elements with low levels of retention – which include::

- The largest trees in CWHxm blocks (when large trees are present – often veterans)
- Moderate to large trees in CWHvm in the former CanFor and WFP operations

- Very large snags in WFP operations (even if these are relatively well-decayed and short veterans from a previous stand)
- Mid-size to moderately large snags in CWHxm. (These snags have different ecological roles and are typically more abundant than very large soft snags).
- In CWHvm, where snag retention was more proportional, important rare features, like big hollow snags, could be emphasized.
- Tall snags (>8m) in CWHxm, which continued to decline in the former MB/W/C tenure. In CWHvm, there was some improvement in retention of this element that had been identified previously as a weakness in MB/W/C operations, but they were rare in CanFor and WFP blocks.
- Soft CWD in CWHvm, and in CWHxm in WFP operations. Reduction of soft CWD indicates considerable ground disturbance during harvesting in these sites, even though overall CWD levels were high.

Some of these apparent weaknesses may just be due to small sample sizes within a particular BEC subzone in each former tenure, and may be associated with different forest types or different harvesting systems, rather than being typical of the former company's operations in general.

3.3.1. Live trees

Live tree density in CWHxm in the MB/W/C tenure was higher (relative to benchmarks) in 2000-2003 (Figure 1 top left), but this was due mainly to retention of more small trees (Figure 2 top left). Basal area of live trees has been declining slightly since 1999 in this subzone (Figure 1 top right), with less retention of larger live trees (Figure 2 top right) and no trees >80cm dbh (Appendix 1). CanFor blocks in 2007 were similar, but with better selection of the range of tree sizes. WFP blocks had a high density of small trees, but basal area retention was equal to the overall retention level.

In CWHvm, the percentage retention of trees increased from 1999 to 2000-03 then levelled off (Figure 3 bottom left), but basal area retention has continued to increase (Figure 3 bottom right). The basal area increase was due to greater retention of large (Figure 3 bottom right) and very large (Appendix 1) trees. CanFor blocks in CWHvm in 2007 had high retention of small and moderate trees, but lower percentages of large and very large trees. The resulting basal area retention was about equal to the overall retention. WFP blocks had reduced percentages of large and very large trees, and therefore basal area retention was also relatively low. The smaller trees retained in the CanFor and WFP blocks may simply represent what was available in those particular blocks. However, if this was the result of intentional selection of small trees for retention, or selection of poorer sites (wetlands, rocky areas) for retention patches, this would be a focus for future operational improvement.

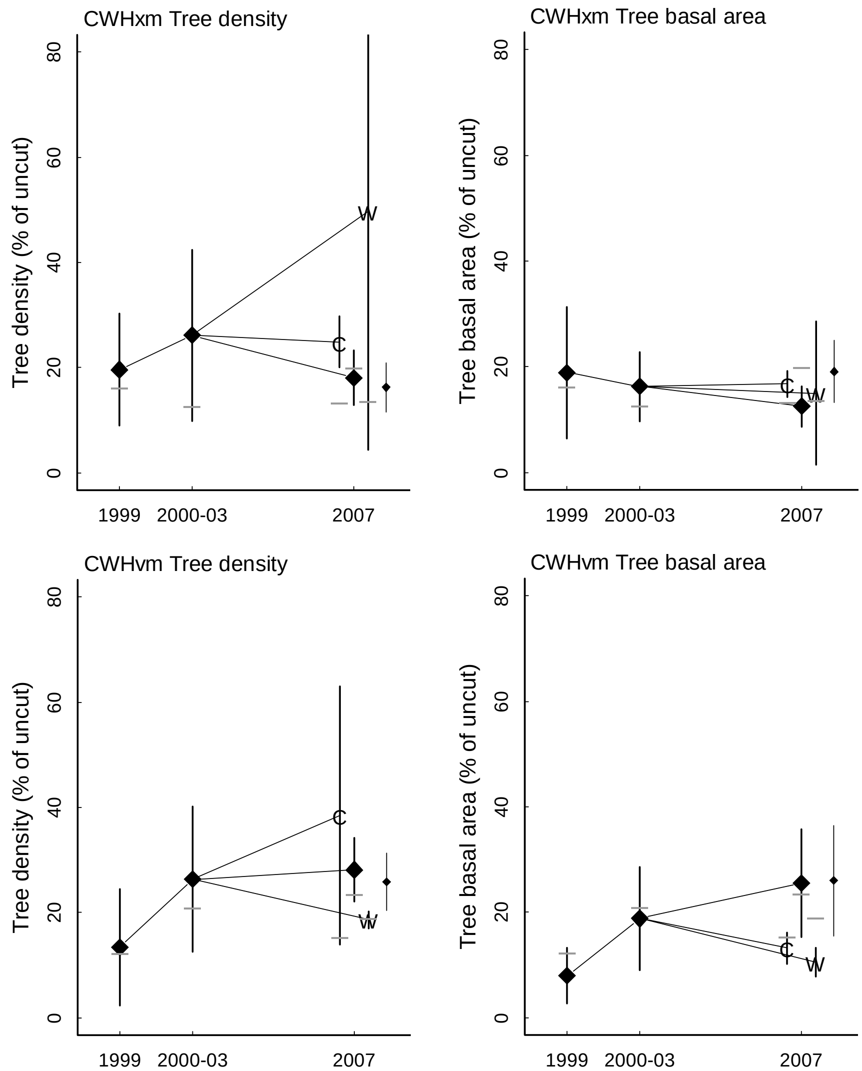

Figure 1. <u>Tree density and basal area</u> in operational group+mixed retention blocks in CWHxm (top) and CWHvm (bottom), 1999-2007. ♦ = MacMillan-Bloedel (1999 monitoring) / Weyerhaeuser (2000-2003 monitoring) / Cascadia (2007 monitoring) blocks; C = CanFor blocks; W = Western Forest Products. All values are expressed *as a percentage of the value in mature stands* in that BEC subzone (except the small ♦, which compares Cascadia's blocks monitored in 2007 to the pre-treatment values in the same blocks). Error bars are 1 SD.

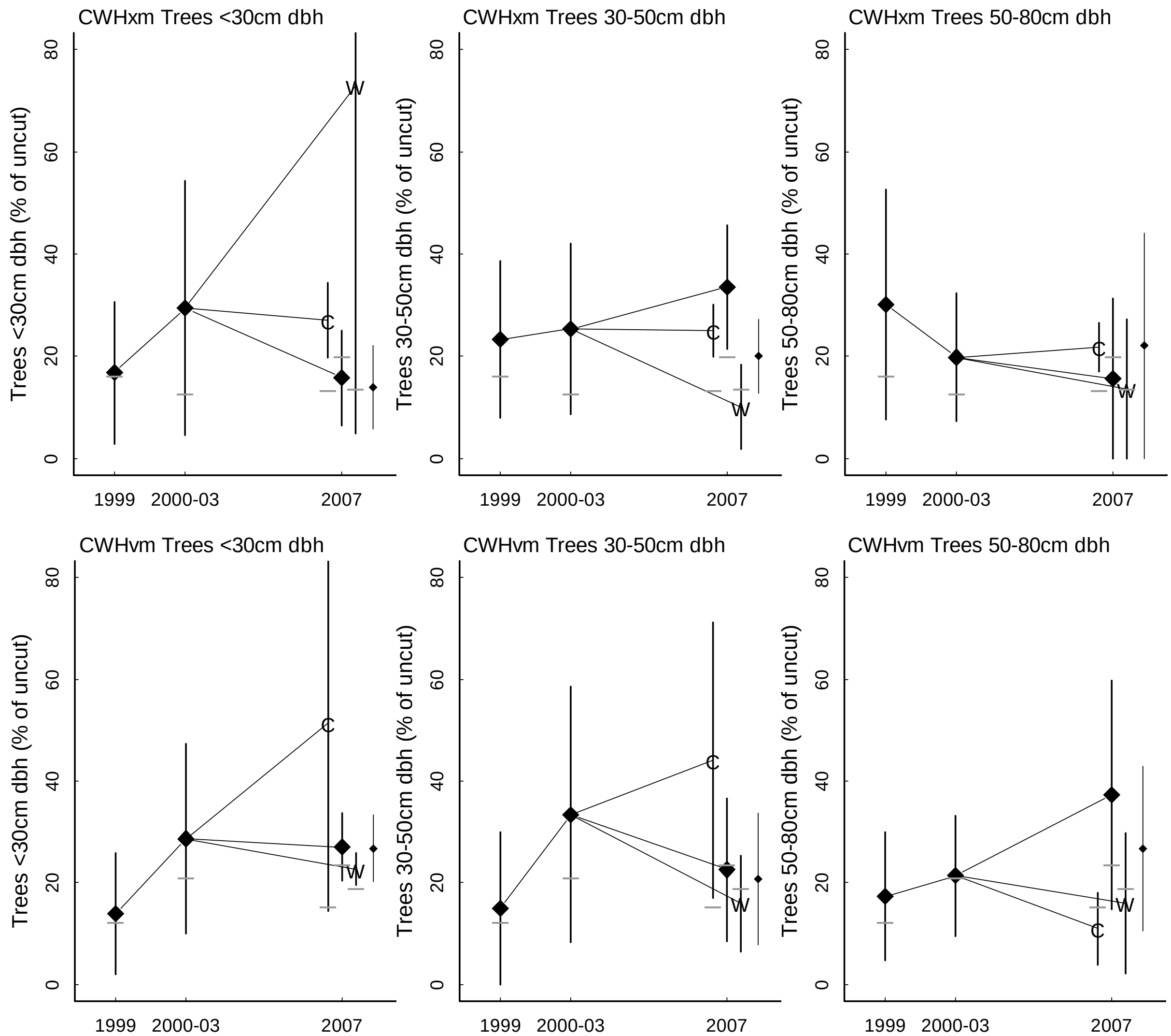

Figure 2. <u>Tree density in 3 size classes</u> in operational group+mixed retention blocks in CWHxm (top) and CWHvm (bottom), 1999-2007. ♦ = MacMillan-Bloedel (1999 monitoring) / Weyerhaeuser (2000-2003 monitoring) / Cascadia (2007 monitoring) blocks; C = CanFor blocks; W = Western Forest Products. All values are expressed *as a percentage of the value in mature stands* in that BEC subzone (except the small ♦, which compares Cascadia's blocks monitored in 2007 to the pre-treatment values in the same blocks). Error bars are 1 SD.

<u>3.3.2. Snags</u>

In the MB/W/C operations in CWHxm monitored since 1999, percent retention of snags increased after 1999 then levelled off (Figure 3 top left). However, basal area of snags has continued to increase (with much variation from stand to stand; Figure 3 top right). VR stands in this subzone now have a snag basal area that is a substantial percentage of the level in benchmark stands. In particular, the very largest snags (>80cm, Appendix 1) have

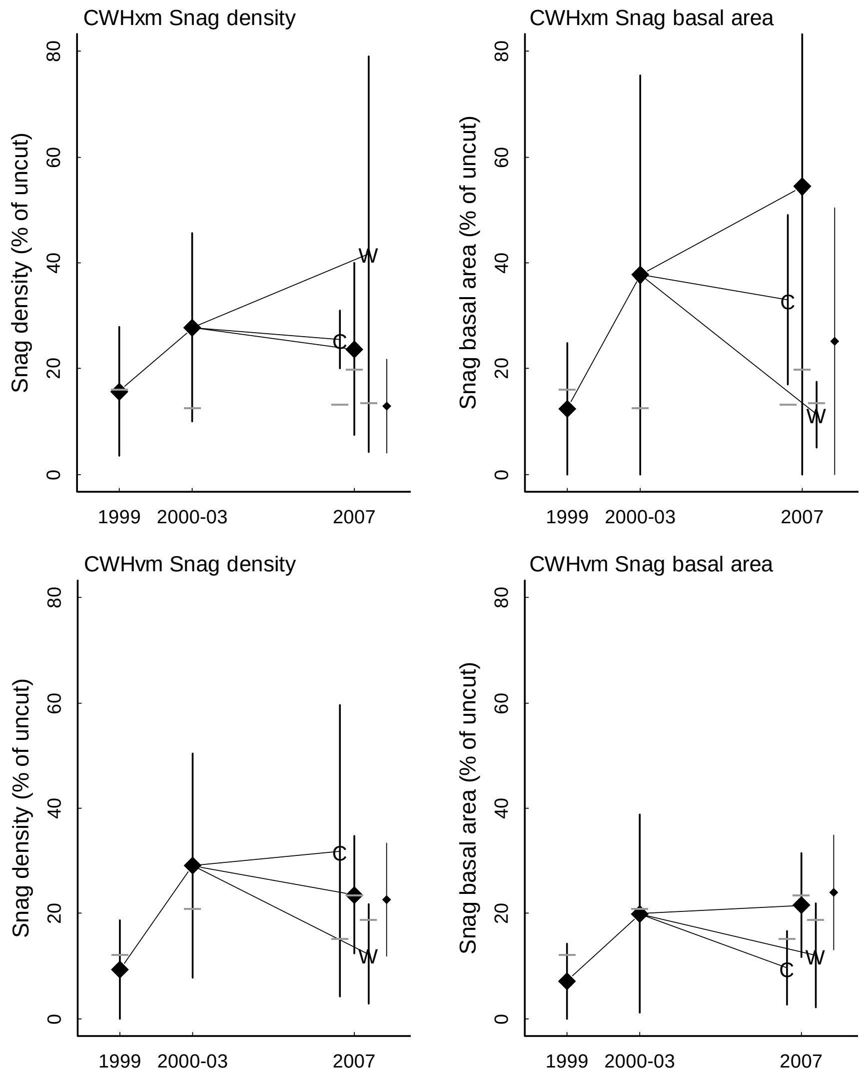

Figure 3. <u>Snag density and basal area</u> in operational group+mixed retention blocks in CWHxm (top) and CWHvm (bottom), 1999-2007. ♦ = MacMillan-Bloedel (1999 monitoring) / Weyerhaeuser (2000-2003 monitoring) / Cascadia (2007 monitoring) blocks; C = CanFor blocks; W = Western Forest Products. All values are expressed *as a percentage of the value in mature stands* in that BEC subzone (except the small ♦, which compares Cascadia's blocks monitored in 2007 to the pre-treatment values in the same blocks). Error bars are 1 SD.

been retained at high percentages. In these second-growth stands, many of these largest snags are veterans from the previous stand, and have important structural and life-boating roles. However, retention of mid-sized snags declined considerably in this tenure in 2007 (Figure 4 top middle and right). Because these mid-sized snags are often younger, taller and with harder wood, as well as being more abundant than very large snags, they also have important roles, and should not be neglected in retention.

The CanFor blocks in CWHxm had relatively high retention of snags (i.e., percentage of snags greater than percent of block area retained), and large snags were included, so that percent retention of snag basal area was also high. However, most of the large snags were in 1 site with riparian retention. For an evaluation of habitat structure across a larger landscape, we would need to know how common these riparian retention patches are. WFP blocks had high percent retention of snags, but biased towards smaller snags. Retention of snag basal area was therefore about equal to percent of area retained.

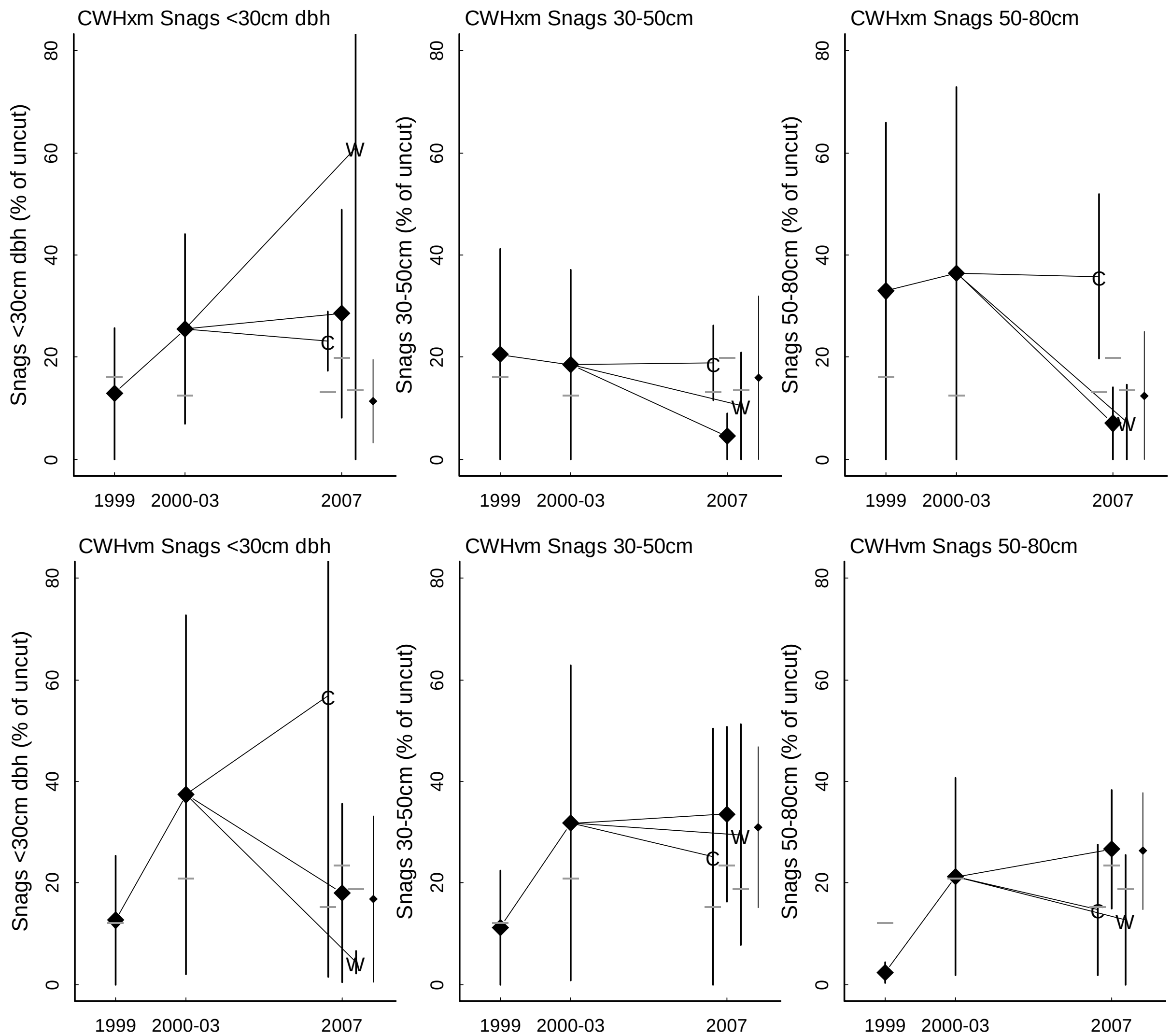

Figure 4. <u>Snag density in 3 size classes</u> in operational group+mixed retention blocks in CWHxm (top) and CWHvm (bottom), 1999-2007. ♦ = MacMillan-Bloedel (1999 monitoring) / Weyerhaeuser (2000-2003 monitoring) / Cascadia (2007 monitoring) blocks; C = CanFor blocks; W = Western Forest Products. All values are expressed *as a percentage of the value in mature stands* in that BEC subzone (except the small ♦, which compares Cascadia's blocks monitored in 2007 to the pre-treatment values in the same blocks). Error bars are 1 SD.

In the CWHvm, snag retention – by density, size classes and basal area – was more closely proportional to the percent of area retained (Figure 3 and 4 bottom). The one exception was high retention levels of small snags in CanFor blocks, along with relatively few large snags.

Well-decayed snags and tall snags are two challenging habitat elements to maintain in managed stands. In the MB/W/C tenure, retention of decayed snags improved after 1999,

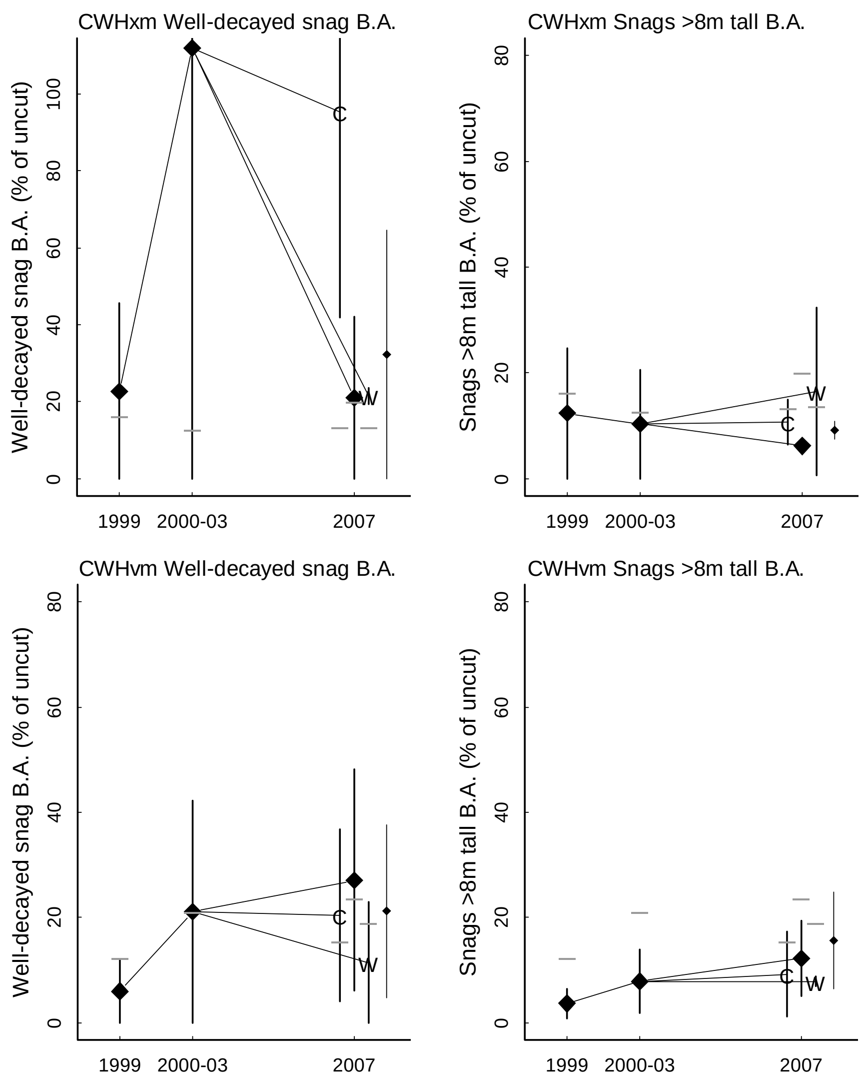

Figure 5. <u>Basal area of well-decayed (class 6+) snags and snags >8m tall</u> in operational group+mixed retention blocks in CWHxm (top) and CWHvm (bottom), 1999-2007. ♦ = MacMillan-Bloedel (1999 monitoring) / Weyerhaeuser (2000-2003 monitoring) / Cascadia (2007 monitoring) blocks; C = CanFor blocks; W = Western Forest Products. All values are expressed as *a percentage of the value in mature stands* in that BEC subzone (except the small ♦, which compares Cascadia's blocks monitored in 2007 to the pre-treatment values in the same blocks). Error bars are 1 SD.

and has remained about proportional to percent retention area since then (Figure 5 left). Retention of well-decayed snags was very high CWHxm for CanFor blocks, also the results of abundant snags in the one site with riparian retention.

Retention of tall snags was identified initially as a problem for MB/W/C operations and remains problematic (Figure 6 right). Tall snag retention has declined in CWHxm, and, while improving in CWHvm, is still well below proportional to overall retention. Tall snags were also rare in WFP blocks in CWHvm. Layout of retention patches and on-the-ground practices that improve retention of tall snags should be a focus.

3.3.3 Coarse woody debris

In contrast to live trees and snags, CWD is abundant in the harvested matrix, and so is typically near or above benchmark levels across post-harvest blocks (Figure 6 left). Only WFP's blocks in CWHxm had overall CWD volumes much below benchmark levels. However, well-decayed soft CWD, especially larger logs, are harder to maintain in the matrix during logging, and less is produced as logging waste. In the CWHxm, blocks in MB/W/C's tenure have maintained soft CWD near or above benchmark levels through time, but blocks in WFP's tenure in this subzone in 2007 had relatively low levels of soft wood (Figure 6 middle and right). All tenures in CWHvm in 2007 had relatively low levels of soft wood, which represents a decline from previous higher levels in MB/W/C blocks. Retention levels of soft CWD, including large soft logs, were nearly proportional to percent retention area in Cascadia and WFP blocks in CWHvm in 2007, implying that very little soft CWD was being maintained outside the retention patches. This suggests greater ground-level disturbance during logging in this subzone than had been the case in previous years. Soft CWD volumes will recover as abundant hard CWD in the harvested areas decays, but maintaining some soft wood shortly after harvest is important as habitat and substrate, as well as recolonization sources for many wood-inhabiting organisms.

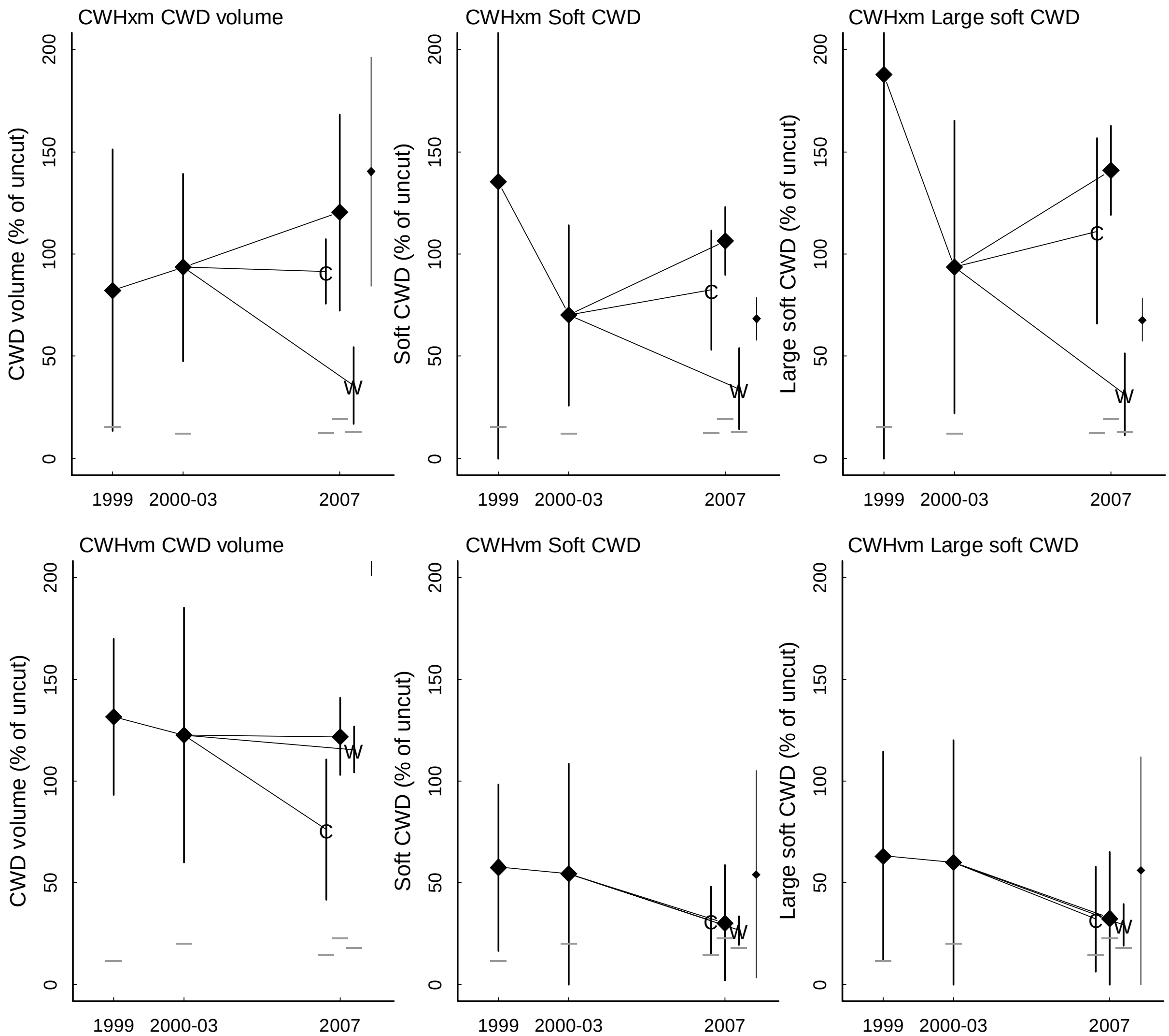

Figure 6. <u>Volume of coarse woody debris (CWD) overall, in soft (class 4) logs and in soft logs >50cm diameter</u> in operational group+mixed retention blocks in CWHxm (top) and CWHvm (bottom), 1999-2007. ♦ = MacMillan-Bloedel (1999 monitoring) / Weyerhaeuser (2000-2003 monitoring) / Cascadia (2007 monitoring) blocks; C = CanFor blocks; W = Western Forest Products. All values are expressed *as a percentage of the value in mature stands* in that BEC subzone (except the small ♦, which compares Cascadia's blocks monitored in 2007 to the pre-treatment values in the same blocks). Error bars are 1 SD.

<u>3.3.4 Cover layers</u>

Canopy closure, as expected, closely follows the percent of area retained (Figure 7 left). The percentage is somewhat higher than the percent of area because of the spread of tree canopies along the edge of retention patches, and contributions from scattered trees left in the harvested matrix.

Moss cover shortly after harvest indicates the degree of ground disturbance during harvest. Moss cover has declined since 1999 in MB/W/C's CWHxm blocks, while remaining at a fairly constant percentage in CWHvm (Figure 7 right). The percent retention of moss in CWHxm is near the percent of area retainedl, implying that little moss is being maintained

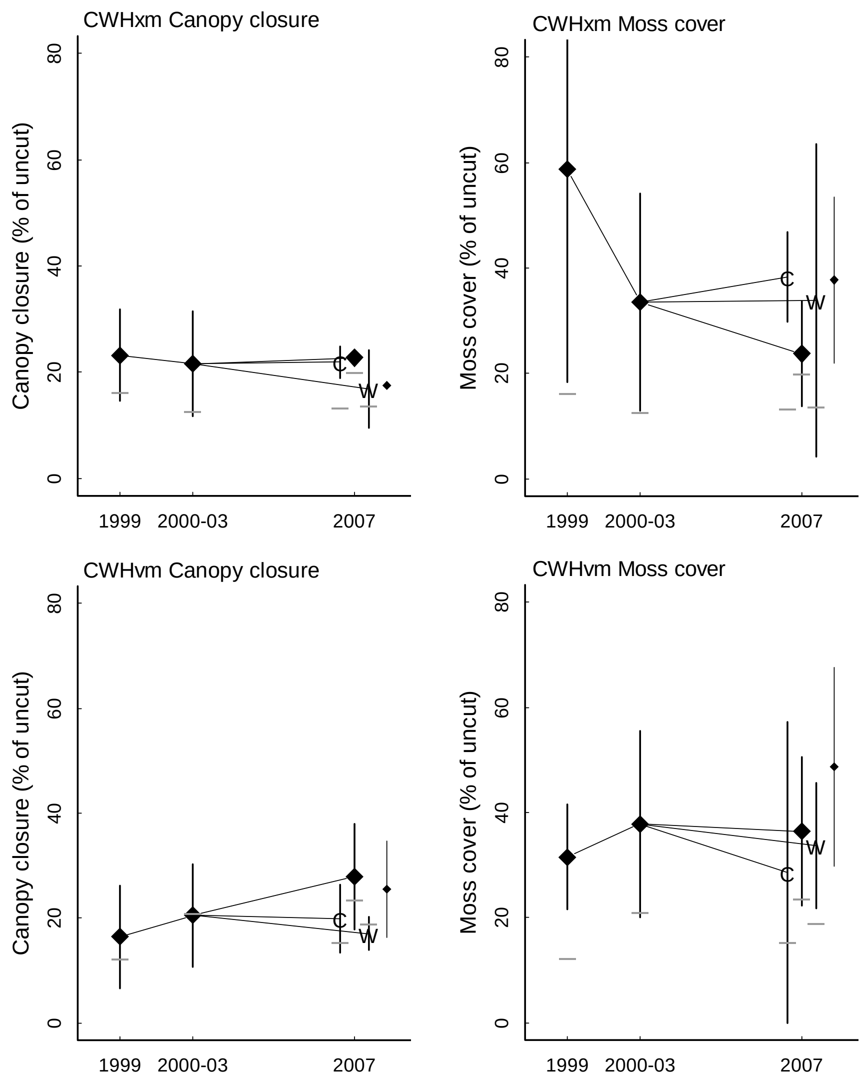

Figure 7. <u>Canopy closure and moss cover</u> in operational group+mixed retention blocks in CWHxm (top) and CWHvm (bottom), 1999-2007. ♦ = MacMillan-Bloedel (1999 monitoring) / Weyerhaeuser (2000-2003 monitoring) / Cascadia (2007 monitoring) blocks; C = CanFor blocks; W = Western Forest Products. All values are expressed *as a percentage of the value in mature stands* in that BEC subzone (except the small ♦, which compares Cascadia's blocks monitored in 2007 to the pre-treatment values in the same blocks). Error bars are 1 SD.

outside retention patches. CanFor and WFP blocks had similar or higher retention percentages for moss, but since their percent area in patches was lower, this implies somewhat better retention of moss in the harvested matrix in these two former tenures.

3.4. Mixed VR block in CWHvm

Retention in the one 2007 block identified as mixed retention in CWHvm was high, even higher than the recorded retention level of 40.2%. Retention percentages for live tree elements were mainly >50% of benchmark levels, canopy closure was 43% of the benchmarks, and other cover layers were near benchmark levels. The main weakness was in retention of snags, which were mainly small, although some larger soft snags were retained. Given a sample size of 1, there may simply have been relatively few snags to retain in this block. A larger sample size of this type of block would be helpful to know if the high retention of many elements and weakness in snags was typical of the system.

3.5. Dispersed VR block in CWHxm

The single operational block with dispersed VR monitored in 2007 showed inexplicably low percent retention of trees – 1% of the density of benchmarks, 1.8% of the basal area – and no retention of snags, despite the recorded retention level of 22.4% (Appendix 1). Possible explanations include random plot locations that missed most of the retention by chance, retention of mainly trees too small to include in the monitoring plots, or a problem with the data collection or processing. The habitat structure monitoring uses nested quadrats of 25x25m and 50x50m in dispersed settings, with 2 randomly-located quadrats per site. This design worked with the fairly uniform dispersed VR practiced by Weyerhaeuser, but could miss most retention by chance if the CanFor system is much patchier. This variation due to subsampling error would average out over several blocks, but might have given an unrepresentative sample of the single site surveyed in 2007. The surveyed block had a high percentage of small tree cover relative to benchmarks, implying that the dispersed retention may have contained many trees too small to qualify for measuring (i.e., <12.5cm dbh). This could be the case if the dispersed VR block was really intended as a “thin-from-above”, or “understory protection” treatment. In any case, with only one site surveyed in this type, conclusions should not be drawn about current implementation of dispersed VR until a larger sample has been surveyed.

4. Discussion

Monitoring operational progress in retaining habitat structure is an important part of the adaptive management program – it indicates whether management practices are improving in response to lessons learned in previous monitoring. Retention of many habitat elements improved from the initial year of VR implementation in 1999 to 2000-03, including those identified as ecologically important and needing improvement in the initial blocks. Changes from 2000-03 to 2007 were more variable, with some elements improving in one or both monitored subzones, but others declining. However, there have been so many larger changes in that time, including changes in company ownership, that it is impossible to interpret these changes as the success or failure of any simple adaptive management feedback loop. Instead, the main benefit of this year's monitoring is to provide a baseline to measure future improvements (assuming the situation with ownership, tenures, markets, etc. remains stable long enough to allow adaptive management learning to be applied) and to point out current weaknesses. Some main apparent weak points to address and to monitor for progress in the future include:

- Trying to retain some larger live trees where these occur in the CWHxm, particularly veteran trees in second-growth stands. Anchoring retention on ecological features like rock outcrops and wetlands is valuable, but should not be used to the exclusion of some retention in the productive mesic sites that usually contain larger trees.
- Operators on MB/W/C's former tenure retain large, well-decayed (but generally short) snags well, but this could be improved for operators on the other two former tenures. In the CWHxm, all operations could retain more mid-sized to large, tall snags, probably by selecting patches where these occur abundantly for retention.
- Reduced soft CWD and moss cover suggest that there is still considerable ground disturbance in the harvested areas, particularly in CanFor and WFP's former tenures (which might just be due to the harvest systems used in those particular blocks). Reducing ground disturbance is generally good for various reasons, but a more important consideration for the CWD is ensuring longer-term recruitment.

Many of these habitat elements – large trees, including large Douglas-firs, large and tall snags, and moss cover – are associated with productive mesic sites. They may be underrepresented in VR blocks if too much emphasis is placed on anchoring retention patches to wetlands or rock outcrops. Mesic sites with higher site index should also be included in retention patches.

Percent of the area of the monitored blocks retained in MB/W/C's former tenure (20.3% in CWHxm, 23.9% in CWHvm) was close to the typical provincial retention levels for the CWH zone (23.7%; Densmore 2007), while the retention levels in WFP and CanFor's former tenures were lower. If these lower overall retention levels are being used, a greater emphasis should be put on active selection of important habitat elements for retention. That is, percent retention of habitat elements such as very large live trees, snag basal area, tall snags, etc. should be higher than the percent of stand area retained, requiring more active selection of good retention patches and efforts to protect habitat elements in the harvested matrix.

The one mixed VR block in CWHvm surveyed in CanFor's former tenure had high retention levels overall, and particularly of important habitat elements. If this block is typical, then this retention system provides a good complement to the lower retention in group VR in this subzone. It would probably be better to maintain the diversity of retention of the lower-retention group VR and high-retention mixed VR, rather than homogenizing all blocks to a single average retention level.

Dispersed VR monitored in past years provided lower retention of many habitat elements, but considerably higher retention of particular elements like very large live trees. It was therefore a useful complement to the more common group VR. Very few trees and no snags were recorded in the one dispersed VR block monitored in 2007, which may have been bad luck with the random plot location in a patchy block, or some problem with the data. The difference between the recorded retention level and the much lower measured retention may also have been due to severe post-harvest windthrow, although this was not specifically noted by the field crew. More dispersed blocks would have to be sampled to know how typical the low retention levels are. Assuming the results for this block were an anomaly, dispersed retention systems (or mixed VR with substantial retention in the matrix) should not be neglected as a management option.

Continued monitoring of operational blocks will improve confidence in measurements of current retention, and will start providing information on operational progress with the current company, tenure and markets. Suggestions for operational monitoring include:

- Focussing on the two ecosystem groups, CWHxm and CWHvm, is probably better than trying to cover all the ecosystems in the tenure. Good information for the one drier and one wetter ecosystem is more helpful than a bit of information from everywhere.
- Using randomly-chosen operational blocks helps ensure that the results are representative. When there are two or more very different systems, such as group VR versus CanFor's

mixed approach in CWHvm, or group+mixed versus dispersed retention in CWHxm, it would be worth intentionally sampling several blocks in each type (e.g., 3 group and 3 mixed VR in CWHvm, even if the mixed system is less common). This would help with comparing the systems as different management options. It would also help to know what percentage of operational blocks use each system – e.g., "10% of operational blocks in CWHvm use the CanFor type of mixed retention."

- The benchmark values are essential to interpreting the percent retention levels of individual habitat elements. There is some concern that the benchmarks established by Weyerhaeuser on their former tenure may not represent the stands that are being harvested on CanFor or WFP's former tenures. More benchmarks in those areas could help. Alternatively, more effort could be made to stratify existing benchmarks by region, to match operational sites to more local benchmarks. However, that would mean smaller sample sizes and greater uncertainty for each benchmark comparison. Probably the best option would be to do pre-harvest measurements in operational blocks where possible, especially in the former CanFor and WFP tenures. These would allow direct calculations of percent retention of elements in those blocks and also contribute to the larger pool of benchmark values.
- More operational blocks with dispersed retention need to be sampled before making conclusions about how this system is currently being implemented. We may also need to consider how to sample in VR blocks that are intermediate between the fairly uniform dispersed retention and the distinct patches of group VR as practiced by MB/W/C. Very clumped individual tree retention, or small retention patches (~0.1ha) might best be sampled by transects, even if these blocks are official called dispersed VR.

References

Densmore, Nancy. 2007. State of cutblocks: Resource stewardship monitoring for stand-level biodiversity, 2005. FREP report #7, Victoria, BC.

Huggard, David J. 2006. Habitat monitoring 1999 to 2006 – Summary and data report. Available from Jeff Sandford at WFP, Campbell River, BC.

Thomas, J.W. (editor). 1979. Wildlife habitats in managed forest in the Blue Mountains of Oregon and Washington. U.S.D.A., For. Serv. Agric. Handb. 553, Washington, DC.

Appendix 1. Detailed results for habitat elements in group+mixed and dispersed retention blocks in CWHxm, and group and mixed retention blocks in CWHvm.

	CWHxm Group+Mixed						CWHxm+mm Dispersed		
	1999	2000-2003	2007			2007	1999	2000-2003	2007
			CanFor	WFP	Cascadia	Cascadia			CanFor
Comparison:			Mature			Pre-harvest		Mature	
Sites	6	26	3	3	3	3	3	16	1
% Retention	16.6	13.0	13.7	13.9	20.3	20.3	5.0	16.2	22.4
Tree Density	19.6	26.1	24.9	49.7	18.1	16.3	8.7	7.2	1.0
Tree Basal Area	18.9	16.3	16.8	15.0	12.5	19.1	11.9	8.3	1.8
Trees Fd Density	10.7	22.2	20.0	4.6	26.4	15.9	19.3	10.5	2.8
Trees Fd Basal Area	15.9	15.0	15.2	2.2	16.9	19.5	9.5	12.3	3.9
Trees HemBal Density	25.4	19.7	20.8	108.3	7.1	12.9			
Trees HemBall Basal Area	19.8	15.1	16.0	53.3	6.4	13.3			
Trees Deciduous	17.8	58.8	51.1	0.0	42.3	20.7			
Trees Deciduous Basal Area	17.3	53.6	46.8	0.0	28.6	20.3			
Trees <30cm dbh Density	16.8	29.4	27.1	72.9	15.8	13.9	9.2	5.6	0.0
Trees 30-50cm dbh Density	23.3	25.3	25.0	10.1	33.6	20.1	2.0	5.3	0.0
Trees 50-80cm dbh Density	30.1	19.8	21.7	13.6	15.7	22.1	10.6	16.1	7.1
Trees >80cm dbh Density	16.0	6.9	8.7	0.0	0.0	0.0	15.3	7.4	0.0
Trees Fd >50cm dbh Density	25.2	16.6	18.2	1.2	14.9	22.1	13.4	18.2	10.1
Snag Density	15.7	27.7	25.5	41.6	23.7	13.0	10.1	10.9	0.0
Snag Basal Area	12.4	37.7	33.0	11.4	54.4	25.2	16.2	45.1	0.0
Snag Fd Density	12.6	22.5	20.7	3.0	24.6	9.1	15.5	13.8	0.0
Snag Fd Basal Area	12.3	51.3	44.0	0.7	13.8	12.3	35.6	75.5	0.0
Snag HemBal Density	34.0	35.9	35.5	166.8	7.6	17.7			
Snag HemBal Basal Area	44.9	17.9	23.0	58.1	1.3	6.4			
Snag Decay 3 Density	3.7	18.8	16.0	35.1	44.5	11.2	8.1	4.5	0.0
Snag Decay 3 Basal Area	3.1	16.3	13.8	13.9	15.7	12.9	16.2	7.6	0.0
Snag Decay 4+5 Density	16.0	26.9	24.9	35.7	14.3	14.9	2.0	5.6	0.0
Snag Decay 4+5 Basal Area	11.1	15.6	14.7	6.8	77.6	25.9	0.7	14.5	0.0
Snag Decay 6 Density	32.7	42.4	40.6	62.4	11.2	33.7	25.8	27.2	0.0
Snag Decay 6 Basal Area	22.8	111.9	95.2	21.5	21.0	32.3	45.3	123.1	0.0
Snag <30cm dbh Density	12.9	25.5	23.1	61.0	28.6	11.4	4.4	3.3	0.0
Snag 30-50cm dbh Density	20.6	18.5	18.9	10.5	4.5	16.1	11.6	5.1	0.0
Snag 50-80cm dbh Density	32.9	36.4	35.8	7.3	7.1	12.5	31.9	20.4	0.0
Snag >80cm dbh Density	3.9	68.1	56.1	0.0	61.4	31.4	11.3	69.8	0.0
Snag >8m Tall Density	6.0	15.5	13.7	37.3	17.1	6.4	0.0	1.2	0.0
Snag >8m Tall Basal Area	12.4	10.3	10.7	16.5	6.2	9.2	0.0	1.7	0.0
Snag >30cm Decay 6+	32.4	46.5	43.9	17.8	12.9	29.0	31.9	36.7	0.0
Snag Douglas-fir >30cm dbh	18.3	26.6	25.0	0.0	3.8	8.1	27.5	27.5	0.0
CWD Volume	82.2	93.5	91.4	35.8	120.3	140.2	103.1	91.5	66.2
CWD Decay 1+2 Volume	122.6	174.9	165.1	58.6	136.3	269.0	260.6	140.4	62.0
CWD Decay 3 Volume	33.8	53.0	49.4	21.4	69.5	88.5	37.7	72.5	89.3
CWD Decay 4 Volume	135.4	70.1	82.4	34.1	106.3	68.3	28.4	70.2	47.1
CWD <30cm Diam Volume	113.6	127.5	124.9	89.5	159.3	192.1	158.7	135.6	67.2
CWD 30-50cm Diam Volume	75.3	79.6	78.8	15.0	128.0	119.6	84.0	75.4	4.7
CWD 50-80cm Diam Volume	66.0	83.2	80.0	14.0	125.1	119.4	33.5	65.0	112.5
CWD >80cm Diam Volume	57.2	67.8	65.8	0.0	28.8	95.3	157.6	95.7	96.3
CWD >50cm Decay 4	187.7	93.6	111.2	31.5	140.9	67.8	22.3	90.0	66.3
CWD Fd >50cm Diam	36.0	86.2	76.8	0.0	26.0	400.3	259.2	107.1	29.5
Canopy Closure	23.2	21.6	21.9	16.9	22.7	17.5	17.2	10.8	0.0
Small-Tree Cover	65.1	39.8	44.5	79.2	74.5	215.2	35.1	43.3	96.2
Mineral Soil	485.6	474.9	476.9	223.1	461.7	2795.6	555.3	426.7	288.6
Moss Cover	58.7	33.5	38.3	33.9	23.7	37.7	10.5	16.2	0.0
Shrub Cover	35.3	39.1	38.4	123.4	64.6	143.9	47.2	31.5	18.1
Herb Cover	27.1	64.4	57.4	94.8	168.5	88.6	64.9	51.6	88.8

	CWHvm Group						CWHvm Mixed		
	1999	2000-2003	2007			2007	1999	2000-2003	2007
			CanFor	WFP	Cascadia	Cascadia			CanFor
Comparison:			Mature			Pre-harvest		Mature	
Sites	6	39	3	2	5	5	1	2	1
% Retention	12.7	21.3	15.6	19.2	23.9	100.0	34.0	48.0	40.2
Tree Density	13.5	26.4	38.5	18.7	28.2	25.9	40.1	66.3	56.4
Tree Basal Area	8.0	18.8	13.3	10.5	25.5	26.0	21.5	31.8	60.6
Trees Cedar Density	11.6	38.6	85.6	1.2	25.1	23.1	21.2	81.2	83.6
Trees Cedar Basal Area	2.1	24.6	12.9	3.9	9.8	18.0	7.2	34.3	78.7
Trees HemBal Density	14.5	24.4	33.1	22.6	30.9	26.3	46.3	67.2	47.7
Trees HemBall Basal Area	12.0	16.9	13.9	16.1	39.4	27.6	33.7	33.9	19.3
Trees <30cm dbh Density	13.9	28.7	51.4	22.7	27.0	26.8	52.3	74.4	52.6
Trees 30-50cm dbh Density	15.0	33.4	44.1	15.9	22.5	20.7	19.8	72.9	53.3
Trees 50-80cm dbh Density	17.3	21.4	11.0	16.0	37.3	26.7	28.7	68.1	61.7
Trees >80cm dbh Density	4.0	13.5	7.2	6.4	27.9	26.6	21.7	16.2	70.6
Trees C >50cm dbh Density	2.0	26.8	8.8	2.9	18.8	17.7	12.7	76.9	183.9
Snag Density	9.3	29.1	31.9	12.3	23.5	22.6	30.2	92.1	24.9
Snag Basal Area	7.2	19.9	9.7	12.1	21.6	24.0	38.7	34.6	8.5
Snag Cedar Density	7.5	49.9	0.0	0.0	26.5	30.8	0.0	112.6	0.0
Snag Cedar Basal Area	15.0	28.3	0.0	0.0	14.1	26.5	0.0	17.1	0.0
Snag HemBal Density	13.5	26.2	38.5	16.0	14.1	11.9	37.8	97.2	17.1
Snag HemBal Basal Area	8.2	15.8	15.0	17.5	16.4	15.2	66.3	33.2	2.8
Snag Decay 3 Density	11.0	40.8	20.8	18.0	37.3	21.8	0.0	86.4	44.7
Snag Decay 3 Basal Area	3.5	23.9	5.1	21.1	64.6	39.7	0.0	24.9	7.8
Snag Decay 4+5 Density	11.0	28.0	19.6	14.5	14.5	22.4	26.9	92.6	9.5
Snag Decay 4+5 Basal Area	8.7	18.3	3.0	10.7	9.0	18.6	47.8	17.3	2.7
Snag Decay 6 Density	5.7	23.9	58.1	5.5	29.8	23.5	53.4	94.8	37.8
Snag Decay 6 Basal Area	6.0	21.1	20.4	11.5	27.1	21.2	36.9	61.8	17.0
Snag <30cm dbh Density	12.7	37.4	56.8	4.4	18.1	16.9	9.9	149.9	23.5
Snag 30-50cm dbh Density	11.2	31.8	25.2	29.5	33.6	30.9	44.1	92.2	66.6
Snag 50-80cm dbh Density	2.4	21.2	14.8	12.7	26.7	26.4	38.8	37.7	10.7
Snag >80cm dbh Density	8.2	17.0	3.9	10.8	20.9	21.9	50.5	28.6	0.0
Snag >8m Tall Density	11.8	21.7	33.1	9.8	16.8	18.2	7.5	79.4	17.8
Snag >8m Tall Basal Area	3.7	7.9	9.2	7.9	12.2	15.6	10.3	13.4	3.6
Snag >30cm Decay 6+	5.4	24.4	29.3	6.4	35.3	25.8	60.7	77.5	48.7
Snag Cedar >50cm dbh	11.6	48.7	0.0	0.0	36.6	30.3	0.0	46.4	0.0
CWD Volume	131.5	122.7	76.3	115.5	121.9	238.3	175.9	94.3	82.9
CWD Decay 1+2 Volume	293.7	279.1	161.3	243.7	254.8	453.3	299.5	186.2	153.0
CWD Decay 3 Volume	58.8	48.0	35.7	73.5	77.8	164.1	162.5	51.9	42.3
CWD Decay 4 Volume	57.6	54.3	31.6	26.6	30.3	54.1	49.0	36.6	70.3
CWD <30cm Diam Volume	199.3	200.0	188.9	210.6	246.5	400.4	166.4	174.7	158.1
CWD 30-50cm Diam Volum	148.7	115.2	50.9	105.2	131.4	206.5	123.9	95.9	84.4
CWD 50-80cm Diam Volum	96.1	81.3	60.8	102.4	88.4	168.8	166.9	76.8	92.0
CWD >80cm Diam Volume	114.5	132.9	46.1	78.2	71.2	242.8	248.6	60.8	17.2
CWD >50cm Decay 4	63.1	59.9	32.2	29.3	32.5	56.1	52.4	34.4	72.6
CWD Cedar >50cm Diam	160.5	366.0	85.6	163.9	122.0	682.2	208.4	272.4	136.4
Canopy Closure	16.5	20.5	19.9	17.1	27.9	25.6	51.3	47.2	43.8
Small-Tree Cover	41.9	45.0	27.7	86.6	76.9	83.8	159.7	90.6	57.9
Mineral Soil	159.0	118.4	73.7	130.7	147.7	177.0	66.4	46.9	96.4
Moss Cover	31.5	37.8	28.6	33.7	36.4	48.7	35.3	82.1	95.0
Shrub Cover	20.9	35.9	100.7	111.0	65.3	81.4	14.2	48.3	66.0
Herb Cover	13.3	38.4	21.4	190.0	42.8	65.7	69.9	41.3	58.6

NOTES: 1) Cascadia blocks monitored in 2007 are compared to benchmark levels and to pre-harvest levels in separate columns. 2) The CanFor dispersed block was in CWHmm, but is compared with earlier Weyerhaeuser dispersed blocks in CWHxm and CWHmm. 3) One 2007 Cascadia block in MH is not included here.

Individually tagged trees after 5 years: Growth, mortality, fall and decay rates

David Huggard, Dec. 7 2007

Summary (update of main report section 3.12.2)

An extensive analysis was undertaken of trees and snags that were individually tagged in the first post-harvest monitoring sessions and included in plots re-measured 5 years later. The analysis used the information on individual stems to calculate rates of diameter growth, mortality and mortality mode (standing versus fallen) of live trees, and fall and decay rates for different classes of snags. Growth, mortality and snag fall rates were compared between dispersed and group+mixed VR for Douglas-fir in CWHxm. With many more tagged trees in group+mixed VR, effects of dbh, tree species and ecosystem groupings on all these parameters were examined, as were any additional effects of distance from the edge of retention patches.

This information is a critical resource for long-term projection modeling of habitat structures, especially snags and CWD, in VR stands. Relatively little good information is otherwise available to support this modeling for VR stands and for the local ecosystem types. Some of the results also have more direct implications for VR management. Because of their importance for projection modeling, the methods and results are presented in detail in Appendix 11.

The main findings include:

Live tree growth

- Measured diameter growth was generally low, but only differed between VR and uncut sites for hemlocks (higher in uncut).
- Growth rates of cedars increased with dbh, and were higher in the CWHmm+dm and CWHwh than in other subzones, while other species showed less effect of dbh and ecosystem.
- Diameter growth of larger Douglas-fir in CWHxm were 3-4 times as high in diserpsed VR as in group+mixed VR, with highest rates in 80cm dbh trees in dispersed VR.
- Growth rates were slightly higher 0-10m into retention patches compared to further into the patch. This may reflect true edge effects from removing adjacent trees, but it may also reflect anchoring many patches on wetlands or outcrops that lower growth rates near the patch centres.

Tree mortality

- Mortality rates for retained Douglas-fir trees decreased with dbh, while cedar and hemlock showed little difference in mortality among small or large trees. Deciduous trees and true fits had very high mortality rates at larger sizes, possibly because they are prone to windthrow, but this is based on a small number of samples.
- Mortality was considerably higher in VR blocks than in uncut forest in most cases.
- Mortality rates of Douglas-fir in CWHxm were higher in dispersed VR than group+mixed VR for smaller trees, but lower for larger trees.
- Mortality was moderately higher 0-10m into retention patches, decreasing with distance into the patch.
- Douglas-fir trees that died in VR blocks – particularly large trees – were much less likely to remain standing than in uncut forest, which reduces how much the extra mortality in VR stands contributes to snag supply. Moderate-sized hemlocks and cedars in drier ecosystems were least likely to remain standing, which is unfortunate since these are the main potential source of snags useful to many wildlife species.

Snag fall

- Fall rates of snags generally did not differ between VR stands and uncut forest, and there was relatively little difference in fall rates among the species.
- Fall rates usually declined with increasing snag diameter. Because decay rates did not change consistently with diameter, large snags are more likely to remain standing long enough to become well-decayed snags.
- Fall rates were somewhat higher for class 6+ (soft) snags, but there was no consistent increase in fall rates from class 3 to class 5.
- There were no apparent edge effects on fall rates of snags, except somewhat elevated fall rates of recent (class 3) snags near edges, as expected from their higher susceptibility to windthrow.

Snag decay

- Decay rates of snags were higher in VR than in uncut forest in a few cases, but the pattern was inconsistent. Decay rates also showed inconsistent relationships with dbh.
- Douglas-fir snags typically decayed more slowly than other species, including red-cedar.
- There were no consistent edge effects on decay rates.

General relationships with dbh

- Averaged across species, ecosystems and treatments, growth and mortality rates increased slightly with tree dbh, snag fall rates decreased in inverse proportion to dbh (doubling dbh halved fall rates), and snag decay showed no relationship with dbh.

APPENDIX 11. FATES OF INDIVIDUALLY TAGGED TREES: GROWTH, MORTALITY, FALL AND DECAY RATES

[2007 update: This section was updated in 2007 to include 4 additional sites remeasured in CWHwh, and with an improved analysis that accounts for the non-independence of trees within sites.]

A11.1 Overview

This section uses information on stems that were tagged immediately after harvest and remeasured 5 years later to estimate rates of growth, mortality and "mortality mode" (standing or fallen) of live trees, and fall and decay of snags, along with the factors that affect those rates. Potential factors include the species of tree, the ecosystem type, the dbh of the stem, the type of VR and the distance to patch edge in group and mixed VR. Within group+mixed VR, these rates are calculated for 5 main species (Douglas-fir, western red-cedar, western + a few mountain hemlocks, amabilis and a few other true firs, red alder), and different ways of grouping 4 ecosystem types (CDF+CWHxm, CWHmm+dm, CWHvm+vh and CWHwh). Effects of distance into the patch (edge effects) were also examined for group+mixed VR. Fewer plots were conducted and remeasured in dispersed VR. Rates in dispersed versus group VR are therefore only examined for Douglas-fir in CDF + CWHxm, for live tree growth, mortality and mortality mode, and for fall rates of hard snags (class 3-5). The data from the remeasured tagged trees can help to fill large gaps in our knowledge of these rates in local ecosystems, and in VR stands, which are critical for projection modeling of the long-term supply of habitat structures provided by VR. Some of the information may also be immediately useful in deciding what stems to retain and how to retain them.

A11.2 Methods

<u>A11.2.1 Field sampling</u>

Live trees and snags were marked with individually-numbered tags during habitat monitoring of operational VR blocks harvested 1-2 years previously, and in uncut control stands. The following were recorded for each stem: species, diameter at breast height (1.3m, dbh), height and decay class (following Thomas et al. 1979: class 1 and 2 are live; class 3 is recently dead; classes 4 and 5 are increasingly decayed but still hard; class 6+ is well-decayed with soft wood). These characteristics were recorded for each tagged stem in remeasurements 5 years after the original measurements, allowing calculations of growth of live trees, rates of standing and fallen mortality of live trees, and rates of fall or decay (change of decay class) of snags.

A total of 103 sites have been remeasured, with 7,954 remeasured tagged stems of the 5 main species groups (Table A11.1). There were an average of 105 individual stems per site in group+mixed VR and mature stands, and 9 stems per site with dispersed retention. Other species, such as yellow cedar, Sitka spruce, pines and western yew were rare, and were not included in the analyses. An additional 278 well-decayed (class 6+) snags that could not be identified to species were included in the analysis of fall rates of class 6+ snags. Using sites as the sample unit, comparisons of rates in mature control stands and VR blocks were possible in CWHvm+vh and CWHwh ecosystems. Comparisons of rates in dispersed and group+mixed VR were only possible in CWD+CWHxm.

Table A11.1. Number of remeasured sites and individual stems by BEC group and harvest treatment.

BEC group	Treatment	Sites	Individually-tagged stems Douglas-fir	Red-cedar	Hemlock	True fir	Red alder	Total
CDF+CWHxm	Group+Mixed VR	18	453	187	510	17	235	1402
	Dispersed VR	15	133					133
	Mature control	1	187	10	35		7	239
CWHmm+dm	Group+Mixed VR	12	172	195	467	105	30	969
CWHvm+vh	Group+Mixed VR	39	131	362	1617	602	50	2762
	Mature control	7	125	138	643	144	20	1070
CWHwh	Group+Mixed VR	7		341	422			763
	Mature control	4		101	495		20	616
Total		103	1201	1334	4189	868	362	7954

A11.2.2 Analyses

Analyses were conducted for the following rates:

- diameter growth of live trees,
- mortality of live trees,
- “mortality mode” of live trees (standing versus fallen),
- fall rates of class 3, 4, 5, 6+ and combined classes 3-5 (hard) snags,
- decay rates (change of decay class) of class 3, 4 and 5 snags.

Growth showed a bell-shaped distribution with extended tails, including negative values, which are possible due to measurement error in dbh. A square-root transformation, preserving the sign for negative values, gave an approximately normal distribution for the analysis. All the other rates are binomial (1/0) variables, and were analysed using a binomial model with logistic link function (logistic regression).

For each rate, the analysis examined how to combine the 4 ecosystem groups, comparing the following possible models

1. Each separate: CDF+CWHxm; CWHmm+dm; CWHvm+vh; CWHwh
2. Wetter subzones combined: CDF+CWHxm; CWHmm+dm; CWHvm+vh+wh
3. Drier and wetter groups: CDF+CWHxm+mm+dm; CWHvm+vh+wh
4. Driest group separate: CDF+CWHxm; CWHmm+dm+vm+vh+wh
5. All combined: CDF+CWHxm+mm+dm+vm+vh+wh (i.e., same rate in all ecosystem groups)

When there was >1 mature control site in an ecosystem group, the analysis also examined whether the rate differed between VR and uncut blocks, and, for Douglas-fir in CDF+CWHxm, whether the rate differed between group+mixed and dispersed VR.

Within each ecosystem grouping and treatment (or combination of the two treatments), 3 or 4 possible relationships between the rate and dbh of the stem were examined:

1. No relationship: Same rate at all dbh values
2. Linear: A linear relationship between the square-root-transformed (growth) or logistic-transformed (others) rate and stem dbh.
3. Quadratic: A quadratic relationship between the square-root-transformed (growth) or logistic-transformed (others) rate and stem dbh. This could include increasingly high rates at the lowest or highest end of the dbh scale, or maximum or minimum values at intermediate dbh values.

(4. Log dbh. For growth only, a model with logarithm of dbh was also used. A log-relationship was not examined for the other rates because, with their logistic transformation, the linear or quadratic models could already capture this form of relationship.)

This type of analysis would normally use an AIC-based model selection approach (Burnham and Anderson 1998). However, this requires calculation of the likelihood of each model, which is not currently possible for binomial models with random effects (due to the blocking by site). Instead, the underlying objective of finding the model with the best predictive ability was assessed using cross-validation. Each model (i.e., each dbh relationship within each way of combining or separating ecosystem groups and treatments) was fit to the data from all but one of the sites, then the sum-of-squares deviations between the model's predictions and the data for each stem in the withheld site were calculated. This was repeated with each site as the withheld test data. The model with the lowest total sum-of-squares across all sites was considered the best model for that rate; this is the model with the best cross-validation predictive ability. The analyses were done separately by species.

A11.2.3 Standardized dbh

The simulation model used by Weyerhaeuser and others to project deadwood over time inputs fall and decay rates for a standardized stem with dbh 40cm. Rates are adjusted for stems of other sizes using a power function. For example, fall rates might decrease as the square root of dbh increases, so that a snag with 80cm dbh would have half the fall rate as a snag with 20cm dbh. Therefore the value for each rate was summarized as the rate for a standardized stem with 40cm dbh, and the exponent of the power relationship for other dbh values. The rates for a 40cm dbh stem were the prediction for each component of the best model (i.e., each ecosystem grouping and treatment in the best model), along with the confidence intervals of the predictions. The exponent was calculated from a power curve fit through the predictions for 20cm- and 80cm dbh stems.

A11.2.4 Edge effects

Edge effects were examined by looking at the residual values for a rate after the best model of ecosystem effects, treatment effects and dbh had been removed, for stems within VR patches. A positive residual at a particular distance means that the rate is higher at that distance than expected from the best model. Mean residuals and their confidence intervals were plotted for 3 edge distances: 0-10m, 10-20m and >20m into the patch. Confidence intervals were generated with bootstrapping, using the site as the resampling unit.

A11.2.5 Note on calculations of snag decay

Classification of snags into decay classes 3, 4, 5 and 6+ is not always certain in the field, because each class is described by a mix of characteristics of branches, bark and wood. Some snags therefore decrease in decay class between the initial measurement and 5-year remeasurement. Because this is not possible in reality, the rate of such backward changes gives an indication of how much "measurement error" there is in classifications among adjacent decay classes. This measurement error also presumably operates in the forward direction – some snags that have not truly decayed to an older class are described as being in the older class. This inflates the apparent rate of decay of snags. The measurement error estimated from the impossible backward transitions was therefore used to correct for this inflation of decay rates.

Combining all species, 15.6% of class 4 snags were classified as class 3 in the remeasurements, 11.0% of class 5 were reclassified as class 4 or 3, and 8.8% of class 6+ were reclassified as class 5, 4 or 3. The values suggest that there is more uncertainty distinguishing class 3 and 4 snags than class 4 and 5 snags, and least uncertainty among well-decayed class

6+ versus younger snags. The error rates of 15.6%, 11.0% and 8.8% were used to reduce the apparent decay rates of snags from class 3→4, class 4→5 and class 5→6+, respectively (i.e., the calculated decay rate from class 3→4 was reduced 15.6%, etc.).

A11.3 Results

A11.3.1 Diameter growth of live trees

Diameter growth rates were relatively low for all species (<2mm/yr), except for larger cedars in some ecosystems. Low growth rates may reflect some growth suppression due to disturbance in recently cut VR stands, but rates were typically the same in uncut mature stands. The exceptions were hemlocks in all ecosystems and cedar in CWHwh, where the mature uncut stands had higher growth rates, particularly of larger diameter trees. The lower growth in retention patches in these cases may reflect either retention of poorer trees

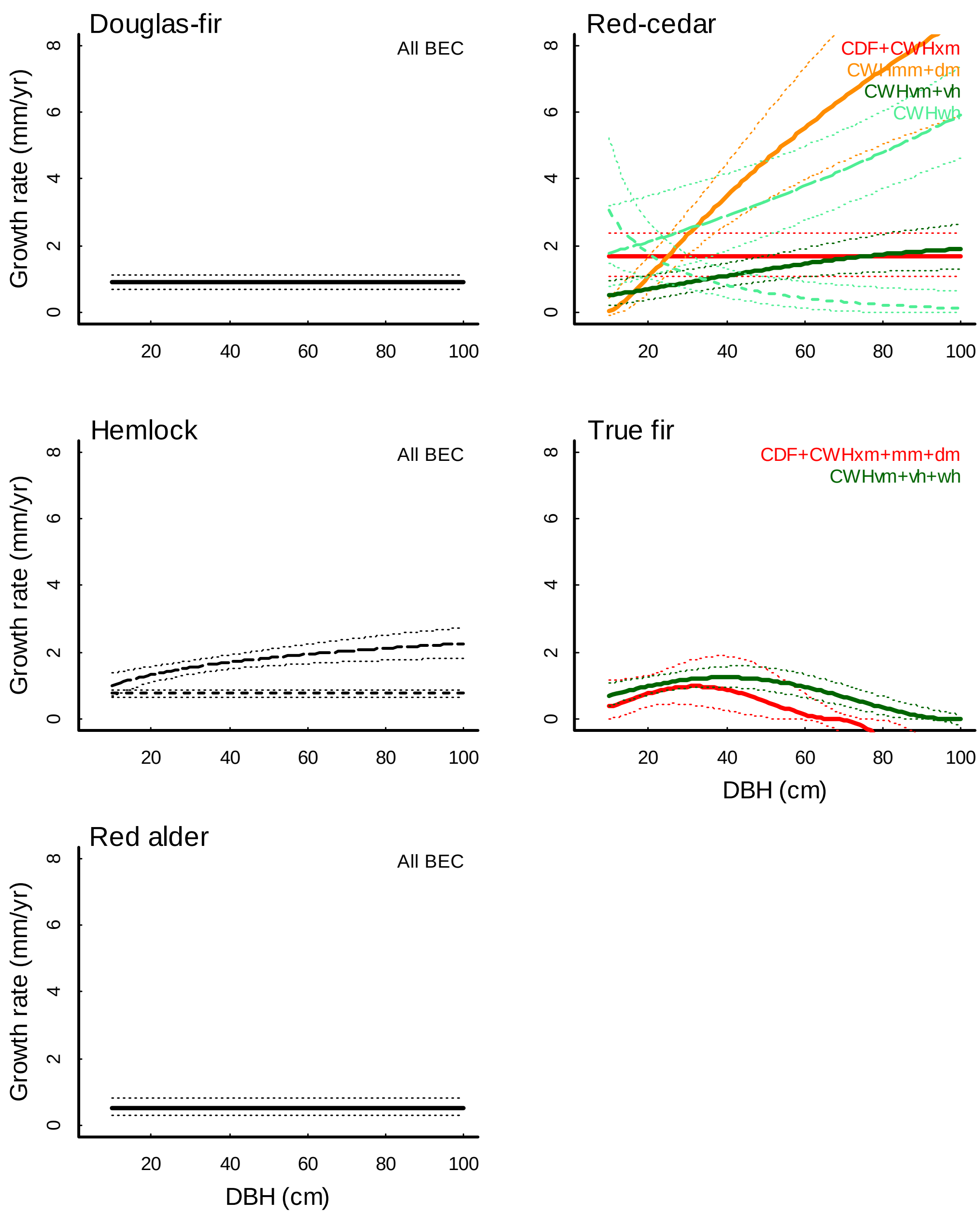

Figure A11.1.1. Diameter growth of live trees (mm/yr) as a function of tree dbh. Solid line = VR blocks and mature controls combined; long dashes = mature controls only; short dashes = VR blocks. Thin dotted lines are 95% confidence intervals. "All BEC" = all 4 ecosystem groups combined; otherwise, colours indicate the different ecosystem groups in the best model.

or trees in poorer growing spots (wetlands, knolls), or reduced growth following harvesting. Slight changes in measurements of dbh could also alter apparent growth rates, although many of the initial and 5-year measurements were made by the same field crews. Because the emphasis of this monitoring was measuring habitat features, dbh measurements may not have been made as precisely as they would be in permanent sample plots for growth and yield.

Table A11.1.1. Diameter growth (mm/yr) of live trees, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

			Growth (mm/yr)			
Species	**BEC Group**	**Treatment**	**Mean**	**LCI**	**UCI**	**Exponent**
Douglas-fir		All	0.911	0.723	1.120	0
Red-cedar	CDF+CWHxm	All	1.684	1.098	2.396	0
	CWHmm+dm	All	3.487	2.624	4.472	1.376
	CWHvm+vh	All	1.110	0.790	1.483	0.648
	CWHwh	UC	2.901	1.859	4.172	0.586
		VR	0.831	0.462	1.308	-1.435
Hemlock	All	UC	1.704	1.499	1.922	0.338
		VR	0.776	0.675	0.885	0.000
True fir	CDF+CWHxm+mm+dm	All	0.888	0.262	1.883	
	CWHvm+vh+wh	All	1.254	0.963	1.584	-0.738
Red alder		All	0.533	0.302	0.829	0

There were only weak suggestions of edge effects on diameter growth of live trees, with slightly higher growth of Douglas-fir, hemlock and alder 0-10m into a patch. However, the absolute magnitude of this effect was very small.

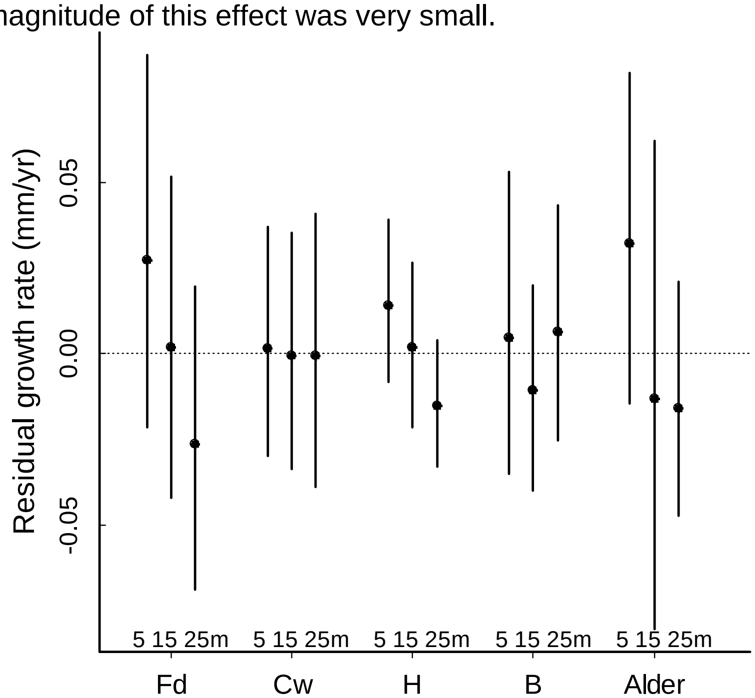

Figure A11.1.2. Edge effects on diameter growth of live trees (mm/yr). Values are the residual growth rates after the predictions of the best model (Figure A11.1.1) have been removed, at 5, 15 and 25+m into retention patches. Error bars are bootstrapped 95% confidence intervals. Fd=Douglas-fir, Cw=western red-cedar, H=hemlocks, B=true firs. All ecosystem groups were combined for the analyses of edge effects.

Growth of Douglas-fir in dispersed retention in the dry CDF+CWHxm ecosystem exceeded growth in group+mixed VR, for trees >25cm dbh, with growth rates up to 4 times as high for 75cm dbh trees in dispersed retention.

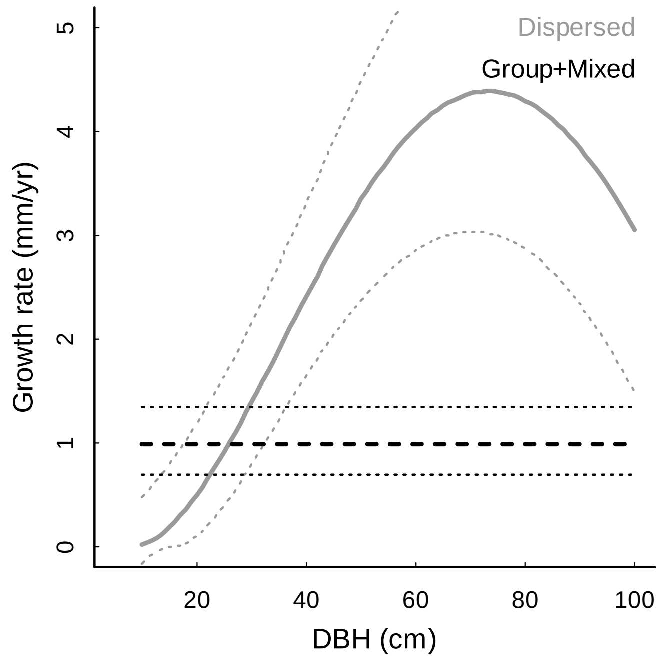

Figure A11.1.3. Diameter growth (mm/yr) of live trees in dispersed (grey solid line) and group+mixed (black dashed line) VR blocks, for Douglas-fir in CDF+CWHxm ecosystems. Thin dotted lines are 95% confidence intervals.

Table A11.1.2. Diameter growth (mm/yr) of live Douglas-fir trees in dispersed versus group+mixed VR in CDF+CWHxm, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

	Growth (mm/yr)			
Treatment	**Mean**	**LCI**	**UCI**	**Exponent**
Dispersed	2.41	1.65	3.31	1.55
Group+mixed	0.99	0.69	1.35	0.00

A11.3.2 Mortality of live trees

Mortality of live trees was considerably higher for all 5 species, overall or in certain ecosystems, in retention blocks compared to uncut stands. Loss of live trees over 5 years in VR stands ranged from 13.5% for cedar, 21.5% for Douglas-fir to 28.9% for hemlock (in CWHvm+vh), 38.4% for true fir and 49% for red alder (calculated for the standardized dbh of 40cm). Mortality rates are expected to be higher shortly after harvest, and should decline in subsequent remeasurement periods. Mortality rates in uncut control stands were mainly near the expected levels of somewhat less than 1%/yr.

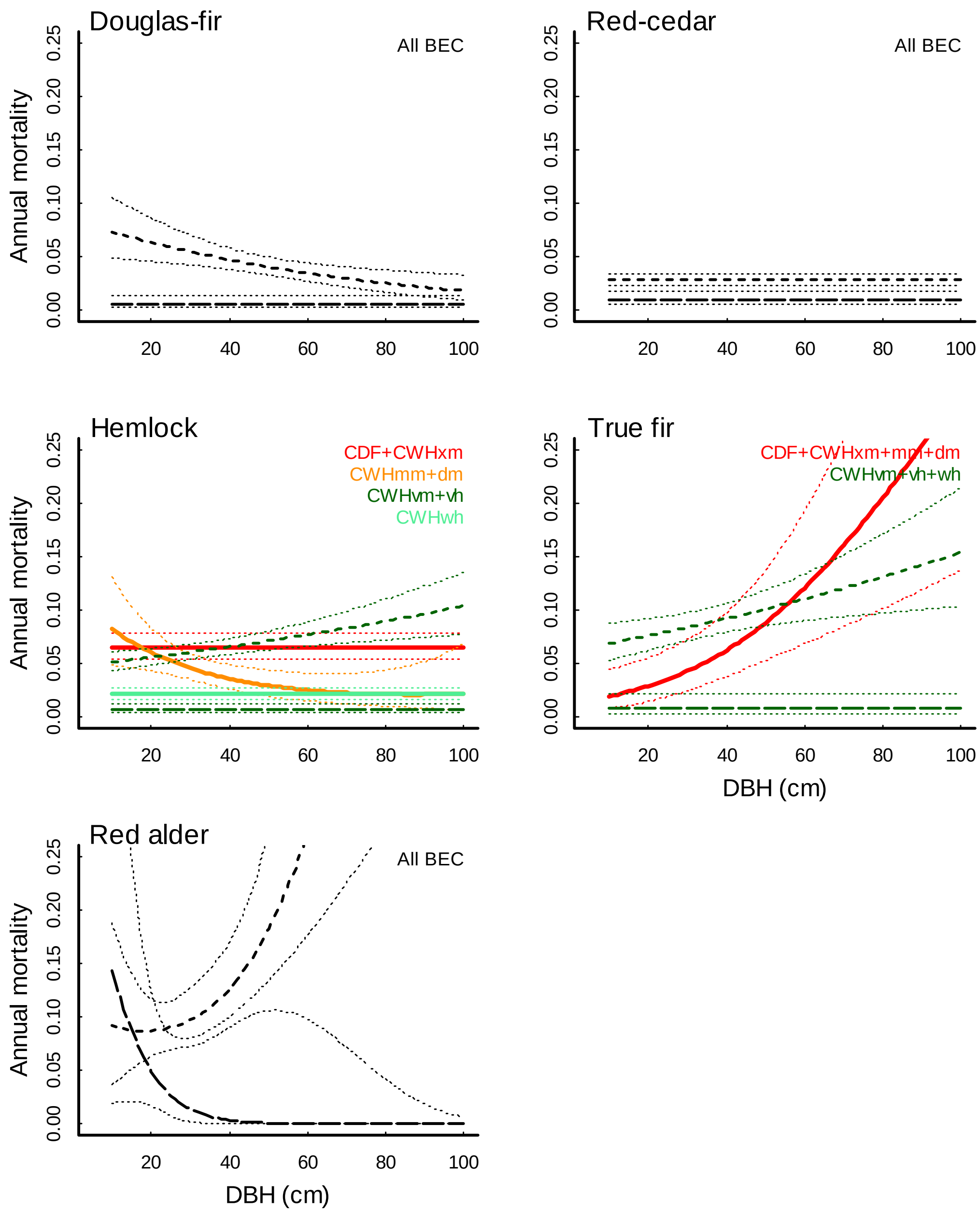

Figure A11.2.1. Annual mortality rate of live trees as a function of tree dbh. Solid line = VR blocks and mature controls combined; long dashes = mature controls only; short dashes = VR blocks. Thin dotted lines are 95% confidence intervals. "All BEC" = all 4 ecosystem groups combined; otherwise, colours indicate the different ecosystem groups in the best model.

Table A11.2.1. Annual (%) mortality rates of live trees, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

			Mortality (%/yr)			
Species	**BEC Group**	**Treatment**	**Mean**	**LCI**	**UCI**	**Exponent**
Douglas-fir	All	UC	0.639	0.299	1.348	0
		VR	4.726	3.820	5.810	-0.662
Red-cedar	All	UC	0.962	0.510	1.792	0
		VR	2.848	2.332	3.466	0
Hemlock	CDF+CWHxm	All	6.508	5.390	7.805	0
	CWHmm+dm	All	3.603	2.617	4.907	-0.747
	CWHvm+vh	UC	0.749	0.461	1.210	0
		VR	6.583	5.892	7.338	0.340
	CWHwh	All	2.152	1.677	2.750	0
True fir	CDF+CWHxm+mm+dm	All	6.247	3.817	9.796	1.404
	CWHvm+vh+wh	UC	0.893	0.364	2.145	0
		VR	9.222	7.942	10.643	0.391
Red alder	All	UC	0.353	0.009	10.037	-5.911
		VR	12.609	9.000	16.981	1.286

Mortality was slightly elevated for all species 0-10m into retention patches, compared to further into the patch. However, there was considerable variation in overall mortality and its edge distribution between individual sites, resulting in wide error bars on the edge effects.

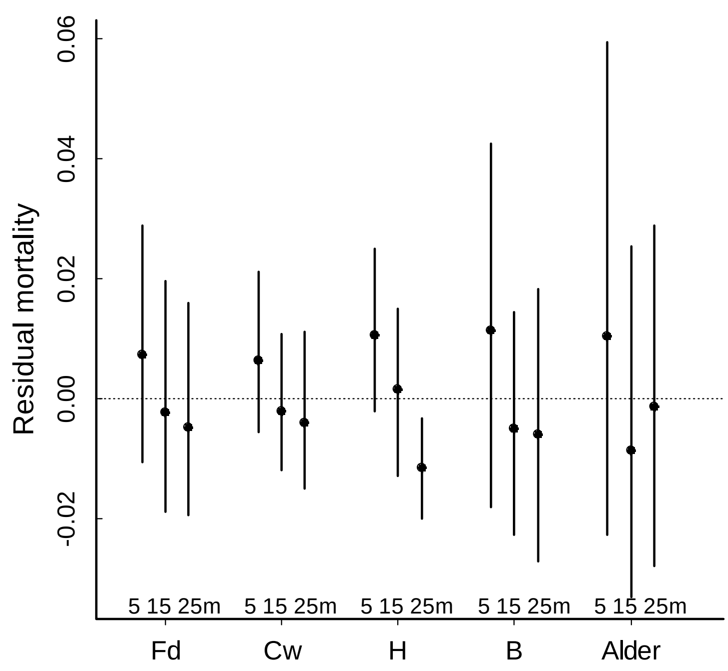

Figure A11.2.2. Edge effects on annual mortality of live trees. Values are the residual annual mortality after the predictions of the best model (Figure A11.2.1) have been removed, at 5, 15 and 25+m into retention patches. Error bars are bootstrapped 95% confidence intervals. Fd=Douglas-fir, Cw=western red-cedar, H=hemlocks, B=true firs. All ecosystem groups were combined for the analyses of edge effects.

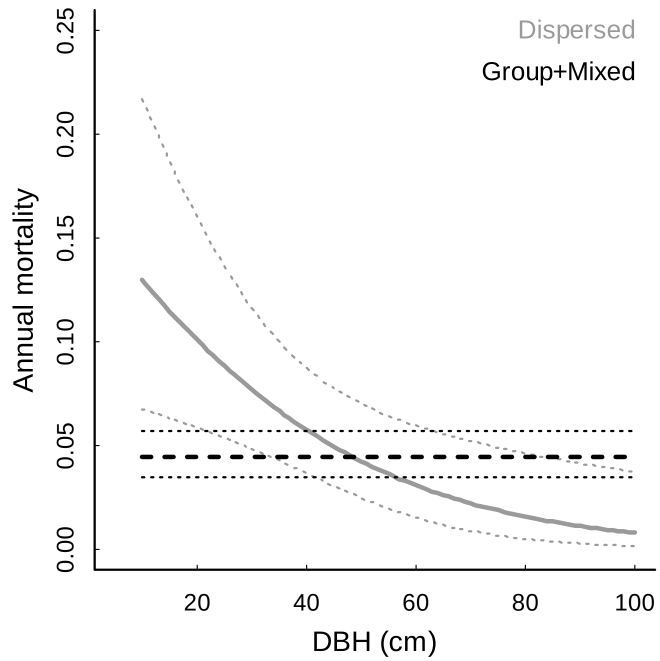

Figure A11.2.3. Annual mortality of live trees in dispersed (grey solid line) and group+mixed (black dashed line) VR blocks, for Douglas-fir in CDF+CWHxm ecosystems. Thin dotted lines are 95% confidence intervals.

Retained live Douglas-fir trees in CDF and CWHxm showed higher mortality in dispersed VR for trees <50cm dbh, but lower mortality for large trees. The lower mortality of large Douglas-fir in dispersed retention likely reflects operational care in retaining healthy, wind-firm large firs for retention. Small trees retained in dispersed VR were likely not selected so carefully, and may have included poor-quality trees that did not survive in the open stands after harvest.

Table A11.2.2. Annual (%) mortality rates of live Douglas-fir trees in dispersed versus group+mixed VR in CDF+CWHxm, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

	Mortality (%/yr)			
Treatment	**Mean**	**LCI**	**UCI**	**Exponent**
Dispersed	5.76	3.67	8.74	-1.33
Group+mixed	4.49	3.50	5.69	0.00

A11.3.3 Mortality mode for live trees

For Douglas-fir and for hemlocks in wetter ecosystems, a higher proportion of dying trees fell, as opposed to died standing, in VR stands than in uncut controls. In these cases, the additional mortality in VR stands will make less of a contribution to maintaining levels of snags. For cedars and hemlocks in the drier ecosystems, most mid-sized trees that died fell, while a higher proportion of small and large trees died standing. This likely reflects susceptibility of the

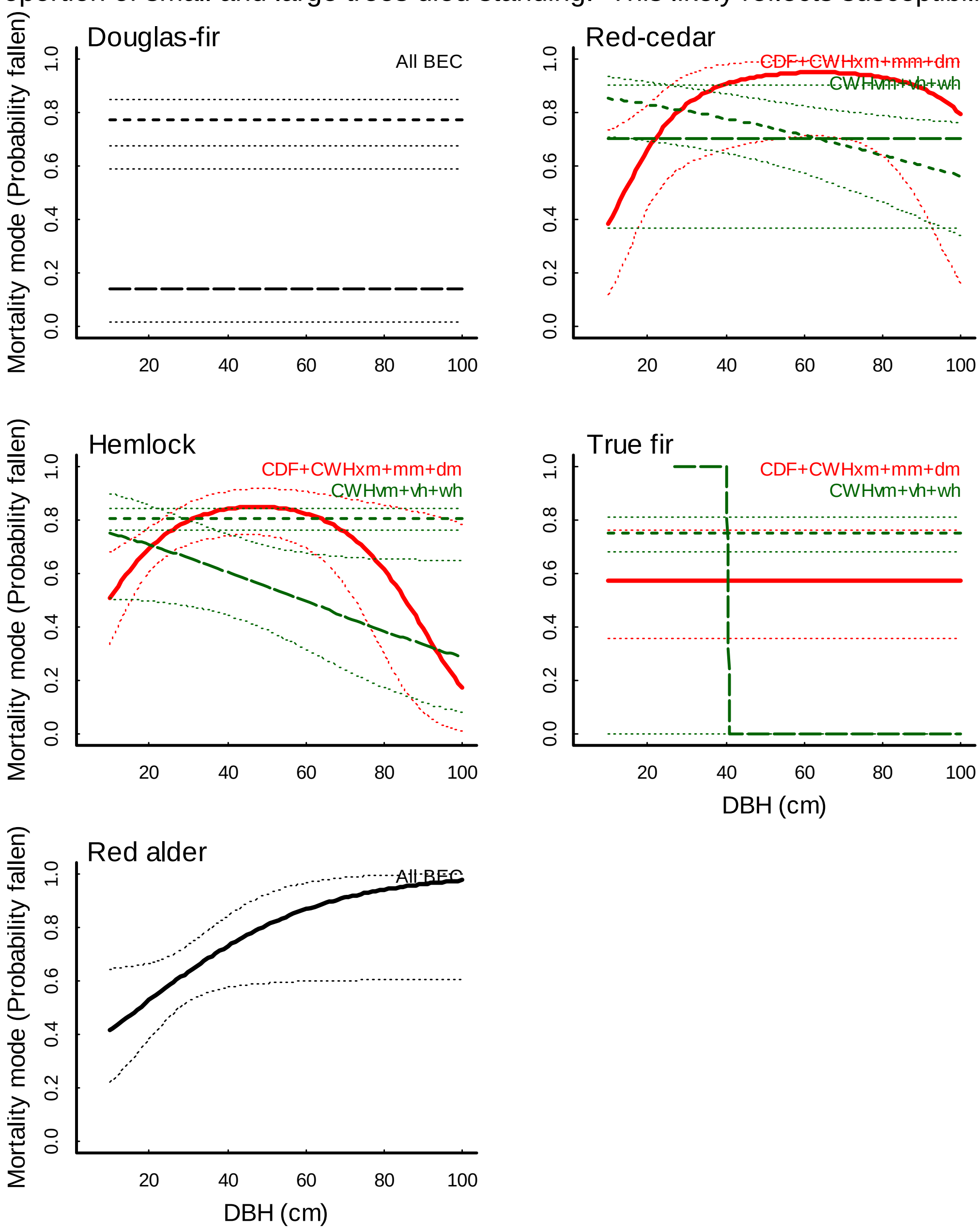

Figure A11.3.1. "Mortality mode" of live trees as a function of tree dbh. The value is the probability the tree will die fallen (e.g., windthrown) as opposed to dying standing. Solid line = VR blocks and mature controls combined; long dashes = mature controls only; short dashes = VR blocks. Thin dotted lines are 95% confidence intervals. "All BEC" = all 4 ecosystem groups combined; otherwise, colours indicate the different ecosystem groups in the best model. Note: The result for true firs in uncut controls in wetter ecosystems is based on too few dying trees to be reliable.

mid-sized trees to windthrow, while larger trees are more windfirm (and have already survived longer in the canopy) and small trees are more likely to die from effects of competition when their environment is changed at harvest.

Table A11.3.1. Mortality mode (% of dying snags that die fallen) of live trees, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

			Mortality mode (% fallen)			
Species	**BEC Group**	**Treatment**	**Mean**	**LCI**	**UCI**	**Exponent**
Douglas-fir	All	UC	3.036	0.380	16.377	0
		VR	25.676	20.246	31.304	0
Red-cedar	CDF+CWHxm+mm+dm	All	37.593	19.545	53.801	0.543
	CWHvm+vh+wh	UC	21.400	8.822	37.247	0
		VR	25.945	18.798	33.424	-0.342
Hemlock	CDF+CWHxm+mm+dm	All	30.668	23.629	37.689	-0.142
	CWHvm+vh+wh	UC	16.998	11.083	24.068	-0.613
		VR	27.976	24.882	31.097	0
True fir	CDF+CWHxm+mm+dm	All	15.588	8.415	25.024	0
	CWHvm+vh+wh	UC	95.249			
		VR	24.214	20.343	28.224	0
Red alder	All	All	22.999	15.749	30.915	0.815

Dying trees near edges were somewhat more likely to fall, while more interior trees died standing, as expected from windthrow around edges of retention patches.

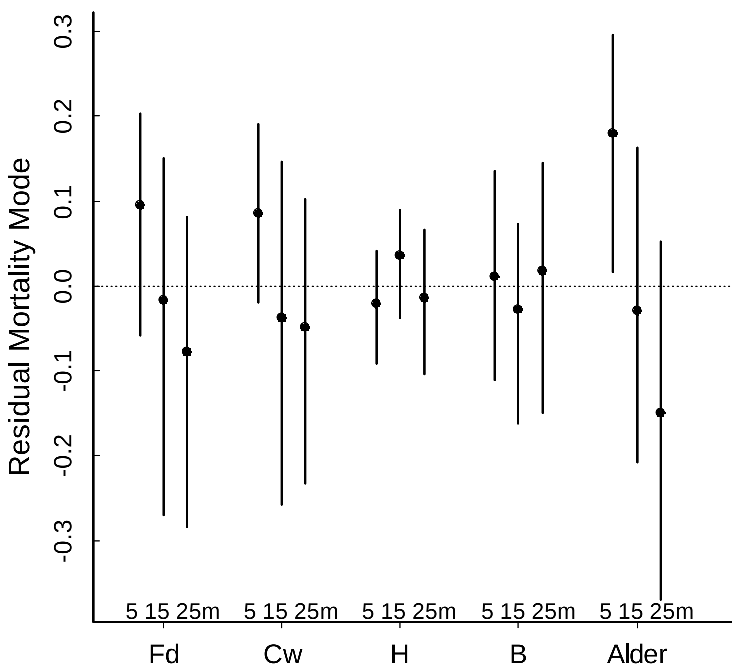

Figure A11.3.2. Edge effects on mortality mode of live trees. Values are the residual mortality mode after the predictions of the best model (Figure A11.3.1) have been removed, at 5, 15 and 25+m into retention patches. Values >0 indicate that trees are more likely to die fallen (windthrow) at that edge position; values <0 indicate that they are more likely to die standing. Error bars are bootstrapped 95% confidence intervals. Fd=Douglas-fir, Cw=western red-cedar, H=hemlocks, B=true firs. All ecosystem groups were combined for the analyses of edge effects.

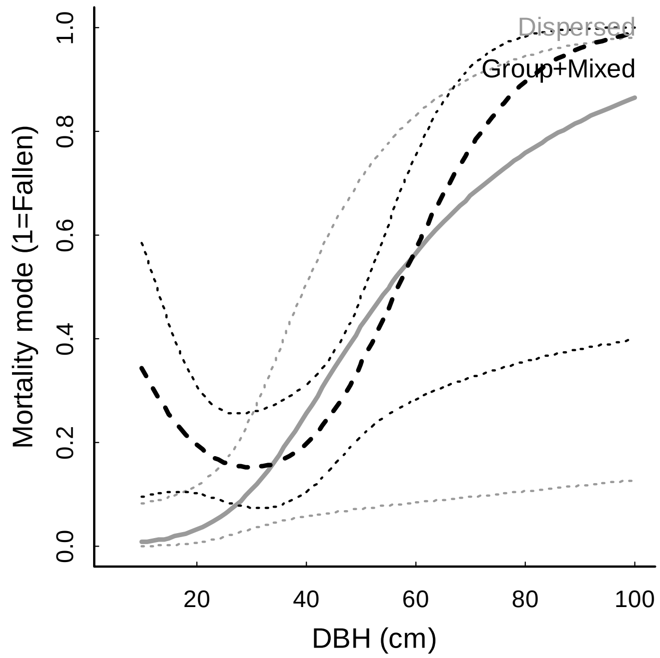

Figure A11.3.3. Mortality mode of live trees in dispersed (grey solid line) and group+mixed (black dashed line) VR blocks, for Douglas-fir in CDF+CWHxm ecosystems. The value is the probability the tree will die fallen (e.g., windthrown) as opposed to dying standing. Thin dotted lines are 95% confidence intervals.

Within the dry ecosystem group, Douglas-fir showed increasing tendency to fall at death with increasing dbh, in both dispersed and group+mixed VR. This contrasts with the main result for Douglas-fir, which combined all ecosystem groups and did not show a relationship with dbh. Smaller Douglas-fir trees may be more prone to dying standing in drier ecosystems, where they are generally growing under a canopy of vigorous second-growth Douglas-fir.

Table A11.3.2. Mortality mode (% of dying snags that die fallen – e.g., windthrow) of live Douglas-fir trees in dispersed versus group+mixed VR in CDF+CWHxm, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

	Mortality mode (% fallen)			
Treatment	**Mean**	**LCI**	**UCI**	**Exponent**
Dispersed	25.59	5.76	50.65	2.27
Group+mixed	19.81	10.49	31.20	1.10

A11.3.4 Fall rates of snags – class 3

Fall rates of recent snags declined with dbh for hemlocks, but showed no changes in the other species. (The results for red-cedar have very wide confidence intervals, because few cedar snags were classified as class 3 – the snag classification system originated with Douglas-fir, and is less clearly applied to cedars). A declining fall rate with increasing dbh is generally expected for snags, but recent snags may be more prone to windthrow, which tends to increase with snag size. No class 3 Douglas-fir snags fell in uncut sites, but this is likely due to the low numbers of recently dead trees in those stands, rather than substantial real differences in fall rates between VR and controls.

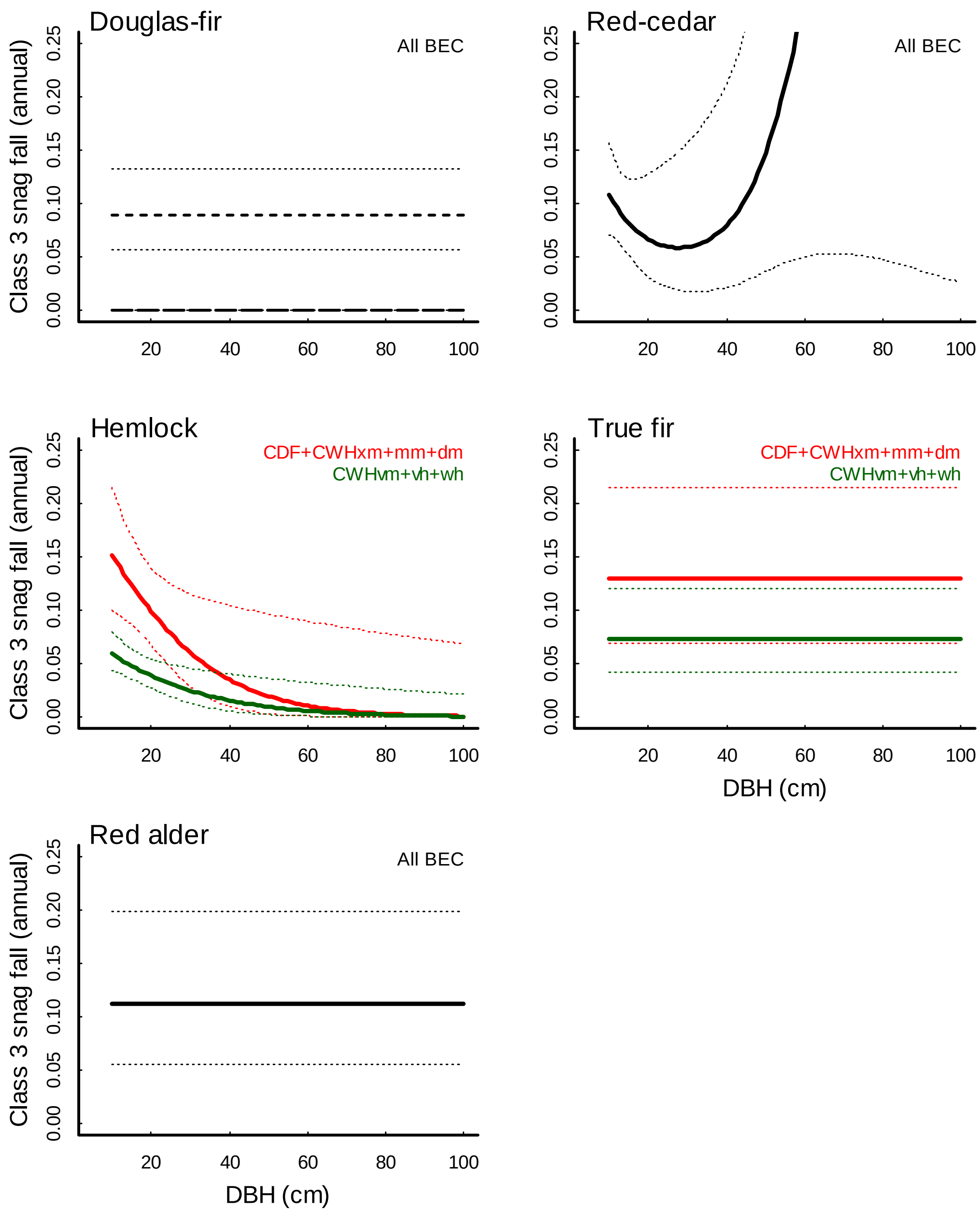

Figure A11.4.1. Annual fall rates of class 3 (recently dead) snags as a function of snag dbh. Solid line = VR blocks and mature controls combined; long dashes = mature controls only; short dashes = VR blocks. Thin dotted lines are 95% confidence intervals. "All BEC" = all 4 ecosystem groups combined; otherwise, colours indicate the different ecosystem groups in the best model. Note: Results for red-cedar are highly uncertain, as there were very few class 3 cedar snags.

Table A11.4.1. Annual (%) fall rates of class 3 (recently dead) snags, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

			Snag fall - class 3 (%/yr)			
Species	**BEC Group**	**Treatment**	**Mean**	**LCI**	**UCI**	**Exponent**
Douglas-fir	All	UC	0.000	0.000	0.000	0
		VR	8.972	5.762	13.307	0
Red-cedar	All	All	7.986	2.174	21.210	1.682
Hemlock	CDF+CWHxm+mm+dm	All	3.523	1.017	10.441	-2.471
	CWHvm+vh+wh	All	1.570	0.581	4.047	-2.032
True fir	CDF+CWHxm+mm+dm	All	12.945	6.854	21.460	0
	CWHvm+vh+wh	All	7.374	4.277	11.969	0
Red alder	All	All	11.270	5.587	19.781	0

Fall rates of recent snags tended to be higher for Douglas-fir and cedar near the edges of patches compared to further from the edge. This may reflect susceptibility of these recently dead trees – which generally retain most of their branches – to windthrow.

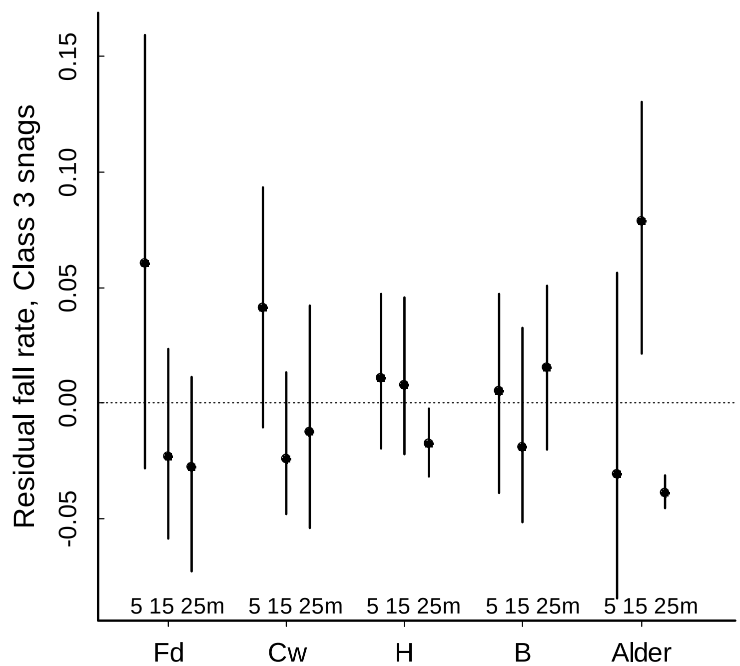

Figure A11.4.2. Edge effects on annual fall rate of class 3 (recently dead) snags. Values are the residual fall rates after the predictions of the best model (Figure A11.4.1) have been removed, at 5, 15 and 25+m into retention patches. Error bars are bootstrapped 95% confidence intervals. Fd=Douglas-fir, Cw=western red-cedar, H=hemlocks, B=true firs. All ecosystem groups were combined for the analyses of edge effects.

A11.3.5 Fall rates of snags – class 4

In most cases, class 4 snags showed declining fall rates with increasing dbh, with a very low proportion of class 4 snags >40cm falling for any species. Fall rates for the standardized 40cm dbh snag were considerably lower for class 4 than class 3 snags, except hemlock which had similar curves for the two classes. This result is contrary to the intuitive expectation that annual fall rates would increase with increasing decay of the snags.

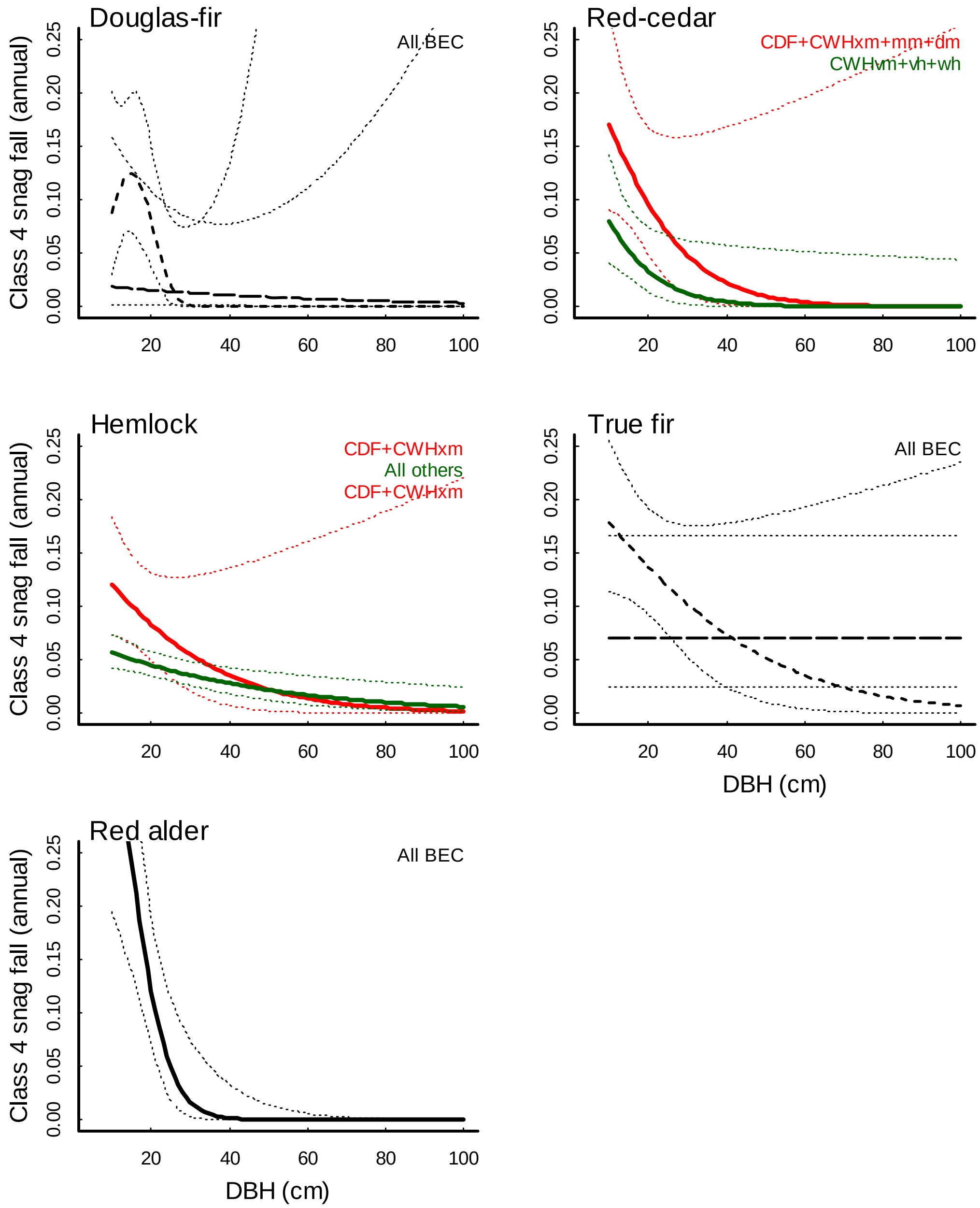

Figure A11.5.1. Annual fall rates of class 4 snags as a function of snag dbh. Solid line = VR blocks and mature controls combined; long dashes = mature controls only; short dashes = VR blocks. Thin dotted lines are 95% confidence intervals. "All BEC" = all 4 ecosystem groups combined; otherwise, colours indicate the different ecosystem groups in the best model.

Table A11.5.1. Annual (%) fall rates of class 4 snags, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

			Snag fall - class 4 (%/yr)			
Species	**BEC Group**	**Treatment**	**Mean**	**LCI**	**UCI**	**Exponent**
Douglas-fir	All	UC	1.090	0.127	7.760	-0.782
		VR	0.000	0.000	13.487	0
Red-cedar	CDF+CWHxm+mm+dm	All	2.234	0.188	16.816	-3.456
	CWHvm+vh+wh	All	0.468	0.033	5.744	-4.357
Hemlock	CDF+xm	All	3.548	0.712	13.598	-2.002
	CWHmm+dm+vm+vh+wh	All	2.804	1.811	4.273	-1.065
True fir	All	UC	7.091	2.477	16.600	0
		VR	7.376	2.438	17.764	-1.534
Red alder	All	All	0.175	0.008	3.322	-9.730

Fall rates of class 4 snags did not show any edge effects, except perhaps for alder snags. With increasing decay class, snag fall may be less affected by wind near an edge, and increasingly a function of physical failure of the decaying snag and its root system.

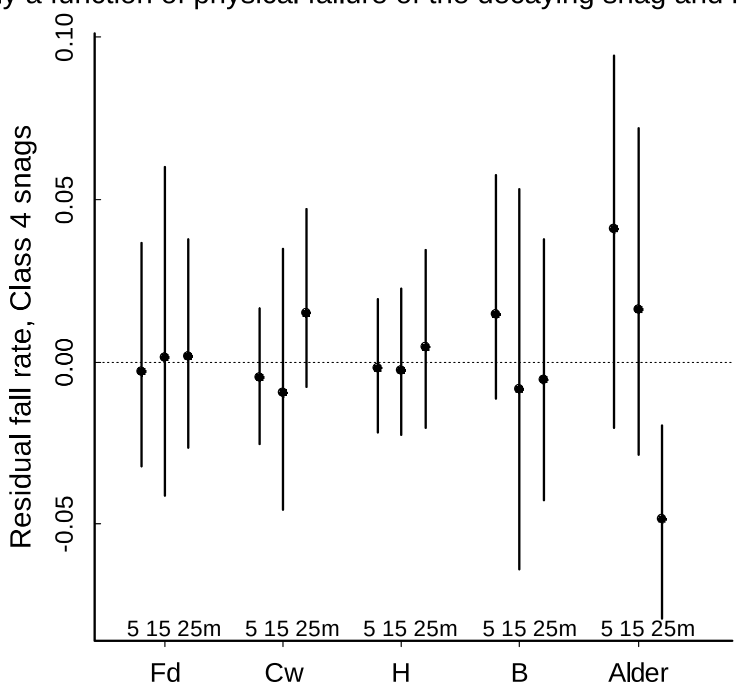

Figure A11.5.2. Edge effects on annual fall rate of class 4 snags. Values are the residual fall rates after the predictions of the best model (Figure A11.5.1) have been removed, at 5, 15 and 25+m into retention patches. Error bars are bootstrapped 95% confidence intervals. Fd=Douglas-fir, Cw=western red-cedar, H=hemlocks, B=true firs. All ecosystem groups were combined for the analyses of edge effects.

A11.3.6 Fall rates of snags – class 5

As with class 4 snags, class 5 snags mostly showed decreasing fall rates with increasing diameter, exept for Douglas-fir in drier ecosystems and true firs. Fall rates for the standardized 40cm snags were similar for class 5 and class 4 snags, and generally lower than for class 3, again contrary to expectation.

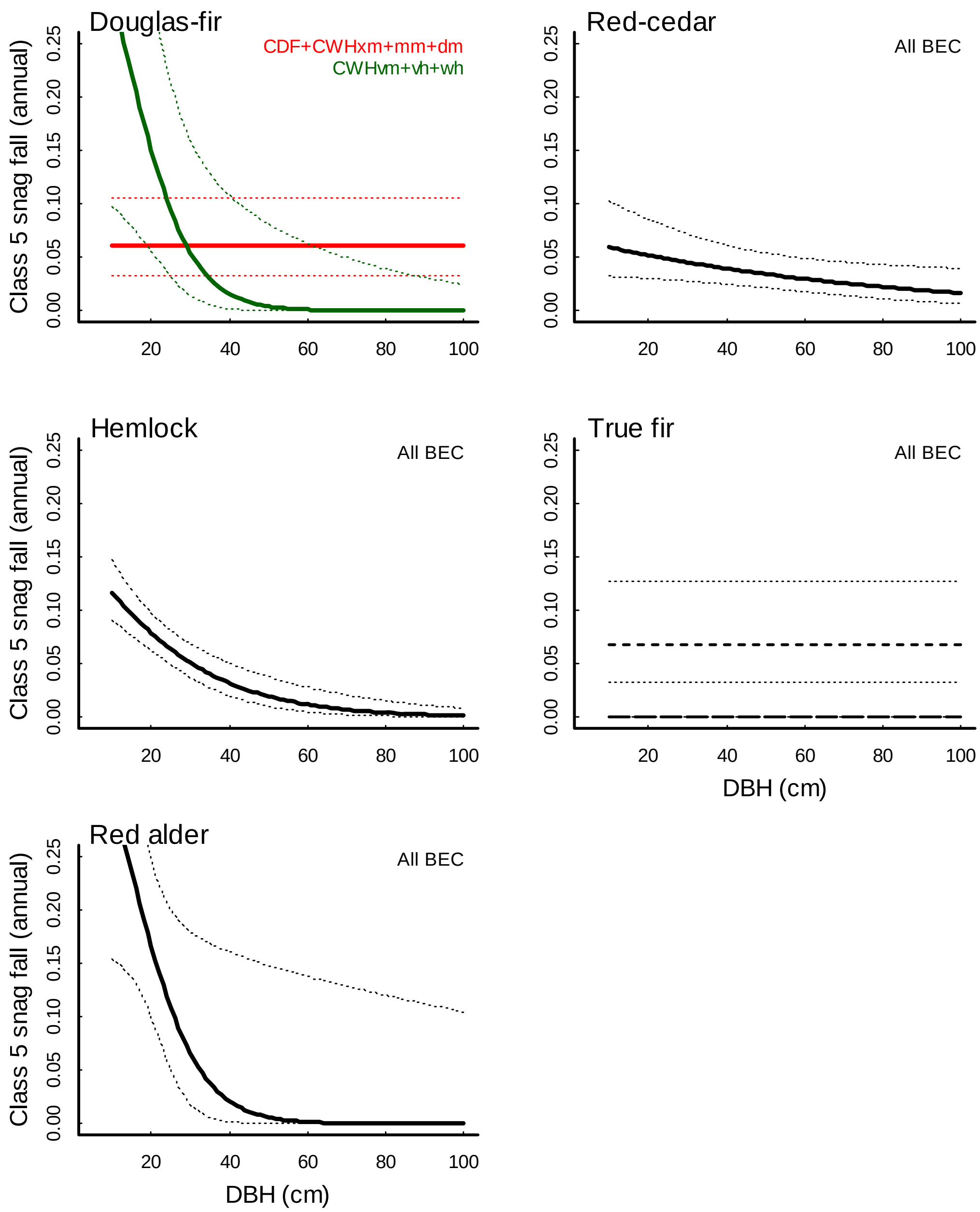

Figure A11.6.1. Annual fall rates of class 5 snags as a function of snag dbh. Solid line = VR blocks and mature controls combined; long dashes = mature controls only; short dashes = VR blocks. Thin dotted lines are 95% confidence intervals. "All BEC" = all 4 ecosystem groups combined; otherwise, colours indicate the different ecosystem groups in the best model.

Table A11.6.1. Annual (%) fall rates of class 5 snags, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

			Snag fall - class 5 (%/yr)			
Species	**BEC Group**	**Treatment**	**Mean**	**LCI**	**UCI**	**Exponent**
Douglas-fir	CDF+CWHxm+mm+dm	All	6.056	3.275	10.507	0
	CWHvm+vh+wh	All	1.577	0.177	10.768	-5.513
Red-cedar	All	All	3.950	2.477	6.144	-0.609
Hemlock	All	All	3.200	1.981	5.059	-2.105
True fir	All	UC	0.000	0.000	0.000	0
		VR	6.787	3.276	12.754	0
Red alder	All	All	2.104	0.179	16.031	-5.159

As with class 4 snags, there was no clear effect of edge position on fall rates of class 5 snags. The lower fall rate 0-10m into the patch for Douglas-fir is assumed to represent a chance occurrence, with a relatively small sample size of class 5 snags of this species.

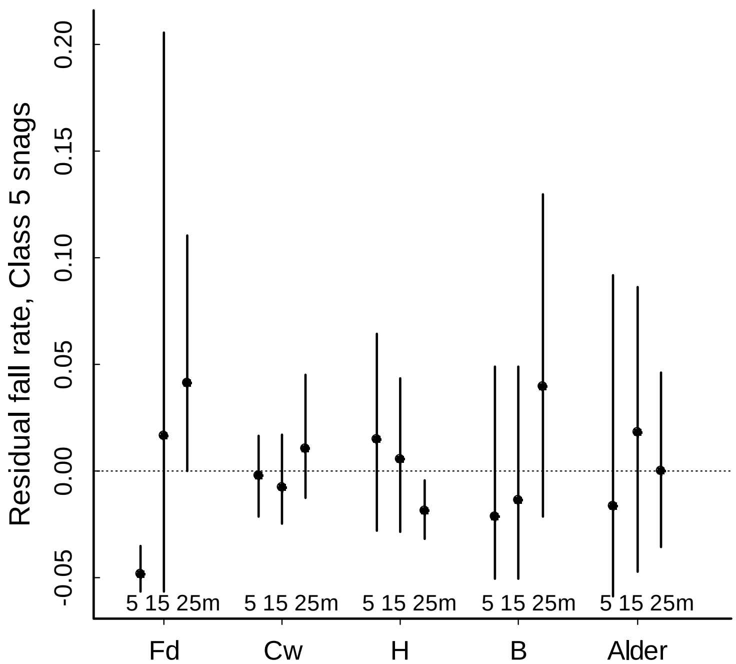

Figure A11.6.2. Edge effects on annual fall rate of class 5 snags. Values are the residual fall rates after the predictions of the best model (Figure A11.6.1) have been removed, at 5, 15 and 25+m into retention patches. Error bars are bootstrapped 95% confidence intervals. Fd=Douglas-fir, Cw=western red-cedar, H=hemlocks, B=true firs. All ecosystem groups were combined for the analyses of edge effects.

A11.3.7 Fall rates of snags – class 3-5 (hard snags)

Combining the three classes of snags with hard wood, fall rates mainly declined with increasing dbh. Exceptions were Douglas-fir in drier ecosystems where there was no apparent relationship with dbh, and Douglas-fir and cedar in uncut controls of wetter ecosystems, where fall rates were low at all dbh values. Hemlock and true fir in drier ecosystems may also show reduced fall rates for the smallest snags, but uncertainty is high because small snags of those species are relatively rare in dry ecosystems. The result for alder in uncut controls is again based on too few snags to be reliable.

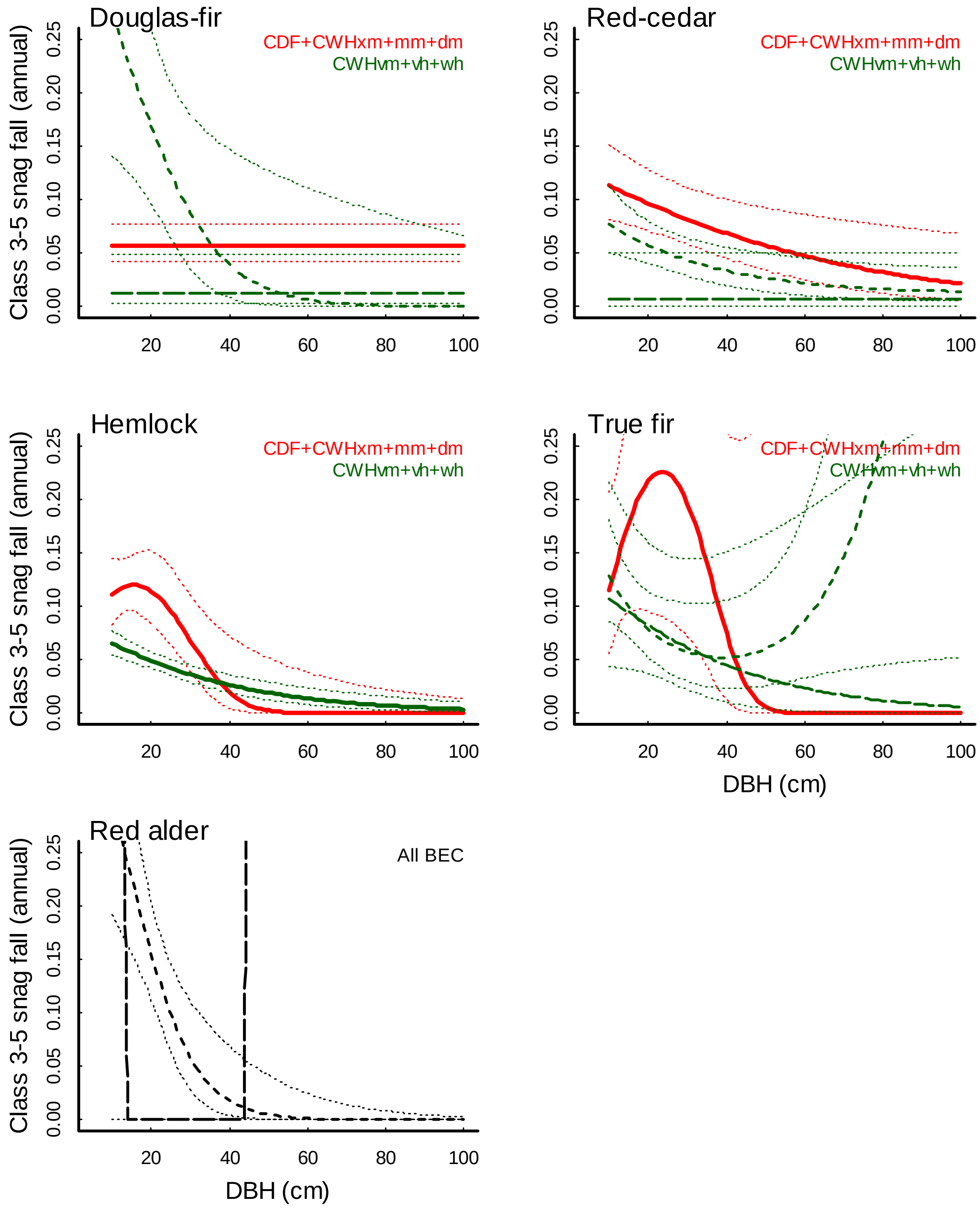

Figure A11.7.1. Annual fall rates of class 3-5 (hard) snags as a function of snag dbh. Solid line = VR blocks and mature controls combined; long dashes = mature controls only; short dashes = VR blocks. Thin dotted lines are 95% confidence intervals. "All BEC" = all 4 ecosystem groups combined; otherwise, colours indicate the different ecosystem groups in the best model.

Table A11.7.1. Annual (%) fall rates of class 3-5 (hard) snags, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

			Snag fall - class 3-5 (%/yr)			
Species	**BEC Group**	**Treatment**	**Mean**	**LCI**	**UCI**	**Exponent**
Douglas-fir	CDF+CWHxm+mm+dm	All	5.715	4.150	7.737	0
	CWHvm+vh+wh	UC	1.282	0.307	4.924	0
Red-cedar	CDF+CWHxm+mm+dm	All	6.844	4.523	10.016	-0.794
	CWHvm+vh+wh	UC	0.752	0.100	5.042	0
		VR	3.351	1.973	5.535	-0.894
Hemlock	CDF+CWHxm+mm+dm	All	1.960	0.470	7.222	-10.461
	CWHvm+vh+wh	All	2.648	1.935	3.596	-1.387
True fir	CDF+CWHxm+mm+dm	All	7.382	1.186	26.154	-13.761
	CWHvm+vh+wh	UC	4.506	1.031	15.074	-1.397
		VR	5.213	2.336	10.600	0.849
Red alder	All	UC	0.000	0.000	0.000	0
		VR	1.768	0.404	6.850	-5.349

There were no obvious edge effects in the fall rates of the 3 combined classes of hard snags.

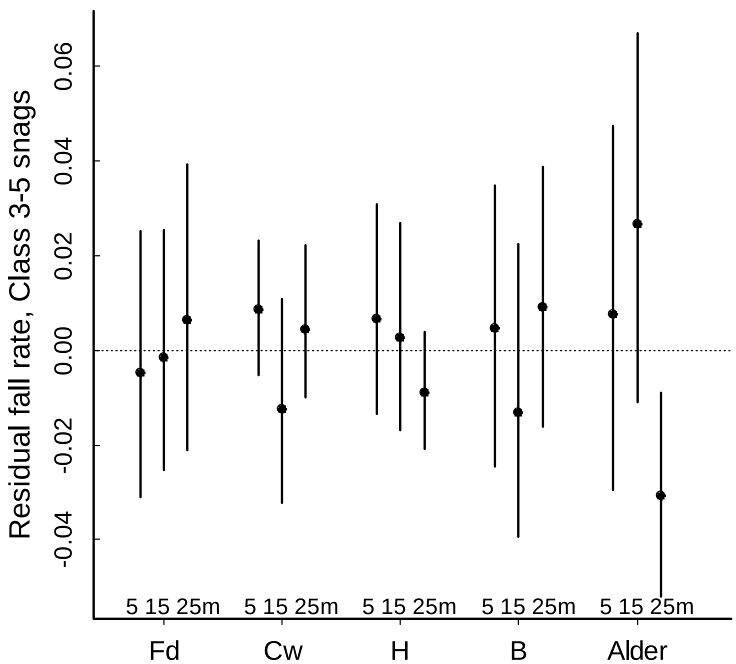

Figure A11.7.2. Edge effects on annual fall rate of class 3-5 (hard) snags. Values are the residual fall rates after the predictions of the best model (Figure A11.7.1) have been removed, at 5, 15 and 25+m into retention patches. Error bars are bootstrapped 95% confidence intervals. Fd=Douglas-fir, Cw=western red-cedar, H=hemlocks, B=true firs. All ecosystem groups were combined for the analyses of edge effects.

Hard Douglas-fir snags had lower fall rates in dispersed VR than in group+mixed VR in CDF and CWHxm. This likely reflects intentional selection of more stable snags for retention in dispersed VR, and also the fact that many of the snags retained within dispersed VR sites were short snags with broken tops.

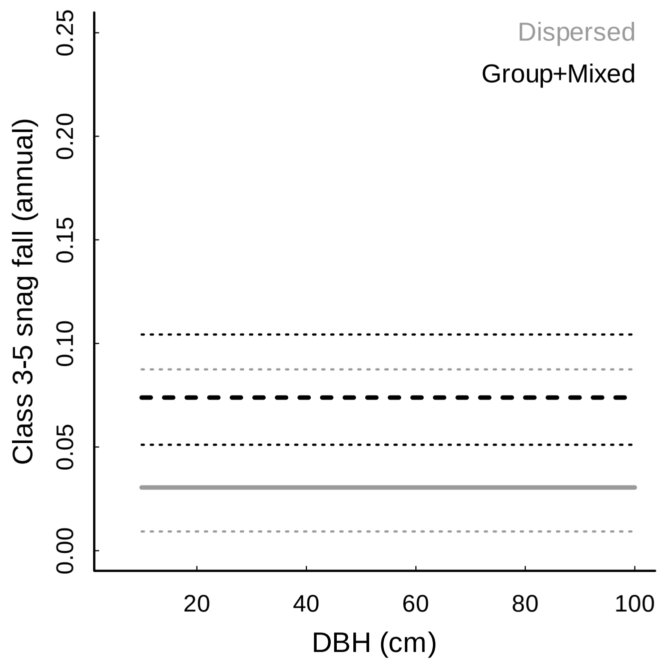

Figure A11.7.3. Annual fall rate of class 3-5 (hard) snags in dispersed (grey solid line) and group+mixed (black dashed line) VR blocks, for Douglas-fir in CDF+CWHxm ecosystems. Thin dotted lines are 95% confidence intervals.

Table A11.7.2. Annual (%) fall rates of class 3-5 (hard) Douglas-fir snags in dispersed versus group+mixed VR in CDF+CWHxm, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

	Snag fall - class 3-5 (%/yr)			
Treatment	**Mean**	**LCI**	**UCI**	**Exponent**
Dispersed	3.04	0.93	8.74	0.00
Group+mixed	7.39	5.09	10.42	0.00

A11.3.8 Fall rates of snags – class 6+ (soft snags)

The analysis of fall rates of soft snags combined all species (because species often cannot be determined for well-decayed snags) and ecosystems (because old snags are rare). Fall rates of soft snags declined with increasing dbh, with fall rates more than twice as high in VR stands than in uncut stands. Fall rates of soft snags were 2-3 times as high as fall rates of hard snags in a given treatment.

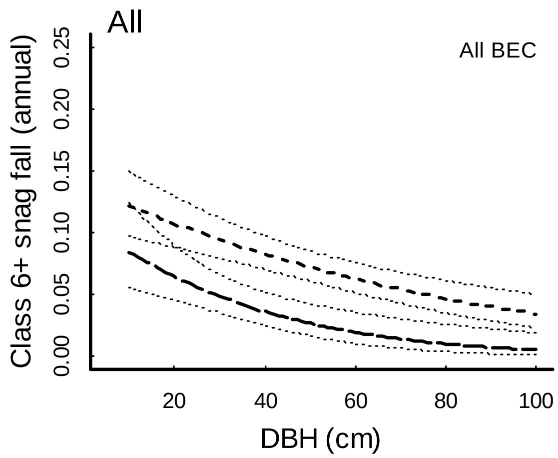

Figure A11.8.1. Annual fall rates of class 6+ (soft) snags as a function of snag dbh, combining all species. Long dashes = mature controls only; short dashes = VR blocks. Thin dotted lines are 95% confidence intervals. "All BEC" = all 4 ecosystem groups combined.

Table A11.8.1. Annual (%) fall rates of class 6+ (soft) snags, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

			Snag fall - class 6+ (%/yr)			
Species	**BEC Group**	**Treatment**	**Mean**	**LCI**	**UCI**	**Exponent**
All	All	UC	3.628	2.497	5.194	-1.324
		VR	8.288	7.026	9.712	-0.600

There were no obvious edge effects on fall rates soft snags, which are expected to fall due to structural failure from decay, rather than from the effects of wind along edges.

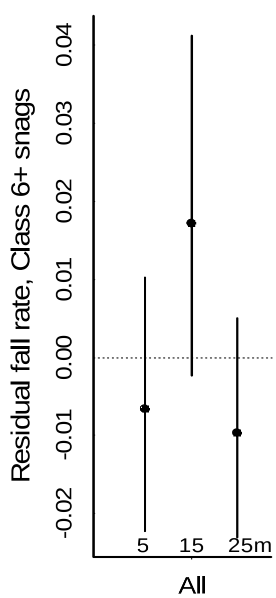

Figure A11.8.2. Edge effects on annual fall rate of class 6+ (soft) snags. Values are the residual fall rates after the predictions of the best model (Figure A11.8.1) have been removed, at 5, 15 and 25+m into retention patches. Error bars are bootstrapped 95% confidence intervals. Fd=Douglas-fir, Cw=western red-cedar, H=hemlocks, B=true firs. All ecosystem groups and species were combined for this analysis.

A11.3.9 Decay rates of snags – class 3→4

Decay rates from class 3 to class 4 snags showed a variety of relationships with dbh. In most cases, confidence intervals were wide, because there are relatively few class 3 snags. Edge effects were similarly variable, with wide uncertainty.

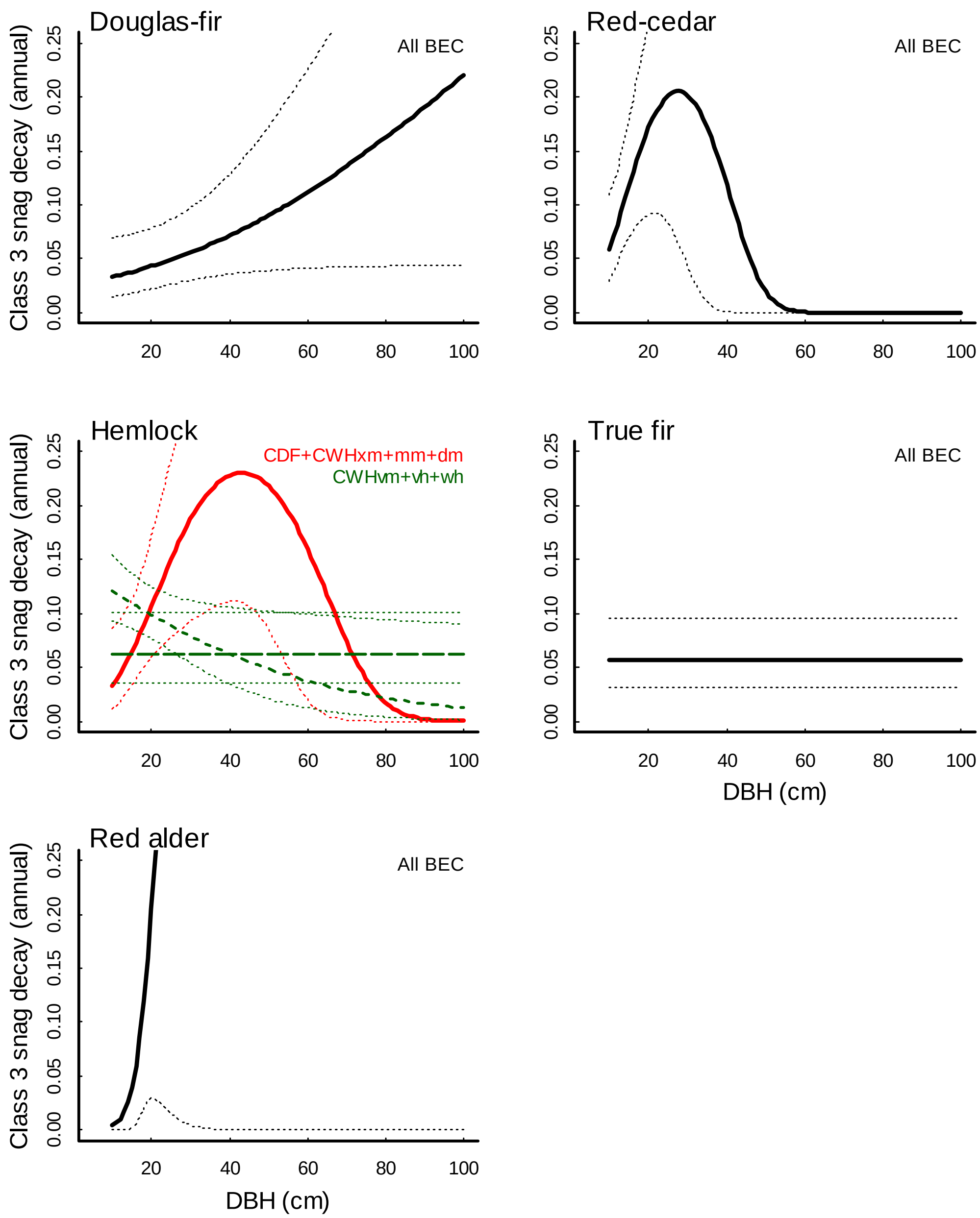

Figure A11.9.1. Annual decay rates from class 3 to class 4 snags as a function of snag dbh. Solid line = VR blocks and mature controls combined; long dashes = mature controls only; short dashes = VR blocks. Thin dotted lines are 95% confidence intervals. "All BEC" = all 4 ecosystem groups combined; otherwise, colours indicate the different ecosystem groups in the best model. Note: Rates for red alder are highly suspect, because there were very few class 3 alder snags that remained standing for the remeasurements.

Table A11.9.1. Annual (%) decay rates of class 3 → class 4 snags, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

			Snag decay - class 3-->4 (%/yr)			
Species	**BEC Group**	**Treatment**	**Mean**	**LCI**	**UCI**	**Exponent**
Douglas-fir	All	All	7.160	3.576	12.871	0.954
Red-cedar	All	All	11.899	0.096	55.905	-11.701
Hemlock	CDF+CWHxm+mm+dm	All	22.829	11.105	35.548	-1.308
	CWHvm+vh+wh	UC	6.226	3.611	10.105	0
		VR	6.259	3.437	10.598	-1.093
True fir	All	All	5.649	3.135	9.547	0
Red alder	All	All	74.685	0.030	84.113	1.020

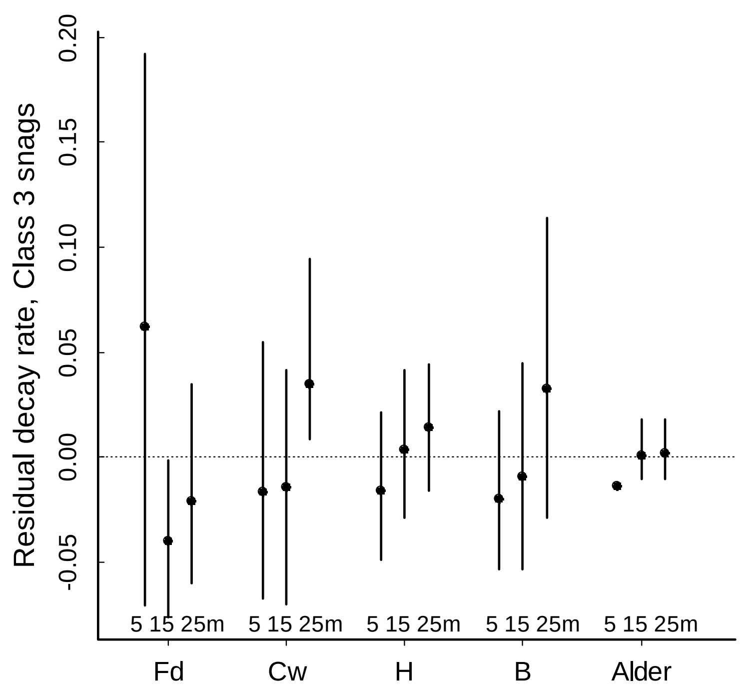

Figure A11.9.2. Edge effects on annual decay of class 3 to class 4 snags. Values are the residual decay rates after the predictions of the best model (Figure A11.9.1) have been removed, at 5, 15 and 25+m into retention patches. Error bars are bootstrapped 95% confidence intervals. Fd=Douglas-fir, Cw=western red-cedar, H=hemlocks, B=true firs. All ecosystem groups were combined for the analyses of edge effects.

A11.3.10 Decay rates of snags – class 4→5

Decay rates from class 4 to class 5 snags were mainly either constant with dbh (Douglas-fir, true fir, alder; hemlock and cedar in some ecosystems). Decay rates of hemlock and fir in the drier ecosystems and in VR stands in wetter ecosystems apparently increased with increasing dbh, but confidence intervals are wide. Edge effects were not apparent.

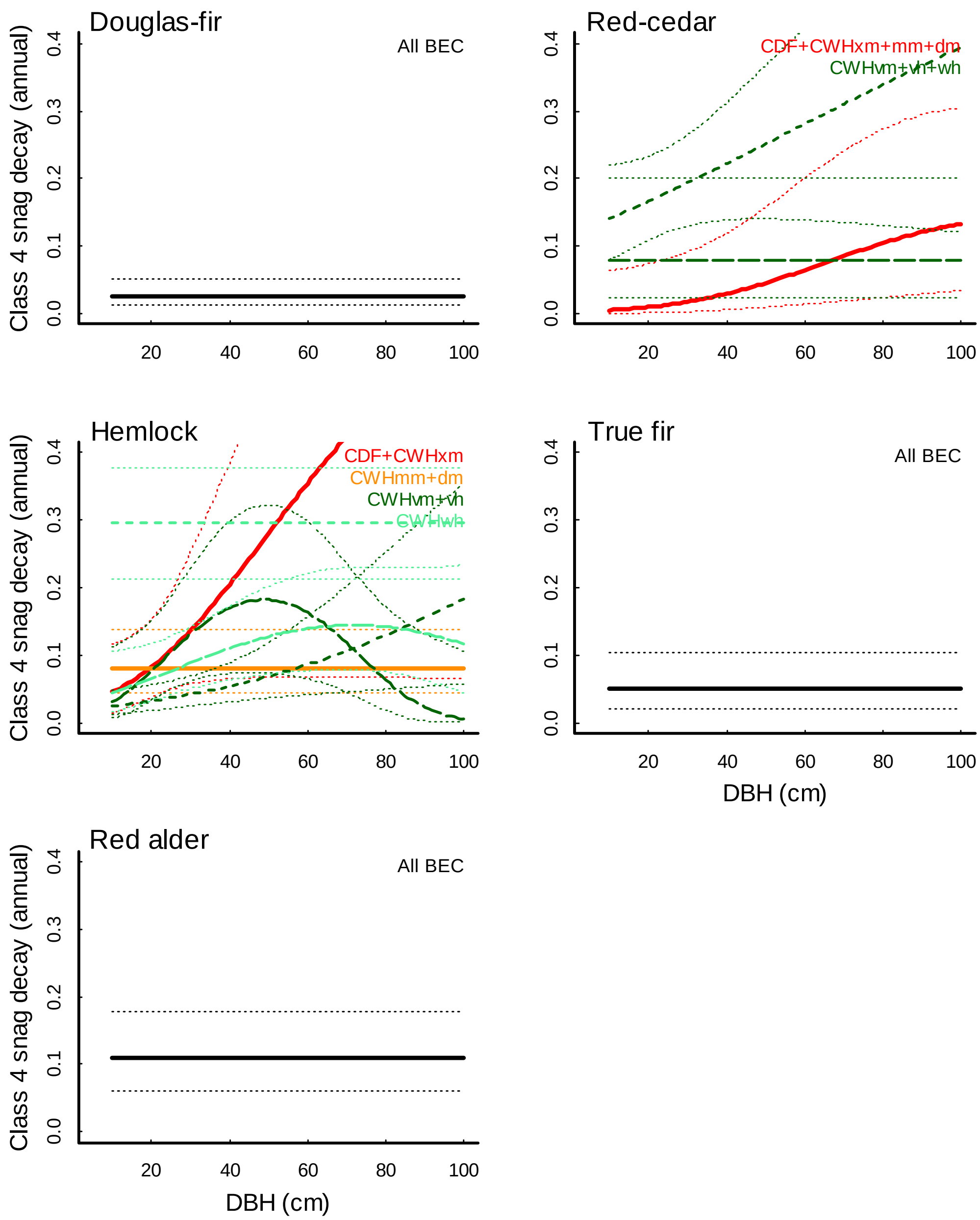

Figure A11.10.1. Annual decay rates from class 4 to class 5 snags as a function of snag dbh. Solid line = VR blocks and mature controls combined; long dashes = mature controls only; short dashes = VR blocks. Thin dotted lines are 95% confidence intervals. "All BEC" = all 4 ecosystem groups combined; otherwise, colours indicate the different ecosystem groups in the best model.

Table A11.10.1. Annual (%) decay rates of class 4 → class 5 snags, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

			Snag decay - class 4-->5 (%/yr)			
Species	**BEC Group**	**Treatment**	**Mean**	**LCI**	**UCI**	**Exponent**
Douglas-fir	All	All	2.537	1.180	5.192	0
Red-cedar	CDF+CWHxm+mm+dm	All	2.926	0.550	11.921	1.731
	CWHvm+vh+wh	UC	7.985	2.291	20.057	0
		VR	22.220	13.865	31.272	0.513
Hemlock	CDF+CWHxm	All	20.494	6.470	38.447	1.283
	CWHmm+dm	All	8.097	4.344	13.747	0
	CWHvm+vh	UC	17.044	7.324	29.822	-0.135
		VR	5.391	3.095	8.913	1.001
	CWHwh	UC	10.989	6.326	17.323	0.564
		VR	29.632	21.275	37.749	0
True fir	All	All	4.976	2.147	10.352	0
Red alder	All	All	10.911	5.963	17.818	0

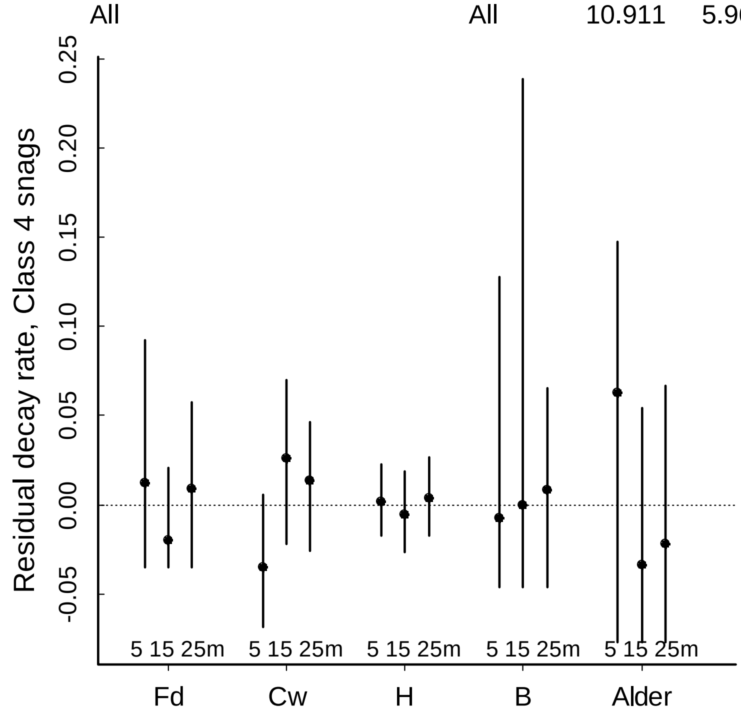

Figure A11.10.2. Edge effects on annual decay of class 4 to class 5 snags. Values are the residual decay rates after the predictions of the best model (Figure A11.10.1) have been removed, at 5, 15 and 25+m into retention patches. Error bars are bootstrapped 95% confidence intervals. Fd=Douglas-fir, Cw=western red-cedar, H=hemlocks, B=true firs. All ecosystem groups were combined for the analyses of edge effects.

A11.3.11 Decay rates of snags – class 5→6+

Decay of snags from class 5 to class 6+ (from hard to soft) occurred at a constant rate of approximately 0.08/yr for all dbh values of the conifers, except for lower rates for Douglas-fir in uncut stands and higher rates for hemlock in VR stands. Results for red alder are based on few class 5 snags for this species and are likely unreliable. Edge effects in decay rates for these snags were again not apparent.

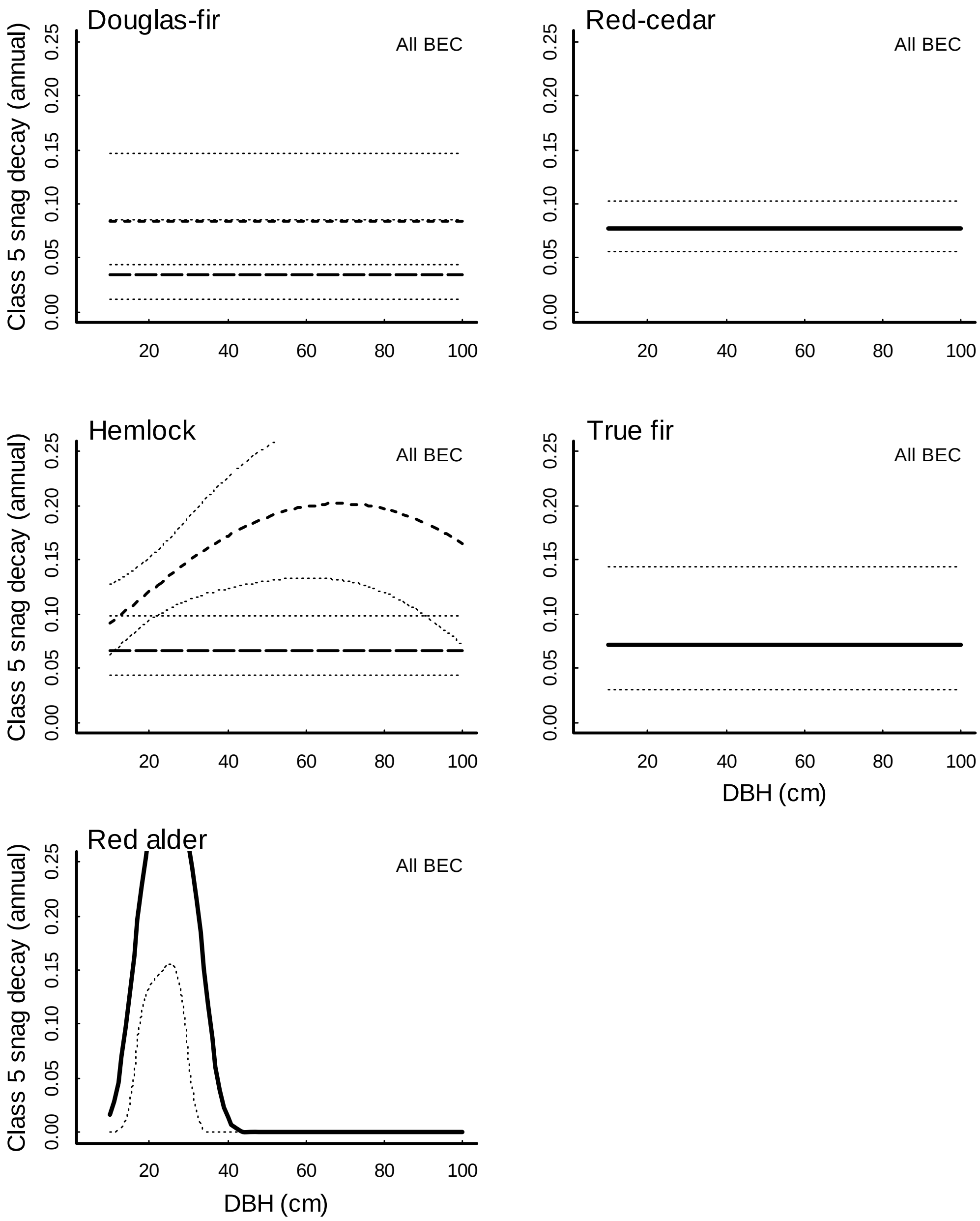

Figure A11.11.1. Annual decay rates from class 5 to class 6 snags as a function of snag dbh. Solid line = VR blocks and mature controls combined; long dashes = mature controls only; short dashes = VR blocks. Thin dotted lines are 95% confidence intervals. "All BEC" = all 4 ecosystem groups combined.

Table A11.11.1. Annual (%) decay rates of class 5 → class 6 snags, standardized to 40cm dbh, and exponent for power relationship for other dbh values (see text).

		Snag decay - class 5-->6+ (%/yr)				
Species	**BEC Group**	**Treatment**	**Mean**	**LCI**	**UCI**	**Exponent**
Douglas-fir	All	UC	3.420	1.227	8.518	0
		VR	8.441	4.382	14.650	0
Red-cedar	All	All	7.715	5.622	10.333	0
Hemlock	All	UC	6.630	4.311	9.817	0
		VR	17.201	12.381	22.636	0.353
True fir		All	7.105	3.029	14.389	0
Red alder		All	1.345	0.000	75.823	

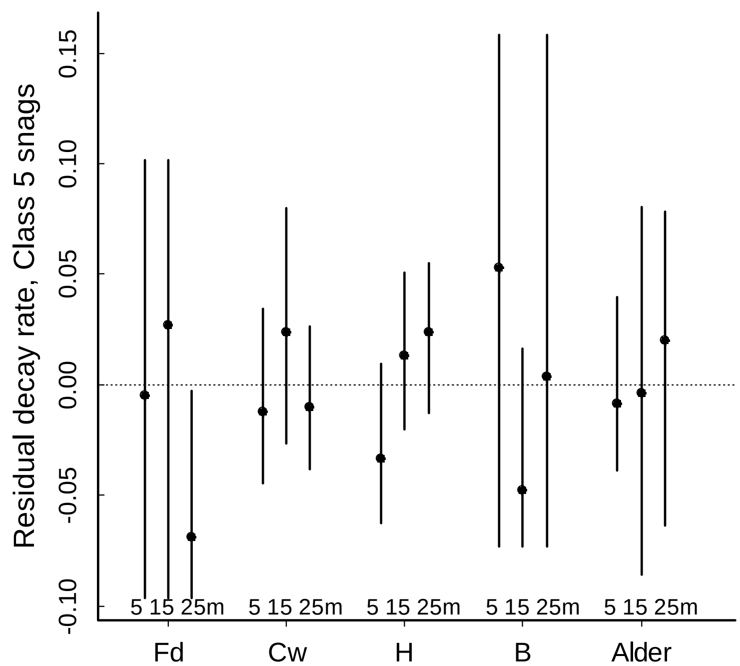

Figure A11.11.2. Edge effects on annual decay of class 4 to class 5 snags. Values are the residual decay rates after the predictions of the best model (Figure A11.11.1) have been removed, at 5, 15 and 25+m into retention patches. Error bars are bootstrapped 95% confidence intervals. Fd=Douglas-fir, Cw=western red-cedar, H=hemlocks, B=true firs. All ecosystem groups were combined for the analyses of edge effects.

A11.3.12 Combined relationships of rates with dbh

To support deadwood modeling work, the exponents of the dbh relationship for the various species, ecosystems and treatments were combined into a weighted mean, for 4 different processes: growth of live trees, mortality of live trees, fall rates of snags and decay rates of snags, and also for fall+decay of snags combined. The exponent is "X" in the equation: Rate at dbh Y = (Rate at 40cm dbh) x $(\text{dbh Y / 40cm})^X$. An exponent of -0.5, for example, means that the rate decreases as the square root of the dbh; an 80cm stem would have a rate 0.71 times the rate at dbh 40cm. Each of the exponents for a given process reported in the tables above was used in a weighted average, where the weight was inversely proportional to the variance of the estimate.

Live tree growth and mortality showed a slight increase with increasing dbh. Growth would be about 12% higher for an 80cm tree compared to 40cm, and mortality 10% higher. Confidence intervals of these estimates include 0, so no relationship with dbh is also feasible.

Fall rates of snags decreased on average in about inverse proportion to dbh, so that an 80cm dbh snag would have a fall rate just less than half that of a 40cm snag. Decay rates of snags, on the other hand, did not change with dbh on average. Although the rates for these two processes are quite different, with non-overlapping confidence intervals, deadwood modeling sometimes uses the same dbh relationship for both snag fall and decay. The combined rate is close to a decrease inversely proportional to the square root of dbh – with the combined rate, an 80cm snag would fall or decay at 66% the rate of a 40cm snag.

Table A11.12. Weighted mean and standard error of exponents for the dbh relationship for 4 processes (and for snag fall+decay combined).

	DBH Exponent	
Process	**Mean**	**SE**
Growth	0.166	0.162
Mortality	0.142	0.156
Fall	-1.054	0.327
Decay	0.018	0.246
Fall+Decay	-0.603	0.226