A study of Douglas-fir leave-tree population dynamics and attributes,
10 to 13 years after timber harvesting on sub-boreal sites in central
British Columbia

Michael J. Jull and Bruce Rogers

Manuscript submitted to journal of Forest Ecology and Management
(Final Report, Forest Science Program Research Project Y092256)
April 15, 2009

1 Corresponding author; address for correspondence:
Aleza Lake Research Forest Society,
University of Northern British Columbia
3333 University Way, Prince George, B.C. V2N 4Z9
Phone: 250-960-6674; e-mail: jullm@unbc.ca

2 British Columbia Ministry of Forests and Range,
Northern Interior Region, Research Section
1011 Fourth Avenue, Prince George, BC
Phone: 250-565-6100; e-mail: Bruce.Rogers@gov.bc.ca
Abstract

This study examined the development and fate of mature Douglas-fir leaf-tree cohorts ≥ 10 years following timber harvesting on sub-boreal sites in central British Columbia. Leaf-trees were reassessed in summer 2007 in 7 cutblocks in three geographically-separate study areas established between 1995 and 1998. Study parameters included post-harvest leaf-tree survival, rates and modes of mortality, diameter and height growth, structural attributes, and indicators of potential wildlife use. 793 Douglas-fir leaf-trees were systematically re-visited and re-assessed. Overall, the 10- to 13-year survival and mortality rates of Douglas-fir leaf-trees were 73.8% survival and 26.2% mortality respectively; average leaf-tree mortality rates by study area ranged from 7.8 to 33.9%. Over the entire monitoring period, mean modes and incidences of leaf-tree mortality were windthrow (18.2%); windsnap (6.3%); and standing mortality (1.8%). Annual rates of wind damage declined from an overall mean of 4.2% per year in the first three-year period, to 1.4% in the latter (4 or more) years following harvest treatments. Distribution of wind mortality by diameter class differed between the early and later monitoring periods. Surviving fir trees generally showed strong diameter growth ranging from 1 to 14 cm diameter increments during the ≥ 10-year monitoring period, and resulted in a mean 10% increase in stem basal area. Height growth response was variable; average height of surviving leaf-trees remained relatively constant.

Live, intact fir leaf-trees had lower incidence of decay or related wildlife Tree attributes than dead standing trees, either intact or broken. Dead fir were observed to have a very high frequency of multiple wildlife Tree types and abundant cavity nester and related users. Observations of carpenter ants (Camponotus spp.) and frass were frequently noted on live Douglas-fir leaf-trees, including 10 to 55% of leaf-trees examined; these were often accompanied by evidence of feeding excavations by woodpeckers, concentrated in the lowest 1 metre of leaf-tree boles.
Introduction and Literature Review

Increasingly, in both coastal and continental (or “Interior”) forest types of British Columbia, as well as elsewhere in North America, forest managers are managing for biodiversity and stand structural complexity using retention silvicultural systems including post-harvest retention of uncut individual leave-trees (Kohm and Franklin, 1997; Mitchell and Beese, 2002). However, mortality and changes in the populations of retained leave-trees after partial-cut retention of leave-trees – i.e. – due to wind, pests, and other biotic and abiotic factors - is a significant uncertainty in the planning, use, and longer-term outcomes of such retention systems. In British Columbia, this topic has been examined in some detail in replicated trials in spruce-subalpine fir forest types (Huggard et al 1999), and Interior cedar hemlock forests (Coates, 1997). Other studies of leave-tree mortality and dynamics after application of partial cutting and retention systems in western North America include temperate Douglas-fir forests in the central Oregon Cascades range (Busby et al, 2006); boreal spruce-deciduous mixedwoods in Alberta (Bladon et al, 2008); and California redwoods and Douglas-fir (Jameson et al, 2005).

Interior Douglas-fir (Pseudotsuga menziesii var. glauca) plays a unique ecological role in the sub-boreal forests of Central British Columbia. Douglas-fir in this region typically occurs as a secondary or minor component of mixed-species even- or two-aged stands of pine, spruce, and/or hardwoods. The thick-barked Douglas-fir is more fire-resistant than other sub-boreal tree species, and can grow to very large sizes (40-50 m and 100-300 cm dbh) and great ages (300 to 500+ years). It is an important and distinctive element of stand-level biodiversity in the Sub-boreal Spruce (SBS) zone (Rogers and Hawkins, 2003; Lousier and Kessler, 1999). The importance of Douglas-fir retention in SBS ecosystems has been recognized in government policy for the last decade (BC Ministry of Forests, 1999). In Central Interior SBS forest types where Douglas-fir (or
“fir”) occurs naturally, post-harvest retention of dispersed mature fir leave-trees is now a common element of operational planning and harvesting in industrial forest operations.

In central British Columbia, a pilot study of mortality trends in retained Douglas-fir leave-trees (Rogers, 2006) focussed primarily on standing leave-tree mortality, and the potential role of various factors, including water stress. Rogers (2006) surveyed a large number of recent SBS cutblocks with fir retention 1 to 5 years following harvesting, finding highly variable rates of standing tree mortality (ranging from about 10 to 20%), but found that there was a lack of conclusive evidence linking any readily-identifiable site factors to rates of leave-tree mortality.

Rogers also found physiological evidence that leave-trees showed distinct signs of water (drought) stress in the first year or so following harvest of the surrounding stand, at levels that are felt induce tree mortality; but leave-trees showed significantly lower levels of water stress after 5 years, suggesting adaptation over time. Rogers could not examine trends in fir leave-tree response after harvest beyond about 5 years following harvest treatment.

This current study in some ways pre-dates but complements the work of Rogers (2006), by broadening the scope of investigations of Douglas-fir leave-tree dynamics through longer-term monitoring. This study examines longer-term outcomes of these Douglas-fir retention treatments, and the fate of fir leave-tree cohorts retained after timber harvesting. More specifically, we focus on the 10- to 14-year development of mature Douglas-fir leave-tree cohorts retained following timber harvesting in several sub-boreal study areas in Central Interior British Columbia. We used direct, ground-based, repeated-measures observations of leave-trees over time, in study populations that have been tracked and monitored since shortly after the initial harvest treatment.

Overall goals of the study were to:
1. To enhance understanding of the long-term dynamics, development, and emerging characteristics of the Douglas-fir mature leave-trees retained after harvest on Central Interior sub-boreal sites.

2. To enhance knowledge of the processes by which Douglas-fir leave-trees persist, and are maintained in stands, and contribute to the maintenance of desired stand structural characteristics. And;

3. To examine longer-term temporal and cumulative trends in Douglas-fir leave-tree dynamics and characteristics after post-harvest retention, including:
   a. Survival of live trees relative to initial post-harvest populations;
   b. Mortality processes and resulting dead-tree characteristics;
   c. Growth responses and morphological characteristics of surviving live trees, and;
   d. Potential habitat values of live and dead standing leave-trees.

The current study (this manuscript) examines the medium-term (one decade or more) development of mature Douglas-fir leave-tree cohorts retained following timber harvesting in sub-boreal study areas in Central Interior British Columbia. This study approach is conceptually similar to that of Busby et al (2006) who examined the fates of live trees retained 9 to 18 years after logging in cutblocks in western Oregon. However, our methodologies differ; unlike the Busby et al study which examined changes in leave-tree population totals and means across different cutblocks as an indirect measure of change in leave-tree cohorts, our study used direct ground-based repeated-measures observations of individual leave-trees and tree cohorts over time, for individuals and populations that have been tracked and monitored since shortly after the initial harvest treatment.

**Study Area Descriptions**
Table 1 provides a summary of study areas and stands examined in this study, by geographic location, administrative identifiers, biogeoclimatic subzone, elevation, slope range, aspect, range of initial leave-tree densities, harvest and monitoring history, and sample sizes. The geographic range of the study is focused on three study areas in the SBSdw2, SBSdw3, and SBSmk1 biogeoclimatic subzones (DeLong et al, 1993).

**Methods**

Leave-tree sampling used the analytical sampling surveys approach described by Schwarz (1998), following a two-stage sampling design. The first stage of sampling described the original post-harvest population of leave-trees following the initial harvest treatment. The second stage (repeated-measures monitoring) consisted of additional, repeated examinations of the same permanent transects over time to examine changes in the population.

In the 2007 field season, a total of 793 Douglas-fir leave-trees were re-located and re-assessed on systematic belt sampling transects at the three primary long-term monitoring areas (Baldy Hughes, Pinchi, and Tako sites) originally established by the primary author between 1995 and 1998. Study parameters examined include trends in post-harvest leave-tree survival, rates and modes of mortality, growth, live crown ratios, structural attributes, and indicators of wildlife habitat suitability (Keisker, 2000).

Original monitoring of leave-trees commenced within approximately a year of harvest in each cutblock, and any post-harvest wind damage or standing mortality since the harvest treatment was recorded at that time. 20-metre wide belt transects were established at 100 metre intervals across the contour (20% sampling intensity), and all fir leave-trees were tagged. Transect centre-lines were marked to aid in re-location for future site visits. Data recorded for each leave-tree on the
transect included: species, diameter at breast height, total height, live crown length, and presence of logging injuries or physical defects. Trees were affixed with numbered tags at dbh for future reference. For wind damage or standing mortality, we recorded the type of mortality or wind damage (windthrow or windsnap as per Stathers et al, 1994), height of wind snap, direction of tree fall (top to roots), and live crown length.

Tree data remeasurement data were organized and summarized in MS Excel spreadsheets. The cumulative sample size (number of trees) at establishment was 1017 trees, of which 793 were Douglas-fir. The 2007 remeasurement relocated all transects and tagged Douglas-fir sample trees within the study areas. Tree status (live or dead) was assessed and verified for all sample trees. Mode of mortality was assessed for trees that died between the 2000 and 2007 measurement periods. For all live or standing sample trees, the following mensurational data was collected: (a) total height; (b) diameter at breast height (live trees); (c) live crown length; (d) crown vigour (good, medium, poor, moribund); (e) wind damage if any, and type and orientation of wind damage; (f) visible logging damage, if any. For all live or dead standing trees, the following data was collected: (g) Wildlife Tree Type (Keisker, 2000); (h) Decay Class; and (i) evidence and type of wildlife use.

Table 2 provides a summary of the standard categorization of Douglas-fir leave-tree status used in the collection, organization and analyses of the data; a detailed description and explanation of each category is provided. Table 3 provides a description of time period categories for the monitoring and analysis of leave-tree data from the 3 main study areas. Table 4 provides a summary of the Wildlife Tree Types used in this study, as per Keisker (2000).
Data Analyses

Data analyses focused on the sampling population of 793 Douglas-fir leave-trees assessed both in the mid- to late-1990’s, and in 2007, at the Baldy Hughes, Pinchi Ridge, and Tako Creek study areas. Tree species on the transects other than Douglas-fir were excluded from this analysis. In addition, some portions of study areas disturbed by subsequent salvage logging of adjacent lodgepole pine (*Pinus contorta var. latifolia*) killed by mountain pine beetle (*Dendrotonus* spp.) where also excluded from the analysis.

Parametric Data (Mensurational / Tree Growth Data):

Tree growth response data (diameter and basal area increments) were analysed using linear regression and a natural log transformation. Individual-tree growth responses were expressed on an annual basis based on comparison of 2007 and initial measurement, divided by the years since initial measurement.

Non Parametric Data (e.g. – Comparison of Expected vs Actual frequency distributions):

For initial data analyses of mortality and survival data, data were pooled and combined for each cutblock and geographic area. Frequency of leave-tree survival or mortality was summarized and examined by tree size classes (e.g. – dbh class and height class), percent live crown classes, and height-to-diameter ratio classes, and measurement period, to identify (i) within-population differences in leave-tree response in a measurement period, and (ii) temporal differences in leave-tree responses between measurement periods. Mortality and survival rates were expressed in all cases, as a proportion or percent of the cohort of Douglas-fir leave-trees in a given class at the beginning of the monitoring period. These analyses were also used to examine the relative frequency of different types of leave-tree mortality (standing mortality or wind damage) over time since the initial harvest. For some analyses and data presentations, total wind damage
mortality during a monitoring period was converted to a mean annual rate by dividing the total proportion of leave-trees with wind-induced mortality by the number of years within the monitoring period.

Statistical analyses of non-parametric data (frequency data and comparison of frequency distributions) used Chi-squared tests (Conover, 1999) to a 95% confidence level. The null hypothesis for this test will be that the frequency of the observed phenomenon is random – or equally probable - across a population, and in the case of Douglas-fir leave-tree populations, is unrelated to tree size or other physical characteristics. For example: If the frequency of mortality or any other phenomenon occurs randomly, then the observed frequency of tree mortality in a given tree class (e.g. – tree size) will not be significantly different than the observed frequency of all live trees in that class at the initial (post-harvest) measurement period.

Frequency of Wildlife Tree Types and observed use were also described, relative to (i) whether the tree is live or dead, (ii) if dead, time since harvest, and (iii) occurrence of physical damage to live or dead trees (e.g. – windsnap).

**Results and Discussion**

Tables 5 and 6 summarize the numbers and condition of Douglas-fir leave-trees at each stand and study area, after 3 years of monitoring and 10+ years of monitoring, respectively.

Figures 1 compares and contrasts mortality and survivorship of fir leave-trees, and frequency of each mode of mortality, in each of the three sample populations. Over ≥ 10-year period for the the 3 sites examined in the analysis, overall Douglas-fir survival and mortality was 73.8% and 26.2%
respectively. By study area, the range of cumulative leave-tree mortality for the period were
similar for the rolling, hilly terrain of the Baldy Hughes and Pinchi sites (33.9 and 26.7% respectively) but lower rates (7.8%) for the less exposed and relatively level Tako site. The leading mode of Douglas-fir leave-tree mortality across 6 out of 7 sites examined is windthrow (uprooting) by high-wind events, with an average of 18.2% of fir leave-trees windthrown since the start of monitoring at all sites. Windthrow rates since harvest ranged from 25.3% at Baldy Hughes, 16.4% at Pinchi, and 5.2% at the Tako site. A somewhat less important but significant mode of wind mortality is windsnap (Dead Standing Broken and Stem Snapped at Base categories) with an average of 6.3% of the total sample trees succumbing to this type of damage.

In only 1 of the 7 stands examined did the rate of windsnap exceed the rate of windthrow.

Comparatively, in a study of the fate of Douglas-fir leave-trees in the Central Cascade mountain range in Oregon, Busby et al (2006) found that, 1 to 10 years after cutting, 65% of the initially retained trees were alive and standing, and 12% had been toppled or topped by wind; 9 to 18 years after cutting, 54% of the original retained trees remained alive and standing, and 10 to 21% had been toppled or topped by wind.

Standing mortality of Douglas-fir leave-trees (Dead Standing Intact category) averaged 1.8% of the total sample population overall, ranging from 1.4 to 3.5% across the three study areas after 10 to 13 years. Rates of standing leave-tree mortality in this study are lower than rates for standing Douglas-fir leave-tree mortality of 10 to 20% observed by Rogers (2006), in his pilot study the SBSdw3 and SBSmk1 subzones of the BC central Interior and Busby et al (2006) who found that 13% had become “snags by natural processes” (equivalent to standing dead trees) 1 to 10 years after cutting, and by 9 to 18 years after cutting, 11 to 22% had become standing snags. Possible explanations for differences in standing-dead mortality rates between the studies may include: (a) geographic or climatic variation between sampling sites; (b) geographic differences in leave-tree
response between different Douglas-fir sub-populations, (c) differences in sampling techniques; (c) and possible differences in site selection techniques between the studies.

Trends in mortality due to wind damage (uprooting and windsnap) were examined broken down by diameter class (Figure 2). Data from the first three years of leave-tree monitoring suggest that windthrow mortality rates decreased more or less inversely with tree diameter during this early post-harvest period. However, conversely, longer-term trends (Years 4 to ≥ 10 years post-harvest) is the reverse, suggesting that wind damage is actually lowest in smaller diameter classes during this period, and highest in larger diameter classes. For the entire 10- to 13-year monitoring period, Chi-squared tests of the distribution of tree windthrow and wind mortality mortality rates by diameter class indicate that there is no significant difference between the observed distribution of and the null distribution (equal probability by dbh class) for all 3 study areas individually, and for pooled data from all sites (p=0.05). However, this apparent lack of trend of wind damage by diameter class over the whole monitoring period appears to mask major differences in wind damage trends by diameter in the “early” (0 to 3 year) post-harvest period versus the “later” period (Years 4 to ≥ 10 years post-harvest).

Examination of trends in annualized wind mortality rates for the two monitoring periods indicates that rates of wind mortality are highest in the early post-harvest period for all 3 study areas, declining substantially in the later post-harvest monitoring period (Figure 3). Mean wind mortality rates over all study areas declined from 4.2% per year for the first 3 years, to 1.4% for the later monitoring period. This observation supports the hypothesis that residual leave-trees will acclimatize to increased wind exposure over time by reallocation of growth resources to enhance windfirmness of individual trees (e.g. – Mitchell, 2000).
Windthrow rates were also examined in relation to Height to Diameter Ratios (HDR) classes (a measure of the relative degree of taper of tree stems). Figure 4 suggests a general trend that tree classes with lower HDR (the most tapered or conical tree stems with HDR < 55) have the lowest wind mortality rates, and wind mortality rates tend to increase with increasing HDR. However there are few apparent differences in windthrow rates for intermediate HDR’s between 55 and 85, suggesting that other environmental or site-specific factors may also play a strong role in influencing wind damage rates. Similar to the tests based on diameter class, Chi-squared tests of the distribution of tree windthrow and wind mortality mortality rates by HDR over the whole monitoring period indicate that there is no significant difference between the observed distribution of wind damage by HDR class, and the null distribution (equal probability by dbh class) for all 3 study areas, and for pooled data from all sites (p=0.05).

Rates of standing mortality of Douglas-fir leaf-trees were also examined as a function of tree diameter class (Figure 5). There appears to be a generally increasing trend towards higher standing mortality of leaf-trees with increasing diameter, suggesting that larger-diameter trees may be stressed by retention in harvested cutblocks, to a greater degree than smaller trees. Chi-squared tests of the distribution of standing mortality by diameter class indicate that there is a significant difference (p<0.01) between the observed distribution of and the null distribution (equal probability by dbh class) for two of the three study areas, and for pooled data from all three sites (p=0.0025). This suggests that larger leaf-trees are significantly more susceptible to standing mortality processes, including water stress (Rogers, 2003).

Surviving Douglas-fir leaf-trees showed strong diameter growth typically ranging from 1 to 14 cm total diameter increase during the monitoring period up to 2007 (Figure 6). Post-harvest leave-tree basal area increment growth of Douglas-fir leaf-trees is positively correlated with initial tree basal area ($r^2 = 0.3286$; Figure 7). This relationship supports general field observations
by the authors that the cohort of Douglas-fir leave-trees that survive the initial physiological and
wind stresses associated with timber harvesting treatments rapidly adapt to more open conditions
after timber harvesting. These leave-trees consistently and vigorously respond to more open
conditions and less surrounding tree competition, and that this basal area growth response is
positively related to initial tree size. In addition, general visual observations by the authors of the
tree crown and epicormic branch development on some trees support the assertion that the crown
development of leave-trees tend to respond well overall (with individual exceptions) to more
open conditions in the decade or more following the initial harvest treatment. Part of this diameter
growth is probably related to reallocation of primary wood production to the lower bole of the
tree stem in response to increased wind loading and mechanical stresses on potentially stable or
expanding tree crowns (Mitchell, 2000).

There is no apparent general trend in tree height over the whole monitoring period (Figure 8). In
general, the majority of surviving green leave-trees increased in height to some degree, but top
damage due to wind and in some cases, minor crown die-back, resulted in reductions in the height
of some surviving leave-trees.

An intriguing and unexpected finding of this study was consistent observations of evidence of
carpenter ant (Camponotus spp.) activity within the lower bole of what otherwise appear to be
live, undamaged, and thrifty Douglas-fir leave-trees. In many cases, evidence of this activity
(including direct observations of the ants and frass at the bottom of tree boles) is accompanied by
abundant evidence of exploratory and sometimes feeding excavations by woodpeckers, possibly
pileated woodpeckers (Dryocopus pileatus). Most of this activity is concentrated in the lowest 1
metre of the tree boles. Figure 9 provides a comparison of the percent frequency of observations
of carpenter ant boring frass on Douglas-fir leave-trees at each of the 3 study areas. Incidence is
at least 9 to 10% for all stands and > 50% at all Pinchi Ridge stands. This data indicates that
carpenter ants are actively colonizing live Douglas-fir leave-trees, resulting in additional habitat structures and feeding opportunities for wildlife in these leave-tree populations over time. These observations are consistent with an study by Bull et al (1992) who found that carpenter ants make up 68% of the arthropod diet of pileated woodpeckers, and are a primary food source for these woodpeckers during all seasons of the year, and.

Detailed analyses of Decay Class and Wildlife Tree Type (WTT) frequency in the Douglas-fir leave-tree populations (Figure 10) indicates that mature, live, intact and thrifty Douglas-fir leave-trees have a low incidence of apparent decay or related Wildlife Tree attributes in the first 10 to 13 years after harvest treatment, other than acting as hunting perch trees for raptors (WTT 10). Arthropod activity (WTT 9) in live undamaged Douglas-fir leave-trees appears to be confined primary to carpenter ants. Dead standing trees and windsnapped standing stems (whether dead or surviving with live residual branches) have a very high frequency of multiple Wildlife Tree types and abundant indicators of cavity nesting birds and related users.

It appears that, for Douglas-fir, low but consistent mortality and damage processes acting on the mature live component of the leave-tree population are, in fact, very important for creating the dead trees that produce much more habitat-rich Douglas-fir stand elements. Study results suggest that a robust population of thrifty Douglas-fir leave-trees in second-growth stands is important as an ongoing source of recruitment for dead trees and snags over the rotation.
Implications for Forest Management and Future Research

The results of this long-term study appear to allay or mitigate many of the initial concerns among forest managers about apparent rates of loss of Douglas-fir leave-trees after harvest on sub-boreal forest sites in the BC Central Interior. Overall mortality has been moderate overall, and more importantly, a large majority (> 70%) of residual leave-trees overall remain in good if not improved vigor and condition after 10 to 13 years following treatment. Initially-higher rates of wind damage and mortality in the first 3 years following harvest treatments has very much declined in latter years of monitoring (4 to ≥ 10 years post-harvest) across all three study areas.

The Douglas-fir leave-trees that died standing, or were wind-snapped, created vertical dead stems (or “snags”) with a much higher frequency of multiple wildlife habitat features than standing live, undamaged Douglas-fir alone. In addition, however, the study noted a high affinity of carpenter ants for colonizing the basal stem of live fir leave-trees, and corresponding frequent evidence of feeding or exploratory activity by woodpeckers apparently utilizing this food source.

Unexpected aspects of the study results are the dramatically different trends in wind damage rates by diameter class relative to time since harvest. Early wind mortality rates and patterns by diameter class in the first three years support the commonly-held assertion that smaller-diameter trees (which are generally more slender, with higher HDR’s) were more prone to wind mortality than large-diameter trees (which are generally more tapered, with lower HDR’s). However, this trend is apparently reversed in later post-harvest periods, 4 to 13 years post-harvest.

Such results suggest that simple indicators of wind mortality risk such as tree diameter and height:diameter ratio are useful for shorter-term estimation of such risk, but may not necessarily be effective indicators of longer-term risks of wind damage. Also, the relative risk of windthrow...
and mortality of different leave-tree cohorts will actually change substantially over time. Therefore, projections of future leave-tree populations and size class structure must go beyond simple linear extrapolation of early wind damage and tree mortality rates. Instead, such projections need to factor in observed or expected changes in mortality rates over as leave-trees acclimatize to new post-harvest conditions, and are differentially affected other biotic and abiotic factors within the leave-tree population over time.

Acknowledgements

This project was funded by British Columbia research funding sources, including the Forest Science Program (Forest Investment Account). Early study area establishment in the 1990’s was funded by Forest Renewal BC. The authors gratefully acknowledge the assistance of research assistants Renata Woodward and Andrea Erwin of the Aleza Lake Research Forest, who participated in the 2007 field data collection. The John Prince Research Forest provided accommodation during field work at the Pinchi Ridge sites. Judy Carlson provided assistance in quality control, data verification, and the initial summary of results. Finally, we thank Andrea Eastham RPBio who provided many helpful comments on the manuscript, and advice and support regarding statistical analyses and interpretations.
Literature Cited


University of Northern British Columbia. Prince George, BC. 92 pp.


<table>
<thead>
<tr>
<th>Study Area</th>
<th>Stand Identifier</th>
<th>Latitude</th>
<th>Longitude</th>
<th>BEC Subzone</th>
<th>Elevation (metres a.s.l)</th>
<th>Slope (%)</th>
<th>Aspect</th>
<th>Date of Harvest Treatment</th>
<th>Leave-tree Density (mean sph)</th>
<th>Leave-tree Monitoring Start Date</th>
<th>Sample size of Douglas-fir leave-trees (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinchi Ridge</td>
<td>PI42</td>
<td>54°40'16&quot;</td>
<td>124°31'49&quot;</td>
<td>SBSmk1/dw3</td>
<td>900-1000</td>
<td>20-60%</td>
<td>SW</td>
<td>Winter 1993</td>
<td>3 – 34</td>
<td>Sept. 1995</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>PI47</td>
<td>54°39'09&quot;</td>
<td>124°30'14&quot;</td>
<td>SBSmk1/dw3</td>
<td>900-1000</td>
<td>20-45%</td>
<td>SW</td>
<td>Winter 1995</td>
<td>22 – 40</td>
<td>Sept. 1995</td>
<td>84</td>
</tr>
<tr>
<td>Tako Creek</td>
<td>TK</td>
<td>53°18'59&quot;</td>
<td>123°05'39&quot;</td>
<td>SBSdw2</td>
<td>780-790</td>
<td>2-5%</td>
<td>Neutral</td>
<td>Winter 1997</td>
<td>35 – 71</td>
<td>Aug. 1998</td>
<td>153</td>
</tr>
</tbody>
</table>

**Total sample size** | 793 trees
Table 2: Standard Coding and Description and Coding of Leave-tree Status (8 classes)

<table>
<thead>
<tr>
<th>Description of Tree Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live-tree Intact</td>
<td>Live tree, standing, no stem breakage.</td>
</tr>
<tr>
<td>Live-tree with Dead top</td>
<td>Live tree, unbroken stem, but with dead top &gt; 1 m in length</td>
</tr>
<tr>
<td>Live-tree Standing Broken</td>
<td>Broken stem &gt; 1.5 m height, surviving green residual crown</td>
</tr>
<tr>
<td>Dead-tree Intact (Standing)</td>
<td>Dead tree, standing, no stem breakage.</td>
</tr>
<tr>
<td>Dead-tree Standing Broken</td>
<td>&gt; 1.5 m height, no surviving residual crown</td>
</tr>
<tr>
<td>Uprooted</td>
<td>Uprooted at roots (root-wad tipped up out of ground. Becomes horizontal woody structure (CWD). No longer part of standing tree leave-tree population after uprooting occurs.</td>
</tr>
<tr>
<td>Snapped at Base</td>
<td>Tree stem snapped or broken off at “base” of tree (&lt; 1.5 metres above point of germination. Becomes horizontal woody structure (CWD). No longer part of standing tree leave-tree population after mortality occurs.</td>
</tr>
<tr>
<td>Salvaged or Cut Down</td>
<td>Tree stem cut by chainsaw at normal stump height. Stem may or may not be salvaged or removed for wood utilization. Tree is no longer part of standing tree leave-tree population after salvage or cutting.</td>
</tr>
</tbody>
</table>
Table 3: Description and Coding of Time Period categories since disturbance for 3 study areas (March 2008)

<table>
<thead>
<tr>
<th>Time Period since Disturbance (years since disturbance)</th>
<th>Applicable monitoring years (for Pinchi Sites)</th>
<th>Applicable monitoring years (for Baldy Hughes, Tako sites)</th>
</tr>
</thead>
</table>
Table 4. Types of Wildlife Trees required by wildlife of north-central British Columbia (Keisker 2000)

<table>
<thead>
<tr>
<th>Main function</th>
<th>Type</th>
<th>Main users</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reproduction/resting:</strong> Substrates for cavity excavation</td>
<td>WT-1</td>
<td>Hard outer wood surrounding decay-softened inner wood</td>
</tr>
<tr>
<td></td>
<td>WT-2</td>
<td>Outer and inner wood softened by decay</td>
</tr>
<tr>
<td>Existing cavities</td>
<td>WT-3</td>
<td>Small, excavated or natural cavities</td>
</tr>
<tr>
<td></td>
<td>WT-4</td>
<td>Large, excavated or natural cavities</td>
</tr>
<tr>
<td></td>
<td>WT-5</td>
<td>Very large natural cavities or hollow trees</td>
</tr>
<tr>
<td></td>
<td>WT-6</td>
<td>Cracks, loose bark, or deeply furrowed bark</td>
</tr>
<tr>
<td>Large open-nest supports and other non-cavity sites</td>
<td>WT-7</td>
<td>Witches’ brooms</td>
</tr>
<tr>
<td></td>
<td>WT-8</td>
<td>Large branches, multiple leaders, or large-diameter broken tops</td>
</tr>
<tr>
<td><strong>Foraging:</strong> Feeding substrates</td>
<td>WT-9</td>
<td>Arthropods in wood or under bark</td>
</tr>
<tr>
<td>Hunting perches</td>
<td>WT-10</td>
<td>Open-structured trees in or adjacent to open areas</td>
</tr>
</tbody>
</table>
Table 5: Numbers and condition of Douglas-fir leave-trees in 7 stands across 3 study areas, following Year 3 of post-harvest monitoring.

<table>
<thead>
<tr>
<th></th>
<th>Baldy Hughes</th>
<th>Pinchi Ridge</th>
<th>Tako</th>
<th>All Sites Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BH371</td>
<td>BH065</td>
<td>BH066</td>
<td>Total BH</td>
</tr>
<tr>
<td>Live Tree Intact</td>
<td>98</td>
<td>103</td>
<td>80</td>
<td>281</td>
</tr>
<tr>
<td>Live Tree Dead Top</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Live Standing Broken Stem</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Dead Standing Intact Stem</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Dead Standing Broken Stem</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Uprooted (root tip)</td>
<td>46</td>
<td>5</td>
<td>8</td>
<td>59</td>
</tr>
<tr>
<td>Stem snapped at base</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>145</td>
<td>113</td>
<td>92</td>
<td>350</td>
</tr>
</tbody>
</table>
Table 6: Numbers and condition of Douglas-fir leave-trees in 7 stands across 3 study areas, by Fall 2007, 10 to 13 Years following commencement of post-harvest monitoring.

<table>
<thead>
<tr>
<th></th>
<th>Baldy Hughes</th>
<th>Pinchi Ridge</th>
<th>Tako</th>
<th>All Sites Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BH371</td>
<td>BH065</td>
<td>BH066</td>
<td>Total BH</td>
</tr>
<tr>
<td>Live Tree Intact</td>
<td>83</td>
<td>72</td>
<td>75</td>
<td>230</td>
</tr>
<tr>
<td>Live Tree Dead Top</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Live Standing Broken Stem</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Dead Standing Intact Stem</td>
<td>2</td>
<td>6</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Dead Standing Broken Stem</td>
<td>7</td>
<td>4</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Uprooted (root tip) Stem</td>
<td>52</td>
<td>23</td>
<td>13</td>
<td>88</td>
</tr>
<tr>
<td>Stem snapped at base</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>146</td>
<td>111</td>
<td>91</td>
<td>348</td>
</tr>
</tbody>
</table>
Figure 1: Percent Douglas-fir leave trees by condition, all study areas, > 10 years after harvest treatment.
Figure 2: Comparison of periodic totals of wind-induced mortality of Douglas-fir leave-trees (a) zero to 3 years and (b) 4 to 10 or 13 years following retention in harvested areas, as a function of initial tree diameter class. Wind-induced mortality includes both uprooting (windthrow) and stem breakage (wind snap).
Figure 3: Comparison of mean annual rates (% per year) of wind-induced mortality of Douglas-fir leave-trees (a) zero to 3 years and (b) 4 to 10 years following retention in harvested areas, as a function of initial diameter class. Wind-induced mortality includes both uprooting (windthrow) and stem breakage (wind snap).
Figure 4: Cumulative rates of wind-induced mortality of Douglas-fir leave-trees 10 to 13 years following retention in harvested areas, as a function of initial tree Height-to-Diameter Ratio (HDR). Wind-induced mortality includes both uprooting (windthrow) and stem breakage (wind snap).
Figure 5: Cumulative rates of standing mortality of Douglas-fir leave-trees (Dead Standing Intact) as a function of initial diameter class, 10 to 13 years following retention in harvested areas.
Figure 6: Scatter-plot of post-release diameter growth (at breast height) of sampled Douglas-fir leave-trees, relative to initial diameter, 10 to 13 years following release. Data pooled for all study areas.
Figure 7: Relationship of individual Douglas-fir leave-tree basal area growth (10-13 years after harvest release, up to 2007) to initial leave-tree basal area. Data pooled for all samples.
Figure 8: Relationship of individual Douglas-fir leave-tree height changes (10-13 years after harvest release, up to 2007) to initial leave-tree height. Data pooled for all samples. Negative values indicate reductions in tree height due to top damage.
Figure 9: Percent frequency of observations of carpenter ant boring frass on the bark or at the base of Douglas-fir leave-trees within the study areas.
Figure 10: Percent frequency of observations of single and multiple Wildlife Tree Types on live Douglas-fir leave-trees (top pie chart) and dead standing Douglas-fir leave-trees (bottom pie chart) within the study areas.