FINAL REPORT

Variable Retention Windthrow Monitoring Project

2001 to 2009

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Executive Summary

The Variable Retention Windthrow Monitoring project was carried out over an eight-year period, the first two years as a pilot study in what are now the Port Alberni, Queen Charlotte, Port McNeill and Mid Island Forest Operations of Western Forest Products (WFP, formerly Weyerhaeuser BC Coastal Timberlands). We chose a random selection of operational cutblocks in several operations each year during the next six years, including Stillwater and South Island (now Island Timberlands). After the merger with WFP, monitoring was expanded in the final two years to four operations on north-western Vancouver Island: Holberg, Jeune Landing, Gold River and Nootka Sound. We also included nine Variable Retention Adaptive Management (VRAM) experimental areas in the monitoring schedule. VRAM sites compare different approaches to stand-level retention, including group and dispersed retention levels, group sizes, riparian retention and group selection.

The distribution of monitoring sites on representative sites across Vancouver Island (VI), the southern BC mainland coast and Haida Gwaii (Queen Charlotte Islands) facilitates evaluation of coast-wide variation in windthrow that is associated with variable retention (VR) harvesting practices, especially the retention silvicultural system. The wide geographic extent, however, complicates data analysis due to the high spatial variability in terrain conditions and wind regimes among the various study areas.

The overall project objectives were:

- Document the amount of wind damage associated with VR.
- Document the spatial distribution or patterns of wind damage associated with VR.
- Document regional differences in the extent of wind damage associated with VR.
- Identify the qualitative and quantitative factors associated with VR wind damage including both environmental factors and treatment effects.
- Identify specific management options to control wind damage associated with VR.
- Develop field indices and decision-making tools to enhance windthrow hazard assessments.
- Communicate the results to operations staff.

The project database contains 4648 plots within 172 harvested cutblocks. Plots represent nearly 366 kilometres of external cutblock boundaries, 26 kilometres of large patch edges, 197 hectares of small retention patches and 50 kilometres of riparian and other strip edges.

The study showed definite regional differences in wind damage[1] for cutblocks that have experienced at least two winter wind seasons. The average percentage of wind damage along external cutblock edges varied from an average of 11% on southeast Vancouver Island (South Island or Island Timberlands) to 25% on northwest VI near Quatsino Sound

[1] Total wind damage % = % windthrow (trees uprooted) + % stem-break + % leaning

(Jeune Landing FO), with an overall average of 16±0.2%[2] across all areas. There were similar regional differences in wind damage for retained patches. The average wind damage along the edges of larger patches was 16% in Stillwater and South Island and 45% in the Queen Charlotte FO with an overall average of 24±0.6%. The average wind damage in small patches (i.e., ≤ 1 hectare in area) ranged from 20% in South Island and 21% in Gold River to 45% in Queen Charlotte and Mid Island FOs with an overall average of 39±0.5%. For the edges of strips of retained timber, the wind damage amounts ranged from 15% on southeastern VI (South Island) to 38% on northern VI (Jeune Landing and Port McNeill), with an overall average of 31±0.6%.

Analyses of the data from the various strata (cutblock edges, patches, strips) suggest the following general relationships:

- Windward edges along external cutblock boundaries, large patches and retained strips are more vulnerable to wind damage than other boundary exposures.
- Wind damage tends to increase with increasing fetch distance to the edges of block boundaries, large patches, small patches and retained strips.
- There is a strong relationship between slope position and the amount of wind damage. Topographically exposed locations such as ridge crests and upper slopes tend to experience more wind damage. This trend matches a general, but weak trend of increasing wind damage with increasing elevation above sea level. There is some indication that steeper slopes may be more vulnerable to wind damage. Slope angle, however, tends to increase with increasing elevation so the relationship between wind damage and slope angle may be correlated with exposure.
- For external edges, large patch edges, smaller patches and retained strips, the amount of wind damage increases with increasing stand height, but also with increasing rooting depth.
- In general, external cutblock edges and the edges of retained strips are more vulnerable to wind damage when they occur along the edges of gullies or stream escarpments than in other topographic locations. Providing setbacks from the edges of these topographic features tends to reduce the amount of wind damage and/or reduces the likelihood that wind damage will penetrate into these features.
- Stands that appear to have established after previous windthrow events appear to be more vulnerable to wind damage than stands originating in other ways (e.g., wildfire, harvesting or without recent stand-replacing disturbance, as is the case for old growth stands). There is some indication in some areas that second growth stands may be more vulnerable to wind damage than old growth stands. In contrast to the above, stands categorized as multi-storied appear to be more vulnerable to wind damage than uniform, single-storied stands.
- Windthrow penetration tends to increase as percent wind damage increases. Penetration distances increase with increasing exposure to wind, being least on lee boundaries and greatest along windward boundaries. A similar relationship occurs with cumulative fetch distance, with penetration increasing as fetch

[2] Standard error of the mean.

distance increases. Windthrow penetration increases with increasing stand height and increasing rooting depth and windthrow penetration distances are greatest along the edges of gullies and steep stream escarpments.

- Among the major coastal coniferous tree species, western hemlock and amabilis fir are the most vulnerable to wind damage. Western redcedar and yellow-cedar are generally less susceptible to damage. Douglas-fir appears to be the most windfirm coastal conifer (with the possible exceptions of lodgepole pine and white pine). Red alder and bigleaf maple are also quite vulnerable to damage on external cutblock edges. There are greater differences among species and greater variation in wind damage for more exposed conditions (e.g. small patches, strips) than for large patches and external cutblock edges.

Management implications from our findings include:

- In situations where the hazard of wind damage is high (i.e., considering geography, site and stand conditions) use large patches and wide retention strips rather than small patches, narrow strips or dispersed retention. Where the hazard of wind damage is very high, clearcut with reserves may be more appropriate than the retention system for maintaining stand-level retention.
- For gully edges and stream escarpments, set back boundaries 10 to 15 metres from the windward edges to reduce the potential for windthrow penetration into gullies and across streams. The data suggest that setbacks of even a few metres will experience lower wind damage rates than boundaries located directly along the edges of gullies and stream escarpments.
- When feasible, top and prune trees along edges where damage is likely to compromise management objectives. Although monitoring findings were inconclusive due to low sample size and high variability, data from other studies suggest that windthrow can be reduced along windward and windward diagonal boundaries with a treatment depth of at least 15 to 20 metres.
- Where possible avoid locating windward boundaries of VR patches or retention strips in tall timber.

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1.0 Introduction

Western Forest Products (WFP) has implemented the Variable Retention (VR) approach to timber harvesting and silvicultural systems on public lands managed by the company.

Many harvest areas use the retention silvicultural system, leaving trees as patches, strips, groups, and small clusters of a few trees or dispersed individual trees. Modified shelterwood and selection systems with long-term reserves are also used.

Variable retention results in an increase in the total length of forest edge associated with forest openings, as well as greater numbers of dispersed trees or trees in retained patches or strips of timber. Due to these changes, there is often an increase in the frequency and extent of windthrow associated with forest openings.

It is important to document the extent of wind damage associated with VR and to determine the best strategies to minimize or manage for wind damage. In many cases, the existing state of knowledge will suffice to develop management strategies; but, in some cases, additional information is required. In order to document the extent of wind damage and to improve windthrow management, it is necessary to monitor the character and location of wind damage over time and to document the management and environmental factors associated with wind damage. This monitoring project is part of Western Forest Products "Western Forest Strategy" which includes an adaptive management program for continual improvement of forest practices. The study described in this report began in 2001. Data collection for the project finished in the fall of 2008 and final data analysis occurred in early 2009.

2.0 Objectives

The project objectives were to:

- Document the amount of wind damage associated with VR.
- Document the spatial distribution or patterns of wind damage associated with VR.
- Document regional differences in the extent of wind damage associated with VR.
- Identify the qualitative and quantitative factors associated with VR wind damage including both environmental factors and treatment effects.
- Identify specific management options to control wind damage associated with VR.
- Develop field indices and decision-making tools to enhance wind damage hazard assessments.
- Communicate the results to operations staff.

3.0 Methods

3.1 Project Phases

The variable retention wind damage monitoring study developed in three phases: preliminary design, a pilot study, and full implementation.

3.1.1 Phase 1 – Preliminary design

This phase of the project focused on development of a field methodology for assessment of post-harvest wind damage associated with VR. The work included limited field assessment of VR areas and associated wind damage. The purpose of this phase was to develop appropriate sampling techniques that account for the variability and character of residual stands and stand edges created by VR. We also developed data fields, codes and a database structure compatible with field data loggers.

3.1.2 Phase 2 – Pilot study

The second phase of the project involved organization and implementation of a pilot field and air photo-monitoring program to test the suitability of the preliminary sampling design, data collection and measurement protocols. The focus of the two-year pilot study was on three areas of wind damage concern: southwest Vancouver Island, the north and northeast coast of Vancouver Island, and the Queen Charlotte Islands. This phase included the development and modification of a database for storing and manipulating windthrow data. This database uses a MS Access platform that is network ready and is capable of importing digital information from field data loggers.

We analyzed the pilot data to determine if the information collected was suitable and sufficient to fulfil the objectives of the monitoring program. When needed, we re-designed and tested field monitoring methods, data compilation and analysis procedures. This phase also included an assessment of the utility of conventional air photos, large-scale air photos and ortho-photo images for windthrow monitoring purposes.

3.1.3 Phase 3 – Implementation

This phase involved implementation of the full-scale monitoring program. We chose a random selection of operational cutblocks in several operations each year over a six-year period, including the former South Island operation of Weyerhaeuser (now Island Timberlands) on southeast Vancouver Island (Table 3.1). After the merger with WFP, monitoring was expanded in the final two years to four operations on northwestern Vancouver Island: Holberg, Jeune Landing, Gold River and Nootka Sound. We also included nine Variable Retention Adaptive Management (VRAM) experimental areas in the monitoring schedule. VRAM sites compare different approaches to stand-level retention, including group and dispersed retention levels, group sizes, riparian retention and group selection. The VRAM sites are the foundation of the "active" monitoring portion of the company's adaptive management program.

We completed data analysis and prepared progress reports annually. We also conducted extension workshops to communicate interim results to WFP operational personnel and the larger forestry community.

Table 1. Windthrow monitoring by Forest Operation over the 8-year study.

Forest Operation:	2001	2002	2003	2004	2005	2006	2007	2008
Port Alberni Forest Operation	X	X	X			X	X	
Queen Charlotte Forest Operation	X		X				X	
Port McNeill Forest Operation		X		X	X		X	
Mid-Island Forest Operation		X	X	X	X	X	X	X
Island Timberlands Forestlands			X					
Stillwater Forest Operation			X	X	X	X	X	X
Holberg Forest Operation							X	
Jeune Landing Forest Operation							X	
Gold River Forest Operation								X
Nootka Forest Operation								X

3.2 Sampling Design

3.2.1 Sample segment delineation and plot selection

All external cutblock boundaries, retention patches, retained strips (e.g., riparian reserve zones and forested riparian management zones[3]), and other types of reserves and any dispersed treatments were sampled if they had experienced at least two fall-winter-spring wind seasons[4] (preferably three wind seasons). In areas such as the southeast coast of Vancouver Island with less frequent strong winds, a longer waiting period may have been preferable.

3.2.2 Group retention and cutblock edges

It was necessary to partition or stratify all retention patches, groups and clusters (patches ≤ 1.0 hectare), strips any specialized reserves and all external falling boundaries into segments or sample plots in a systematic fashion so that the plot data was suitable for statistical analysis. Sampling occurred both in patches of timber and along edges of timber (e.g. boundaries along external cutblock edges or retained strips), consequently, the sampling design dealt with both spatial and linear features. There were two obvious choices available for the delineation of sample plots: equal area and/or equal length plots, or plots of unequal area and/or unequal length. The sampling design adopted used plots of unequal-size, and then area-based or length-based weighting during data analysis to accommodate differences in plot size. Forest stands and coastal terrain do not

[3] The term “forested riparian management zone” is used to distinguish between “forested” riparian management zones where trees are retained and riparian management zones where all or almost all trees are cut. Riparian areas where small conifers (i.e. generally less than 2-3 metres tall) were retained were not sampled.
[4] For this study, we defined one wind season as one fall-winter-spring season—typically the period experiencing the most damaging winds for coastal BC (i.e., October to April).

conveniently split apart into equal-sized pieces. We found it logistically easier to use unequal rather than equal area plots for rapid, low-resolution field surveys.

The sampling design stratified all cutblock edges, retention patches and retained strips into distinct and relatively homogeneous stand, geomorphic and/or geometric "entities" (areas or lengths). Smaller patches of trees (i.e., those less than 50 metres across) were difficult to split into separate plots even if the stands and terrain within these areas were not homogeneous; therefore, we treated them as single samples (plots). When a retention patch had a diameter greater than approximately 100 metres or an area greater than one hectare, we sampled the edges of the patch in the same way that an external boundary was sampled. This stratification approach created plots of unequal length or unequal area. We estimated the amount (percent) of windthrow for a nominal depth of 25 metres in from the edge of external boundaries, the edges of larger patches, and the edges of retained strips. In the case of retained strips that were less than 25 metres wide, we estimated wind damage for the full width of the strip. Figure A1, Appendix A illustrates the variety of strata that were often present in a single cutblock.

Stratification or separation used the following field criteria:

- Significant changes in the orientation (aspect) of a falling boundary (e.g., a 30° change in boundary aspect).
- Visible and significant changes in slope angle, terrain (surficial materials), slope morphology, soils, or soil drainage along a falling boundary or along a strip.
- Changes in forest (stand) type (species composition or height) along a boundary or along a strip.
- Type of edge treatment: untreated, feathered, thinned, topped and pruned, etc.
- The type of forested riparian area. Riparian areas were classified as one or two-sided leave areas (i.e., external stand edges versus strips of timber bounded by "clearcut" areas on either side).
- Change in the character of stream channels contained within riparian areas.
- Two-sided riparian strips were sampled on both sides; each side of the strip was treated as a separate sample. Strip shelterwood treatments were sampled in the same way.
- Change in the amount or character of wind damage was not a criterion for sample selection.
- The sample segments (plots) were generally a minimum of 50 metres long; however, shorter segments that were very distinctive were occasionally sampled as separate plots. Short segments similar to adjacent areas were incorporated in the most similar adjacent plot.

All external edges, large patch edges, strips, and small patches (clusters and groups) within a cutblock were sampled.

The stratified, unequal length or unequal area plots improved sampling efficiency and ensured sampling of visible environmental differences that may exert a significant effect on wind damage response. Sample segment length does not affect the two important target variables (percent wind damage and distance of penetration of windthrow); consequently, the differences in the lengths of the edge plots should not significantly affect the outcome of the study. Some terrain/soil types are highly variable over relatively short distances so sampling the full length of such "complex terrain strata" should generate a more representative estimate of the amount wind damage occurring within these heterogeneous terrain/soil types. For the objective of estimating cumulative wind damage along falling boundaries, sampling segments of unequal length work as well as plots of equal length; however, the same may not hold true for patches. As patch/group size increases, the amount of wind damage in the interior of the patch/group may change (i.e., it is likely to be less). If the interior of a patch had less wind damage than the sampled edges, then our sampling over-estimated the amount of damage for large patches; however, by measuring penetration distance we were able to account for such differences.

3.2.3 Dispersed retention

VR treatments that involve the retention of individual, dispersed trees are sampled by counting all standing and wind damaged trees. The total number of dispersed, individual trees within a cutblock is often in the range of 30 to 100 trees so it is feasible to count all the trees. Each cutblock with dispersed retention is stratified into distinct areas (strata) based on terrain, soils, slope aspect and slope position. These "terrain strata" are outlined on the cutblock maps in the same way that soils or terrain polygons are mapped. Dispersed stand densities (individual trees/hectare) are calculated on an area basis for each "plot polygon" or terrain strata within a block.

Only a few areas of dispersed retention occur within the study areas, so analysis of the effect of wind on areas of dispersed retention is relatively limited.

Similarly, only a few harvest areas that involve the retention of more closely spaced individuals (e.g., a conventional shelterwood cut) occur within the study areas. These areas were defined as dispersed retention for the purpose of this study. The site characteristics (flat ground and minimal under story vegetation) facilitated a count of all trees within the plot area.

3.3 Data Collection

3.3.1 Field data collection

Much of the data collected in the field consisted of visual classification of such environmental attributes as soil type, slope morphology, surficial materials, edge geometry and stand structure. In order to streamline data collection, there was limited collection of data on the actual number of trees damaged by wind. Wind damage estimates (% windthrow, % stem-break and % of trees leaning) relied on visual assessment of the amount of wind damage present using nominal classes of: 0, 1, 2, 5%

and then increasing increments of 5% or 10% for the first 25 metres into a stand edge or within a small patch or narrow strip. For small patches (groups or clusters of trees), both standing and wind-damaged trees were counted.

Visual estimates of the depth of penetration of windthrow into the stand edge, and the approximate primary and secondary orientations of windthrown trees were made in each plot. The orientations of each individual windthrown tree were not measured. A wind exposure index or ranking matrix (Figure 2, Appendix A) provided a qualitative assessment of the vulnerability of boundaries that are apparently subject to winds from more than one direction.

Species composition percentages were based on the merchantable stems in a stand and were estimated visually. Where possible, species composition estimates were compared to forest cover information included on the logging plan map for the block.

The data set includes records of any stand edge treatments that occurred along or within each sample segment or sample area. There are only a limited number of samples with treated edges within the data set; consequently, no substantive analysis was attempted. Rather we simply documented this information as it represents additional variation within the data set that may confound other relationships.

Appendix V provides simple descriptions and explanations of the various categorical and scale variables that comprise the data set.

3.3.2 Office methods

A number of procedures performed for each site were common to both field assessment and air photo and map interpretation. The office tasks take between 0.25 and 0.5 person-days per block including mapping work and data entry, depending on the number of plots in a block.

First, we measured the length of the plots for external block edges, or plot areas when plots consisted of entire retention patches. We then created a windthrow orientation histogram using the windthrow orientations (azimuth bearing) for each plot in the block. The two most numerous (dominant) windthrow orientations within the block were determined from the histogram. We assumed that the reverse bearings (orientation direction in degrees minus 180º) represented the likely primary and secondary strong wind directions for each block. A protractor, ruler and transparency with boundary exposure types outlined in degrees (Figure 3, Appendix A) were used to determine the type of boundary exposure based on the two dominant wind directions derived from the windthrow orientation data. The centre of the transparency was placed in the middle of the boundary edge orientated so that the north arrow was perpendicular to the boundary edge. A protractor was then placed on top and orientated parallel to the north lines of the map, with the centre of the protractor over the centre of the transparency. The boundary exposure type was defined by the quadrant of the transparency that the assumed wind direction goes through, after it passes the boundary edge.

For each plot, we classified and tabulated fetch type (Section 7.1 and Appendix E). Fetch distance was measured for plots that had windward or windward diagonal boundary exposures. Fetch type and distance were determined using the primary and secondary wind directions for each block. Fetch distance was arbitrarily set at zero for plots with lee, lee diagonal and parallel boundary exposures.

Finally, we tabulated the stand height upwind of the plot using the stand heights recorded for the plot upwind of the exposed boundary for each fetch direction.

4.0 Study Areas

Plots for the monitoring study occur in seven widely separated geographic areas. The WFP Forest Operation locations are shown in Figure 1:

- Haida Gwaii / Queen Charlotte Islands, Queen Charlotte Forest Operation (QC).
- Areas of the Port Alberni Forest Operation that lie southeast and northwest of Alberni Inlet and Barkley Sound on southwest Vancouver Island. A limited number of the sample sites established in this area occur on Island Timberlands Limited Partnership (Island Timberlands) forestlands and some sample areas are within forestlands now managed by British Columbia Timber Sales.

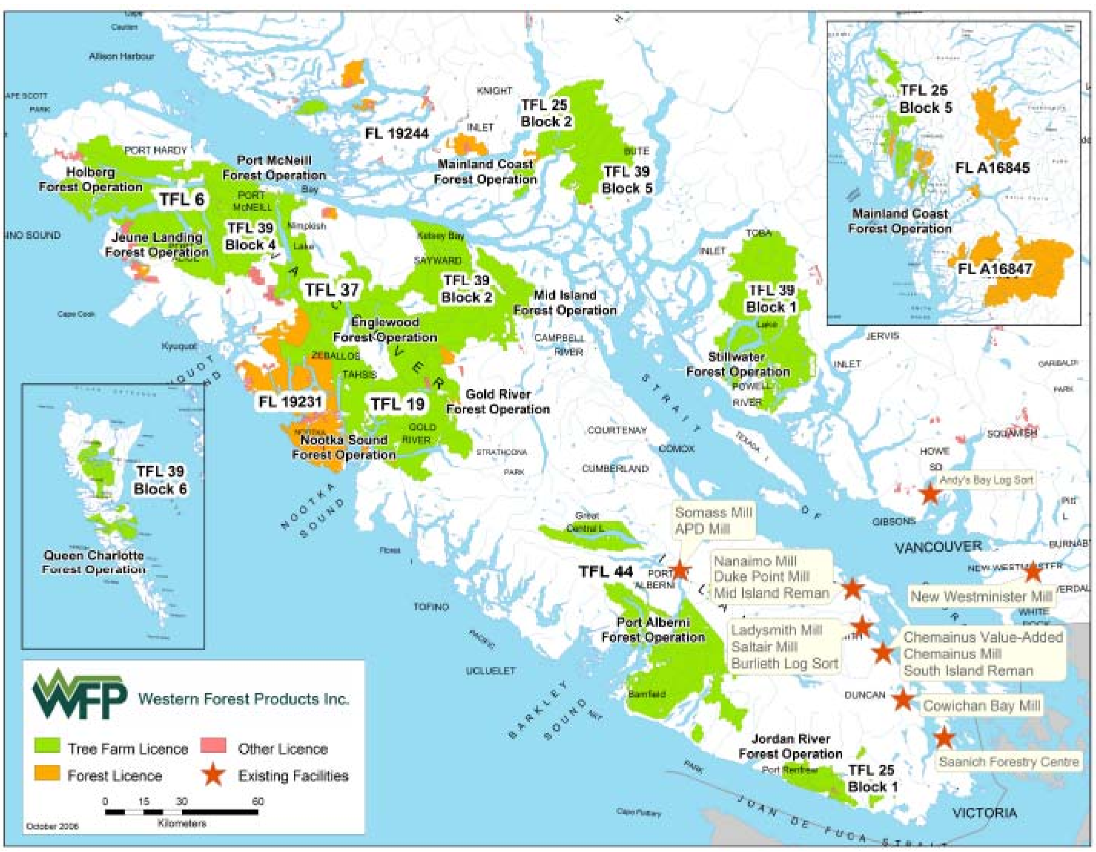

Figure 1. Location of Western Forest Products (WFP) Forest Operations.

- The Port McNeill, Holberg and Jeune Landing Forest Operations on northern and northwest Vancouver Island.

- The Mid-Island Forest Operation on the central northeast coast of Vancouver Island. This area includes sites originally established in the Tsitika River on lands now managed by British Columbia Timber Sales.

- The Gold River and Nootka Sound Forest Operations on the central west coast of Vancouver Island.

- Island Timberlands private lands on the southeast coast of Vancouver Island. These areas are referred to as South Island in this report.

- Stillwater Forest Operation (near Powell River) in the southwest portion of the Coast Mountains.

Some, but not all of these areas are dissimilar from both an ecological and a geomorphic point of view. See Tables B1 to B4 in Appendix B for a summary of some of these characteristics.

The sampling areas within the Port Alberni Forest Operation southeast of Alberni Inlet range from the Very Dry Maritime Subzone (CWHxm) to the Southern Very Wet Hypermaritime Variant of the Coastal Western Hemlock Zone (CWHvh1 - Table 4, Appendix A). The Port Alberni sampling areas occur within the Vancouver Island Ranges in the west central part of Vancouver Island, along the coastal plain on the southwest coast of Vancouver Island and on hillsides on the western flanks of the Vancouver Island Ranges. Elevations within the sampling areas range from 50 to 750 metres above sea level (asl).

The Mid-Island sample areas include the mid reaches of the Tsitika watershed on the central north coast of Vancouver Island. Additional sampling areas occur in the middle reaches of the Eve River and Salmon River and the upper reaches of the East Memekay River. Elevations within the sampling areas range from 20 to 750 metres asl, although as with most of the study areas the surrounding mountains extend higher. The Mid-Island sites range from the CWHxm to the Submontane Very Wet Maritime Variant (CWHvm1). Localized areas at Menzies Bay and within the Iron River operation of Island Timberlands south of Campbell River have also been included in the Mid-Island study area.

The Gold River and Nootka sample areas are located within the western and central portions of the Vancouver Island Ranges and include typical mountain and valley terrain as well as ridges and mountains separated by deep fiords. Elevations within these two study areas range from about 70 to 700 metres above sea level. The Gold River study areas include portions of the CWHvm1 and CWHvm2 (Montane Very Wet Maritime Variant) while the Nootka study areas include portions of the CWHvm1 and the CWHmm1 (Submontane Moist Maritime Variant).

The Port McNeill sample areas are located within the Nahwitti Lowland subdivision of the Hecate Depression on Northern Vancouver Island and the Vancouver Island Mountains. The Nahwitti Lowland encompasses the northern end of Vancouver Island north of a line drawn between Englewood and Quatsino Sound. It is an area of low, rounded hills and ridges within the Hecate Depression. Elevations within the Port McNeill study areas range from 25 to 1000 metres asl. Most of area lies within the CWHvm1 and CWHvh1. Western hemlock, amabilis fir and western red cedar dominate the forest cover within the area. There are large areas of second-growth plantations within the area as well as extensive areas of uniform 80 to 90-year-old stands that developed after severe wind events in the early part of the 20th century. Port McNeill has a somewhat wetter and cooler climate and generally stronger and more frequent winds than the Port Alberni and the Mid-Island study areas. More sampling occurred in the TFL39 portion of Port McNeill than the TFL6 portion.

The Holberg Forest Operation occurs within the Nahwitti Lowlands. Elevations range from 150 to 600 metres above sea level. This area includes portions of the CWHvm1, CWHvm2 and CWHvh1 variants. The Jeune Landing Forest Operation occurs within the Vancouver Island Mountains[5] and includes the CWHvm1, CWHvm2 and only minor amounts of CWHvh1.

The Queen Charlotte Islands study area is located within the Wet Hypermaritime Coastal Western Hemlock Subzone (CWHwh). This subzone has a significantly wetter and cooler climate and generally stronger winds than other coastal areas, with the exception of the NW coast of Vancouver Island. The Queen Charlotte Islands sample areas are located on low to moderately high rounded hills and ridges within the Skidegate Plateau and low-lying coastal plain areas within the Queen Charlotte Lowlands. Elevations within the sampling areas range from 20 to 350 metres asl.

The Stillwater sites are located primarily in the Southern Fiord Ranges (Pacific Ranges) of the Coast Mountains (Mathews 1986), and to a lesser extent on the lower hills and coastal lowlands that lie south of the mountains. Elevations within the sampling areas range from 90 to 700 metres asl. The Stillwater sampling area includes portions of the CWHxm, CWHdm (Dry Maritime subzone) and CWHvm2 biogeoclimatic variant.

The Island Timberlands sites are located along the northern flanks of the southern Vancouver Island Mountains and on localized coastal lowlands that lie northeast of the mountains. Elevations within the sampling areas range from 80 to 600 metres asl. The South Island operating area includes portions of the Coastal Douglas Fir Zone, Moist Maritime Subzone (CDFmm), the CWHxm subzone, and Coastal Western Hemlock, Montane Moist Maritime Variant (CWHmm2). This area has a generally drier climate than the other coastal areas included in the study.

The study database consists of 4648 plots. Of these, 232 are in Gold River, 165 in Nootka, 163 are in Holberg, 92 in Jeune Landing, 696 in Mid-Island, 603 in Port

[5] We follow the physiographic subdivisions of Holland (1964). The latest version of the Ecosection classification for BC (Demarchi 1995) includes the Jeune Landing area in the Nahwitti Lowlands but the terrain for our samples more closely resembles the VIM.

McNeill, 443 in the Queen Charlotte Islands, 698 in Stillwater, 1353 in Port Alberni and 203 on Island Timberlands forestlands.

The study database includes 172 harvested areas (cutblocks), representing 366 kilometres of external cutblock boundaries, 26 kilometres of large patch edges, 197 hectares of small retention patches and 50 kilometres of riparian and other strip edges (Appendix B, Tables B6a to B6d).

About 62.3% (Table B5b) of the sample plots were located along external cutblock edges and 5.1% along the edges of larger retention patches. Approximately 19.6% of the samples represent small clusters and groups of trees (small patches), and about 10.6% occur along strips of timber. Dispersed retention accounts for only 2.3% of the plots.

There were 2897 plots along external falling boundaries. The minimum plot length for external falling boundaries was 20 metres (Table B6a). The maximum length was 380 metres, and the average length was about 126 metres.

There were 238 plots along the edges of large, internal patches (Table B6b). These patches were generally one hectare or larger. The average length of patch edge sampled was 109 metres with a minimum length of 40 metres and a maximum length of 280 metres.

There were 914 sample plots representing retained groups and small clusters of trees. These plots generally ranged in size from 0.01 to <1.0 hectare and averaged 0.2 hectares (Table 6c).

There were 482 plots representing retained strips of timber, including the strata categories: bulges, peninsulas, ribbons, narrow strips and wide strips. These plots ranged from 5 metres to 120 metres in width and from 25 metres to 265 metres in length (Tables 6d and 6e). The mean width was 44 metres. Peninsulas and bulges form variable length and shape protrusions along external cutblock edges, which tend to behave more like retained strips (generally riparian areas or gullies) than external edges, but can have similar amounts of wind damage to patch edges. They were sampled as separate strata; but due to a relatively small sample size are included in the analysis of wind damage associated with other retained strips.

The majority of the sample blocks were logged two to five wind seasons prior to sampling; a small number of the samples were less than two years old. Previous analyses (included in our progress reports from 2002 to 2006) indicated that areas experiencing less than 1.5 wind seasons may have slightly lower wind damage values than older areas. This finding is similar to trends in wind damage over time found in areas of dispersed retention, at the Roberts Creek Study Forest on the Sechelt Peninsula (B. D'Anjou, pers. comm. 2003). Consequently, the analysis in the following sections uses only those plots that experienced at least two wind seasons prior to sampling. At least one study on Vancouver Island has recorded significant windthrow up to 13 years after harvest (W. Beese, unpublished data, Montane Alternative Silviculture Systems study) so even applying a minimum two wind-season limit our analysis may still underestimate long-term trends in wind damage.

7.0 Data Analysis – Results and Discussion

Analysis of the project data included tabular and graphical analysis to identify trends. We applied non-parametric tests (Kruskal-Wallis for categorical data and Spearman for scale data) to determine the level of significance for differences among dependent and independent variables as the dependent variables (wind damage and windthrow penetration) were generally not normally distributed (Appendix C, Plots B1 and G1, Appendix D, Tables D1 to D11). Significant differences among categorical variables were also evaluated using ANOVA (Appendix D, Tables D1 to D6). To obtain valid means for percent wind damage, plots of unequal length and unequal area were weighted using length and area-based weighting factors. The nominal length used to develop the length-based weighting factor was 25 metres, and the nominal area to develop the area-based weighting factor was 0.1 hectare. As noted above the analysis was restricted to plots that experienced at least two fall-winter-spring wind seasons prior to sampling.

The analysis separated area data (groups, clusters and areas of dispersed retention) from the edge and strip data. External boundaries (edges) and large patch edges were also analysed separately. Because of relatively small sample sizes for some sampling strata, the analysis combined narrow and wide retained strips with ribbons, peninsulas and bulges as these strata have similar geometric characteristics even though the range in windthrow distributions for these strata can be large (Table B12).

Data from Island Timberlands private lands (South Island and local areas in Mid Island and Port Alberni) were collected independently at their cost. These areas were included in the following summaries, and the tables and graphs in the appendices, to provide a more comprehensive picture of VR-associated windthrow on the BC coast.

Most of the blocks in the project data set are variable retention blocks, a few cutblocks representing 393 of a total of 4648 plots or less than 10% of the samples are clearcuts. Most of the variable retention blocks contain groups and/or strips of trees and occasionally large patches of retained trees. A limited number contain dispersed individual trees in addition to or instead of patches, groups and strips (Table B15).

The tables in Appendix B summarize all the data collected up to September 2008 Plots in Appendix C and tables of significance in Appendix D provide supporting graphical and statistical documentation for the discussion that follows.

An extreme windstorm in December 2001 likely affected some Mid-Island blocks. This windstorm caused extensive damage in some forestlands on Vancouver Island north of Campbell River. Some of the values in the data set for the Mid-Island Forest Operation are a legacy of this storm; consequently, this data may overestimate longer-term endemic wind damage trends in this area.

7.1 Wind Damage Relationships - External Edges

The amount of windthrow along cutblock edges varied geographically, with Jeune Landing and the QCI having the highest values, and South Island, Stillwater and Port McNeill the lowest (Table B7, Figure B2). Wind damage varied along external edges among major physiographic divisions, but there was also significant variation within a single physiographic region, such as the broad Vancouver Island Mountains region (Table B13).

The average amount of wind damage along external edges was 16±0.2[6]% (Table B7). The mean wind damage values ranged from 11% in South Island to 25% in Jeune Landing.

The penetration of windthrow into a stand is the distance to the last upturned root mass in from the edge of the cutblock. The average windthrow penetration along external edges was 12±0.2 metres and ranged from a mean of 6 metres in South Island to 20 metres in Jeune Landing.

The partition of wind damage into its component parts (i.e., windthrow, stem-break and leaning trees) is tabulated in Table B7. Typically, windthrow dominates, but the ratio of windthrow to other forms of wind damage appeared to vary geographically and possibly with stand characteristics (e.g., windthrow along external edges may be more prevalent in windthrow origin stands than in old growth stands, Table B14).

The graphical and statistical analysis presented in Appendices C and D suggests the following relationships:

- The amount of wind damage correlates positively with the degree of exposure of block edges to storm winds. Edges that are directly exposed to the wind (windward and windward diagonal boundaries) tend to suffer considerably more wind damage (>20%) than lee and parallel boundaries (10 to 15%) (Figure B3).

- The trend for boundary exposure is similar to that for the wind exposure index, a simple ranking method that combines the exposure classes for the two dominant wind directions in an area (Figure B4)).

- Wind damage tends to increase with increasing fetch distance[7] across a cutblock (Figure B5). There is no clear trend suggesting that the presence of retention elements (groups, patches, strips, etc.) within a cutblock results in a significant reduction in the rate of wind damage along external boundaries compared to open, clearcut-like situations (Figure B6). That is, these features do not appear to shelter downwind stands from strong winds to any significant degree.

[6] Standard error of the mean.

[7] Parallel boundaries were arbitrarily assigned a zero fetch distance which is likely not entirely appropriate due to the fact that block boundaries are rarely exactly parallel to the assumed damaging wind direction and most boundaries are somewhat irregular.

- Topographic position influences the amount of wind damage. Lower slopes and mid slopes tend to have lower damage rates and upper slopes and ridge crests have the highest wind damage rates (Figure B8a). Moderate wind damage rates associated with valley floor locations may be due to a higher percentage of boundaries in second growth timber in these areas. Removal of second growth edges from the data set and re-analysis of the data resulted in slightly lower rates of wind damage on valley floor sites (Figure B8b). Second growth timber may be somewhat more vulnerable to wind damage than old growth timber in similar topographic locations (Figure B8c). A similar topographic trend occurs between elevation and wind damage. Damage rates tend to increase as elevation increases. Table D7 documents a significant and positive correlation between wind damage and block elevation.

- There is a strong increase in wind damage along external boundaries as stand height increases (Figure B9).

- There are significant differences in wind damage along external cutblock boundaries with changes in stand dominance by the major conifer species (Figure H1). Results suggest that cutblock edges dominated by Douglas-fir are the least susceptible to damage, and stands edges dominated by western hemlock and amabilis fir are the most susceptible, with a difference of about 8% to 10% total wind damage. Cutblock edges dominated by western redcedar and yellow-cedar had similar levels of damage to cutblock edges dominated by Douglas-fir.

- There are substantively higher wind damage rates when falling boundaries are located along gully edges and the upper edges of stream escarpments rather than at other locations. Boundaries that are set back from the edges of gullies or stream escarpments tend to have lower wind damage amounts (by about 10%) than those located along the edges of these features (Figure B13).

- There is some indication from an analysis of harvested areas within the Vancouver Island Ranges that external edges in clearcut blocks suffer slightly higher levels of wind damage (4%) than external edges in group retention blocks (Figure B15). This may be a function of the location of the clearcuts (i.e., possibly a higher proportion in more windy areas), which represent a smaller sample size than group retention blocks. This result also contrasts with the analysis of fetch character in Fig B6, which did not show a reduction in wind damage along edges of cutblocks with internal retention versus clearcuts. The fetch results, which included the entire dataset, may be confounded by the wide range in wind environments and fetch distances across the study area.

7.2 Wind Damage Relationships – Large Patch Edges

The average amount of wind damage along patch edges was 24±0.6% (Table B8 and Figure C1). The mean values ranged from 45% wind damage in QCI to 16% in Stillwater and South Island. Port McNeill was the only other operation with above-average damage levels (30%) for large patch edges.

The average penetration distance was 12±0.4 metres along large patch edges and ranges from a mean of 2 metres in South Island to 17 metres in QCI. South Island, QCI and Port McNeill appeared to suffer relatively high levels of stem-break (~9%) along large patch edges (Table B8).

The graphical and statistical analysis presented in Appendices C and D suggests the following relationships:

- The amount of wind damage along the edges of large patches increases with increasing exposure. Edges directly exposed to the wind (windward and windward diagonal boundaries) tend to suffer more wind damage than lee and parallel boundaries (Figure C1). Similarly, we see a general increase in wind damage with increases in the wind exposure index (Figure C3).

- There is a substantial reduction in wind damage when cumulative fetch distance is under 50 metres (i.e., from about 30% to 10%), but damage did not differ among fetch classes of 50 metres and above (Figure C4). The presence of retention elements does not appear to affect the amount of wind damage (Figure C5), but variations in fetch distances may confound these relationships. Large patch edges that are sheltered by standing timber (i.e., the lee edge of a large patch) may exhibit lower wind damage rates.

- Topographic location appears to exert some influence on the amount of wind damage along the edges of larger patches with areas higher in the landscape being more vulnerable that areas lower in the landscape. Valley flat locations are an exception to this trend. This may be a reflection of the fact that the valley flat sample population is composed entirely of second growth stands.

- There is a general increase in wind damage rates along large patch edges as stand height increases with the exception of the tallest stands (i.e., over 40 metres, Figure C8). Open stands appear to suffer less wind damage that moderately dense and dense stands (Figure C9) and multi-storied stands are somewhat more vulnerable than uniform single-storied stands (Figure C10). There is also a tendency for wind damage to increase as rooting depth increases (Figure C11).

- As with external cutblock edges, there are significant differences in wind damage occurring along large patch edges with changes in stand dominance by the major conifer species (Figure H2). Stands dominated by western hemlock and amabilis fir are more susceptible to damage than Douglas-fir. Stands dominated by western redcedar have intermediate levels of damage.

- Gully edges appear to have higher wind damage rates than other edge geometry categories; however, there are a limited number of samples for this category as few large patches are located in gullies (Figure C12). There is no obvious explanation for why the category 'hillslope' (boundaries running along the contour on a hillside) have higher wind damage rates than other categories. This apparent difference may be a function of small sample size.

7.3 Wind Damage Relationships - Retained Groups and Clusters

The analysis lumps groups and clusters (small groups) of trees together and uses the term "group" to refer to both groups and clusters of trees. The split between small patches (groups) and the larger patches described above occurs at about one hectare.

The average amount of wind damage in retained groups ranges from 20±1.2% in Stillwater to 45% in the QCI and Mid Island. The average wind damage rate for all groups and clusters is 39±0.5% (Table B9) compared to an overall average of 24±0.6% along the edges of larger patches and 16±.2% along external edges (Tables 6 and 7). This index relies on an estimate of the amount of wind damage occurring over the entire area of each retained group or cluster, whereas the large patch edge and external edge wind damage indices are of the amount present in a nominal 25 metre-wide band along stand edges. These wind damage indices are not strictly comparable.

The graphical and statistical analysis presented in Appendices C and D suggests the following relationships:

- There was no obvious trend in wind damage as group size increases up to about one hectare (Figure D1). We had expected that there might be some decrease in wind damage as patch size increased. Many other factors such as differences in tree height, slope position and geographic region may confound the results. The lower average amounts of wind damage recorded along the edges of larger patches suggests a reduction in wind damage rates for larger patches compared to smaller patches (i.e., <1ha versus ≥1ha). Analysis of the windthrow penetration data suggests that wind damage does not penetrate into the core of larger patches (Section 7.6 and Table B8).

- There is a general increase in wind damage rates as fetch distances increase (Figure D2). There are no obvious differences wind damage with changes in the character of the fetch surface, except that patches that are close to and in the lee of external boundaries appear to exhibit lower wind damage rates.

- Slope position appears to have a moderate influence on the degree of wind damage in groups and clusters of trees. Sites on valley floors and lower slopes have the lowest damage rates; upper slopes and ridge crests the highest rates (Figure D5). The relationship depicted in Figure 5 becomes more definitive if the analysis excludes more vulnerable second growth stands, which predominantly occupy valley flat locations. There is a corresponding though weak trend of increasing wind damage with increasing elevation (Table D9).

- There is a trend of increasing wind damage rate with increasing stand height in small patches for stands greater than 30 metres tall; there is no difference up to 30 metres tall (Figure D6). Wind damage tends to decrease as stand density decreases (Figure D7). There are no significant differences in wind damage between multi-storied and single-storied stands (Figure D8). As with other strata, there is a general but not entirely consistent trend of increasing wind damage as rooting depth increases (Figure D9). Poorly- and imperfectly-drained mineral soils (e.g., Gleysols, Gleyed podzols) tend to have the highest wind damage rates (Figure D10).

- Differences in wind damage among stands dominated by different tree species are most pronounced for small patches (Figure H4), with stands dominated by Western hemlock and amabilis fir showing the most damage. Stands were Yellow-cedar and Douglas-fir are dominant show the least damage, with stands dominated by Western redcedar showing slightly higher levels of damage. The range among species varied from 20% to over 50%, in contrast to a roughly 10% range among species for external edges.

- There is little indication that the shape of small patches is a significant factor for damage that occurs (Figure D11) although there is some suggestion that patches that are more symmetrical have slightly higher wind damage rates (Figure D12).

7.3 Wind Damage Relationships - Strips

These areas include riparian reserves and other strips left for a variety of reasons ranging from wetland protection to visual aesthetics. The average amount of total wind damage is 31±0.6% (Table B10) and ranges from 15% to 38% among the various operations.

The graphical and statistical analysis presented in Appendices C and D suggests the following relationships:

- The wind damage rates along the edges of the strips (31%) are substantially higher than wind damage rates found along external boundaries (24%) and the edges of large patches (16%). This appears to be the case even along relatively wide strips (e.g. strips >50 metres wide, Table B12).

- Wind damage rates appear to decrease as strip width increases, except for the widest strips, which have higher wind damage rates (Figure E1). This may occur in part because a higher percentage of the wider strips are located along gully edges and stream escarpments, locations which tend to be more vulnerable, and possibly, because the wider strips appear to be associated with slightly taller stands. A comparison of strip width to tree height found that there is a slight, but significant, increase in stand height as strip width increases. This may mean that the apparent trend of decreasing wind damage with increasing strip width is somewhat confounded by the increase in stand height.

- There is a general increase in wind damage from less exposed to highly exposed boundaries. Windward edges tend to have greater amounts of wind damage than other boundary exposures (Figures E2 and E3).

- There is an increase in wind damage as fetch distance increases within a cutblock (Figure E4). The presence or absence of retention elements on the upwind fetch surface does not appear to affect the amount of wind damage along strips, but situations where at least one of the damaging winds comes across a forest canopy (i.e., a lee edge) there is a reduction in wind damage. (Figure E5).

- Strips on ridge crests appear to have higher wind damage rates than strips in other topographic locations. There is a trend of increasing wind damage from lower to upper slopes (Figure E7). Strips on valley floors had similar damage to mid-slope positions. As with the other sample strata, wind damage rates for valley floor locations are slightly lower when the analysis excludes second growth stands.

- There is a general trend of an increasing amount of wind damage as average stand height increases above 25 metres. Stands less than 25 metres high have wind damage rates averaging about 23%, whereas stands greater than 40 metres in height have average rates averaging about 40%. Multi-storied stands tend to have substantively higher wind damage rates than uniform or single-storied stands (Figure E10). Like other strata, there is a general increase in wind damage as rooting depth increases (Figure E11). Imperfectly drained mineral soils tend to exhibit the highest wind damage rates (Figure E12).

- As with other categories of edges, there are significant differences in wind damage for tree species dominance (Figure H3). Stands dominated by western hemlock and amabilis fir are more susceptible to wind damage than those dominated by Douglas-fir. Stands dominated by western redcedar damage have intermediate levels of damage. There was a wider range in average damage for strips (20% to 40%) than for cutblock edges (10% to 20%).

- Strips of retained timber with boundaries located along gully edges exhibit wind damage rates nearly twice as high as strip boundaries that are set back some distance from gully edges (Figure E13). Similarly, boundaries along the edges of stream escarpments have two times the wind damage of boundaries set back some distance from the edge of the stream escarpment. It appears that even modest setbacks from the edges of gullies can result in reductions from 60% wind damage to rates of about 30% (Figure E14). Other strip edge locations are typically less vulnerable than the edges of gullies edges or stream escarpments.

7.4 Wind Damage Relationships - Areas of Dispersed Retention

The data set for areas of dispersed retention is limited to 108 plots from the Port Alberni, Port McNeill, South Island, and Stillwater areas (Table B5a and Table B11). These plots show a mean of 25± 1.8% wind damage with a range of 9± 1.6% to 37± 4.1% among these four areas. The minimum and maximum total wind damage values range from zero to 75% for areas of dispersed retention.

While the sample size is small and not all independent variables apply, there is a general increase in wind damage as stand height increases (Table D5). Multi-storied stands tend to be more vulnerable to wind damage that single-storied stands. There is some indication that second growth stands are more vulnerable than old growth. The levels of significance presented in Table D5 suggest that there are also significant differences between the amount of wind damage and slope position. The limited data available suggest that wind damage in areas of dispersed retention is somewhat less than that in small patches and comparable to that found along the edges of retained strips. However, dispersed retention tends to be done only where windthrow risk is thought to be low. The sample size for areas of dispersed retention remains small so field planners should extrapolate these results with caution.

7.6 Windthrow Penetration

The distance windthrow penetrates into a forest stand can have significant implications. As noted above, penetration distance is the distance from the stand edge to the furthest upturned root mass, not the top of the tree. Data characterizing expected windthrow penetration distances is important for some forest management decisions; for example, determination of prudent setback distances from gully escarpments and stream edges or from potentially unstable areas. Our analysis suggests that windthrow penetration distances tend to be directly proportional to windthrow rates (Table D11).

The statistics on the depth of windthrow penetration can be biased by the size of retained groups and the width of retained strips (that is, windthrow can penetrate to the far side of small groups or narrow strips), consequently, only penetration distances along external boundaries and the edges of larger patches are discussed below. Tables B9, B10 and B12, provide summary statistics on windthrow penetration for groups and strips and do suggest that penetration distances are somewhat greater in smaller patches and strips than along external edges or the edges of large patches. Readers should interpret these values with caution because of the inherent bias introduced by patch diameter and strip width.

Mean penetration distances along external cutblock edges and large patch edges averaged about 12 metres (Tables B7 and B8). The mean values found within different Forest Operations indicate a significant regional variation in windthrow penetration rates (Tables 6 and 7 and Figure G2). The highest mean penetration for external edges was 20 metres at Jeune Landing. Maximum penetration distances along external edges recorded during this study ranged from 25 metres in South Island to 380 metres in Port McNeill.

For the following summary data for external cutblock edges and for large patch edges are combined. The graphical and statistical analysis presented in Appendices C and D suggests the following relationships:

- Mean windthrow penetration distances increase with increasing boundary exposure; lee and parallel boundaries tend to have relatively short penetration distances (i.e., 8 to 10 metres) whereas mean penetration distances on windward boundaries can be almost twice those along lee boundaries (Figures G3 and G4).

- There is an increase in penetration distance with increases in fetch distance for cumulative fetch distances over 50 metres (Figure G5). There is no consistent relationship between windthrow penetration and the character of the upwind fetch surface, except that those fetch categories associated with lee and parallel boundaries (e.g., edges and forests) experience substantively lower penetration distances (Figure G6).

- There is a clear trend of increasing penetration distance with increasing stand height (Figure G7). Penetration distance tends to decrease as stand density decreases (Figure G8). Penetration distance tends to be greatest in stands that established after earlier windthrow events (Figures G16 and G17). There is a general trend of increasing penetration depths as rooting depths increase (Figure G11).

- There is a general trend of increasing penetration distance as slope position changes from the valley flat locations to ridge crests (Figure G9). A similar relationship occurs with elevation with penetration distances tending to increase as elevation increases, but the correlation, though significant, is weak(Table D11).

- There is no definitive pattern in the degree of windthrow penetration along external edges of cutblocks with changes in edge geometry (Figure G11). There may be slightly greater penetration distances along the edges of stream escarpments than in areas where the boundary is set back from the edge of the escarpment. Unlike wind damage, there is no similar relationship for gully edges and setbacks from the edge of gullies (Figures G12 and G13).

- In the case of strip edges, windthrow penetration averaged about 28 metres along gullies and streams when strip boundaries were set at the edge of gullies and/or stream escarpments. Penetration averaged about 20 metres along gullies and 5 metres along streams when there was a modest setback from the edge of the gully or stream escarpment (Figures G14 and G15).

8.0 Summary

As expected, the study found distinct regional differences in wind damage. The amount of wind damage along external cutblock edges varied from an average of 11% in South Island to 25% in Jeune Landing with an overall average of 16%. The edges of larger patches show a similar relationship with 16% wind damage in South Island and Stillwater, 45% in the QCI (Haida Gwaii) and a coast-wide average of 24%.

There is a similar trend with wind damage in smaller patches (groups and clusters of trees). The average wind damage in small patches is 20% in the South Island area and 45% in the Queen Charlotte Islands and Mid-Island, with a coast-wide average of 39%. Overall, small retention patches (<=1 ha) appear to be more vulnerable to wind damage than the edges of larger retention patches even though the metrics for reporting wind damage from large patch edges and small patch areas are slightly different. This result corresponds with findings of an inverse relationship between patch size and wind damage found in two other recent studies in British Columbia (Burton, 2001, DeLong, et.al. 2001).

For retained strips of timber, a similar geographic pattern is evident. Average wind damage rates range from 15% in South Island to 38% in Port McNeill and Jeune Landing. The coast-wide average for wind damage along the edges of retained strips is about 31%. These wind damage rates are substantively higher than wind damage rates along external cutblock edges and similar, but still higher than the edges of large patches.

There is an obvious and not surprising trend in the data indicating that windward edges are more vulnerable to wind damage than other boundary exposures.

Wind damage generally increases with increasing fetch distance for all plot strata although the relationship is somewhat variable. The character of the fetch surface (i.e., whether there is retention between the rated edge and the edges in the two dominant wind directions) may affect the amount of wind damage in a limited manner, but there is no clear pattern among different plot strata. There is some indication, at least when comparing clearcut to retention system cutblocks, that external boundaries in retention cutblocks have slightly lower rates of wind damage than external boundaries in clearcut areas.

There is no clear indication that pruning or topping and pruning treatments reduce the amount of wind damage along the edges of larger patches or cutblock edges; however, as the data set for these treatments is small and the geographic variation between sites is great, this conclusion should be considered tentative. A 2004 retrospective study focusing on topping and pruning treatments along external cutblock edges in North Island showed a definite decrease in wind damage rates with treatment, particularly where the treatments extended 15 to 20 metres into standing timber (Rollerson, et. al., 2004).

There is a generally strong relationship between slope position and the amount of wind damage. Topographically exposed locations such as upper slopes and ridge crests typically experience more wind damage than lower slopes and valley floors across all plot strata. A similar trend is seen for elevation, with wind damage increasing as elevation increases.

For both external, and large patch edges, strip edges and small patches, the amount of wind damage tends to increase with increases in stand height.

Both external cutblock edges and the edges of retained strips tend to be most vulnerable when located along the edges of stream escarpments or the upper edges of gully sides. Similar boundary orientations set back a modest distance from the edges of these features tend to be less vulnerable to wind damage.

There is modest trend of decreasing wind damage with increasing strip width. A previous study of wind damage along riparian strips on northern Vancouver Island found a similar relationship (Rollerson and McGourlick, 2001).

The distance that windthrow penetrates into stand edges appears to be affected in the same way and by the same environmental variables as windthrow rate. Penetration distance varies directly with and is proportional to the windthrow rate or overall wind damage rates. For example, our analysis indicates that penetration varies with changes in boundary exposure. Penetration distances are less on lee boundaries compared to windward boundaries. A similar relationship is seen with fetch distance, as fetch distance increases so does the distance windthrow penetrates into a stand edge. Penetration distances tend to increase as stand height increases.

9.0 Adaptive Management Implications

The following recommended practices and strategies are based on the results of the VR windthrow monitoring study, other studies in coastal BC and the experience of the authors. These recommendations are not necessarily comprehensive. We suggest that forestry planners implement these strategies operationally, but continue to monitor and modify practices as necessary to adjust to local experience.

- For sites or landscapes with a high hazard of wind damage (e.g., upper slopes and ridge crests; north-western Vancouver Island) use large patches or clearcut with reserves and wide retention strips rather than a larger number of smaller patches or narrow strips. The recommended minimum patch size for these areas is 0.5 ha, and patches over 1.0 ha are preferred. When it is critical to minimize damage to the leeward portion of patches, ensure that the radius of these patches exceeds the maximum penetration distance documented for the area.

- Where possible avoid locating windward boundaries of retention patches or strips in tall timber. If this is not possible, mitigation strategies include minimizing fetch distances, minimizing the length of windward boundaries (e.g., straight boundaries have less exposed edge than jagged boundaries), and using large patches or wide strips.

- Set back boundaries 10 to 15 metres from the windward edges of gullies and stream escarpments to reduce both the potential for wind damage and to minimize the distance windthrow penetrates into gullies and/or across streams. The data suggest that setbacks of even a few metres will experience lower wind damage rates than boundaries located directly along the edges of gullies and stream escarpments. Focus the establishment of wider riparian and gully reserves in higher risk environments. For example, steep gully headwalls at higher elevations where the potential for debris flow initiation and long landslide travel distances and/or significant down slope damage are greater if severe windthrow occurs.

- When feasible, top and prune trees along edges where damage is likely to compromise management objectives. Feathering, which selectively removes more vulnerable and taller trees along high hazard edges, may also reduce the potential for wind damage. Although our monitoring findings were inconclusive due to low sample size and high geographic variability, data from other studies suggest that these types of treatments can reduce wind damage. To ensure that these treatments are cost effective, carry out pre-harvest windthrow orientation (wind direction) assessments to identify high hazard boundaries (e.g., windward edges).

8.0 Extension

Throughout the term of this monitoring program, results were communicated to field planners so that findings could help improve cutblock design. We accomplished this through presentations at a variety of workshops and seminars, as summarized below. The annual progress reports were also distributed to WFP operations, other BC forest companies and to some forest company and agency staff in Washington State.

In the 2005-06 fiscal year, presentations were made at a workshop for the VR Working Group, a workshop for consulting geoscientists and engineers and at a one-day Windthrow Workshop in Campbell River sponsored by FERIC. Seminars outlining the initial results of the windthrow monitoring project were held in the Stillwater Forest Operation, Mid-Island Forest Operation, Port McNeill Forest Operation and at the Hayes Forest Management office in Duncan. A number of foresters and forest engineers from both Cascadia (now Western Forest Products) and Island Timberlands attended the workshop for consulting geoscientists and engineers.

The results of the study were presented as part of a poster session at a Variable Retention Science Symposium held in Nanaimo in the spring of 2005.

In early March 2007, a seminar on the VR windthrow monitoring project was held for staff and forestry consultants at the Port Alberni Forest Operation. Presentations were also given at Queen Charlotte, Mid-Island, Gold River, Englewood and Pt. McNeill (including staff from Holberg and Jeune Landing) Forest Operations in April 2007 and at Stillwater Forest Operation in October 2007. A field reconnaissance was carried out at Jeune Landing and Holberg to discuss VR-related windthrow conditions with local foresters and to set sampling priorities for monitoring. The results of the VR windthrow monitoring program were presented at an international windthrow conference at UBC in the summer 2007.

This final report will be widely circulated. A paper presenting key findings will be submitted to a peer-reviewed journal for publication.

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Appendix A
Figures

Figure A1. Example of typical plot strata distribution.

Figure A2. Wind Exposure Index/Wind Exposure Class

Boundary exposure 1		**Boundary exposure 2** →	Lee	Lee diagonal	Parallel	Windward diagonal	Windward
			1	2	3	4	5
Lee	1			**3**	**4**	**5**	**6**
Lee diagonal	2		**3**	**4**	**5**	**6**	**7**
Parallel	3		**4**	**5**	**6**	**7**	**8**
Windward diagonal	4		**5**	**6**	**7**	**8**	**9**
Windward	5		**6**	**7**	**8**	**9**	

Note: Wind Exposure Index = (Boundary exposure 1 rank) + (Boundary exposure 2 rank)

Wind Exposure Index (sum of ranks)	Wind Exposure Class	Wind Exposure Class number
0-1	Very low	1
2-3-4	Low	2
5-6	Moderate	3
7-8	High	4
9-10	Very high	5

The wind exposure index (WEI) is a simple, qualitative scoring scheme developed for the riparian windthrow study that ranks the expectation that a specific falling boundary segment will be affected by strong winds from more than one direction. The primary and secondary (or co-dominant) windthrow orientations for a block are compared in turn to each specific boundary segment orientation (aspect) to determine the primary and secondary exposure categories for that boundary segment (i.e., lee, windward or an intermediate exposure category). The assumption is made that the post-logging windthrow orientations in a sample block or boundaries in the immediate vicinity indicate the dominant wind directions that may affect a specific boundary segment. A simple ranking matrix is then created that lists boundary exposure categories along the x and y axes, defined as lee through windward and ranks them consecutively (i.e., lee = 1, parallel = 3, windward = 5). The individual rank values are added vertically and horizontally to determine the WEI for specific boundary segments or riparian sample strips. When there is only one windthrow (wind) orientation the WEI can be less than 3.

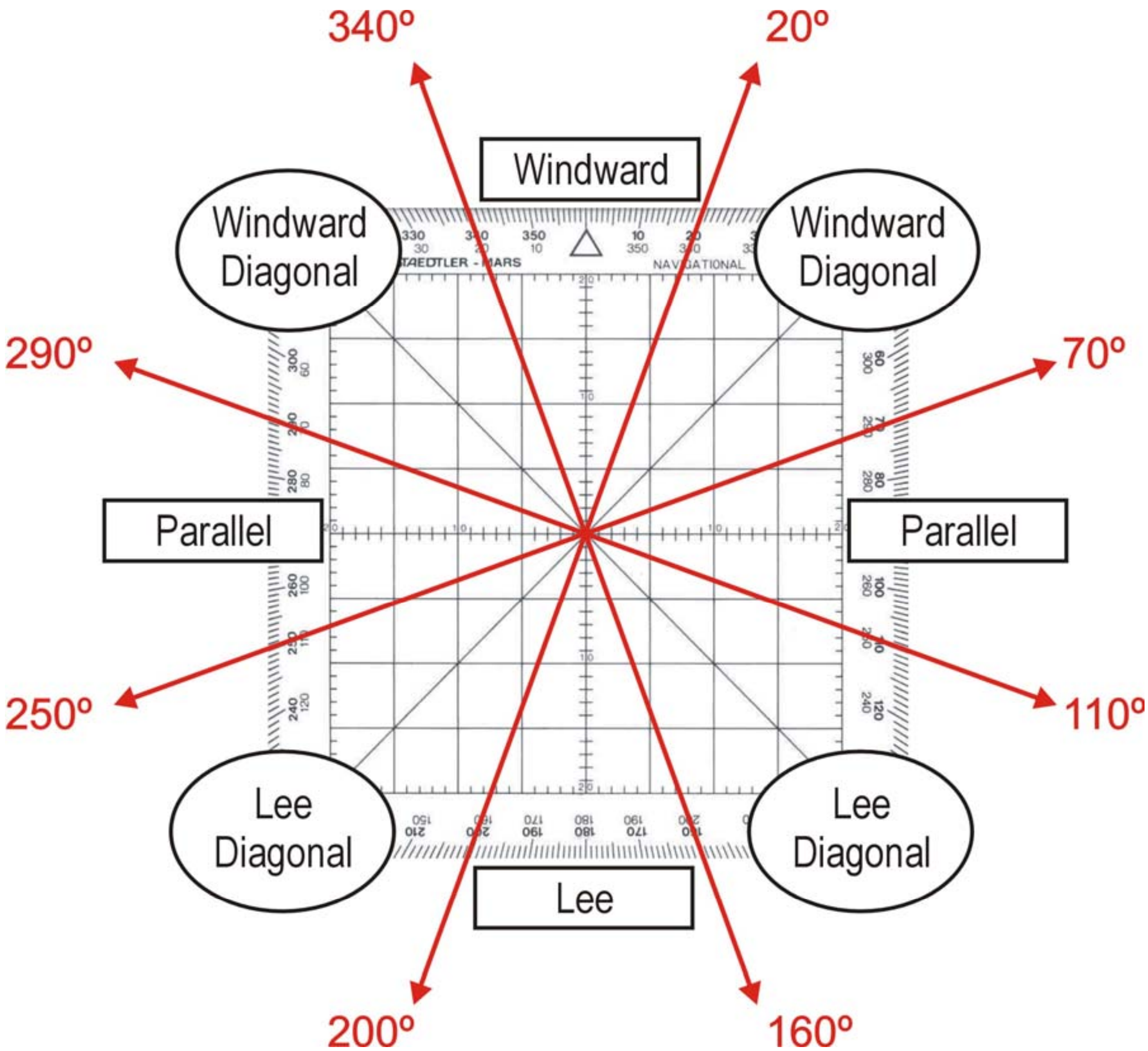


Figure A3. Transparency used for determining boundary exposure.

Appendix B
Tabular Analysis

Table B1. Distribution of plots by topography and Forest Operation (FO).

Topography	Gold River	Hol-berg	Jeune Landing	Mid Island	Nootka	Port Alberni	Port McNeill	QCI	South Island	Still-water	Total
Broad Deep Valley			15							24	39
Broad Moderate Valley	14		27	151		148		37	118	240	735
Coastal Plain				46			310	185			541
Deep Valley	17										17
High Hills	161	110	13	81	83	209	80		15		752
Low Hills				53		294	58	162	30	91	688
Moderate Hills	40	53	37	216	25	282	155	59	40	264	1171
Moderate Valley				149	49	301				79	578
Narrow Deep Valley					5	93					98
Narrow Moderate Valley					3	26					29
Total	232	163	92	696	165	1353	603	443	203	698	4648

Table B2. Distribution of plots by topography and physiographic unit.

Topography	Coast Mountains	Nahwitti Lowland	Nanaimo Lowland	Queen Charlotte Lowlands	Skidegate Plateau	Vancouver Island Mountains	Total
Broad Deep Valley	24					15	39
Broad Moderate Valley	240				37	458	735
Coastal Plain		310	46	185			541
Deep Valley						17	17
High Hills						752	752
Low Hills	91			87	75	435	688
Moderate Hills	264				59	848	1171
Moderate Valley	79					499	578
Narrow Deep Valley						98	98
Narrow Moderate Valley						29	29
Total	698	310	46	272	171	3151	4648

Table B3. Distribution of plots by FO and physiographic unit

Forest Operation	Coast Mountains	Nahwitti Lowland	Nanaimo Lowland	Queen Charlotte Lowlands	Skidegate Plateau	Vancouver Island Mountains	Totals
Gold River						1055	1055
Holberg		832					832
Jeune Landing						493	493
Mid Island			198			2063	2261
Nootka						842	842
Port Alberni						4322	4322
Port McNeill		1060				1042	2102
QCI				968	702		1670
South Island						395	395
Stillwater	2682						2682
Total	2682	1892	198	968	702	10212	16654

Table B4. Distribution of plots by biogeoclimatic variant and FO.

BEC variant	Gold River	Hol-berg	Jeune Landing	Nootka	Mid-Island	Port Alberni	Port McNeill	QCI	South Island	Still-water	Total
CDFmm									91		91
CWHdm										582	582
CWHmm1				33		51	35				119
CWHmm2						14			36		50
CWHvh1		61				44		8			185
CWHvm1	22	42	92	325	131	682	523				2015
CWHvm2	12	6			34	3				9	145
CWHwh1								326			326
CWHwh2								37			37
CWHxm				338		532			76	17	1053
MHmm1							45				45
Total	232	163	92	696	165	1353	63	443	23	698	4648

Table B5a. Distribution of plots by strata category and FO.

Plot strata by count	Gold River	Hol-berg	Jeune Landing	Mid-Island	Nootka	Port Alberni	Port McNeill	QCI	South Island	Still-water	Total
Bulge				9		14	1	4	1	4	33
Cluster	2	3		37	5	114	35	4	39	7	246
Dispersed Individuals				13		32			16	47	108
External Edge	172	136	79	397	142	789	396	3	61	425	2897
External Group	2			7	1	4			1	1	16
External Strip	1	4		4		2			1	12	33
Group	36	12	12	121	4	174	73	7	56	94	652
Patch Edge	2			25		67	51	23	8	62	238
Peninsula	6	5	1	2	9	59	2	19	1	35	175
Ribbon		1		4		12	1			3	21
Strip <50m wide	2	2		51	2	6	11	14	19	7	168
Wide Strip >50m				8	2	26	15	9		1	61
Total	232	163	92	696	165	1353	63	443	23	698	4648

Table B5b. Distribution of plots (%) by strata category and FO.

Plot strata	Gold River	Hol-berg	Jeune Landing	Mid-Island	Nootka	Port Alberni	Port McNeill	QCI	South Island	Still-water	Total
Bulge				0.2		0.3	0.0	0.1	0.0	0.1	0.7
Cluster	0.0	0.1		0.8	0.1	2.5	0.8	0.1	0.8	0.2	5.3
Dispersed Individuals				0.3		0.7			0.3	1.0	2.3
External Edge	3.7	2.9	1.7	8.5	3.1	17.0	8.5	6.5	1.3	9.1	62.3
External Group	0.0			0.2	0.0	0.1			0.0	0.0	0.3
External Strip	0.2	0.1		0.1		0.0			0.0	0.3	0.7
Group	0.8	0.3	0.3	2.6	0.1	3.7	1.6	1.5	1.2	2.0	14.0
Patch Edge	0.0			0.5		1.4	1.1	0.5	0.2	1.3	5.1
Peninsula	0.1	0.1	0.0	0.4	0.2	1.3	0.4	0.4	0.0	0.8	3.8
Ribbon		0.0		0.1		0.3	0.0			0.1	0.5
Strip <50m wide	0.0	0.0		1.1	0.0	1.3	0.2	0.3	0.4	0.2	3.6
Wide Strip >50m				0.2	0.0	0.6	0.3	0.2		0.0	1.3
Total	5.0	3.5	2.0	15.0	3.5	29.1	13.0	9.5	4.4	15.0	100.0

Table B6a. External edge plots - length (m) summary by FO.

Forest Operation	N	Sum	Mean	Std. Dev.	Min	Max
Gold River	172	24525	143	46	50	270
Holberg	136	20275	149	47	55	310
Jeune Landing	79	12325	156	49	65	360
Mid-Island	397	50835	128	53	35	325
Nootka	142	20600	145	44	50	305
Port Alberni	789	93035	118	56	20	380
Port McNeill	396	45155	114	52	30	355
QCI	300	35680	119	51	40	330
South Island	61	7415	122	43	55	305
Stillwater	425	56140	132	47	40	320
Total	2897	365985	126	53	20	380

Table B6b. Large Patch edge plots - length (m) summary by FO.

Forest Operation	N	Sum	Mean	Std. Dev.	Min	Max
Gold River	2	380	190	42	160	220
Holberg	0	0	0	0	0	0
Jeune Landing	0	0	0	0	0	0
Mid-Island	25	2910	116	32	70	185
Nootka	0	0	0	0	0	0
Port Alberni	67	7410	111	45	40	280
Port McNeill	51	4535	89	28	40	160
QCI	23	2525	110	33	50	160
South Island	8	990	124	24	95	150
Stillwater	62	7140	115	36	40	190
Total	238	25890	109	38	40	280

Table B6c. Retention group and cluster area (ha) summary by FO.

Forest Operation	N	Sum	Mean	Std. Dev.	Min	Max
Gold River	40	10.4	0.26	0.37	0.01	2.05
Holberg	15	4.8	0.32	0.27	0.04	0.95
Jeune Landing	12	2.0	0.17	0.14	0.05	0.51
Mid-Island	165	41.9	0.25	0.22	0.01	0.97
Nootka	10	2.0	0.20	0.28	0.02	0.73
Port Alberni	292	44.2	0.15	0.18	0.01	0.99
Port McNeill	108	24.4	0.23	0.22	0.01	0.94
QCI	74	19.5	0.26	0.17	0.02	1.00
South Island	96	12.1	0.13	0.12	0.02	0.68
Stillwater	102	35.4	0.35	0.24	0.00	1.20
Total	914	196.6	0.22	0.22	0.00	2.05

Table B6d. Strip* length (m) summaries by Forest Operation. *(includes strip shelterwood data).*

Forest Operation	N	Sum	Mean	Std. Dev.	Min	Max
Gold River	12	1320	110	40	70	175
Holberg	12	1195	100	30	50	150
Jeune Landing	1	100	100	.	100	100
Mid-Island	95	10735	113	46	25	260
Nootka	12	995	83	49	40	190
Port Alberni	173	17070	99	45	30	265
Port McNeill	48	4165	87	42	30	225
QCI	46	4515	98	34	50	185
South Island	22	2425	110	34	45	180
Stillwater	61	7100	116	46	40	225
Total	482	49620	103	44	25	265

Table B6e. Strip* width (m) summaries by Forest Operation. *(data weighted by strip length).*

Forest Operation	N-weighted	Mean	Std. Dev.	Min	Max
Gold River	53	29	17	10	75
Holberg	48	38	12	5	60
Jeune Landing	4	50	0	50	50
Mid-Island	428	41	17	12	90
Nootka	40	53	19	25	75
Port Alberni	683	42	21	10	120
Port McNeill	167	47	18	15	70
QCI	181	63	21	25	100
South Island	97	28	14	10	60
Stillwater	284	48	19	15	90
Total	1984	44	21	5	120

*Includes strips classified as ribbons, peninsulas and bulges and strip shelterwood data

Table B7. Wind damage summary for external edges in place for two or more wind seasons by FO (*includes treated edges*).

Damage index	Forest Operation	N-weighted	Mean	Std. Dev.	Min	Max	Std. Err of Mean
% windthrow	Gold River	981	12	14	0	70	0.4
	Holberg	806	15	15	0	70	0.5
	Jeune Landing	493	18	19	0	75	0.8
	Mid-Island	2033	14	16	0	80	0.4
	Nootka	824	9	12	0	75	0.4
	Port Alberni	3721	11	17	0	90	0.3
	Port McNeill	1624	8	8	0	46	0.2
	QCI	1282	13	18	0	90	0.5
	South Island	297	6	8	0	40	0.5
	Stillwater	2246	11	14	0	75	0.3
	Total	14307	12	15	0	90	0.1
Windthrow penetration (m)	Gold River	823	13	18	1	125	0.6
	Holberg	727	14	20	0	150	0.8
	Jeune Landing	481	20	15	0	75	0.7
	Mid-Island	1933	13	15	0	100	0.3
	Nootka	631	7	7	1	50	0.3
	Port Alberni	3721	10	15	0	150	0.2
	Port McNeill	1592	11	31	0	380	0.8
	QCI	1201	9	12	0	95	0.3
	South Island	297	6	7	0	25	0.4
	Stillwater	1965	14	23	0	200	0.5
	Total	13370	12	19	0	380	0.2
% stem-break	Gold River	981	2	3	0	20	0.1
	Holberg	806	3	3	0	17	0.1
	Jeune Landing	493	4	5	0	40	0.2
	Mid-Island	2033	3	5	0	30	0.1
	Nootka	824	4	5	0	20	0.2
	Port Alberni	3721	3	5	0	31	0.1
	Port McNeill	1624	4	5	0	30	0.1
	QCI	1282	3	5	0	24	0.1
	South Island	297	3	3	0	15	0.2
	Stillwater	2246	2	3	0	25	0.1
	Total	14307	3	4	0	40	0.0
% leaning trees	Gold River	981	2	3	0	18	0.1
	Holberg	806	2	3	0	13	0.1
	Jeune Landing	493	2	2	0	20	0.1
	Mid-Island	2033	1	2	0	15	0.0
	Nootka	824	2	4	0	20	0.1
	Port Alberni	3719	1	2	0	15	0.0
	Port McNeill	1615	2	2	0	12	0.1
	QCI	1282	3	4	0	30	0.1
	South Island	297	2	3	0	15	0.2
	Stillwater	2246	1	2	0	12	0.0
	Total	14295	2	2	0	30	0.0
Total wind damage (%)	Gold River	981	16	16	0	90	0.5
	Holberg	806	19	18	0	82	0.6
	Jeune Landing	493	25	23	0	92	1.0
	Mid-Island	2033	18	19	0	95	0.4
	Nootka	824	15	14	0	79	0.5
	Port Alberni	3719	16	21	0	95	0.3
	Port McNeill	1615	14	13	0	68	0.3
	QCI	1282	19	22	0	100	0.6
	South Island	297	11	11	0	63	0.7
	Stillwater	2246	14	16	0	85	0.3
	Total	14295	16	19	0	100	0.2

Table B8. Wind damage summary for large patch edges in place for two or more wind seasons by FO (*includes treated edges*).

Damage index	Forest Operation	N-weighted	Mean	Std. Dev.	Min	Max	Std. Err of Mean
% windthrow	Gold River	15	16	2	14	18	0.5
	Mid-Island	116	16	12	4	55	1.1
	Port Alberni	296	19	20	0	70	1.2
	Port McNeill	181	18	15	0	70	1.1
	QCI	101	32	17	3	65	1.7
	South Island	40	5	3	2	10	0.4
	Stillwater	286	11	15	0	75	0.9
	Total	1036	17	17	0	75	0.5
Windthrow penetration (m)	Gold River	15	8	3	5	10	0.7
	Mid-Island	116	13	10	1	40	0.9
	Port Alberni	296	13	14	0	50	0.8
	Port McNeill	181	14	11	0	40	0.8
	QCI	101	17	9	2	30	0.9
	South Island	40	2	1	0	5	0.2
	Stillwater	286	11	11	0	45	0.7
	Total	1036	12	12	0	50	0.4
% stem-break	Gold River	15	5	2	3	7	0.5
	Mid-Island	116	2	2	0	7	0.2
	Port Alberni	296	2	2	0	12	0.1
	Port McNeill	181	9	7	0	32	0.5
	QCI	101	9	7	0	25	0.7
	South Island	40	9	6	2	20	1.0
	Stillwater	286	3	3	0	10	0.2
	Total	1036	4	5	0	32	0.2
% leaning	Gold River	15	1	2	0	3	0.4
	Mid-Island	116	3	3	0	10	0.3
	Port Alberni	289	2	2	0	7	0.1
	Port McNeill	181	3	3	0	13	0.2
	QCI	101	4	3	0	11	0.3
	South Island	40	1	2	0	4	0.3
	Stillwater	286	2	2	0	10	0.1
	Total	1028	2	3	0	13	0.1
Total wind damage (%)	Gold River	15	23	3	20	25	0.7
	Mid-Island	116	21	14	5	63	1.3
	Port Alberni	289	22	22	0	77	1.3
	Port McNeill	181	30	21	0	92	1.6
	QCI	101	45	22	6	85	2.2
	South Island	40	16	7	4	27	1.2
	Stillwater	286	16	16	0	81	0.9
	Total	1028	24	21	0	92	0.6

Table B9. Wind damage summary for clusters and groups in place for two or more wind seasons by FO. (*includes treated edges*).

Damage index	Forest Operation	N-weighted	Mean	Std. Dev.	Min	Max	Std. Err of Mean
% windthrow	Gold River	209	16	17	0	100	1.2
	Holberg	95	30	26	3	75	2.6
	Jeune Landing	40	26	14	5	55	2.3
	Mid-Island	838	37	25	0	100	0.9
	Nootka	41	32	10	26	88	1.5
	Port Alberni	884	34	27	0	100	0.9
	Port McNeill	366	20	17	0	90	0.9
	QCI	390	35	24	3	100	1.2
	South Island	242	13	15	0	75	1.0
	Stillwater	707	31	28	0	100	1.1
	Total	3811	30	25	0	100	0.4
Windthrow penetration (m)	Gold River	187	7	4	1	20	0.3
	Holberg	95	7	7	1	25	0.7
	Jeune Landing	40	14	7	5	35	1.0
	Mid-Island	823	19	13	0	60	0.5
	Nootka	41	15	9	1	25	1.4
	Port Alberni	884	16	11	0	40	0.4
	Port McNeill	364	14	12	0	40	0.6
	QCI	390	17	10	1	40	0.5
	South Island	242	11	9	0	40	0.6
	Stillwater	647	15	10	0	40	0.4
	Total	3712	15	11	0	60	0.2
% stem-break	Gold River	209	3	4	0	18	0.3
	Holberg	95	3	3	0	14	0.3
	Jeune Landing	40	6	5	0	18	0.8
	Mid-Island	838	6	6	0	25	0.2
	Nootka	41	3	3	0	20	0.5
	Port Alberni	871	7	9	0	67	0.3
	Port McNeill	366	8	7	0	56	0.4
	QCI	390	6	7	0	50	0.4
	South Island	242	4	6	0	42	0.4
	Stillwater	707	4	5	0	25	0.2
	Total	3798	6	7	0	67	0.1
% leaning	Gold River	209	2	2	0	11	0.1
	Holberg	95	4	3	0	20	0.4
	Jeune Landing	40	3	4	0	10	0.6
	Mid-Island	838	2	2	0	18	0.1
	Nootka	41	3	2	0	10	0.3
	Port Alberni	870	2	3	0	40	0.1
	Port McNeill	366	2	2	0	15	0.1
	QCI	390	4	3	0	20	0.2
	South Island	242	2	4	0	35	0.3
	Stillwater	707	2	3	0	20	0.1
	Total	3797	2	3	0	40	0.0
Total wind damage (%)	Gold River	209	21	20	0	100	1.4
	Holberg	95	37	25	7	82	2.6
	Jeune Landing	40	35	17	10	65	2.8
	Mid-Island	838	45	29	0	100	1.0
	Nootka	41	38	9	34	88	1.5
	Port Alberni	870	43	32	0	102	1.1
	Port McNeill	366	30	23	0	100	1.2
	QCI	390	45	26	5	100	1.3
	South Island	242	20	18	0	90	1.2
	Stillwater	707	38	32	0	100	1.2
	Total	3797	39	29	0	102	0.5

Table B10. Wind damage summary for strips in place for two or more wind seasons by FO (*includes treated edges*).

Damage index	Forest Operation	N-weighted	Mean	Std. Dev.	Min	Max	Std. Err of Mean
% windthrow	Gold River	53	22	26	0	70	3.6
	Holberg	48	22	22	0	65	3.2
	Jeune Landing	4	32	0	32	32	0.0
	Mid-Island	429	29	25	0	84	1.2
	Nootka	40	15	21	0	70	3.3
	Port Alberni	683	29	25	0	95	1.0
	Port McNeill	167	25	16	1	75	1.3
	QCI	142	21	21	0	80	1.8
	South Island	97	7	7	0	30	0.7
	Stillwater	284	11	11	0	60	0.7
	Total	1947	24	23	0	95	0.5
Windthrow penetration (m)	Gold River	32	13	11	1	35	1.9
	Holberg	44	16	16	1	60	2.4
	Jeune Landing	4	20	0	20	20	0.0
	Mid-Island	426	15	10	0	35	0.5
	Nootka	26	21	16	5	60	3.2
	Port Alberni	683	18	16	0	70	0.6
	Port McNeill	167	16	10	2	40	0.8
	QCI	141	9	8	0	25	0.7
	South Island	97	3	3	0	10	0.3
	Stillwater	277	10	11	0	60	0.7
	Total	1897	14	13	0	70	0.3
% stem-break	Gold River	53	3	3	0	10	0.4
	Holberg	48	2	2	0	6	0.3
	Jeune Landing	4	2	0	2	2	0.0
	Mid-Island	429	6	7	0	35	0.3
	Nootka	40	4	4	0	12	0.6
	Port Alberni	683	5	6	0	25	0.2
	Port McNeill	167	10	8	0	36	0.6
	QCI	145	5	6	0	27	0.5
	South Island	97	6	5	0	20	0.5
	Stillwater	284	3	4	0	25	0.3
	Total	1950	5	6	0	36	0.1
% leaning	Gold River	53	2	2	0	6	0.3
	Holberg	48	1	1	0	5	0.2
	Jeune Landing	4	4	0	4	4	0.0
	Mid-Island	429	2	2	0	7	0.1
	Nootka	40	3	3	0	10	0.5
	Port Alberni	683	2	3	0	15	0.1
	Port McNeill	167	3	3	0	8	0.2
	QCI	145	2	4	0	15	0.3
	South Island	97	2	2	0	8	0.2
	Stillwater	284	2	2	0	7	0.1
	Total	1950	2	2	0	15	0.1
Total wind damage (%)	Gold River	53	27	29	0	85	4.0
	Holberg	48	25	21	0	67	3.1
	Jeune Landing	4	38	0	38	38	0.0
	Mid-Island	429	37	29	0	99	1.4
	Nootka	40	22	22	0	79	3.5
	Port Alberni	683	36	29	0	95	1.1
	Port McNeill	167	38	21	1	100	1.6
	QCI	142	28	26	0	95	2.2
	South Island	97	15	9	0	32	0.9
	Stillwater	284	17	14	0	76	0.8
	Total	1947	31	27	0	100	0.6

Table B11. Wind damage summary for areas of dispersed retention in place for two or more wind seasons by FO (*non-weighted data*).

Damage index	Forest Operation	N	Mean	Std. Dev.	Min	Max	Std. Err of Mean
% windthrow	Mid-Island	13	27	15	0	58	4.3
	Port Alberni	32	22	17	0	50	2.9
	South Island	16	17	11	0	35	2.8
	Stillwater	47	9	12	0	45	1.7
	Total	108	16	15	0	58	1.5
% stem-break	Mid-Island	13	0	0	0	0	0.0
	Port Alberni	32	0	0	0	0	0.0
	South Island	15	0	1	0	2	0.1
	Stillwater	26	2	8	0	30	1.6
	Total	86	1	5	0	30	0.5
% leaning	Mid-Island	13	9	7	0	24	2.0
	Port Alberni	32	13	12	0	40	2.2
	South Island	16	13	10	0	33	2.5
	Stillwater	47	2	2	0	7	0.3
	Total	108	7	10	0	40	0.9
Total wind damage (%)	Mid-Island	13	1	2	0	6	0.5
	Port Alberni	32	2	4	0	16	0.7
	South Island	16	1	2	0	5	0.4
	Stillwater	47	1	1	0	4	0.1
	Total	108	1	2	0	16	0.2

Table B12. Wind damage summary for strips in place for two or more wind seasons by strip strata (*includes treated edges*).

Damage index	Strata	N-weighted	Mean	Std. Dev.	Min	Max	Std. Err of Mean
% windthrow	Bulge	103	16	15	0	54	1.5
	External Strip	161	17	21	0	79	1.7
	Peninsula	600	21	22	0	90	0.9
	Ribbon	95	26	27	0	90	2.8
	Strip <50m wide	671	28	24	0	95	0.9
	Strip >50m	316	27	23	0	85	1.3
	Total	1947	24	23	0	95	0.5
Windthrow penetration (m)	Bulge	99	13	11	0	45	1.1
	External Strip	143	10	10	0	60	0.8
	Peninsula	582	13	13	0	60	0.5
	Ribbon	95	8	5	0	20	0.5
	Strip <50m wide	668	13	10	0	50	0.4
	Strip >50m	309	23	17	0	70	1.0
	Total	1897	14	13	0	70	0.3
% stem-break	Bulge	103	4	4	0	18	0.4
	External Strip	161	4	5	0	20	0.4
	Peninsula	603	5	6	0	25	0.2
	Ribbon	95	6	5	0	15	0.5
	Strip <50m wide	671	6	7	0	35	0.3
	Strip >50m	316	7	7	0	36	0.4
	Total	1950	5	6	0	36	0.1
% leaning	Bulge	103	2	2	0	7	0.2
	External Strip	161	2	2	0	6	0.2
	Peninsula	603	2	2	0	15	0.1
	Ribbon	95	1	2	0	8	0.2
	Strip <50m wide	671	2	2	0	8	0.1
	Strip >50m	316	3	3	0	15	0.2
	Total	1950	2	2	0	15	0.1
Total wind damage (%)	Bulge	103	22	18	0	70	1.8
	External Strip	161	23	23	0	90	1.8
	Peninsula	600	27	25	0	95	1.0
	Ribbon	95	33	28	2	90	2.9
	Strip <50m wide	671	36	27	0	100	1.1
	Strip >50m	316	37	28	0	92	1.6
	Total	1947	31	27	0	100	0.6

Table B13. Wind damage for external edges in place for two or more wind seasons by physiographic region and Forest Operation (*includes treated edges*).

Damage index	Physiography	Forest Operation	N-weighted	Mean	Std. Dev.	Min	Max	Std. Err of Mean
Total wind damage (%)	Coast Mountains	Stillwater	2246	14	16	0	85	0.3
		Total	2246	14	16	0	85	0.3
	Nahwitti Lowland	Port McNeill	781	15	13	0	61	0.5
		Total	781	15	13	0	61	0.5
	Nanaimo Lowland	Mid-Island	198	22	14	3	60	1.0
		Total	198	22	14	3	60	1.0
	Queen Charlotte Lowlands	QCI	727	14	18	0	92	0.7
		Total	727	14	18	0	92	0.7
	Skidegate Plateau	QCI	556	25	25	0	100	1.1
		Total	556	25	25	0	100	1.1
	Vancouver Island Mountains	Gold River	981	16	16	0	90	0.5
		Holberg	806	19	18	0	82	0.6
		Jeune Landing	493	25	23	0	92	1.0
		Mid-Island	1835	18	20	0	95	0.5
		Nootka	824	15	14	0	79	0.5
		Port Alberni	3719	16	21	0	95	0.3
		Port McNeill	833	13	13	0	68	0.4
		South Island	297	11	11	0	63	0.7
		Total	9788	16	19	0	95	0.2
Means for Forest Operations	All	Gold River	981	16	16	0	90	0.5
		Holberg	806	19	18	0	82	0.6
		Jeune Landing	493	25	23	0	92	1.0
		Mid-Island	2033	18	19	0	95	0.4
		Nootka	824	15	14	0	79	0.5
		Port Alberni	3719	16	21	0	95	0.3
		Port McNeill	1615	14	13	0	68	0.3
		QCI	1282	19	22	0	100	0.6
		South Island	297	11	11	0	63	0.7
		Stillwater	2246	14	16	0	85	0.3
		Total	14295	16	19	0	100	0.2

Table B14. Wind damage for external edges in place for two or more wind seasons by stand origin.

Damage Index	Stand origin	N	Mean	Std. Deviation	Minimum	Maximum	Std. Error of Mean
% windthrow	Fire	1775	13	15	0	65	0.4
	Harvest	4649	9	12	0	85	0.2
	Unknown[8]	7642	13	17	0	90	0.2
	Windthrow	240	17	17	0	55	1.1
	Total	14307	12	15	0	90	0.1
Windthrow penetration (m)	Fire	1643	16	25	0	200	0.6
	Harvest	4402	10	11	0	130	0.2
	Unknown	7121	12	21	0	380	0.2
	Windthrow	204	18	27	0	150	1.9
	Total	13370	12	19	0	380	0.2
% stembreak	Fire	1775	2	2	0	17	0.1
	Harvest	4649	3	4	0	30	0.1
	Unknown	7642	3	5	0	40	0.1
	Windthrow	240	3	3	0	15	0.2
	Total	14307	3	4	0	40	0.0
% leaning	Fire	1775	2	3	0	30	0.1
	Harvest	4649	2	2	0	15	0.0
	Unknown	7630	2	3	0	30	0.0
	Windthrow	240	1	2	0	15	0.1
	Total	14295	2	2	0	30	0.0
Total wind damage (%)	Fire	1775	17	17	0	81	0.4
	Harvest	4649	14	15	0	90	0.2
	Unknown	7630	17	21	0	100	0.2
	Windthrow	240	20	20	0	62	1.3
	Total	14295	16	19	0	100	0.2

[8] The category unknown typically indentifies old growth stands where there is no evidence of recent stand-replacing disturbance.

Table B15. Silvicultural System[9] by Forest Operation.

Forest Operation	Clearcut	Group Removal	Group Retention	Mixed (Group & Dispersed)	Strip Shelterwood	Aggregated Dispersed	Uniform Dispersed	Total
Gold River	98		134					232
Holberg	58		105					163
Jeune Landing	50		42					92
Mid Island		59	637					696
Nootka	118		47					165
Port Alberni	6	18	1172		51		106	1353
Port McNeill	63	14	442		40	44		603
QCI			443					443
South Island			196			7		203
Stillwater		115	407	11		83	82	698
Total	393	206	3625	11	91	134	188	4648

[9] All clearcuts were "clearcut with reserves" (i.e., with retained riparian strips or wildlife tree patches adjacent to or within the cutblock); group selection and group shelterwood systems were combined under group removal; aggregated dispersed retention means that small groups or clusters of trees were retained; uniform dispersed retention means that individual trees were retained.

Appendix C
Graphical Analysis

Note: The number of samples (N) tabulated on any of the figures showing percent windthrow values are the weighted number of pseudo-replicate samples not the true number of samples unless otherwise noted.

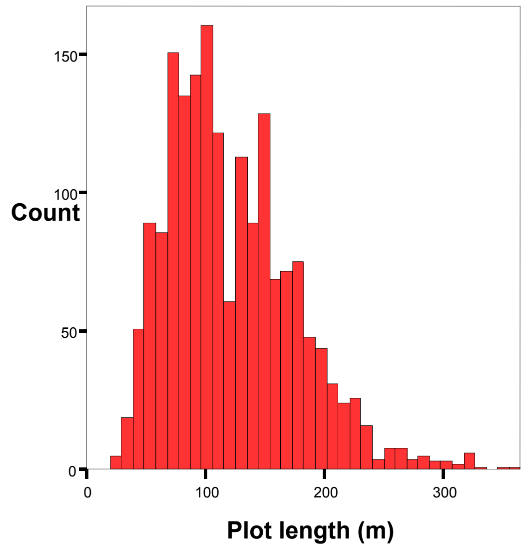


Figure A1. Distribution of plot lengths (m) along external edges.

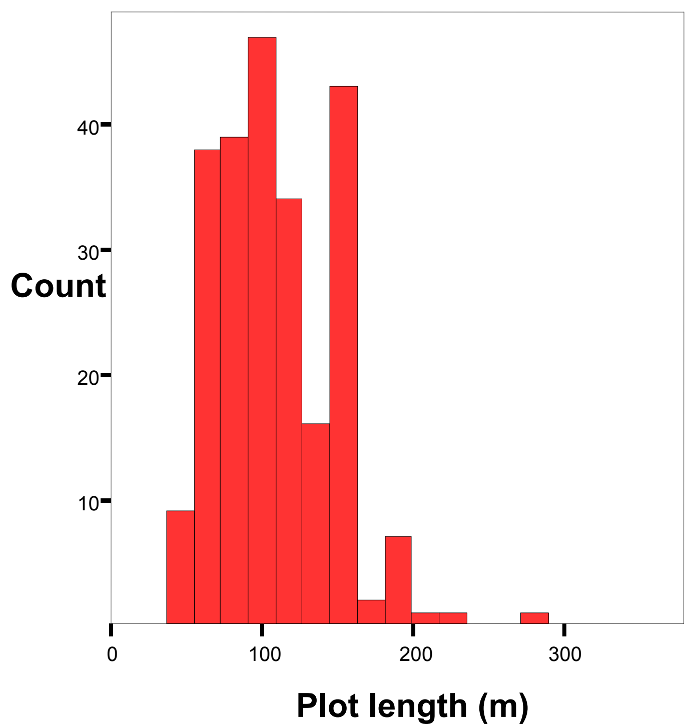


Figure A2. Distribution of plot lengths (m) along large patch edges.

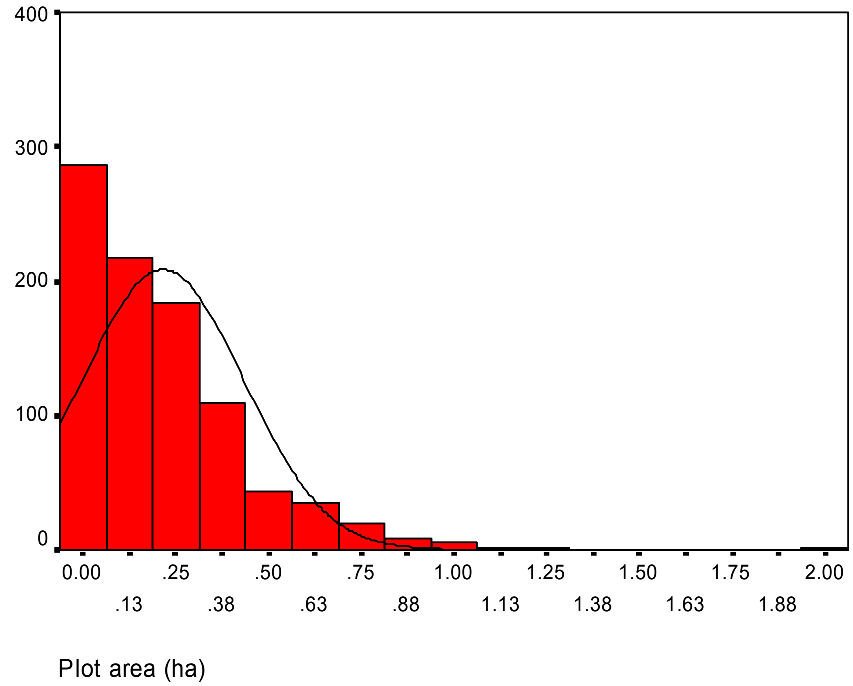


Figure A3. Distribution of retained groups and clusters by plot area (ha).

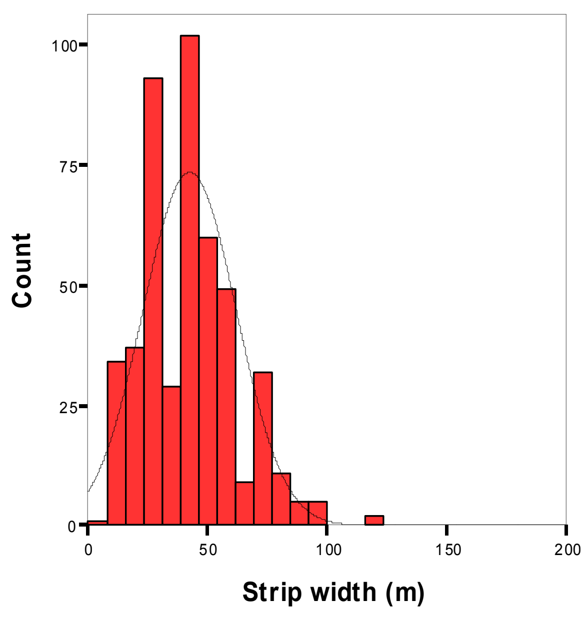


Figure A4. Distribution of strip widths for retained strips.

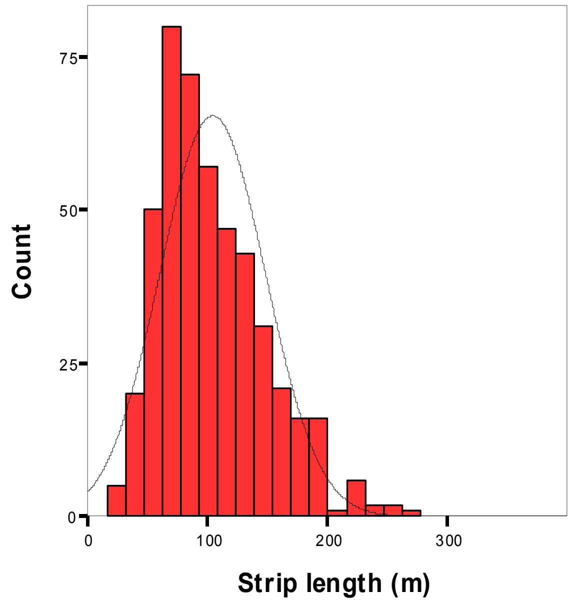
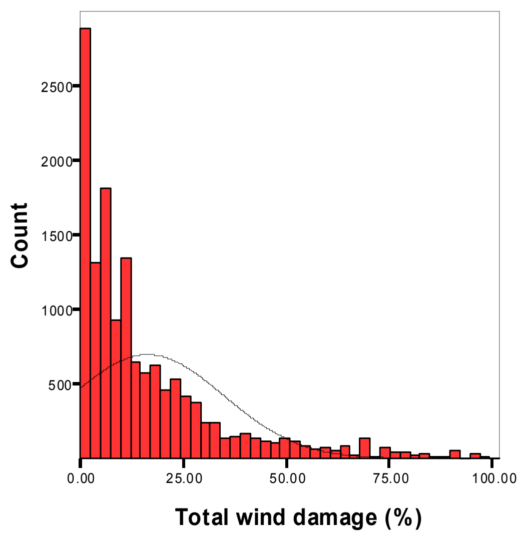


Figure A5. Distribution of strip lengths for retained strips.



Cases weighted by a plot length based weighting factor.

Figure B1. Distribution of wind damage along external edges that are ≥ (GE) 2 wind seasons old.

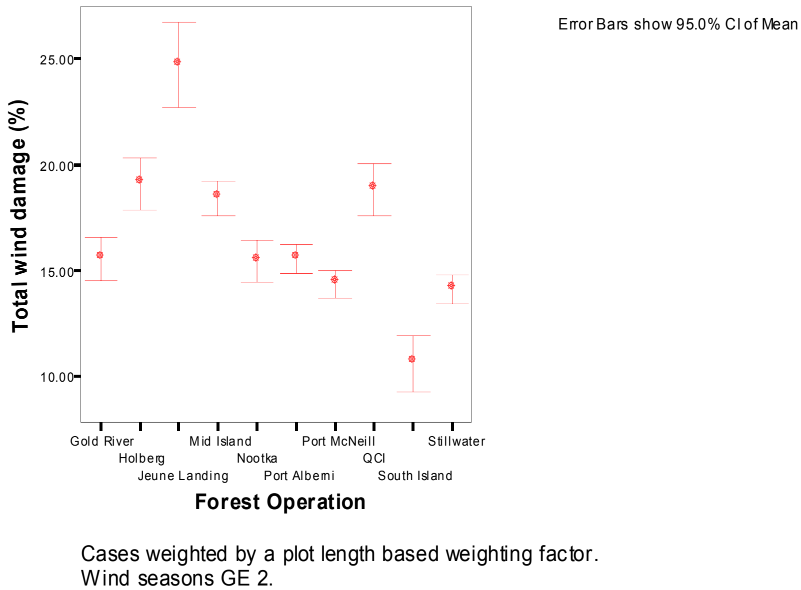


Figure B2. Distribution of wind damage along external edges by Forest Operation.

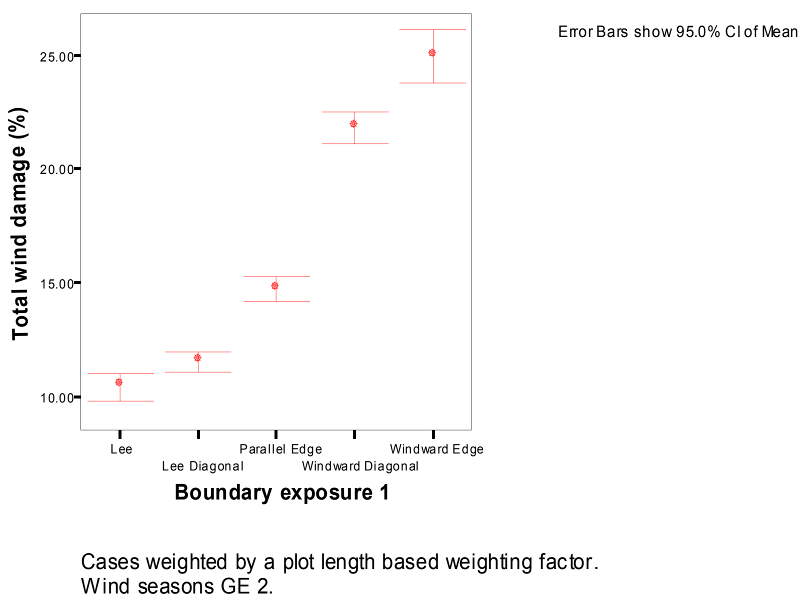
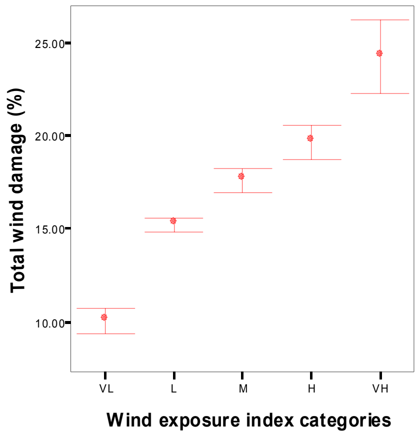
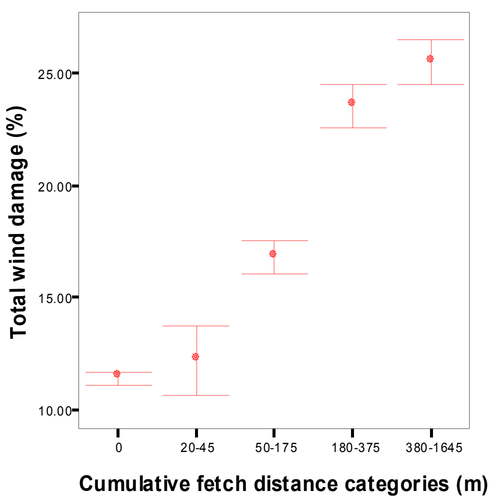


Figure B3. Distribution of wind damage by boundary exposure along external edges.



Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure B4. Distribution of wind damage by wind exposure index along external edges.



Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure B5. Distribution of wind damage by cumulative fetch classes along external edges (winds from two directions).

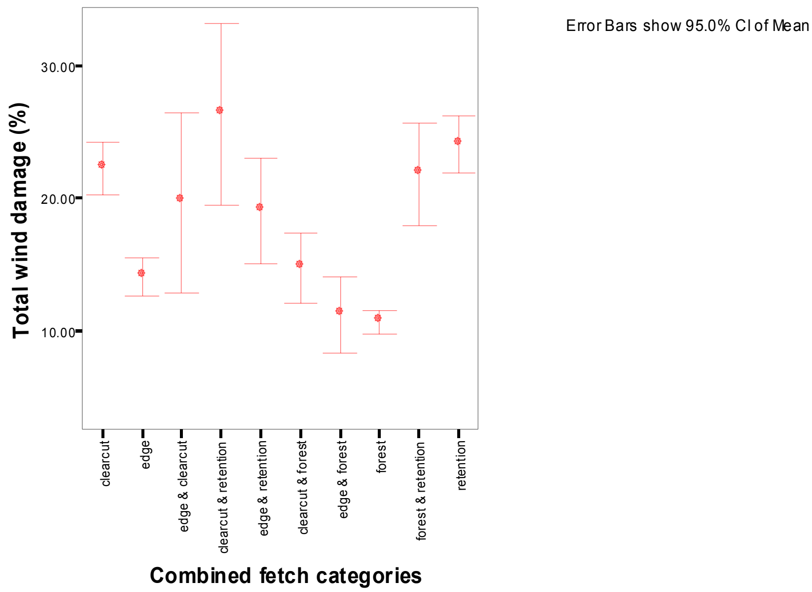


Figure B6. **Distribution of wind damage along external edges with changes in combined fetch types (winds from two directions).**

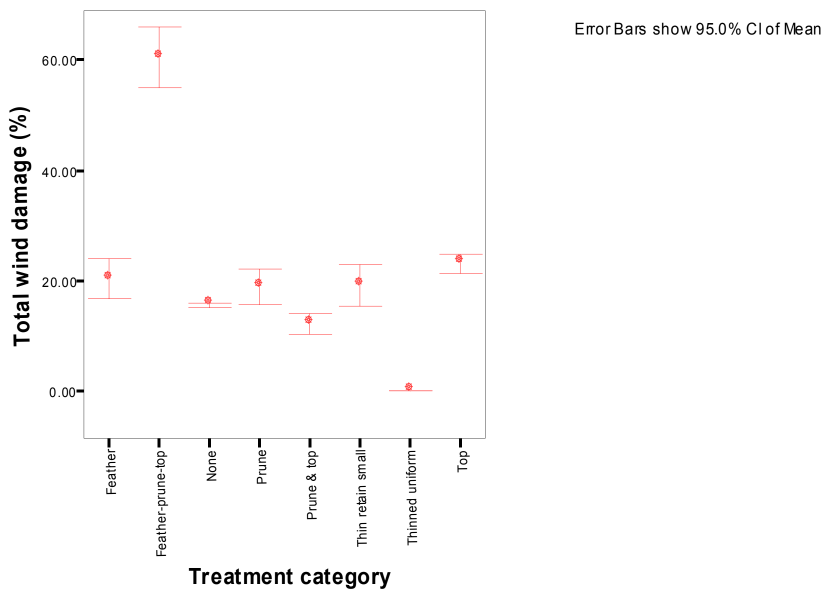
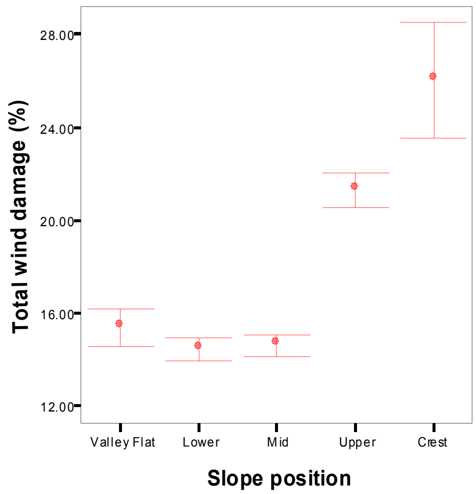
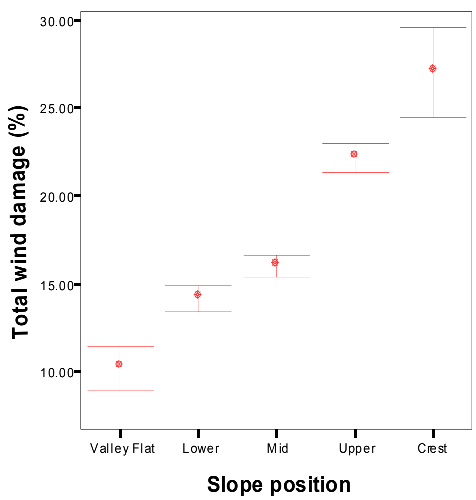


Figure B7. **Distribution of wind damage by treatments along external edges. (*Note*: *Probably few valid comparisons)*.**



Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure B8a. Distribution of wind damage along external edges by slope position (all stands).



Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure B8b. Distribution of wind damage along external edges by slope position (second growth stands removed from sample).

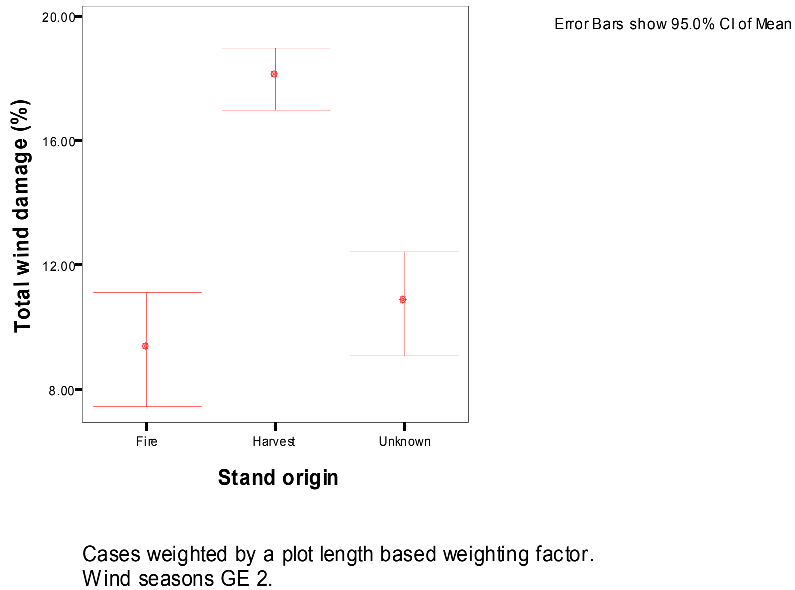


Figure B8c. Distribution of wind damage along external edges by stand origin on valley floors.

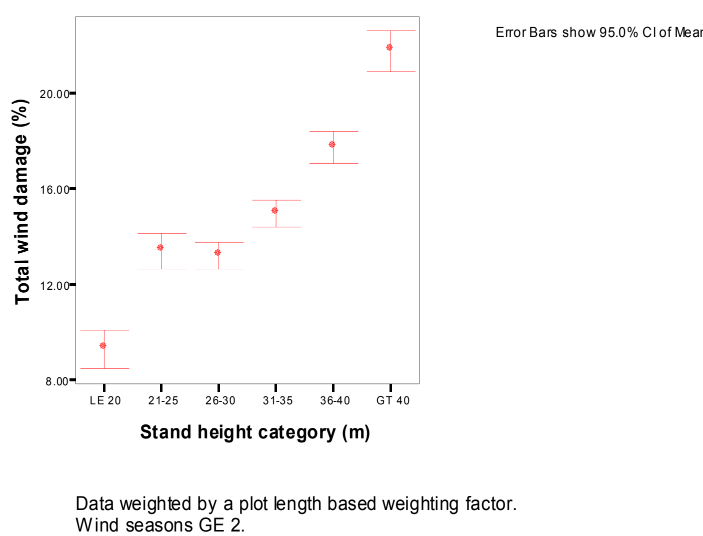
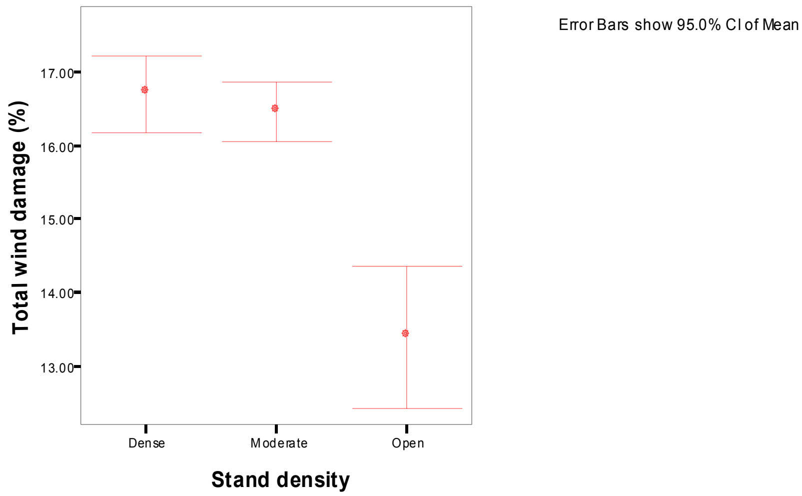
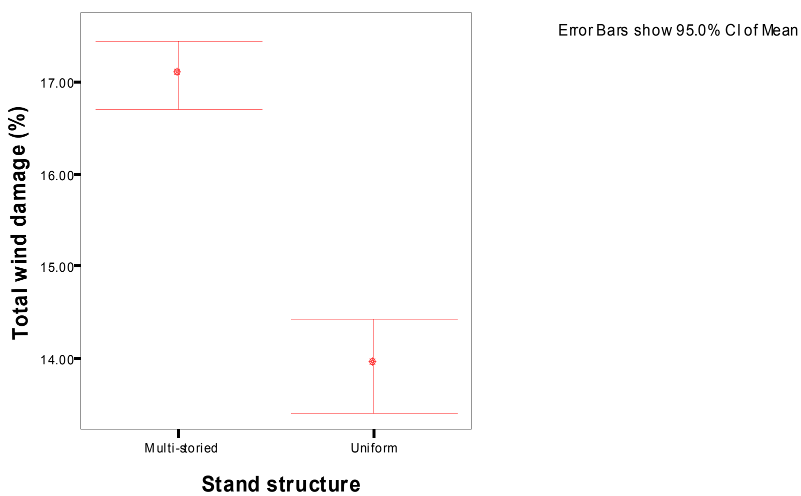


Figure B9. Distribution of wind damage along external edges with changes in average stand height.



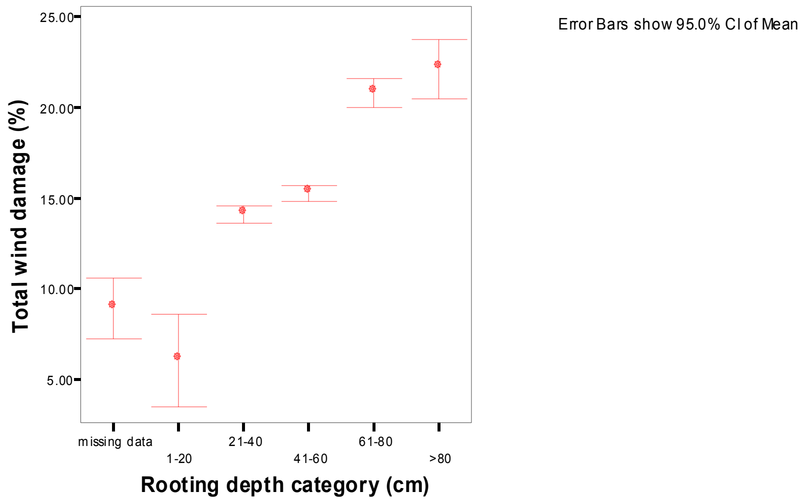
Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure B10. Distribution of wind damage along external edges with changes in stand density.



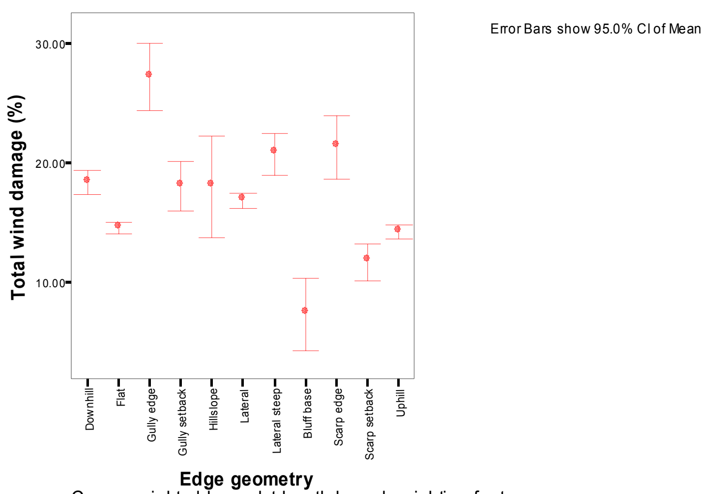
Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure B11. Distribution of wind damage along external edges with changes in stand structure.



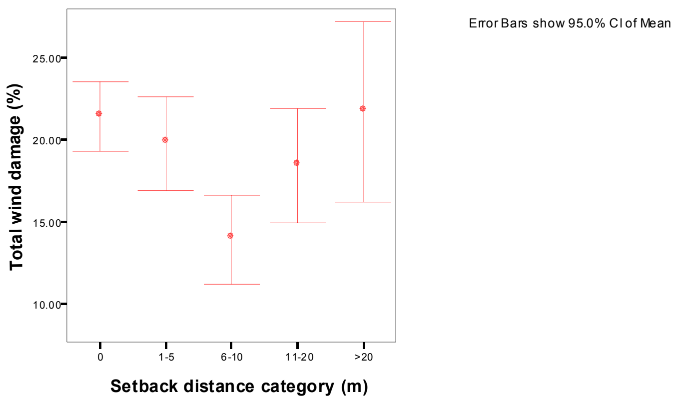
Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure B12. Distribution of wind damage along external edges with changes in rooting depth.



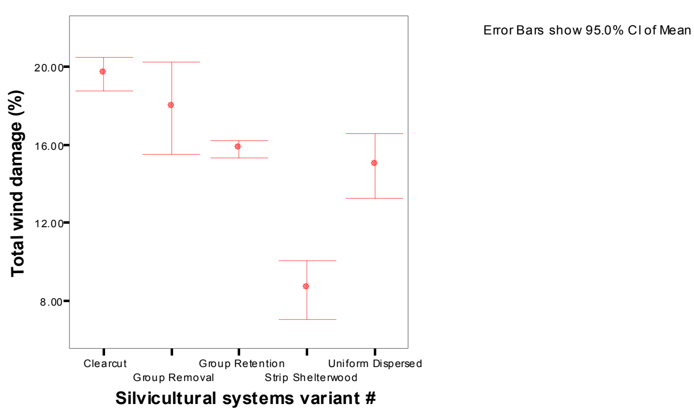
Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure B13. Distribution of wind damage along external edges with changes in edge geometry.



Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure B14. Setback distance versus percent windthrow along external edges along gullies and stream escarpments.



Data weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure B15. Silviculture system variant versus percent windthrow along external edges within the Vancouver Island Ranges.

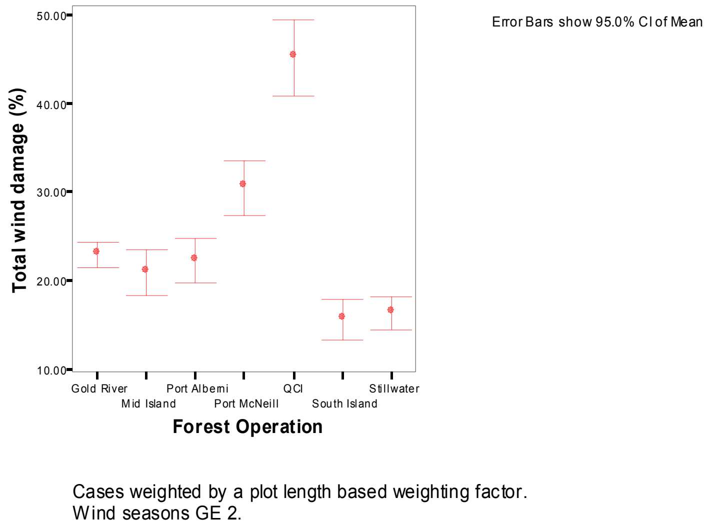


Figure C1. Distribution of windthrow along large patch edges by Forest Operation.

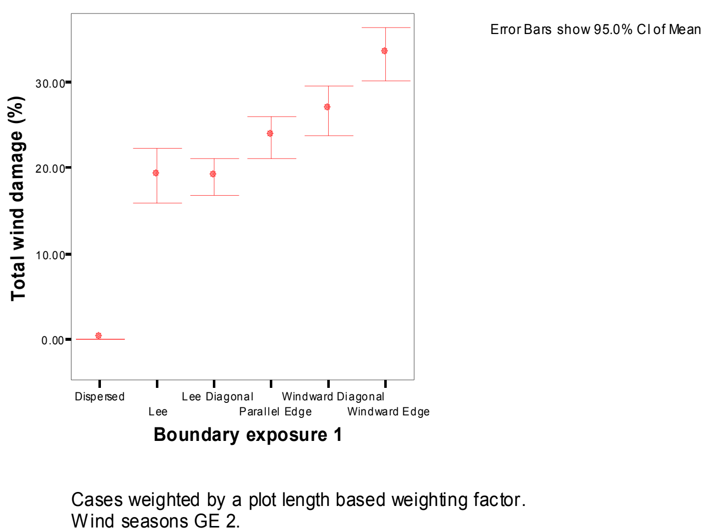


Figure C2. Distribution of wind damage by primary boundary exposure along large patch edges.

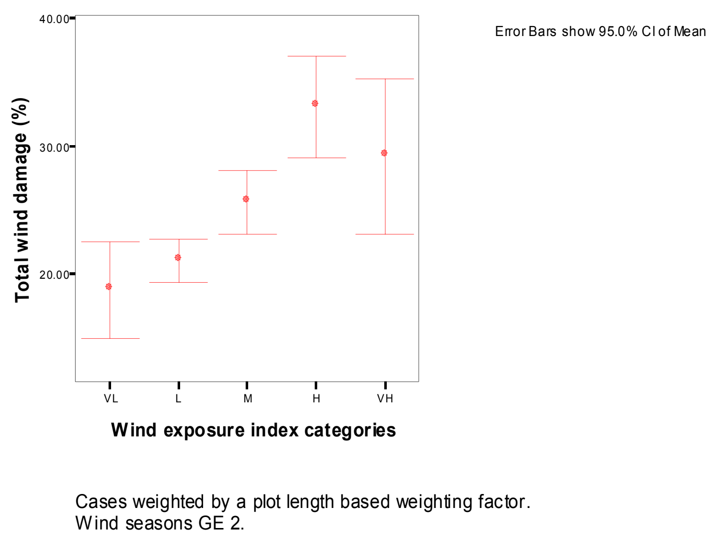


Figure C3. Distribution of wind damage by wind exposure index category along large patch edges.

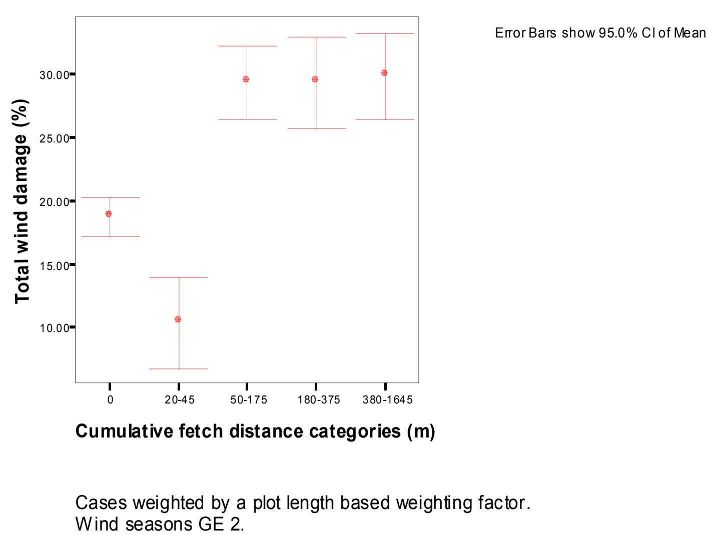


Figure C4. Distribution of wind damage by cumulative fetch classes along large patch edges.

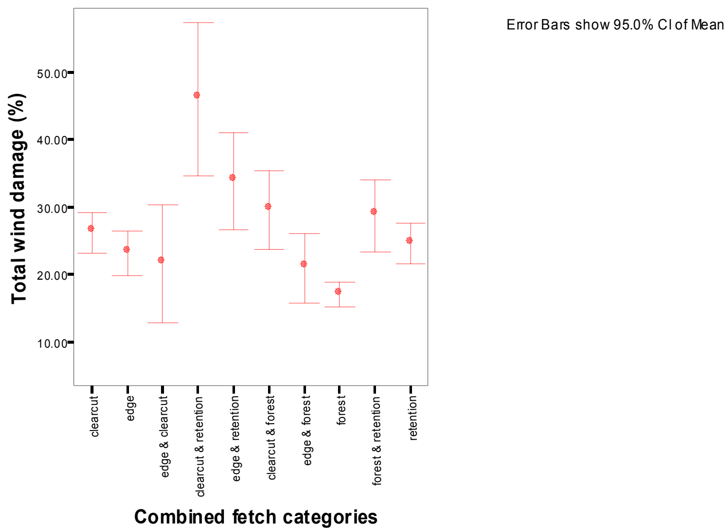


Figure C5. Distribution of wind damage along large patch edges changes in combined fetch categories.

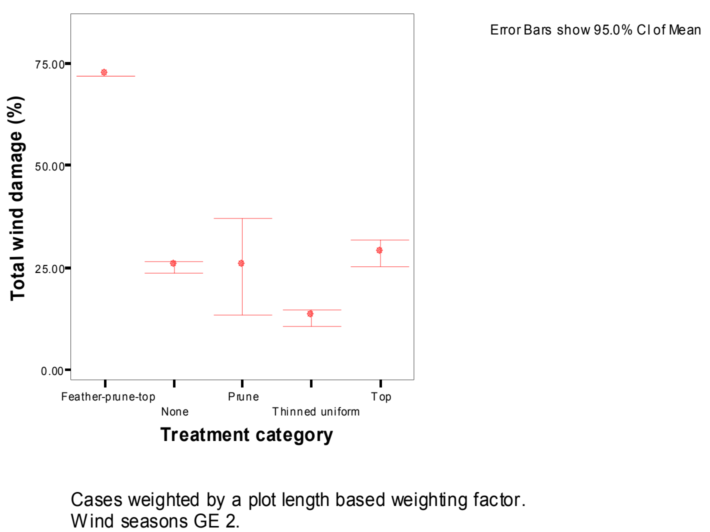
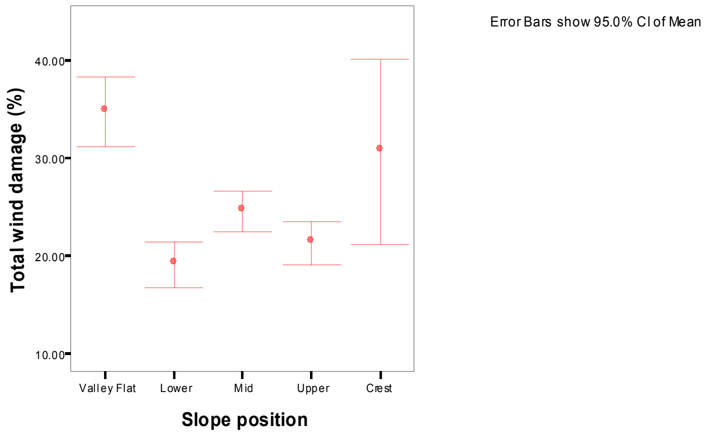
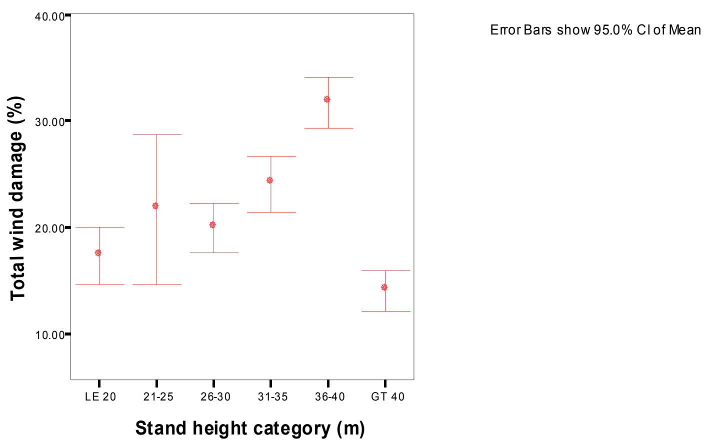


Figure C6. Distribution of wind damage by edge and crown treatments along large patch edges. (Note: few valid comparisons.)



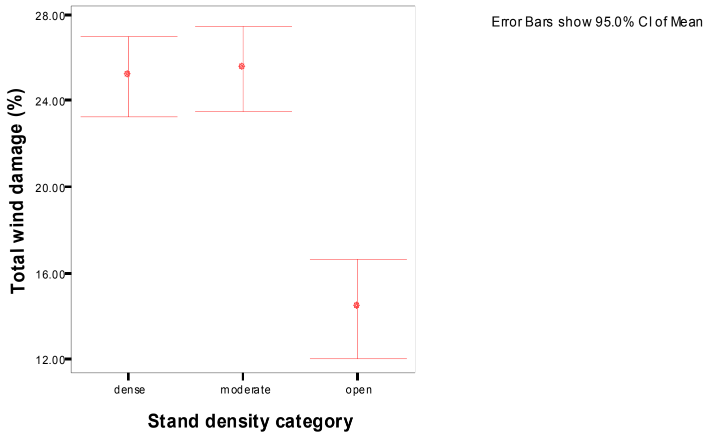
Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure C7. Distribution of wind damage along large patch edges by slope position



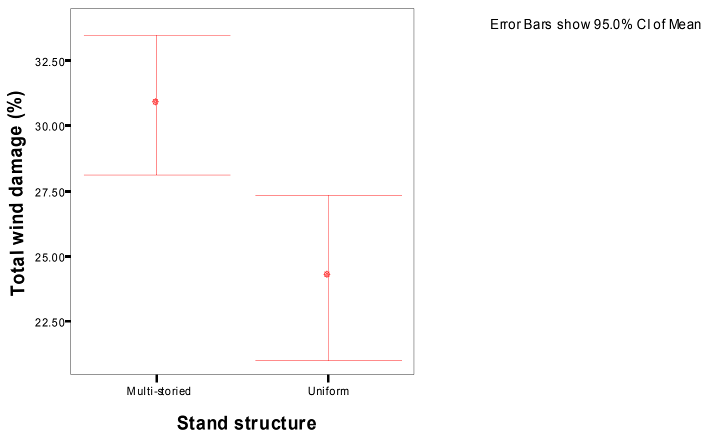
Data weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure C8. Distribution of wind damage along large patch edges with changes in average stand height.



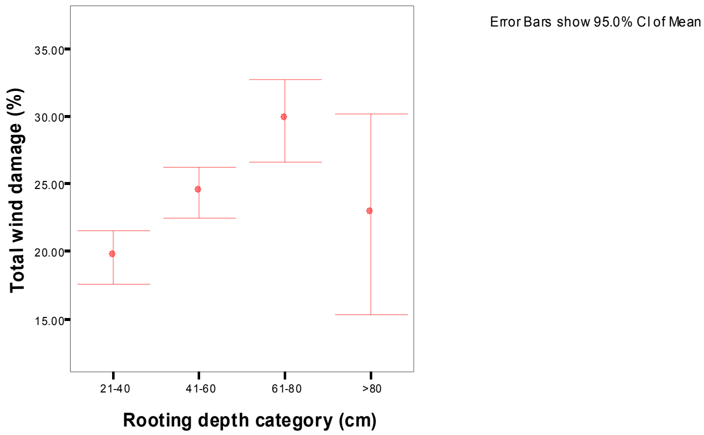
Data weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure C9. Distribution of wind damage along large patch edges with changes in stand density.



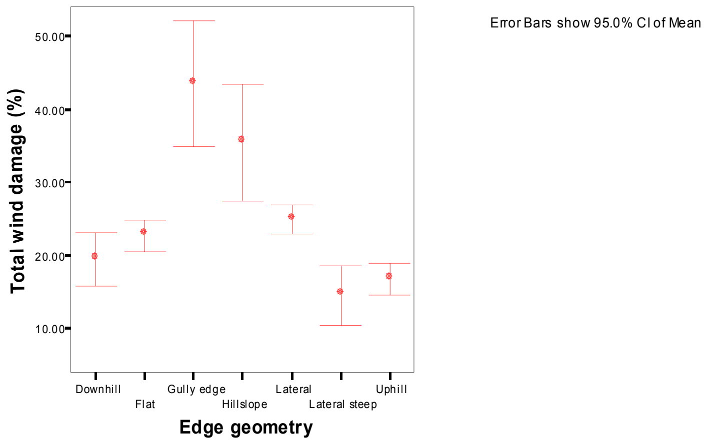
Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure C10. Distribution of wind damage along large patch edges with changes in stand structure.



Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure C11. Distribution of windthrow along patch edges with changes in rooting depth.



Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure C12 Changes in wind damages rate with changes in edge geometry along large patch edges.

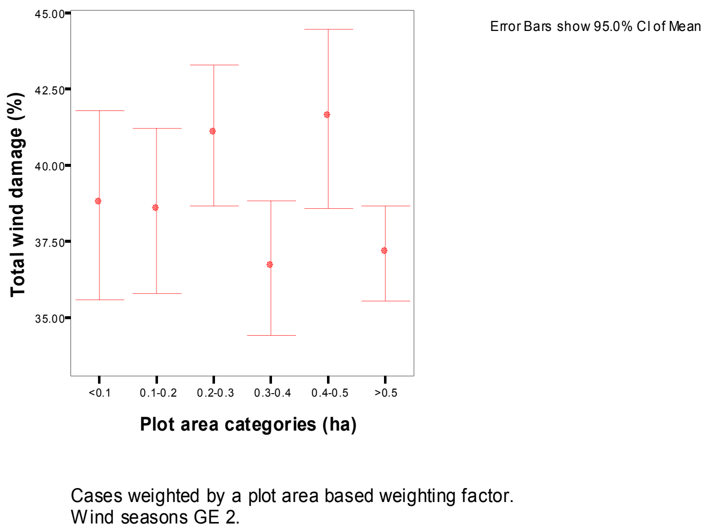


Figure D1. **Distribution of wind damage in groups and clusters with changes in patch area (ha).**

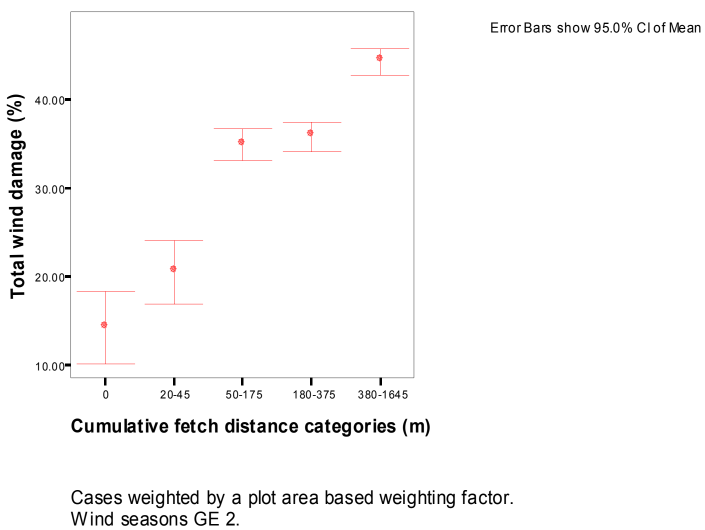
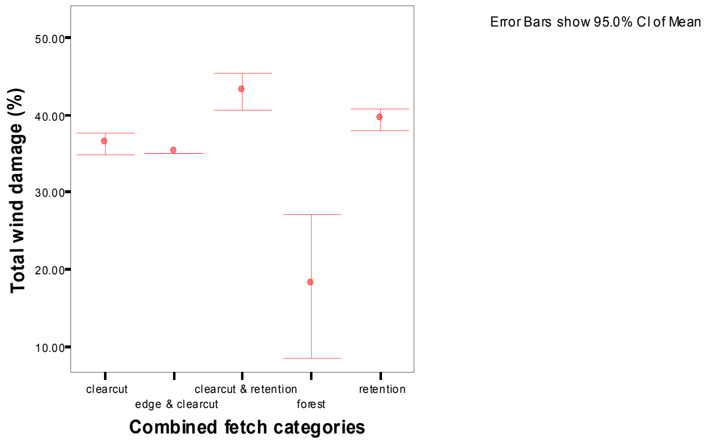


Figure D2. **Distribution of wind damage in groups and clusters with changes cumulative fetch distance class.**



Cases weighted by a plot area based weighting factor.
Wind seasons GE 2.

Figure D3. Distribution of wind damage in groups and clusters with changes generalized fetch type.

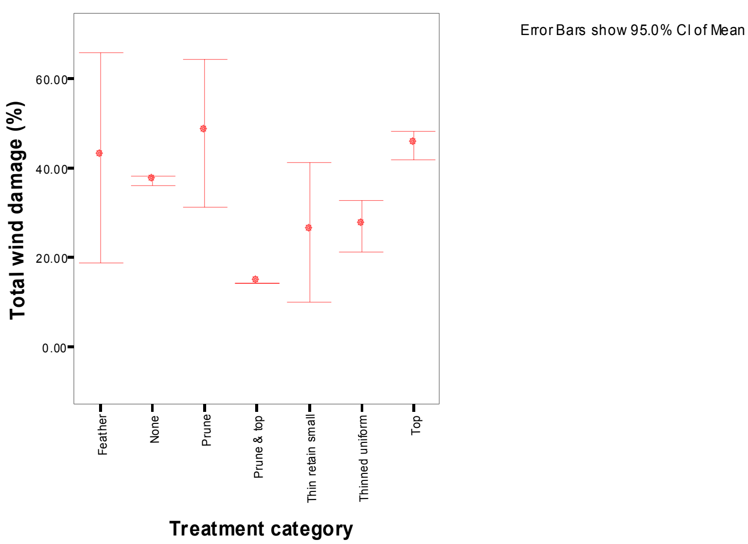
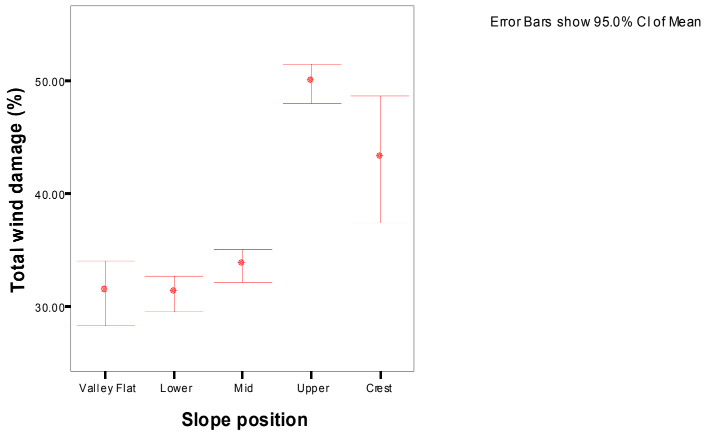
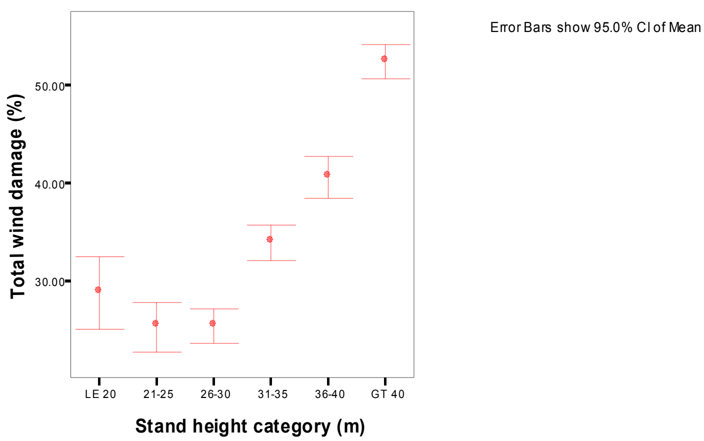


Figure D4. Distribution of wind damage in groups and clusters with changes in edge treatment.



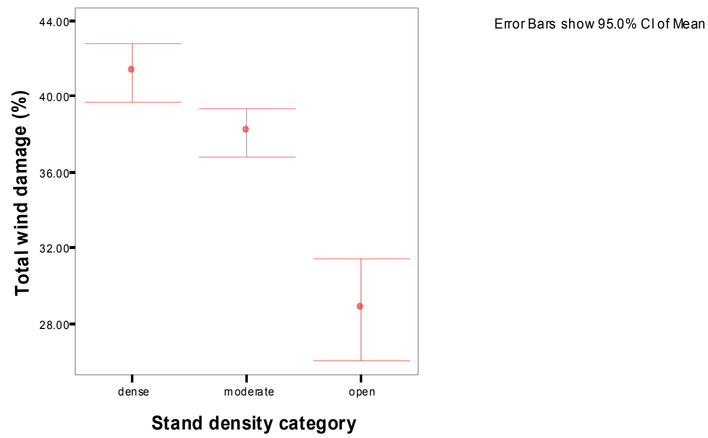
Cases weighted by a plot area based weighting factor.
Wind seasons GE 2.

Figure D5. Distribution of wind damage in groups and clusters with changes in slope position.



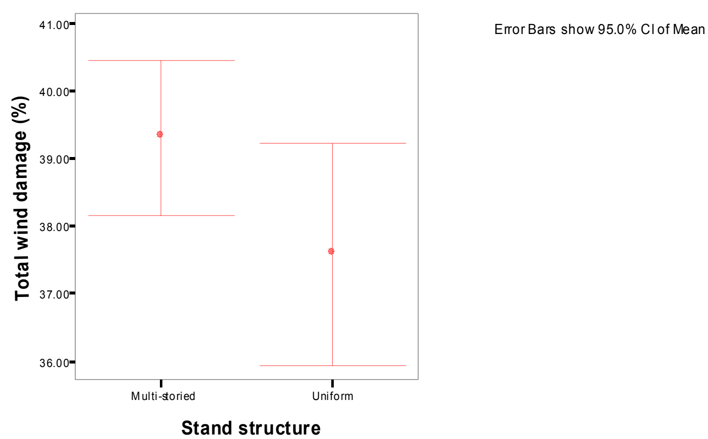
Cases weighted by a plot area based weighting factor.
Wind seasons GE 2.

Figure D6. Distribution of wind damage in groups and clusters with changes in estimated average stand height.



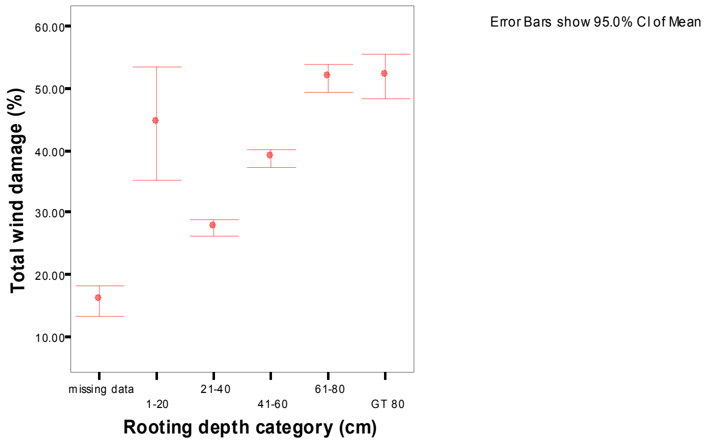
Cases weighted by a plot area based weighting factor.
Wind seasons GE 2.

Figure D7. Distribution of wind damage in groups and clusters with changes stand density class.



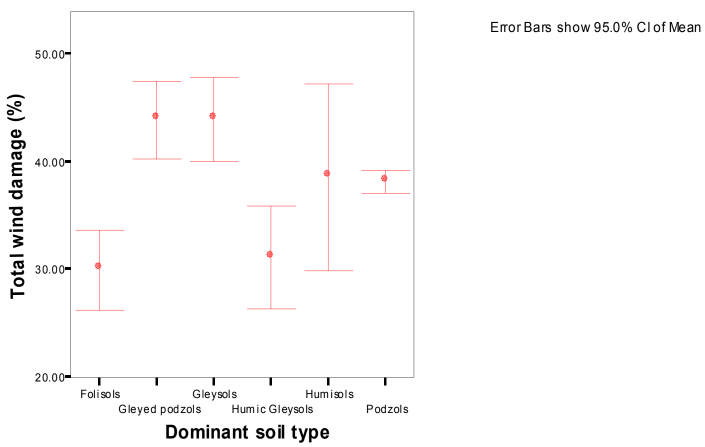
Cases weighted by a plot area based weighting factor.
Wind seasons GE 2.

Figure D8. Distribution of wind damage in groups and clusters with changes in stand structure class.



Cases weighted by a plot area based weighting factor.
Wind seasons GE 2.

Figure D9. Distribution of wind damage in groups and clusters with changes in rooting depth.



Cases weighted by a plot area based weighting factor.
Wind seasons GE 2.

Figure D10. Distribution of wind damage in groups and clusters with changes in dominant soil type.

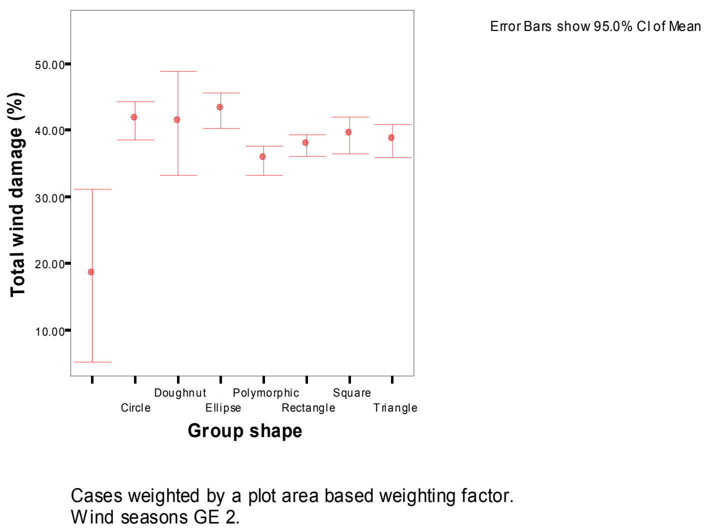


Figure D11. Distribution of wind damage in groups and clusters with changes in group shape.

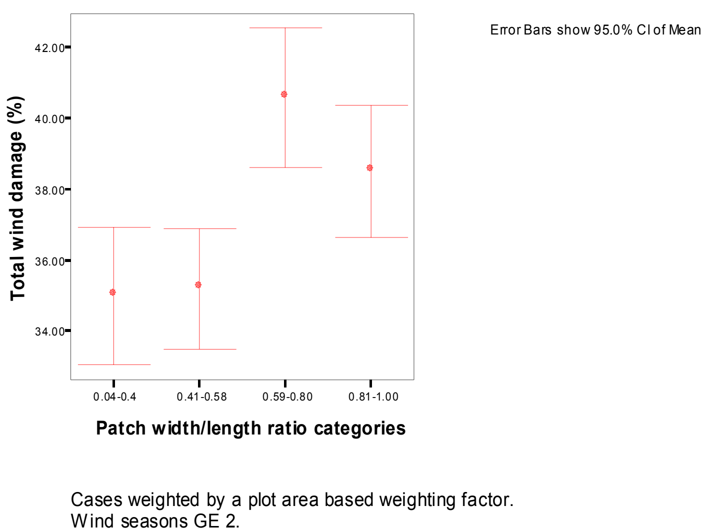
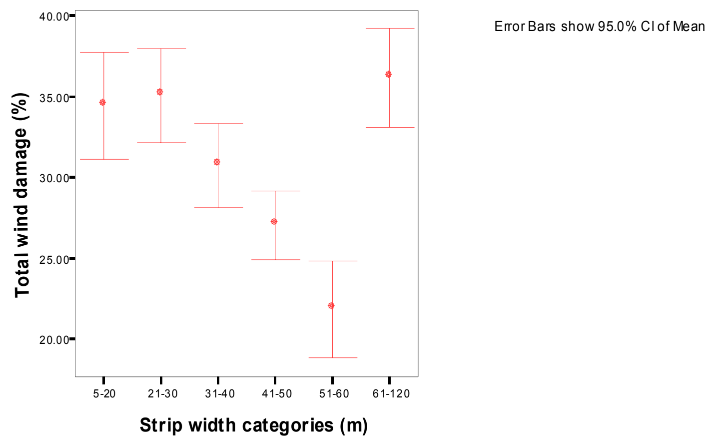
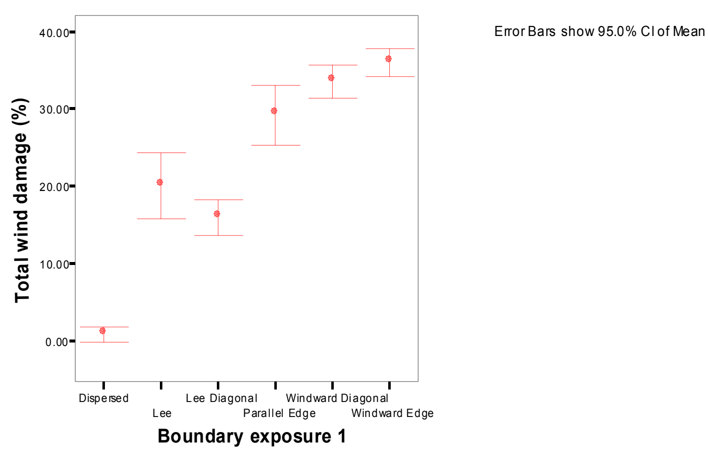


Figure D12. Distribution of wind damage in groups with changes in length/width ratios. **(this may fall into the who cares category)**



Cases weighted by a strip length based weighting factor.
Wind seasons GE 2.

Figure E1. Distribution of windthrow in retained strips with changes in strip width class.



Cases weighted by a strip length based weighting factor.
Wind seasons GE 2.

Figure E2. Distribution of wind damage in retained strips with changes in primary boundary exposure class.

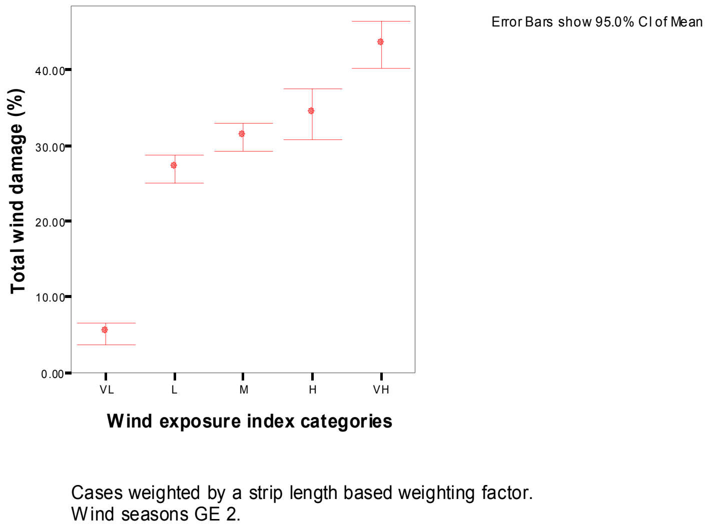


Figure E3. Distribution of wind damage in retained strips with changes in wind exposure index category.

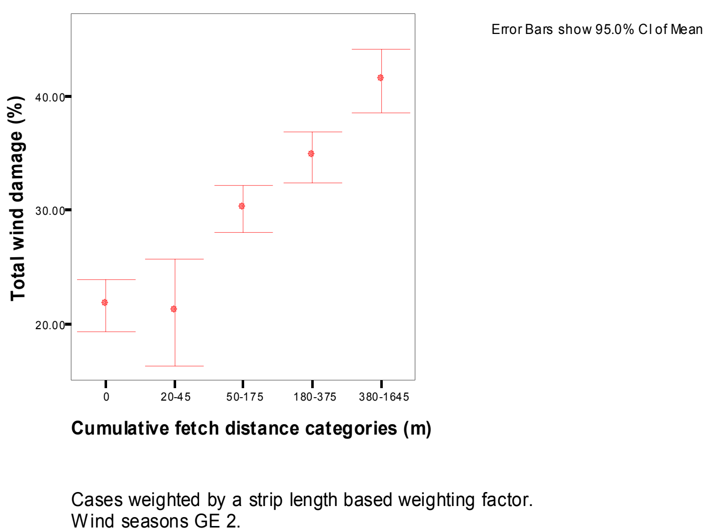


Figure E4. Distribution of wind damage in retained strips with changes in cumulative fetch distance category.

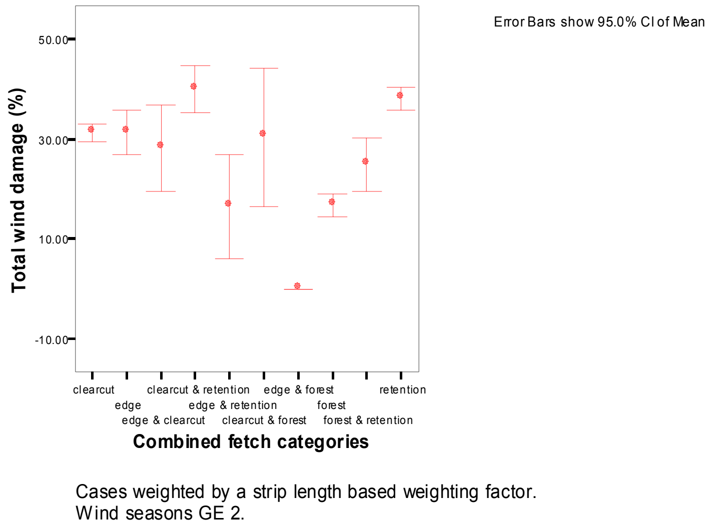


Figure E5. Distribution of wind damage in retained strips with changes in general fetch type.

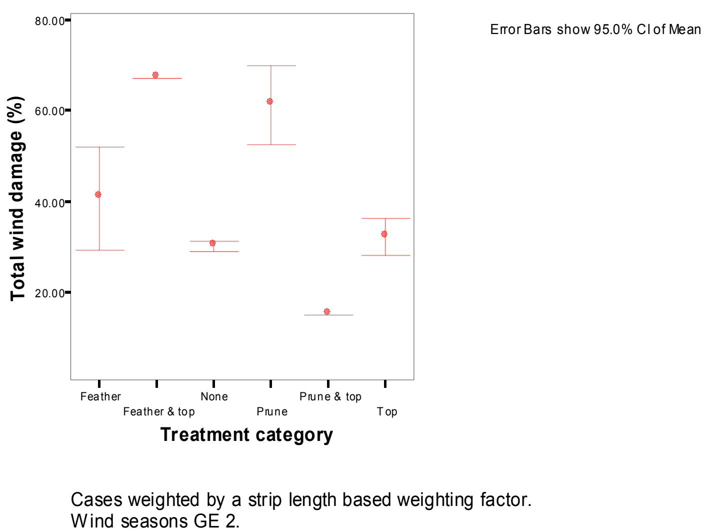


Figure E6. Distribution of wind damage in retained strips with changes in edge treatment type.

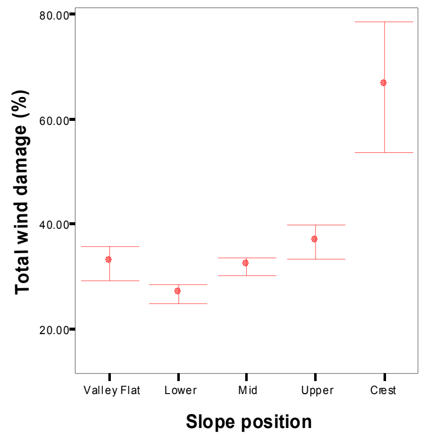


Figure E7. Distribution of wind damage in retained strips with changes in slope position.

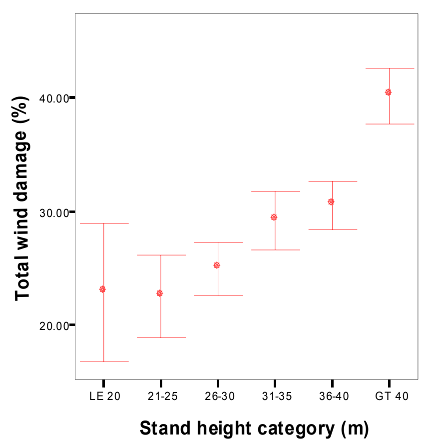


Figure E8. Distribution of wind damage in retained strips with changes in stand height. ***(Note: there are a limited number of samples in the 17-20 m height classes.)***

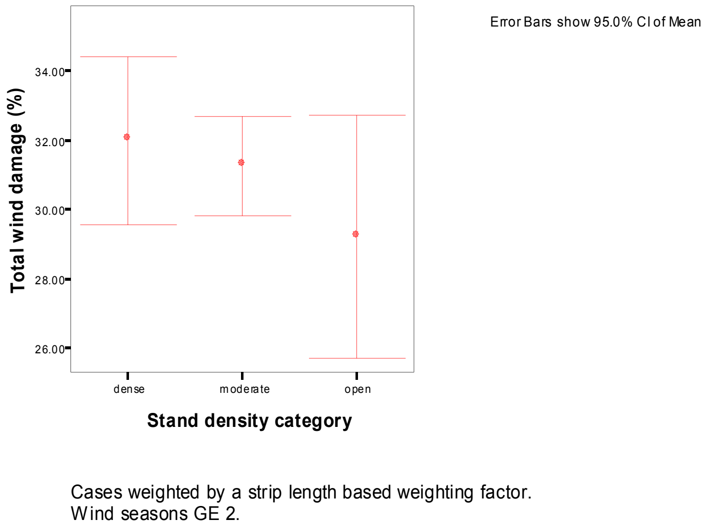


Figure E9. Distribution of windthrow in retained strips with changes in stand density class.

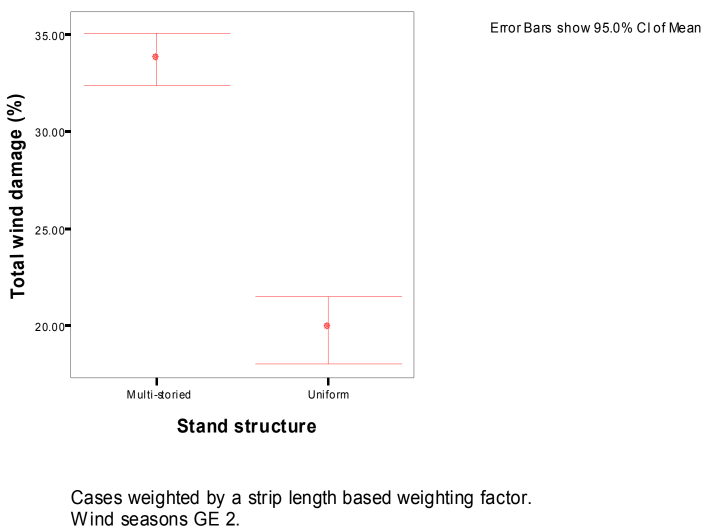


Figure E10. Distribution of windthrow in retained strips with changes in stand structure.

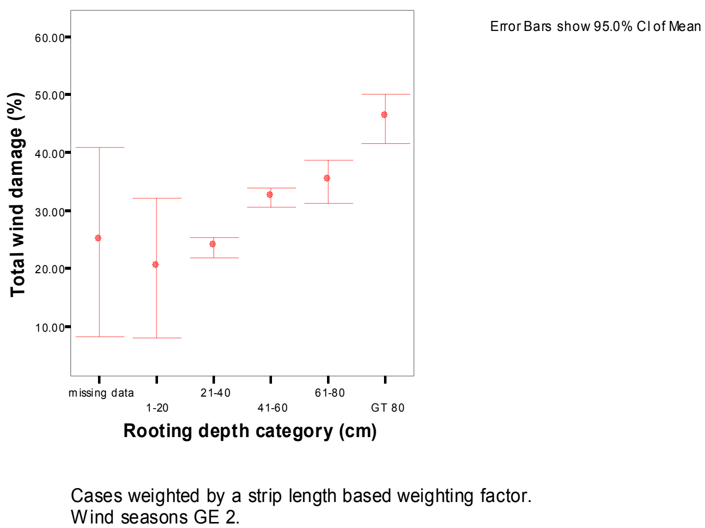


Figure E11. Distribution of wind damage in retained strips with changes in rooting depth.

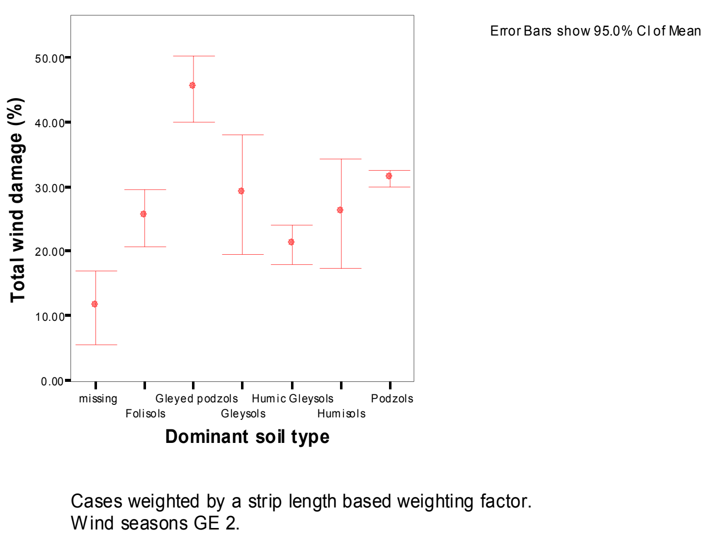
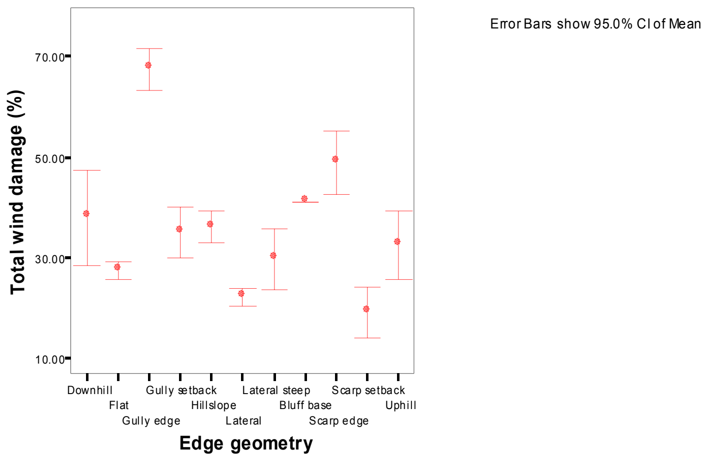
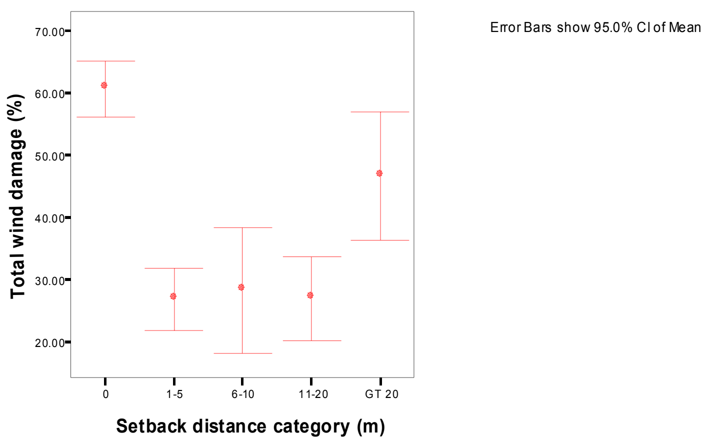


Figure E12. Distribution of wind damage in retained strips with changes in dominant soil type.



Cases weighted by a strip length based weighting factor.
Wind seasons GE 2.

Figure E13. Distribution of wind damage in retained strips with changes in edge geometry categories.



Cases weighted by a strip length based weighting factor.
Wind seasons GE 2.

Figure E14 Effect of setback distance on wind damage in strip edges located along gully edges and stream escarpment edges.

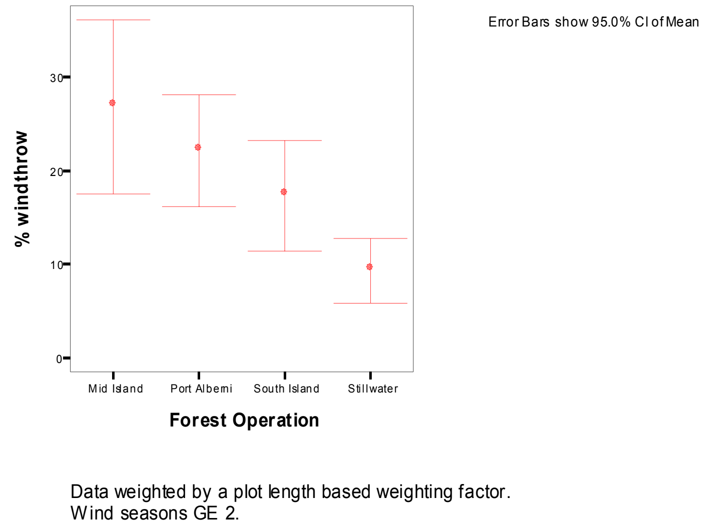


Figure F1. Distribution of windthrow in areas of dispersed retention by Forest Operation.

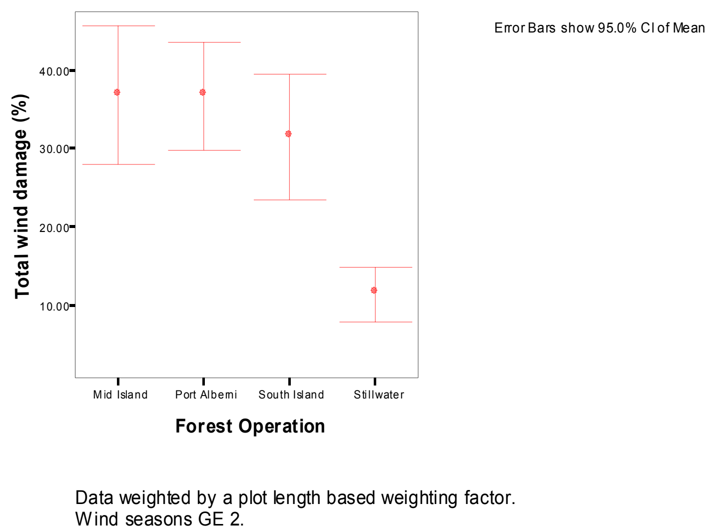


Figure F2. Distribution of total wind damage in areas of dispersed retention by Forest Operation.

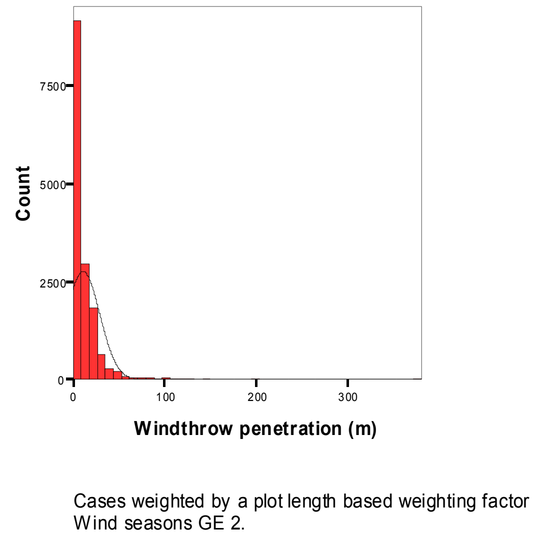


Figure G1. Frequency distribution of windthrow penetration along external edges and large patch edges.

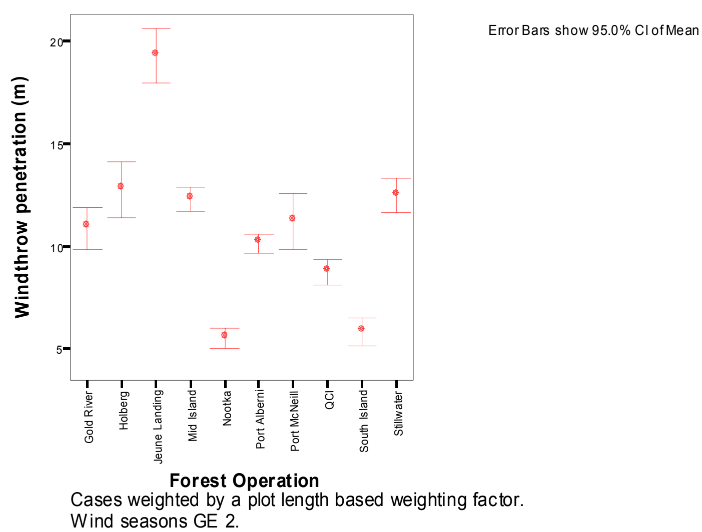
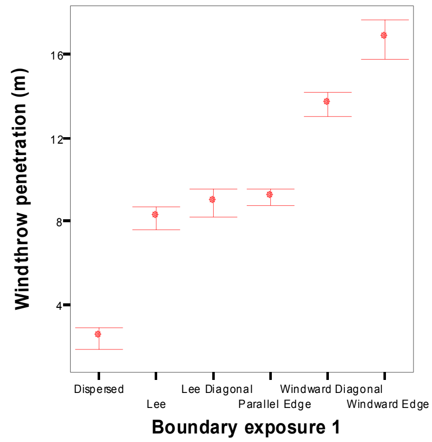


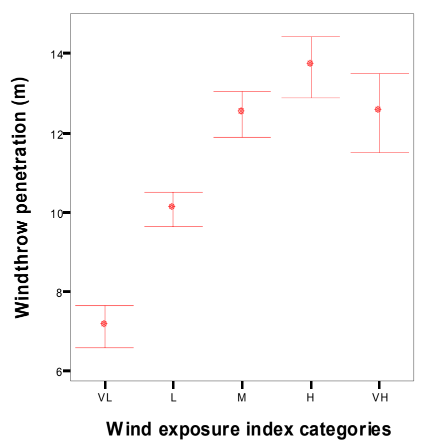
Figure G2. Distribution of windthrow penetration along external edges and large patch edges by Forest Operation.



Error Bars show 95.0% CI of Mean

Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure G3. Distribution of windthrow penetration along external and large patch edges with changes in boundary exposure.



Error Bars show 95.0% CI of Mean

Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure G4. Distribution of windthrow penetration along external and large patch edges with changes in wind exposure index.

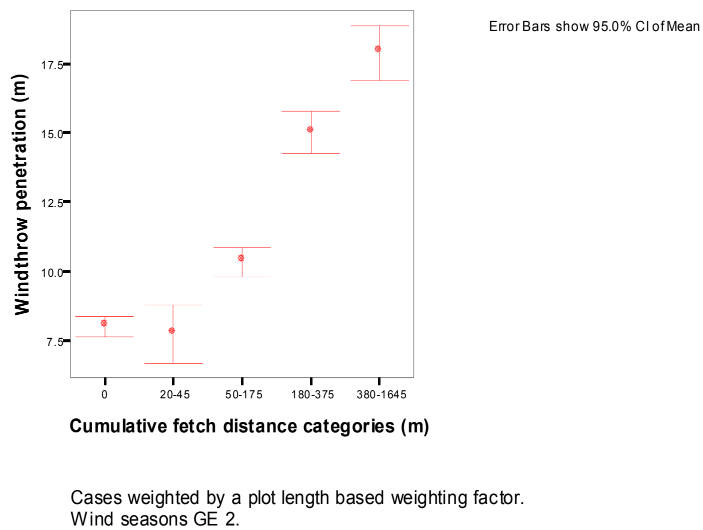


Figure G5. Distribution of windthrow penetration along external and large patch edges with changes in cumulative fetch.

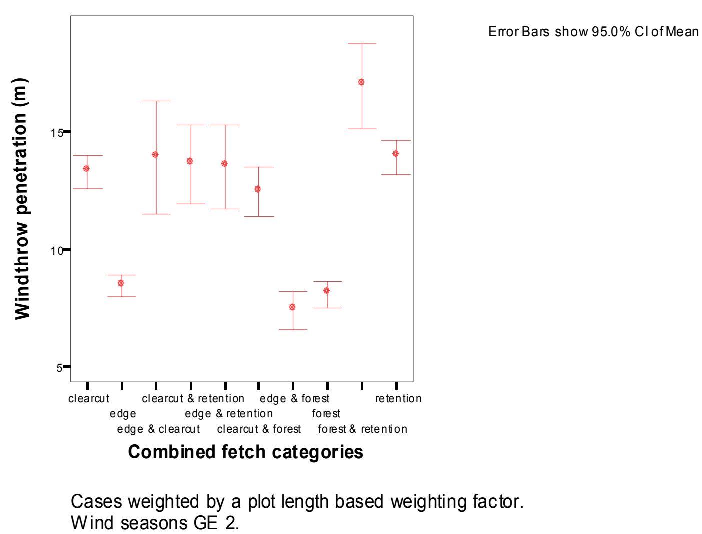
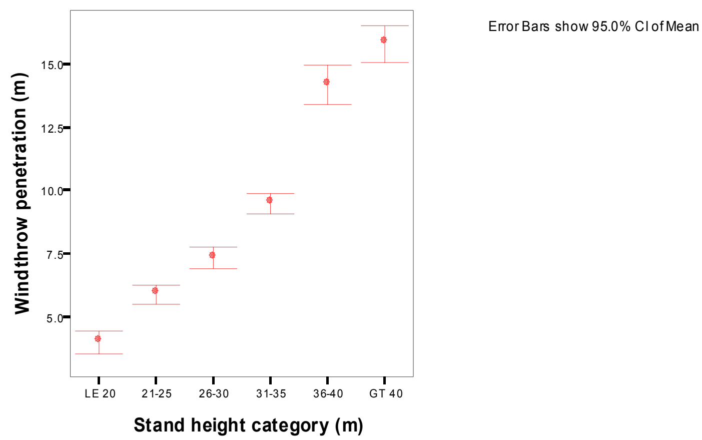
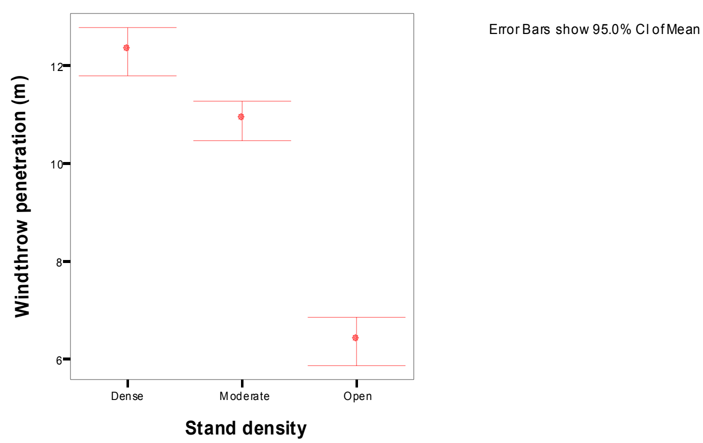


Figure G6. Distribution of windthrow penetration along external and large patch edges with changes in the upwind surface.



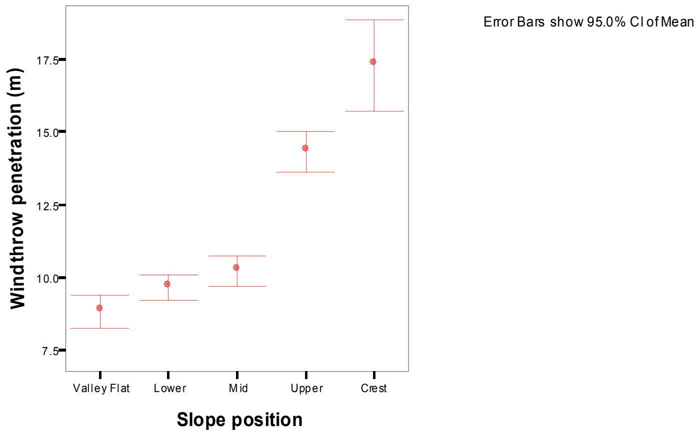
Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure G7. Distribution of windthrow penetration along external and large patch edges with changes in estimated average stand height.



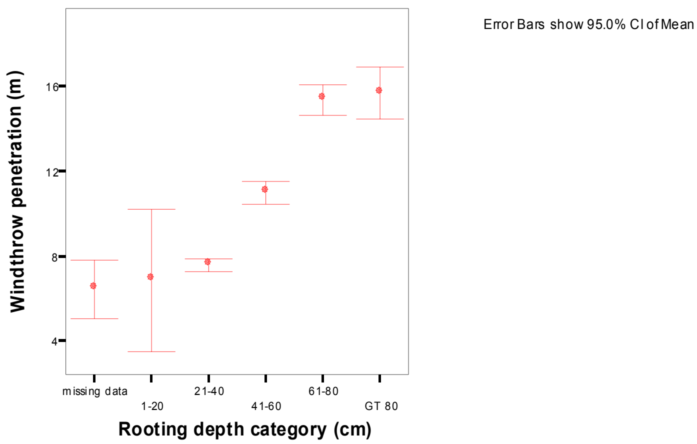
Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure G8. Distribution of windthrow penetration along external and large patch edges with changes in stand density.



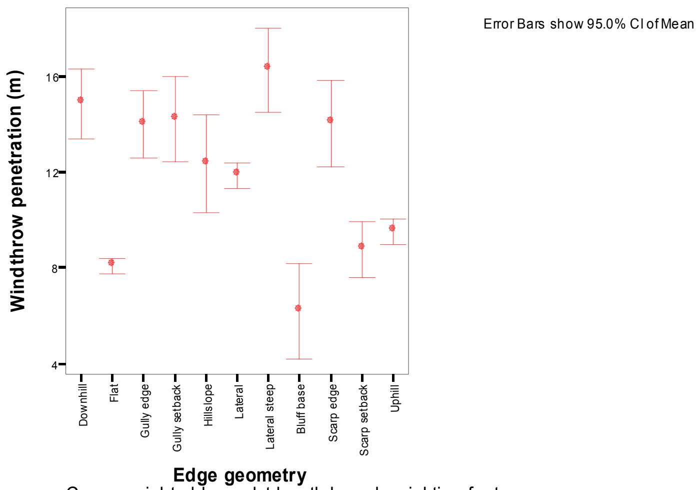
Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure G9. Distribution of windthrow penetration along external and large patch edges with changes in slope position.



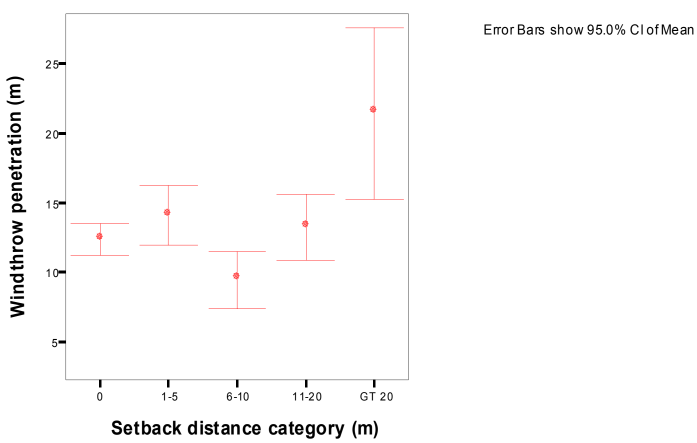
Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure G10. Distribution of windthrow penetration along external and large patch edges with changes in rooting depth.



Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure G11. Distribution of windthrow penetration along external edges and large patch edges with changes in edge geometry.



Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure G12. Setback distance versus windthrow penetration along external edges and large patches for gullies and stream escarpments.

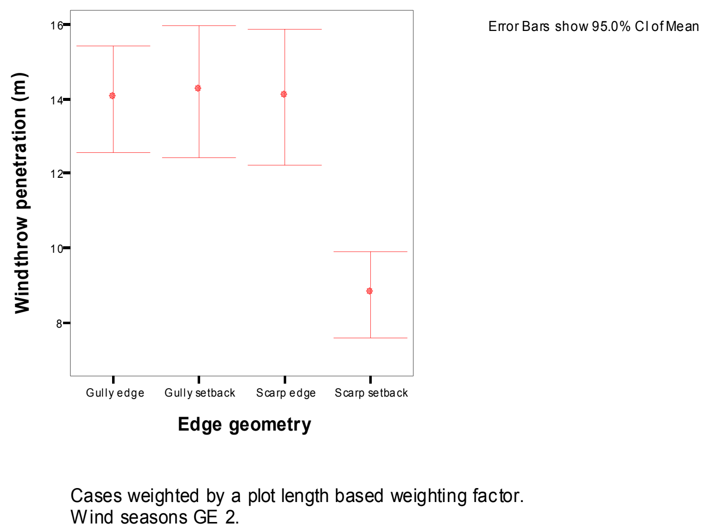


Figure G13. Effect of setbacks on windthrow penetration along external edges and large patches for gullies and stream escarpments.

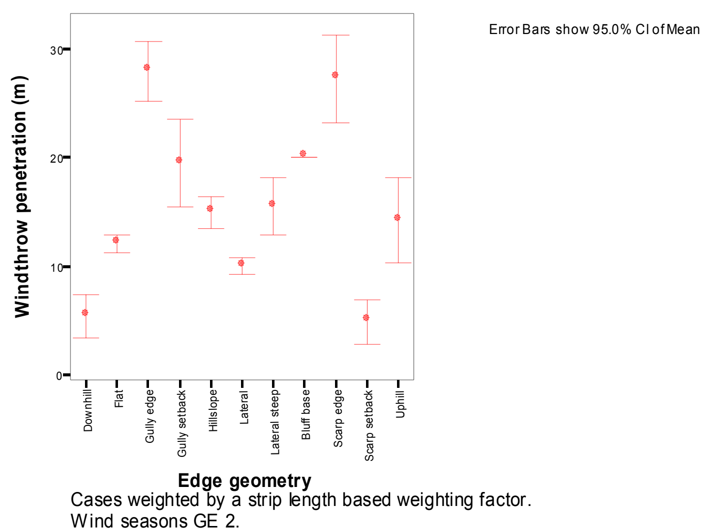


Figure G14. Distribution of windthrow penetration along strip edges with changes in edge geometry.

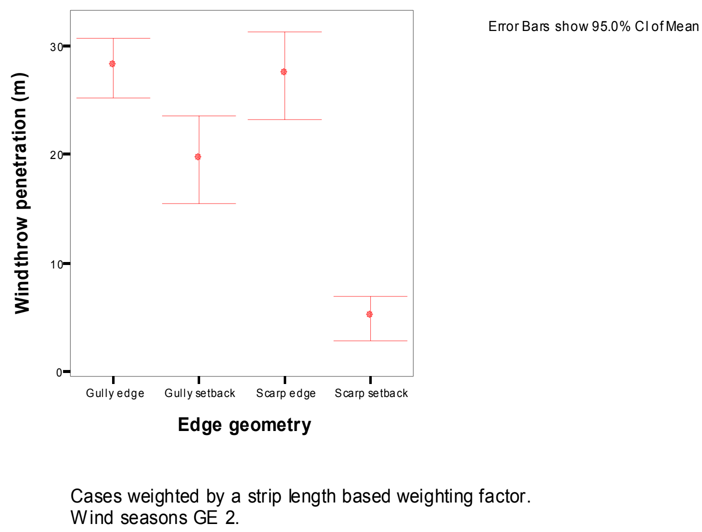


Figure G15. Distribution of windthrow penetration along strip edges associated with gully and stream escarpment setbacks.

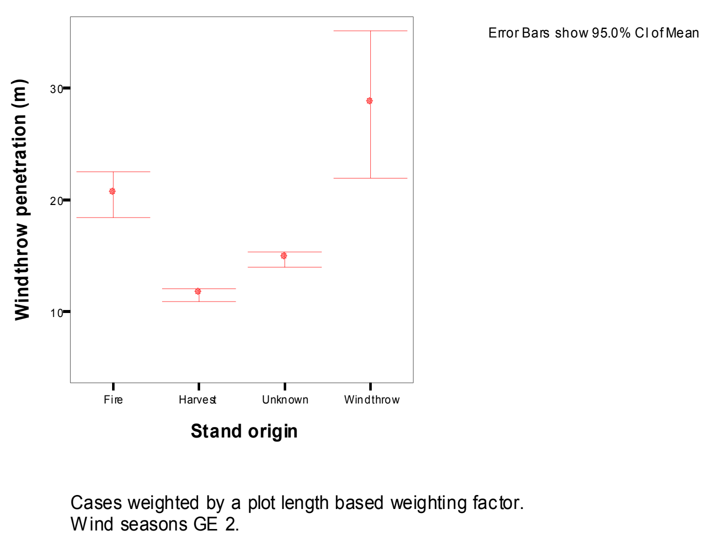
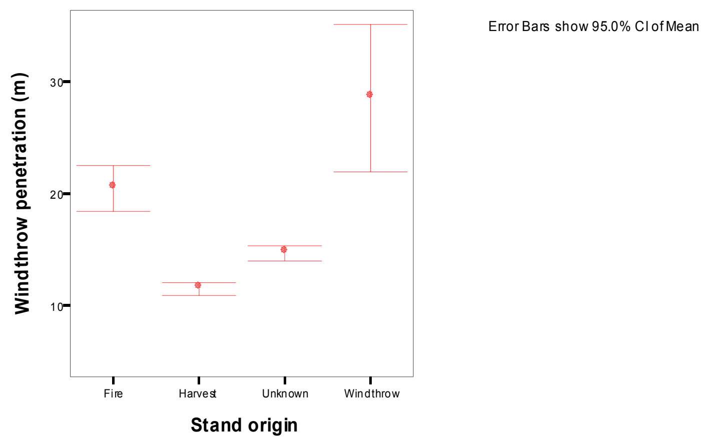
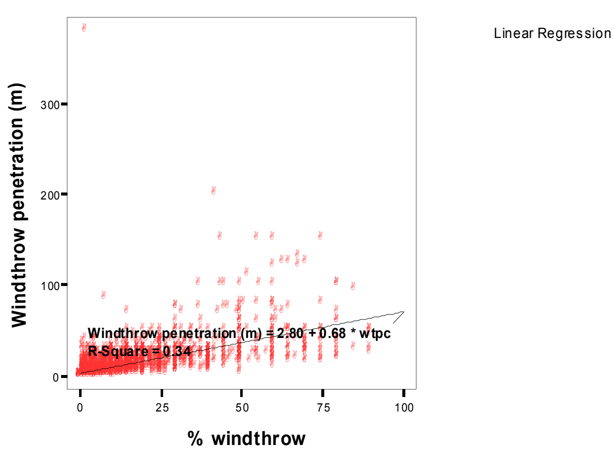


Figure G16. Windthrow penetration along external edges and large patch edges for differences in stand origin for all edge exposures.



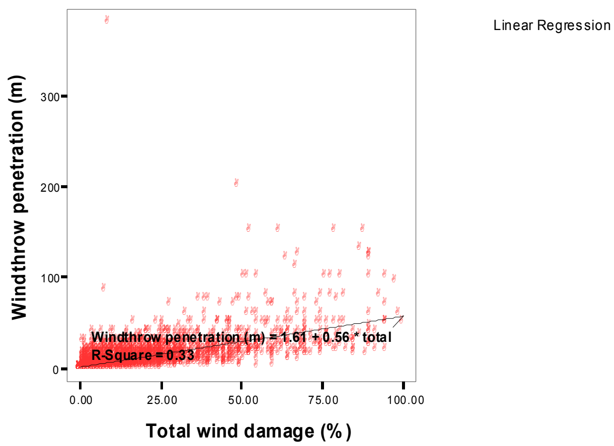
Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure G17. Windthrow penetration along external and large patch edges for differences in stand origin and only windward edges.



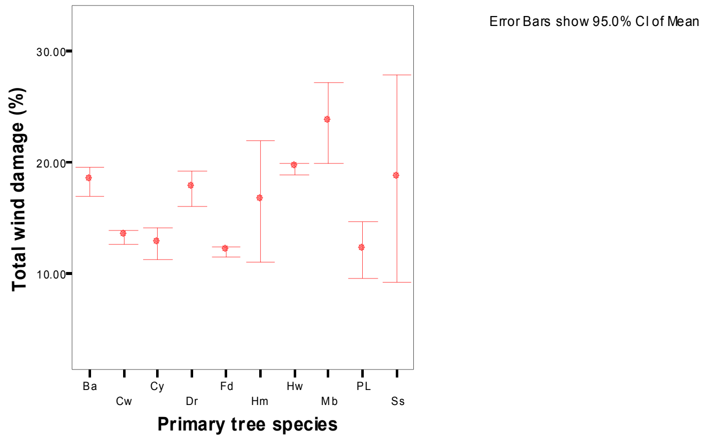
Cases weighted by a strip length based weighting factor.
Wind seasons GE 2

Figure G18. Relationship between windthrow penetration and windthrow rate along external and large patch edges.



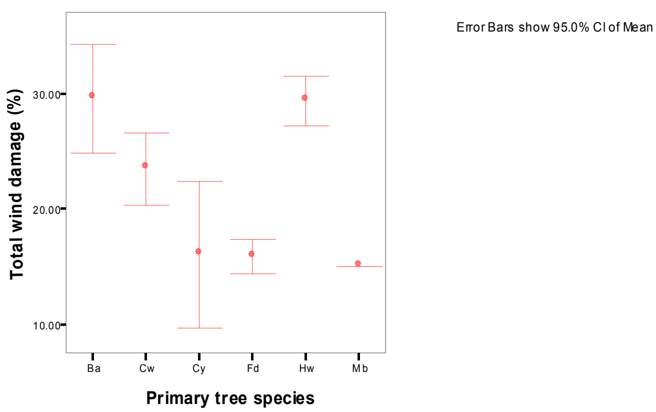
Cases weighted by a strip length based weighting factor.
Wind seasons GE 2

Figure G19. Relationship between windthrow penetration and total wind damage along external and large patch edges.



Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure H1. Relationship between tree species and total wind damage along external cutblock edges.



Cases weighted by a plot length based weighting factor.
Wind seasons GE 2.

Figure H2. Relationship between tree species and total wind damage along external edges of large patches.

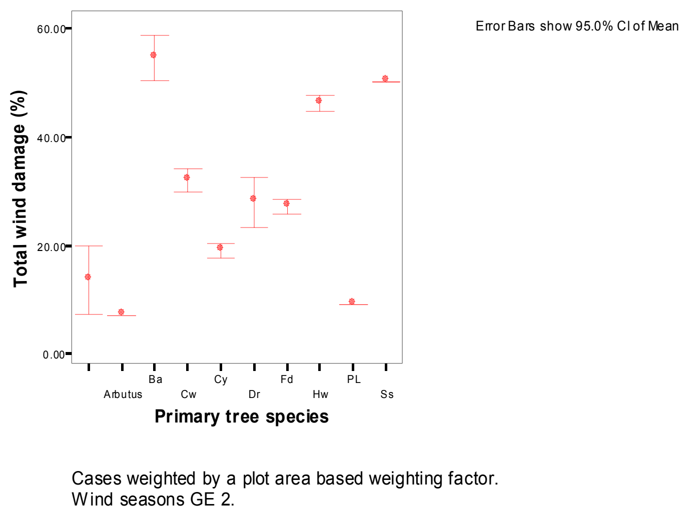


Figure H3. Relationship between tree species and total wind damage along external edges of small patches.

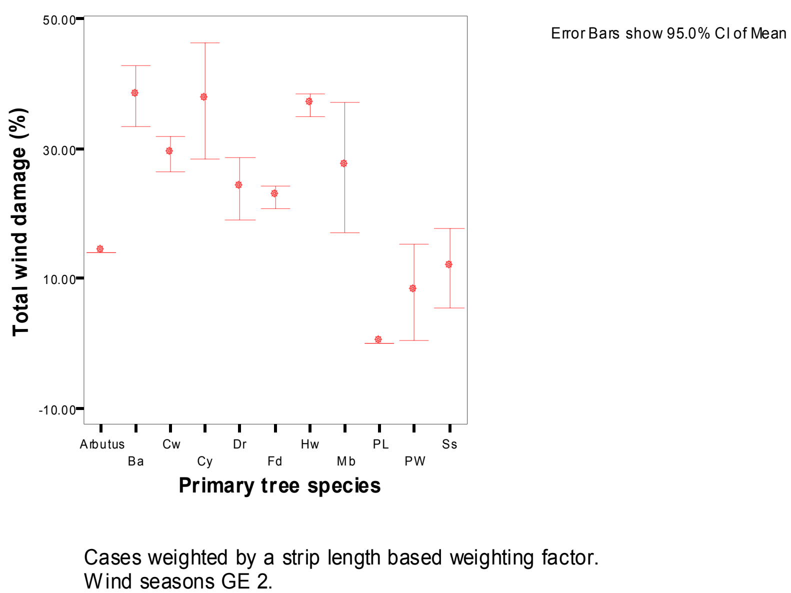


Figure H4. Relationship between tree species and total wind damage along external edges of strips.

Appendix D
Statistical Data Analysis Summary

All analyses in this appendix utilize weighted data unless otherwise noted.

Table D1. External Edges – Total Wind Damage.

Independent Variable	Significance level – Kruskal-Wallis	Significance level - ANOVA
Forest Operation	.000	.000
Boundary Exposure	.000	.000
Wind Exposure Index	.000	.000
Cumulative Fetch Distance	.000	.000
Combined Fetch Categories	.000	.000
Treatment Category	.000	.000
Slope Position	.000	.000
Stand Origin	.000	.000
Stand Height Category	.000	.000
Stand Density Category	.022	.000
Stand Structure	.000	.000
Rooting Depth Category	.000	.000
Edge Geometry	.000	.000
Setback Distance Category	.000	.015

Table D2. Large Patch Edges – Total Wind Damage.

Independent Variable	Significance level – Kruskal-Wallis	Significance level - ANOVA
Forest Operation	.000	.000
Boundary Exposure	.000	.000
Wind Exposure Index	.000	.000
Cumulative Fetch Distance	.000	.000
Combined Fetch Categories	.000	.000
Treatment Category	.000	.000
Slope Position	.000	.000
Stand Origin	.000	.000
Stand Height Category	.000	.000
Stand Density Category	.148	.000
Stand Structure	.303	.000
Rooting Depth Category	.000	.000
Edge Geometry	.000	.000

Table D3. Small Patches – Total Wind Damage.

Independent Variable	Significance level – Kruskal-Wallis	Significance level - ANOVA
Forest Operation	.000	.000
Boundary Exposure	.000	.000
Wind Exposure Index	.000	.000
Cumulative Fetch Distance	.000	.000
Combined Fetch Categories	.000	.000
Treatment Category	.001	.013
Slope Position	.000	.000
Stand Origin	.000	.000
Stand Height Category	.000	.000
Stand Density Category	.000	.000
Stand Structure	.110	.149
Rooting Depth Category	.000	.000

Table D4. Strips – Total Wind Damage.

Independent Variable	Significance level – Kruskal-Wallis	Significance level - ANOVA
Forest Operation	.000	.000
Boundary Exposure	.000	.000
Wind Exposure Index	.000	.000
Cumulative Fetch Distance	.000	.000
Combined Fetch Categories	.000	.000
Treatment Category	.000	.000
Slope Position	.000	.000
Stand Origin	.000	.000
Stand Height Category	.000	.000
Stand Density Category	.257	.533
Stand Structure	.000	.000
Rooting Depth Category	.000	.000
Edge Geometry	.000	.000
Setback Distance Category	.001	.000

Table D5. Dispersed Retention – Total Wind Damage. (non-weighted data)

Independent Variable	Significance level – Kruskal-Wallis	Significance level - ANOVA
Forest Operation	.000	.000
Cumulative Fetch Distance	.125	.043
Slope Position	.001	.000
Stand Origin	.000	.000
Stand Height Category	.000	.000
Stand Density Category	.008	.022
Stand Structure	.015	.024
Rooting Depth Category	.071	.194

Table D6. External Edges and Large Patch Edges – Windthrow Penetration.

Independent Variable	Significance level – Kruskal-Wallis	Significance level - ANOVA
Forest Operation	.000	.000
Boundary Exposure	.000	.000
Wind Exposure Index	.000	.000
Cumulative Fetch Distance	.000	.000
Combined Fetch Categories	.000	.000
Treatment Category	.000	.000
Slope Position	.000	.000
Stand Origin	.000	.000
Stand Height Category	.000	.000
Stand Density Category	.000	.000
Stand Structure	.000	.691
Rooting Depth Category	.000	.000
Edge Geometry	.000	.000
Setback Distance Category	.000	.000

Table D7. External Edges – Total Wind Damage.

Independent Variable	N-wieghted	Spearman correlation coefficient	Significance level
Wind Exposure Index	14267	.192	.01
Cumulative Fetch Distance	14267	.291	.01
Stand Height Category	14267	.136	.01
Rooting Depth Category	14267	.117	.01
Elevation (m)	14301	.053	.01
Slope gradient (%)	14301	.065	.01

Table D8. Large Patch Edges – Total Wind Damage.

Independent Variable	N-wieghted	Spearman correlation coefficient	Significance level
Wind Exposure Index	1029	.227	.01
Cumulative Fetch Distance	1029	.272	.01
Stand Height Category	1029	-.009	ns
Rooting Depth Category	1029	.164	.01
Elevation (m)	1029	-.026	ns
Slope gradient (%)	1029	-.037	ns

Table D9. Small Patches – Total Wind Damage.

Independent Variable	N-wieghted	Spearman correlation coefficient	Significance level
Wind Exposure Index	3800	.099	.01
Cumulative Fetch Distance	3800	.227	.01
Stand Height Category	3800	.348	.01
Rooting Depth Category	3800	.311	.01
Elevation (m)	3800	.100	.01
Slope gradient (%)	3800	.010	ns
Patch area (ha)	3800	-.034	.05

Table D10. Strip Edges – Total Wind Damage.

Independent Variable	N-wieghted	Spearman correlation coefficient	Significance level
Wind Exposure Index	1998	.276	.01
Cumulative Fetch Distance	1998	.297	.01
Stand Height Category	1998	.215	.01
Rooting Depth Category	1998	.191	.01
Elevation (m)	1998	.169	.01
Slope gradient (%)	1998	.079	.01
Strip Width (m)	1998	-.050	.05

Table D11. External Edges and Large Patch Edges–Windthrow Penetration.

Independent Variable	N-wieghted	Spearman correlation coefficient	Significance level
Wind Exposure Index	15675	.186	.01
Cumulative Fetch Distance	15675	.260	.01
Stand Height Category	15675	.225	.01
Rooting Depth Category	15515	.170	.01
Elevation (m)	15607	.094	.01
Slope gradient (%)	15670	.099	.01
% Windthrow	15670	.809	.01

Appendix E
Data Coding Documentation

Note: The data coding conventions included in this appendix are those used for the variable retention windthrow monitoring project.

Windthrow Assessment Codes and Coding Procedure[10]:

Enter a unique plot number and the block number, division, watershed, silviculture system and date falling was completed for the block across the top of the form.

Falling Corner Range

- Enter the falling corners that define the two ends of the plot. Where a plot boundary falls between two falling corners list the distance in metres past the last falling corner (e.g. FC 17+50)

Terrain* (From Terrain Classification System for British Columbia)

- O – organic M – moraine,
- C – colluvial, R – bedrock,
- F – fluvial, L – lacustrine,
- W - marine

Slope position

- C – crest (i.e., a ridge crest)
- U – upper
- M – mid
- L – lower
- VF – valley flat

Slope morphology

- P – planar or uniform – any slope angle
- U – undulating, - generally level to gently sloping areas
- I – irregular – generally limited to surface irregularities ≤ 1- 2 metres
- B – benchy
- H – hummocky – surface irregularities generally of ≥ 5 metres
- D – dissected (more than one gully across the slope)
- G – single gully generally ≥ 3 metres deep
- E – stream escarpment generally ≥5 metres high
- S - depressional

Soils*

- P – podzols – brown to orange coloured, well drained mineral soils
- GP – gleyed podzols – imperfectly drained soils, evidence of gleying (mottles) in the mineral soil

[10] Combinations of some of these variable codes are possible.

- G – gleysols – grey coloured soils often with a black organic upper horizon, poorly drained soils
- HG – Humic gleysols – gleysols with a thick upper humus (humic) layer above the mineral soil
- H – humisols (organic soils – boggy areas)
- F – folisols (thick humus over bedrock)

Soil Drainage Class

- R – rapidly drained (colluvial veneers and/or bedrock)
- W – well drained (podzols in relatively deep materials and moderate to steep slopes)
- M – moderately well drained (podzols and gleyed podzols in deep materials on receiving sites)
- I – imperfectly drained (gleyed podzols)
- P – poorly drained (gleysols)
- VP – very poorly drained (organic soils – bogs)

Slope aspect

- The azimuth bearing perpendicular to and away from the slope.

Rooting depth

- Estimate average tree rooting depth to the nearest 10 cm increment for the leave area (plot).

Stand structure

- MS – dominantly multi-storied
- U – moderately uniform

Stand height

- Estimate average height of stand in the plot to the nearest metre (metres)

Stand origin

- U – unknown
- H – harvest (i.e. second growth timber)
- W – windthrow
- F – windfire
- I – insect

Tree species 1, 2, 3 and % for each species

- As on forest cover map or best estimate if forest cover map is not specific in order of dominance, with percent (%) as an integer to the nearest 10% (e.g., 3=30%)

Age class

- An integer (1, 2, 3 etc.) as on the forest cover map.

Density

- 1- dense
- 2 – moderate
- 3 - open

Windthrow (WT) %

- Estimate amount of windthrow as percentage of trees in stand that are >15 cm DBH within the first 25 metres into the stand edge or patch or strip. Do not include saplings and regeneration in these estimates.

WT Spatial pattern – pattern of windthrow along/within boundary or leave area:

- U – uniform (well dispersed and continuous)
- I – irregular (more or less continuous but non-uniform pattern)
- G – small discrete groups of 1-5 trees
- P – patches (small discrete patches of windthrow, 1-2 tree lengths across, e.g., 10-20 trees)
- S – sections (> 5 tree lengths)
- WE – windward edge(s) of groups (patches)
- N – none
- NS – non-specific edges of groups

WT penetration

- A visual estimate of the maximum distance (in metres) that upturned roots (not tops) of windthrown trees penetrate into a leave area/strip, stand edge, patch or group. Penetration distance is defined as the distance from the edge of a cutblock (stand edge) to the base (roots) of the windthrown tree furthest from the edge of the cutblock. Consequently, this measurement represents the maximum distance that windthrow penetrated beyond the edge of each plot not the average penetration distance at that plot. The average penetration distance values reported in the analysis are averages of the maximum penetration distance recorded at each plot.

WT Orientation 1 and 2 and 3

- Estimate the average direction of the primary and secondary and teritiary orientations of windthrow in the plot. The direction of orientation is the direction parallel to the stem taken from the roots towards the top of the tree. In some cases, there will only be one orientation.

% Stem-break/ % Leaning

- Estimate the percentage of trees in the plot that have broken stems and the percentage of trees that are leaning strongly (i.e., at an angle of >30 degrees away from the vertical) as a result of wind storms.

*WT treatment Rx**

- F – feathered edge (can only occur in a RMZ), FS – a feathered edge where only saplings are left
- P – pruning
- T – topping
- N – none known or observed
- X – thinned uniform– uniform tree removal throughout strip, all stem sizes retained (RMZ)
- Y – thinned small retained – generally only smaller merchantable trees retained (RMZ)
- PT – pruned and topped
- FP – feathered and topped
- FPT – feathered pruned and topped

Timing of treatment

- B – before harvest
- C – concurrent with harvest
- BW – before first winter
- AFW – after first winter
- ASW – after second winter

Slope angle in plot

- Record the average slope across the leave area except where the leave consists of gentle or moderate slopes adjacent to or above a gully or stream escarpment. In the latter case, record in this field the average slope angle on the hillslope area adjacent to the gully or escarpment and record the gully wall or escarpment slope angle in the gully/escarpment angle field in the stream/gully section of the field data form. If this is a conventional boundary record the slope angle for the first ±20 metres into the standing timber.

Boundary aspect

- Record the direction perpendicular to and away from the stand (reserve) boundary edge. In the case of 2-sided reserve strips the aspect of both boundaries (sides) of the strip are recorded as both sides of the boundary are traversed and treated as separate samples.

Edge geometry categories

- U – uphill – the boundary is on the upslope side of the block.
- BB – uphill boundary at the base of an escarpment (e.g., bedrock scarp or bluff), typically but not always, along the upper edge of a block.
- D – downhill (the boundary is on the downhill side of the opening and the slopes are generally >40%, up to 70%).
- LG – lateral (a boundary running roughly perpendicular to the horizontal contour and slopes along within the leave strip or cutblock edge are generally range from 10 to 40%). Dispersed retention is usually described nominally as lateral.
- F – flat or level or undulating
- GE – gully edge (falling boundary runs along the edge of a gully).
- GS – gully setback: boundary is located on the hillside slope adjacent to the gully (the leave strip includes both the gully and a strip of standing timber along the hillside beside or above the gully. The falling boundary is often 5 to 20 metres away from the edge of the gully. The slopes within the hillslope portion of the leave strip are less steep than those on the gully side.)
- SE – Escarpment (scarp edge). Slope angles are generally >70% when this designation is used.
- SS – scarp setback: the hillside slope along or above a stream escarpment or other definite escarpment. (The leave strip includes both the escarpment and a strip of standing timber along the hillside beside or above the escarpment. The falling boundary is often 5 to 20 metres away from the edge of the escarpment. The slopes within the hillslope portion of the leave strip are less steep than those on the escarpment.)
- LS – lateral steep - used when the boundary is running perpendicular to the contours and the slopes are between 40 and ≥70%.
- H – hillslope - used when the boundary is running perpendicular to the contours and the slopes are between 40 and 70%.

Boundary shape

- 1 - concave
- 2 – convex
- 3 – straight
- 4 – complex (irregular)

Influences

- S – possible shelter by an adjacent boundary
- E – possible increased exposure because of an adjacent boundary
- O – possible increased exposure because of the opposite side of the strip edge is a windward boundary
- T – possible shelter by topography
- L – Lake adjacent (i.e., one side of strip or patch, is bounded by a lake)
- W – Wetland adjacent
- P – Plantation adjacent
- N – nominal (nothing obvious)
- D - Dispersed trees retained in surrounding area

Harvesting system

- G - Grapple
- T - High lead tower
- H - Hoe
- R - Helicopter
- S - Skyline

Plot type (strata)

- E - External block edge
- P – Large Patch edge
- WS -'Wide' strip edge > 50 m wide
- P - Peninsula a strip of timber that extends into an opening but is attached to the external boundary
- B – Bulge – a stubby peninsula that is wider than it is long
- S - Strip < 50 m wide – strips have straight edges
- R - Ribbon – strips with curves
- ES – External strip – strip located on the edge of a block adjacent to a young plantation.
- EG – External Group – as for external strip.
- G - Group – groups are groups of trees 20 to 50 m wide
- C - Cluster – groups of trees less than about 20 metres wide
- D - Dispersed individuals

Group/cluster/patch shape

- S - Square
- C - Circle
- R - Rectangle
- E - Ellipse
- P - Polymorphic

- T - Triangle
- D – Doughnut (typically polymorphic or irregular with a low area in the centre of the group or patch containing small trees or no trees)

Boundary purpose

- R – Riparian - streams
- L – Lake riparian
- T - Terrain stability
- W - Wildlife
- V - Visual
- G – Generic
- S – Wetland

Leave strip width *(treated and/or untreated)*

- This is the distance in metres from the edge of the riparian reserve zone or management zone (leave area) to the opposite side of the strip. If the margin or all of the leave area has been treated (e.g. feathered, thinned, topped, pruned) then record the width of this zone in the treated width field. Record the entire leave strip width in the untreated width field.

Treatment depth (width) and percentage

- Distance in metres that pruning or feathering etc. extends into the stand edge and the approximate percentage of trees treated or removed from the stand edge within that distance.

Fetch Type

- C - Clearcut
- S - Strip(s)
- R - Ribbon(s)
- G - Groups
- X - Clusters
- GX - Groups and clusters
- D - Dispersed individuals
- GD - Groups and dispersed individuals
- XD – Clusters and dispersed individuals
- GXD - Groups /clusters / dispersed individuals
- GDZ – Groups, dispersed individuals and dispersed saplings and/or groups of saplings (Z)
- GXDZ – Groups/ clusters/ dispersed individuals and saplings (saplings = non-merchantable)
- E – Edge - A block boundary roughly parallel to the subject wind. Within the plot, if not further upwind the wind is running parallel to the edge of the block.

Setback distance

- Distance a boundary is setback from the edge of a gully or escarpment.

General topography of area

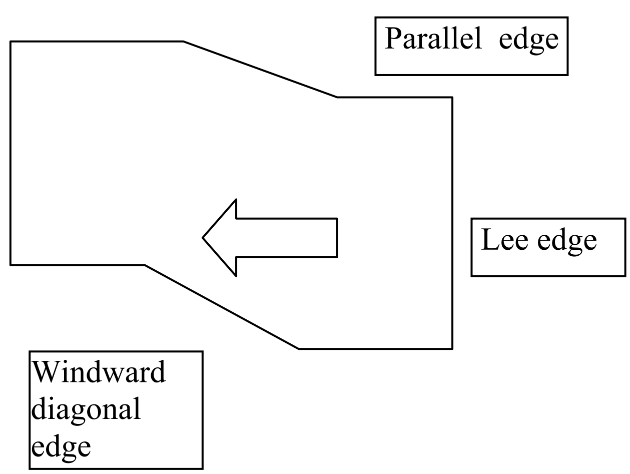
- CP – coastal plain
- LH – low hills (relative relief = 50 – 200 metres), no well defined valleys
- MH – moderate hills (relative relief = 200 – 500 metres), no well defined valleys
- HH – high hills (relative relief = 500 – 1000 metres), no defined valleys
- SV - Shallow well defined valley (relative relief is less than 200 metres)
- MV – Moderately deep, well defined valley (relative relief 200 – 500 metres)
- DV – deep, well defined valley (relative relief 500 – 1000 metres)
- VDV – very deep, well defined valley (relative relief is greater than 1000 metres)
- MVN – narrow (V-shaped), moderately deep, well defined valley
- MVB – broad (U-shaped), moderately deep, well defined valley
- DVN – narrow, deep, well defined valley
- DVB – broad, deep, well defined valley

Boundary exposure (1st, 2nd)

For external boundaries and long-axis exposure for patches/groups

- This is the boundary exposure or orientation relative to the apparent primary and secondary windthrow (wind) orientations recorded for the block (there may be no clear dominance). Windward and lee refer to the standing timber edge (e.g., a stand edge that has a wind blowing directly into it from the 'open clearcut area' is defined as a windward boundary). Make these estimates in the office after all plot data has been collected for a given block. Use the apparent dominant direction of windthrown trees around the perimeter of the block to make this estimate not just the windthrow orientations from a single plot. Be careful not too generalize too much. In some cases, for example if a block straddles a ridge line at the intersection of two valleys (e.g., an east-west valley and a north-south orientated valley), the dominant wind directions may vary from one side of the block to another.

- W – windward edge
- L – lee edge
- P – parallel edge
- WD – windward diagonal
- LD – lee diagonal



Valley axis orientation

Take this measurement from a 1:50,000 scale map so that the general orientation of the valley in the vicinity of the block can be easily seen. Where a block is exposed to two different valley orientations (e.g., a block which straddles a ridge line) then record the valley orientation relevant to each individual plot. This data is evaluated to determine how strongly the orientation of specific valleys influences or does not influence the direction of damaging winds.

- N-S
- E-W
- NW-SE
- NE-SW

Stream name

- Record from the logging plan map

Stream class

- S1 –S6 as per the BC Forest Practices Code

Reserve type

- **RRZ-1**– 1-sided riparian reserve zone (streams)
- **RRZ-2**– 2-sided riparian reserve zone (streams)
- **FRMZ-1** – 1-sided forested riparian management zone. Usually refers to strips where most larger trees are left but can be a feathered edge where only a few of the larger large trees are left by the fallers. If the riparian management zone is composed only of stumps (e.g. there are no residual trees) then do not record the RMZ as being present.
- **FRMZ-2** – 2-sided forested riparian management zone.
- **WTP** wildlife tree patch
- **GR –** gully reserve

Stream width and depth

- Estimate the stream width and depth in metres at bankfull discharge.

Bed and bank materials (textures)

- c – clay
- z – silt, zs – silt and sand
- s – sand, sg – sand and gravel

- g – gravel, gk – cobbles and gravel
- k - cobbles
- b – boulders, bk –boulders and cobbles, bkg – boulders, cobbles, gravel
- r – rubble
- a – blocky
- R - bedrock

These codes can be used when there is a mixture and/or distinct zones of the above textures/materials.

WT Proximity – proximity of windthrown trees to the stream channel

- N – none apparent - no windthrow reaches the stream
- T – touching - tops of some trees touch and a few windthrown trees may cross the stream
- A – across – a large number of the windthrown trees fall across the stream and most are lying □2 metres above the stream
- B – bank – trees in and along bank are uprooted
- X – trees on both sides of the stream are uprooted
- S – suspended – most windthrown trees are > 2 – 3 metres above the stream
- AX – across and there are uprooted trees on both sides of the stream
- AB – across and uprooted trees along stream bank

Stream Effects

- N – none apparent
- B – limited bank disturbance (estimate % of bank length disturbed: 1%, 2%, 5%, 10%, up to 20%)
- C – channel and stream banks are significantly disrupted (more than 30% of channel is disturbed – estimate % length of channel disturbed).
- S – some sediment delivery to channel visible or very likely
- U – unknown