PROGRESS REPORT

Variable Retention Windthrow Monitoring Pilot Project

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Forest Renewal BC

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EXECUTIVE SUMMARY

The pilot project was carried out in Weyerhaeuser's West Island Timberlands unit (WI) on southwestern Vancouver Island and the Queen Charlotte Timberlands unit (QCI). These areas were selected as they are dissimilar from both an ecological and geomorphic point of view. The QCI has a significantly wetter and cooler climate and generally stronger winds than the WI. The WI blocks were located within moderately deep valleys whereas the QCI blocks are located on low to moderately high rounded hills and ridges and low lying coastal plain areas. Locating the pilot study sites in these areas allows us to better evaluate the possible extremes of windthrow that may be associated with variable retention silvicultural practices.

The overall project objectives that are partially addressed by the pilot project are:

- Document the amount of windthrow associated with VR.
- Document the spatial distribution or patterns of windthrow associated with VR
- Document regional differences in the extent of windthrow associated with VR.
- Identify the qualitative and quantitative factors associated with VR windthrow including both environmental factors and treatment effects.
- Identify specific management options to control windthrow associated with VR.
- Develop field indices and decision-making tools for windthrow hazard assessment by operational planners.
- Communicate results to field staff to help reduce the potential for wind damage by improving harvesting layout and silvicultural treatments.

Approximately half the 419 sample plots for the pilot study are located in the QCI and half in the WI operation. About 75 percent of the sample plots are external setting edges, 20 percent represent retained patches or groups of trees and five percent occur in strips of timber. A total of 28 kilometers of external falling boundary were sampled, 15 kilometers in the QCI and 13 kilometers in the WI operation. The sample plots representing retained groups of timber range in size from 0.1 to 0.55 hectares.

There are some regional differences in windthrow. The average amount of windthrow along external setting boundaries varied from an average of six percent on the WI blocks to ten percent in the QCI blocks with an overall average of eight percent. There is a similar regional trend with windthrow for retained groups. The average windthrow in retained groups is 18 percent in the WI area and 39 percent in the QCI with an overall average of 27 percent. Overall retained groups appear to be more vulnerable to windthrow than external setting edges, however the cumulative amounts of windthrow are less.

The data indicate that windward edges on external setting boundaries are more vulnerable to windthrow than other boundary exposures. There appears to be a trend of increasing windthrow with increasing average fetch distance for external boundaries, this effect may be less pronounced at greater distances. The character of the fetch surface may affect the amount of windthrow along external edges. External boundaries downwind of areas of

dispersed retention or mixtures of dispersed retention and retained groups may be subject to less windthrow. There are no similar trends with retained groups.

There is some indication that feathering or topping and pruning treatments reduce the amount of windthrow along external boundaries but as the data set for these treatments is small this conclusion should be considered tentative.

There may be some relationship between topographic location and the amount of windthrow, topographically exposed locations tend to experience more windthrow. These results are confounded by corresponding differences in average stand heights with taller trees generally occurring in the more exposed locations.

For both external edges and retained groups the amount of windthrow tends to increase with stand height. There is some indication that windthrow along external edges varies with the dominant tree species in a stand. In the QCI stands dominated by cedar tend to be more windfirm. At WI the sample areas dominated by Douglas-fir had more windthrow than those and in dominated by western hemlock. This finding is contrary to the conventional wisdom that Douglas-fir is generally more windfirm than western hemlock and is likely due to other factors associated with the small number of sample areas. Height and species trends were not apparent in the data on retained groups.

There is a fairly strong trend of decreasing amounts of windthrow as the size of the retained group increases. Windthrow in retained groups tends to be concentrated along the windward sides of these groups. The *area windthrown to area harvested ratio* increases from about 4 hectares to 6 hectares of windthrow per 100 hectares logged (i.e., 0.04 to 0.06) when VR practices are compared to current clearcutting practices. While rare and not present within the current data set, areas of extensive windthrow can occur along external setting edges. These additional areas of external edge windthrow can significantly alter the *area windthrown to area harvested* ratio.

The distance that windthrow penetrates into a stand edge tends to be affected by some of the same factors that control percent windthrow. Penetration increases as percent windthrow increases. Penetration tends to vary with changes in boundary exposure. Penetration distances are less on lee boundaries than windward boundaries. A similar relationship is seen with average fetch distance, penetration increasing as fetch distance increases. However, fetch varies as boundary exposure changes, consequently the apparent relationship between fetch distance and penetration distance as well as with percent windthrow (see above) may be an artifact of a relationship between fetch distance and boundary exposure.

A reconnaissance survey of damage from the December 14, 2001 storm was carried out on February 7th, 2002. Whether a clearcut edge or VR block was damaged appeared to have more to do with where the storm winds touched down than to the size or design of the block. Windthrow within VR groups or single tree retention was a relatively small proportion of the total forest damage caused by this storm. Within individual VR blocks, there was often a higher volume of windthrow associated with the external block boundary than with the groups left within the block.

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1.0 INTRODUCTION

Weyerhaeuser, BC Coastal Group has adopted the Variable Retention (VR) approach to harvesting and silviculture for most of the company's public and private forestland. The goal is to phase-in variable retention over 5 years, increasing the amount by 20% per year (i.e., 100% VR in 2003). Most of the variable retention blocks use the retention silvicultural system, leaving trees as groups or as dispersed individual trees or small clusters of a few trees. Modified shelterwood and selection systems with long-term reserves are also used. Variable retention will result in an increase in the total length of forest edge associated with forest openings, as well as greater numbers of dispersed trees. Because of these changes, we expect to see a limited increase in the frequency and extent of windthrow associated with forest harvesting. It is therefore important to document the extent of windthrow associated with VR harvesting and to determine the best strategies to minimize or manage for windthrow. In many cases, the existing state of knowledge will suffice, but in some cases, additional information will be required. In order to document the extent of windthrow and to improve windthrow management, it is necessary to monitor the character and location of windthrow over time and to document the management and environmental factors associated with windthrow.

2.0 PROJECT OBJECTIVES

- Document the amount of windthrow associated with VR.
- Document the spatial distribution or patterns of windthrow associated with VR
- Document regional differences in the extent of windthrow associated with VR.
- Identify the qualitative and quantitative factors associated with VR windthrow including both environmental factors and treatment effects.
- Identify specific management options to control windthrow associated with VR.
- Develop field indices and decision-making tools for windthrow hazard assessment by operational planners.
- Communicate results to field staff to help reduce the potential for wind damage by improving harvesting layout and silvicultural treatments.

3.0 METHODOLOGY

3.1 Project Phase In

The variable retention windthrow monitoring project is being developed in three phases as follows:

3.1.1 Phase 1 – Preliminary design

- Development of a field methodology (including one or more sampling designs) for assessment of post-harvest windthrow associated with VR. This work included limited field assessment of VR areas and associated windthrow. The purpose of this work was to develop appropriate sampling techniques that account for the variability and character of residual stands and stand edges created by VR.

- Development of data fields/categories that are compatible with hand-held field data recorders and an MS Access database.

3.1.2 Phase 2 – Implementation of pilot design and testing program

- Organization and implementation of a pilot field and air photo-monitoring program to test the suitability of the preliminary sampling design and data collection and measurement methods. The focus of this sampling was on two areas of windthrow concern: Franklin River (southwest Vancouver Island) and the Queen Charlotte Islands.
- Development and modification of a database for storing and manipulating windthrow data. This database was constructed in MS Access. It is network ready and is capable of importing and processing digital data from field data recorders.
- Limited analysis of the pilot data set to determine if the data collected is suitable and sufficient to fulfill the objectives of the monitoring program.
- Re-design and re-test the monitoring methodology and sampling design and data compilation and analysis procedures.
- Assessment of the utility of large-scale air photos and orthophotos for windthrow monitoring purposes and, where appropriate, incorporating the use of air photos into the monitoring methodology.

3.1.3 Phase 3 – Implementation

- Implement a full-scale field and air photo-monitoring program.
- Incorporate monitoring into Weyerhaeuser's experimental VR comparison blocks.
- Data analysis and interim reporting on an annual basis.
- Extension of results to operational personnel.

3.2 Sampling Design

3.2.1 Sample segment delineation and plot selection

All external falling boundaries, variable retention (VR) patches and groups, riparian reserve zones and forested riparian management zones[1] and other types of reserves and dispersed treatments are sampled if they have experienced at least two fall-winter-spring wind seasons (preferably 3 wind seasons). In areas such as the SE coast of Vancouver Island that rarely experience strong winds, a four to five year waiting period may prove more appropriate.

[1] 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 conifer regeneration (i.e. generally less than 2-3 metres tall) are retained are not sampled.

3.2.2 Group retention and setting edges

It is necessary to partition or stratify all VR patches, groups and clusters (very small groups), any specialized reserves and all external falling boundaries into segments or sample plots in a systematic fashion so that the plot data will be suitable for statistical analysis. Because we are dealing with both patches and groups of timber and timber along external setting edges we are faced in a general sense with dealing with both areas (i.e., patches or groups) and lengths (i.e., external stand edges). There are two obvious choices available for the delineation of plots. We can create equal area and/or equal length plots or we can accept unequal area and/or unequal length plots. Because forest stands and terrain do not conveniently split apart into equal sized pieces it can be logistically easier to deal with unequal sized plots when carrying out rapid, low-resolution field-surveys. For the purposes of the pilot study we decided to use unequal sized plots, and then use area-based or length-based weighting during the data analysis phase to accommodate differences in plot size.

Each boundary edge or VR patch/group or specialized reserve, if it is large enough, is stratified into distinct and relatively homogeneous stand, geomorphic and/or geometric 'entities' (areas or lengths). Retained groups and clusters of trees are generally small enough (i.e., less than 50 metres across) that it is difficult to stratify them into separate plots even if stand or geomorphic characteristics of these areas are not homogeneous so they were treated as single sample entities (plots). When an internal group had a diameter greater than approximately 50 metres then the edges of the group were sampled in the same way that an external boundary was sampled[2]. This stratification approach resulted in the creation of unequal length or unequal area plots or 'sample segments'.

Stratification or separation was based on 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 within a patch.
- Changes in forest (stand) type (species composition or height) along a boundary or within a patch.
- Type of edge treatment: untreated, feathered, thinned, topped and pruned, etc.
- The type of forested riparian area. Riparian areas are classified as 1-sided leave areas or 2-sided leave areas (i.e., external stand edges versus strips of timber bounded by 'clearcut' areas on either side).
- Change in reach classification of the streams contained within riparian areas.
- Two-sided riparian strips are sampled on both sides, each side of the strip is treated as a separate sample. Strip shelterwood treatments are sampled in the same way.
- Changes in the amount or character of windthrow do not affect sample selection.
- The sample segments (plots) should be a minimum of 50 metres long. However, shorter segments that are very distinctive should be sampled as separate plots. Short

[2] This size criterion may be changed based on the results of the pilot study.

segments similar to adjacent areas should be incorporated in the most similar adjacent plot.

All external edges, groups and patches within an opening are sampled.

We used stratified, unequal length or unequal area samples (plots) to improve sampling efficiency and to ensure that any visible environmental differences that could potentially exert a significant effect on windthrow response were sampled. For example, random or systematically located plots that fall across significant changes in soil type or boundary orientation could well confound any subsequent analysis if these factors strongly affect windthrow susceptibility. Because the two important target variables (percent windthrow and distance of penetration of windthrow) should not be affected by sample segment length we did not feel that differences in the length of the plots would significantly affect the outcome of the study. Additionally, some terrain/soil types are inherently quite variable over relatively short distances so sampling the full length of such ‘strata’ should generate a more representative estimate of the amount windthrow occurring within these more heterogeneous terrain/soil types. For the objective of estimating cumulative windthrow along falling boundaries, unequal length/ sampling segments work as well as equal length plots. However, the same may not hold true for patches/groups; as patch/group size increases the amount of windthrow in the interior of the patch/group may change. We may be able to deal with this problem by using patch/group size as a predictor variable.

All segments along all edges or areas traversed were sampled. As noted above we used a minimum sample segment distance of 50 metres because we were interested in making a qualitative assessment of the spatial patterns of windthrow present in the area and were concerned that shorter sampling segments might obscure any spatial pattern that might exist. However, a limited number of segments less than 50 metres long were sampled because they were significantly different than the adjacent boundary segments.

3.2.3 Dispersed Retention

VR treatments that involve the retention of individual, widely dispersed trees (e.g. a seed tree-like treatment) were sampled by counting all standing and windthrown trees within unique strata (areas) of a setting. The total number of widely dispersed individual trees within a setting is often in the range of 30 to 100 trees so it is feasible to count all the trees. Each setting where dispersed retention occurred was stratified into distinct areas based on terrain type, slope aspect and slope position. These “terrain strata” were mapped on the setting maps in the same way that soils or terrain polygons would be mapped. Dispersed stand densities (individual trees/ha) can be calculated on an area basis for each “terrain polygon” or strata within a block. In a number of the settings where we observed this particular treatment the retained trees tended to be of the same species and have a similar form. This part of the monitoring was carried out after the ground surveys of setting boundaries and VR patches by using setting maps and terrain/soils and tree species data from the original edge and patch plots to define the boundaries of dispersed plots.

VR treatments that involve the retention of more closely spaced individuals (e.g., a conventional shelterwood cut) will be sampled using randomly located equal area plots within distinct "terrain strata" within a setting (no areas fitting these criteria occurred in the pilot study areas). The approach will be to map or split the setting into "terrain or stand strata" using the approach outlined in the above paragraph but then rather than counting all trees, randomly locate plots within each strata. These plots will have an area of 0.1 ha (17.84m radius), and there will be 3 plots per strata.

3.3 Data Collection

3.3.1 Field data collection

Much of the data collected in the field was restricted to visual classification of such environmental attributes as soil type, slope morphology, surficial materials, boundary geometry, and stream class. In order to streamline data collection we did not collect data on the actual number of trees windthrown or standing. Instead, we generally made visual estimates of the amount of windthrow present based on nominal classes of: 0, 1, 2, 5% and then increasing increments of 5 or 10% for the first 25 metres into a stand edge. In small VR groups and clusters it proved most appropriate to count the number of standing and windthrown trees. Similarly, we visually estimated the depth of penetration of windthrow into the stand edge and the approximate primary and secondary orientations of windthrown trees in each plot rather than the orientation of each individual tree. We used a qualitative wind exposure index, or ranking matrix (Appendix IV, Figure 1), to represent the vulnerability of boundaries that are subject to winds from more than one direction. Species composition and windthrow percentages were based on the merchantable stems in a stand and were estimated visually. Where appropriate, species composition estimates were compared to forest cover information included on the logging plan map for the block. We also recorded any stand edge treatments that occurred along or within each sample segment or sample area.

3.3.2 Office map work methodology

There were a number of procedures performed for each site that are common to both field assessment and air photo or map interpretation. The office tasks took 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, the length of the plots for external block edges or the area of the plots when the plots consisted of entire retention groups or patches was measured. A histogram was then developed using the windthrow orientations (azimuth) for each plot in the block and the two most numerous (dominant) windthrow orientations were determined. The reverse bearings (orientation direction in degrees - 180º) represent the estimated primary and secondary wind directions for each block. A protractor, ruler and transparency with boundary exposure types outlined in degrees (Plate 1, Appendix I) were used to determine boundary exposure type based on the two dominant wind directions. The center 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, orientated parallel to the north lines of the map, with the center of the protractor over the center of the transparency. The boundary exposure type was then determined by the quadrant of the transparency that the wind direction passed into, after it went through the boundary edge. For each plot fetch type (Appendix IV) was tabulated and fetch distance 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, the stand height upwind of the plot was tabulated using the stand heights recorded for the plot upwind of the exposed boundary for each fetch direction.

4.0 DATABASE DEVELOPMENT

The database which is used to hold and manipulate the data for the variable retention windthrow monitoring project is based on Microsoft Access 97 Service Release-1. Database programming was done by Piet Terpstra of Zavenstar Canada Ltd.

The database provides for downloading of data from a hand held field data logger (see section 5.0). Data can also be edited or entered directly into the database at any time, by authorized users. The direct data entry/editing facility allows editing or entry of data collected on paper field forms or data derived from map or air photo interpretation in an office environment.

The database is designed to be set up on a network, and as such allows for various levels of user access, ranging from read only access to data entry and editing. The database structure is hierarchical, the primary level in the database is the harvest unit (block) within which sampling has occurred. The second layer in the hierarchy is composed of the sampled plots within each harvest unit. A third layer in the database allows for ongoing monitoring of selected plots to update changing conditions, primarily the amount of windthrow and the distance windthrow has penetrated into adjacent stands or reserve areas. A separate section of the database contains contact information for the various individuals involved in the project. Digital images (e.g., photographs or maps) can be inserted into the database, both at the block and plot levels. A separate set of stream data is retained at the plot level for those plots that encompass riparian reserves or management zones.

The database is set up to facilitate filtering of the data using a series of primary variables or parameters linked either to harvest unit or plot data fields. These fields include block name, Weyerhaeuser Timberland and operating area, date of data collection, watershed, silvicultural system variant and biogeoclimatic unit. The filtering facility enables the user to rapidly sort though the database and access as small or large a portion of the data as is desired (Plate 2, Appendix I).

User accessible reference tables are provided so that variable attributes can be easily updated when new conditions are found in the field.

The database provides a default system for exporting selected data to an Excel file for manipulation or secondary export to a statistical package for further analysis.

Plates 2, 3 and 4 in Appendix I show the main harvest unit listings, the main plot, data entry screen and the block and plot summary screen respectively.

5.0 DATA LOGGER PROGRAMMING AND DATA ENTRY

Much of the data for the project is entered into a hand held Allegro field data logger using a custom data entry program. Jeff Sandford of Weyerhaeuser's BC Coastal Group, Woodlands Services Division, did data logger programming for the hand held for this project.

The data logger allows for rapid and systematic entry of field data (see the field data form and data coding documentation in Appendices IV and V for an outline of the data collected for the project). Data collected in the field using the data logger is identified by way of shaded cells on the mock-up of the field data form. The data logger uses a custom data entry and data storage program. Data from the data logger is downloaded into a desktop computer at Woodlands Services and exported to the network-based database (section 4.0) for permanent storage and further data entry or data editing.

6.0 STUDY AREAS FOR THE PILOT PROJECT

The pilot project was carried out in two widely separated geographic areas: Weyerhaeuser's West Island Timberlands (WI) on southwestern Vancouver Island and Queen Charlotte Timberlands (QCI). These areas are dissimilar from both an ecological and geomorphic point of view. The WI sample areas were located within the Very Dry Maritime Coastal Western Hemlock Subzone (CWHxm) and the QCI sample areas were located within the Submontane Wet Hypermaritime Coastal Western Hemlock Variant (CWHwh1) which has a significantly wetter and cooler climate and generally stronger winds than the CWHxm. The WI sample areas occur within moderately deep valleys within the Vancouver Island Ranges whereas the QCI sample areas occur on low to moderately high rounded hills and ridges within the Skidegate Plateau and low lying coastal plain areas within the Queen Charlotte Lowlands (Table 1).

Locating the pilot study sites in these areas allows us to better evaluate the possible extremes of windthrow that may be associated with variable retention silvicultural practices. Most of the pilot study areas were logged recently so it may turn out that the results of the pilot study slightly underestimate long-term trends in windthrow occurrence.

Approximately half the 419 sample plots are located in the QCI operation and half in the WI operation (Table 2). About 75 percent of the sample plots are external setting edges, 20 percent represent patches or groups of trees and five percent occur in strips of timber (Table 3). A total of 28 kilometers of external falling boundary were sampled, 15 kilometers in the QCI and 13 kilometers in the WI operation (Table 4). The average plot length for these external falling boundaries was 94 metres (Table 4a, Figure 1). The average for the QCI was slightly longer (102 metres) than the average length for the WI plots (86 metres).

The sample plots representing retained groups of timber ranged in size from 0.1 to 0.55 hectares and averaged 0.18 hectares (Table 4b and Figure 22). The plots representing retained strips of timber ranged in length from 40 metres to 200 metres and in width from 10 metres to 50 metres. Samples from the QCI operation were slightly wider on average (40 versus 25 metres) than samples from the WI operation, however the QCI samples were dominated by strips associated with strip shelterwoods whereas the WI strips were primarily riparian buffers. As there were only a small number of samples (26 strips) so only minimal analysis was conducted on this portion of the data set. Similarly, there were only 23 samples of boundaries along the edges of large internal patches representing about 1890 metres of large patch edges, so only minimal analysis was conducted on these samples. The average length of large patch edge sampled was 82 metres with a minimum length of 35 metres and a maximum length of 160 metres.

These differences likely reflect both differences in boundary conditions and differences in sample delineation as different field crews sampled the QC and WI study areas.

7.0 ANALYSIS OF PILOT PROJECT DATA AND PRELIMINARY RESULTS

Analysis of the pilot project data consisted of simple tabular and graphical analysis to identify trends in the data and to evaluate the suitability of the data and database structure for future analysis.

7.1 Windthrow Relationships Along External Block Boundaries

A number of environmental variables or attributes were compared to the amount of windthrow along external block boundaries. All the blocks in the pilot project data set are variable retention blocks, and contain either groups of trees or dispersed individual trees or both.

The average amount of windthrow along external block boundaries was about eight percent (Table 5 and Figure 2). These amounts varied between the WI sites and the QC sites, with an average of about six percent for the WI sites and about ten percent for the QCI sites. As noted in the methods section percent windthrow is visually estimated for a nominal zone 25 metres deep along block boundaries. At the same time the penetration of windthrow into the stand is estimated as the distance to the last upturned root mass from the edge of the block. In the case of WI the average penetration distance is six metres and in the QCI seven metres. In both areas, wind damage in the form of stem breakage and leaning trees is negligible.

The amount of windthrow is positively correlated with the degree of exposure of the block boundaries to storm winds. Boundaries that are directly exposed to the wind (windward and windward diagonal boundaries) suffer considerably more windthrow than lee and parallel boundaries (Figure 3). This relationship is not as obvious for wind exposure index, a simple ranking method that combines the exposure classes for the two dominant wind directions in an area.

Fetch is measured as the distance from the center of a sampling strip on an external boundary, patch edge or retained group of trees to the upwind external block boundary in the direction of the primary and secondary windthrow orientations in a block. Lee boundaries and parallel boundary exposures were assigned a nominal fetch distance of zero metres. For purposes of analysis the primary and secondary fetch distances were combined to derive an "average fetch distance" [average fetch = (fetch1 + fetch 2)/2] as a semi-quantitative way of recognizing that wind forces may have been applied to a boundary by winds from more than one direction. To simplify data analysis and allow for the large variation in fetch distances, fetch distances were combined into 8 categories ranging from zero metres to greater than 500 metres.

Figures 5 and 6 present the apparent relationship between fetch distance and windthrow for the primary fetch and the average fetch distances respectively. It appears that windthrow increases with increasing fetch distance beyond about 100 to 200 metres from setting edges and then may decrease at fetch distances above 300 to 400 metres. The apparent decrease at distances greater than 300 metres is quite possibly a function of the small sample size for these fetch distance categories. The trends are smoother for the WI than for the QCI when the data for these areas are analyzed separately (Figures 7 and 8). These results may be confounded to some degree by differences in the character of the fetch surface, that is, whether it is forested, clearcut or represents some form of variable retention silviculture.

The character of the fetch surface is described by the fetch category. Fetch categories vary from forest (standing timber) through groups or patches of timber, groups of timber mixed with dispersed trees, dispersed trees and clearcut areas. We would expect that increasing tree cover in the area upwind of a boundary might shelter the boundary to some degree. Figures 9 and 10 show differences in the amount of windthrow associated with different fetch conditions; however, the result is not always what we might anticipate. As would be expected, boundaries with standing timber upwind (lee boundaries) have very low amounts of windthrow. However, boundaries with clearcut areas upwind appear to behave the same as boundaries with either an upwind mixture of retained groups and dispersed trees or dispersed trees alone. Boundaries with only retained groups of trees upwind appear to fare the worst.

Table 6 shows a moderately strong correspondence between fetch distance and the character of the upwind surface. Boundaries with clearcut areas upwind, for whatever reason, have very short fetch distances relative to some other areas. This may account for the lower frequency of windthrow along these boundaries. Conversely, upwind areas dominated by retained groups tend to have longer fetch distances than other areas and this may account for the higher incidence of windthrow along these boundaries. Boundaries with groups mixed with dispersed trees and areas of individual dispersed trees have intermediate upwind fetch distances. It would appear that these areas do provide some protection to downwind boundaries as they have similar amounts of windthrow as boundaries with clearcut areas upwind and short fetch distances.

There are only a limited number of sites in the pilot data set where edge treatments were carried out to reduce the potential for windthrow along external boundaries. These include two feathered edges, three pruned edges and three pruned and topped edges (Table 7). In general, the average amount of windthrow is reduced by these treatments from about eight percent along untreated boundaries to four percent on the feathered boundaries, two percent on the pruned boundaries and less than one percent along the pruned and topped boundaries (Figure 11). However, the sample size is small (3% or 850 metres of the total edge length) and some treatments may have occurred along lee or parallel boundary exposures so although the trend is encouraging we cannot demonstrate conclusively that these treatments are reducing the potential for windthrow.

Topography appears to exert some influence on the amount of windthrow. Reference to Figure 12 shows that coastal lowland areas in the QCI are less prone to windthrow than low relief hills and ridges, or moderate relief hills and ridges. These results may be confounded by stand height relationships, as the coastal lowlands and the moderate hills and ridges tend to have lower stand heights than the low relief hills and ridges (Figure 13). The moderate relief valley side and floor category depicted on Figure 12 represents the WI data set so should not be interpreted to mean that these topographic conditions will necessarily have lower amounts of windthrow than other topographic conditions in that area.

There are a number of stand characteristics that may be related to the amount of windthrow experienced along external block boundaries. These characteristics include stand height, tree species, stand density and stand structure.

Figure 14 shows a general but modest increase in the amount of windthrow along external boundaries as stand height increases up to a height of about 35 metres. Above 35 metres there is a dramatic increase in the amount of windthrow. This trend is obvious in both the data from the Queen Charlottes and from the WI operating area.

There are limited but not necessarily consistent differences among stand density categories for the QCI and WI study areas. In the QCI dense stands appear to be less vulnerable to windthrow than moderately dense stands, but in the WI study areas, denser stands appear to be more vulnerable (Figure 15). Similarly, the relationship of windthrow to stand structure appears to vary, with multi-storied stands in the QCI being more vulnerable than uniform stands, while the opposite is the case in the WI areas. In the case of the QCI most of the uniform stands are shorter stands located in coastal lowland areas while many of the multi-storied stands are taller and are located on upland sites.

Windthrow appears to vary with tree species in both areas. In the QCI, stand edges dominated by cedar appear to be more windfirm than those dominated by western hemlock (Figure 17). Small sample sizes for other species preclude any assessment of their vulnerability to windthrow. In the WI areas stand edges dominated by Douglas-fir had more windthrow than western hemlock and other species. This finding is contrary to the conventional wisdom that Douglas-fir is generally more windfirm than western hemlock and is likely due to other factors associated with the small number of sample areas.

There is not strong a strong relationship between rooting depth and windthrow (Figure 18). There is limited indication that windthrow may increase as rooting depth increases in the QCI study areas, but there is no apparent relationship in the data from the WI study areas.

Soil type appears to have some relationship to the amount of windthrow present along external block boundaries in both study areas. Interestingly, imperfectly and poorly drained soils have less windthrow than well-drained soils (Figure 19) in the QCI. This phenomena may result in part from the presence of taller trees on well and imperfectly drained soils compared to more poorly drained soils (Figure 20), even though rooting depths tend to be deeper on well than poorly drained soils (Figure 21). A similar relationship may be present on the WI sites; however, because of small sample sizes for the imperfectly and poorly drained soils the trend is not as obvious. In the case of the WI the occurrence of shorter trees on areas dominated by folisols may explain the lower incidence of windthrow on these sites.

7.2 Windthrow Relationships in Retained Groups and Patches

As noted above the sample size for edges of large retained patches was fairly small (23 samples) so only very limited statistics were developed for this data. The average amount of windthrow along patch edges was 19 percent. Average windthrow amounts ranged from 34 percent in the QCI to 6 percent in the WI area. Like external block boundaries the percent windthrow statistic for large retention patches is a visual estimate of the amount of windthrow in a 25 metre wide strip within the standing timber along the patch edge. Penetration of windthrow along patch edges averaged 12 metres and ranged from 20 metres in the QCI and six metres in the WI area.

The average amount of windthrow in retained groups and clusters ranged from 39 percent in the QCI to 18 percent in WI and averaged 27 percent overall. This statistic is based on an estimate of the amount of windthrow over the entire area of the retained group or cluster. For purposes of this analysis we lumped groups (0.25 ha and larger) and clusters (small groups) of trees together and use the term group to refer to both groups and clusters of trees. Because the blocks that we assessed were early examples of VR, the size of groups was smaller than current practice. Most of the groups and clusters were less than the 0.25 ha Weyerhaeuser guideline (Figure 22).

There appears to be a strong trend of decreasing windthrow as group area increases from less than 0.1 hectares up to 0.5 hectares (Figure 23). This trend is present in both the QCI and WI data sets for retained groups of trees. Consequently, monitoring of more recent cutblocks is likely to find a lower percentage of windthrow with the larger groups that are being prescribed in VR blocks.

There is no obvious change in the amount of windthrow as average fetch distance increases (Figure 24). Any effect of fetch is likely confounded by the relationship between group size and windthrow severity. With a larger data set and stratification by group size, a fetch distance - windthrow relationship for groups might become more obvious. There were no obvious differences in windthrow amounts associated with different fetch types but this result may again be a function of the small sample size.

There is only one sample in the data set of retained groups where an edge treatment was carried out so no results are reported.

Topographic location appears to influence the degree of windthrow in retained patches in the same manner as for external boundaries (Figure 25). QCI sites located in coastal lowlands and moderate hills had less windthrow than those located on low hills. There is no obvious reason for this result other than that tree heights are lower in coastal lowland areas and moderate hills that low hills (Figure 26). This same relationship is present for external boundaries as discussed above in section 7.1. The topographic category "moderate valley" represents the WI data.

There is a strong trend of increasing windthrow with increasing stand height for the QCI retained group samples (Figure 27). There may be a very slight increase in windthrow with stand height but no strong trend is obvious in the data from WI. There seems to be a definite trend of increasing windthrow as stands become less dense (Figure 28), which corresponds with less windthrow in uniform stands as compared to multi-storied stands in the QCI. There is no difference in windthrow with differences in stand structure for the WI (Figure 29), this may in part be because the WI sites are primarily second growth stands and the stand structure differences are not significant. For neither area are there any distinctive differences in windthrow for differences in dominant tree species for retained groups (Figure 30). The lack of any definite trend in windthrow severity for these attributes may be a function of the small sample size that we are working with at this time. It may also be that retained groups are less sensitive to these factors than factors such as group size or stand height.

There are no definite trends present in the retained group data for either rooting depth or soil type (Figures 31 and 32).

7.3 Windthrow Relationships in Strips

The data set at the present time is extremely limited for retained strips of timber (26 samples). These strips were found in one strip shelterwood block in the QCI and riparian reserves and management zones left along streams within blocks. There are a total of 13 strips developed as part of shelterwood cuts and another 13 riparian strips along streams in the interior of blocks. The average length of the shelterwood strips is 76 metres and the average width is 40 metres. The average length of the riparian strips is 86 metres and the average width is 25 metres. The average amount of windthrow along the strips in strip shelterwood cuts was 17 percent and the average amount of windthrow in riparian strips was 31 percent. Riparian strip widths varied from 10 metres to 50 metres in total width but there are insufficient samples to determine if windthrow varies with strip width.

7.4 Windthrow Relationships in Areas of Dispersed Retention

The data set for areas of dispersed retention is limited to 13 plots from two blocks in the QCI. These plots have an average of 16 percent windthrow, and range from zero to 60 percent stems windthrown. No analysis to relate windthrow conditions to environmental attributes has been carried on this data at this time due to the small sample size. Analysis of windthrow relationships in areas of dispersed retention has been postponed until we have a larger data set.

7.5 Relative Comparison of Windthrow along Edges and in Groups

As we discuss at the beginning of this report there is concern that VR silviculture systems will result in more windthrow than would occur with clearcutting alone. In order to compare the amounts of windthrow along external block boundaries to windthrow along patch edges and within retained groups of trees we generate area-based data so that we can compare relative amounts of windthrow in these different locations.

Windthrow percentages along external edges and patch edges are estimated within an arbitrary 25-meter wide strip. Multiplying this 25 meter distance by individual plot lengths and then multiplying the product by the percent windthrow in the plot we can estimate the cumulative area of windthrow within the plot in hectares (e.g., a 1000 meter long plot with 10% windthrow would represent 0.25 ha of windthrow). By summing all individual edge plot windthrow areas, we can estimate the cumulative area of windthrow along external edges for all blocks sampled. A similar approach using the area of each individual group and the windthrow percentage in the group allows us to estimate the cumulative area of windthrow in retained groups.

For the 10 blocks (cumulative area harvested = 190 ha) sampled during the pilot study we find that there are approximately 5.7 hectares of timber windthrown along external edges and 3 hectares windthrown in retained groups. There is an additional 1 hectare windthrown along patch edges and 1.6 hectares along riparian strips and shelterwood strips (a total of 11.3 ha of windthrow for the 190 ha of logged area). Assuming that riparian strips and patches would occur as a result of current clearcutting practices under the BC Forest Practices Code, then this preliminary data suggests that VR silviculture practices may be resulting in a 36 percent increase in the amount of windthrow compared to what would occur with clearcutting (11.3 ha vs. 8.3 ha). This would increase the *area windthrown to area harvested ratio* from 0.044 (8.3/190) to 0.059 (11.3/190) or from about 4.5 hectares to 6 hectares of windthrow per 100 hectares harvested. This comparison is based on a very small data set and does not include windthrow occurring beyond the 25-meter wide sampling strip along external edges.

7.6 Windthrow Penetration

The distance windthrow penetrates into a stand edge can have significant consequences and so data on penetration is important for some forest management decisions, for example, for determining reasonable setbacks from gully escarpments and stream edges. As noted earlier, penetration distances are fairly similar for both the QCI and the WI with the QCI penetration distances being slightly greater. At this time, because of the small size of the data set, we are reporting only two comparisons: penetration distance versus boundary exposure and penetration distance versus fetch distance.

There is an obvious increase in average penetration distance with changes in boundary exposure. Lee boundaries tend to have very short penetration distances (3 to 6 metres) whereas the penetration distance on windward boundaries is almost twice that on lee boundaries (Figure 33). There is also a general increase in penetration distance as the wind exposure index increases but the trend is not as pronounced as that shown in Figure 33 for boundary exposure.

There appears to be a general though not entirely consistent increase in penetration distance with increases in average fetch distance (Figure 34). However, this relationship may be confounded by the apparent relationship between fetch distance and boundary exposure (Figure 35). There is a general and not unsurprising increase in fetch distance with changes in boundary exposure from lee to windward. Average fetch distances are very short or non-existent for lee boundaries and quite long for windward diagonal and windward boundaries. It could well be that the apparent correspondence between fetch distance and also percent windthrow reported earlier is simply an artifact of the correspondence between fetch distance and boundary exposure.

Finally we should point out that there is a general if weak correlation between percent windthrow and penetration distance (Figure 36). As percent windthrow increases there tends to be a corresponding increase in the distance that windthrow penetrates into a stand edge. In this case if regression analysis is carried out, an R^2 of 0.46 is achieved and the relationship takes the form: windthrow penetration = 3.79+0.34* percent windthrow.

8.0 AIR PHOTO INVENTORY APPROACH AND RESULTS

High-resolution (20 cm pixel) orthophotos generated from air photos in combination with 1:5000 operational cutblock maps and MrSID™ Geoviewer software were used in an preliminary attempt to inventory windthrow within and along boundary edges of VR cutblocks.

Based on our experience with this preliminary assessment, the following information can be obtained from the orthophoto interpretation:

- Stand density (dense, moderate or open) of the boundary edge and retention patches based on the density of the remaining canopy cover.

- An estimate of percent windthrow per plot based on the counting of windthrown trees and dividing by the total number of trees (i.e., windthrown trees plus standing trees within patches/groups or in a 25 metre wide strip along external boundary edges).
- Windthrow spatial pattern (i.e., the pattern of windthrow along/within a boundary or leave area).
- Windthrow orientation (i.e., the direction parallel to the stem taken from the roots towards the top of the tree).
- Boundary aspect (i.e., the direction perpendicular to and away from the stand boundary) measured off a 1:5000 setting map or a hard copy of the air photo.
- Boundary shape (i.e., concave or straight) and the boundary purpose (i.e., riparian, terrain stability or visual).
- Plot type (i.e., whether the plot is part of an external block edge, a patch edge or a complete group).
- Plot influence (i.e. the possible influence of adjacent areas on a plot, such as when the plot is sheltered by an adjacent boundary or has a plantation or wetland adjacent to it).

The advantages of an orthophoto inventory approach include:

- The data collection time per site is approximately four times faster for an air photo survey than for a complete field assessment (0.25-0.5 person-days per block compared with 1-2 person-days per block for a field assessment).
- There is no travel time to and from each site and no truck use to account for, which reduces the time spent on and cost for each site.
- There are no lost days to extreme weather conditions such as high winds, which can force field workers out of a site.
- An air photo survey is safer, as serious accidents are less likely to occur in the office than in the field.
- You can get a rough idea of how much windthrow has occurred in a large number of blocks over a short period of time.

Disadvantages and limitations of the orthophoto inventory approach include:

- High-resolution air photos are needed for each site. There is a cost associated with obtaining custom air photo images.
- Making observations on a computer monitor is hard on the observer’s eyes when used for extended periods of time, as the observer needs to look intently to identify windthrown trees.
- Windthrow can be hard to see on orthophotos especially where shadows are cast by retained trees within the block and/or by the trees along the block boundary.
- The method often resulted in underestimation of the actual amount of windthrow that had occurred at each site. Windthrown trees are not easily visible through the canopy of the retained patches or the external block boundary and may not be counted as part of the total number of windthrown trees in each plot. Windthrown trees may also be missed if they have fallen in a group and are lying on top of each other. As well, windthrown trees can look like logging debris and so may not be counted as

windthrow, especially if the site is older and the foliage of the windthrown trees has dropped.
- Windthrow penetration is hard to determine on the orthophotos as windthrown trees and their root masses are not easily visible through the tree canopy.
- The air photo survey will not detect salvage operations that have occurred after windthrow events. This can usually be done on the ground. As a result, salvaged windthrow will not be identified and the true amount of windthrow will be underestimated.
- If there were windthrow control treatments such as the feathering of an edge, tree topping or pruning they will not be visible on the orthophoto and the effectiveness of the treatment will not be assessed.
- Broken stems and leaning trees cannot be identified, in certain circumstances these may form a significant component of total wind damage.
- Post-windthrow stand density estimates may not reflect original stand densities.

There was an opportunity to compare the data collected through air photo interpretation with the field assessment on block 1709 in West Island Timberlands Franklin River Operation. The main difference between the two surveys was in the length of the plots. The orthophoto assessment reduced the number of plots from 51 with the field survey to 30 for the air photo survey. This is one reason why the air photo survey is much faster than the field survey. With the air photo survey the plots were separated only when significant changes in the orientation (aspect) of the falling boundary occurred (e.g., a 30º change in boundary aspect). The site characteristics that cannot be determined from the orthophotos including information on slope angle, terrain (surficial materials), slope morphology, soils, soil drainage, forest type (species or height) and edge treatment (feathered, thinned and/or topped etc.) were not used to separate the edges into different plots. This loss of detail in data collection results in less available information for study or management of windthrow in future blocks in the same area or other areas with similar features.

9.0 NORTH ISLAND CATASTROPHIC WINDTHROW EVENT

A catastrophic and widespread windstorm occurred on December 14th, 2001. This windstorm caused significant damage to forests in a number of areas on Vancouver Island. Wind damage also occurred in some areas on the mainland coast but there has been little systematic documentation of the effects of this storm. The following section outlines observations made during a reconnaissance survey of catastrophic wind damage that occurred in portions of Weyerhaeuser's North Island Timberlands (NIT) division (TFL 39 Block 2) between Menzies Bay and the Tsitika River on the east side of Vancouver Island.

In comparison, wind damage from a storm on October 17, 1996 was measured at the MASS study area in the Iron River operation of NIT. The 1996 storm winds were from the southeast and resulted in much less damage than the 2001 storm. Nevertheless, windthrow at the MASS site, which had been logged in 1993, was significant in partially cut stands. This storm doubled the cumulative windthrow in shelterwoods with 25%

retention (9.5 stems per ha (sph) damaged in the storm) and increased windthrow in 5% dispersed green tree retention blocks by 36% (2.4 sph). Surprisingly, there was no significant windthrow on the edges of the patch cuts (0.1 sph) and a nearby clearcut from this storm. Windthrow in adjacent, unlogged old growth was not assessed immediately after the storm, but was found to be minimal during the annual summer measurement.

9.1 Observations from the Reconnaissance Survey

A helicopter reconnaissance survey of damage from the December 2001 storm was carried out on February 7th, 2002. We viewed wind damage in the Amor de Cosmos, Adam, Eve and Tsitika watersheds within the NIT operations. On the following day, we made ground assessments and estimated the extent of windthrow in four variable retention cutblocks. We also viewed salvage operations that were underway, and obtained stereo air photos and uncontrolled air photo mosaics that were produced by Mindseye Images Inc. in Campbell River. NIT used these images to help plan extensive salvage operations.

9.1.1 Extent of Damage

From the air photo mosaics and inventory data, NIT estimated that about 500 thousand cubic metres of wood volume was windthrown within TFL 39, Block 2. Based on an average volume of 750 cubic metres per hectare, this represents over 660 hectares of forest on a total productive forest landbase of 169 thousand hectares (or about 0.4% of the area). The actual area affected by this storm is considerably greater because:

a) stands had varying amounts of windthrow (even in the worst areas there were some trees standing);
b) the emphasis of the NIT surveys was to identify areas of significant windthrow that were worth salvaging (smaller patches of windthrow were not mapped);
c) windthrow on adjacent tenures was not included in the NIT estimates. For example, Western Forest Products Ltd. Nootka Region made initial estimates of an additional 40 thousand cubic metres of windthrown timber in their operating areas.

The storm damaged undeveloped old growth and older second growth stands (i.e., generally over 60 years old), the edges of clearcut and VR blocks, retention (groups and single trees) within blocks and other natural stand edges such as stream banks. Recently established plantations and younger second growth did not appear to suffer significant damage. Selected photos to illustrate the extent of damage are included in Appendix VI.

9.1.2 Direction, pattern and distribution of windthrow

Based on the observations of the dominant windthrow orientations, it appears that the storm winds originated from the northwest. Windthrow direction varied from one drainage to another due to the effects of local topography and valley orientation with some areas showing more westerly wind directions. Prevailing storm winds on the North

Island are generally from the southeast or southwest. Because of this, a storm from the northwest is potentially more damaging because some stands may have developed more resistance to prevailing winds than to winds from other directions.

The pattern of windthrow suggested undulating waves or cells of very strong winds that touched down periodically as the storm moved across the landscape. The storm affected ridges and valley bottoms as well as mid-slope positions. Heavily damaged stands were found adjacent to areas with apparently similar conditions that were virtually untouched. Some stands had narrow bands of windthrow (Appendix VI, Photo 1), and some had broad areas of windthrow with a few untouched trees or groups of trees while others had a more uniform distribution of windthrow as if the stand had been partially cut as a shelterwood (Photo 2).

Although all species were affected, hemlock and amabilis fir had greater wind damage than Douglas-fir or western redcedar. Some old growth stands had scattered redcedar vets that survived the storm while the surrounding “hem-bal” was on the ground (Photo 3). Areas that were most affected were the lower Adam (Photo 4), where there are extensive stands of windthrow origin (“1908 Blowdown”), and old growth stands in the Eve River and Tsitika River drainages (Photo 3). Damage was least prevalent in the White and Memekay tributaries of the Salmon River. Some VR blocks had extensive damage and others were largely untouched.

Whether a clearcut edge or VR block was damaged appeared to have more to do with where the storm winds touched down than to the size or design of the block. Windthrow within VR groups or single tree retention was a relatively small proportion of the total forest damage caused by this storm. Within individual VR blocks, there was often a higher volume of windthrow associated with the external block boundary than with the groups left within the block, as we observed with the monitoring at WI and QCI. Retention within the block did not appear to have any obvious influence on the amount of windthrow along the block edge for a storm of this magnitude. We did not have any direct comparisons of clearcut and retention blocks in close proximity to test this observation.

9.2 Windthrow in Variable Retention Blocks

Windthrow in retention patches and along cutblock boundaries was estimated from a ground survey of four VR cutblocks: two in the lower Adam River (LA4A6, LA20), one at Eve River (S8) and one at Amor de Cosmos Creek (E. Amor Main). The Eve block was in old growth and the remaining blocks were in mature second growth; consequently, our observations apply mostly to second growth stands. The dense, uniform second growth hemlock and Douglas-fir stands in the lower Adam were hardest hit. The trees in these stands tend to be relatively tall with large height-to-diameter ratios. Plates 6 to 9 in Appendix I are orthophotos of these blocks showing the estimated percent windthrow in VR patches and the location of windthrow along the cutblock boundaries. A total of 37 retention groups were assessed. Figure 37 shows that there was a wide range of windthrow damage in these groups with almost half of the groups having over 50% windthrow. Average percent windthrow within groups for the four blocks (weighted by group size) ranged from about 30% to 70%, with the greatest damage in block 4912 on LA4A6 (Photo 5). This block was hemlock dominated and had relatively small groups. Windthrow in block 4925 (LA20) had two large patches that had windthrow on the edges that represented 5% to 10% of the patch. Most of the other groups had windthrow over 40%. The VR block at East Amor had an average of 35% windthrow in patches and an extensive area of edge windthrow on the eastern boundary of the cutblock (Photo 6). In contrast to the Lower Adam blocks, most of the patches at East Amor had less than 40% windthrow. The small old growth block (OP 4000, S8) in Eve River had only two patches that were 50% and 70% damaged. Although there was little damage along the edges of this cutblock, there was extensive windthrow on the other side of a gully bordering the eastern edge of the block.

9.3 Recommendations for Catastrophic Windthrow Salvage

The forest ecosystems of northern Vancouver Island have evolved with periodic stand-replacing windthrow. A logical assumption is that some species are favored by or may even depend upon such events for their habitat. Observation of the stand structure resulting from the December 2001 windthrow provides some insights for variable retention strategies. The following recommendations apply to new salvage blocks as well as salvage in existing variable retention blocks:

1. Utilize a range of approaches to maintain safety, achieve economic and operational efficiencies and meet ecological goals for structural retention. The same guiding principle applies to salvage as we have used for variable retention: don’t do the same things everywhere.
2. Don’t try to get it all. Maintaining patches of windthrow on the landscape will provide habitat for some plant and animal species. It is unlikely that all of the wind-damaged areas can be salvaged before wood quality is degraded by insects and decay; therefore, planning up front for retention where salvage would be more costly can help meet ecological objectives while optimizing economic returns.
3. Don’t try to make it neat and tidy. The tendency to want to make salvage areas look good may be counter to ecological objectives. Yarding unmerchantable logs, piling and burning of slash and other ‘cleanup’ operations may leave less desirable habitat conditions (e.g., concentration or removal of coarse woody debris). These activities are extra costs that can be avoided—unless they are necessary for safety.
4. Maintain the minimum retention levels for the zone (i.e., Timber = 10%) in salvaged cutblocks, even where they are “clearcut with reserves”. This will meet the habitat objectives of variable retention even where the spatial distribution requirements of the “retention system” are not possible in some salvage blocks.
5. Maintain naturally “feathered” edges along block boundaries where safety permits, rather than creating straight, clean stand edges. Experience has shown that this approach will help minimize further windthrow on windward edges.

6. Leave some patches of windthrow within salvage blocks where possible; this will maintain some of the diverse stand structure that these events create. If these patches are placed in areas where timber values are lower, or yarding costs are higher, then the profit margin of a block can be improved.
7. In existing VR blocks, try to maintain as much of the retention that is still standing as possible. Partially windthrown groups still provide important structure. A dense patch of second growth may have 50 percent windthrow leaving the stand at a similar density to an old growth stand. Obviously, groups that are almost entirely blown down, that have good road access and high value timber are better candidates for salvage than groups with low levels of windthrow and more difficult access.

10.0 SUMMARY CONCLUSIONS AND DISCUSSION

In this section we focus on the more obvious and definitive trends in the data. The reader who is interested in some of the more obscure or variable trends will need to spend time reading the results section and inspecting the tables and plots in the Appendices.

As expected, there are some regional differences in windthrow amounts. The average amount of windthrow along external setting boundaries varied from an average of six percent on the WI blocks to ten percent in the QCI blocks with an overall average of eight percent. The values for the QCI blocks are substantively less than those recorded in a earlier study of windthrow along late 1970’s falling boundaries in the QCI[3]. In that study about 38 percent of the trees along setting edges where windthrown. This difference suggests that the current QCI results may not cover the full range of stand types present in the area, or that logging is not occurring in the same stand types that it was in the late 1970’s. There is a similar regional trend with windthrow in retained groups. The average windthrow in retained groups is 18 percent in the WI area and 39 percent in the QCI with an overall average of 27 percent. Overall, retained groups appear to be more vulnerable to windthrow than external setting edges, however the cumulative amounts of windthrow are less (see below).

There is a fairly obvious and not surprising trend in the data indicating that windward edges along external setting boundaries are more vulnerable to windthrow than other boundary exposures. This finding suggests that it will be important to identify likely windward boundaries and concentrate windthrow control strategies in these areas, especially in high risk situations (i.e., areas where the consequences of windthrow may be severe).

There appears to be a trend of increasing windthrow with increasing average fetch distances for external boundaries, this effect may diminish at greater distances. The character of the fetch surface may affect the amount of windthrow along external edges. External boundaries downwind of areas of dispersed retention or mixtures of dispersed retention and retained groups may be subject to less windthrow. There are no similar trends with retained groups.

[3] T. Rollerson, 1981, Queen Charlotte Woodlands Division Windthrow Study, LUPAT, Woodlands Services, MacMillan Bloedel Ltd.)

There is some indication that feathering or topping and pruning treatments reduce the amount of windthrow along external boundaries but as the data set for these treatments is small this conclusion should be considered tentative. Where utilized, these treatments should focus on windward boundaries; occasionally these treatments occurred on lee edges so were likely unnecessary.

There may be some relationship between topographic location and the amount of windthrow. Topographically exposed locations tend to experience more windthrow; however, these results are confounded by corresponding differences in average stand heights with taller trees generally occurring in the more exposed locations.

For both external edges and retained groups, the amount of windthrow tends to increase with increases in the average stand height. This finding suggests that where possible preferential selection of shorter stands for retained groups or windward external edges will help reduce the potential for windthrow. There is some indication that windthrow along external edges varies with the dominant tree species in a stand, with cedar being the most windfirm. These trends are not apparent in the data on retained groups, suggesting that factors other than tree species differences may be more important in these situations.

There is a fairly strong trend of decreasing amounts of windthrow as the size of the retained group increases. This phenomena may overwhelm the influence of other factors and may explain why we see some differences in the trends between external edges and retained groups. The decrease in windthrow with increasing group size corresponds to a general trend of decreasing windthrow with increasing riparian strip width described in a recent study of windthrow on Northern Vancouver Island.[4] It also corresponds with findings of an inverse relationship between patch size and windthrow found in several other recent studies in BC.[5] These results suggest that retaining larger groups should decrease the amount of windthrow associated with VR silvicultural practices.

We have the general impression from our anecdotal observations of windthrow in retained groups in a variety of areas that windthrow tends to be concentrated along the windward sides of these groups. This finding, if collaborated by more detailed data collection, suggests that in high risk situations limited removal of more vulnerable stems or topping and pruning along the windward edges of retained groups may reduce windthrow.

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[4] Rollerson, T. K. McGourlick. 2001. Riparian Windthrow – Northern Vancouver Island. In: Proceedings of the Windthrow Researchers Workshop, 31 January 31 – February 1 , 2001. Richmond, B.C. (compiled by S.J. Mitchell and J. Rodney).

[5] Burton, P.J. 2001. Windthrow Patterns on Cutblock Edges and in Retention Patches in the SBCmc. In Proceedings of the Windthrow Researchers Workshop, January 31-February 1, 2001. Richmond, B.C. (compiled by S.J. Mitchell and J. Rodney).

DeLong, S.C., Burton, P.J., Mahon, T., Ott, P. and Stevenson, D. 2001. In Proceedings of the Windthrow Researchers Workshop, January 31-February 1, 2001. Richmond, B.C. (compiled by S.J. Mitchell and J. Rodney).

Scott, R., B. Beasley. 2002. Variable Retention Windthrow Monitoring Report. A survey of eleven variable retention cutblocks in the Long Beach Model Forest, BC. Long Beach Model Forest Society.

As outlined in section 7.5, the *area windthrown to area harvested ratio* increases from about 4.5 hectares to 6 hectares of windthrow per 100 hectares logged (i.e., 0.045 to 0.06) with VR practices compared to current clearcutting practices. Given that the functional ecological utility (forest structure) of most VR groups has likely not been seriously compromised over the long-term (i.e. the average windthrow in retained groups is about 27 %), the windthrow occurring as a result of VR practices is probably acceptable. This is particularly the case both in dense second growth stands where natural mortality will likely reduce the stem count over time. We should caution that this comparison involves a small data set and does not consider areas of windthrow that may occur beyond the nominal 25 meter wide sampling strip along external edges. While rare and not present within the current pilot study, areas of extensive windthrow can occur along external setting edges. These additional areas of external edge windthrow can significantly increase the *area windthrown to area harvested* ratio.

The distance that windthrow penetrates into an external stand edge tends to be affected by some of the same variables as percent windthrow and tends to increase as the percent of the stand windthrown increases. Our limited 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 average fetch distance; however, as fetch tends to increase as boundary exposure changes from less to greater wind exposure, the apparent relationship between fetch distance and percent windthrow may be an artifact of the correlation between fetch distance and boundary exposure.

Further investigation of the apparent geometric relationship between boundary exposure and fetch distance will be important. An obvious initial response to the apparent relationship between fetch distance and windthrow severity is to suggest that smaller openings will reduce fetch distance and so reduce windthrow severity. However, if the relationship is spurious and simply a function of a geometric correlation with boundary exposure, then the assumption that reducing fetch distance will reduce windthrow is flawed.

11.0 RECOMMENDATIONS FOR FUTURE MONITORING

The current sampling approach tends to result in a large number of plots along external block boundaries but a smaller number of samples for internal patch edges or retained groups of trees. It would be useful to obtain a larger patch and group data set more quickly, to facilitate assessment of the effect of such factors as group size and stand characteristics on windthrow severity in patches and groups. The easiest way to do that is to reduce the number of blocks where external edges are sampled and include an equal or larger number of blocks were patches and groups only are sampled.

The difficulty in estimating types and amount of windthrow damage accurately significantly reduces the utility of using orthophotos as a tool for windthrow monitoring. These photos may be useful for identifying large patches of severe windthrow but not the finer estimates demanded by this monitoring project. We would suggest that orthophotos or regular air photos and setting maps be used in preliminary plot stratification to help reduce the total number of plots sampled but not for more detailed data collection work.

Separating plots only when significant changes in the orientation (aspect) of the falling boundary occurs, as with the orthophoto survey, would reduce the number of plots at each site. This should make the field data collection quicker and increase the number of blocks surveyed over a given time period.

One way to improve the efficiency of the field data collection would be to have one or two designated field crews carry out all windthrow monitoring. A significant amount of time was consumed in teaching new crews how to collect the data. With one or two designated field crews, the data would be collected more efficiently and more consistently.

One type of data that was not collected during the pilot study was to describe whether or not the windthrow occurring in retained groups was occurring uniformly throughout each group or if it is generally concentrated on windward edges. This information should be collected as it may assist in the management of retained groups. If windthrow is occurring on windward edges then specific action could be taken along those edges to reduce the potential for windthrow.

We often find anecdotal observations when carried out systematically and carefully documented by an experienced individual(s) can be a very efficient way to identify significant trends in local or regional areas. The section in this report describing the catastrophic windthrow event in Weyerhaeuser's North Island Operating Unit is a good example of this approach. Consideration should be given to allocating a certain amount of time each year to anecdotal surveys rather than dedicating all available resources to the more systematic plot surveys. Interpretations and recommendations based on rapid but careful and systematic field observations balanced with past experience can be an effective and efficient way to practice adaptive management as well as directing changes in more intensive monitoring efforts.

APPENDIX I. PLATES

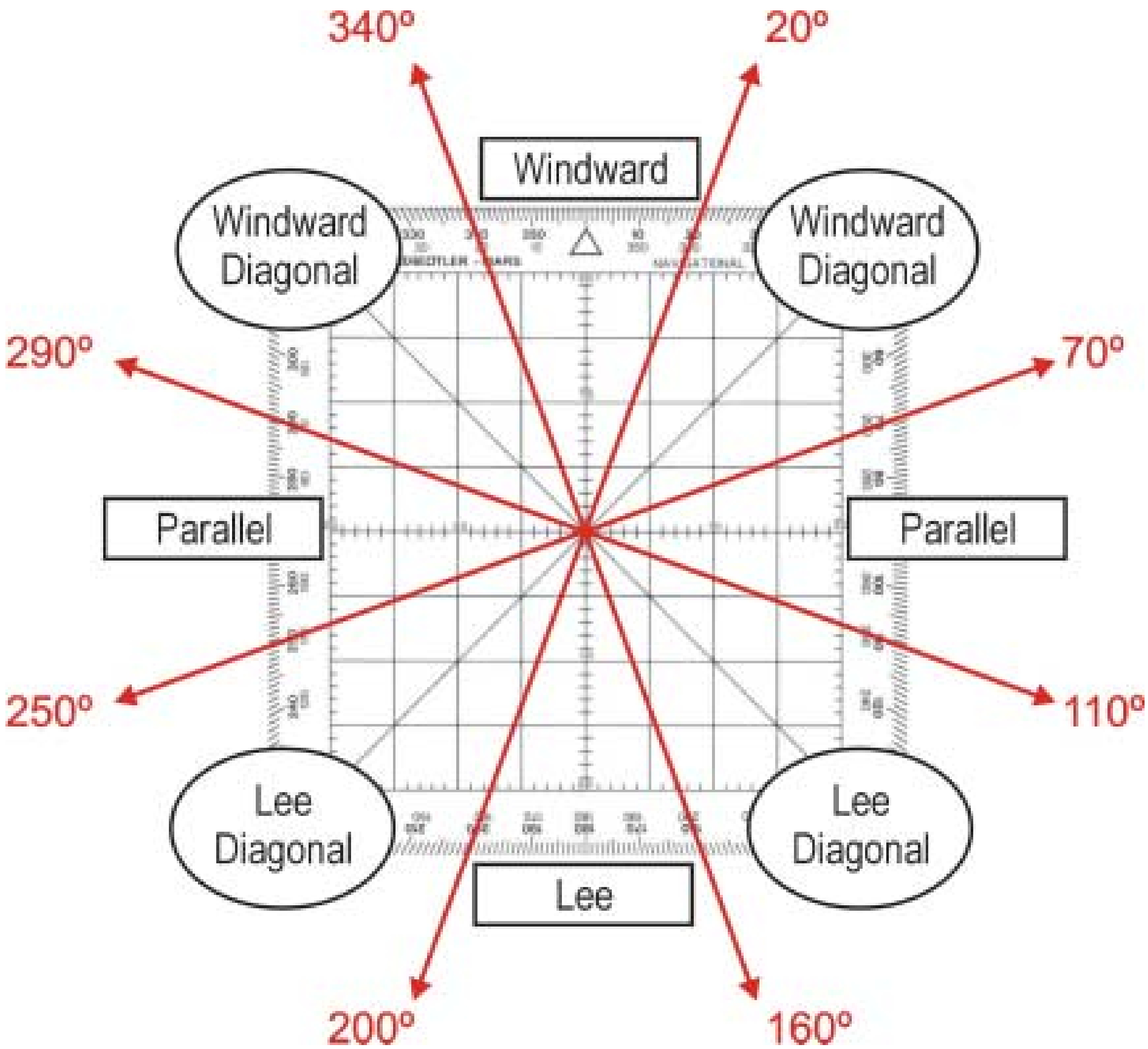


Plate 1. Transparency used for determining boundary exposure

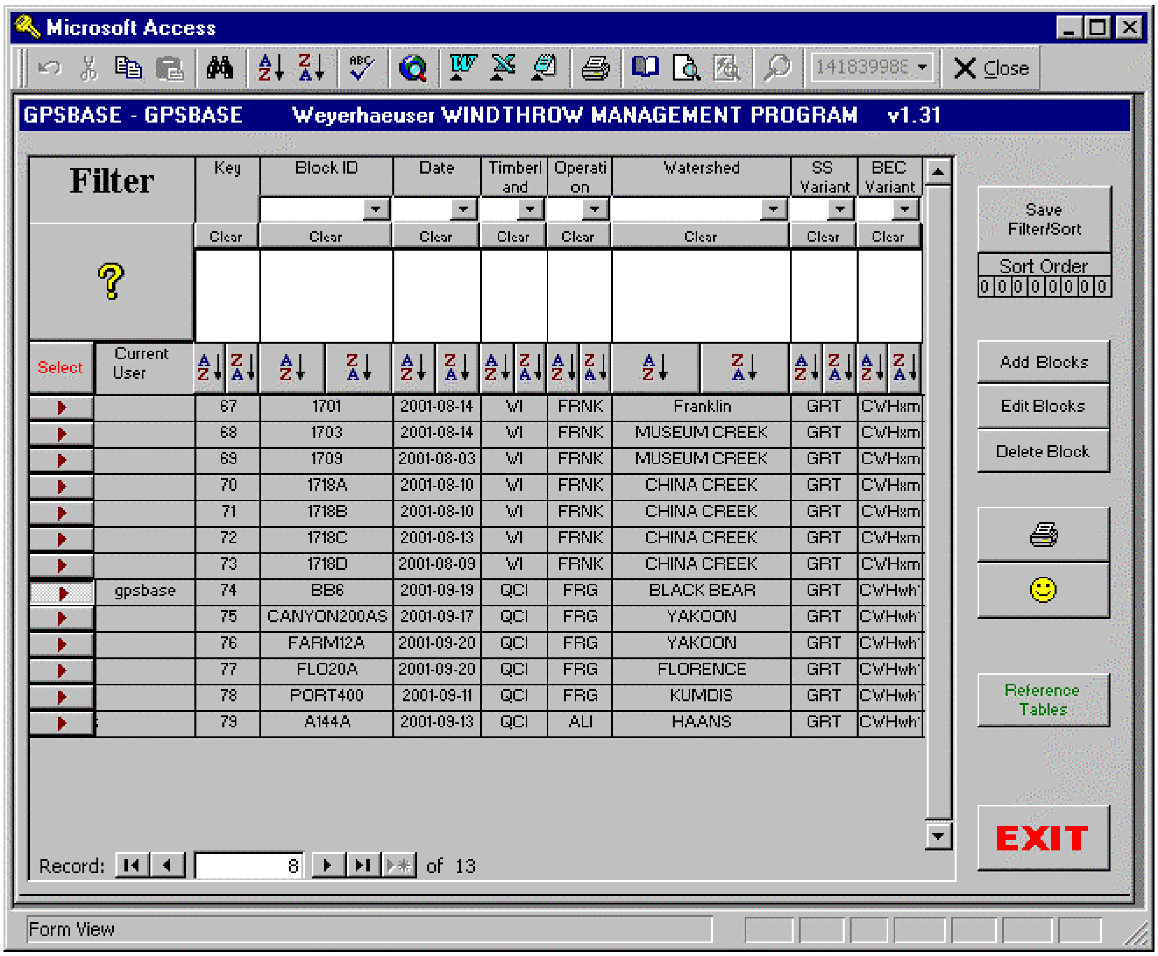


Plate 2. Database primary block summary and entry screen

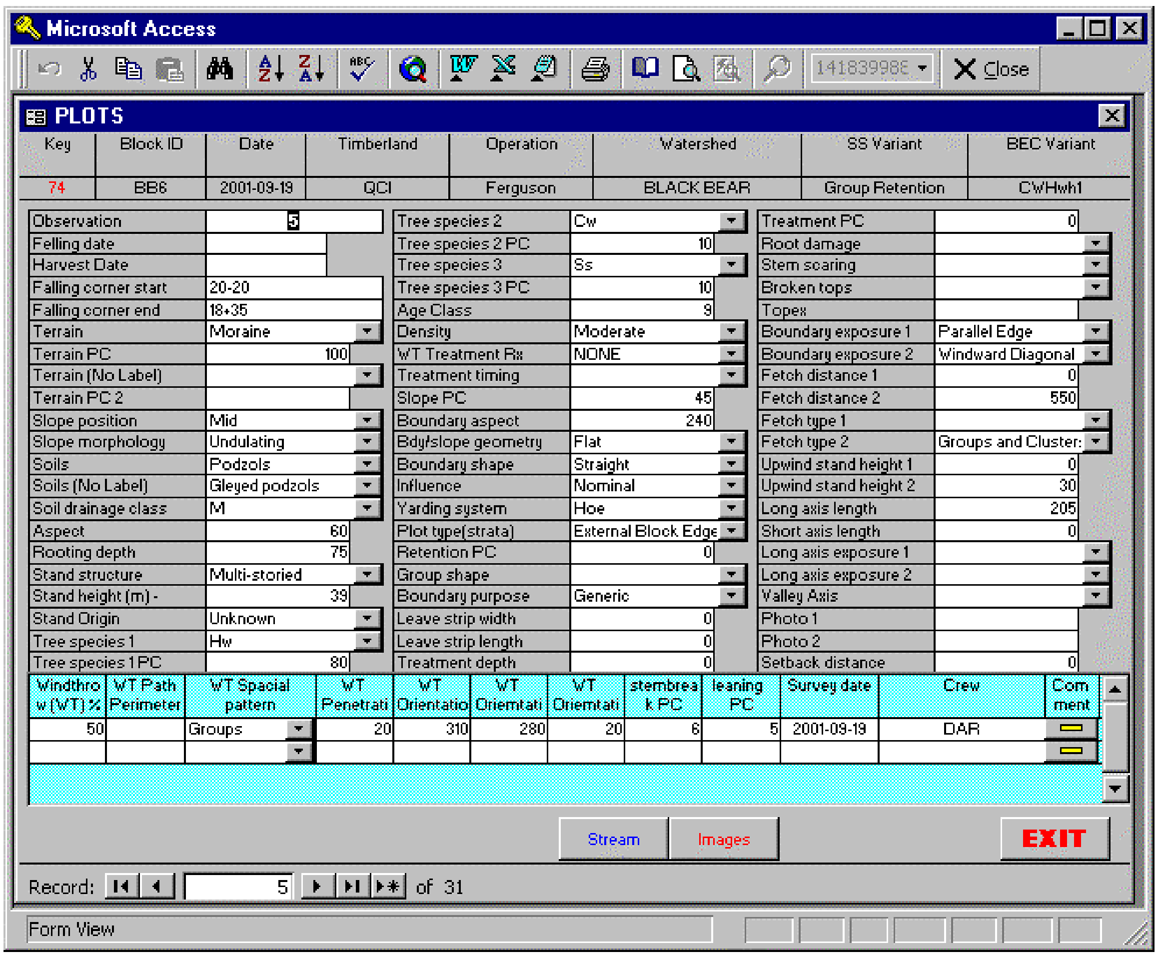


Plate 3. Database plot data entry/summary screen

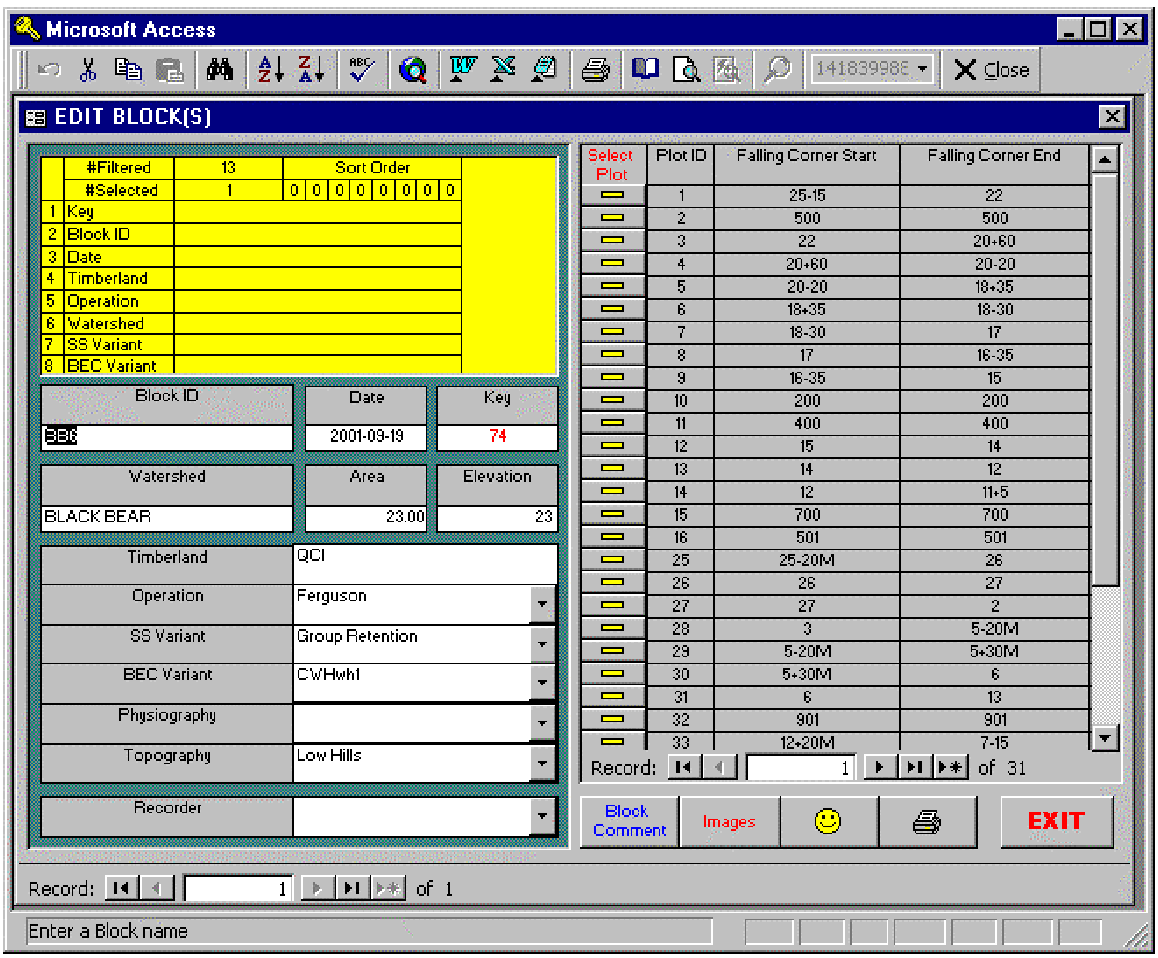


Plate 4. Database block plot summary screen

Plate 5. Orthophoto of OP4912, LA4A6 at North Island Timberlands showing the percent windthrow in retention groups and the location/direction of windthrow along boundaries resulting from the December 14, 2001 storm.

Plate 6. Orthophoto of OP4925, LA20 at North Island Timberlands showing the percent windthrow in retention groups and the location/direction of windthrow along boundaries resulting from the December 14, 2001 storm.

Plate 7. Orthophoto of OP2226, East Amor ML at North Island Timberlands showing the percent windthrow in retention groups and the location/direction of windthrow along boundaries resulting from the December 14, 2001 storm.

Plate 8. Orthophoto of OP4000, S8 at North Island Timberlands showing the percent windthrow in retention groups and the location/direction of windthrow along boundaries resulting from the December 14, 2001 storm.

(see four separate files on CD: Ortho #.PDF)

APPENDIX II TABULAR ANALYSIS

Table 1. Topographic distribution of plots

Topography	QCI	West Island	Total Plots
Coastal plain	71		71
Low hills/ridges	87		87
Moderate hills/ridges	35		35
Moderately deep valley		226	226
Total Plots	193	226	419

Table 2. Distribution of sample plots by operating unit

Block Number	QCI Plots	West Island Plots	Total plots
1701		48	48
1703		35	35
1709		51	51
1718A		13	13
1718B		9	9
1718C		14	14
1718D		56	56
A144A	35		35
BB6	31		31
CANYON200AS	33		33
FARM12A	30		30
FLO20A	23		23
PORT400	41		41
Total plots	193	226	419

Table 3. Distribution of sample plots by strata category

Strata catetgories	QCI	West Island	Total
External block edge	148	154	302
Group	22	40	62
Patch edge	9	14	23
Peninsula	1	4	5
Strip/ribbon	13	14	27
Total plots	193	226	419

Table 4a. External edge plots length summary

Unit	Sum of plot lengths	Number of plots	Mean plot length	Std. Deviation	% of Total Sum	% of Total N
QCI	15055 m	148	102 m	47 m	53	49
West Island	13315 m	154	86 m	44 m	47	51
Total	28370 m	302	94 m	46 m	100	100

Table 4b. Variable retention group area summary

Unit	Number of plots	Mean plot area	Std. Deviation	% of Total N	Minimum area	Maximum area
QCI	22	0.21 ha	0.09	35.48	0.03 ha	0.38 ha
West Island	40	0.16 ha	0.13	64.52	0.01 ha	0.55 ha
Total	62	0.18 ha	0.12	100.00	0.01 ha	0.55 ha

Table 5. Wind damage summary for external setting edges

Unit	Factor	N	Mean	Std. Deviation	Maximum	Minimum
QCI	% windthrow	148	10	17	80	0
	% stembreak	148	1	3	15	0
	% leaning	148	2	4	30	0
	windthrow penetration	148	7	7	30	0
West Island	% windthrow	154	6	14	75	0
	% stembreak	154	0	0	3	0
	% leaning	154	0	2	20	0
	windthrow penetration	154	6	9	40	0
Total	% windthrow	302	8	15	80	0
	% stembreak	302	1	2	15	0
	% leaning	302	1	4	30	0
	windthrow penetration	302	7	8	40	0

Table 6. Comparison of fetch category, fetch distance and percent windthrow

Fetch 1 category	Mean distance (m)	N weighted	Percent Windthrow
Forest	42	741	6
Clearcut	101	159	9
Groups	168	63	24
Groups and Dispersed	266	91	10
Dispersed	173	81	8
Average	85	1135	8
Fetch 2 category			
Forest	0	673	4
Clearcut	91	156	11
Groups	306	93	24
Groups and Dispersed	348	107	14
Dispersed	155	106	9
Average	85	1135	8

Table 7. Comparison of edge treatments to boundary exposure

Boundary exposure 1	Lee	Lee diagonal	Parallel	Windward diagonal	Windward	Totals
None	32	75	96	58	33	294
Feathered	1			1		2
Pruned		1			2	3
Pruned and topped				1	2	3
Plot total	33	76	96	60	37	302
Boundary exposure 2						
None	29	81	67	86	31	294
Feathered			1	1		2
Pruned			1	2		3
Pruned and topped			1	2		3
Plot total	29	81	70	91	31	302

APPENDIX III GRAPHICAL ANALYSIS

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

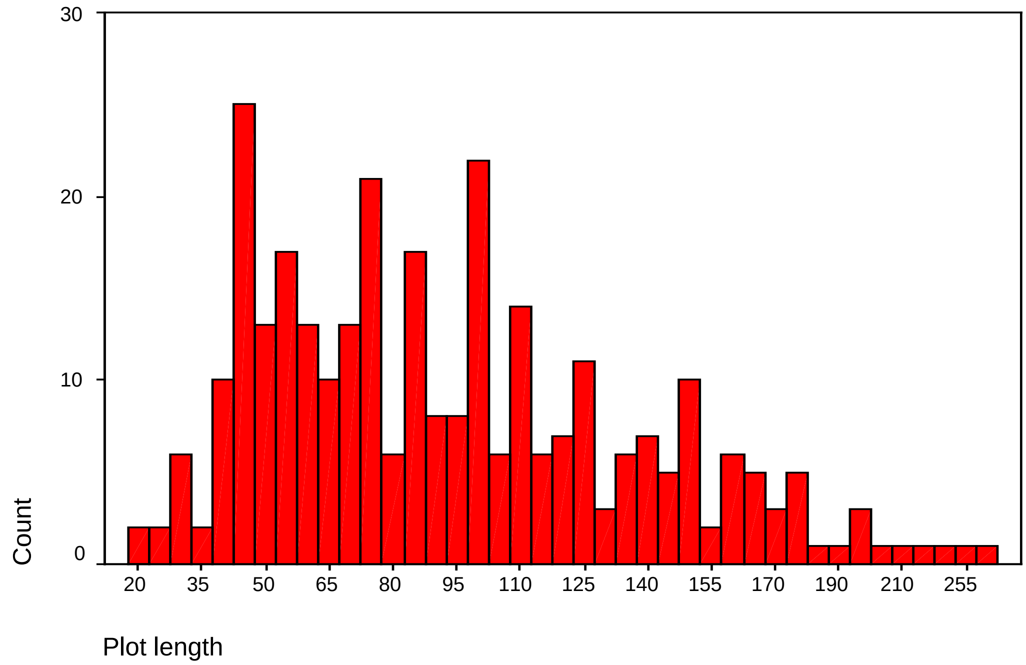


Figure 1. Distribution of plot lengths for external block edges all areas

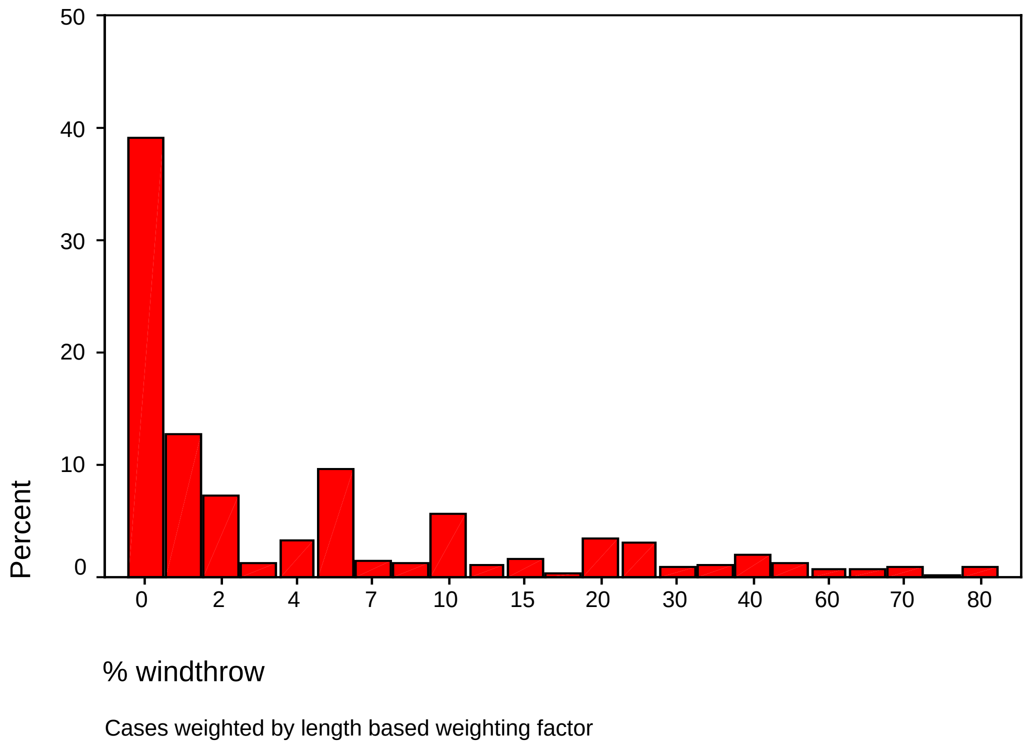


Figure 2. Distribution of windthrow along external block edges - all areas

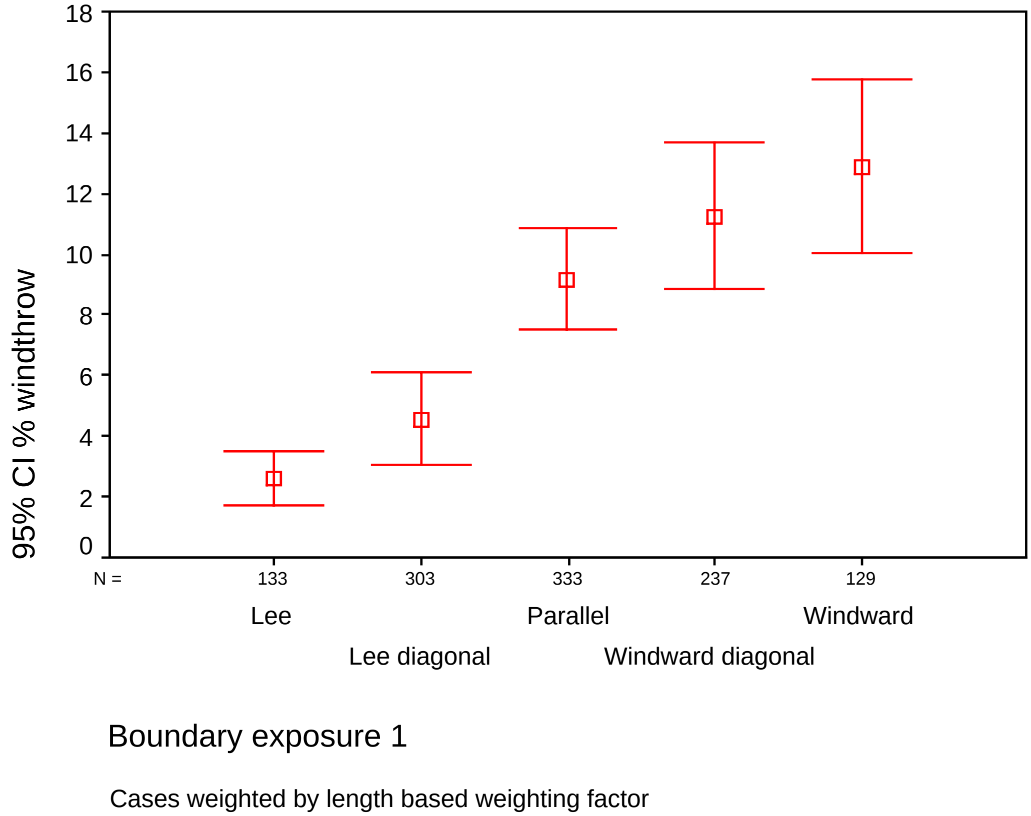


Figure 3. Percent windthrow versus boundary exposure class - all external edges

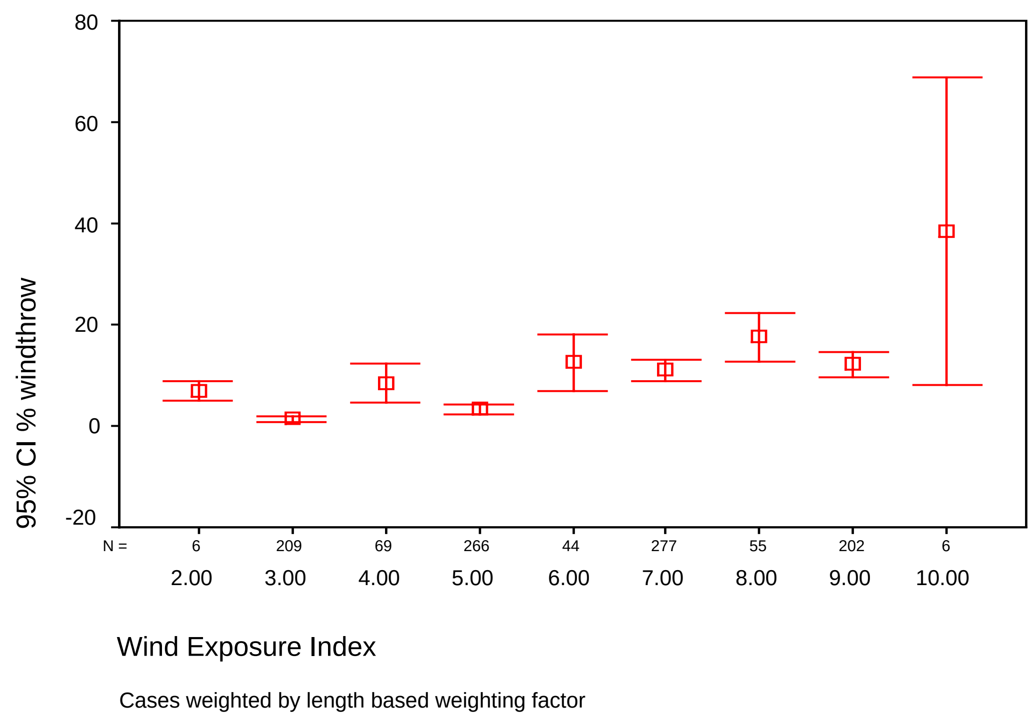


Figure 4. Percent windthrow versus wind exposure index all external edges

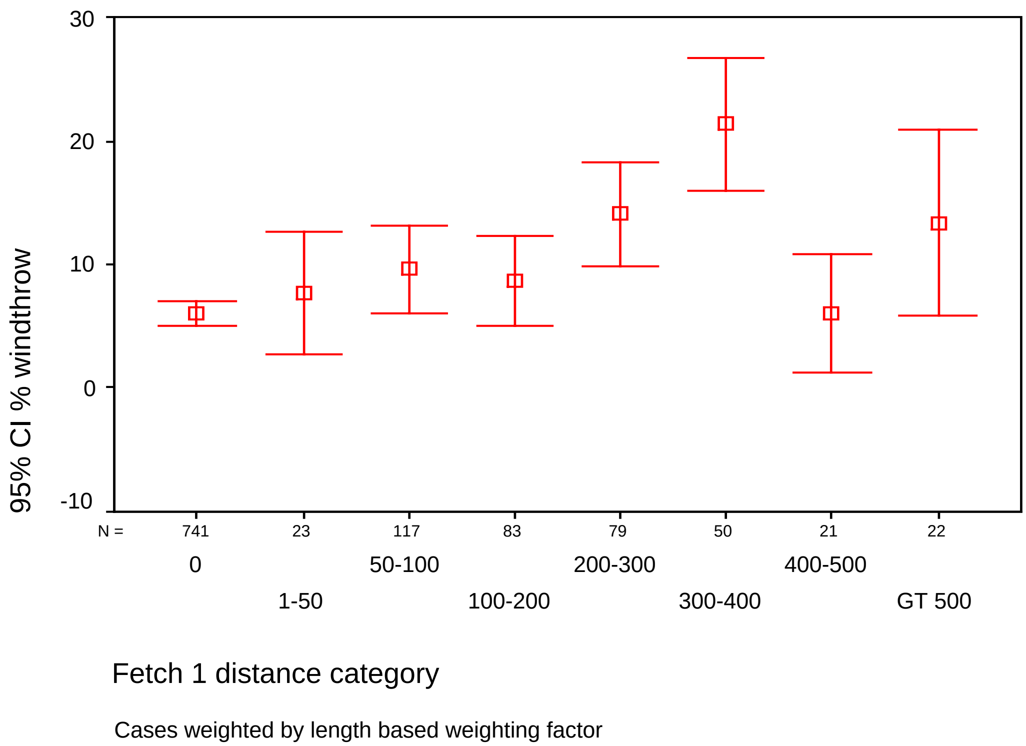


Figure 5. Percent windthrow versus primary fetch distance all external edges

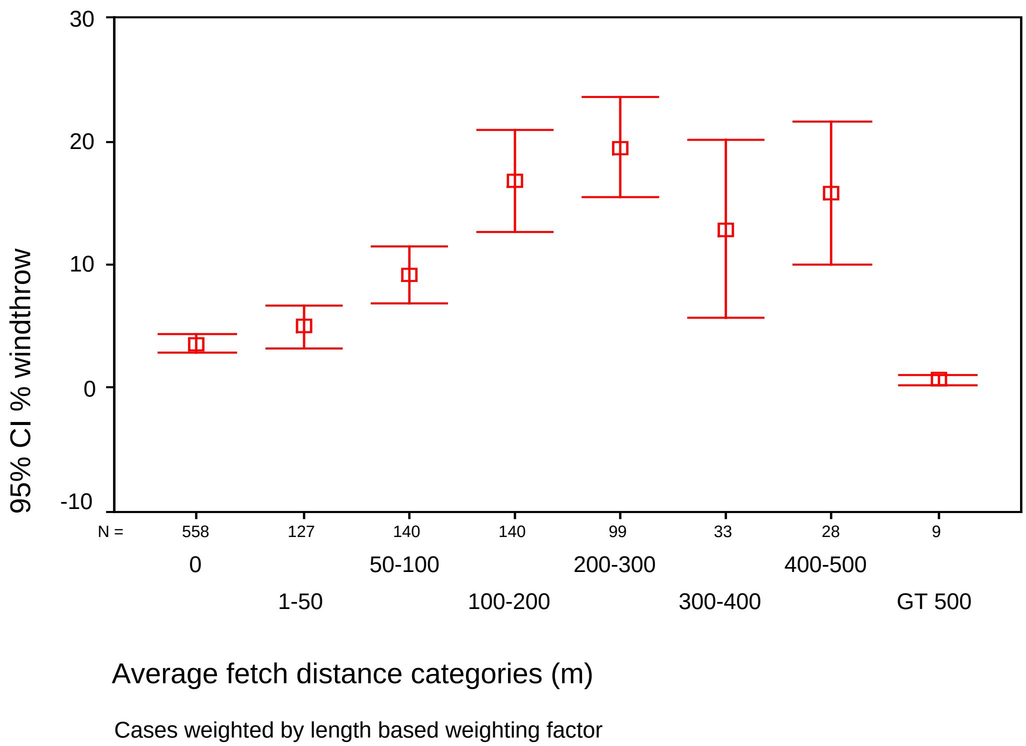
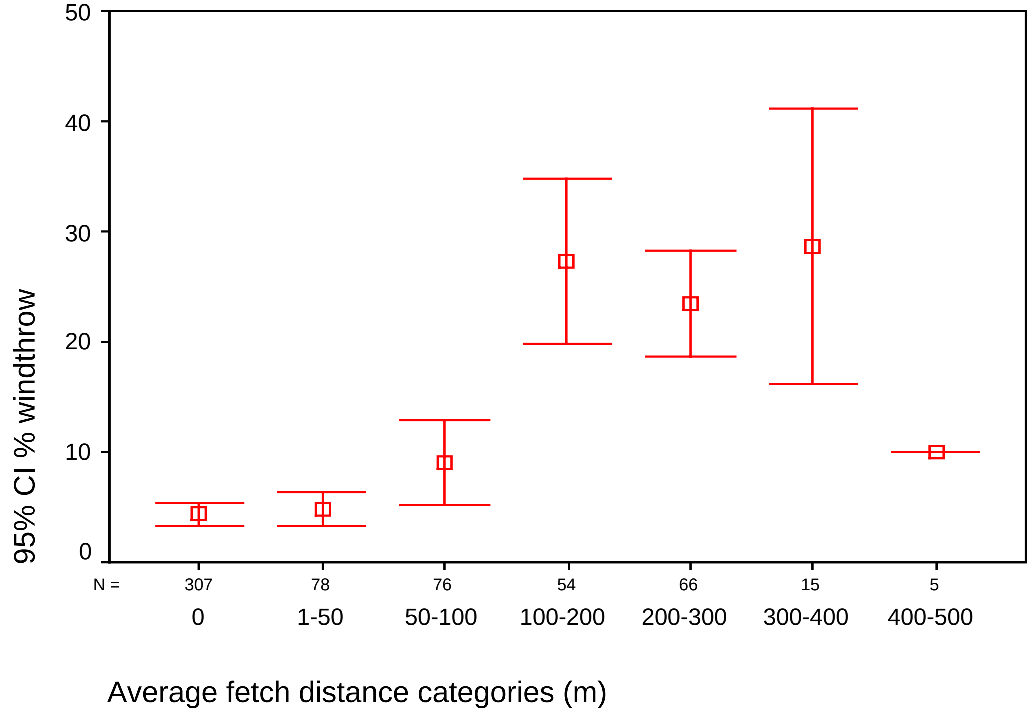
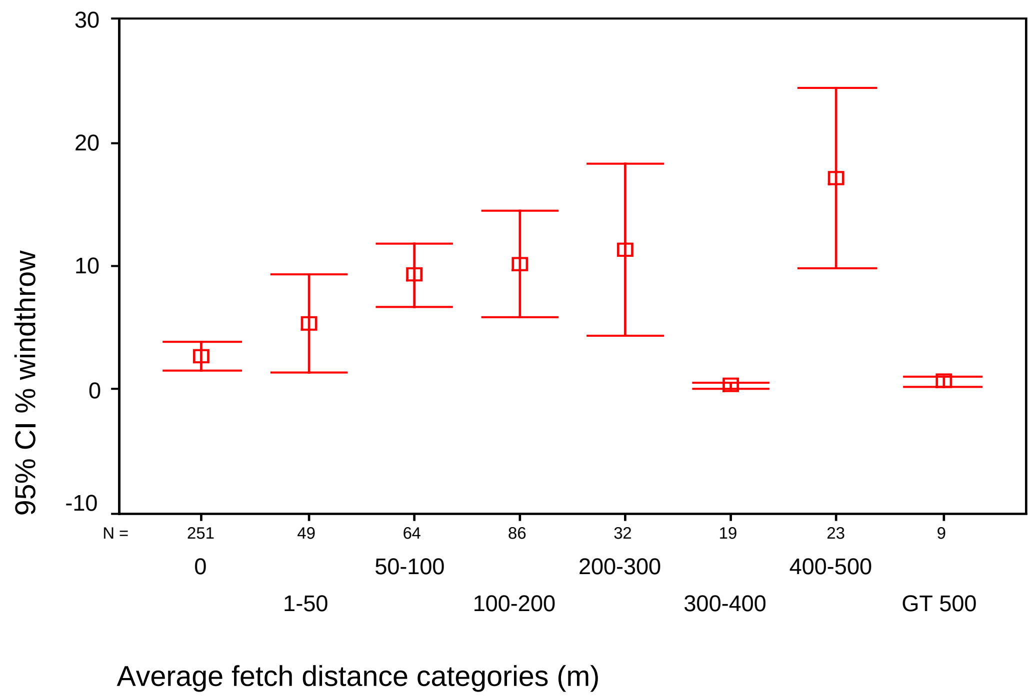


Figure 6. Percent windthrow versus average fetch distance all external edges



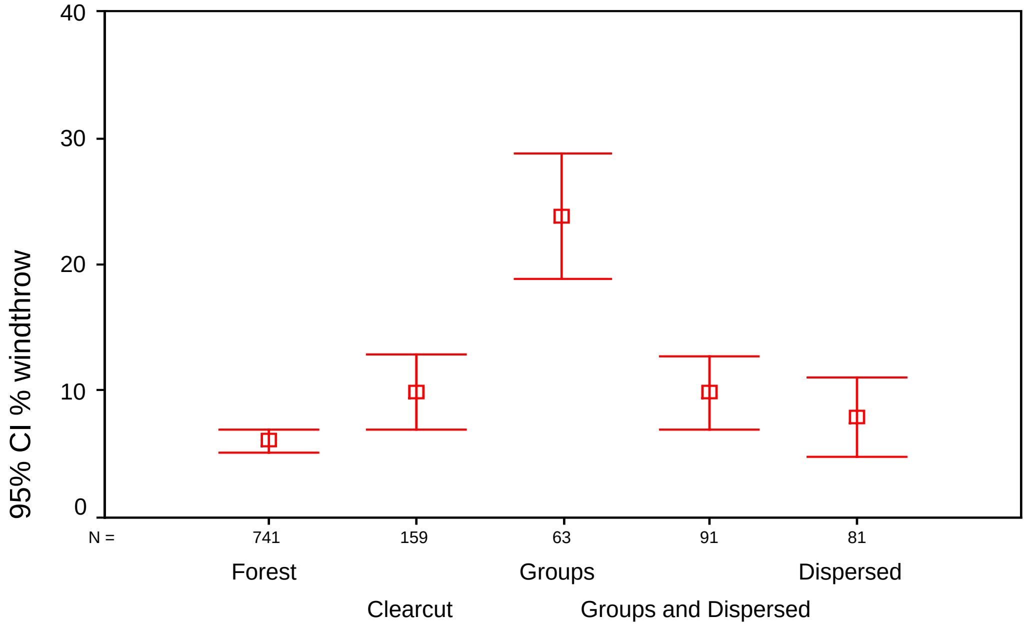
QCI data cases weighted by lenght based weighting factor

Figure 7. Percent windthrow versus average fetch distance - QCI external edges



West Island data cases weighted by length based weighting factor

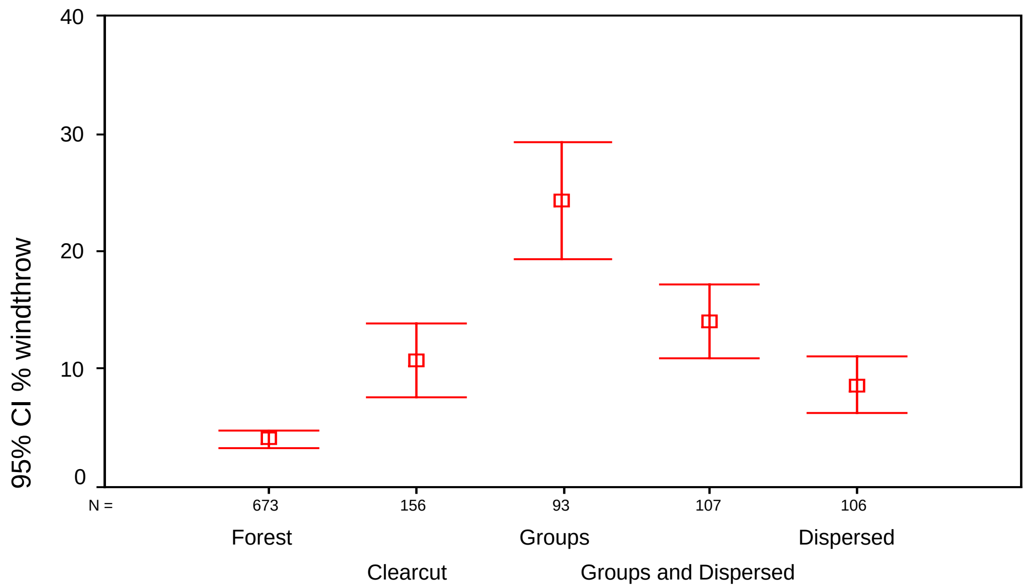
Figure 8. Percent windthrow versus average fetch distance - West Island edges



Fetch 1 category

Cases weighted by length based weighting factor

Figure 9. Fetch 1 categories versus percent windthrow - all external edges



Fetch 2 category

Cases weighted by length based weighting factor

Figure 10. Fetch 2 categories versus percent windthrow – all external edges

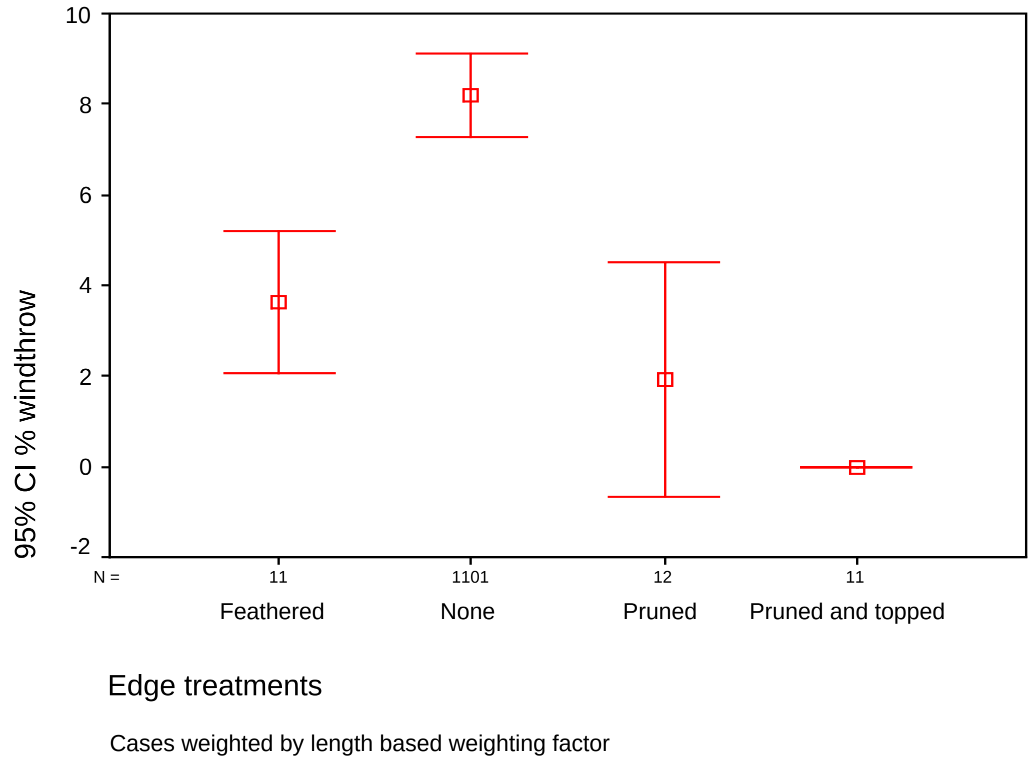


Figure 11. Edge treatment versus percent windthrow - all external edges

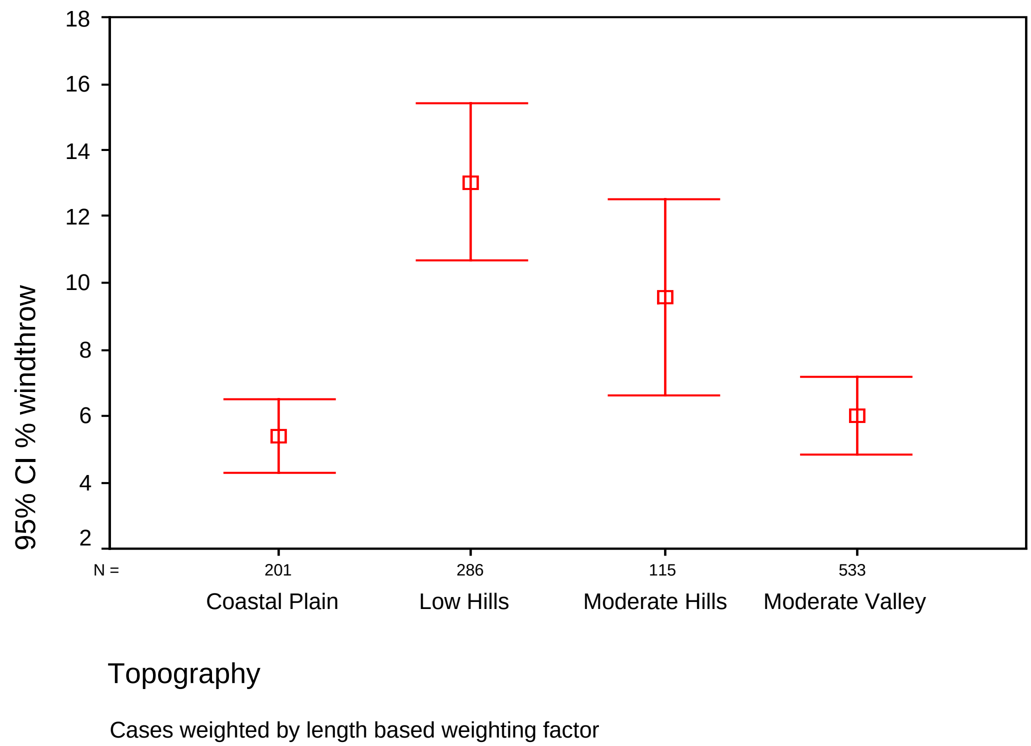


Figure 12. Topography versus percent windthrow - all external edges

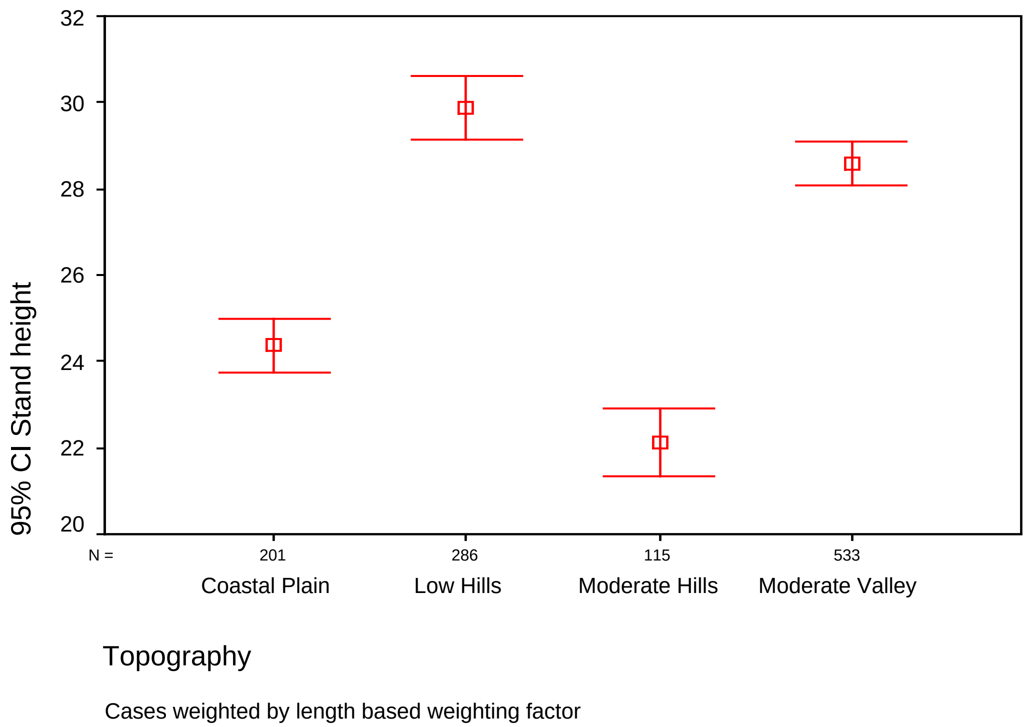


Figure 13. Comparison of tree height to topographic position – all external edges

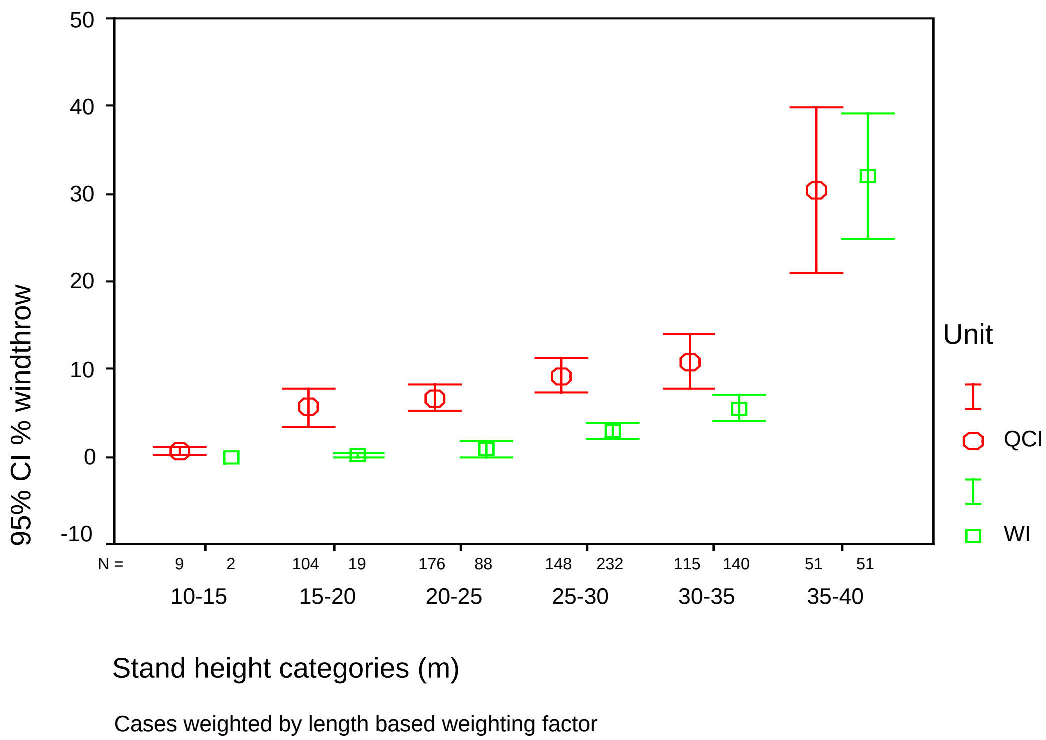


Figure 14. Comparison of stand height to percent windthrow – external edges

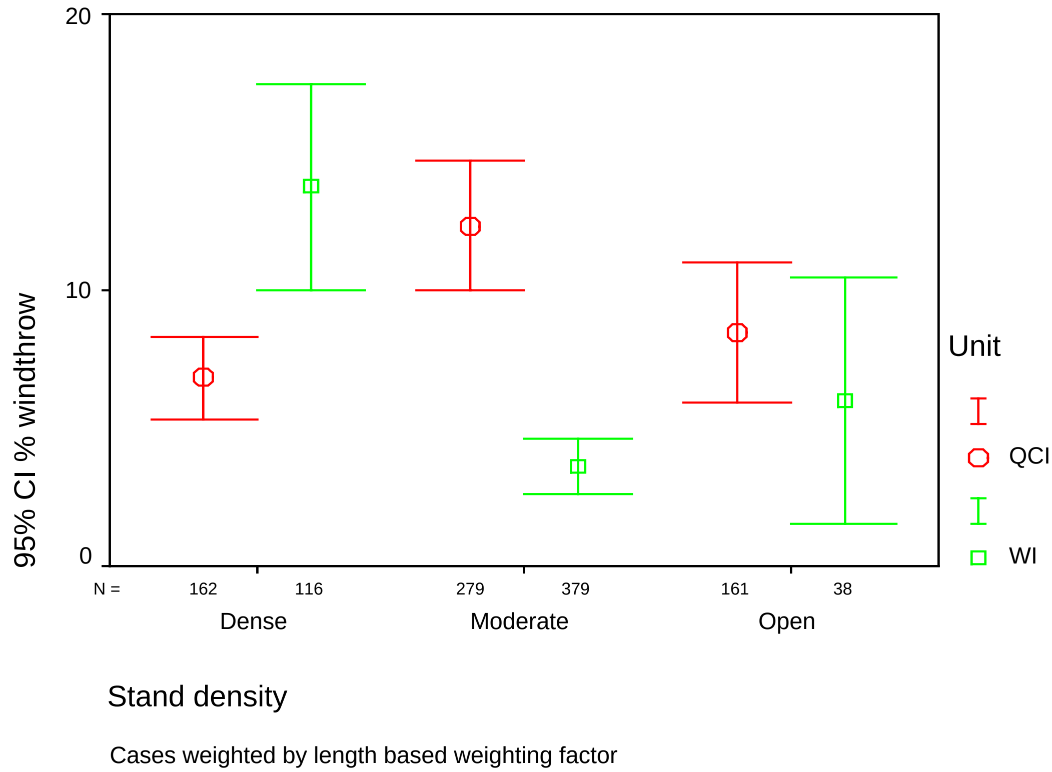


Figure 15. Comparison of stand density to percent windthrow – external edges

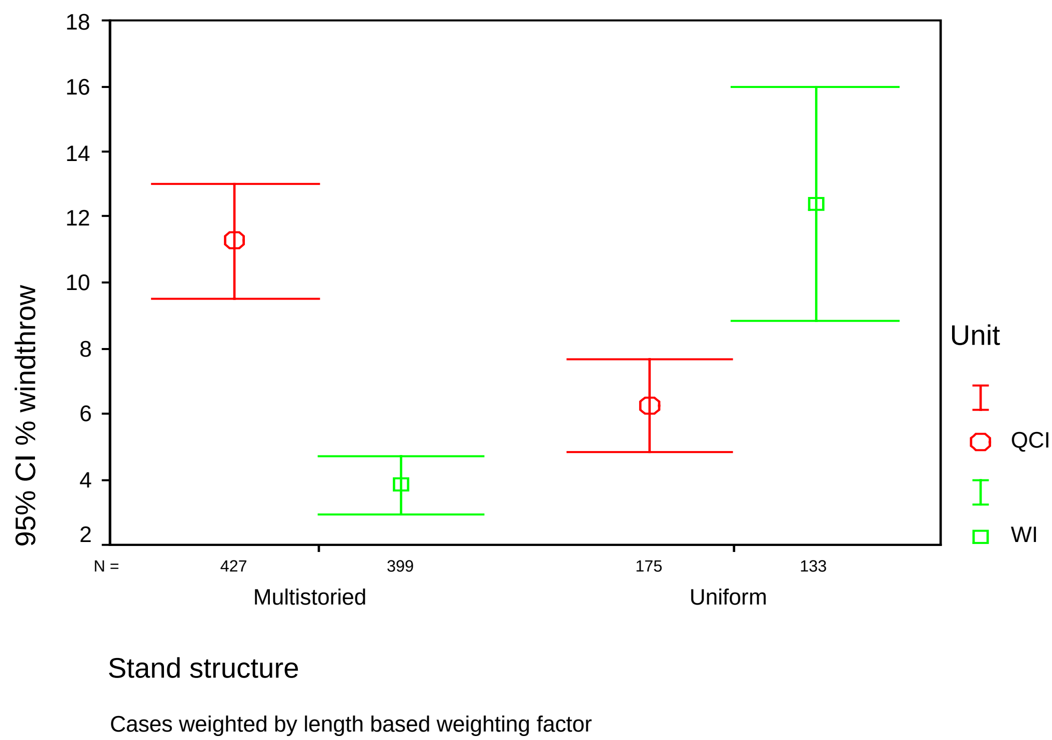


Figure 16. Comparison of stand structure to percent windthrow – external edges

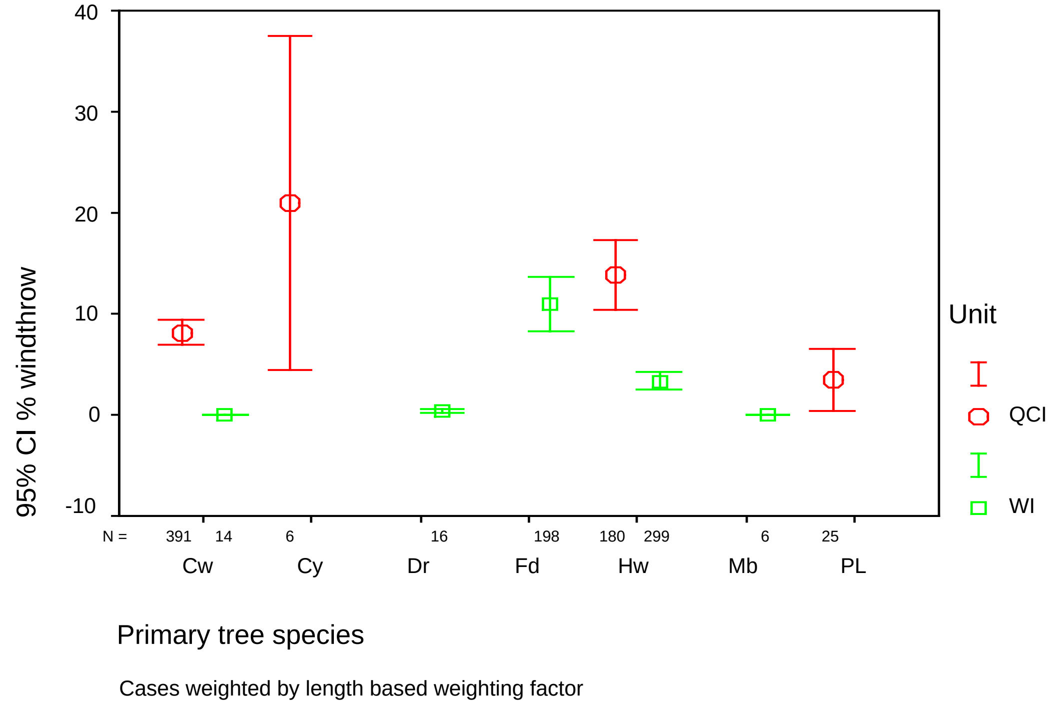


Figure 17. Comparison of dominant tree species to percent windthrow

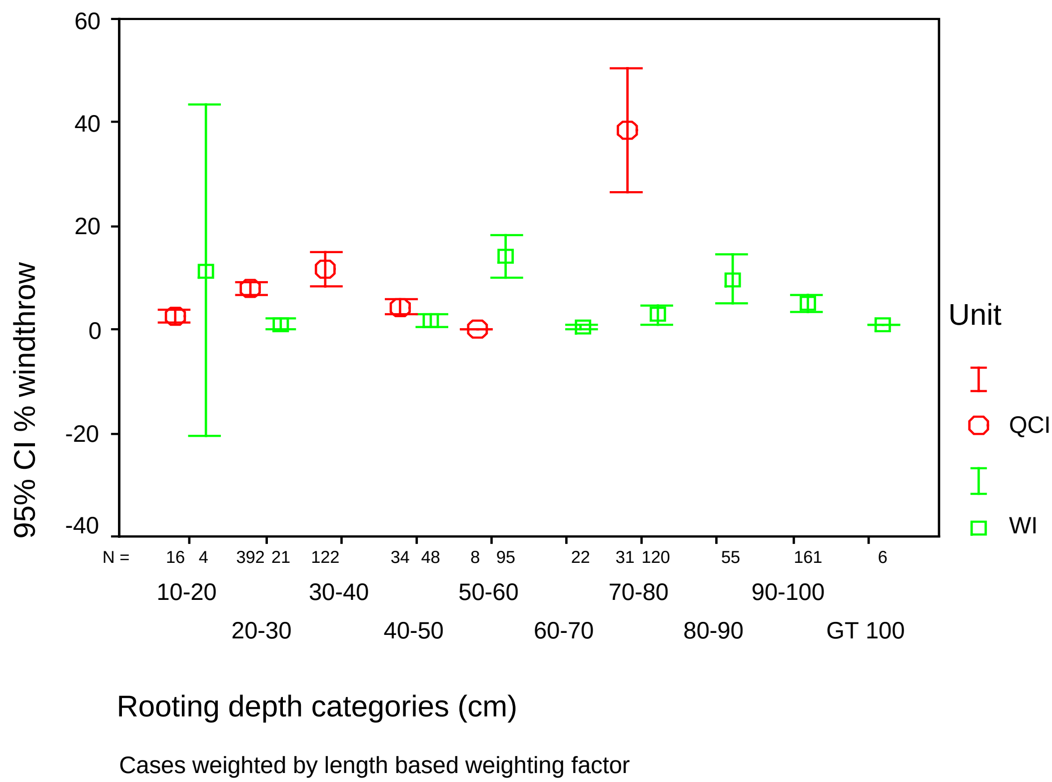


Figure 18. Comparison of rooting depth to percent windthrow – external edges

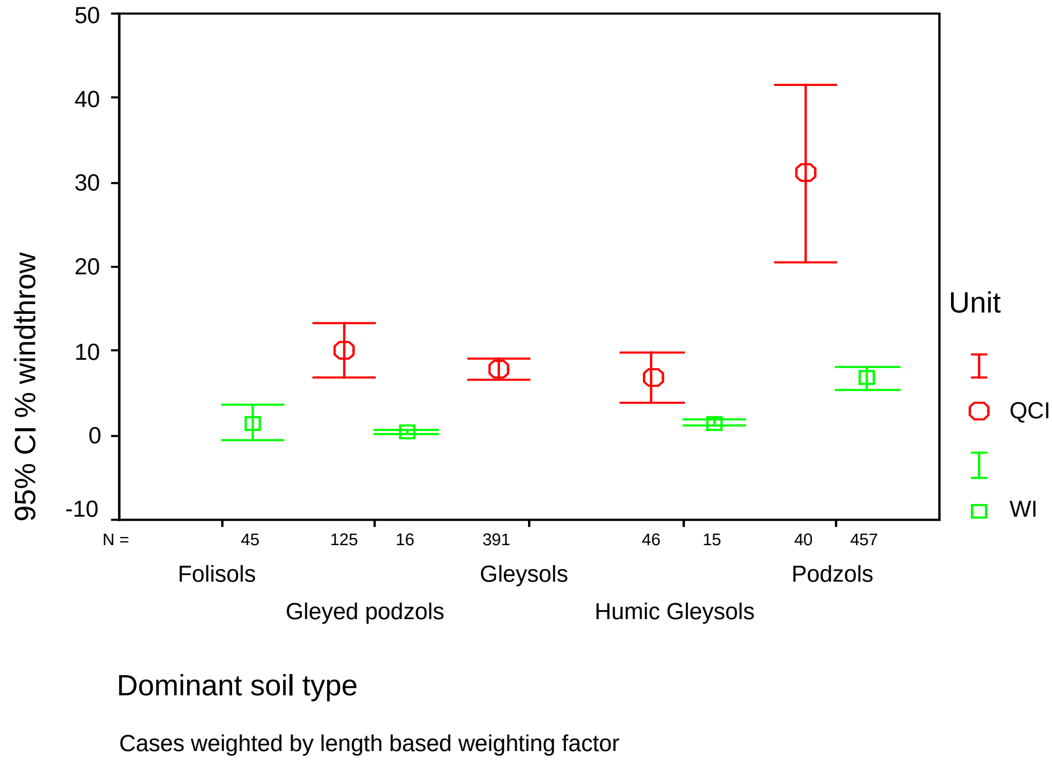


Figure 19. Percent windthrow versus dominant soil type – external edges

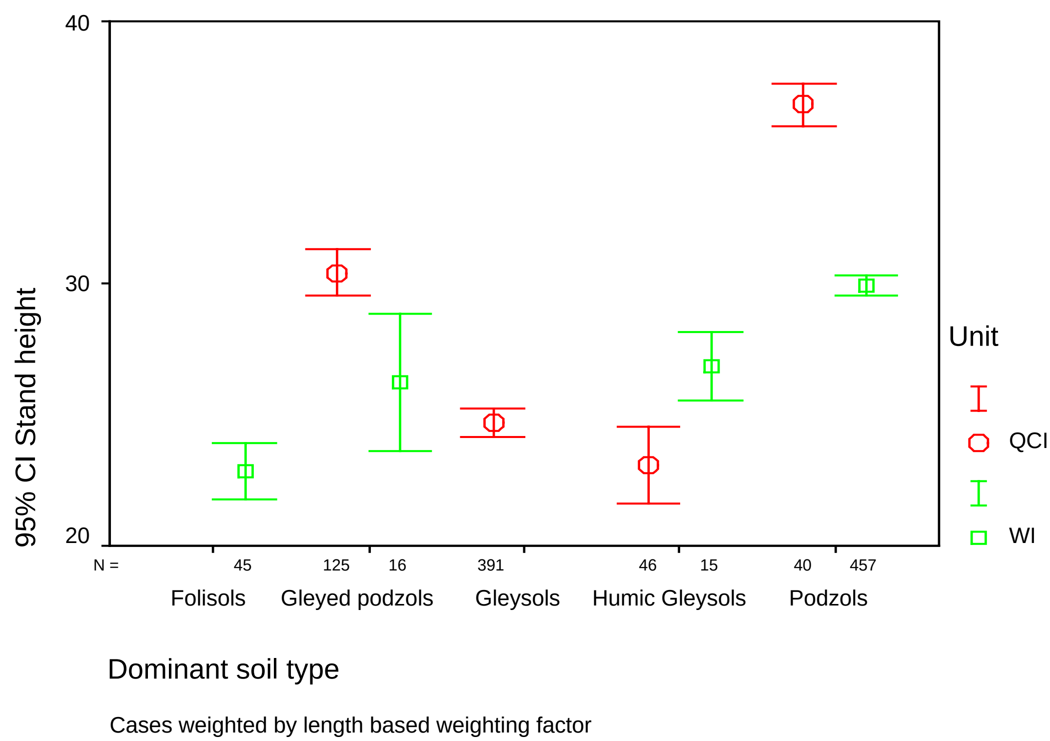


Figure 20. Dominant soil type versus estimated stand height – external edges

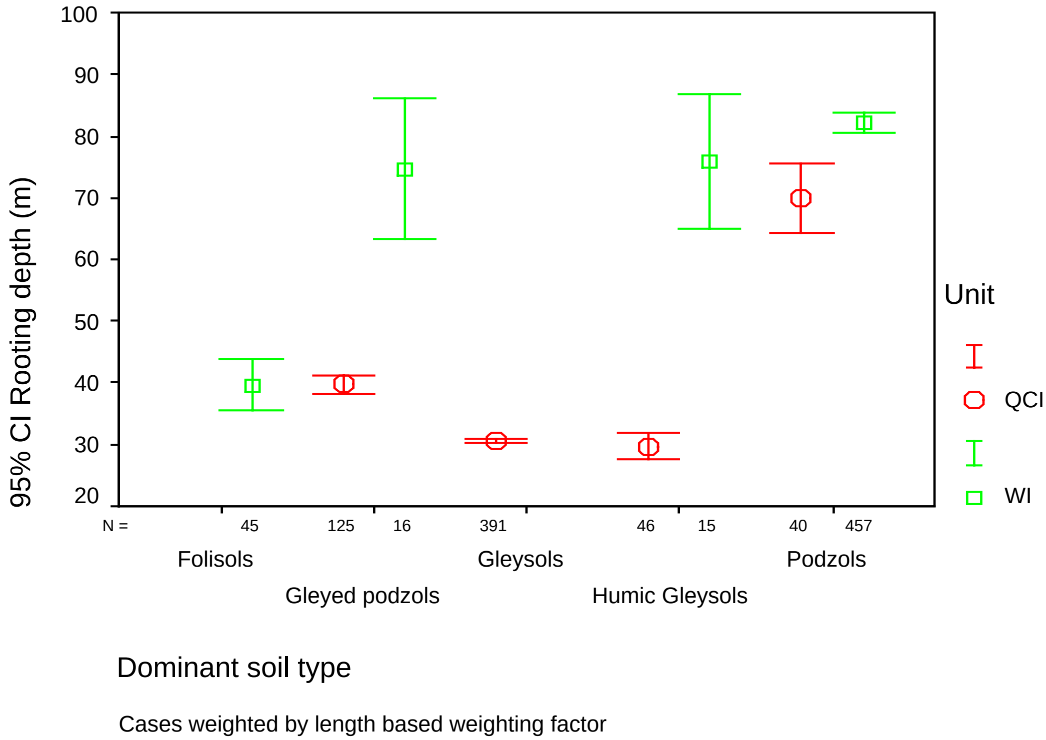


Figure 21. Comparison of dominant soil type to rooting depths – external edges

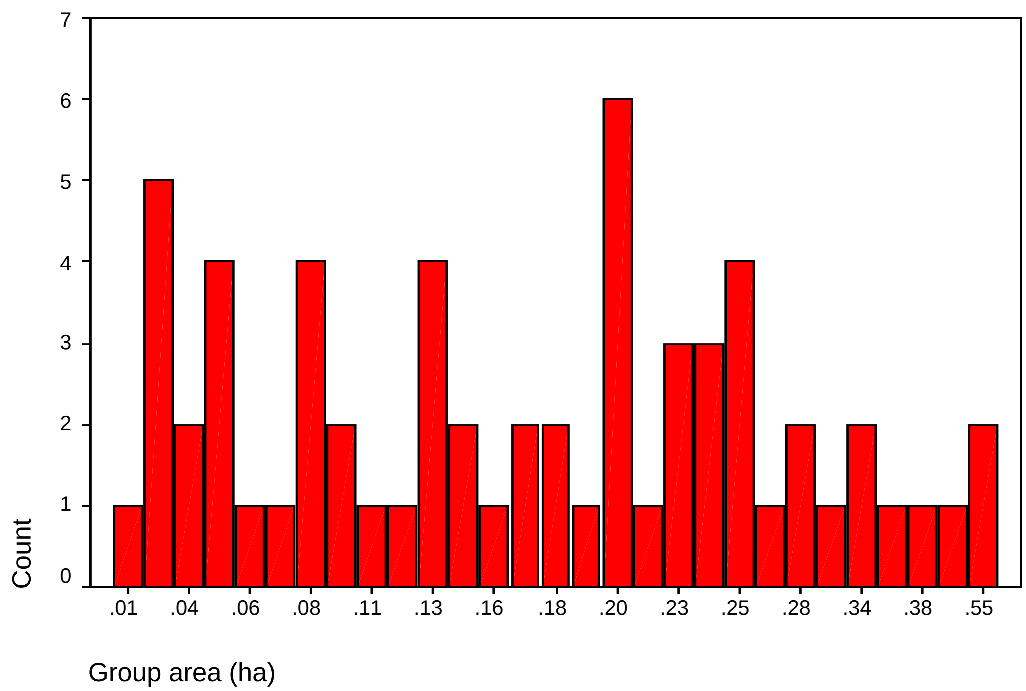


Figure 22. Distribution of group area for retained groups – all data

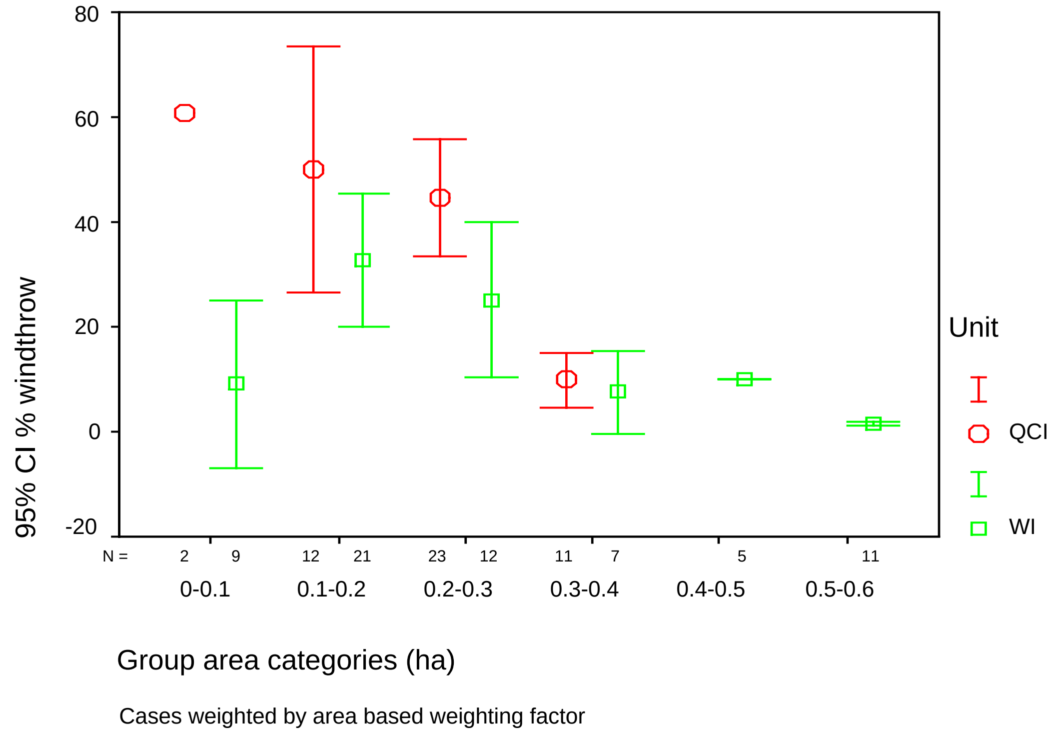


Figure 23. Comparison of group area to percent windthrow

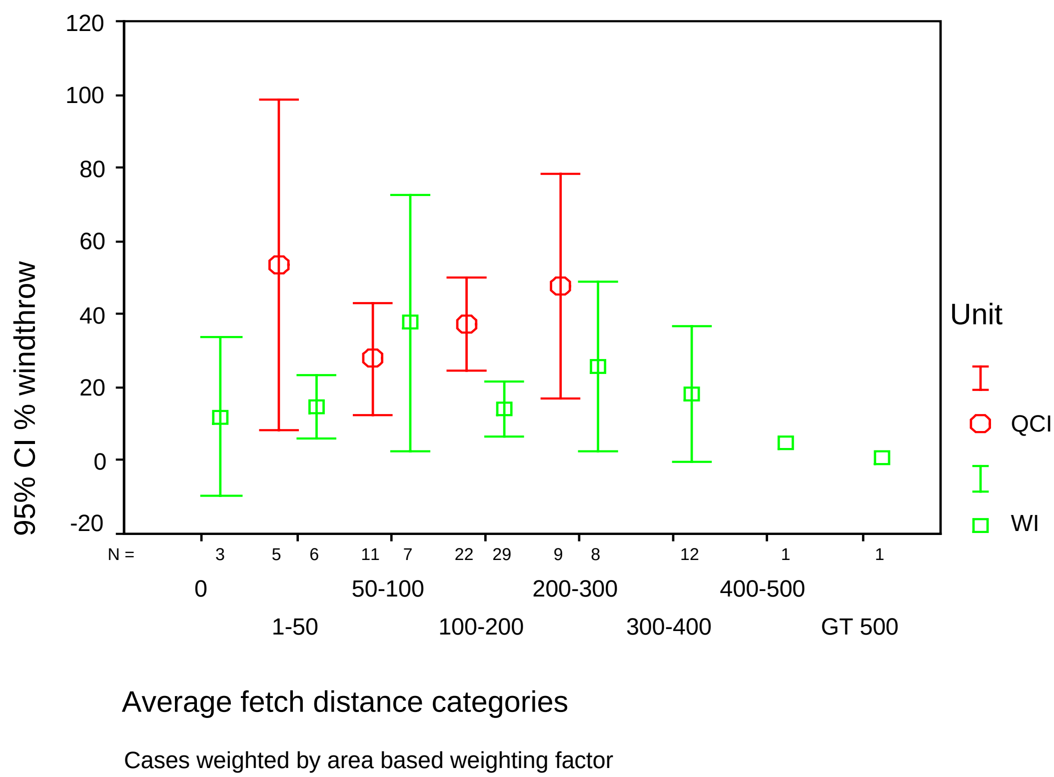


Figure 24. Comparison of average fetch distance to percent windthrow for groups

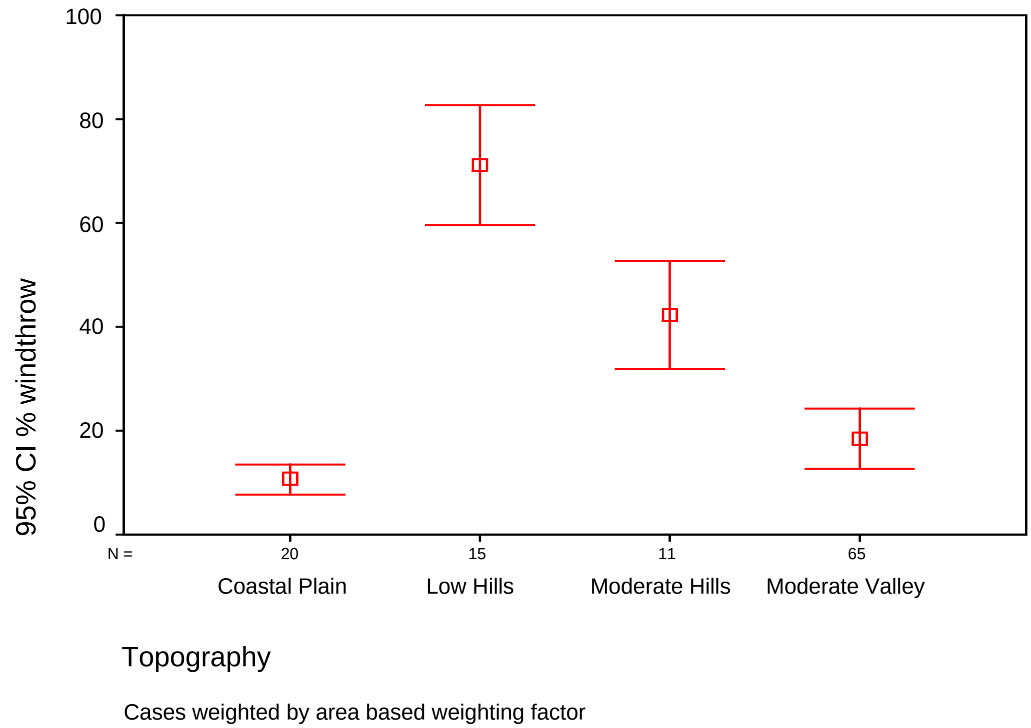


Figure 25. Comparison of topographic location and percent windthrow– all groups

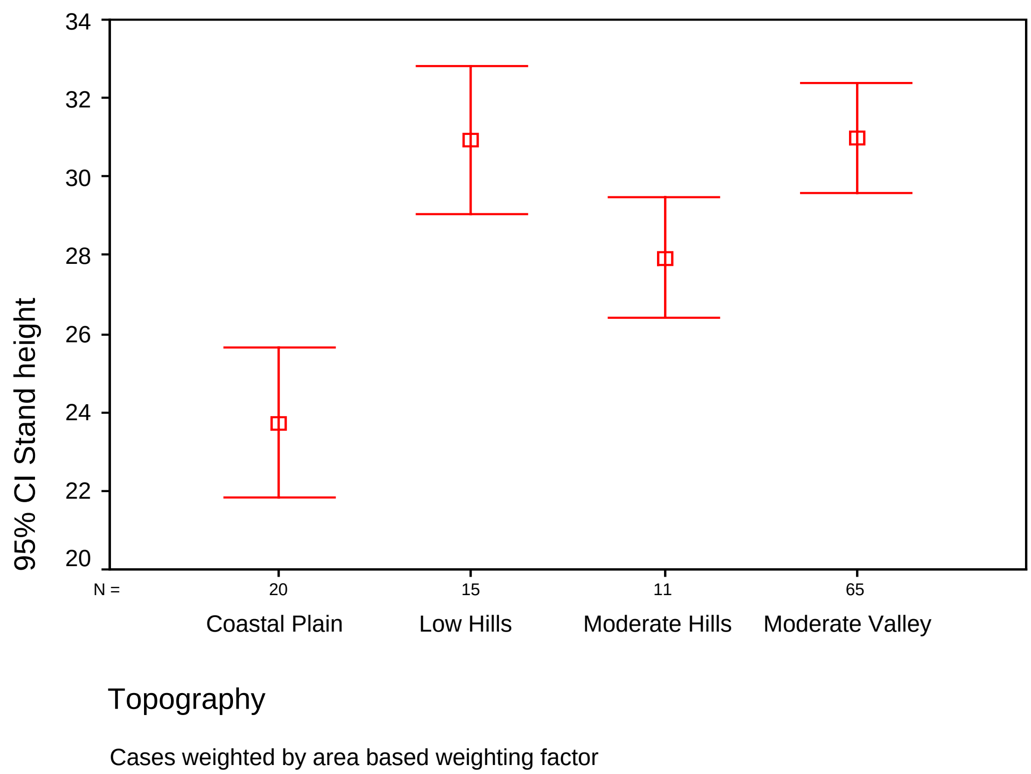


Figure 26. Topography versus stand height for retained groups – all groups

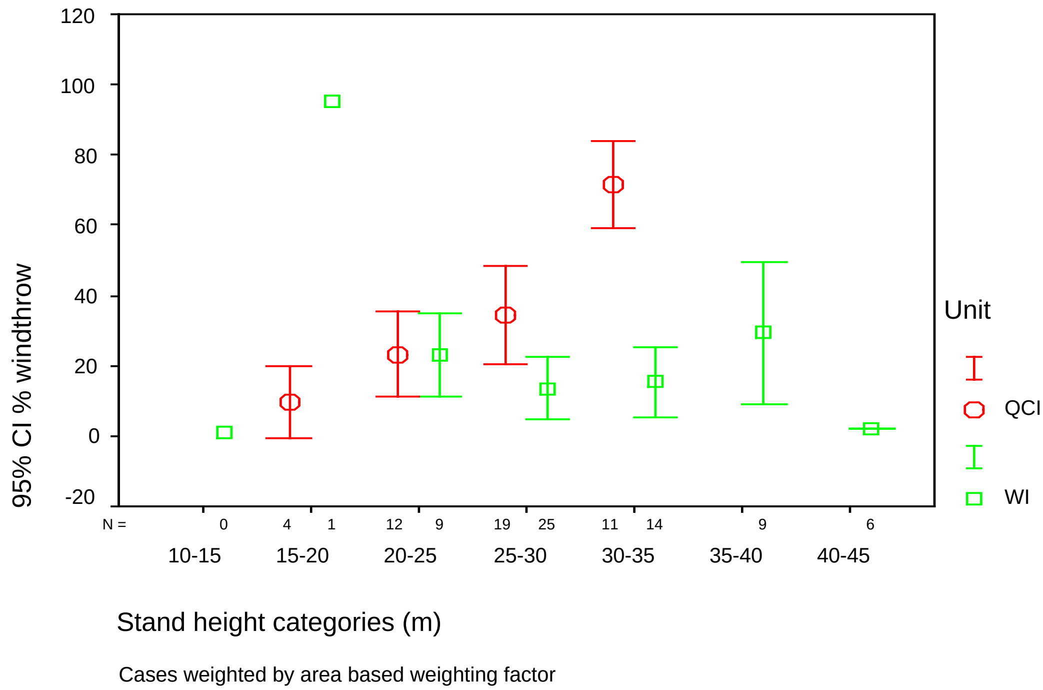


Figure 27. Stand height versus percent windthrow – all groups

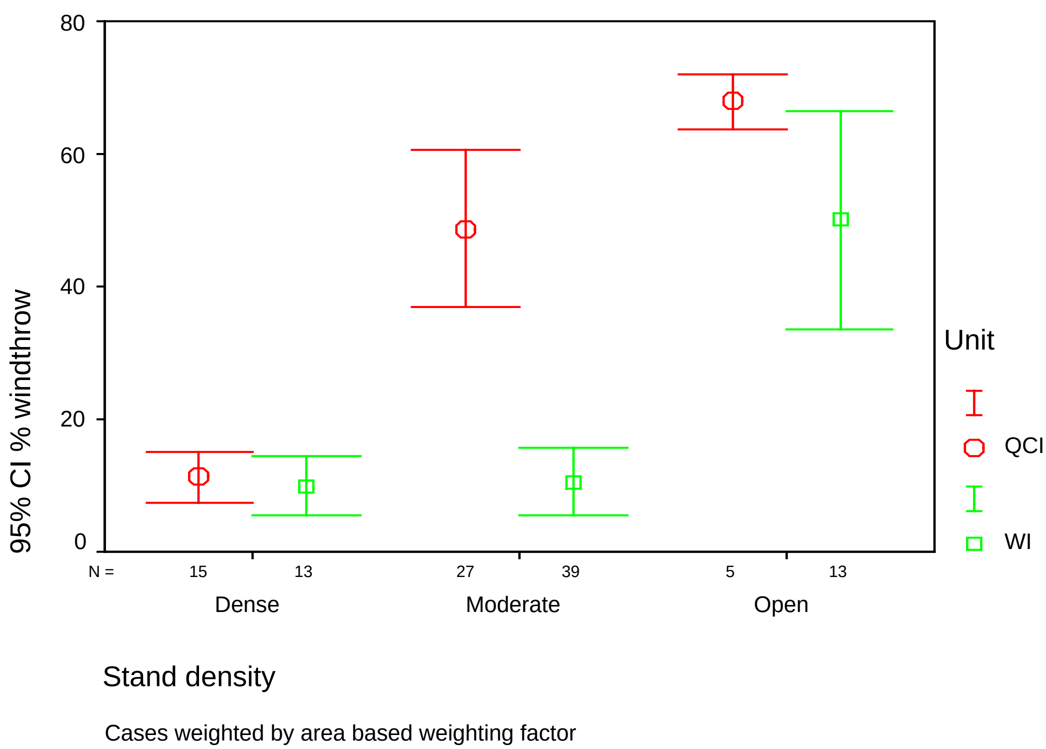


Figure 28. Stand density class versus percent windthrow - all groups

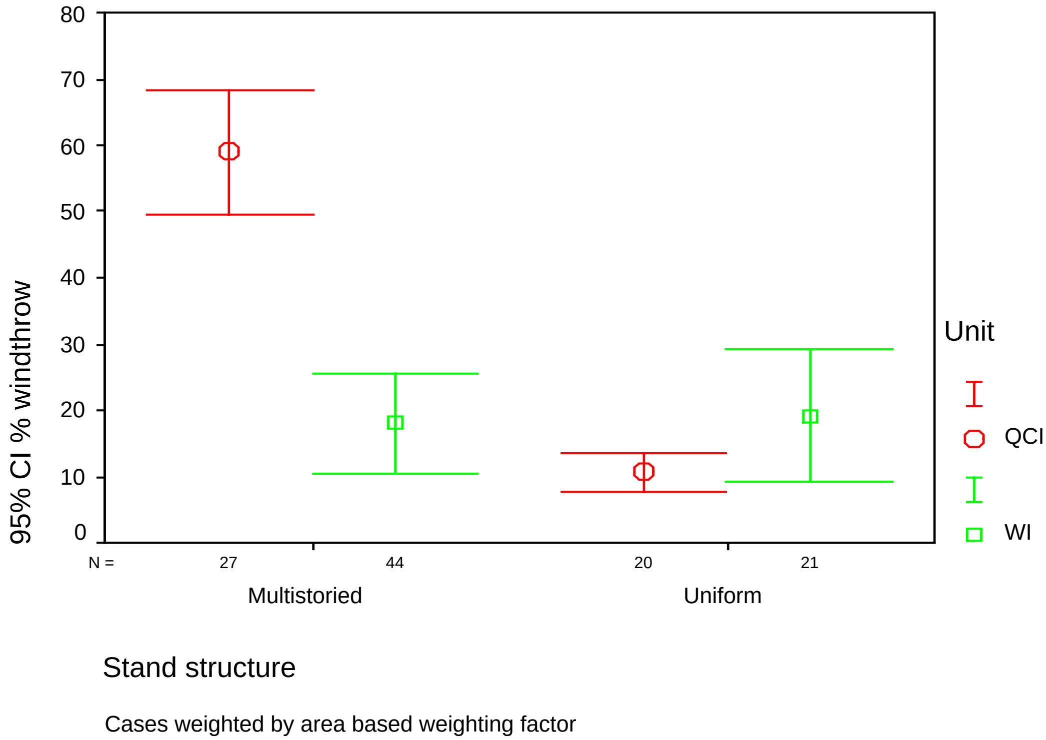


Figure 29. Stand structure versus percent windthrow - all groups

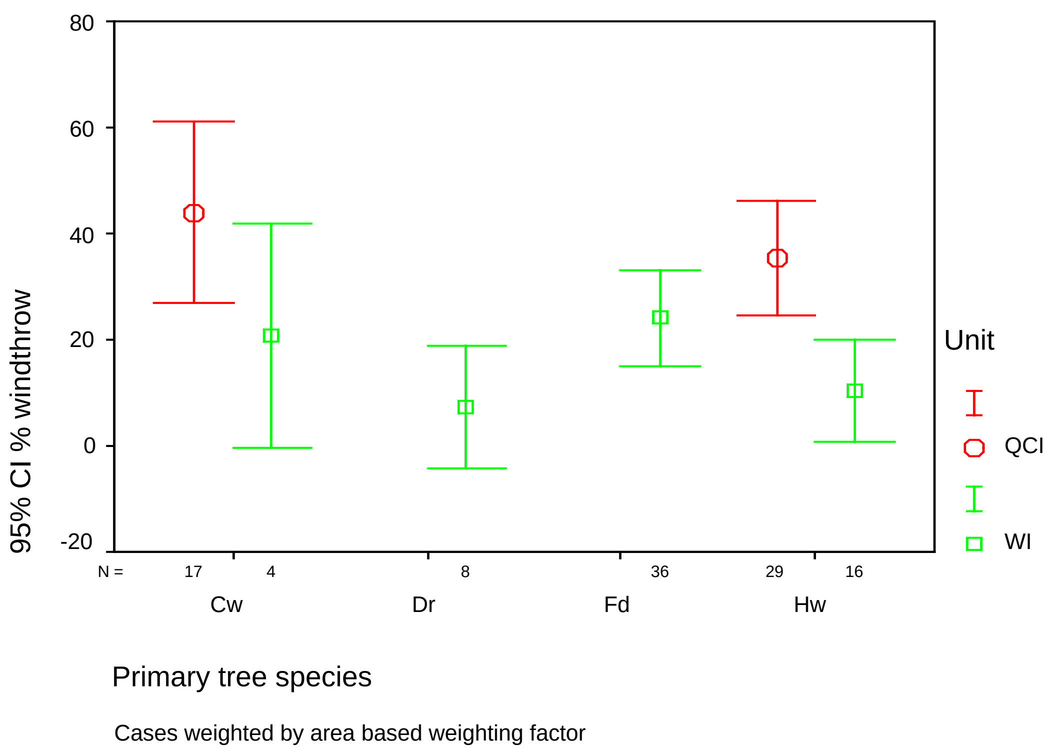


Figure 30. Dominant tree species versus percent windthrow - all groups

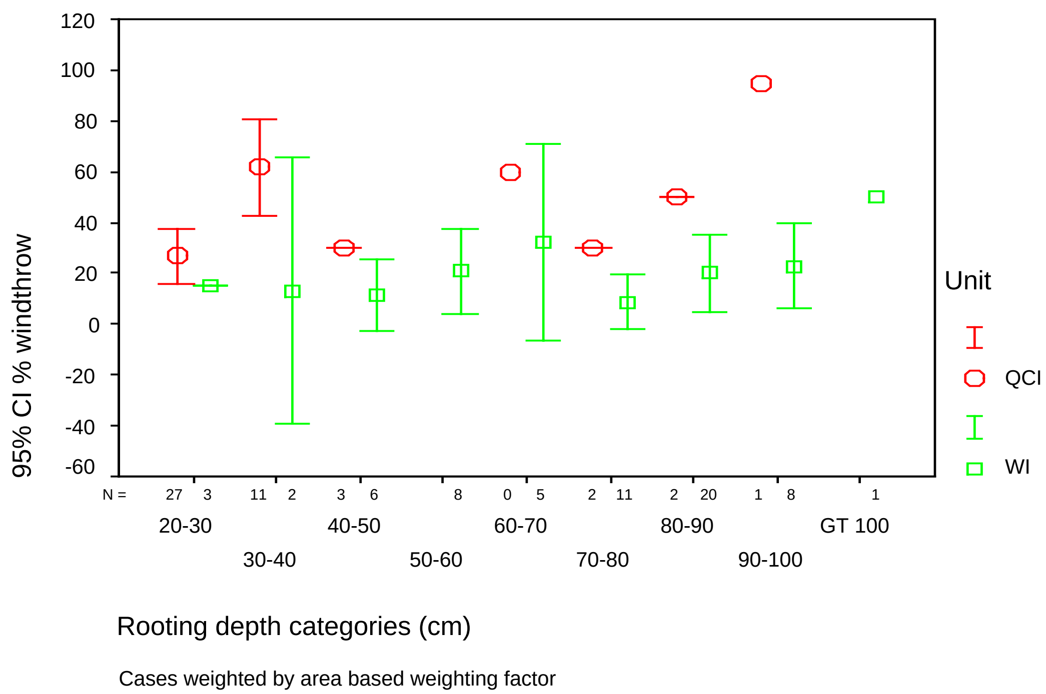


Figure 31. Rooting depth versus percent windthrow - all groups

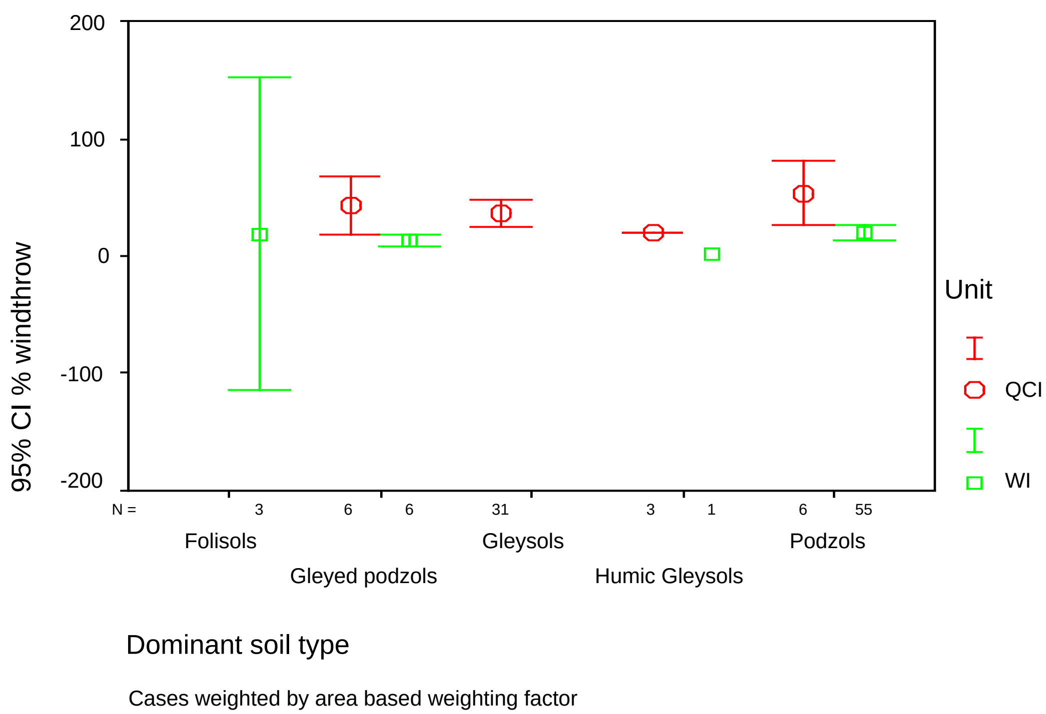


Figure 32. Soil type versus percent windthrow - all groups

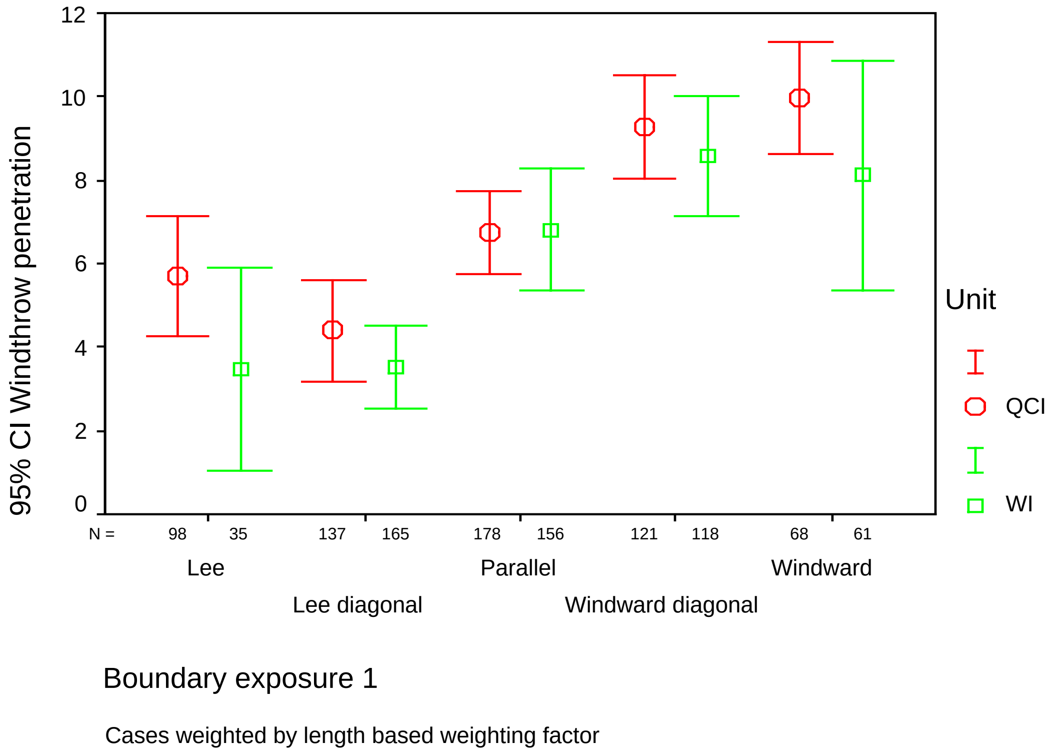


Figure 33. Windthrow penetration versus boundary exposure - all edges

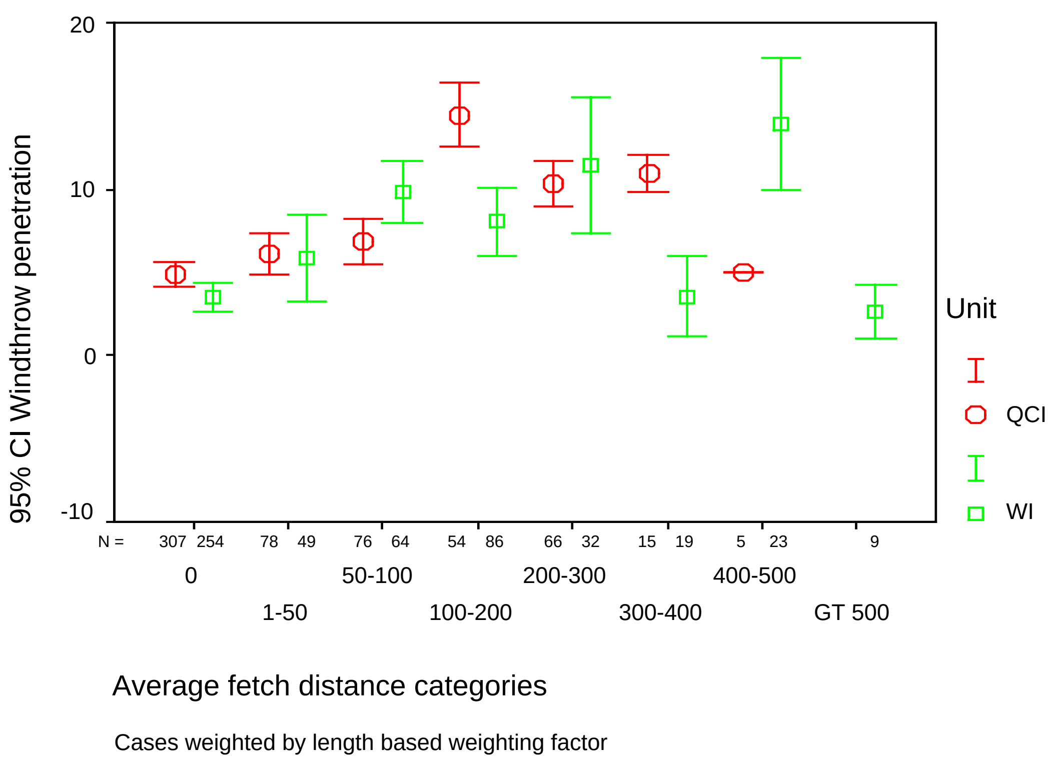


Figure 34. Windthrow penetration versus average fetch distance - all edges

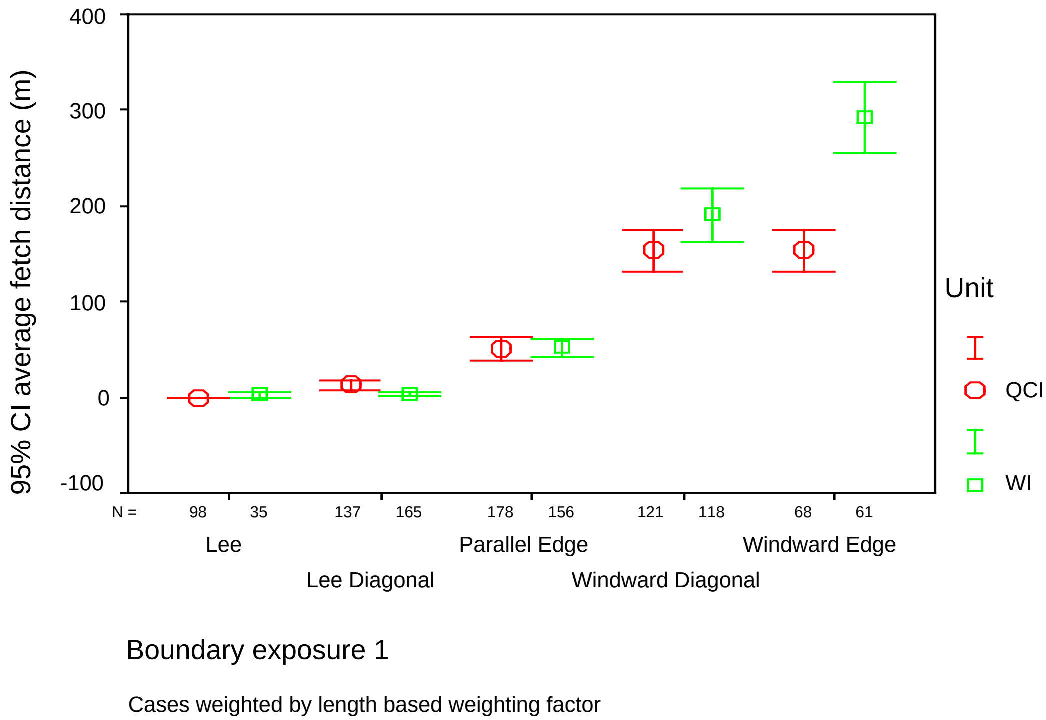


Figure 35. Boundary exposure versus average fetch distance - all edges

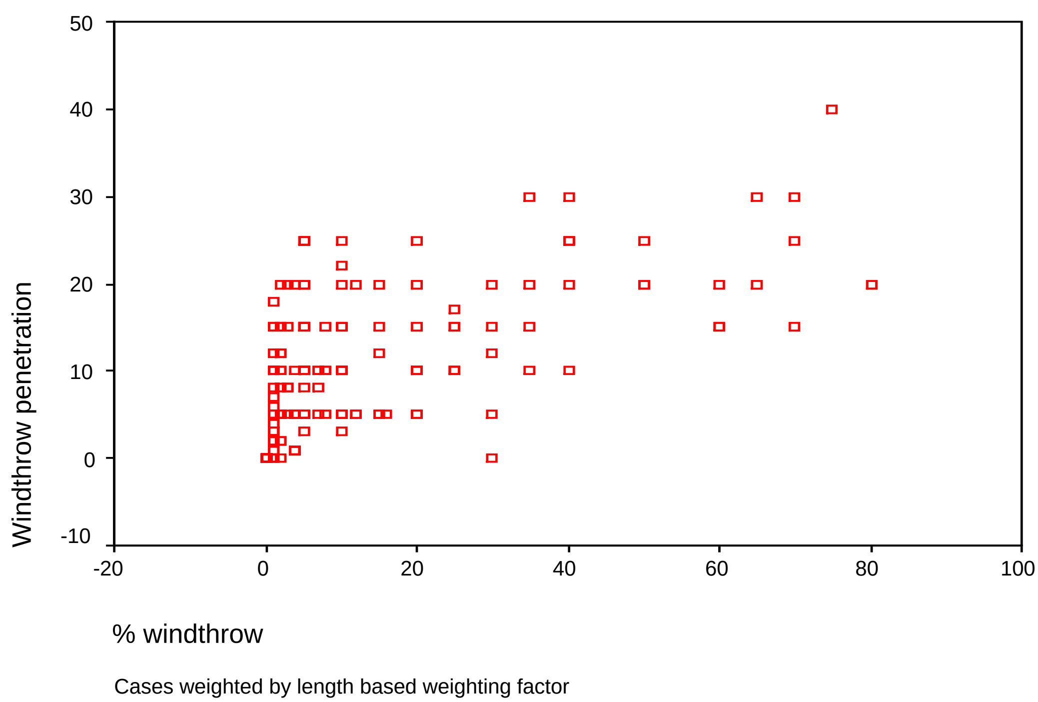


Figure 36. Percent windthrow versus penetration distance - all edges

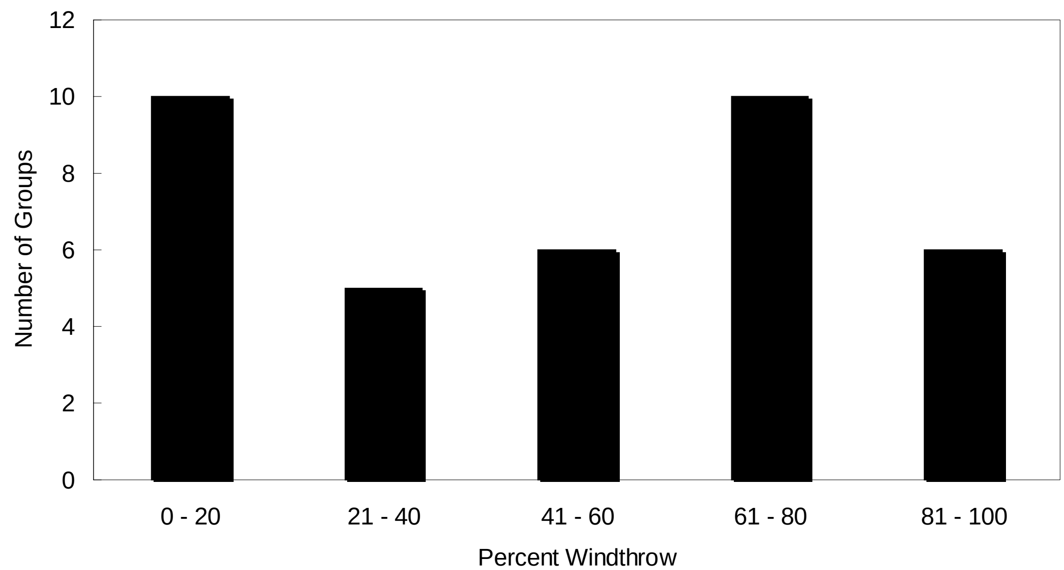


Figure 37. Percent windthrow in 37 groups from four VR cutblocks at North Island Timberlands after the 14 December 2001 storm.

APPENDIX IV DATA CODING DOCUMENTATION

Windthrow Assessment Codes and Coding Procedure[6]:

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*

- 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 colored, well drained mineral soils
- GP – gleyed podzols – imperfectly drained soils, evidence of gleying (mottles) in the mineral soil
- G – gleysols – grey colored 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)

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

- 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 percent (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 group 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)

WT penetration

- Visually estimate the distance (in metres) that upturned roots (not tops) of windthrown trees are found into the leave area, stand edge, patch or group.

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.

% Stembreak/ %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.

Boundary/slope geometry

- U – uphill – the boundary is on the upslope side of the block.
- UE – uphill boundary at the base of an escarpment.
- D – downhill (the boundary is on the downhill side of the opening and the slopes are generally ⁄40%, up to 70%).
- L – lateral (slopes along the boundary and within the leave strip are generally range from 10 to 40%)
- F – flat or level or undulating
- GE – gully edge (falling boundary runs along the edge of the gully
- HG – hillslope along gully (the leave strip includes both the gully and a strip of standing timber along the hillslope 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.)
- E – Escarpment. Slope angles are generally ⁄70% when this designation is used.
- HE – hillslope 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 hillslope 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.)

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)

Harvesting system

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

Plot type (strata)

- E - External block edge
- P - Patch edge
- WS -‘Wide’ strip edge > 50 m wide
- PE - Peninsula edge a strip 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 – have curves
- GE - Group edge
- G - Group – groups are groups of trees 20 to 50 m across
- X - Cluster – groups of trees less than about 20 metres across
- 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 center of the group or patch)

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 stream or other feature. 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 untreated 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)

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)

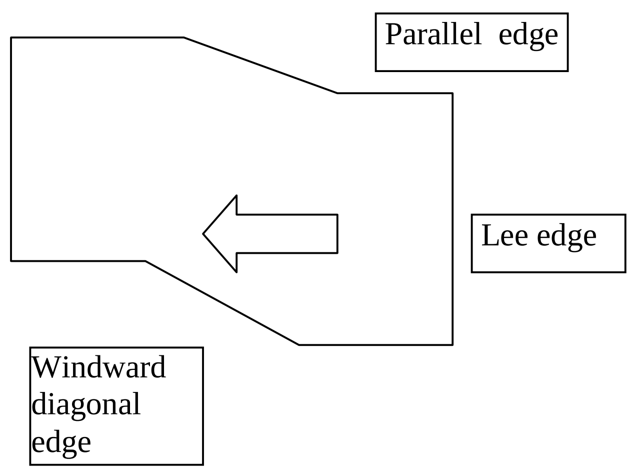
- VDV – very deep, well defined valley (relative relief is greater than 1000 metres)
- MVN – narrow (V-shaped), moderately deep, well defined valley
- MVB – broad (U-shaped), moderately deep, well defined valley
- DVN – narrow, deep, well defined valley
- DVB – broad, deep, well defined valley

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 perimetre 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

- S! –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

Figure I Wind Exposure Index

Boundary exposure 1 \ **Boundary exposure 2**		Lee 1	Lee diagonal 2	Parallel 3	Windward diagonal 4	Windward 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 rank:
3= very low
4 = low
5-7 = moderate
8 = high
9 = very high

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.

APPENDIX V PROTOTYPE DATA FORM

Post-logging windthrow assessment : Block:_________________ Page_____of_____

Plot number						
Falling corner range						
Terrain						
Slope position						
Slope morphology						
Soils						
Soil drainage class						
Slope aspect						
Rooting depth ~						
Stand structure						
Stand height (m) ~						
Stand origin						
Tree species 1 / %						
Tree species 2 / %						
Tree species 3 / %						
Age class						
Density						
Windthrow (WT) %						
WT Spatial pattern						
WT Penetration (m)						
WT Orientation(°) *first*						
WT Orientation (°) *Second*						
WT Orientation (°) *Third*						
% stembreak / % leaning						
WT treatment Rx						
Timing of treatment						
Slope ∠ % in plot						
Boundary aspect						
Bdy/slope geometry						
Boundary shape						
Influences						

Post-logging windthrow assessment : Block:________________ Page_____of_____

Plot number						
Yarding system						
Plot type (strata)						
% retention (dispersed)						
Group shape						
Boundary purpose						
Leave strip width *(m)*						
Leave strip/plot length						
Treatment depth (m) and percentage	/					
Root damage						
Stem scaring						
Broken tops						
Topex						
Boundary – *exposure 1*						
Boundary – *exposure 2*						
Fetch distance 1						
Fetch distance 2						
Fetch type 1						
Fetch type 2						
Height of upwind stand 1						
Height of upwind stand 2						
Group dimensions:						
Long-axis length *(length - m)*						
Short-axis length *(width - m)*						
Long-axis exposure 1						
Long-axis exposure 2						
Valley axis						
Photo #'s						
Setback distance (m)						

Post-logging windthrow assessment : Block:________________ Page_____of_____

Plot number						
Stream #/name						
Stream class						
RRZ &/or FRMZ						
Stream width (m)						
Stream depth (m)						
Bank material						
Bed material						
WT proximity to cr.						
Stream effects						
Gully/Stream ∠%						
Gully depth (m)						
Gully floor width						
Gully wall ∠ %						
Photos:						
Comments / photos diagrams / options*						
Block Data:	Block area: ha			Topography:		

Block #		Physiographic region:	
Felling date:		Logging date:	
Division:		Operation:	
Elevation (m):		Silvicultural system variant:	
Watershed:		BEC variant	

Recorded by: ______________________________ Date: _________________________

APPENDIX VI. PHOTOS OF WIND DAMAGE FROM THE DECEMBER 14, 2001 STORM.

Photo 1. Narrow bands of windthrow occurred in some stands.

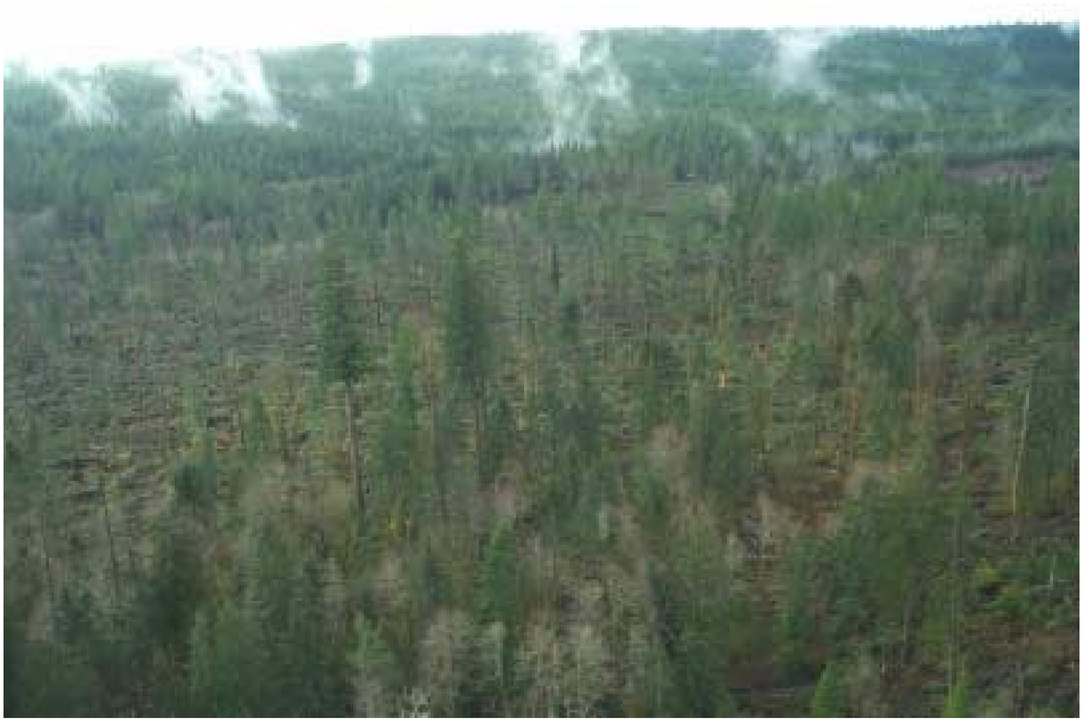


Photo 2. Windthrow leaving a dispersed “shelterwood” structure.

Photo 3. Windthrow in old growth stands at Eve River with surviving redcedar and Douglas-fir.

Photo 4. Wind damage to second growth stands in the lower Adam River drainage.

Photo 5. Windthrow on the eastern boundary of OP 4912 (LA4A6) in the lower Adam River.

Photo 6. Windthrow in VR (OP 2226) at Amor de Cosmos Creek; note edge damage on right.