BCTS WINDTHROW MANUAL:

A Compendium of Information and Tools for Understanding, Predicting and Managing Windthrow on the BC Coast

By Ken Zielke RPF, Bryce Bancroft RPBio, Ken Byrne MSc, and Dr Steve Mitchell PhD, RPF.

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NOTE TO THOSE USING THIS MANUAL:

This manual represents the best currently available information for windthrow in BC, focusing on the Coast. It reviews and explains the mechanics, prediction, and management of windthrow in forestry operations. It brings together numerous tools and guidelines in one package and explores them with examples to reflect our current understanding of these concepts. For someone new to management of windthrow, this information is a good grounding to start addressing windthrow. It is not a cookbook.

The tools provided here must be integrated with considerable field experience and a sound understanding of local value objectives, ecosystems, stand types and wind conditions. As you read this manual it will become clear that windthrow assessment and management is complex. There is still much to learn that cannot be acquired from a book.

Acknowledgements

This project could not have been possible without the vision and support of Enrique Sanchez, BCTS, Chinook Business Area. The project was originally conceived by Enrique and Dr. Stephen Mitchell of the University of British Columbia. Funding was provided by the BCTS Chinook and Georgia Straits Business areas. Dave Hamilton (BCTS Georgia Strait Business Area) was instrumental in the project initiation and organization.

The authors also wish to thank the BCTS staff and contractors who helped us to understand issues specific to the Chinook business area, and BCTS requirements to address windthrow. These people included: Chris Johnston (BCTS), Chris Runnals (BCTS), Andrew Brown (Infinity-Pacific Stewardship Group), Chris Gruenwald (Infinity-Pacific Stewardship Group), Rob Deines (Chartwell Consultants Ltd.), and Ryan Turner (Chartwell Consultants Ltd.).

The authors acknowledge that this manual merely brings together work that has been on-going in BC for some time. Much of what is provided here mostly came from: provincial training manuals designed by Mitchell and Zielke; monitoring, modeling and other work completed by Dr. Steve Mitchell and his UBC Windthrow research group; monitoring by Weyerhauser BC Coastal Group led by Terry Rollerson; Chuck Rowan's work on edge treatments; and monitoring by Zielke and Bancroft for Weyerhaeuser BC Coastal Group, Western Forest Products Ltd., Canadian Forest Products Ltd., and the Coast Forest Conservation Initative.

1. Table of Contents

Section 1 – How to Use this Manual ***3***

Section 2 – Overview of Windthrow Management Concepts – Including key definitions ***2-1***

Section 3 – Background: Coastal Windthrow Damage Trends ***3-1***

Section 4– Windthrow Management Protocol ***4-1***

Section 5– Assessment of Windthrow Hazard and Likelihood ***5-1***

Section 6 – Determining Windthrow Risk ***6-1***

Section 7– Windthrow Best Management Practices ***7-1***

Section 8 – Windthrow Monitoring ***8-1***

APPENDICES ***A-1***

1. How to Use this Manual

Overview

Windthrow is a common challenge for BC forest managers. Research into windthrow damage and the systematic assessment of windthrow risk started in BC less than 20 years ago. Since that time, considerable knowledge has been acquired, especially on the coast. The Windthrow Handbook was published in 1994. The first provincial windthrow hazard and risk assessment cards were developed by Dr. Mitchell of the University of BC in 1998. The Windthrow Workshops, first offered in the mid-1990's have been revised several times to reflect more recent data and knowledge (Mitchell and Zielke 2006). This manual was produced to bring together: the current approach to windthrow hazard and risk assessment; up-to-date research results, and the current thinking on windthrow monitoring, salvage and other management strategies.

Those who would find this manual useful

This manual is designed for three user groups: those who are relatively new to windthrow hazard and risk assessment and management; those who are experienced in windthrow management, but are interested in picking up some new ideas; and those who are experienced but need to consult a manual from time to time to test new ideas or for due diligence.

Section 2 – Overview of Windthrow Management

This section reviews the conceptual basis for windthrow risk assessment and management. It defines most of the key terms, and provides a basic understanding of climate weather and wind that is relevant to coastal BC. The key windthrow hazard components are then carefully stepped through and explained, as are the biophysical concepts and mechanics.

Section 3 – Background: Coastal Windthrow Damage Trends

This section synthesizes and summarizes trends in key data collected and analyzed in the BCTS Chinook Operation windthrow modeling project (Mitchell and Lanquaye-Opoku 2009), as well as other data and trends relevant to Coastal BC from studies by Rollerson, Peters and Beese (2009) and others. Trends across different parts of the coast are described and compared, with interpretations provided to explain differences. This section provides a useful introduction to windthrow for particular parts of the coast, contrasting it with other areas.

The trend section provides useful context for assessments, prescriptions and management of specific stands. For this reason, it will be important for field staff to return to this section from time to time to reinforce the context.

Section 4 – An Overview of the Windthrow Management Framework.

This section provides managers with a high level perspective for windthrow management. It ties together the many aspects of windthrow assessment and management.

Section 5 – Assessment of Windthrow Hazard and Likelihood

Field personnel are stepped through the process to assess windthrow hazard and risk assessment as designed by Mitchell (1998) and updated by Mitchell and Zielke (2006), while incorporating field experience to the updated framework. The new BCTS field cards, designed to fit with this manual, are referenced section-by-section to help through this process. A number of other useful tools and procedures are outlined.

Section 6 – Determining Windthrow Risk

Windthrow Risk examines windthrow likelihood in the context of the associated potential consequences. This section integrates the added factor of consequences to the hazard and likelihood assessment. Consequences of likely windthrow, related to management objectives for the key forest values gets to the heart of what matters most to forest managers. Consequences, due to windthrow, are considered with key diagnostic questions for the range of important forest values.

These questions are meant to help practitioners rank consequences and set thresholds of acceptable windthrow. The premise is that not all windthrow is inherently a reflection of poor management decisions leading to poor outcomes. Thus, some level of windthrow may be considered acceptable, but anything above the threshold would result in unacceptable consequences.

Accordingly, these thresholds provide a basis for comparison when likelihood of windthrow is determined for a particular situation such as an edge segment. Again, the BCTS field cards are used with an example to illustrate the considerations to determine windthrow risk. At the end of the section nine more example case studies are used to illustrate the difference between hazard, likelihood and risk.

Section 7 – Best Management Practices

This section approaches suggestions for best practice with a two pronged approach. First, some general best management practice suggestions are provided that should be initially be considered for all layout. Secondly, considerations that will be useful to alter layout or prescriptions are provided where the assessed likelihood of windthrow is greater than the thresholds set for acceptable windthrow. These considerations, or 'best management practices' (BMPs) are based on experience, monitoring and research data. Few are universal in their application. They will need to be carefully considered and applied in situations where they are most relevant.

The best management practices do not just apply to layout alterations but also include considerations for salvage planning and windfirming treatments.

Section 8 – Windthrow Monitoring

This section provides detailed guidance for development of a Windthrow Monitoring Program, it includes: monitoring objectives, sampling design; monitoring variables; sampling frequency; and feedback to operations.

References

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2 OVERVIEW OF WINDTHROW MANAGEMENT CONCEPTS – Including key definitions

Contents

Overview 3
Introduction 3
Intent 3

Definitions 3

Understanding Climate, Weather and Wind 7

Windthrow Hazards - Topographic Exposure. 11
Diagnostic Question for Topographic Exposure hazard 13

Windthrow Hazard – Stand Characteristics 14
Tree mechanics 14
Diagnostic Question for Stand hazard: 16

Windthrow Hazards - Soil 23
Diagnostic Question for Soil hazard 23

Biophysical Hazard 26

Some Common Questions 27
Isn't windthrow too unpredictable to manage? 27
Aren't the taller trees more vulnerable to windthrow? 27
Once windthrow starts in a stand, doesn't it just continue for many years? 27
Isn't shallow rooting the most important consideration? 27

References: 28

Overview

Introduction

Windthrow results when wind loads on trees exceed the resistance of tree stems or anchorage. The loading and resistance of trees reflect the short and long term interaction of tree, stand and landscape level factors and is influenced by forest management and block layout decisions. Local outcomes reflect local conditions, but there are general principles and processes that apply across all sites. A good understanding of the conceptual basis for windthrow is necessary.

The following section, is mostly based on Mitchell and Zielke (2006)[1] and will cover the main concepts of windthrow management, beginning with wind and weather, moving to site and stand conditions and how they work together to influence the amount of windthrow.

Intent

This section is intended for either:

- those who are relatively new to the assessment of windthrow hazard, prediction of windthrow likelihood, and management of windthrow, or,
- those experienced assessors who are cross-checking their prescription for due diligence.

Definitions

Various terms are used to describe windthrow and how it is managed. It is important to understand the terms to ensure clear and concise communication. The following are common definitions used in this document.

Endemic and Catastrophic Windthrow:

- *Windthrow* - is tree uprooting or stem breakage that results when wind loads exceed stem or anchorage strength.
- *Endemic Windthrow* - is caused by peak winds which recur every 1-3 years (i.e. endemic) on the BC Coast, resulting in uprooting more than stem breakage. Damage is concentrated in areas where stand edges or residual trees have been exposed by harvesting, thinning or right-of-way development. The likelihood of endemic windthrow occurring can be predicted from local stand and site conditions, and management practices (e.g. Figure A).
- *Catastrophic Windthrow* - is caused by extreme (catastrophic) winds which recur infrequently (typically > 20 years between events), such as the December 2006 wind event that damaged Stanley Park. These events damage standing timber as well as recently exposed stand edges. The damage may include a higher proportion of stem

[1] Mitchell, S.J. and K. Zielke 2006. Windthrow prescription workshop (revised). Facilitators Guide. B.C. Min. For. Forest Practices Branch. Victoria, BC.

breakage (Figure B). It is difficult to predict the local likelihood of catastrophic windthrow from stand and site conditions.

Figure 2- A. endemic windthrow is located on the shoulder above the road.

Figure 2-B. Catastrophic windthrow in unlogged old growth stand from Dec 2001 hurricane force winds on north central Vancouver Island.

Examples of typical winds causing endemic windthrow:

Haida Gwaii

Summer northwesterlies may reach speeds up to 65 km/hr, however, winter winds are often more problematic. In general:

- average winter winds over the Islands are between 22-27 km/hr.
- lighter winds occur about 45% of the time.
- winds of 43-60 km/hr occur about 20% of the winter period.
- winds of 60-75 km/hr occur about 3% of the winter period.
- occasional winds of greater force occur almost every winter.

Squamish and Chilliwack

Most winds are from the northwest in the summer and southeast in the winter. Winter outflows can be particularly strong through Squamish out into Howe Sound and down the Fraser Valley often creating the highest winds for the area. In general:

- winter averages are approximately 17 km/hr.
- more than 50% of the winter winds are less than the average.
- 45-60 km/hr winds occur about 8% of the winter period due to winter outflows and frontal storms.
- 60-75 km/hr winds occur about 2% of the winter.
- winds > 75 km/hr from rarer storms probably occur every 2 to 3 years depending on the location and exposure, but are less frequent than in Haida Gwaii.

(source: Environment Canada 2003).

In coastal BC, Pacific low pressure systems, which are a form of extra-tropical cyclone produce most of our wind storms and wind damage. These storms produce counter-clockwise rotating regional-scale wind fields that interact with local geography and terrain. In routine events, local geography and terrain produce predictable differences in local wind speeds. The most intense of these systems cause catastrophic damage patterns. In these extreme events, the behaviour of the weather system including the storm track and involvement of upper-level winds produce damage patterns that are less dependent on local terrain.

Windthrow Hazard definitions

- *Biophysical Hazard* - is the intrinsic stability of the stand in its pre-treatment condition. This inherent ability to resist wind damage is the cumulative result of topographic, soils and stand features (expressed as hazard components) interacting as the stand develops with endemic windloading (prior to harvesting or other treatments).

- *Windloading* - can be either static, with constant wind, or dynamic with gusts or pulses of wind. Dynamic windloading (gusts) can have a much larger effect than a static load (steady winds) of the same magnitude. Resistance to dynamic loading depends on the tree or stand's ability to respond quickly to the loading.
- *Treatment Hazard* - is the way in which a particular treatment increases or decreases the windloading or wind resistance of trees. A simple example of treatment hazard is the influence of harvesting to expose new edges (Figure 7-C). Treatment hazard can be reduced by further treatments such as pruning, or topping - see Best Management Practices Section 7 for more details.

Windthrow impact definitions

- *Windthrow Likelihood* - is the expected level of damage from endemic winds. It combines Biophysical Hazard and Treatment Hazard.
- *Windthrow Consequences* - is the probable level of impact on specific management objectives, or sensitivity of those objectives, if the expected level of windthrow occurs.
- *Windthrow Risk* - is the potential for a negative consequence from windthrow caused by endemic winds. It is the combination of Windthrow Likelihood and Consequence. The process of assessing windthrow consequence and risk will be covered in Section 6.

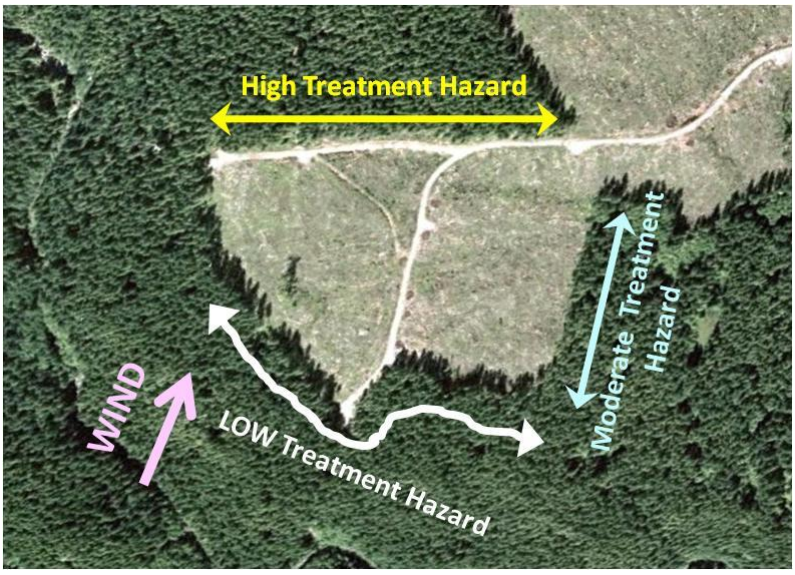

Figure 7-C. A simple example of treatment hazard. Where: treatment maximizes windloading the hazard is high; where treatment minimizes windloading, hazard is low; and where it is something in between (as in a parallel boundary),hazard is moderate.

Understanding Climate, Weather and Wind

When assessing potential impacts from windthrow one must begin with a simple question: Is this a windy area?

To understand and predict windthrow hazard and risk you need to know local wind and precipitation patterns. 'Weather' refers to the atmospheric conditions at a particular time and place. 'Climate' refers to the long term weather patterns at a given location. For example by monitoring hourly weather for many years at airport and lighthouse weather stations, Environment Canada is able to produce Climate Normals that describe the mean and extreme conditions at these locations in each month of the year.

There is considerable literature available on the subject of climate and weather. Basically, forecasters use equations to calculate surface, upper level and atmospheric winds from large scale temperature and pressure gradients detected by satellites and direct atmospheric measurements. These calculations are complex and meteorologists use the largest and fastest computers to help forecast hourly data up to 7 days ahead. However, it is not necessary for you to be a meteorologist to understand your local weather patterns.

The following is a summary of what causes wind and why it varies, beginning with the big picture. For purposes of this manual, the focus will be on the most common driving factors of gale (62 – 88 km/h), storm (89 – 117 km/h) and hurricane (> 118 km/h) force winds – the type of winds which cause windthrow damage. Because of the potential for wind speeds greater than 62 km/h to cause damage or disrupt transportation, wind warnings are issued by weather forecasting centres when winds of these speeds are predicted. It is the tradition in weather terminology to refer to winds by the direction from which they come. So a 'southeaster' is a wind that comes from the southeast (e.g. is blowing towards the northwest). The terms windward means toward the wind, and leeward means away from the wind.

A good starting point to get an understanding of your local weather history is found at:

http://www.climate.weatheroffice.gc.ca/Welcome_e.html,

Choose Canadian Climate normals and then BC for a list of a number of locations in BC. Choose one near you to view normals and extremes. Note – some sites have wind speeds others do not, you may need to look at a number of locations to see wind trends.

The most common cause of stand damaging winds is the westerly movement of extra-tropical low pressure systems (extra-tropical cyclones) from the Pacific Ocean across North America. These storms produce large scale wind fields that circulate in an anti-clockwise direction around the low pressure centre. Depending on the track of these storms, which depends on the upper level jet stream, surface winds usually blow from the southeast in advance of the centre of the low pressure system. The wind usually shifts to northwest after the low passes (on the backside of the system). The reason for these surface wind patterns is that, like any fluid, air moves from areas of high pressure to areas of low pressure.

Any weather map which shows the pattern of isobars, lines of equal pressure, is a useful tool in determining the strength and direction of surface winds (Figure 2-D). You might expect that the wind would run perpendicular across the isobars from high pressure to low, but since the earth is spherical, the Coriolis force produces a shift to the right in the northern hemisphere (and to the left in the southern hemisphere), and this leads to a rotating storm system. The steeper pressure gradient (i.e. isobars which are close together) the stronger the wind will be.

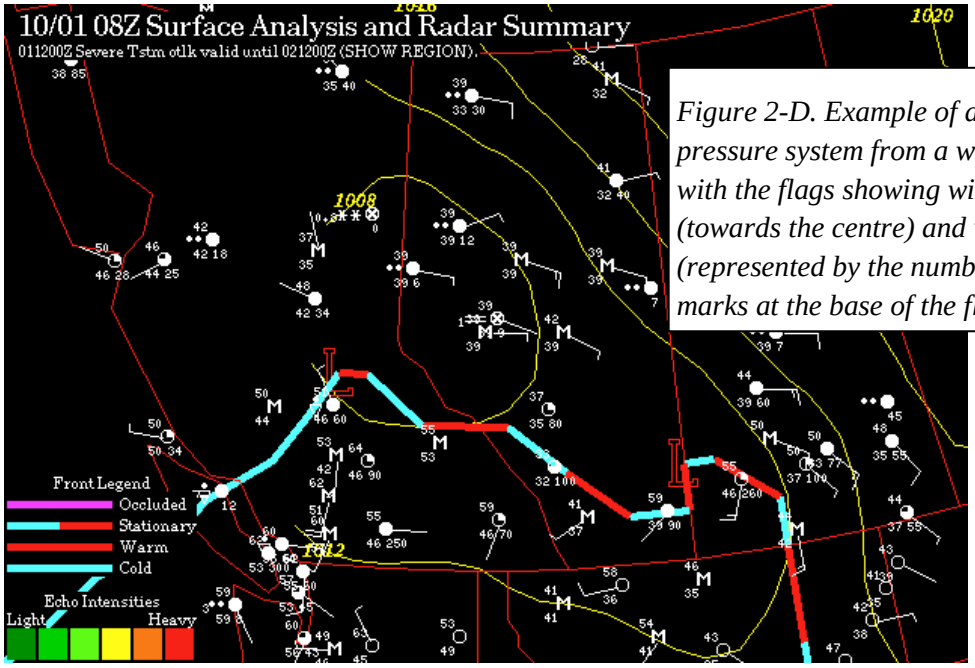

Figure 2-D. Example of a low pressure system from a weather map with the flags showing wind direction (towards the centre) and wind speed (represented by the number hash marks at the base of the flag).

Pacific low pressure systems are strongest from October to April, last for up to 2 days as they pass over the coast, and are accompanied by gusty winds and high rainfall. The long duration of these storms and the high rainfall may be significant factors in windthrow risk since root-soil cohesion breaks down as trees rock back and forth in wet soil.

The other large scale weather systems which can cause stand damaging winds are arctic ridges of high pressure (Figure 2-E). These cold, dry systems typically sit over the northern part of the interior of BC, but occasionally move south over the interior of BC and outward toward the coast. Strong outflow winds through major valleys are associated with these winter systems, particularly when there is an offshore low pressure system and therefore a steep differential gradient in surface air pressure (high to low). These outflow winds are concentrated in coastal valleys that extend up into the interior and the areas on the southcoast and islands that are exposed to these outflow jets. Winter outflows bring very cold dry air from the interior. If this air meets cool wet coastal air, we get snow, and often wind-driven snow as the front passes. Once the high has moved out onto the coast, we typically experience sub-freezing weather with clear skies.

It is important to understand the interplay of coastal and contintental air masses, and the typical movement of large scale weather systems in your area. It is also important to understand the behaviour of small scale local wind patterns. Local sailors and aircraft pilots pay close attention to weather systems and can be a good source of information.

The damaging wind events due to large scale extra-tropical cyclones and arctic high pressure systems occur during the cooler months (i.e. October to April). Local wind effects occur when the winds from these systems are modified by local geography and topography.

In the summer, local wind effects are created where strong differences in air temperature develop. So on-shore winds develop in the afternoon as the land heats up relative to the ocean. Since the surface air above the Strait of Georgia and associated parts of Vancouver Island and the mainland is typically warmer than the west coast of Vancouver Island, strong winds can funnel from the west through down the Alberni Canal and through the Cameron Valley. These are locally known as 'Qualicum' winds. Similar strong daily winds develop through the major valley systems that cut through into the interior. As the BC interior heats up, a temperature differential with the coastal air masses produces strong winds up the inlets and valleys into the interior.

Summer time heating also produces upward rising air that cools as it hits the upper atmosphere and then rapidly descends. These small short-lived systems are called convective storm cells and produce thunderstorms and local wind downbursts . These downbursts can cause significant local damage. Convective storm cells can also develop along cold fronts and generate strong local winds away from and in advance of the centre of the front. Since these convective cells are embedded in broad scale regional air flow, the storm trackway reflects the general large scale movement of air on that day. Localized windthrow can occur as shown below in this thunderstorm track in the upper Fraser Valley east of Prince George (Figure 2-F). Damage is severe along the path of the downburst and reflects the storm track rather than terrain, stand or soil attributes.

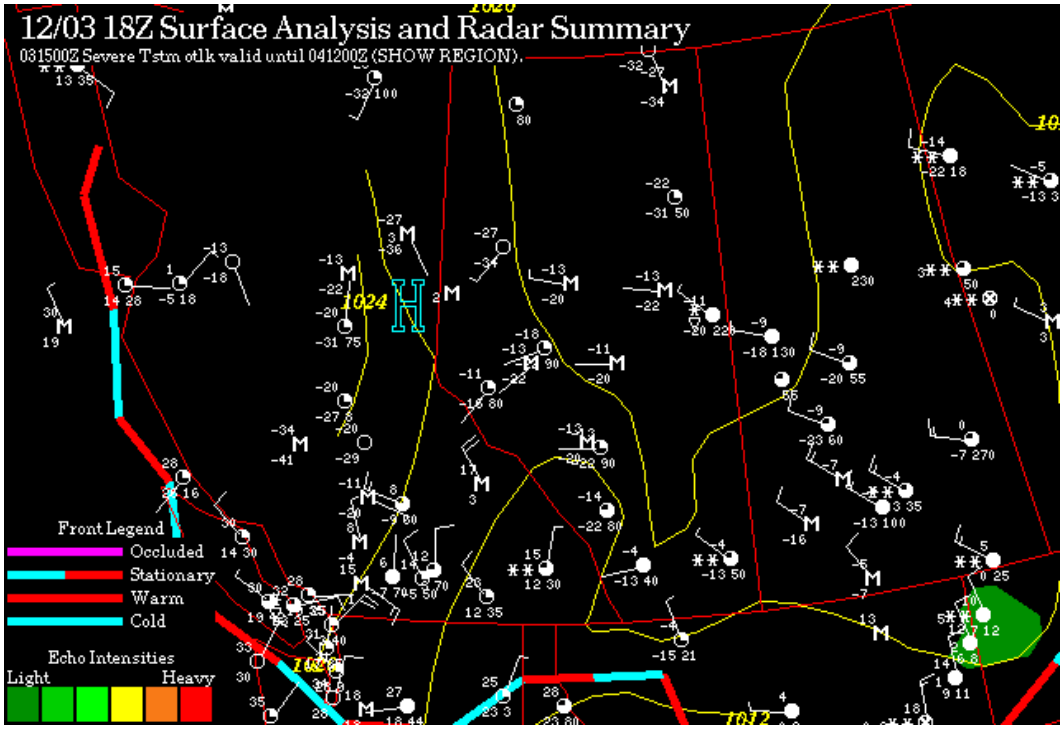

Figure 2-E. Example of a high pressure system from a weather map with the flags showing wind directions radiating out from the centre.

Figure 2-G – Thunderstorm track cutting a swath through standing timber.

Windthrow Hazards - Topographic Exposure.

Large scale weather patterns drive wind development, however, these wind fields are modified by local terrain and topography leading to local patterns in wind speed and direction. Visualize wind as a fluid moving over the ground surface. Where terrain features are low, broad or gentle the air moves smoothly, flowing over and around objects. Where terrain features are high, angular or rough, the air becomes turbulent and gusty. Variation in local terrain means that some areas will have direct exposure to the wind while others will be sheltered compared to the average over the landscape.

Winds will be accelerated by topographic conditions, for example, funneling through valley gaps and over terrain obstacles. Wind speed increases as it rises over obstacles such as ridges (Bernoulli's principle). Consequently, there is a higher potential for windthrow on ridges (Figure 2-H) or wherever a higher volume of any fluid (in this case air) is forced through a small opening or around an obstruction. On the opposite side of sharp terrain breaks, the wind becomes turbulent and gusty, and during high wind events, this can drive high winds down into areas of terrain that are normally sheltered.

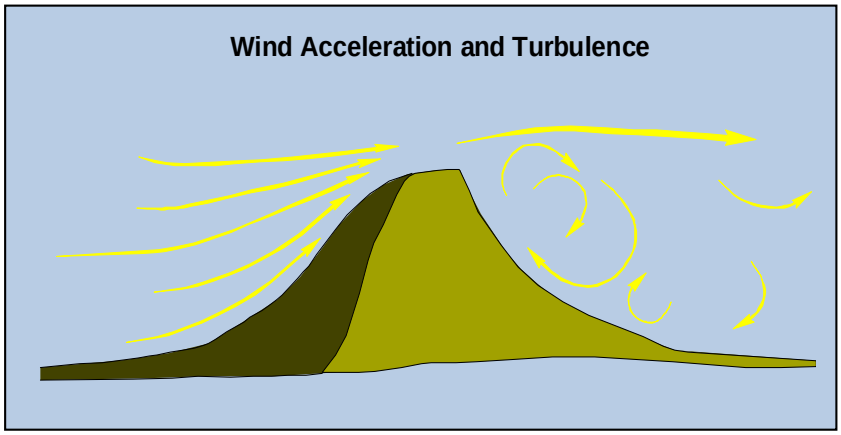

Figure 2-H. Impact of topography on wind.

For the purpose of windthrow hazard evaluation, topographic exposure to wind is ranked according to how wind is felt on the ground. This is called Topographic Exposure Hazard rating and varies somewhat by slope position depending upon the wind direction (Figure 2-I). Note – ridges always have a high topographic exposure (Figure 2-J).

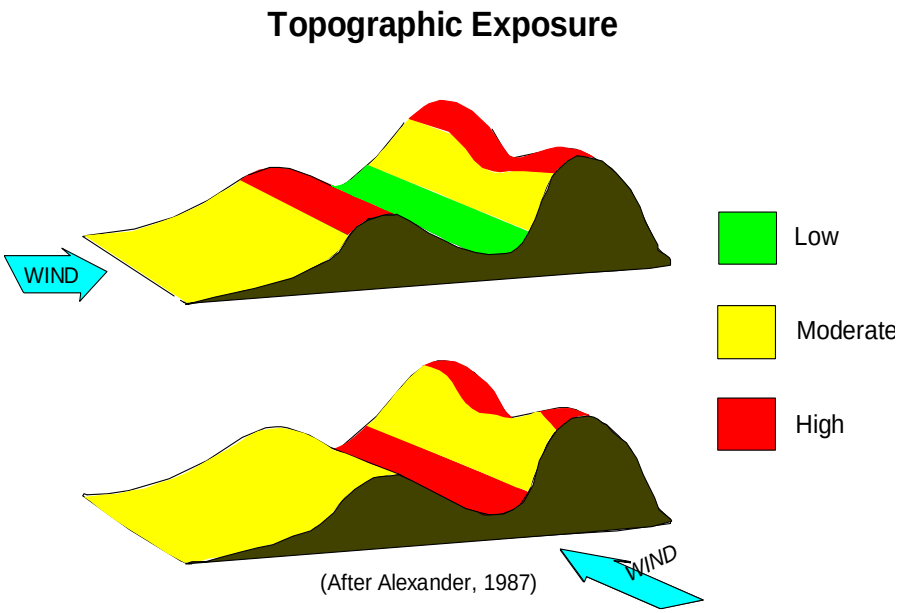

Figure 2-I, Impact of Topography on wind, Topographic Exposure.

Figure 2-J. The influence of topographic exposure - showing high levels of windthrow on an edge positioned on highly exposed ridge (windthrow actually progressed with turbulence down the leeward side for 50 m or so).

Diagnostic Question for Topographic Exposure hazard

QUESTION: **Are regional winds accelerated by local terrain conditions?**

Topographic hazard can be determined based on the above question. It is important to consider this question carefully in your local setting. All coastal studies show that topographic exposure is often the driving factor controlling the likelihood of windthrow. As terrain becomes more complex, local wind patterns can develop. These examples illustrate situations where local knowledge and interpretations are extremely useful:

- Notches or gaps funnel the wind and cause increased velocity (Figure 2-K).
- Similarly, when wind direction is parallel to valleys, acceleration will be experienced on the valley floor with lower speeds on adjacent midslopes. Winter outflow winds are a common parallel valley weather pattern for some of the major coastal valleys and inlets.
- Regional prevailing winds may be altered by diverse patterns of ridges and valleys, which modify the general direction of endemic winds and windthrow.

- Sheltering influences can be misleading. The leeward side of steep ridges may incur considerable turbulence, which can produce relatively high winds and associated damage. Ridges that have gentle leeward slopes may provide sheltering influences higher up on the leeward side, as the wind profile may be more readily deflected rather than broken into turbulent patterns.

Fig 2-K - A vulnerable edge due to funneling of wind through a small notch or saddle. Note – funneling can also be caused by treatment effects when openings are long, relatively narrow and oriented in the direction of potentially damaging winds.

It is important to become comfortable with the general wind patterns and the potential for acceleration and shelter in an area. Discussing past experiences with senior personnel and consulting probabilistic windthrow mapping for the area of interest is a good starting point. In the end, nothing is better than thoughtful observations of similar past logging in the vicinity of the proposed cutblock.

Remember 'Biophysical Hazard' is the combination of the topographic, soils and stand hazard components. It represents the windloading and stability of trees on the site prior to treatment.

Windthrow Hazard – Stand Characteristics

Stands have inherent above ground characteristics which determine their susceptibility to windthrow. To understand the hazards associated with these stand characteristics, a good understanding of individual tree mechanics and built-in windthrow resistance mechanisms is required.

Tree mechanics

Trees are like big levers. They are attached at the bottom and sway freely at the top. The lever arm is the distance from the point of root attachment (rotation) to the centre of the crown. The crown of the tree is like a sail. Wind acting on the crown creates a 'drag force' which is proportional to the frontal area of the crown at a given wind speed, and the square of the wind speed. Unlike solid structures, such as buildings, the flexibility of tree branches and foliage enables trees to reconfigure and streamline under high wind loads, leading to a wind-speed specific frontal area. Experiments have shown that the drag on tree crowns is proportional to crown mass. This is important to know if you are thinking of crown pruning, since you can reduce the force on a tree by 1/3 by taking out 1/3 of the branches. The drag force is multiplied by the lever arm to produce a turning moment around the point of root attachment. The tree will try to rotate vertically around this point when under wind loading.

Because trees are flexible, the crown can move in the wind, shifting the mass of the tree so that it is no longer directly above the base of the stem. This deflection adds an additional self-loading component to the turning moment at the base of the tree. The product of crown mass and gravitational pull is multiplied by the horizontal displacement to produce an additional turning moment as a result of sway. Larger crowns have more weight resulting in greater stress on the tree when displaced, and slender trees deflect more than trees with tapered stems. Tree stems acclimate to this stress by devoting more resources to diameter growth in the lower stem. (see Acclimative Growth below).

As trees grow taller, the length of the lever arm increases. This means that the turning moment will increase even if the crown stays the same size. At some point the diameter may not be large enough to withstand wind induced forces and the tree blows over due to stem break or root failure (Figure 2-L). This is especially common in dense stands where the trees are devoting more resources to height growth to survive competition.

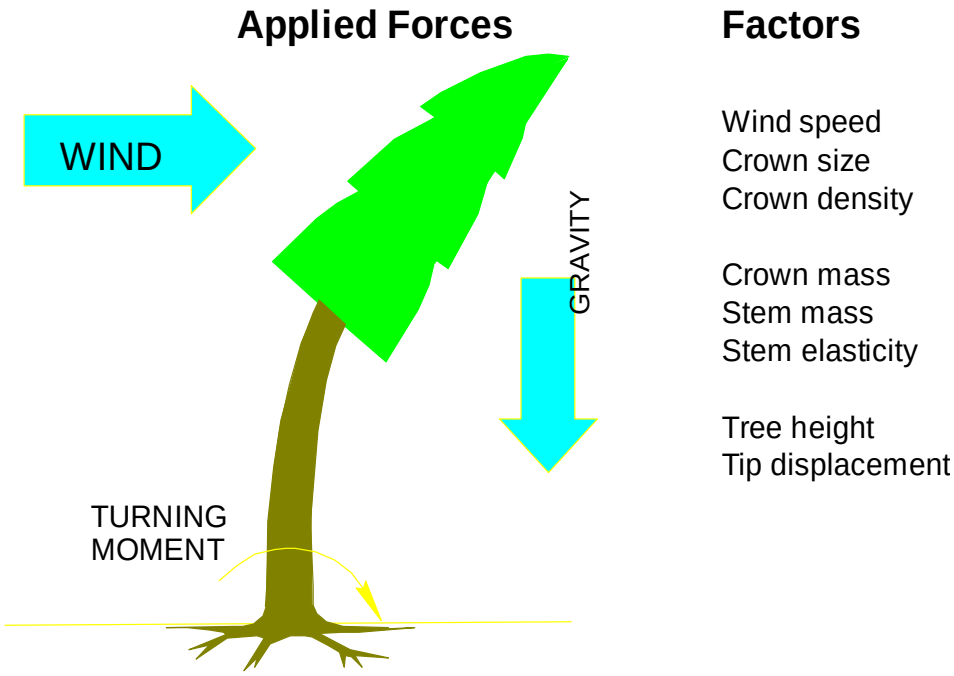

Figure 2-L. Effects of wind on trees.

Bole strength and root/soil strength enable trees to resist breakage or overturning. Strong, tapered stems resist bending and stay straight, which reduces the potential to blow over due to crown displacement. Stem strength increases as the diameter increases by a factor of the radius cubed! – Thus any increases in radius radically increase bole strength significantly.

The resistance of the root/soil system to uprooting and overturning also depends on rooting strength which is a combination of good rooting arrangement, a large root/soil mass, and a cohesive bond between roots and soil (see soil hazard). Bole strength is not usually affected as a tree sways back and forth during a wind storm. However, the root/soil bond can break down, especially if the soils have low strength or are wet. Consequently, a high stand hazard and high soil hazard may have a higher cumulative influence on windthrow risk.

Stand characteristics generally have a greater influence on windthrow hazard than soil characteristics. As previously mentioned, stands with deep unrestricted rooting may have a high windthrow hazard due to stand characteristics. However, very short, open stands in a coastal pine bog, with highly restricted rooting, may have a low windthrow hazard (Figure 2-M).

Figure 2-M. A short forest with saturated soils (forested bog) on Haida Gwaii. Even though it is highly exposed to endemic winds, close to the top of a ridge, and rooting is highly restricted, windthrow likelihood is low entirely due to stand characteristics. It is not tall, and grew slowly in open conditions allowing for good acclimation over time to high winds.

Diagnostic Question for Stand hazard:

QUESTION A: Are the individual trees in the stand adapted to endemic wind loads? In other words, are trees poorly adapted to peak wind loads?

QUESTION B: If the trees were uprooted, would most of the trees fall through the canopy to the ground?

Acclimative Growth

Trees are self-designing structures. They have many design features that enable them to elevate their canopies above competing plants and withstand self-loading from gravity and bending loads from snow or wind loading. Since trees have evolved to compete with other trees and other plants for growing space, they are also very efficiently designed, using the minimum material necessary for structural growth. For example, stems are typically circular in cross section, and this means they can resist bending equally well from any direction. In contrast, structural roots are often figure-eight in cross section, like an I-beam and this is an efficient design to resist downward or upward bending.

The main stem and structural roots are relatively stiff so that they don't move too much during wind events, but the top of the stem, the branches and the foliage are flexible so that

they streamline. This reduction in frontal area during high winds reduces the drag force acting on the crown. Some trees shed branches or leaves during wind storms, and this reduces drag. Deciduous trees have about ½ of the drag in the winter time when they are leafless compared to the summer when they are in full leaf.

The living tissues in trees sense and respond to the movement and stresses that result from wind loading. This enables trees to allocate growth resources and maintain relatively uniform strength throughout the stems, branches, bole and roots. During the growing season, cells in the cambium sense compressive stresses and excessive displacement and respond by increasing the rate of cell division. This plasticity of form can be seen in trees that grow in locations with strongly directional winds. The tree crown may be asymmetric or 'flagged' away from the wind, stems are more strongly tapered and have more growth on the side of the stem opposite to the wind.

Thinning treatments in stands can produce an immediate change in growth allocation within remaining trees. When these trees experience increased wind loads after a thinning operation, they reduce height extension and allocate more wood to diameter increment in the lower stem and structural roots. Over several growing seasons, this leads to a more tapered stem. If a tree remains tilted after an extreme loading event, compression wood (in conifers) or tension wood (in broadleaves) is formed. This reaction wood has thicker cell walls and creates internal growth strains that help to move the stem of the tree back into a vertical position.

Trees vs. Stands

While trees have all of the mechanisms described above to sense and respond to windloading, growth responses are limited by competition with other trees. Trees have an allocation hierarchy for growth resources. The first priority is for the production of new foliage and upward expansion of the crown. The second priority is for production of new feeder roots. Only after addressing the first two priorities, does allocation to structural increments occur.

Trees grown in the open are more exposed to high loads and have the growth resources to acclimate to these wind loads as they grow (large diameter, high degree of taper and large spreading roots). They become highly resistant to windthrow even though they may be tall with large crowns. When trees grow in stands, they shelter each other from high, above-canopy winds. Collisions between crowns while trees are swaying helps absorb the wind energy and reduces further gravitational stresses on the stem and root system. The competition between trees for light, moisture and nutrients also means that structural increment takes a lower priority. Diameter growth is affected more than height growth. Trees in dense stands become slender, with insufficient long term allocation to stem or root thickening. They lose individual windfirmness and ultimately the whole stand can become vulnerable to failure during routine storm events.

Intact stands are often less prone to windthrow than recently exposed individual trees since trees provide mutual shelter and mechanical support. When stands are partially opened by partial cutting (Figure 2-N) or fresh edges are exposed (Figure 2-O), windthrow likelihood

increases. For this reason, the diagnostic questions for windthrow stand hazard address tree and then stand characteristics.

Figure 2-N. Susceptible trees made more vulnerable once the stand is uniformly opened through partial cutting.

Figure 2-O. Windthrow in uniform stand on a "high treatment hazard" edge.

Slenderness Coefficient - Ht:Diameter Ratio

As previously mentioned, taller stands can be more susceptible to windthrow unless individual trees can counter the influence of increased height with larger diameters and thicker roots. Because diameter and more specifically, the amount of taper, greatly influences individual tree susceptibility to windthrow, the ratio of height to diameter is useful to consider when assessing stand hazard. This ratio is also called the 'slenderness coefficient' or 'slenderness'.

To calculate this ratio, divide the tree height in metres by the breast height diameter (dbh) in metres. For example, a 35 m tall tree with a dbh of 35 cm (0.35 m) has a height to diameter ratio of 100. A 35 m tall tree with a dbh of 70 cm has a height to diameter ratio of 50. Strongly tapered trees with low height to diameter ratios (< 60) are much less likely to blow down than slender trees with high ratios (Figure 2-P). Another way to view this is that trees with a low slenderness ratio will require a much higher critical wind speed to blow over than trees with a high slenderness ratio (Byrne 2005 – Figure 2Q).

Ability to Fall Through the Canopy

In dense and relatively short stands, edge-trees are often highly susceptible to windthrow. However, sometimes these stands are so dense that most edge trees lean back into the stand unable to fall through the canopy. Such edges tend to self-stabilize with minimal penetration of windthrow into the edge (Figure 2-R). In contrast, where trees are tall and large, with high centres of gravity, they can damage other trees as they fall, leading to a domino effect and extensive propagation of damage through the stand (Figure 2-S).

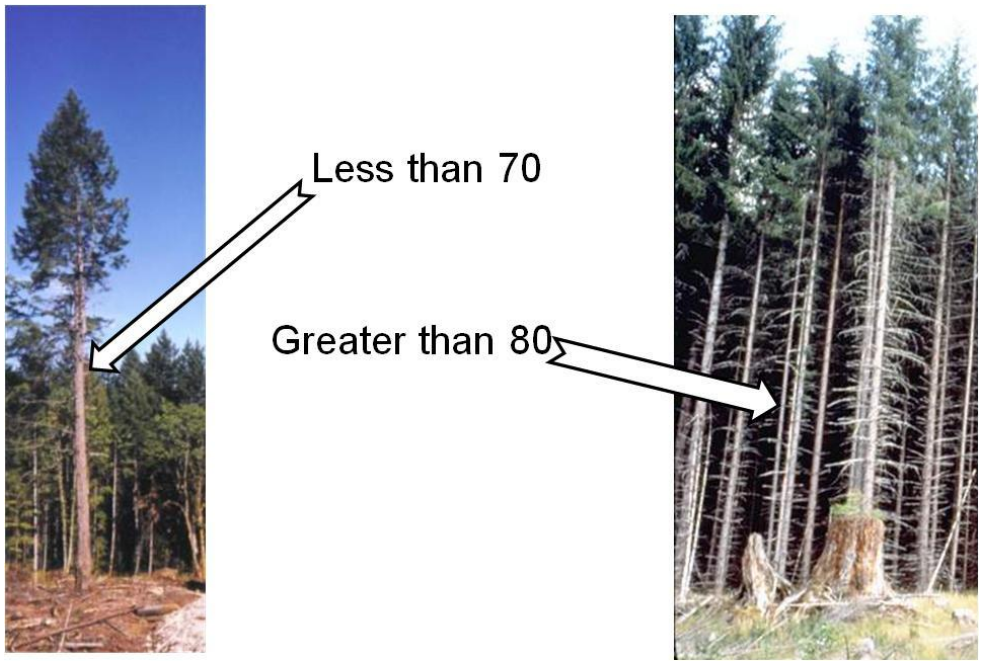

Figure 2-P. Using Height to Diameter ratio to help assess stand hazard. The tree on the left has a Ht/Diam ratio approaching 30, and the trees on the right closer to 100.

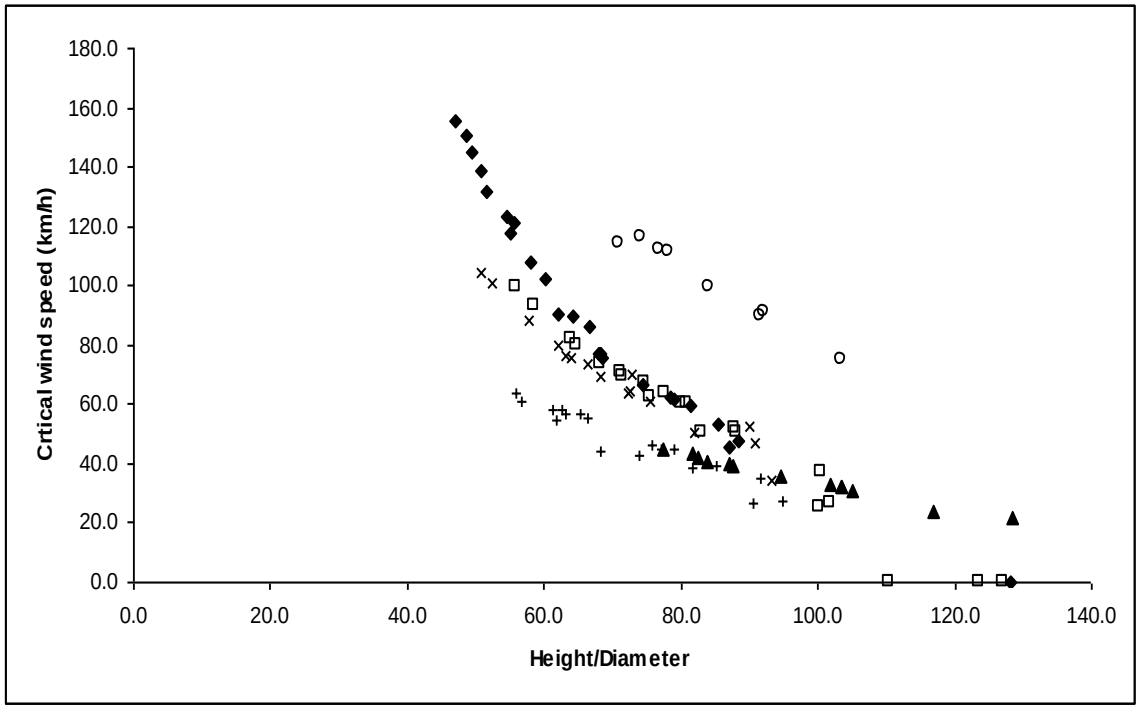

Figure 2-Q. Critical (failure) wind speeds for stand grown trees if they were individually exposed by removal of their neighbours, versus tree height to diameter ratio. BC lodgepole pine (▲), western redcedar (♦), BC western hemlock (□), hybrid spruce (+), United Kingdom lodgepole pine (×),United Kingdom western hemlock (○). Critical wind speed occurs when the applied load from the wind and deflected stem exceeds the tree's maximum resistance to windthrow (Byrne 2005)

Figure 2-R. An example of a stable edge of short, dense second growth hemlock and redcedar with many leaning trees.

Figure 2-S. The effect of stand height on damage propagation. Note the increasing penetration of damage from left to right along this cutblock edge as the stand gets taller. The stand height increases as drainage improves away from the wetland edge.

Species Considerations

Some species can develop more resistance to windthrow than others, on a given site. However, the growth history and dominance of a tree are typically more important than tree species in determining relative stability of trees in mixed species stands. Also, different species tend to dominate stands on different site types. So generalizations about species susceptibility and resistance must take into account stand development history, site conditions and position in the landscape.

Some general observations:

- Fast-growing shade intolerant or semi-tolerant species such as Douglas-fir typically survive only as well expressed dominants or emergents. In this canopy position, they have had long term exposure and ample resources, so they are typically more windfirm than other trees within the same stand.
- Long lived species can produce veteran trees. Veteran trees are, by definition, trees that have survived an earlier stand damaging disturbance. They have survived one or more periods of full exposure to winds. They may have had crown or top damage while continuing to add diameter, producing relatively low height to diameter ratios.

However, accumulated damage and old age can lead to increased root and stem decay.

- Species with decay resistant wood such as redcedar and Douglas-fir are less prone to stem failure in mature stands.
- Dwarf mistletoe can produce internal stem defects and lead to decay, making stem snap more likely in infected stands.
- Species that are susceptible to root diseases are more prone to uprooting in stands where these diseases are present.
- Redcedar often has some unique characteristics that provide a degree of windthrow resistance in certain situations. When it is young, its crown easily bends and wraps behind it toward the leeward to shed strong winds. Redcedar foliage has a very low drag coefficient meaning that its foliage streamlines very effectively in the wind.
- Older dominant or veteran redcedar are often highly tapered with sparse crowns (often with a dead top) reducing drag forces even further on larger trees. However, slender codominant or subdominant redcedar in dense second growth stands are relatively unstable and may experience a high degree of windthrow if left as residuals. Also, redcedar become the dominant species on wetter sites with high water tables where root anchorage may be restricted.
- Hemlock is perhaps the most commonly windthrown species on the Coast. This trend is likely influenced by the fact that hemlock is shade tolerant and forms high density stands, and is vulnerable to dwarf mistletoe, decay and root disease. It is often found as a prolific, slender, codominant tree in many Coastal stands. Yet, hemlock foliage has a very high drag coefficient meaning that its foliage does not streamline very efficiently. Hemlock also frequently germinates on logs or mounds of rotten wood, potentially reducing the stability of the root system.
- Amabilis-fir is highly shade tolerant and suppressed seedlings accumulate in the understory. This makes it well adapted to stand replacing windthrow. Look for patterns of dense, uniform stands or this species across Coastal landscapes for clues as to where stand-replacing windthrow is a recurring event.
- Douglas-fir is generally considered relatively resistant to windthrow, and this is true when it is a well expressed dominant, canopy emergent or veteran. Yet, in landscapes dominated by dense second growth stands, Douglas-fir may dominate the species composition of the windthrow. Winching studies in Britain indicate that Douglas-fir require less force to pull over than Sitka spruce on a similar site. The conceptual bias that spruce is more susceptible to windthrow than Douglas-fir probably has more to do with site and stand effects on tree form.
- We generally think of deciduous broadleaf trees as being relatively windfirm due to their lack of crown during coastal winter storms. However, where these trees exist in a closed canopy stand prior to harvest, they can be very slender (ht:diameter ratios of 100 or more) and often exhibit considerable windthrow and breakage when left in a highly exposed situation. Red alder also dominates on wet sites where anchorage may be restricted.

It is best to become familiar with the species composition of windthrow in various situations in your local area – close to your proposed cutblock. Look at the species mix of downed trees compared to standing trees within the same section of cutblock boundary. See how this varies

from site to site. Ensure interpretations of species susceptibility are linked to factors associated with the three windthrow hazard ranking categories, and assess your cutblock in that context.

Windthrow Hazards - Soil

Trees are anchored by their roots. Rooting is another important consideration in assessing the Biophysical Hazard. Keep in mind however, that open grown trees are able to anchor on a wide variety of substrates, so development of root anchorage also ties in with inter-tree competition and stand characteristics. Figure T identifies the key features for soil/root stability.

Diagnostic Question for Soil hazard

QUESTION: Is root anchorage restricted by an impeding layer (e.g. rock, cemented horizon or other impediment to rooting), low strength soil (e.g. fine silt or sand), or poor drainage (e.g. saturated conditions)?

In answering this question, consider the depth and strength of the soil material, and how this might vary from season to season with soil moisture content or freezing. Also examine the nature of the root system. Trees grow on a variety of substrates. They can form deep tap root systems on well drained, deep soils, plate root systems on very thin or waterlogged soils, or send roots into cracks in surface bedrock. However the relative efficiency of different root systems varies and it takes more resources for trees to form effective root systems on shallow or in low strength soils.

The shape and condition of the root system is your best evidence as to the strategy that trees are using to maintain stability on a site. . For example, shallow soils over rock may indicate a high soil hazard, but not necessarily. If the rock is sufficiently fissured or broken, some tree species will penetrate deep into these cracks and fissures to gain a solid hold on the rock as identified by the soil and root tension (Figure 2-T). In windthrown trees, look for evidence of a pattern of long term loss and regrowth of roots due to fluctuating water tables, abrasion against stones or rock, and root disease.

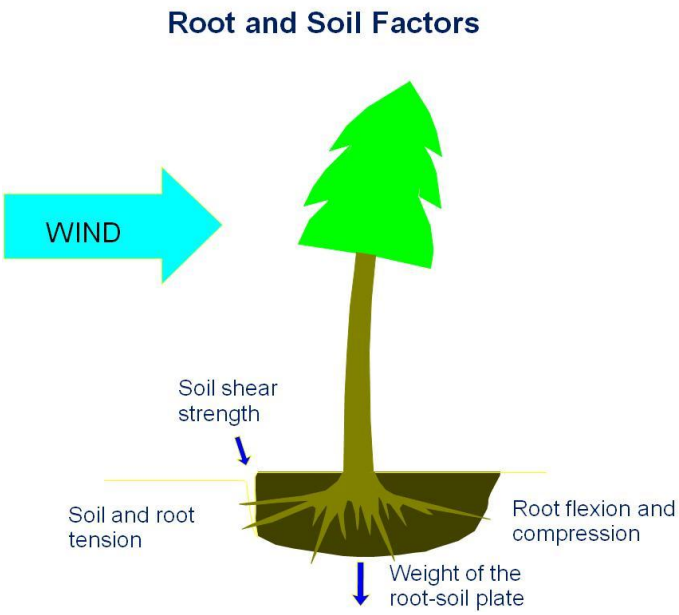

Figure 2-T– components of the Soil Hazard rating.

Road cuts near the area being assessed, or old windthrow found in similar situations associated with older adjacent blocks are excellent places to make these kind of observations. Flat plate-like root systems are very restricted (Figure 2-U), while slightly flattened root systems may be slightly restricted or neutral. A bowl-shaped root system, sometimes with thick taproots connected to and penetrating lower soil layers, is unrestricted (Figure 2-V).

Restricted rooting can be a big problem where stand stability is already suspect – for example, unstable slopes and gully sidewalls with relatively shallow, compacted layers, often slippery with seepage over compact silts and clay. Tree rooting can also be asymmetrical on steep slopes or gully sidewalls which could further reduce stability.

Root anchorage may be a problem due entirely to the nature of the soil. Where soils are pure silts or sands, or composed of peat, soil strength is low and swaying trees will easily work roots out of such a medium. Optimal soils for rooting are deep, well-drained, with a good mix of fine and coarse fragments, and no restricting layer.

When examining root systems, be on the lookout for evidence of root disease. *Phellinus* and *Tomentosus* are wide spread in BC and can damage the structural integrity of root systems long before causing tree mortality. Uprooted trees with root disease often show 'brash' failures in structural roots. In brash failures, the wood fibres have lost their strength, so the failure zone is compact. In contrast, in sound wood compression or tension failures usually cause strips of wood to pullout.

A confusing fact is that deeply rooted stands often show high levels of windthrow. Stands grow dense and tall on rich, well-drained soils with adequate or abundant moisture. These stand characteristics when combined with topographic exposure increase the biophysical hazard for windthrow, even if anchorage is unrestricted. In contrast, sites with shallow soils, because of waterlogging or near surface bedrock are often low productivity and support only short, low density stands. In these open stands, the trees have long term acclimation to wind

loads and are relatively windfirm. The most vulnerable sites are where thin or low strength soils receive seepage and so enable development of tall, dense stands. Soil influences become more obvious where topographic exposure and stand hazards are relatively consistent across the landscape. For example, small gullies or depressions have moister soils and slightly taller trees than on either side. It is in these instances changes in soil characteristics can significantly influence the windthrow hazard. Soils in the BC interior become saturated during spring breakup, and at this time even deeply rooted trees may be susceptible to rotational failures.

Figure 2-U. Severely restricted rooting. Note the plate like structure that resulted from saturated soil conditions (lack of oxygen restricts respiration and root growth).

Figure 2-V. A bowl shaped root ball for a deeply rooted Douglas-fir. A large taproot is shown to the left of the hardhat, two metres below the original root collar. It is still penetrating into the soil beyond this point.

Biophysical Hazard

To determine the Biophysical Hazard all three of the component hazards (topographic exposure, stand, and soil hazard) must be considered together for the area in question. This will be covered in Section 5.

Don't be surprised if assessment in most of your stands results in a moderate biophysical moderate. On typical sites, trees have optimized their growth to balance competition with stability and are reasonably windfirm. Exposing stand edges results in loss of just a few of the most unstable trees at the new stand edge. You want to distinguish sites where trees are particularly windfirm, usually because competition is lower and many, or all trees are well acclimated, and sites which are particulary unstable. On the latter sites, higher fertility and stand development history has lead to dense stands with lots of trees whose stability depends on having neighbours in place. Removing these neighbours destabilizes the stand and damage can propagate from new edges for considerable distances. In areas that are routinely exposed to very high winds because of high terrain exposure, trees will show crown flagging, bole asymmetries etc. In these locations, opening up stand edges can result in severe damage.

Some Common Questions

Isn't windthrow too unpredictable to manage?

This is only true if you are not familiar with how it works. Windthrow is a recurring natural disturbance agent in many BC ecosystems and management activities that expose previously sheltered trees to higher wind loads increase the likelihood of damage. An understanding of local wind patterns and impacts is critical in designing harvest patterns to limit the impact of windthrow. The following section describing *Best Management Practices* provides an overview of our understanding windthrow from operational trials and model outputs. While it may be impossible to manage against catastrophic windthrow, it is rare on any given boundary location. Due diligence should limit impacts to management objectives from endemic windthrow.

Aren't the taller trees more vulnerable to windthrow?

Dominant trees that have likely grown most of their life with their crown above the main canopy are more likely to be windfirm than co-dominants. Typically, they will have acclimated to more exposure and higher wind speeds above the canopy as they grew over time. These trees usually have the highest degree of taper in the stand (lowest ht:diameter ratio).

This trend should not be confused with tall dense stands which exhibit very little dominance of individual trees. Trees within these kinds of stands have all developed with a high degree of sheltering and support from neighbours and are collectively susceptible to windthrow. They usually have low degrees of taper (higher ht:diameter ratios).

Once windthrow starts in a stand, doesn't it just continue for many years?

While windthrow may continue for years following harvest, coastal studies show that most windthrow occurs within the first three years. Within those three years, the most windthrow occurs in the first storms after harvest (trees are exposed to new conditions that they may not be adapted to, susceptible trees are sorted out quickly). In the BC interior, strong winds don't occur each winter, so it may be several years after clearcutting before storms cause damage. Again, however, once an edge has been exposed to a storm, the edge stabilizes. Salvaging damaged edges to a clean face just starts the process all over again. See our suggestions in Section 7 concerning salvage strategies.

Isn't shallow rooting the most important consideration?

Soil type and rooting are only part of the windthrow hazard equation. All three hazard rating factors (Topographic Exposure, Stand and Soil) must be considered. These factors are generally not equal in their importance and the significance of each will vary from site to site. Therefore, each site must be considered independently. When the biophysical hazard rating is something other than moderate (i.e. high or low) there are usually one or two considerations dominating all others.

However, this is not always clear. Compensating factors will vary from site to site. On the Coast, topographic exposure and/or stand factors may often combine to compensate for soil and rooting considerations – but conditions may vary at the site level. Again this is where observations and interpretations in similar blocks close to the proposed cutblock will help.

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3. BACKGROUND: Coastal Windthrow Damage Trends

CONTENTS

Sources of Information ____ **3**

Overview of General Levels of Damage Across the Coast ____ **3**

Trends in Windthrow Damage based on Biophysical Features ____ **4**

Recommended Caution when Considering Broad Trends for Damage ____ 4
Geographic and Topographic Influences ____ 5
Species Composition in Local Stands ____ 6
Influence of Stand Height and Site Productivity ____ 7
Influence of Cutblock Boundary Locations ____ 7

Data Summaries from Modeling and Monitoring Across the Coast ____ **8**

Overall Damage ____ 8
Topographic Attributes ____ 8
Stand Characteristics ____ 11
Soils ____ 15
Layout Design Attributes ____ 15
Time Since Logging ____ 17

References ____ **18**

FOR TABULAR SUMMARIES – See the end of this section

Sources of Information

The following section summarizes data from several key sources. Most information comes from three modeling projects for BCTS (Mitchell and Lanquaye-Opoku 2009). Information is also included from modeling projects completed for Weyerhaeuser in Haida Gwaii (Mitchell and Lanquaye 2004), in West Island Division (Mitchell 2003) and in North Island Division (Lanquaye 2003). In addition, information is drawn from extensive multi-year field monitoring of windthrow in variable retention cutblocks throughout Western Forest Products tenures on Vancouver Island, the Coastal mainland and Haida Gwaii (Rollerson et al. 2009).

Overview of General Levels of Damage across the Coast[1]

Rollerson et al. (2009) compared windthrow damage on cutblock edges across all Western Forest Products (WFP) tenures in coastal BC, including Gold River, Holberg, Jeune Landing, Mid Vancouver Island, Nootka Sound, Port Alberni (West Island), Port McNeil, Haida Gwaii, South Island and Stillwater (Powell River). They found 6-18%[2] of all stems to be damaged (on average) in 0.1 ha segments that were 25 m into the edge. This proportion was highly variable ranging up to 90% for such segments. Rollerson's data was averaged across all edge orientations.

Mitchell et al. (2003, 2009) and Lanquaye (2003) reported on the proportion of segments (25m by 25m) with more than 20% canopy loss in more than 30% of the area of the segment. Using these data, windthrow as a general damage concern can be compared across various geographic areas on the coast (Table 1).

Haida Gwaii generally experiences the most windthrow damage on the coast, with significantly higher levels than those experienced on the South Coast or Vancouver Island. Southwestern Vancouver Island (Port Alberni Operations Unit) ranks second in the level of damage, although it was significantly lower than Haida Gwaii. Elevated levels of damage in this area are likely influenced by the exposure of stands on the Coastal plain near the West Coast to intense Pacific storms, and the exposure of dense second growth stands to winds off the Alberni Inlet. Trends found here may be useful for other Coastal plain stands further south, or at the northern end of Vancouver Island.

Northeastern Vancouver Island (Campbell River to Woss) has lower (moderate) levels of damage, likely because a mix of ridges and valleys modifies and dampens impacts of storms off the Pacific.

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[1] NOTE: Geographic references here to Haida Gwaii, Port Alberni, Squamish, and Chilliwack are for the BCTS operational units. Trends for some of these areas may apply to other similar areas on the Coast. For example, some of the information for Squamish and Chilliwack may be equally valid in inland portions of the Sunshine Coast.

[2] The low average (6%) was for Southern Vancouver Island, while the high average was for Jeune Landing – with Haida Gwaii at 13%, Port Alberni and Stillwater at 11%, Holberg at 15%, and Port McNeil at 8%. Note: this information is based on a proportion of stems measured on the ground – therefore a large number of small stems can provide a large value.

Chilliwack and Squamish have the lowest levels of damage on the coast reflecting their complex terrain, and distance from the open Pacific - although the Strait of Georgia, Howe Sound and the Fraser Valley all experience periodic high winds.

Table 1. Windthrow damage as experienced by various geographic areas on the coast. Damage is expressed by the number of edge segments (25 x 25m) that have experienced a certain level of damage[3].

Geographic Area	Proportion of edge segments with (x% canopy loss) and (y% of the segment area)			Total # of segments sampled
	% of segments with 20,30	% segments with 50,90	% segments with 50,100	
1. Haida Gwaii	27%	5%		5,000
2. West Van. Island	19%		4%	22,000
3. North Van. Island	12%	7%		6,700
4. Sunshine Coast (Stillwater)	10%	2%		14,800
5. Chilliwack	7%	0.3%		6000
6. Squamish	5%	1%		6000

Trends in Windthrow Damage based on Biophysical Features

There are distinct differences between BCTS geographic areas across the coast, both in terms of the magnitude of damage experienced with various biophysical variables, and some subtle differences in how the variables themselves influence windthrow locally. Note that these trends were based on damage experienced on existing edges, so they reflect susceptibility of those areas favoured for harvesting in the past.

Recommended Caution when Considering Broad Trends for Damage

The variation in windthrow damage experienced in these regions of the coast, summarized by various biophysical features, illustrates well the complexity of local windthrow hazard and likelihood assessments. The local wind regime and topographic exposure generally are the driving factors for wind damage. However, the influence of some factors often overwhelms or masks the influence of other factors, and these may not always be anticipated.

It is useful to map probability of windthrow damage broadly across a region so the most troublesome areas are evident (i.e. those areas where windthrow should drive prescriptions and layout rather than those areas where it is an important factor, but not a prescription driver).

[3] See references above for sources of data.

The information and data that follows should be viewed with caution when drawing conclusions for specific geographic locations. These data are averaged over large areas. As well, different studies quantify damage differently. Broad geographic trends regarding hazard and windthrow likelihood are useful, but should not be applied to individual stands without taking local evidence into account. Furthermore, while wind regime and topographic exposure drive windthrow hazard, local stand and soil conditions may increase or reduce tree stability.

In the summary below, we report the association of individual factors with windthrow outcomes, even though these outcomes always reflect the interaction of multiple factors. For example, some site and stand factors are associated with marked increases in damage, and yet only 30-40% of cutblock edges with these high susceptibility conditions were actually damaged. It is likely that in the other 60-70% of locations, other factors compensated, leading to greater stability than the single factor alone would indicate. It is critical to make local observations of past windthrow near newly proposed cutblocks to draw conclusions regarding local influences on windthrow and to calibrate assessment of hazard and risk accordingly.

Geographic and Topographic Influences[4]

Haida Gwaii experiences more windthrow damage than the two southern BCTS business areas. This is due to an increased consistent exposure to frequent, more extreme wind events in this geographic location. A significant proportion of area is uniform and relatively flat providing little shelter the winds that come off Hecate Strait or the Pacific.

Inland areas with highly complex topography (such as West Vancouver Island, North Vancouver Island, Chilliwack or Squamish) generally show less consistent patterns with topography over the whole area, than does Haida Gwaii. Topographic influences, while important, must be examined within the context of geographic location, and at finer scales. Basically for windthrow, geographic exposure to high winds takes precedence over topographic influences.

Note that in the Chilliwack operating area, and possibly in the vicinity of Squamish, major valleys are exposed to summer inflows and winter outflows, likely causing localized damage that is not evident in the overall trends shown in the data generated by Mitchell and Lanquaye-Opoku (2009). Similar trends may be found in large coastal inlets on the Mid and North Coast.

In Haida Gwaii some topographic variables show clearer trends in terms of damage than in other areas (West & North Vancouver Island, Chilliwack and Squamish). Yet, it is not quite that simple. In Haida Gwaii, significantly higher precipitation inputs and less rugged terrain subdues the gradient of decreasing site productivity with elevation to a degree. This means that relatively taller, less open stands on mid-to-upper slopes in Haida Gwaii possibly contribute to higher levels of damage when exposed than those in North and West Vancouver Island, Chilliwack and Squamish. Different rooting environments in Haida Gwaii also likely play a role.

Generally speaking, windthrow increases in all areas with increasing elevation. Significant sheltering in lower elevations is only felt in Haida Gwaii below 100 m,

[4] For Sources of data – see the data summaries at the end of this section.

where it is evident in Chilliwack below 500 m and in Squamish below 1000 m. However, in West Vancouver Island, damage was found to be highest at low elevations, reflecting the higher annual (and peak) windspeeds on the Coastal Plains close to sea level along the West Coast (Mitchell 2003).

In Squamish, Chilliwack, and North / West Vancouver Island no particular windthrow trends were attributed to slope steepness, while a clear trend is evident in Haida Gwaii with significantly more damage on slopes over 20%. Again this likely reflects the differences in terrain complexity, stand types and rooting environments.

In all areas more windthrow was noted with cublocks located on north rather than south hillslope aspects, being somewhat counter-intuitive, considering that damaging winds are typically from the south. However, it is presumed that on south slopes stands are more acclimated, having developed under the influence of strong winds. This is a topographic aspect effect, and should not be confused with the orientation of cutblock boundary edges.

Species Composition in Local Stands[5]

On West and North Vancouver Island and Squamish trends for species susceptibility follow those found across the coast, with more damage generally in hemlock and balsam (Abies amabilis)[5] stands and less in cedar (western red and yellow) and Douglas-fir[6]. Haida Gwaii also follows these trends, but there are no amabilis fir stands. In Chilliwack, Douglas-fir stands appear slightly more vulnerable than hemlock and amabalis/subalpine fir (although the difference is not large). Likely this difference is due to the structure of the stands rather than the species composition. Chilliwack has a dominance of second growth Douglas-fir, which is usually more dense, tall and slender, especially on the productive mid-lower slopes where many of these stands are found.

In West Vancouver Island, Douglas-fir and yellow-cedar dominated stands suffered the least windthrow damage compared to those dominated by other species. Hemlock stands had the highest loss. Stands dominated by alder, Douglas-fir, Sitka spruce and yellow-cedar were less frequently damaged than those dominated by western redcedar, amabilis fir and hemlock. Western redcedar in West Island may show more damage than in other areas, since it dominates stand composition on the Coastal plain, which is exposed to much higher winds than other portions of the area.

In Northern Vancouver Island stands dominated by western redcedar were less frequently damaged in the first 25 m of an edge than amabilis fir leading stands. However, damage penetration to 50 m was more common in hemlock stands than stands of other species. On vulnerable edges in Northern Vancouver Island: amabilis fir leading stands had the highest percent canopy loss; hemlock stands had medium canopy loss; and western redcedar dominated stands had the lowest amount of canopy loss.

For comparison, Rollerson et al. (2009) found cutblock edges to have more total wind damage when dominated by hemlock, red alder and amabilis fir, while edges

[5] For Sources of data – see the data summaries at the end of this section.

[6] Excluding Haida Gwaii where this species is not found.

dominated by Douglas-fir, western redcedar, yellow-cedar and shore pine had lower levels of damage. Rollerson found highly variable, but generally higher levels of edge damage associated with Sitka spruce.

Influence of Stand Height and Site Productivity[7]

Across all areas the most vulnerable stands are relatively tall (i.e., about 35 m in height), with much less damage in shorter stands (i.e., closer to 15 m). However, the tallest stands in a given area typically had a little less damage than stands of average height, perhaps because they are older, less dense and slender, and may be in more sheltered geographic positions. The slenderness coefficient (height to diameter ratio) is strongly correlated with windthrow damage. A value of 60 appears to be a good threshold with much more damage for height:diameter ratios of greater than 60 and significantly less damage as values drop below 60.

More damage was found on richer sites (SI_{50}> 20) in Haida Gwaii, and on Vancouver Island. However, moderate site indices in Chilliwack had greater damage, while in Squamish site indices below 20 showed increased damage. In these locations, site index declines rapidly with elevation and the higher elevation stands are exposed to higher wind speeds.

Influence of Cutblock Boundary Locations[6]

Layout decisions have a clear influence on windthrow. In all areas (regardless of aspect) southern-exposed boundary orientations experience much more damage since they are the most exposed to that southerly winds (SE-SW) that accompany winter storms . Fetch is the term used to describe the width of the opening in the direction of wind. Openings with larger fetch have increased damage. Boundary projections that are exposed to several wind directions have greater damage. Narrower (<20 m) internal retention strips experience more damage, as do small retention patches and dispersed trees. Boundaries located on the slope break into gullies (compared to those set back in upland terrain).

[7] For Sources of data – see the data summaries at the end of this section.

Data Summaries from Modeling and Monitoring Across the Coast

Overall Damage

DATA - BASED ON # of SEGMENTS (25 m by 25 m) DAMAGED – with more than 20% of canopy loss over more than 30% of the area of the segment.	**SOURCE**
• AVERAGE - 27% damaged (over 5000 segments) • (5% damaged with 50% canopy loss over 90% of area in segment)	**BCTS Haida Gwaii** (Mitchell and Lanquaye-Opoku 2009)
• AVERAGE – 6.6 % damaged (over 6000 segments) • (0.3% damaged with 50% canopy loss over 90% of area in segment)	**BCTS Chilliwack** (Mitchell and Lanquaye-Opoku 2009)
• AVERAGE – 5.4 % damaged (over 6000 segments) • (1% damaged with 50% canopy loss over 90% of area in segment)	**BCTS Squamish** (Mitchell and Lanquaye-Opoku 2009)
• AVERAGE 19% damaged (over 22,000 segments) • A total of 20% of all boundary segments had levels of damage detectable from aerial photographs. However, only 4% of segments had more than 100% area loss and 50% of canopy loss.	**Weyerhaeuser, West Island** (Mitchell 2003)
• AVERAGE 12% damaged (over 6715 segments) • (7 % damaged with 50% canopy loss over 90% of area in segment,)	**Weyerhaeuser, North Island** (Lanquaye 2003)

Topographic Attributes

Slope Position and Features

(ROLLERSON ET AL. 2009) trends across all WFP tenures:

- Exposed positions such as ridge crests and upper slopes experience more damage – confirms somewhat Mitchell's elevational data.
- Mid slopes tend to have lower damage.
- Valley floor positions had moderate damage rates.

- Damage on internal groups and clusters, was found to be less in valley floor and lower slope locations and relatively high on upper slopes and ridges.

Topex Score at 1 km

- Higher numbers indicate less exposed and lower numbers are more exposed (can be significantly negative in value). Note: these Topex scores are regardless of the general exposure direction.

DATA - BASED ON # of SEGMENTS (25 m by 25 m) DAMAGED – with more than 20% of canopy loss over more than 30% of the area of the segment.	**SOURCE**
• < 100 = > 30% damaged	**BCTS Haida Gwaii** (Mitchell and Lanquaye-Opoku 2009)
• NO STRONG PATTERN • Reflects the complex pattern of extreme wind with geographic position and terrain.	**BCTS Chilliwack** (Mitchell and Lanquaye-Opoku 2009)
• NO STRONG PATTERN • Reflects the complex pattern of extreme wind with geographic position and terrain.	**BCTS Squamish** (Mitchell and Lanquaye-Opoku 2009)
• Did not report on Topex 1000, for Topex 3000 values less than 125 had approximately 20% damage.	**Weyerhaeuser West Island** (Mitchell 2003)
• Topex damage levels were not reported on, however Topex 1K was found to have a correlation coefficient of 0.7.	**Weyerhaeuser, North Island** (Lanquaye 2003)

Elevation

NOTE: Elevation strongly influences local relative windspeeds, but it becomes a much more variable predictor of damage in complex terrain.

DATA - BASED ON # of SEGMENTS (25 m by 25 m) DAMAGED – with more than 20% of canopy loss over more than 30% of the area of the segment.	**SOURCE**
• MORE DAMAGE higher up (300-500 m) – 35 to 50% damaged • LESS lower down at 100 m – less than 25% damaged • NOTE – Mitchell found NO STRONG CORRELATION – on Weyerhaeuser lands - Slightly more damage from 200-600 m. Likely because the area included more younger second growth stands and flat terrain on the Hecate lowlands (with little sheltering effect).	**BCTS Haida Gwaii** (Mitchell and Lanquaye-Opoku 2009)
• Less below 500 m - 4% • More above 500 m – but erratic (between 5% and 8.5% and it goes up and down several times as elevation increases)	**BCTS Chilliwack** (Mitchell and Lanquaye-Opoku 2009)
• LESS LOWER (below 1000m) - <5% • MORE HIGHER (above 1000m) – 8-23%	**BCTS Squamish** (Mitchell and Lanquaye-Opoku 2009)
• DAMAGE BY ELEVATION VARIED LITTLE – varying between 21 and 22% • Slightly higher at low and high elevations (200 and 1000m), • Intermediate at 600 m	**Weyerhaeuser West Island** (Mitchell 2003)
• No information for North Island	**Weyerhaeuser, North Island** (Lanquaye 2003)

% Slope

DATA - BASED ON # of SEGMENTS (25 m by 25 m) DAMAGED – with more than 20% of canopy loss over more than 30% of the area of the segment.	**SOURCE**
• < 20% = < 30% damaged • > 20% = > 30% damaged up to over 40%	**BCTS Haida Gwaii** (Mitchell and Lanquaye-Opoku 2009)
• NO PARTICULAR PATTERN FROM SLOPE • Presumably due to the complexity of the terrain	**BCTS Chilliwack** (Mitchell and Lanquaye-Opoku 2009)
• NO PARTICULAR PATTERN FROM SLOPE • Presumably due to the complexity of the terrain	**BCTS Squamish** (Mitchell and Lanquaye-Opoku 2009)
• No information on % slope for West Island	**Weyerhaeuser West Island** (Mitchell 2003)
• No information on % slope for North Island	**Weyerhaeuser, North Island** (Lanquaye 2003)

Aspect

- Generally less on South than North Aspects – across all three areas. Likely stands on south aspects are slightly more acclimatized to southerly winds.

Stand Characteristics

- Less important than topographic attributes and boundary orientation across all areas.
- Crown closure, stand heights and slenderness all have increased damage as they increase – up to a point then decline. This reflects increasing damage in dense, slender, tall stands. Vulnerability decreases where second growth becomes very dense and stems lean back into the stand and stabilize (rather than falling through). Older stands with tall emergent trees have less damage than stands with uniformly dense overstories.
- HAIDA GWAII – BCTS operations are dominated by mature and older stands, except for the Hecate Lowlands.
- CHILLIWACK – BCTS operations are dominated by stands less than 200 years old.
- SQUAMISH – BCTS operations are dominated by stands less than 200 years old, with similar but with slightly more old growth stands than in Chilliwack.

Species Composition

DATA - BASED ON # of SEGMENTS (25 m by 25 m) DAMAGED – with more than 20% of canopy loss over more than 30% of the area of the segment.	**SOURCE**
• **Hemlock stands – more frequent at 35% (key is hemlock up to 230 years for vulnerability, especially when > 30 m tall)** • Sitka spruce – 27% • Western redcedar – 23% (at 110 to 210 years – as much damage as older stands) • NOTE MITCHELL (2004) FOUND NO STRONG SPECIES CORRELATION ON WEYERHAESER LANDS - presumably due to the very strong influence of the dense even aged second growth stand structures where all species become vulnerable.	**BCTS Haida Gwaii** (Mitchell and Lanquaye-Opoku 2009)

• **DOUGLAS-FIR stands – more frequent – but still only 8%**
• Hemlock and amabalis fir – 6%
  • NOTE: Many second growth stands here are dominated by Douglas-fir. Stands can be dense, tall, slender and therefore potentially vulnerable.
  • Basically here Douglas-fir stands of 130-170 years are most frequently damaged while hemlock stands between 50 and 110 years are most frequently damaged. Both these stand types are more frequently damaged on sites with moderate fertility.
	BCTS Chilliwack (Mitchell and Lanquaye-Opoku 2009)

• **Amabalis fir, hemlock and Sitka spruce stands** – most frequently damaged (7-14% of segments) • Douglas-fir stands – least damaged (2% of segments)	**BCTS Squamish** (Mitchell and Lanquaye-Opoku 2009)
• Stands dominated by alder, Douglas-fir, Sitka spruce and yellow-cedar were less frequently damaged than those dominated by western redcedar, amabilis fir and hemlock. • Douglas-fir stands were damaged less than other stands, however these stands were typically located in inland areas with lower mean wind speeds and greater topographic shelter. Western redcedar stands were less damaged than hemlock stands. Amabilis fir stands have been found to be more vulnerable than hemlock and western redcedar in other coastal studies, but this was not found in WI.	**Weyerhaeuser West Island** (Mitchell 2003)

DATA - BASED ON # of SEGMENTS (25 m by 25 m) DAMAGED – with more than 20% of canopy loss over more than 30% of the area of the segment.	**SOURCE**
• Hemlock dominated stands were more frequently damaged than stands dominated by western redcedar in both the 25 and 50 m buffers. Western redcedar was the least frequently damaged among all species. • The differential between hemlock and western redcedar was even more pronounced in the 50 m buffer indicating that hemlock stands are more vulnerable to more deeply penetrating damage.	**Weyerhaeuser, North Island** (Lanquaye 2003)

Height

(ROLLERSON ET AL. 2009) trends across all WFP tenures:

- Confirmed the general increase in damage with height, as below.

DATA - BASED ON # of SEGMENTS (25 m by 25 m) DAMAGED – with more than 20% of canopy loss over more than 30% of the area of the segment.	**SOURCE**
• Above 30 m - 30% of segments show damage with less below that (15% at 15 m)	**BCTS Haida** Gwaii (Mitchell and Lanquaye-Opoku 2009)
• Above 30 m – damage up to 10% • Below 30 m – damage < 8% • Stands in the 35 m height class had the most damage for all species. This presumably may be where height and slenderness make the stands most vulnerable due to density and crown closure.	**BCTS Chilliwack** (Mitchell and Lanquaye-Opoku 2009)
• Most damage in 35 m ht class (6-7%) • Slightly less damage at 15-25 m (4-6%) • Less damage at 45 m (4-5%)	**BCTS Squamish** (Mitchell and Lanquaye-Opoku 2009)
• No information from West Island as age and height data were incomplete in the forest cover database	**Weyerhaeuser West Island** (Mitchell 2003)
• Not reported on for North Island	**Weyerhaeuser, North Island** (Lanquaye 2003)

Slenderness

DATA - BASED ON # of SEGMENTS (25 m by 25 m) DAMAGED– with more than 20% of canopy loss over more than 30% of the area of the segment.	**SOURCE**
• > 60 – up to 33% (may be less when > 70 with very dense stands) • < 60 –tends to be < 20%	**BCTS Haida Gwaii** (Mitchell and Lanquaye-Opoku 2009)
• > 60 – damage up to 10% • < 60 - < 6% damaged	**BCTS Chilliwack** (Mitchell and Lanquaye-Opoku 2009)
• More damage when > 60 – (5-10%) • Less damage when < 45 (0-4%)	**BCTS Squamish** (Mitchell and Lanquaye-Opoku 2009)
• No information from West Island	**Weyerhaeuser West Island** (Mitchell 2003)
• Not reported on for North Island	**Weyerhaeuser, North Island** (Lanquaye 2003)

Site Index

DATA - BASED ON # of SEGMENTS (25 m by 25 m) DAMAGED– with more than 20% of canopy loss over more than 30% of the area of the segment.	**SOURCE**
• Above SI 20 - >30% of segments show damage. • Below SI20 – can still have 20-30%	**BCTS Haida Gwaii** (Mitchell and Lanquaye-Opoku 2009)
• DOUG-FIR - Most damage at SI 17-25 – 8-10%. Above or below this there is less (6% or less). ◦ Topographic features – sheltering or speed-up of winds may be more important here for richer sites. • HEMLOCK – most damage at SI > 20 – up to 18%. Below this there is much less damage (4-6%)	**BCTS Chilliwack** (Mitchell and Lanquaye-Opoku 2009)

DATA - BASED ON # of SEGMENTS (25 m by 25 m) DAMAGED– with more than 20% of canopy loss over more than 30% of the area of the segment.	**SOURCE**
• Below SI 20 – MORE DAMAGE (6-10%) • Above 20 – 2-4% • This is likely because the low site index sites are at higher elevations and have greater wind exposure.	**BCTS Squamish** (Mitchell and Lanquaye-Opoku 2009)
• No clear trends from West Island	**Weyerhaeuser West Island** (Mitchell 2003)
• Not reported on for North Island	**Weyerhaeuser, North Island** (Lanquaye 12003)

Soils

Mitchell and Lanquaye-Opoku (2009) didn't look specifically at surficial material in the 2009 modelling.

Mitchell and Lanquaye (2004) on Haida Gwaii - looked at soils as an influence – found more windthrow on colluvial soils and organic soils and less on morainal, and especially fluvial soils.

- This factor had a lower influence on windthrow than stand factors, and a much less influence than topographic factors and boundary orientation.
- Drainage and fertility and their effects on stand height and stand density are probably more important that soil origin. Low fertility, poorly drained organic sites typically have lower damage than better drained higher fertility sites.

Rollerson et al. 2009 across WFP Coastal tenures:

- Found the highest wind damage on poor-imperfectly drained mineral soils (gleysols or gleyed podzols)
- Also found a general but not consistent trend of more damage on deeper soils – presumably this is likely due to the presence of the denser, taller, more slender second growth stands generally found on such sites.

Layout Design Attributes

Boundary orientation (along with topographic attributes) more strongly influences windthrow than stand and soil characteristics – in all coastal studies.

Exposed Boundary Orientation

- SOUTHERN FACING BOUNDARIES- Strong correlation to damage –are the worst in all Coastal studies.

- NORTHERN CUTBLOCK BOUNDARIES NEAR RIDGELINES – once the acclimated stand on the windward side of the ridge is removed, trees near the top on the lee side are exposed to large increases in wind loading and damage progresses down the lee slope, sometimes for considerable distances (Mitchell and Lanquaye 2004)
- Boundaries with multiple exposures to damaging winds typically have more damage, for example inward projections from boundaries, and boundaries on smaller reserve patches.

DATA - BASED ON # of SEGMENTS (25 m by 25 m) DAMAGED– with more than 20% of canopy loss over more than 30% of the area of the segment.	**SOURCE**
• SOUTH TO WEST – 30-40% • NORTH TO EAST – 15-22% • NOTE – Mitchell found similar trend on Weyco lands in 2004	**BCTS Haida Gwaii** (Mitchell and Lanquaye-Opoku 2009)
• SOUTH – 12-14% • NORTH – 2% • EAST & WEST – 4-6%	**BCTS Chilliwack** (Mitchell and Lanquaye-Opoku 2009)
• SOUTH – 9% • NORTH – 2-3% • EAST & WEST – 4-6%	**BCTS Squamish** (Mitchell and Lanquaye-Opoku 2009)

Influence on external edges of cumulative fetch distance across the block.

Rollerson et al. (2009) across WFP Coastal tenures:

- Found less than 10% windthrow with less than 100 m fetch.
- Damage rose to almost 20% at 200-300 m fetch
- No clear influence of internal retention patches, groups, and strips.

Influence of external edges located along edges of gullies and stream escarpments.

Rollerson et al. (2009) across WFP Coastal tenures:

- SUSTANTIALLY HIGHER damage found here.
- When boundaries are set back damage goes down significantly (by about 10%). Rollerson recommends setbacks of at least 10-15 m.
- Rollerson also cautions to increase setbacks and riparian reserve widths for steep gully headwalls at higher elevations where the potential for debris flow initiation and long landscape travel distances with significant downslope damage is high.

Damage in internal patches (groups and clusters).

Rollerson et al. (2009) across WFP Coastal tenures (averaged across the whole group or cluster):

- Ranged from 20% in Powell River up to 39% in QCI and mid-Vancouver Island.
- Slope position (see below) influenced damage rates
- Height influenced damage rates, as indicated below for Mitchell data.
- Species – generally least damage with yellow-cedar and Douglas-fir. Western redcedar had slightly higher levels of damage. Hemlock and amabalis fir showed the highest levels of damage.
- In Mitchell's West Island Timberlands study, they found that internal patches had about 10% greater damage than edge segments, all other factors being the same.
- Scott and Mitchell (2005) found that damage to retained tree and patches declined with increasing internal retention.

Damage in internal strips.

Rollerson et al. (2009) across WFP Coastal tenures (averaged in the edge of the strip):

- Substantially higher than in external edges (31% compared to 24%).
- Less damage as strip width increases from 10-20m (close to 30%) to 30-50+ m (10-15%).
- Strips experience more damage from factors like stand height, species (as in groups and clusters) and location along gullies and stream escarpments. Note that even moderate setbacks of strips from the edges of gullies may cut damage rates in half.
- Found more damage in multi-storied stands than in uniform even aged stands – this is curious and may be due to exposure of numerous slender understory trees (while overstory trees may stay intact – making up few stems but most of the volume). Note: Rollerson calculated percentages based on number of stems.

Time Since Logging

- Generally there was increasing damage with time since logging, but most activity occurs in the first 2 years.
- Beyond that:
    - HAIDA GWAII AND CHILLIWACK (Mitchell 2009) - No apparent pattern.
    - SQUAMISH – damage more frequent on blocks 3-7 years since logging – may just reflect changes in cutblock design or concentration of harvesting in more vulnerable locations.

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4. Windthrow Management Protocol

CONTENTS

Overview 3

Training 4

Identifying and Filling Strategic Gaps 4

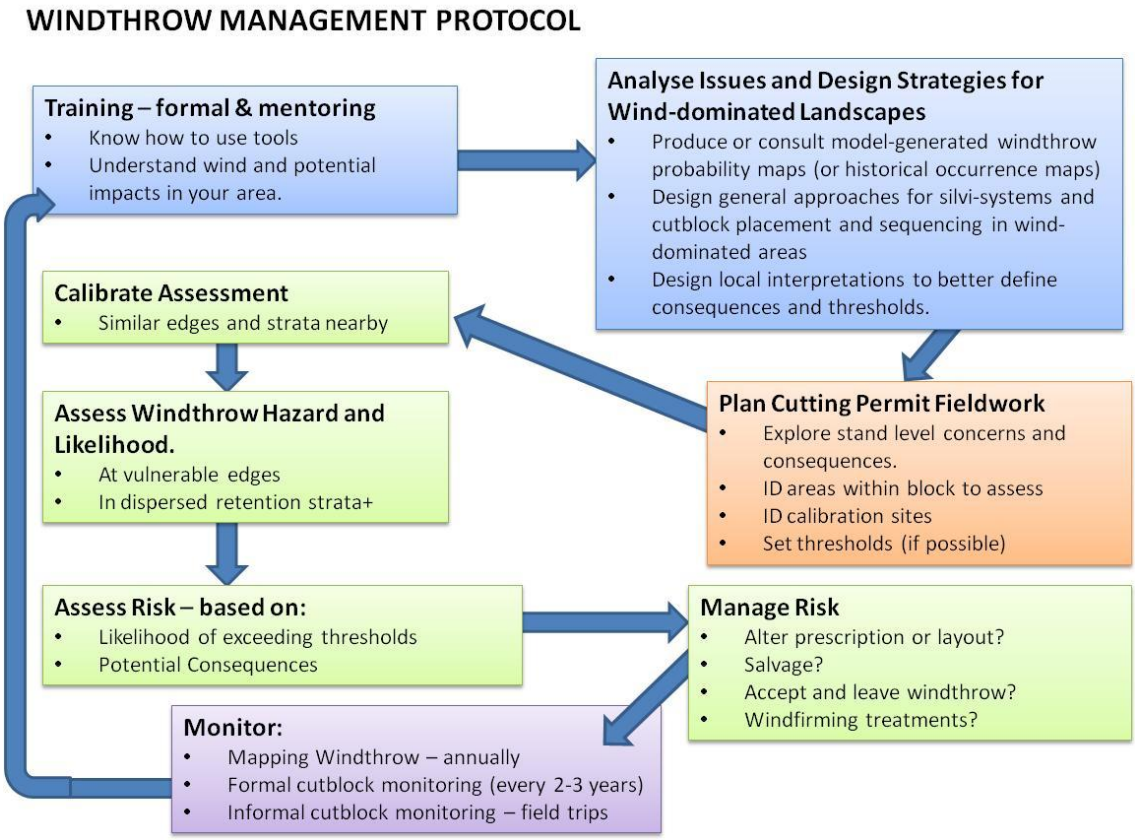
Planning fieldwork, conducting risk assessments, managing risk and monitoring 4

Overview

Windthrow management is a multi-scale challenge. Endemic windthrow is generally triggered by stand level harvesting activities. The risk to management (windthrow risk) is is connected to planning values and objectives at the management unit scale through consequences. Site-level biophysical hazard, windthrow likelihood, and windthrow risk all gain important context at the landscape scale. For example, in landscapes where windthrow is a significant recurring management challenge, it is important to build windthrow management into the sequence and location of harvesting rather than trying to solve all problems at the cutblock scale.

Effective windthrow management therefore requires a multi-scaled approach. Because it is highly technical, bringing together a wide range of knowledge and skills, training is essential. Because windthrow management is relatively young in its development in British Columbia, monitoring is important to provide feedback to those who are trying to predict and manage for windthrow so that assessment and management practices can be adjusted or refined.

The diagram below shows steps in the protocol. The blue boxes set the stage for assessment and management. Strategic gaps are filled at the management unit and landscape scales. The orange box is office-based prior to the field-based stand level work (green). Monitoring occurs both at the landscape and stand level and therefore is highlighted in purple.



Training

Many of the tools, guidelines and protocols listed in this document may be new to various staff. It is therefore important that all staff learn how to use the tools and understand the principles and knowledge they are built upon. The information in this manual provides a framework and starting point for greater awareness and expertise in windthrow management. When this knowledge is applied and augmented by field experience over time, a more complete understanding and developed skill set will be acquired.

Training, either formally using workshops, or informally using mentoring will greatly facilitate this process. Workshops can incorporate discussions and field exercises, conducted with peers and windthrow specialists over several days to promote a structured learning environment. For those who are somewhat familiar with windthrow, but not entirely comfortable with their prescriptive judgments or their ability to interpret some of the information in this manual, mentoring is a good approach.

Mentoring can be conducted as a one-on-one exercise or with a group. It is informal training whereby a specialist or highly skilled practitioner works for a number of days with field staff to hone their predictive and interpretive skills, and ensure analytical tools, guidelines and protocols are being used correctly. It has the advantage of being operational in that it can be done in the process of completing layout and prescriptions for current harvesting. Fieldwork may be slowed but not interrupted by training in this setting.

Identifying and Filling Strategic Gaps

Once staff have acquired a reasonable level of skill and knowledge with windthrow risk assessment and management, and they are familiar with general trends and concerns on the management unit, they are in a position to identify and fill strategic gaps for windthrow management. The Chinook Business Area has probability mapping created by computer simulation (Mitchell and Lanquaye-Ooku 2009) to characterize windthrow probability at a coarse scale across the management unit. To provide a similar level of direction, Georgia Strait and other Business Areas will need to either acquire this information through monitoring at the landscape level, by conducting a similar modeling exercise, or through other means.

In any case, it is useful to become aware of those portions of the management unit where harvesting and prescriptions are generally driven by wind, separate from those areas where wind is an occasional concern. In wind driven areas, management strategies may need to be specifically designed and tested over time to create a specific area-specific set of guidelines for harvesting approaches and prescription strategies.

While it may not be possible to set thresholds to be applied over large areas, as these generally must be very site and situation specific, guidance on approaches to thresholds will be useful. As new management objectives or targets for certain values emerge from planning, consideration of guidance for windthrow thresholds should be promoted.

Planning fieldwork, conducting risk assessments, managing risk and monitoring

SEE the appropriate sections that follow in this manual.

References

Mitchell, S., Lanquaye-Opoku, N. 2009. Windthrow Hazard Mapping using GIS, Chilliwack, Queen Charlotte Islands, and Squamish Operation. Final Reports for BCTS - March 2009.

5 Assessment of Windthrow Hazard and Likelihood

CONTENTS

Overview of Process _____ **3**

Step One – Understand General Wind and Windthrow Trends _____ **4**

Step Two – Explore Potential Windthrow Concerns Prior to Fieldwork. _____ **8**

Step Three – Choose Areas to Assess in the Proposed Cutblock _____ **11**

Step Four – Choose Calibration Site(s) near the Proposed Cutblock _____ **13**

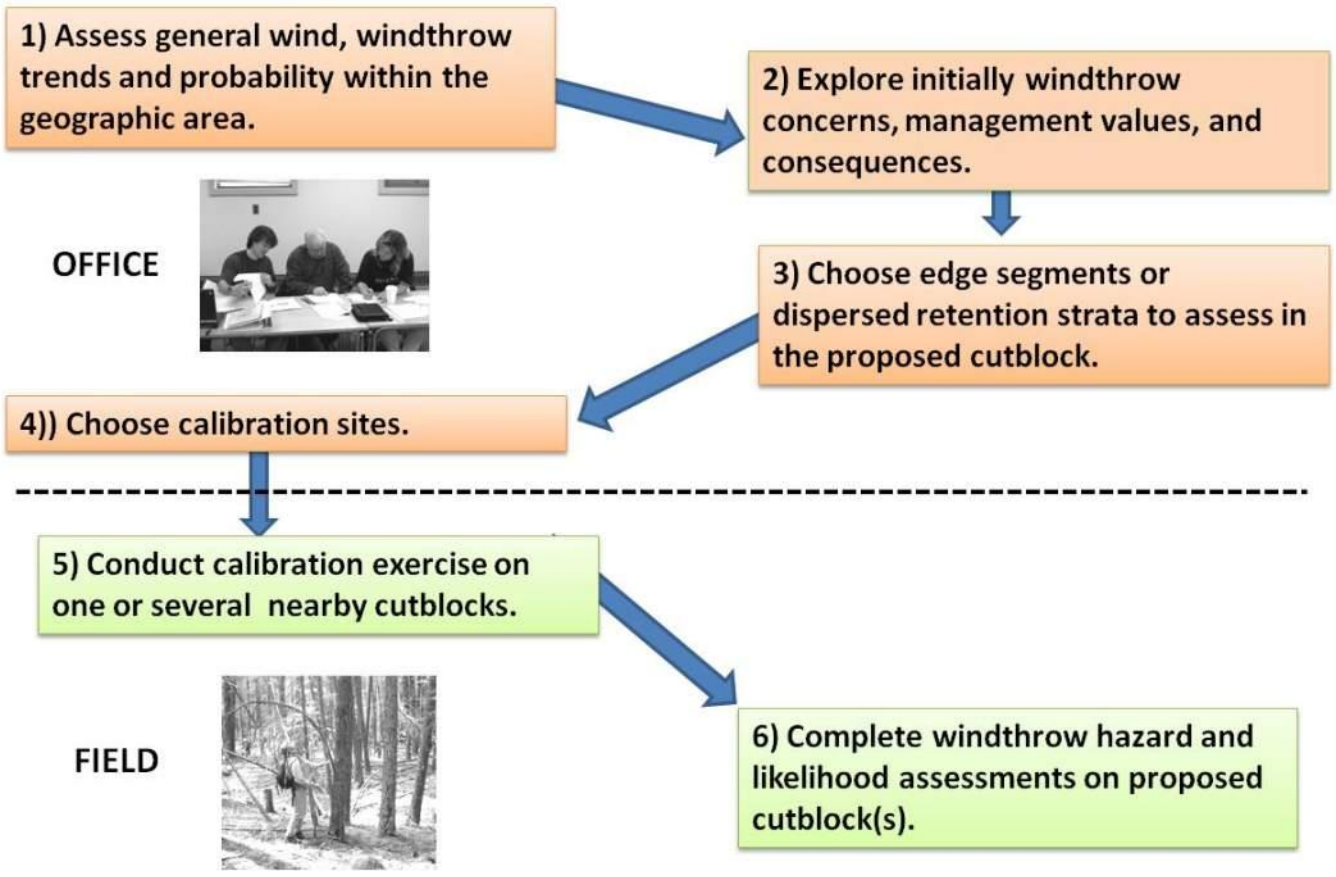
Step Five – Conduct Calibration in nearby cutblock(s) _____ **14**

Step Six –Complete Assessments on the Proposed Cutblock(s). _____ **17**

Overview of Process

The assessment of windthrow hazard and likelihood is a key process to help manage windthrow. It requires a solid understanding of: storm winds in the broad geographic area; local prevailing storm wind directions and the potential for subsequent damage in the local area. It also requires an understanding of windthrow mechanics and concepts; including the three main factors used to rank hazard and how they may interact so that windthrow is more or less likely.

The determination of windthrow likelihood sets the stage to assess windthrow risk based on consequences (Section 6).



Step One – Understand General Wind and Windthrow Trends

DIAGNOSTIC QUESTION1: Are you in a windy area?

DIAGNOSTIC QUESTION 2: Where, how often and how severe is windthrow damage within operating area?

DIAGNOSTIC QUESTION 3: From the pattern of damage and salvage, can you identify a dominant damaging wind direction and an association with particular stand or topographic conditions?

RATIONALE

Answering these diagnostic questions together will help you become aware of windthrow as a challenge (or not) for layout and forest management in the area. More importantly, if photo images are available, you will have an initial impression of the general likelihood for windthrow by reading clues across the landscape to understand windthrow history on similar cutblocks logged in the past. You may also be able to identify dominant damaging wind direction, stand and topographic hazards.

PROCEDURE

Obtain key materials:

- Wind data from various sources.
- Overview maps.
- Higher Level Plans and other plans that help determine key management values, objectives and priorities.
- Satellite imagery, e.g., GoogleEarth™ if local resolution is high.
- Recent aerial photographs.
- Landscape-level windthrow prediction map – produced for BCTS Chinook Business Area (by Dr. Mitchell of UBC - 2009).
- Geotechnical reports and other relevant site-level assessments (if available).
- Trends from monitoring – Start with the Trends Section in this Manual and consult reports from recent monitoring.

Explore prevailing storm characteristics.

Weather station data

Application: To determine peak winds which newly exposed edges must withstand, and to help plan cutblock layout, edge exposures and fetch distances.

Methods:

- Consult the National Climate Data and Information Archive - www.climate.weatheroffice.ca/Welcom_e.html
  - Download daily, monthly or annual peak wind data and then graph results over time to pick up trends (e.g., Figure 5-A)

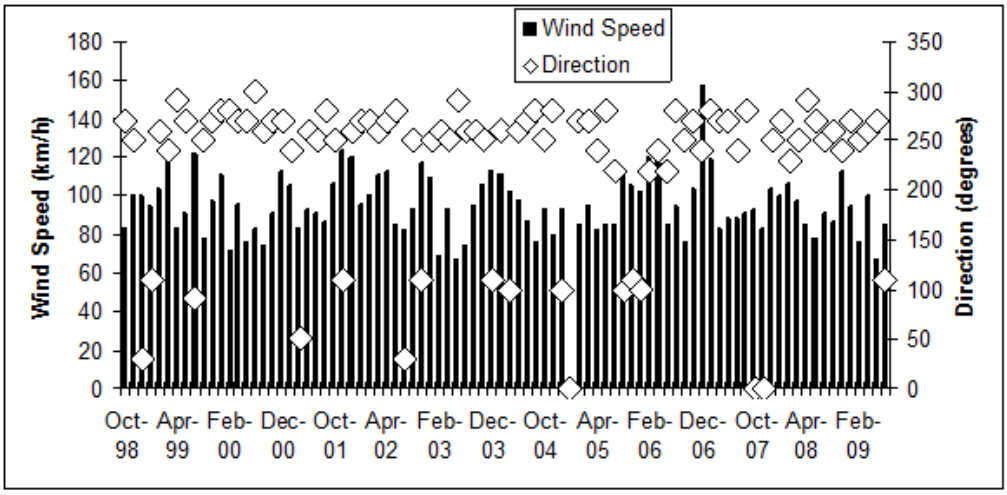


Figure 5-A Wind data for Race Rocks light station near Victoria, BC (peak monthly velocities/directions Oct. – May)

Key points in this example (Figure 5-A):

- Most of the peak monthly wind speeds are from the west.
- Less frequent peak winds are from the east or southeast.
  - As weather stations can be widely separated geographically, and on the coast are often near the ocean, they provide pretty coarse data – helpful to gain a general idea of storm flows across the coast, and general wind speeds but not to understand wind on a specific stand or cutblock. Note that not all weather stations record wind speed, wind speed not recorded for all time intervals.
  - Highest wind speed (158 km/h) on this graph is from the December 2006 hurricane.

Other Web-based Wind Data Sources

Applications

- To obtain Short term 3-day hourly wind speed and direction forecasts at a 1.3 km grid scale level. UBC Earth and Ocean Sciences – Weather Forecast Research Team - http://weather.eos.ubc.ca/wxfcst/.
- To obtain insight into the seasonal windiness of locations throughout Canada and corresponding geophysical factors. Environment Canada: Canadian Wind Energy Atlas - http://www.atlaseolien.ca/en/maps.php.

Key points from these data:

- The Environment Canada Data are good for seasonal averages - a limitation is the information is non-directional.
- The UBC data provides directional flow information and rough speed variations geographically, but is at a coarse scale and is limited to a forecast for a very short time frame. It is useful though to check during a typical winter storm.

Review the landscape-level windthrow prediction map for the general probability of windthrow.

- Locate your proposed cutblock.
- Note windthrow probabilities within vicinity of proposed block. Ensure you understand what these mean (Figure 5-B).
    - Consider the probability for wtt2030 on a typical BCTS Chinook Business Area prediction map – it is the windthrow probability over a 10 year period on a highly exposed windward edge for <u>at least</u> 30% of the area to be damaged in a 25m x 25 m segment, with at least 20% associated canopy loss.
        - Note that high probabilities for wtt2030 are not common, generally confined to specific topographic and stand conditions.

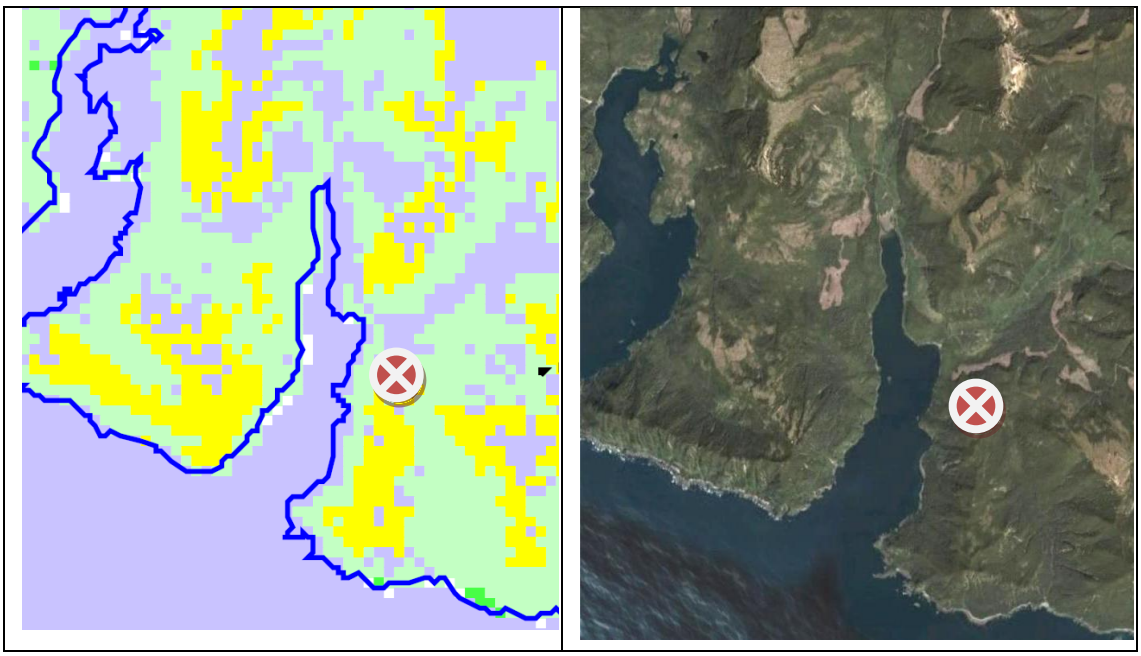


Figure 5-B A small portion of the probability map (left) for Haida Gwaii (West Coast of Graham Island), showing a hypothetical proposed block location (X). The corresponding location is also shown on a GoogleEarth™ image (right). The light green in the probability map indicates a probability of 0.30 – 0.45 (wtt3020) – meaning that over a 10 year period it is predicted that a highly exposed windward edge would experience at least 20% canopy loss over 30% of the area on 25m by 25m edge segments, 30 to 45 times out of 100. Actual windthrow may be considerably more (occasionally), and 55% of the time - less. Note the blue on the map indicates area other than mature forest - marsh, bog, open water, young or stunted stands. Note: the yellow areas indicate a wtt3020 of 0.45 to 0.60. This is a landscape of concern for windthrow.

NOTE:

- Windthrow prediction maps identify those locations in the landscape where windthrow is more or less likely, based on past outcomes.
- For boundaries with similar topographic, soil, stand and treatment conditions, and hazards, the incidence of windthrow can be predicted using "probabilities". Yet, it will vary from boundary segment to boundary segment. This is in part due to small differences in susceptibility from segment to segment, but also due to spatial variability in wind speeds during storm events. For this reason, consulting the probability maps is just the first step – assessments on the ground are also necessary.

Look for evidence of past windthrow, and windthrow salvage.

- Review airphotos, satellite images, and maps for evidence of past windthrow and associated salvage in the landscape around your prospective cutblock.
- Use GoogleEarth™ images – if at a high resolution, these can be extremely helpful (e.g., Figure 5-C). Not only are these useful to identify windthrow and general forest types, but also the effect of topographic position and exposure to endemic winds, and dominant direction of damaging winds.

Figure 5-C Examples of past windthrow on 10 year old edges near Port Clements, Haida Gwaii (from GoogleEarthTM). If the general trend is for damage on these northwest edges, then it can be assumed that the endemic storm winds are coming out of the southeast. Note the variation in windthrow penetration depth on the right. The bulge of windthrow is in a poorly drained area with restricted rooting.

- NOTE windthrow damage patterns:
    - Ragged edges or larger plumes of windthrow along boundaries of older clearcuts close to your prospective block.
    - The sides of blocks that are consistently damaged.
    - Severity of damage.
    - Association of damage with forest cover, topographic position, and geographic position.
    - Be cautious – windthrow observed on aerial/satellite images should be checked for a salvage history. Partial salvage along such edges may exacerbate windthrow penetration and degree of damage apparent.
- Also, look for patterns of recurrent strips of salvage, generally on similar edge orientations – this will indicate a chronic pattern of wind from one prevailing storm direction.
- Identify locations in landscape that are relatively windfirm. These will be useful as you plan future boundary locations and harvesting sequence.

Interview people experienced with past logging and management in the area.

- Sailors and pilots often have a good knowledge of local weather patterns. Ask locally experienced people about the direction of endemic winds, the frequency of peak winds and past blowdown events.
- Consider, but be wary of anecdotal information (a classic example is when old timers suggest that " it all blew down" – which is rarely true), look for confirmation on images or maps.

Step Two – Explore Potential Windthrow Concerns Prior to Fieldwork.

DIAGNOSTIC QUESTION 1: Which portions of the proposed cutblock will be most exposed to prevailing storm winds?

DIAGNOSTIC QUESTION 2: Where in the proposed layout could windthrow result in significant consequences?

DIAGNOSTIC QUESTION 3: Where potential consequences are identified, how much windthrow can be tolerated?

RATIONALE

Answering these diagnostic questions together will help provide a sound understanding of management values and associated consequences that windthrow could influence. It will help highlight potential problem areas on the proposed cutblock where consequences are possible, helping to plan an efficient approach to windthrow hazard and likelihood assessment on the ground. Lastly, if sufficient information has already been gathered through previous

reconnaissance field visits, it is useful to determine thresholds of acceptable windthrow for edges and portions of the proposed block where concerns are present.

PROCEDURE

Consider treatment hazards

- Using the general knowledge you gained of local wind patterns, identify areas with a moderate to high treatment hazard.
- In the proposed cutblock note:
    - Meso-topographic location and exposure to the prevailing storm flows (Figure 5-D).
    - Proposed paper-plan boundary orientations (Figure 5-E).
    - Fetch.
    - Location of road right-of-ways
- Also take note of other treatments or modifications:
    - Opening size, shape and removal sequence.
    - Intentions for leave tree percentage, species and crown class (if known yet).

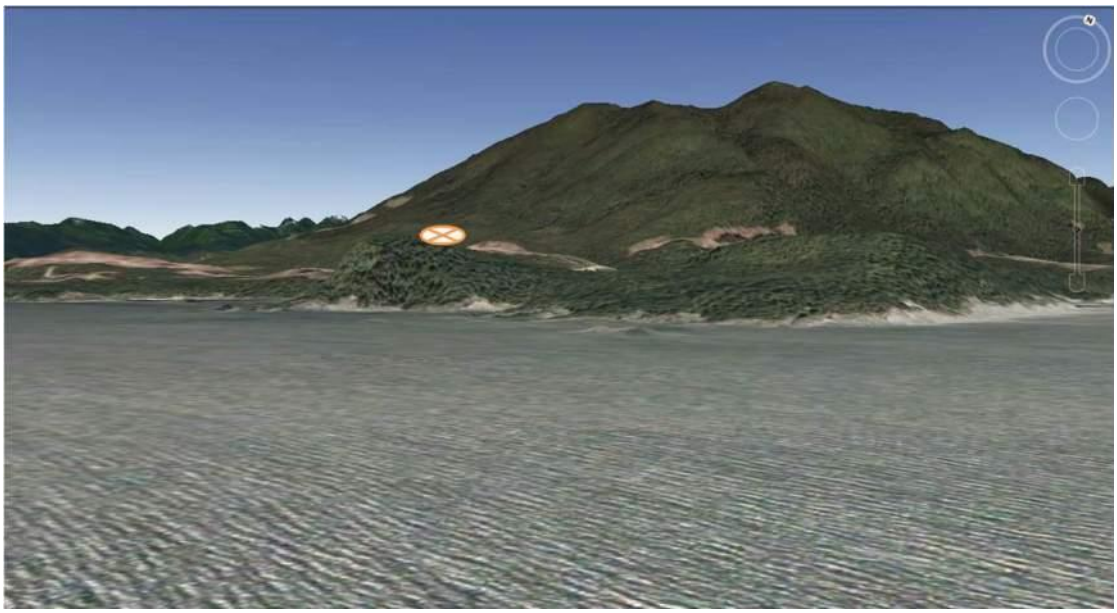


Figure 5-D Use of GoogleEarth™ to explore potential exposure of a prospective block location (X) to prevailing storm winds, the example provided above is on the West Coast of Vancouver Island. The view is from the sound toward the cutblock from the southeast (the direction of the prevailing storms).

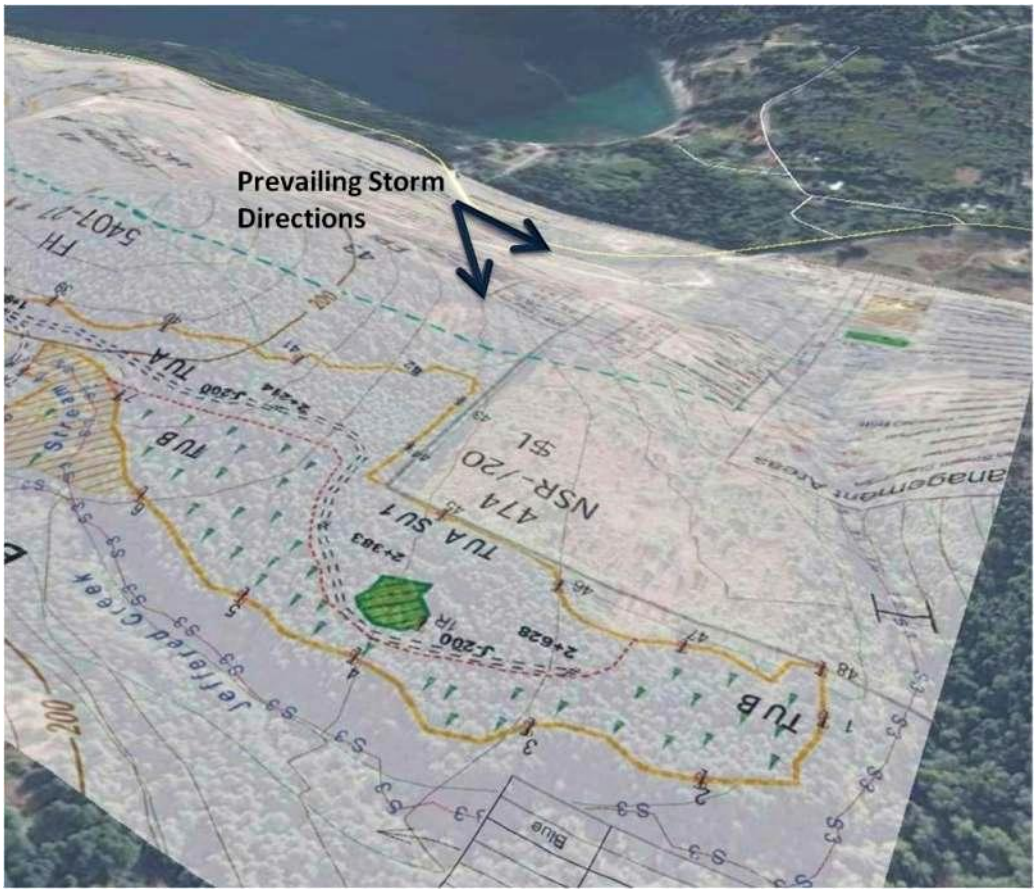


Figure 5-E Use of the overlay feature in GoogleEarth™ to explore exposure of planned boundaries to prevailing storm winds, by overlaying the block map as an image.

Determine Initial Consequences (SEE: Determining Windthrow Risk - Section 6)

- Review all relevant plans to identify and understand the key strategic and tactical objectives for management in the block and the general area. Look specifically for strategic objectives for which windthrow is relevant – salvage strategies for timber, retention strategies or targets for biodiversity. Ensure you understand the strategic planning context for the layout.
- If possible, based on planning documents, or reconnaissance information, identify areas within the vicinity of the prospective block that may have specific non timber objectives, e.g., CMTs, fish bearing streams, etc. .
- On the cutblock paper-plan, identify where the key internal reserve patches or strips are to be left to satisfy a specific objective for a key management value (e.g., bear den, CMT, active fluvial unit, fish-bearing stream, etc.). Also, identify external boundary edge segments that are adjacent to key management features or area of management concern.
- Assess the potential for negative consequences (SEE: Section 6 for Details).

- Note there may be sufficient information from the reconnaissance and existing plans and assessments to assess potential consequences for non-timber values at the paper planning stage.
- You may wish to assess consequences of windthrow for timber values in the field (rather than the office), since the values and harvesting logistics will be clearer.

- If necessary - make recommendations for further data collection, or field examination by specialists to confirm the potential for negative consequences, and help to set thresholds.

Step Three – Choose Areas to Assess in the Proposed Cutblock

DIAGNOSTIC QUESTION 1: Which edge segments or dispersed retention strata <u>may</u> have some windthrow risk[1]?

RATIONALE

This diagnostic question goes to the heart of what is of most interest. It is not the same as asking which segments may have a likelihood of windthrow. Risk is about consequences for either timber or non-timber values. Efforts to carefully assess windthrow likelihood and subsequent risk should therefore be focused on the edges that <u>may</u> harbour a concern or a consequence. If layout and prescription crews have considerable local experience and they have done sufficient pre-layout preparatory work, this should be possible.

By focusing on those edges with possible risk (based on likelihood and consequences) fieldwork will be more efficient; more time will be spent collecting data on those edges with a possible moderate or higher risk, and less time on those with little or no risk, resulting in less paperwork and a more focused assessment. In any case, it is still important that layout and prescription crews think about windthrow as they move through the area. They should be making observations and notes on all portions of the cutblock and boundaries to confirm their initial determination of where risk is most likely.

PROCEDURE

Plan assessments and inspections of edge segments or dispersed retention strata that <u>may have</u> a windthrow risk based on the office review process.

- NOTE: At this point windthrow risk (based on likelihood of windthrow and consequences) has not been assessed. However, based on knowledge of local winds, and an exploration of potential windthrow concerns (previous steps) segments that MAY have some significant risk will be apparent.
- Use whatever you have as a paper plan to identify these areas.
- Bring together those areas or edges that show a high exposure to prevailing storm winds and a potential for negative consequences from windthrow.

[1] Remember windthrow risk is the combination of how likely windthrow will be and whether it will have a negative consequence.

- The image overlay of a block map on GoogleEarth™ can be quite effective for this (e.g., Figure 5F). In this example layout has obviously been completed with falling corners established. Alternatively one could start the process using a rough block sketch at the pre-layout stage. Key points for assessments can still be determined and entered into a GPS unit for location on the ground. Also note that there is less interest in leeward boundaries and those sheltered by the knoll in the top left.

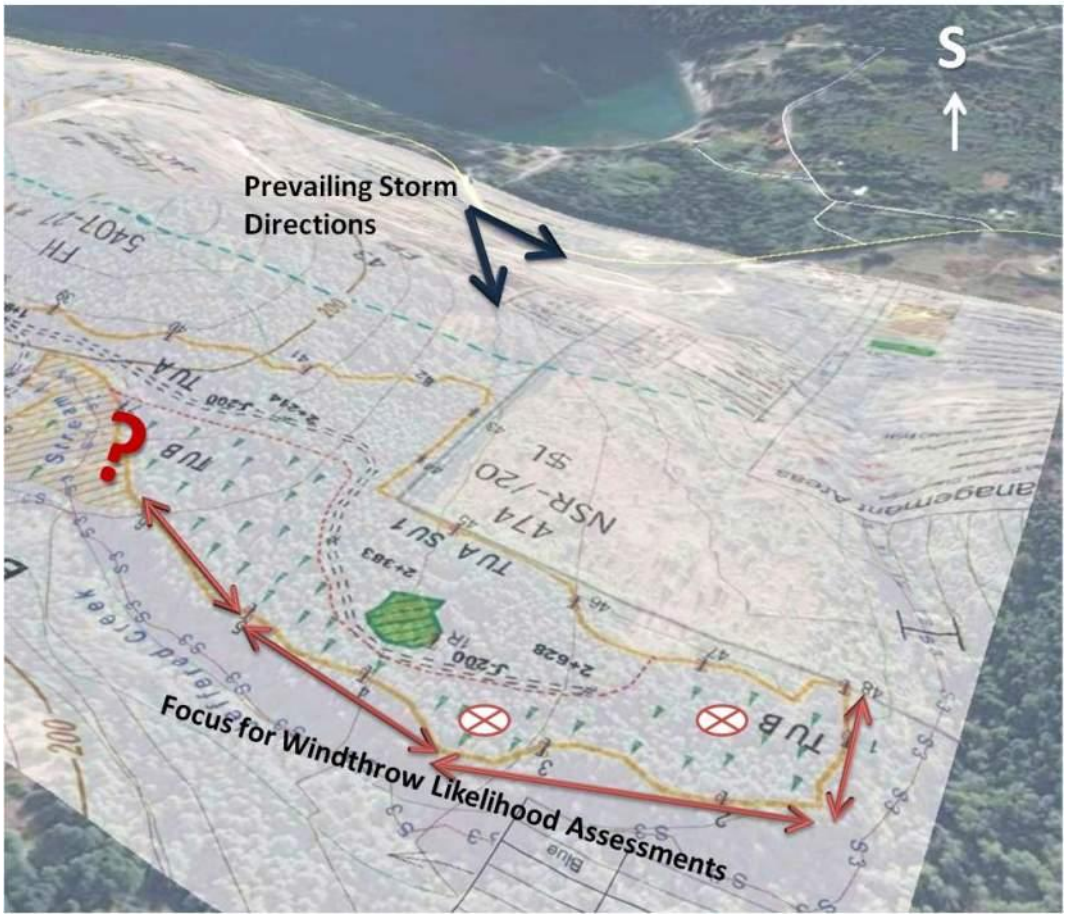


Figure 5-F. Choosing key edge segments for windthrow hazard and likelihood assessments on the proposed cutblock. Edge segments are indicated with the double-headed red arrows, while dispersed retention assessment points are indicated with the circled X's. The "?"indicates a possible assessment that should be decided by a field check. What is at question here is the placement of the boundary in the proximity of the break into the stream (however, the edge is significantly sheltered by the knoll to the south).

- Points on boundary segments with less concern should be identified for a visual check (after the key assessments are made) to ensure no unexpected factors are missed. Check any assumptions as much as possible on the ground.
- Plan an efficient route through proposed block and key edges and strata of interest.

- Consider a full field day just for windthrow assessments in blocks that have a complexity of concerns and features. This will help ensure that you maintain focus and don't miss anything.

Step Four – Choose Calibration Site(s) near the Proposed Cutblock

DIAGNOSITIC QUESTION1: Which portions of older cutblocks nearby may be useful to visit due to similarities with the proposed cutblock?

RATIONALE

This question builds on the general learning from predictive mapping, airphotos, plans, and other sources (steps 1 and 2), to examine closely similar older cutblocks that may tell the story of how windthrow could develop on the proposed cutblock.

PROCEDURE

Identify candidate edges for field calibration.

- From nearby cutblocks in the vicinity of the proposed cutblock.
- With a history of at 2-5 winters of storms.
- Focusing on boundaries that are:
    - fully exposed to endemic winds (high treatment hazard).
- Focusing on edges that have similar topographic, stand and soil characteristics as potential high risk edges for the proposed cutblock and that have similar orientation and boundary exposure to wind.
- Choose a range of edges to investigate, including those showing the most windthrow (paying close attention as to how they differ from other edges with little windthrow).

Plan field inspection:

- Plan time for assessment of older blocks for calibration - 3 or 4 cutblocks may require a whole day. This may be worthwhile depending on your past experience in the area, or the potential risks (based on likelihood and consequences) associated with the proposed cutblock.

Step Five – Conduct Calibration in nearby cutblock(s)

DIAGNOSITIC QUESTION1: How close are your predictions of windthrow to actual windthrow?

RATIONALE

The calibration exercise is a chance to explore vulnerable edges in older cutblocks that are similar in their exposure, orientation and treatment hazard. Completing a windthrow hazard and likelihood assessment on the edge and comparing the results with the windthrow that is present performs several useful functions:

- First, it allows the assessor to determine if something is being "missed" for example the way biophysical features are being interpreted and windthrow hazards are being assessed. Often one or several features overwhelm or compensate for others in a more significant manner than might be found on many other sites. By observing these differences, the assessor can "calibrate" their approach – incorporating these compensating factors into their decision process.
- Second, assessors measure and describe actual windthrow on edges that are similar to those expected to be created in the proposed cutblock. This will allow them to fine tune their predictions for amount of windthrow, penetration, and the types of trees expected to blow down.

PROCEDURE – On each calibration edge candidate:

a. Conduct a Windthrow Hazard and Likelihood Assessment:

- Using a BCTS Form 2 as in Step 6.
- That information is then transferred onto the BCTS Calibration Form 1 (in the "initial evaluation" section (Figure 5G).

BCTS Coastal Windthrow Assessment Calibration FORM 1 – Side A

ADMINISTRATIVE				
Location	Opening ID	Block #	Examiner/Date	Segment/Portion

COMPARISON OF PREDICTED WINDTHROW TO THRESHOLDS:

1 Complete the BCTS Coastal Windthrow Hazard & Likelihood Assessment (FORM 2) in a nearby 2-5 year old cutblock on a high treatment hazard boundary that has damage levels typical of what you have observed in your review of aerial photographs from the area, and similar to high treatment hazard boundaries in your proposed cutblock(s).

2 Record the initial evaluation of windthrow likelihood and hazard components from the Assessment Card.

Initial Evaluation (transfer from a Assessment Card – Form 2)

	Very High	High	Moderate	Low	Very Low	None
Topographic Hazard	☐	☐	☐	☐	☐	☐
Soil Hazard	☐	☐	☐	☐	☐	☐
Stand Hazard	☐	☐	☐	☐	☐	☐
Overall Biophysical Hazard	☐	☐	☐	☐	☐	☐
Treatment Hazard	☐	☐	☐	☐	☐	☐
Windthrow Likelihood	☐	☐	☐	☐	☐	☐

CALIBRATION – of windthrow likelihood classification

5 *R*ecord observed damage on calibration boundary.

Estimates of Actual Windthrow Damage – to help refine predictions

Measured windthrow penetration into edge	Average (m)		Range (min to max)	
Estimated amount of windthrow throughout the penetration zone	Average % of total m2		10% Range (e.g. 30-40)	

Actual Damage Calibration Categories - to calibrate windthrow likelihood class

Basal Area (m2/ha) Damaged	High	Mod	Low	Estimate
In the First Tree Length from the edge	☐>70%	☐10-70%	☐<10%	_____%
In the Second Tree Length	☐>70%	☐10-70%	☐<10%	
In the Third Tree Length	☐>70%	☐10-70%	☐<10%	
	☐Extensive	☐Extensive	☐Extensive	

6 Look up the expected level of damage for your initial Windthrow Likelihood Class on SIDE B of this Form, and compare with actual damage calibration categories.

Figure 5-G BCTS Windthrow Calibration Field Card.

b. Record the observed damage on the calibration boundary:

- Penetration – average and range.
- Amount of windthrow throughout the windthrow zone – estimated % and 10% range (i.e. 20-30%, 40-50% etc.).
- Estimated windthrow in tree-length categories to help calibrate assessment.

c. Compare the actual windthrow to expected windthrow.

- Using the descriptions of windthrow likelihood classes from Form 1- Side B card – below.

EXPECTED DAMAGE – for the estimated class of windthrow likelihood	
Windthrow likelihood Class	**Expected Damage**
Very Low	Little or no damage along recent cutblock edges or in recent partial cut strata.
Low	Less than 10% of the basal area is uprooted or snapped along recent cutblock edges. Less than 5% in recent partial cut strata.
Moderate	Partial damage along recent cutblock edges. Between 10 and 70 percent of the basal area is in uprooted or snapped trees within the first tree length in from the edge. Between 5 and 30 percent of the basal area damaged within recent partial cut strata.
High	Heavy damage along recent cutblock edges. More than 70% of the basal area within the first tree length damaged (less than 30% remains standing). Between 30 and 70% of the basal area is damaged within recent partial cut strata.
Very High	Very severe damage along recent cutblock edges. More than 70% of the basal area damaged in both the first and second tree lengths into the edge (and damage may extend beyond the second tree length). More than 70% of basal area damaged in recent partial cut strata.

d. Use the feedback from this comparison to adjust or validate assessments on the proposed cutblock.

- Using the guidance from Form 1- Side B card – below.

BCTS Coastal Windthrow Assessment Calibration FORM 1 – Side B

DIAGNOSTIC QUESTION FOR CALIBRATION: Is the level of damage observed along the calibration boundary consistent with that expected for the estimated class of Windthrow Likelihood?(See table below)	
IF	**Action**
☐ Yes, damage is consistent with expected level	Use the topographic, soils and stand indicators as done here to indentify hazard classes for each of the Exposure, Soil, and Stand Hazard components - on similar edges in proposed cutblocks
☐ No, there is LESS damage	Consider which of the component hazards (Exposure, Soils, or Stand) might have been rated too highly in the initial evaluation. Adjust ratings accordingly for similar edges in proposed cutblocks.
☐ No, there is MORE damage	Consider which of the component hazards (Exposure, Soils, or Stand) might have been rated too low in the initial evaluation. Adjust ratings accordingly for similar edges in proposed cutblocks.
1 Use the adjusted interpretations and ratings for classifying Soils, Topography and Stand Hazards for proposed cutblocks.	
2 Alternatively, if you think one of the three component hazards should be weighted more heavily then adjust the weighting factors (for this area) – see the numerical factors at the bottom of the Assessment Form 2.	

Step Six –Complete Assessments on the Proposed Cutblock(s).

OVERVIEW

The hazard and likelihood assessment is conducted on those areas in the stand that may have a risk to values or objectives as a result of windthrow.

1. The general focus for the assessment is to use a set of diagnostic questions to assess various hazards for windthrow.
2. Three hazard components (topographic, stand and soil) are assessed and then brought together in a ranking table to provide an overall biophysical hazard for windthrow. The three components take into account where the block is, what the stand is like and what it is growing on - all factors that are critical to assess the inherent hazard of the area for windthrow – i.e., the biophysical hazard. For more information on the characteristics of each component hazard, see Section 2 (Windthrow Concepts).
3. The biophysical hazard is then used along with an estimate of treatment hazard (based on the proposed layout) to rank the likelihood of windthrow occurring on the edge segment or for internal dispersed retention. Treatment hazard ranges from low to high depending on how or where harvesting will be applied (e.g., from a single tree removed to a large opening with a large fetch created). The two working together give an indication of how likely windthrow will be on the edge or within a dispersed retention stratum, (i.e., the likelihood of windthrow).
4. Once we know the likelihood of windthrow, consequences are considered to provide an assessment of **windthrow risk**. Windthrow risk is the combination of the likelihood of windthrow and the potential consequences of that windthrow. (For the Determination of Windthrow Risk – see Section 6).

PROCEDURE – On each calibration edge candidate:

a. Assess Topographic Exposure Hazard to Wind:

- Using a BCTS Form 2 – Side A (as below)

TOPOGRAPHIC EXPOSURE TO WIND:			
***DIAGNOSTIC QUESTION 1:* Is this a windy area?**			
CONSIDERATIONS - Regional Windiness increases with: • Proximity to the Open Ocean, large inlet or lake. Consider general wind direction and sheltering features (question 2) • Plateaus, rolling plateaus, or Coastal Plain (lowlands near ocean). • Increasing elevation.			
DIAGNOSTIC QUESTION 2: Are local wind speeds accelerated by terrain constrictions, OR is wind reduced by sheltering influences?			
CONSIDERATIONS – Windiness increases with: • Proximity to ridge crest for winds perpendicular to valleys. • Valley floor and lower side walls for winds parallel to valleys. • Mid or upper slope shoulders. • Valley gaps, constrictions or ridge saddles where winds are funnelled. • Tree-level indicators – flagging (asymmetry) of tree crowns.		CONSIDERATIONS – Windiness decreases with: • Proximity to lower slopes for winds perpendicular to valleys. • Ridges, hills, knobs and other topographic features that can deflect winds. • Sheltering features must be high enough to deflect the general wind profile up and over the stand. • If the backside slope of a sheltering feature is steep – turbulent winds may carry a considerable distance down the leeward side.	
Topographic Hazard Class:	☐ High (very wind exposed)	☐ Moderate (intermediate)	☐ Low (very wind sheltered)

Considerations

- Note that the form is not structured as a key or "if-this-then-that" approach. This is because various factors compensate for others in different ways on different sites. How this occurs cannot be summarized or written into a process, without getting overly complex. Therefore the approach taken is to list factors to consider while pondering the diagnostic question. The key is to draw on what you have learned from your calibration edges and other windthrow experience in similar stands and situations.
- Note the questions for topographic hazard - these may be answered in the office with your preparatory work. Especially helpful, as already noted, are good air photos or high resolution GoogleEarth™ imagery. It will be difficult to make observations regarding topographic exposure inside the stand at the preharvest stage.
- For more information on the significance of these factors – see Section 2 (Windthrow Concepts).

b. Assess Stand Stability Hazard to Wind:

- Using a BCTS Form 2 – Side A (as below)

STAND STABILITY			
DIAGNOSTIC QUESTION 1. Are trees poorly acclimated to wind loading?			
CONSIDERATIONS - Acclimation decreases with: • Long term shelter of individual trees from wind. • Closed canopied stands • Away from natural stand edges (margins of wetlands, lakeshores, rivers, rock-bluffs, meadows etc) • Tall stands on high quality sites. • Tree level indicators: Small live crowns and high degree of slenderness - ht to diameter ratio closer to 100 than 50 - with 100 being very slender			A TREE-LEVEL INDICATOR OF ACCLIMATION: • Relatively thick stems with long live crowns. • High degree of taper – ht to diameter ratio close to or less than 60.
DIAGNOSTIC QUESTION 2. If uprooted, would trees fall through the canopy to the ground?			
CONSIDERATIONS - Potential for damage progression increases: • With increasing stand maturity, height, and a reduction in stem numbers (below high densities). • Where similar clearcut edges indicate –few trees leaning or supported by their neighbours following a windthrow event.			
Stand Hazard Class:	☐ High (very unstable)	☐ Moderate (neutral)	Low (very stable)

Considerations

- You need to be able to critically evaluate your stand. Stand features can make a significant difference, but may be challenging to discern. It is important that you understand the influence of stand features based on observation from your calibration edges.
- Pay close attention to details. Small factors like root disease, or dwarf mistletoe (if it affects the main stem) can increase vulnerability considerably. Not all these considerations will be found on your card. A good understanding of tree physiology, silvics, stand dynamics and forest health, together with local experience is important. See Section 2 (Windthrow Management Concepts).
- Species susceptibility is important, but is only one factor to consider. Refer to Section 2 (Windthrow Management Concepts) regarding general considerations, and Section 3 (Windthrow Trends) regarding trends in your general area.
- Be prepared to make some measurements to verify the considerations for the diagnostic question.
- Note the second diagnostic question. If your stand is relatively short and dense, windthrown trees will often have difficulty falling through the stand. The edge will have many leaning stems. While this may be unsightly, it is a positive feature for edge stability. Many leaning stems on an edge allows them to stabilize, with minimal windthrow penetration. The leaning stems together with the dense standing stems behind, will deflect the wind profile up and over the stand.
- See Section 2 (Windthrow Concepts) for more information.

c. *Assess Soil Anchorage Hazard to Wind:*

- Using a BCTS Form 2 – Side B (as below)

BCTS Coastal Windthrow Likelihood Assessment FORM 2 – Side B

SOIL ANCHORAGE			
DIAGNOSTIC QUESTION 1. Is root anchorage restricted by an impeding layer, low strength soil, or poor drainage?			
CONSIDERATIONS - Restricted anchorage contributes to instability: • Where local variations in drainage and soil depth restrict rooting in otherwise closed canopied stands (e.g. in draws and gullies) • In conspicuous pockets of higher productivity - seepage over basal till or bedrock, saturated or seasonally saturated riparian soils. • On smooth rock outcrops or bedrock where roots cannot penetrate cracks and fissures. • Where root balls are shallow, flat and plate-like, rather than deep and bowl-shaped (Look at windthrown trees on similar edges or at root systems in road cuts) • Where root systems are asymmetrical along gully sidewalls or on steep slopes.			
DIAGNOSTIC QUESTION 2. Is this a closed-canopied stand?			
COMMENT: On low quality sites where short stands are open-canopied, root-system strength and short acclimated stems compensate for restricted rooting depth. Therefore, STAND HAZARD = LOW			
Soil Hazard Class:	☐ High (very restricted)	☐ Moderate (neutral)	☐ Low (unrestricted)

Considerations

- Soil and root systems can be difficult to observe in a stand. Again observations of rootballs on past windthrow on calibration edges will be useful.
- You should cross check with a soil pit to ensure your soil profile and potential rooting restrictions are similar to your corresponding calibration sites.
- Another good source of information is a nearby roadcut, where available. Ensure the roadcut is representative of conditions at your edge or data point.
- Note the second diagnostic question. Short open stands on low productivity sites are an exception - they are often very windfirm in spite of rooting being highly restricted by a water table or rock.
- See Section 2 (Windthrow Concepts) for more information.

d. *Assess Treatment Hazard for Wind:*

- Using a BCTS Form 2 – Side B (as below)

TREATMENT				
DIAGNOSTIC QUESTION. Will the proposed harvesting strategy substantially increase wind loading on trees along the stand edge or retained trees?				
CONSIDERATIONS - Post harvest wind loading increases where: • Fetch increases (wind loading increases linearly as distance across an opening increases from 0 to 5 tree lengths with no further increases after 10 tree lengths). • Boundaries face directly toward damaging winds. • Boundaries are exposed to multiple wind directions (boundary projections, small patches/groups). • Narrow strips or small patches/groups are retained. • Tree removal in uniform partial cuts is increased (dispersed retention or thinned areas). • NOTE: It is common to have more than one damaging wind direction – make observations on similar edges.				
Treatment Hazard Class:	☐ High (large increase)	☐ Moderate (moderate increase)	☐ Low (minimal increase)	☐ Very Low (no susceptible timber)

Considerations

- The key considerations are the degree of exposure of edges to prevailing storm force winds and the "openness" of uniform partial-cuts.
- Exposure of edges depends on the horizontal distance into prevailing storm winds that will be harvested and open. Consider also the slope (%) since it is open horizontal distance that matters for true exposure. For example, a harvested opening may be relatively narrow, translating into a narrow treatment-created fetch. However, if it is on a steep slope, with several kilometers for post-harvest horizontal visibility from the edge into the wind, then it must be considered to have a high treatment hazard, as the actual fetch is much greater than five tree lengths.
- Openness of uniform partial cuts applies to silvicultural systems (seed tree, shelterwoods, selection, dispersed retention) and to treatment entries (thinning). The more open, the greater the treatment hazard.
- Strips or patches that are one tree-length or less in width can be susceptible to windthrow, depending on the windthrow hazard. If windthrow spreads right through the strip or patch the wind profile will subsequently be allowed to penetrate right through the timber. This means that each tree will start to feel the maximum drag force from every storm.
- For more information explore the trends emerging from research and data on the Coast for edges and dispersed trees in Section 2 (Windthrow Concepts) and Section 7 (Best Management Practices).

- ***Determining Biophysical Hazard for Wind: Using a BCTS Form 2 – Side B (completed with an example scenario below)***

WINDTHROW LIKELIHOOD EVALUATION

Add Topographic, Stand and Soil Hazards to get Biophysical Hazard; then add Treatment Hazard to Biophysical Hazard to get Windthrow Likelihood. ***If Treatment Risk is 'None', then Windthrow Likelihood is 'None'.***

	Very High	High	Moderate	Low	Very Low	None
Topographic Hazard		3	2	1	-	-
Stand Hazard		3	2	1	-	-
Soil Hazard		2	1	0	-	-
Biophysical Hazard	8	6-7	4-5	<4	-	-
Treatment Hazard		6	4	2	-	✓
Windthrow Likelihood	14	12-13	10-11	6-9	<6	

High

Considerations

- Above is the ranking table as found on the fieldcard with hypothetical rankings circled for topographic hazard (high or 3), stand hazard (moderate or 2), and soil hazard (moderate or 1). The ranking values are then added for the biophysical hazard, which in this case would be a value of 6 – therefore biophysical hazard is High.
- You will note that topographic exposure and stand hazards carry more weight in the determination of biophysical hazard, than does soil (as in the example above a moderate stand hazard is ranked with a value of 2, while a moderate soil hazard has a ranking of 1). This is based on clear trends from research across the BC Coast (See Section 2, 3, and 7).
- You will also note that as you become more experienced with windthrow in a particular area, with confidence from numerous calibrations on actual edges – you may be able to make more creative use of the numerical values to support your interpretations.
    - For example in the table above the numerical ranking is 6 for a high category which is defined as 6-7. If you are comfortable enough from your calibration sites and other experience, you may interpret this as High-minus or the low end of High.
    - As well, if your extensive experience suggests a stand hazard between low and moderate, the numerical ranking could become a value of 1.5.
    - This will be useful in the next step to forecast likelihood.

e. Determining Windthrow Likelihood:

- Using a BCTS Form 2 – Side B (as in the example scenario shown below)

WINDTHROW LIKELIHOOD EVALUATION

Add Topographic, Stand and Soil Hazards to get Biophysical Hazard; then add Treatment Hazard to Biophysical Hazard to get Windthrow Likelihood. ***If Treatment Risk is 'None', then Windthrow Likelihood is 'None'.***

	Very High	High	Moderate	Low	Very Low	None
Topographic Hazard		3	2	1	-	-
Stand Hazard		3	2	1	-	-
Soil Hazard		2	1	0	-	-
Biophysical Hazard	8	6-7	4-5	<4	-	-
Treatment Hazard		6	4	2	-	✓
Windthrow Likelihood	14	12-13	10-11	6-9	<6	

Moderate

Considerations

- Following with the same example from the previous page, the treatment hazard here is estimated to be moderate (perhaps a boundary that is parallel to prevailing storm winds). With moderate carrying a ranking of 4, and the previous value for biophysical hazard being 6, these two values are added together to give a likelihood ranking of 10 or moderate.

f. Determine Consequences and Windthrow Risk

- See Section 6 – Determination of Windthrow Risk.

6. Determining Windthrow Risk

CONTENT

INTRODUCTION ____ **3**

Overview of Process ____ 3

1. CONSEQUENCES – Assess Potential Consequences and Set Thresholds. ____ **4**

ASSESS POTENTIAL CONSEQUENCES ____ 4

ASSESS WINDTHROW HAZARD AND LIKELIHOOD. ____ 10

SET THRESHOLDS OF ACCEPTABLE WINDTHROW ____ 10

EXAMPLE: Setting thresholds for acceptable windthrow: ____ 12

2. Windthrow Risk ____ **13**

ASSESSING WINDTHROW RISK ____ 13

EXAMPLE: For the previous threshold scenario: ____ 15

MANAGE WINDTHROW RISK ____ 15

EXAMPLES - Combinations of windthrow likelihood, consequences and risk: ____ **16**

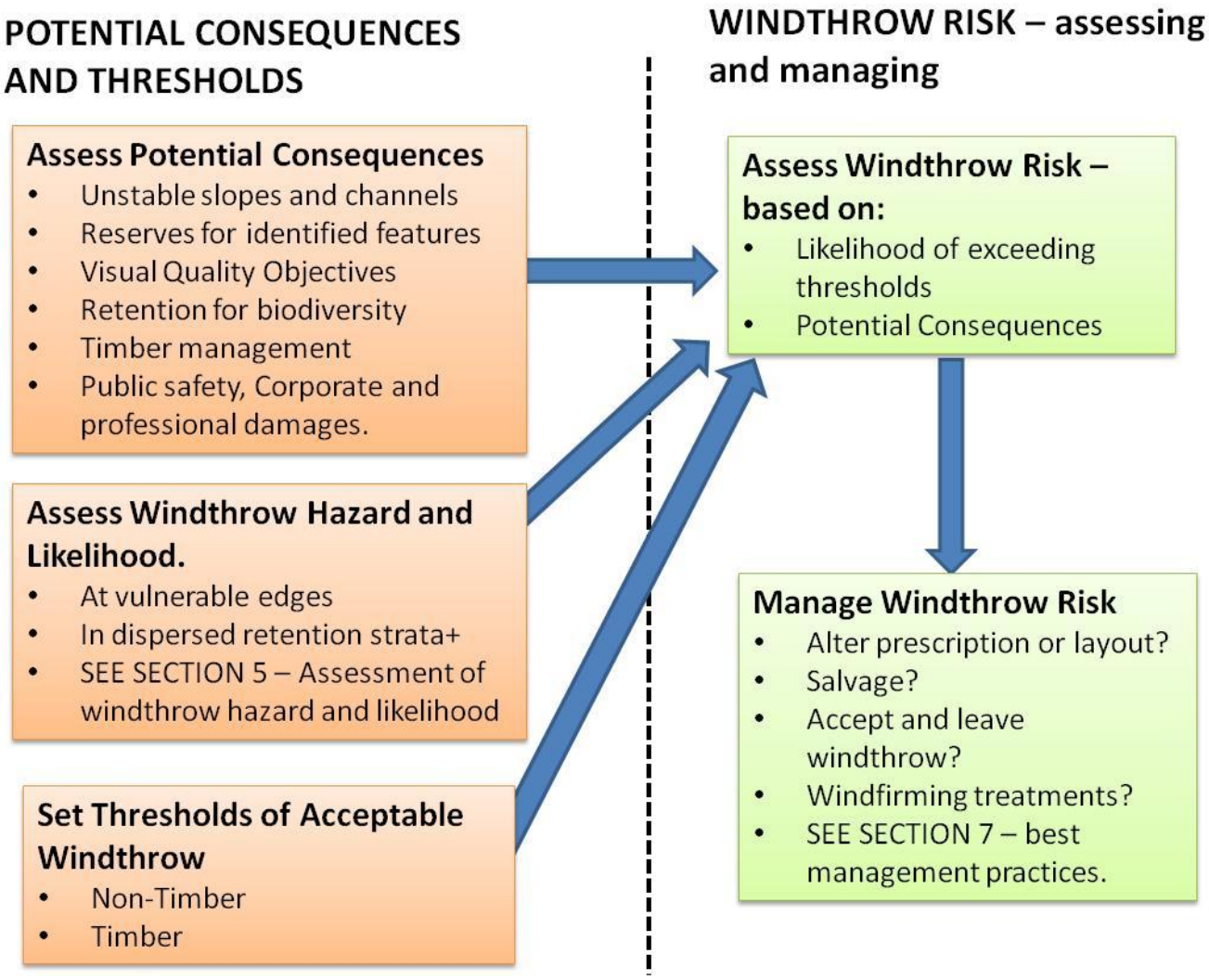
Background ____ 16

Intent ____ 16

INTRODUCTION

Not all windthrow associated with forest management should be avoided or prevented. Harvesting will expose individual trees or new forest edges to increased windloading and trees that are not acclimated or accustomed to the normal (climatic) wind regime will be damaged. Yet, it is not windthrow per se that a manager is trying to avoid, but rather significant adverse consequences that windthrow may create due to forest management decisions.

Overview of Process



1. CONSEQUENCES – Assess Potential Consequences and Set Thresholds.

To adequately evaluate windthrow risk, it is necessary to assess potential consequences and associated windthrow thresholds, some of them can be done prior to formal layout. Some consequences can be initially explored with mapping, orthophotos, and background plans prior to the initial field visit, and then refined or modified as field reconnaissance information clarifies the key values and management features in the area being developed.

All consequences must be considered to determine windthrow risk. However, first the likelihood of windthrow is assessed so it can be determined if acceptable thresholds for windthrow may be exceeded, or not.

ASSESS POTENTIAL CONSEQUENCES

General

Assess Potential Consequences

- Unstable slopes and channels.
- Reserves for identified features.
- Visual Quality Objectives
- Retention for biodiversity
- Timber Management
- Public Safety, Corporate & Professional Damages

Windthrow consequence is ranked based on the features and/or values in the vicinity of potential windthrow. It may be ranked prior to initial layout, or during the likelihood assessment - this will depend on the values and the cutblock. Most non-timber values may be ranked for potential consequences based on pre-layout reconnaissance, assessments and plans or strategies. Precise layout information may not be important to determine potential consequences. It may be enough to know the rough intent for location of edges and retention. However, potential timber consequences may be easiest to rank at the same time as the windthrow likelihood assessment, since questions about timber value and possible salvage are always easiest to consider once you know specifically what you are dealing with.

Considerations:

- Rank the consequences based on the values associated with the edge (stratum - if dispersed retention is being considered).

Make judgments based on the answers to the diagnostic question(s) in the section that follows - ranking using both the subjective category (Nil to Very High).

CONSEQUENCES –Categories				
Nil	Low	Mod	High	Very High

- Rank for each relevant value and then use the highest ranking as the general consequence ranking of the edge (or stratum) for windthrow (See Example that follows).
- NOTE: You will need to return to each potential consequence ranking and associated rationale and consider them again individually when windthrow risk is determined.

- NOTE too, the rankings are specific to the values and one very high ranking (for Public Safety and Corporate/Professional Damages) may trump all others.

EXAMPLE OF A RANKING FOR POTENTIAL WINDTHROW CONSEQUENCES:

Values	Answers to Diagnostic Questions			Ranking
	#1	#2	#3	
Slopes or banks with instabilities[1]	N/A			Nil
Reserves for an identified feature	Cultural	Moderate rarity	Significant	High
Visual landscape quality objectives	-	-	-	Nil
Retention for biodiversity	Long–100+ yrs	Old remnant (1 of many)	No legal requirement	Mod
Timber Management Objectives	Low amount	Mod difficult	Not really	Low
Public Safety and Corporate or Professional Damages	**No**	**YES**	**No**	**Very High**

Comments on the Example:

- This example shows what is intended by a consequences ranking. A similar table has been included in the BCTS field cards. The diagnostic questions to complete this table follow – after these comments.
- This example illustrates a situation where a cutblock is logged with a retention patch or reserve is left that protects a cultural feature. This feature may be significant to local First Nations, or is a heritage feature for a community nearby. Yet, this feature is deemed to be vulnerable to windthrow on at least one edge.
- The reserve to protect the feature is also serving to provide more stand level habitat diversity, but clearly the most important value is the cultural feature.

- Rank based on regret - For any values relevant to the cutblock, rank potential consequences based on the amount of regret you and your organization would have if windthrow significantly impacted the forest value in the manner being considered. More regret equates to a higher ranking.

- NOTE: The consequences ranking is a starting point to provide guidance when setting thresholds for windthrow (which may be done prior to, or during the windthrow hazard and likelihood assessment – depending on the associated values).

[1] Gullies, escarpments, other slopes with questionable stability or banks of active fluvial streams.

==========

Diagnostic Questions – Use To Rank Potential Consequences

NOTE: You may wish to consider the Public Safety and Corporation / Professional Damage questions (end of this list) first, although it may be easier to consider them after considering other values/concerns.

Gullies, Escarpments, and Slopes with Questionable Stability, or Banks of Active Fluvial Streams. (Rank before or during layout) – note one question only for this value.

DIAGNOSTIC QUESTION 1 - What is the potential for windthrow to have a significant impact on the slope / gully / escarpment / bank?

Guidance:

You may need to confer with a geotechnical and/or other specialists (e.g., hydrologist / fish biologist or others).

Consider:

- The potential for initiation of a mass wasting event or debris flow and the potential impacts of such an event:
    - The potential for chronic sedimentation into streams due to destabilization of the gully / slope / escarpment or streambank.
    - The potential for downstream impacts on other values – drinking water, fish habitat, crossing structures.
    - The potential for productivity loss on slopes affected by mass wasting.
    - A loss of terrestrial habitat (riparian or otherwise).
    - Public safety, corporate or professional damages – If applicable, SEE the last set of diagnostic questions for potential consequences.

Reserves for an Identified Feature:

DIAGNOSTIC QUESTION 1 - What is the sensitive feature?

Guidance:

Consider any feature or structure that could be damaged or negatively affected by windthrow. These may be man-made or natural. Either may have regulations or policies that guide activities around or near them.

Consider:

- Cultural – First Nations, historic, other.
- Habitat – bear den, nest, rare and/or special habitat or ecosystems.
- Recreational – trail, built structures, park boundaries.
- Private – boundary, built structures.

DIAGNOSTIC QUESTION 2 – How important is the feature at this location?

Consider:

- Rarity and local significance – how rare or how redundant is the feature?
- Value – monetary or intrinsic.

Reserves for an Identified Feature (continued)

DIAGNOSTIC QUESTION 3 – How might windthrow damage or impair the feature?

Consider:

- Direct impacts – windthrow directly damages the feature – (e.g. the tree with the feature falls; a tree falls on or against the feature).
- Indirect impacts – windthrow in the general area reduces the value of the feature.

Visual Landscape Quality Objectives:

DIAGNOSTIC QUESTION 1 – How important is the viewscape in which the block is embedded?

Consider:

- Visual landscape goals.
- Local landuse context.

DIAGNOSTIC QUESTION 2 – Does windthrow have a strong potential to significantly impact visual quality objectives – if so, where – which edges or portions of the block?

Consider:

- Viewpoints – viewing distance, and angle of viewing.
- Visual absorption capacity – the ability for the landscape matrix to absorb the windthrow disturbance.
- Roadcuts and other block features that are to be screened by timber vulnerable to windthrow.

DIAGNOSTIC QUESTION 3 – How long might windthrow affect visual quality objectives?

- Consider - Time to visually effective green up.

Retention for Biodiversity:

DIAGNOSTIC QUESTION 1 – Is the retention long term or short term?

Consider:

- If the retention will be left for the entire rotation or most of it – then long term (which increases its importance for biodiversity).
- Is there a potential to harvest (if a patch or strip) over the next 20-50 years – short term (not as valuable for biodiversity).

DIAGNOSTIC QUESTION 2 – What function does the retention serve?

Consider:

- Is it a remnant old growth or is it second growth intended for old growth recruitment? Based on the surrounding forest matrix, how important might this retention be for biodiversity?
- Is it a patch of special or unique habitat? If so, go to "identified features" previous.
- Is it just intended to provide some vertical structural diversity or species diversity in the landscape? If so, how important is it for this function?

Retention for Biodiversity (continued)

DIAGNOSTIC QUESTION 3 – Is there a legal requirement for this retention?

Consider:

- Legal objectives for retention targets?
- Legal targets for ecosystem representation?
- Legal objectives for special, rare, red or blue ecosystems – SEE: Identified Feature previously listed.

Timber Management Objectives *(Likely best answered after hazard and likelihood is assessed on the proposed edge or in block retention)*

DIAGNOSTIC QUESTION 1 –How much timber value could potentially be lost to windthrow in the proposed block?

Consider:

- Tree sizes, species and potential grades for the trees most susceptible to windthrow. You may wish to conduct this analysis during the windthrow hazard and likelihood assessment unless you are comfortable with your knowledge of similar edges in the vicinity of the block.
- Is there a potential for windthrow to encourage further losses to standing timber – as with Douglas-fir bark beetles?
- Is there a general strategy for timber salvage? If so, what are the requirements or guidance for salvaging?

DIAGNOSTIC QUESTION 2 – If anticipated windthrow occurs, how easy would it be to successfully salvage?

Consider:

- Salvage harvesting is usually more challenging with more safety concerns than harvesting standing timber, especially if people are required to be on the ground (not just in heavy equipment).
- Logistics associated with the harvesting equipment to be used and terrain considerations.
- Access to the windthrow without significantly damaging planted trees and other values.
- The potential for salvage to further destabilize the edge, leading to even more windthrow. Consider experience on other similar blocks in the vicinity. Generally very dense edges where many leaners are found may be relatively stable in that state. Removing leaners in the salvage operation, which may be necessary for safety reasons, will likely encourage more windthrow.

Timber Management (continued)

DIAGNOSTIC QUESTION 3 – Can an alternative approach be used that will cost-effectively reduce timber losses to windthrow?

Guidance:

You may wish to consult the Best Management Practices Section before answering this question. In some landscapes, such as those dominated by dense tall second growth, few options may be available outside of careful strategic salvage.

Consider:

- Ability to move the boundary to make it less vulnerable.
- Ability to alter retention, for example leave specific tree species, sizes or patch/clump/strip sizes and locations.
- The ability to affect fetch distances (while still able to meet all objectives).
- Options (and cost) to treat the edge.

Public Safety And Corporate Or Professional Damages

These considerations trump all others. You may have already considered them in your ranking of the first step. Generally values need to be considered first to provide enough context.

DIAGNOSTIC QUESTION 1 (SAFETY): Is there is a potential for a significant safety issue to arise for the public (i.e. windthrow on trails and other frequently used areas)?

Note: This was not meant to include the incidental possibility of public presence on forest roads, or in cutblocks.

- IF THE ANSWER IS YES – Consequence Ranking is **(Very High)**.

*DIAGNOSTIC QUESTION 2 (CORPORATE DAMAGE): If the potential for the following is moderate or higher, consequence ranking is **(Very High)**.*

Consider:

- Significant fine under land management legislation.
- A lawsuit.
- Significant damage to the corporate image that could strongly influence future business ventures, or harvesting opportunities.
- A damaged relationship with a key stakeholder that could significantly impact planning and future management and harvesting.

*DIAGNOSTIC QUESTION 3 (PROFESSIONAL DAMAGE): If the potential for the following is moderate or higher, consequence ranking is **(Very High)**.*

- Consider:
  - A lawsuit.
  - Significant damage to professional credibility that could significantly impact future professional relationships.

ASSESS WINDTHROW HAZARD AND LIKELIHOOD.

General

Assess Windthrow Hazard and Likelihood.
- At vulnerable edges
- In dispersed retention strata+
- SEE SECTION 5 – Assessment of Windthrow Hazard and Likelihood

Before windthrow risk can be assessed, biophysical hazard and likelihood of windthrow must be assessed, e.g., complete the field cards – see Section 5 – Assessment of Windthrow Hazard and Likelihood.

Considerations

- You will need to know approximate locations of outer block boundaries, and edges of strips or patches of retention. As well, areas of dispersed retention (uniform partial-cutting) must be known along with preferences for species, and tree sizes or classes.
- As a minimum, a paper plan for layout will be needed. For some operations it may be most efficient to complete an initial formal layout on the ground (with flagging).
    - However, it may be best to avoid blazing and painting of falling corners at this point as things may yet be changed after formal windthrow hazard and likelihood assessments are completed.
- As a general rule it is probably best to put less energy into formal layout prior to the windthrow hazard and likelihood assessment where there are numerous concerns regarding windthrow consequences on the block.
    - This is why it is worthwhile to consider your management values and consequences, as much as possible, prior to layout.

SEE: Assessing Windthrow Hazard and Likelihood (Previous section) for more details.

SET THRESHOLDS OF ACCEPTABLE WINDTHROW

Set Thresholds of Acceptable Windthrow.
- Non-Timber
- Timber

Windthrow thresholds are set separately for non-timber and timber consequence concerns for several reasons. Windthrow impacts on non-timber values are not common, but can be very significant. Normally, little can be done to ameliorate the situation, once the impact occurs. Either: windthrow penetrates an edge and directly damages a feature; or the amount of windthrow significantly reduces the value of retention or reserves left behind to promote a value; or windthrow initiates other damaging processes (like channel erosion or landslides) that

damages features or values[2]. For this reason it is useful to set penetration and amount thresholds for non-timber values separately.

Loss of timber value on the other hand is probably the most common windthrow concern. In some cases the only choice is to alter layout design or the prescription. However, there must be significant amounts of windthrow with higher value trees to warrant a concern about timber losses, except where forest health concerns exist (generally due to bark beetles). Also, in many cases, the impact on timber values can be addressed after windthrow occurs - through salvaging. This makes timber a special case that should be considered with its own threshold.

Non-Timber Values/Objectives Thresholds:

A. Limit to Windthrow Penetration

THRESHOLD QUESTION A: Based on the consequences to windthrow, associated consequences and the nature of the feature, patch, strip, reserve or edge, is there a specific limit to windthrow penetration, to adequately protect values and objectives?

Consider:

- Is it possible to have a certain amount of windthrow penetrating into the edge / patch / strip with no particular limit? For example, in a patch of retention for biodiversity, the issue may not be penetration – if a certain proportion of the basal area remains standing, the value of the retention may still be high regardless of windthrow penetration.
- OR - Is there a zone of zero tolerance for windthrow (induced by management/harvesting) – because of a feature that may be damaged or an event that may be initiated etc? If so, where would that zone of zero tolerance be located?

B. Amount of Windthrow that is Acceptable

THRESHOLD QUESTION B: Is there a zone where it would be acceptable to lose a proportion of the basal area to windthrow - on the edge of the block; through an entire strip/patch; through a portion of a strip/patch; or through an entire dispersed retention stratum?

Consider:

- How many standing trees are required to ensure proper function for the value of concern, for example:
  - In an old growth patch you would want to consider how much of the patch could be lost to blowdown before it no longer resembles an old growth patch.
  - In a second growth patch intended to be recruited to old growth over time, it may actually be desirable to lose up to 50% of the basal area to windthrow to open up the stand, encourage vertical structural diversity and improve growth on remaining trees.

[2] Where other processes are initiated – follow-up actions may be taken unrelated to the windthrow (such as sediment control), however it is better to proactively avoid the windthrow.

- Does this zone have a limit, or is it essentially the entire patch/strip, or an indeterminate distance into the block edge?

Timber Value Threshold

(Determined after windthrow hazard and likelihood assessment)

<u>THRESHOLD QUESTION C</u>: Is it likely that sufficient economic value of timber will be lost to windthrow to either warrant – a plan for salvage, changes to layout, or changes to the prescription?

Consider:

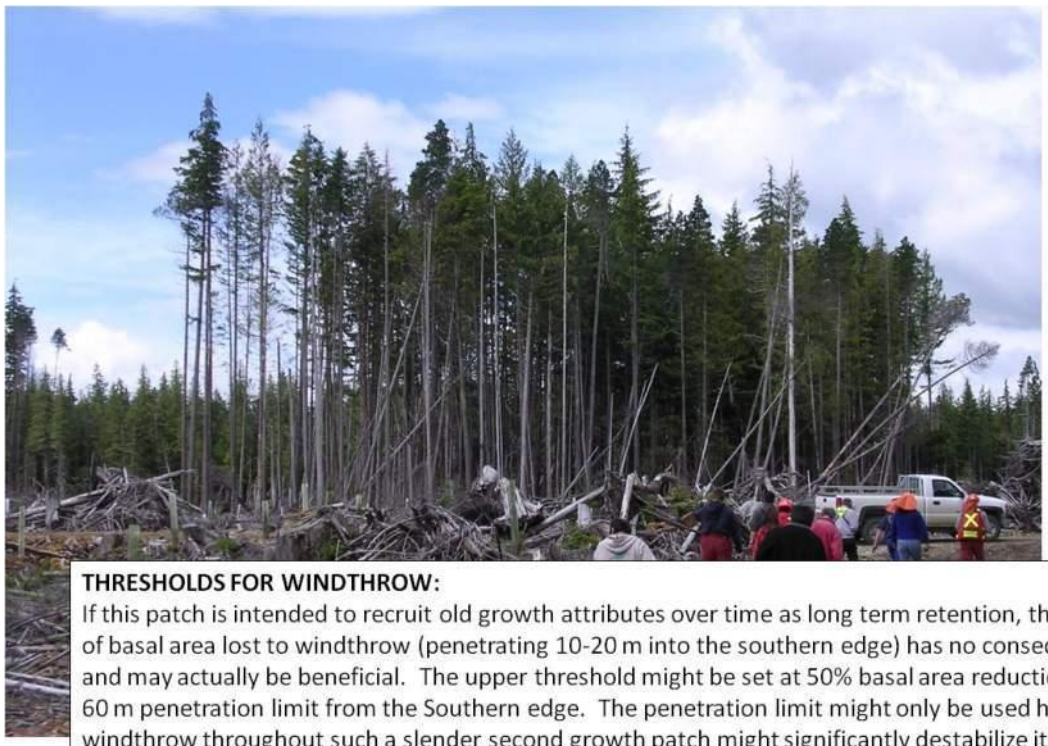
- The predicted likelihood for windthrow in terms of - amount, species, and sizes of trees.
- The forecasted potential consequences based on the diagnostic questions for timber (earlier in Section 6). Consider the answers to the diagnostic questions carefully.
- A reconsideration of those sensitivities if they were considered prior to layout.

EXAMPLE: Setting thresholds for acceptable windthrow:

BCTS Coastal Windthrow Consequences and Risk FORM 3 – Side B

COMPARISON OF PREDICTED WINDTHROW TO THRESHOLDS:			
PREDICTED WINDTHROW – from hazard and likelihood assessment – FORM 2			
Predicted Edge Penetration (m):	20 m	Predicted amount in an identified zone (%):	25% (in 20 m)
WINDTHROW THRESHOLDS - based on consequence sensitivity and considerations the BCTS Windthrow Management Manual. *Where either a penetration or amount threshold does not apply - NA.*			
NON-TIMBER Max Penetration (m):	60 m	NON-TIMBER Max Amount in an identified area (% of total basal area):	50% (in 60 m)
EXCEEDING TIMBER THRESHOLD – Based on predicted windthrow is it likely that sufficient economic timber value will be lost to warrant: a plan for salvage, changes to layout, or changes to the prescription? (Yes or No)			No
Comments: The patch is for recruitment of old growth attributes over time. The windthrow in this second growth Hw will increase habitat variability and may promote growth on the remaining stems.			

SEE – The photograph and the explanation that follows.



THRESHOLDS FOR WINDTHROW:
If this patch is intended to recruit old growth attributes over time as long term retention, the 20-25% of basal area lost to windthrow (penetrating 10-20 m into the southern edge) has no consequences and may actually be beneficial. The upper threshold might be set at 50% basal area reduction within a 60 m penetration limit from the Southern edge. The penetration limit might only be used here since windthrow throughout such a slender second growth patch might significantly destabilize it. There are no consequences for timber management since this timber was already written off as retention. Also, salvage may destablize the patch and encourage more windthrow. If there was a feature such as a bear den in the patch, the penetration limit would be set to maintain the integrity of the den and sufficient habitat around the den.

2. Windthrow Risk

ASSESSING WINDTHROW RISK

Assess Windthrow Risk – based on:
- Likelihood of exceeding thresholds
- Potential Consequences

Windthrow risk reflects the risk to management associated with the layout design, considering the likelihood of windthrow against limits (thresholds) that are set based on consequences. Windthrow risk is not equal to the likelihood of windthrow. We may expect considerable windthrow, but if there are no consequences, there is little risk. That being said, there are some layout design tips that will generally result in less windthrow overall, and are worthwhile even where the risk associated with that windthrow is small. An example is a cutblock with several avoidable boundary peninsulas that will likely end up as windthrow. While the resulting windthrow from these peninsulas may not be large, and the risk for management values is low, if there is no compelling engineering rationale for them and they can be avoided with no added cost, it only makes sense to do so.

Risk highlights the need to alter layout design and the prescription where windthrow has the potential to impact management values and compromise objectives. While assessment of risk helps managers to highlight the priority areas for windthrow management, it also provides a rationale to accept a certain level of windthrow in many situations where values would not be affected.

Windthrow risk can be simply defined as follows:

WINDTHROW RISK = function of (A) and (B).

Where

A = the likelihood of exceeding the thresholds for acceptable windthrow.

B= Consequences.

Determining A – Likelihood of Exceeding Thresholds for Windthrow

A –is determined by considering the difference between the assessed likelihood of windthrow and the most restrictive thresholds for acceptable windthrow - in terms of penetration distance and amount of windthrow as a proportion of the basal area of the stand.

The following categories are used to assess considering likelihood and thresholds for potential consequences:

Nil	- Both assessed likelihood for penetration and amount are not close to thresholds.
Low	- Assessed likelihood does not exceed either thresholds but may be close.
Mod	- Assessed likelihood somewhat exceeds amount threshold, but does not seem to exceed penetration threshold (where applicable).
High	- Assessed likelihood considerably exceeds amount threshold, and/or seems to exceed penetration thresholds by a small amount (if applicable).
Very High	- Assessed likelihood considerably exceeds penetration threshold, as well as amount threshold (if both apply).

Windthrow Risk Category

Considering your assessed *likelihood of exceeding the acceptable thresholds* set for your edge or stratum, consider the consequences again carefully (Step 1 and 2) to answer the following diagnostic question:

DIAGNOSTIC QUESTION: If the thresholds for windthrow are exceeded as expected, what will be the consequences for management values, safety, liabilities and other management concerns?

VERY HIGH – very negative consequences	HIGH – negative consequences
MODERATE – slightly negative consequences	LOW – minimal to no consequences

Considerations:

Reconsider the consequences used to set thresholds originally (STEP 1 AND 2).

Be realistic and suitably prudent – ensure the consequences are real and not incidental and expected. Where serious consequences are possible, be proactive – wishful thinking is not useful.

EXAMPLE: For the previous threshold scenario:

LIKELIHOOD OF EXCEEDING WINDTHROW THRESHOLDS:		
Likelihood categories.		
Nil	- Both assessed likelihood for penetration and amount are not close to thresholds.	
Low	- Assessed likelihood does not exceed either thresholds but may be close.	
Mod	- Assessed likelihood somewhat exceeds amount threshold, but does not seem to exceed penetration threshold (where applicable).	
High	- Assessed likelihood considerably exceeds amount threshold, and/or seems to exceed penetration thresholds by a small amount (if applicable).	
Very High	- Assessed likelihood considerably exceeds penetration threshold, as well as amount threshold (if both apply).	
Estimated likelihood of exceeding windthrow thresholds:	**Non-Timber**	**Timber**
	NIL	NIL

WINDTHROW RISK ASSESSMENT				
DIAGNOSTIC QUESTION: If the thresholds for windthrow are exceeded as expected, what will be the consequences for management values, safety, liabilities and other management concerns??				
Risk =	☐ **Very High** (very negative)	☐ **High** (negative)	☐ **Moderate** (slightly negative)	☑ **Low** (minimal to no consequences)

MANAGE WINDTHROW RISK

Manage Windthrow Risk
- Alter prescription or layout?
- Salvage?
- Accept and leave windthrow?
- Windfirming treatments?
- SEE SECTION 7 – best management practices.

Once risk has been assessed, you may wish to discuss the situation with colleagues, specialists, and your supervisor. Not all situations require a reduction to low or nil for risk. However, this does depend on the situation. Generally *Very High*, or *High* risk situations must be addressed to lower risk. You may address a *Moderate* risk situation with mitigation measures, depending on the consequences. This may be a strategic decision over a large landscape. For example, in the BC Southern Interior one licensee used several salvage crews to recover more than 100,000 m^3/year of windthrow on the edges of lodgepole pine stands in the mid 1990's. This strategy may change with timber values.

If you must address risk by modifying layout design, refer to guidance on Best Management Practices.

EXAMPLES - Combinations of windthrow likelihood, consequences and risk:

Background

The following examples were chosen to provide an illustration of a range of coastal situations that may be encountered with various combinations of windthrow likelihood, consequences and resultant windthrow risk. Note that *likelihood* is the *likelihood of windthrow occurring*, not the likelihood *to exceed a windthrow threshold*. *Risk* is reported to show what should have been viewed as the risk at the layout stage, prior to harvesting.

The photographs illustrate actual windthrow to provide a more explicit representation of what to expect for certain windthrow likelihood scenarios. For this reason the windthrow penetration and amount (as a % of total volume or basal area) are reported under *windthrow* rather than *likelihood*, except for "example I" where it is considered at the preharvest stage, so the penetration and amount are linked to likelihood as it is an estimate of potential rather than a confirmation of actual windthrow.

Intent

The intent of this section is to illustrate that windthrow likelihood may be moderate, while risk varies from low, to very high (Example A, B, D, F, H). The large variation in risk from similar windthrow likelihood categories is related to the associated consequences and the threshold set for acceptable windthrow. Accordingly, likelihood may be high with a moderate risk, or conversely likelihood may be low while the risk may be high or very high (Example I).

Using visual representations, it becomes apparent that windthrow may be significant visually, while the consequences and risk associated with that windthrow could be low. As well, windthrow may be hardly apparent visually, while the risk may be high or very high. Consequences must be carefully considered to make good risk determinations.

B) EXPOSED EDGE:
Likelihood = Mod
Windthrow = Penetration 10-30 m with 30-50 % windthrow (100% loss in chunks due to subsequent landslides)
Consequences Consideration: Significant Stability issues with steep slopes. Subject to significant penalties under FRPA.
Risk = High to Very High.

C) EXPOSED EDGE:
Likelihood (right) = V. High – Penetration 70-80 m with 60-80 % windthrow.
Consequences Consideration: Consequences significant if yellow line is a park boundary.
Windthrow Risk = High to V. High

D) EXPOSED EDGE:
Likelihood = Mod - High
Windthrow = Penetration 20-50 m with 20-70 % windthrow (20-30 cm dbh Hw)
Consequences Consideration: If only timber – the question becomes – how much of this edge type is there ? What are the options for management? How easy is it to salvage and what is the value of the timber?
Risk – could be moderate, but may be hard to avoid.

E) EXPOSED RIPARIAN STRIP:
Likelihood = HIGH
Windthrow – Penetration throughout with 80-90 % windthrow.
Consequences Consideration: S6 stream / little concern for sediment downstream / strip intended to satisfy EBM retention target.
Risk = High (due to EBM target)

F) EXPOSED LARGE PATCH:
Likelihood = Mod to High
Windthrow = Penetration 30-50 m with 30 % windthrow total through patch - Hw (Cw).
Consequences Consideration: Long term retention or WTP requirement.
Risk = Low to Moderate.

G) EXPOSED SMALL PATCH:
Likelihood = Mod
Windthrow = Penetration throughout with 20-30 % windthrow (20-30 cm dbh codominants)
Consequences Consideration: May actually improve value as long term retention. **Risk** = Low

H) EXPOSED MEDIUM PATCH:
Likelihood = Mod
Windthrow = Penetration 20-25 m with 30-40 % windthrow (20 - 40 cm dbh codominants)
Consequences Consideration: High value bark stripping CMT in centre.
Risk = Could be High to Very High

I) FUTURE EDGE (ribbon / hardhat):
Likelihood = Low – expect Penetration 0 – 10m with 0-5 % windthrow (sheltered)
Consequences Consideration: Past slumping on escarpment indicates slope instability that geotech expects will be exacerbated by windthrow. Stream below is used for community water supply 2 kms away. Lawsuits could occur.
Risk – Very High

7. Windthrow Best Management Practices

CONTENT

Introduction ____ **3**

A Treatment Perspective on Windthrow Likelihood Scenarios ____ **3**

PLANNING LAYOUT – BMPs for High and Low Likelihood Scenarios. ____ **4**

BMPs for Some High Likelihood Scenarios - that signal caution or avoidance ____ 5

Some Low Likelihood Scenarios – that signal opportunities for naturally windfirm boundaries. ____ 6

Treatment Options - Where the Initial Plan has Significant Risk ____ **8**

Significant Risk = Moderate (or higher) Risk of Exceeding Thresholds for Windthrow ____ 8

ALLOW FOR WINDTHROW AND SALVAGE – for either edges or uniform partial cutting. ____ 10

OTHER OPTIONS FOR CLEARCUT AND PATCH/STRIP RETENTION EDGES ____ 12

Change Layout - Adjust Boundary Edges ____ 12

Change Layout - Adjust size and shape of internal retention patches or strips ____ 17

Change Layout - Reduce fetch ____ 20

Change Approach to Layout – Prescribe a Multi-pass Silvicultural System ____ 24

Windfirming Treatments ____ 28

OPTIONS FOR UNIFORM PARTIAL CUTTING (other than planning salvage) ____ 35

Background ____ 35

Modify leave tree parameters ____ 36

References ____ **42**

Introduction

Best Management Practices (BMPs) provide some initial direction for practitioners approaching layout or designing prescriptions to address windthrow concerns. They are based on principles emerging from experience, monitoring data and research. They are not rules but should be considered as a starting point for prescription or layout design. As generalizations, their usefulness and applicability must be judged in context with specific stand and site conditions, along with consequence considerations.

Note – BMPs are not intended as "rules" *- but as useful trends, general tendencies or considerations. Judge every situation based on site specific attributes, and objectives!*

BMPs are useful to consider at THREE stages:

1. Strategically at the development planning stage over an entire landscape - Ideally consideration of BMPs starts before cutblock locations and harvesting sequence are finalized. Trying to solve all of the windthrow challenges at the cutblock design stages generally leads to problems in windthrow dominated landscapes.
2. When planning layout - at the initial planning stages based on reconnaissance data to avoid situations where unnecessarily high levels of windthrow may occur (as in high likelihood scenarios).
3. When it is clear that the initial layout and/or prescription needs to be altered - based on windthrow hazard and risk assessments. BMP's will be useful to ensure that the thresholds set for acceptable windthrow are not exceeded and associated consequences are avoided - i.e., windthrow risk is reduced.

This section provides treatment perspectives on windthrow likelihood and risk, then guides practitioners through the most current treatment options and their applications.

A Treatment Perspective on Windthrow Likelihood Scenarios

Much of the time, the combination of biophysical hazard and initial layout results in a moderate likelihood of windthrow on windward facing boundaries. Appropriate responses to moderate likelihood scenarios can be challenging since they vary widely, depending upon the consequences.

Assess Moderate Likelihood Scenarios carefully for risk *- There are many situations where a moderate likelihood carries a low risk and doing nothing is the most appropriate treatment. These are the scenarios where a certain level of windthrow is both likely and acceptable, based on few or no consequences.*

At the upper end of the "moderate" likelihood range, a poorly thought out windthrow management strategy may needlessly create a high likelihood scenario, the opposite of a best management practice. Conversely, an over-reaction at the low end of the range could waste time and resources addressing concerns that have a relatively low likelihood of occurrence,

and minimal consequences. An example is top pruning trees on a sheltered slope with no significant value consequences.

Figure 7- A shows diagrammatically the relative proportion of time and effort generally needed to work out appropriate layout or prescription options for the various likelihood scenarios. The potential for high likelihood scenarios is often evident even before layout begins, and layout or the prescription can be initially designed to avoid such scenarios. Low likelihood scenarios are also often evident prior to layout. They generally are a low priority for detailed hazard and risk assessment and may offer an opportunity to anchor harvesting on a windfirm boundary.

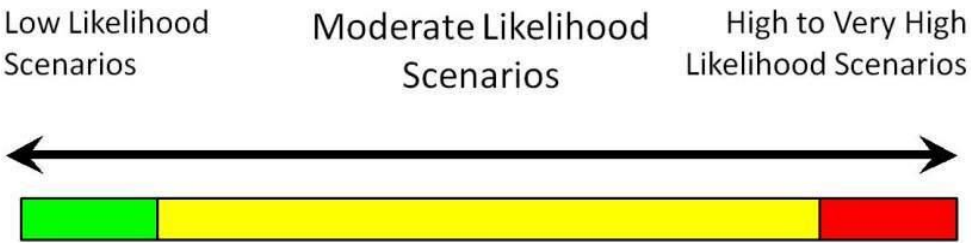


Figure 7-A. A general approximation of the usual proportion of time and resource allocation to high, moderate and low likelihood windthrow scenarios, using the size of the coloured bar as an indication of time allocated. The moderate (yellow) bar is clearly the largest.

PLANNING – BMPs for High and Low Likelihood Scenarios.

Figure 7-B lists some typical high and low windthrow likelihood scenario conditions. Figure 7-C to E illustrate some typical high windthrow likelihood scenarios that should generally be avoided, to prevent situations where a large amount of windthrow is almost certain to happen. Figure 7-F&G show some common low likelihood scenarios, which often do not require any special layout or cutblock edge treatment considerations. As stated above these low likelihood scenarios may offer significant opportunities for layout to anchor a block on a windfirm edge.

Potential opportunities for windfirm boundaries	Use Caution or Generally Avoid
• Wind-sheltered edges which are not adjacent to gullies or streams. • Edges on the leeward side of topographic obstructions which are not steep ridges. • Natural breaks and edges where trees have acclimated to the local wind climate (i.e. trees rooted into rock, located along the edges of bogs, shorelines, etc.)	• Wind exposed edges on gully or escarpment breaks • Small retention patches of slender susceptible trees on exposed block locations (i.e. high ridge, knoll, etc.) • Exposed, susceptible individual dispersed trees • Funnelling winds with boundary location and orientation.

Figure 7-B. Some common conditions which characterize high and low likelihood scenarios

BMPs for Some High Likelihood Scenarios - that signal caution or avoidance

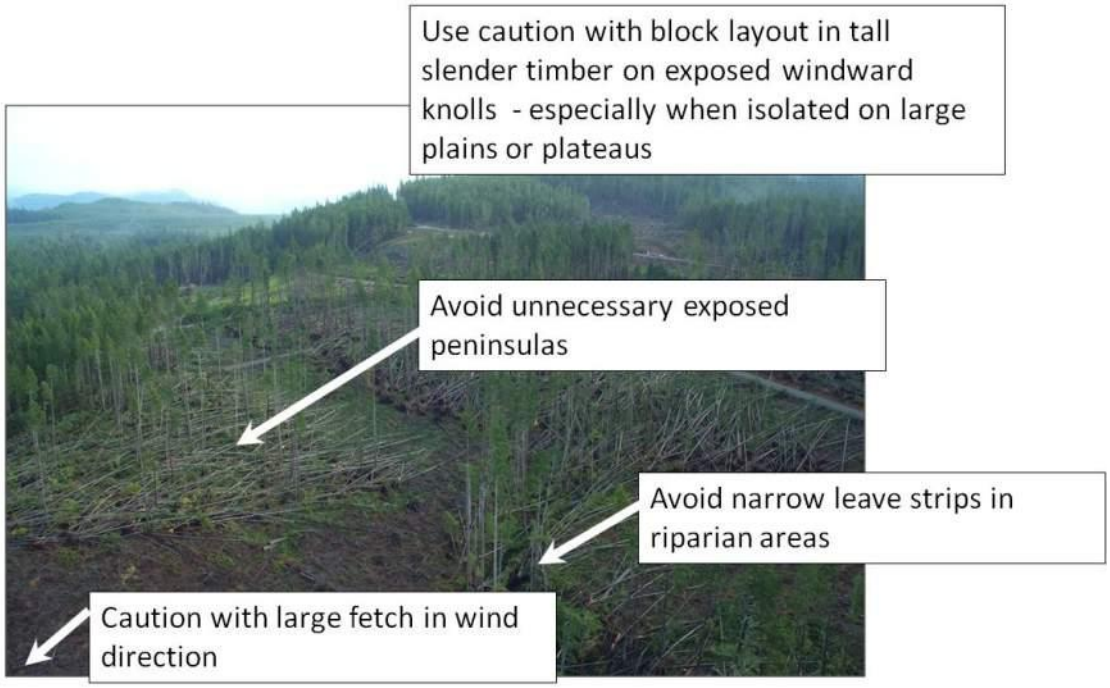


Figure 7-C. Several BMPs for tall slender timber.

Figure 7-D. Use caution when locating retention or edges on smooth rock that roots cannot penetrate.

Figure 7-E. BMPs for breaks into gullies, escarpments, and incised streams.

Some Low Likelihood Scenarios – that signal opportunities for naturally windfirm boundaries.

The scenarios that follow often do not require windthrow management treatments, unless a small amount of windthrow may occur which carries high consequences (Figures _7-F,G, H). These scenarios may in fact present opportunities to "anchor" windfirm" boundaries for harvesting on the wind-exposed side of the opening.

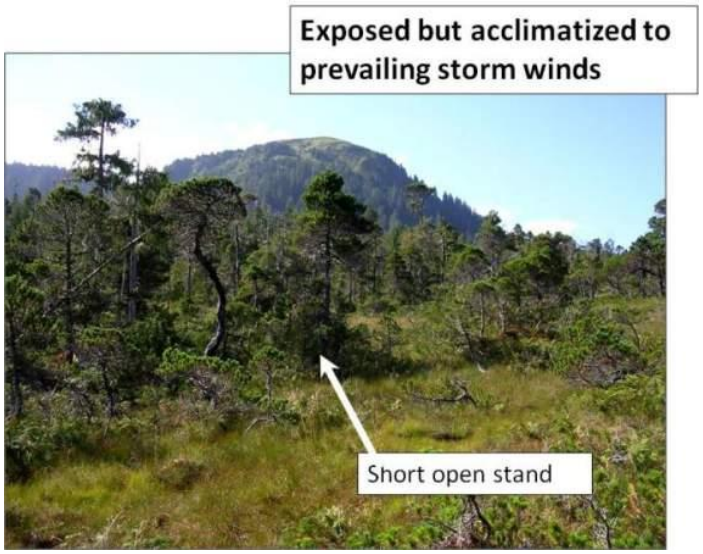


Figure 7-F. Windfirm forest edge on exposed upper elevation bog.

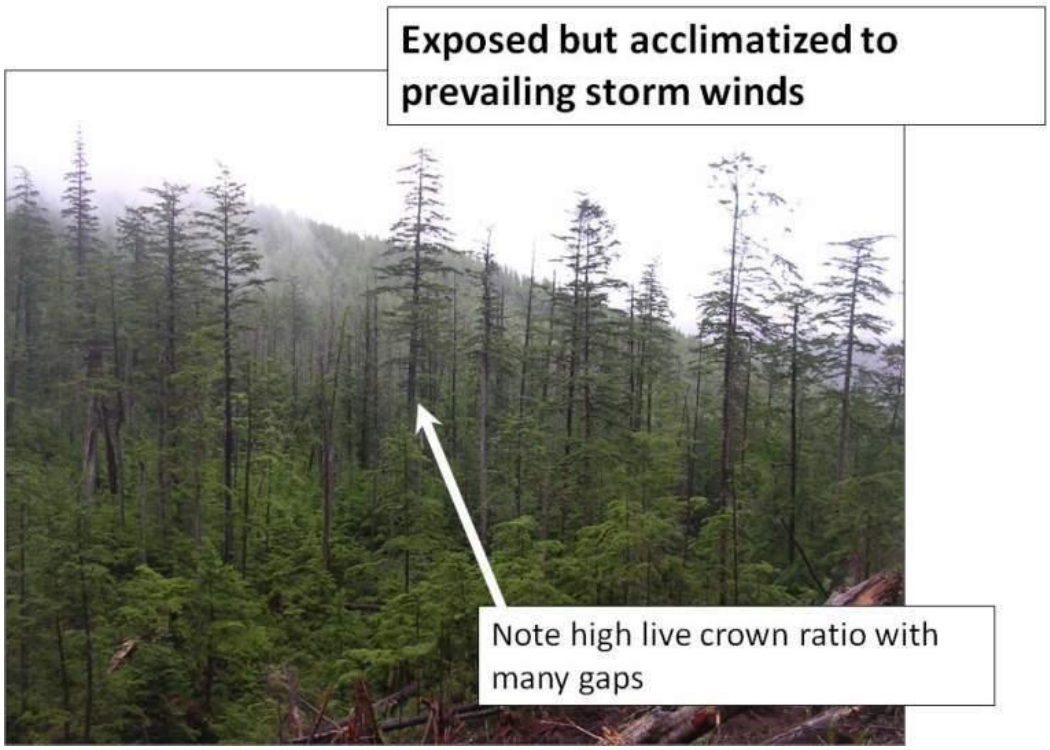


Figure 7-G. Highly exposed, wind-tattered and acclimated stand.

Figure 7-H. A dry rocky site with an relatively open, short, well acclimated stand and some veteran trees – another low likelihood scenario even when highly exposed as in this situation on central Vancouver Island.

Strategic Planning – Designing strategies at the landscape level to address windthrow in a wind-dominated landscape.

In wind-dominated landscapes, windthrow becomes a primary planning concern. Windthrow occurrence is historically significant on most cutblocks, and options for addressing windthrow are challenging if not impossible when dealt with solely at the cutblock layout stage.

In these landscapes, at the development planning or other suitable stages, it is best to start addressing windthrow management by designing broad strategies at the landscape level. The general BMPs for high and low likelihood scenarios (on the previous pages) are first considered to design strategies that may include:

- Identification of natural or man-made "anchor points" for cutblock layout. These anchor points stand out as having a low windthrow likelihood in a wind-dominated landscape. These points are useful to anchor high likelihood boundaries in initial cutblocks.
- Recommendations for selection and application of silvicultural systems. Some silvicultural systems are designed specifically to address windthrow concerns. However, these systems require diligence in planning and implementation of follow-up treatments and harvesting entries (see BMPs later in this section).
- Recommendations for timing and sequencing of harvesting entries.
    - Future harvesting entries should build on existing harvested blocks, or portions of blocks, to create windfirm edges for new logging.
    - Sequencing harvesting into the wind from older regenerated units provides a low stand hazard on a high treatment hazard risk.
    - This approach can be used for multiple cutblocks over time, or for multiple entries within the context of a multi-entry silivcultural system with strip or group openings (see later in this Section).

Treatment Options - Where the Initial Plan has Significant Risk

Significant Risk = Moderate (or higher) Risk of Exceeding Thresholds for Windthrow

Prior to the consideration of specific layout and windfirming options, to mitigate the impact of windthrow, it is important to take a moment to reflect on the consequence thresholds set in windthrow risk assessments and their related consequences. Both non-timber and timber thresholds should be considered.

> ➢ ***Where consequences are minimal, thresholds for windthrow should reflect a high tolerance for windthrow. Therefore, often no treatment modifications will be required*** *(see Section 6 – determining windthrow risk).*

When there is a danger that windthrow could exceed consequences thresholds, based on the estimates of likely windthrow (penetration and amount), some treatment or planning alteration is required. The first consideration is whether or not post-windthrow salvage is an option to address the situation, without a major change in layout or the prescription. It is

important to understand the conditions where salvage may be a viable option and provides some precautionary considerations to avoid windthrow subsequent to the salvage operation.

If salvage is not a viable option, the other options include: alterations to layout; a different approach to silvicultural systems; and incorporation of windfirming treatments for edges or leave trees.

TREATMENT OPTIONS - WHERE ASSESSMENT SHOWS SIGNIFICANT RISK.

For Clearcut and Patch/strip Retention Edges:

1. ***Allow Windthrow and Salvage***
2. ***Change Layout***
    - Adjust boundary
    - Adjust size and shape of internal retention patches or strips
    - Reduce fetch
    - Change to a Multi-pass Silvicultural System
3. ***Windfirming Treatments***
    - Topping and Pruning
    - Feathering

TREATMENT OPTIONS - WHERE ASSESSMENT SHOWS SIGNIFICANT RISK (continued).

For Uniform Partial Cutting

1. ***Allow Windthrow and Salvage***
2. ***Modify leave tree parameters***
    - Change leave tree criteria
    - Change the density and distribution of dispersed leave trees
    - Windfirm – topping or pruning
3. ***Change general silvicultural system design***
    - Smaller openings with less fetch
    - Patch/strip retention
    - Other

ALLOW FOR WINDTHROW AND SALVAGE – for either edges or uniform partial cutting.

Is salvage an option to deal with the risk?

Salvaging is an option where the anticipated windthrow will not impact non-timber objectives and salvaging can also be undertaken without impacting those objectives. Where timber management is the only relevant value on the site, sometimes allowing windthrow to occur and planning salvage is the easiest option. The assessment of consequences and risk will help with this determination (See Section 6). Salvaging windthrow helps to address the timber concern for losing too much volume of valuable timber.

With that in mind, it is best to consider carefully the importance of the timber that may be lost as windthrow, and the challenges for salvaging it. These considerations should have already been made in a general sense when determining consequences and risk, but they are worth revisiting before choosing the salvage option.

As well, once windthrow has occurred, these questions will be worth considering once again since damaged timber, and potential issues can be clearly evaluated.

Questions to consider before choosing the salvage option:

1. *Will salvage be necessary, even at relatively low levels to avoid a larger management issue? - e.g,. Douglas-fir bark beetles on the Sunshine Coast or in the Coast-Interior Transition.*

   If this is the case, informal follow-up monitoring of such an area is essential to detect these low levels of windthrow before they become a problem.

2. *Is the windthrow anticipated in a reserve or retention where there are restrictions on salvage based on the targets, legal objectives and other parameters associated with the reserves or retention?*

   The answer to this question may preclude any consideration of salvage. Even where salvage is legal, one should consider the ability for the reserve or retention to continue to fulfill its function after the salvage operation – or put another way, the impact of the harvesting on the remaining structural elements. It may not be worth salvaging, if many standing trees must be removed for access and safety, or if it encourages further instability to the reserve or retention.

3. *How much timber value could potentially be lost to windthrow in the proposed block?*

   It is helpful to design a general strategy to guide planners - outlining species, sizes, and minimum amounts to even consider salvage. There may be different categories defined that allow for more or less costly harvesting operations. These minimums may change with market demands.

4. *Are there other blocks within a reasonable distance also with similar windthrow that could be tied into one salvage operation?*

   Often salvaging is a landscape level consideration. It is not the amount of timber on one edge, or even in one block that makes a salvage operation worthwhile, but the

amount of timber within a cutting permit or a portion of a landscape that will provide a significant opportunity. Where tenures overlap, cooperation and coordination between licensees can help.

5. *How easy is the timber to salvage? - Harvesting equipment, costs, safety issues, impacts on other values?*

   This consideration is pure harvesting operational logistics. The safety of the salvage operation will depend on the amount and the complexity of the windthrow situation. Variability in orientation, height off the ground, and the amount of timber under stress will all increase the challenge. Safety will greatly depend on the harvesting equipment to be used. Safety concerns increase with the work that must be done in the damaged timber by a person on the ground.

   Harvesting equipment, the location and the nature of the anticipated windthrow, terrain, yarding, skidding or forwarding distance will impact potential costs as well. Lastly, consider indirect impacts on other values which could also increase costs or decrease the value of the operation – e.g. damage to adjacent plantations.

6. *Can a cost-effective alternative approach be used that can reduces timber losses to windthrow?*

   If timber is the only concern, can one of the other options be used incurring less cost overall while protecting most of the timber value in the adjacent stand?

NOTE: For other detailed considerations associated with these questions, see diagnostic questions for timber in Section 6.

BMPs When Salvaging in Clearcut and Patch/Strip Retention Edges

- ***If planning for salvage ensure access is maintained*** – delay debuilding roads and landings and maintain skidding or yarding access.
- ***Avoid salvage strips that create another fresh edge, similar to the initial edge*** – retain standing trees within the damage area where possible since they help to stabilize the edge; if salvaging ccreates a new fresh edge, you can expect the same windthrow to result that occurred on the initial edge if all other conditions remain the same.
- ***Be cautious on edges with lots of leaning stems –*** edges with a high number of leaning stems often have a high degree of inherent stability because damage doesn't propagate into the edge (See Section 2 – Concepts). Salvage activities may cause this stability to unravel. Consider that for every leaning stem removed, another will often result after subsequent storms.
- ***Be cautious salvaging in blocks consisting of many small dispersed openings*** – More windthrow may result if salvaging removes many standing stems, opens up new access corridors and encourages patches to coalescence with increased opening size and fetch[1].

BMPs When Salvaging in Uniform Partial Cutting

- ***Choose the salvage option realistically*** – it may not be possible to salvage throughout a dispersed retention block if it will be planted before windthrow occurs.

[1] Fetch refers to the distance across an opening where wind can flow unobstructed.

- ***Be cautious salvaging in dispersed retention or thinned stands*** – avoid damage to leave trees which may decrease their stability or value as leave trees.

OTHER OPTIONS FOR CLEARCUT AND PATCH/STRIP RETENTION EDGES

Change Layout - Adjust Boundary Edges

Overview

Adjusting the boundary location of an edge is likely the most common approach to addressing windthrow concerns and ensuring thresholds are not exceeded. This is especially true where the key consideration is a penetration issue, but not necessarily. It may also be useful where moving the boundary helps to avoid an area of susceptible timber (perhaps from root disease) or susceptible soil (a site with restricted rooting).

A key challenge for such approaches is the inclination for layout crews to focus on optimal yarding or forwarding and maximum volume recovery. This key driver for layout may not always fit with windthrow management goals. A common example is the tendency for layout crews to locate boundaries at the edge of a break down into a stream.

BMPs for Boundary Edges In Riparian Or Wet Seepage Areas

- ***Avoid leaving highly exposed[2] edges on breaks into gullies, escarpments or incised streams –*** Locate exposed windward edges <u>at least</u> 10 metres into the wind and upland from the slope break into the riparian area (Figure 7-I).

  Rollerson et. al. (2009) recommend such an approach to significantly reduce amount and penetration of windthrow into the riparian zone. When reserve strips were increased in such a manner, on the windward side near gully breaks, they found up to 50% less damage overall and decreased penetration of almost 30% (Figure 7-J). Moreover, simply by moving the boundary back and away from the break, reduced the chance of penetration over the break into less stable conditions.

  Note – 10 metres should be considered a starting point. Larger setbacks may be required depending on stand/site conditions, the risks, expected windthrow penetration and your risk-management philosophy. For example, increase the setback where there are steep gully headwalls, especially at higher elevations where there is a potential for debris flow initiation (see Section 3 – Windthrow Trends).

- ***Avoid highly exposed edges in or on the edge of a wet depression / seepage zone*** - moving a boundary back into drier upland soil and establishing a 10-30 m buffer (depending on the situation) in the upland area may prevent penetration carrying several tree lengths across, or right through the wet area.

- ***Look for windfirm riparian areas to use as boundary anchors*** - If stands in and adjacent to water saturated soils have large gaps and trees exhibit acclimation to the local wind regime, consider using this as a natural edge for the harvest area (see Figure 7-F).

- ***Consider that one-sided riparian reserve strips with lee or parallel edges[3] will have fewer concerns where consequences are high*** (Figure 7-K) - Using a two-edged riparian

[2] Highly exposed edges – is meant to imply that the edge is exposed to prevailing storm winds with significant fetch in front of it.

reserve strip often ensures that one edge will be more exposed to the prevailing wind direction The trends shown in Figure 7-K are instructive but need to be used with full consideration of the possible site and stand factors which may have contributed to the range (error bars) associated with the sample. Local calibration is extremely helpful.

- ***Avoid highly exposed narrow reserve strips (riparian or otherwise) or conduct crown modification on most trees in the strip–*** When strip reserves are narrow and some windthrow starts to occur, subsequent winds will often blow right through the entire strip resulting in maximum drag force occurring on all trees.

  In windthrow prone areas, monitoring indicates increasing total reserve strip width beyond 30m (Figure 7-L) will lower the proportion of the strip blown down.. Monitoring of riparian reserves indicates that increasing reserves to 25-30 m (each side of a stream) results in a lower proportion of the reserve blown down (Figure 7-M).

  Riparian areas are more vulnerable to wind damage as soils are wet, trees are tall (due to increased productivity) and rooting may be asymmetrical (if on gully sidewalls). While Figure 7-M shows 30 metre reserves (each side of stream) to have the least windthrow, this width may need to be increased (or decreased) depending on the site and stand conditions, the proximity of important forest values and the expected level of windthrow penetration into the edge.

  Narrow strips may have a chance for success where they are open/gappy with widely spaced larger susceptible trees that are suitable for topping and pruning to reduce susceptibility. Such investments should be balanced against the objectives and the tradeoffs with larger buffers. See "windfirming" later in this section.

BMPs for Other Edges

- **Use caution when designing irregular shaped downwind edges (facing the wind) because it may expose trees to higher wind loads than necessary** (Figure 7-N). The data in this figure are from wind tunnel experiments on model forests and assume the stand is on flat ground. The relative loads on trees in these scenarios may increase or decrease depending on the upwind shelter or exposure due to topographic features, site and stand conditions.
- **Consider wind turbulence on steep leeward slopes of ridges or topographic obstructions** - variable strong gusts may cause windthrow in these areas a considerable distance downslope off the ridge– possibly in the opposite direction of the prevailing wind.
- **Look for windfirm scenarios with a low likelihood of windthrow** – to anchor boundaries – see previous Figures 7-F to 7-H. Old cutblock edges which have stabilized over time should be left intact where possible and can provide the leading edge on retention patches in second pass blocks.
- **Look for opportunities to utilize patches of advance regeneration if available to help lift the wind profile in front of an exposed edge** – This has been reported as an option on some blocks. However it is likely rare that such an opportunity will exist where it is most needed, since stands with a well-developed understory usually have an open canopy, and therefore are relatively windfirm.

[3] Relative to the prevailing storm winds.

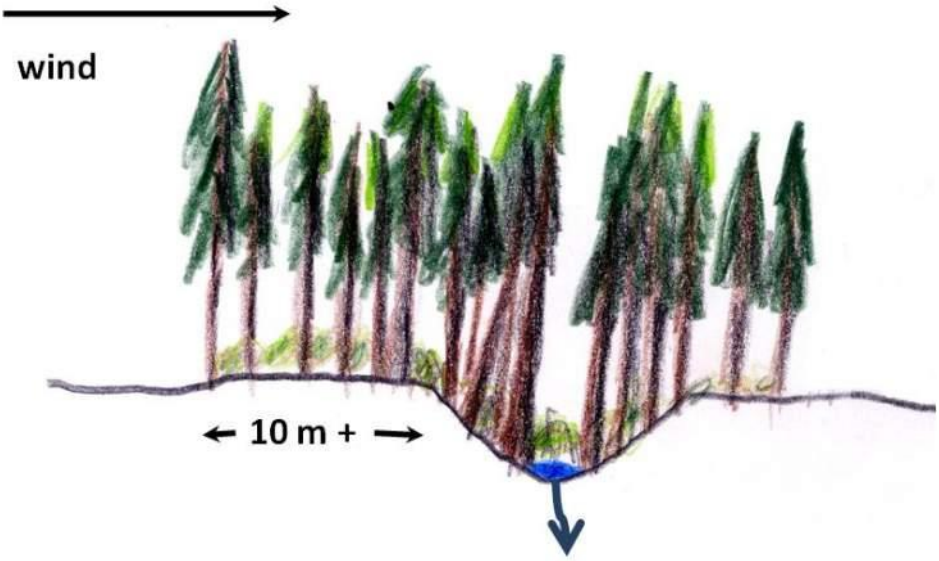


Figure 7-I. An illustration of a reasonable setback to avoid windthrow penetration into less stable riparian gullies or swales.

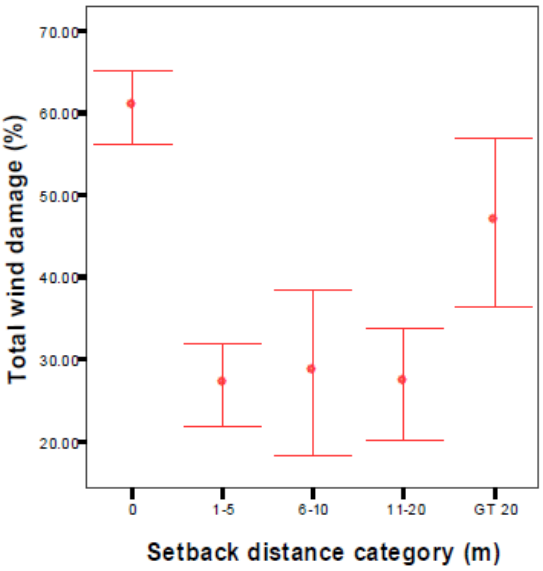


Figure 7-J. *Data from Rollerson et. al. (2009) collected right across the BC coast from southern Vancouver Island to Haida Gwaii. Note even modest setback can make a large difference.*

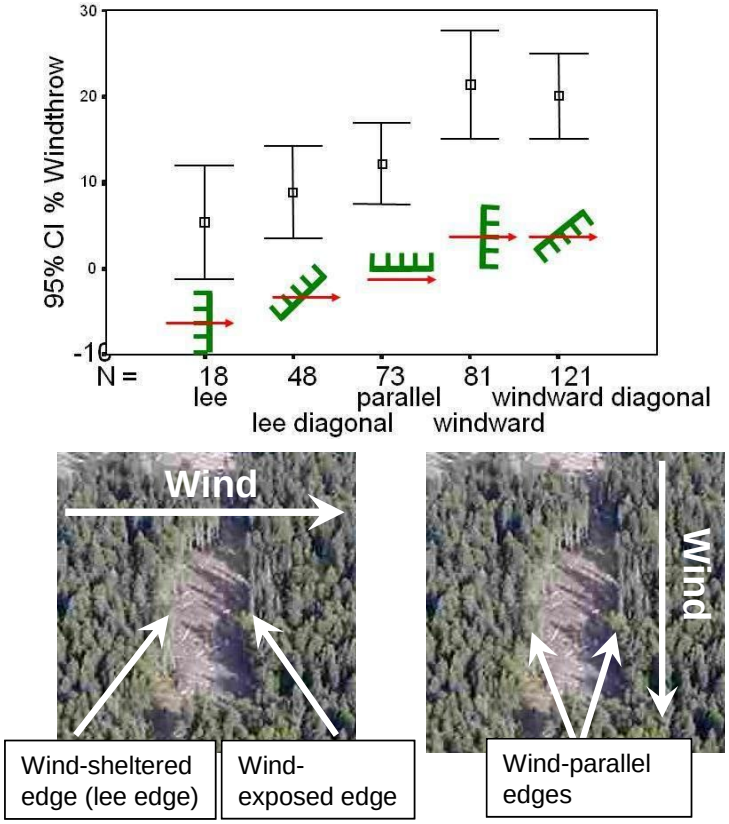


Figure 7-K. Boundary orientation relative to the wind direction and its effects on percent windthrow (Rollerson and McGourlick 2001).

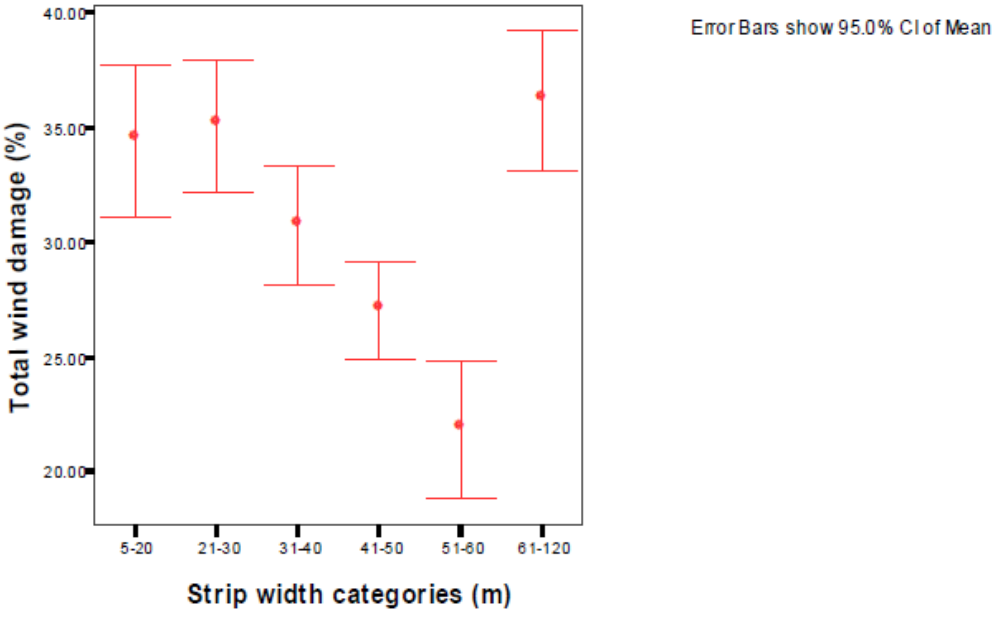


Figure 7-L Data from Rollerson et. al. (2009) collected across the BC coast from Vancouver Island to Haida Gwaii.

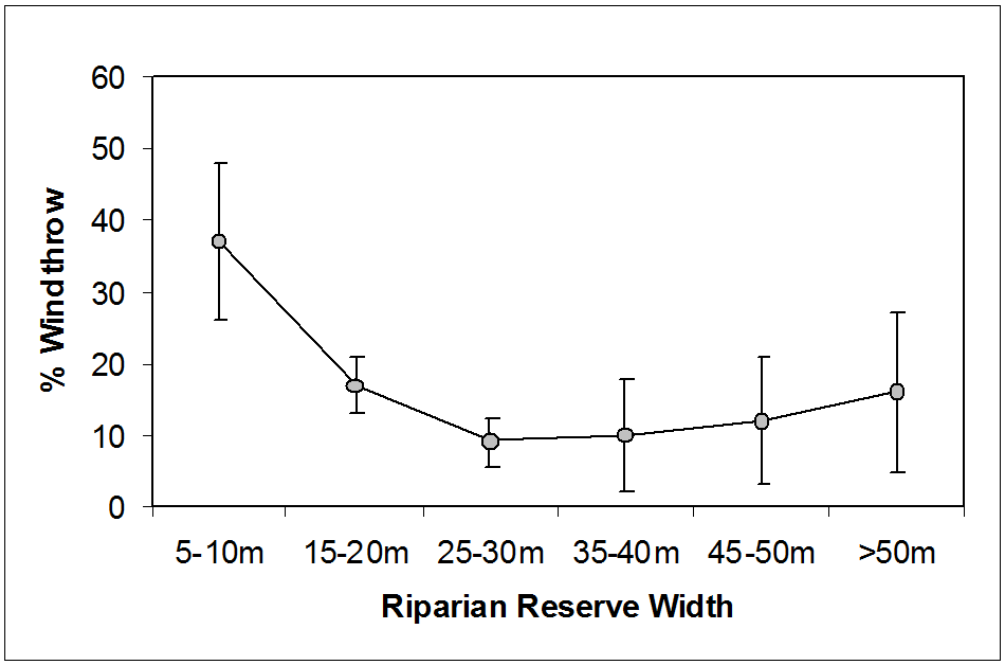


Figure 7-M.Relationship between riparian reserve width and windthrow damage (Rollerson and McGourlick 2001). Note – there were fewer larger reserve widths sampled in this study (i.e. > 35 m) contributing to the larger error bars.

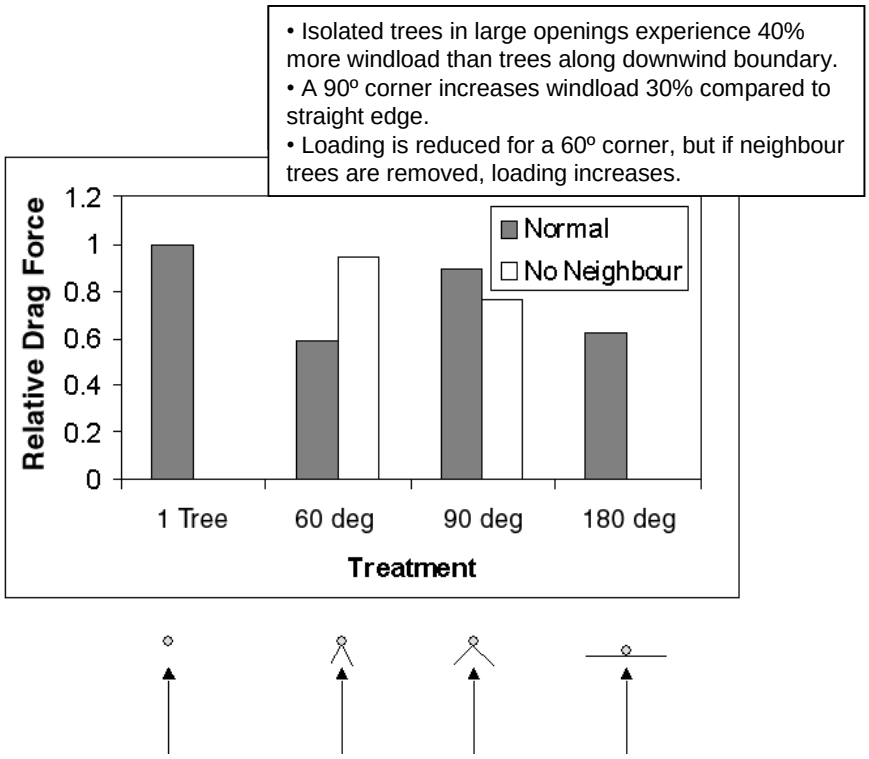


Figure 7-N. Relationship between relative drag force and wind-exposed edge shapes at the downwind side of a large opening (Novak 2000).

Change Layout - Adjust size and shape of internal retention patches or strips

On the coast variable retention or VR has become a popular one-entry approach to non-clearcut prescriptions to meet objectives for a range of values. As variable retention is often left for the long term, there may be a desire to minimize the timber volume left, leading to excessively small clumps or narrow strips. When the retention is highly exposed and the trees in the small clumps and strips are vulnerable to wind, high levels of windthrow can result.

BMPs for Internal Patch or Strip Retention

- ***Consider increasing patch size –*** to help protect an identified feature. However, be aware that the amount of retention damaged by wind may not be reduced. In fact, it could increase, because more retention is being exposed to wind. The key is ensuring that this windthrow is sufficiently far enough away from the feature.
- ***In addition to increasing patch size, consider locating and orienting the patch to protect a feature (where relevant)*** (Figure 7-O) - favourably orient somewhat elongated patches into the wind direction to protect identified forest values and/or features at their centres (e.g.,. CMT, receiving sites, wildlife trees, etc.).

  While these trends are a useful guide for principles of patch size and orientation, it should be noted that the data for this study is from the BC interior and patch sizes should be calibrated to the local area site, stand and meteorological conditions.

- ***Avoid pointed leading edges for patches facing into the wind.*** Elongation of patches at the leading edge may be carried too far. Narrow "points" on the end of leading edges of patches are not more aerodynamic (contrary to intuition).

  Such a design will usually encourage windthrow at "the point", resulting in a blunt rounded edge. This is because prevailing winds will always vary somewhat, hitting a leading "point" from either side, with trees at the point quickly losing neighbors and catching 100% of the drag force. The principle is similar to that shown in Figure 7-L.

- ***Consider that most windthrow along edges of wider strips and larger patches occurs within the first tree length -*** This is generally true if you have a "moderate likelihood" for windthrow, which is the most common situation. Note that edges with a "high likelihood" for windthrow may see damage extend beyond one tree length.

  In moderate likelihood scenarios, windthrow is usually focused within 30 – 50 metres, and then stabilizes (Figure 7-P). Depending on the width of the strip or patch size and the proximity of the forest value it is designed to protect, it may be reasonable to leave damaged stems where they rest – especially where trees do not fall through the canopy and serve to stabilize the edge (See "ability to fall through the canopy" in Section 2 – Windthrow Concepts).

- ***Observe the penetration of damage into old cutblock edges -*** this gives you an idea of the minimum patch size necessary to retain timber beyond the edge damage zone.

- ***Consider opportunities to leave some smaller "clumps" of less susceptible individual trees, (possibly with top-pruning) instead of leaving larger patches*** – where***:***

  - Small clumps will satisfy non-timber objectives <u>if they remain standing</u>.
  - <u>Less susceptible trees</u>[4] are present that can be left in clumps (and perhaps top-pruned).
  - The timber is generally high value so there is a desire to do more with less volume.

  See the information regarding windfirming in this section. The value of the extra timber harvested should be higher than the cost of top pruning the clumps. Trees will need to be climbed in advance of harvesting and costs will be at the high end of such crown modification work (when compared to treating an edge). This is because little crown-to-crown transfer will be possible and clumps will be a considerable distance apart.

[4] Section 2 – Conceptual Basis for Windthrow

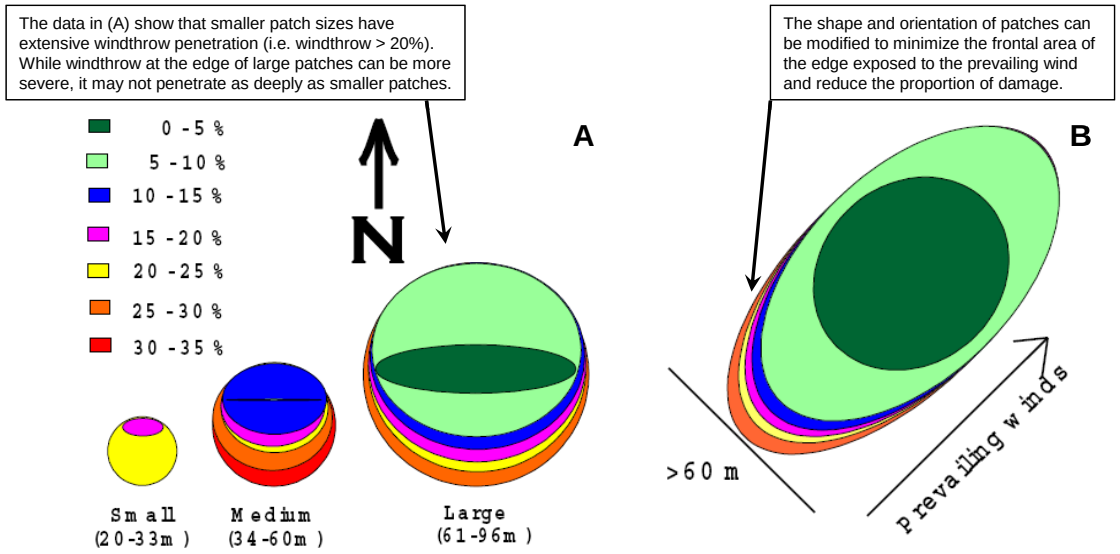


Figure 7-O. *Effects of patch size and patch orientation to the wind direction on windthrow penetration (Burton 2001).*

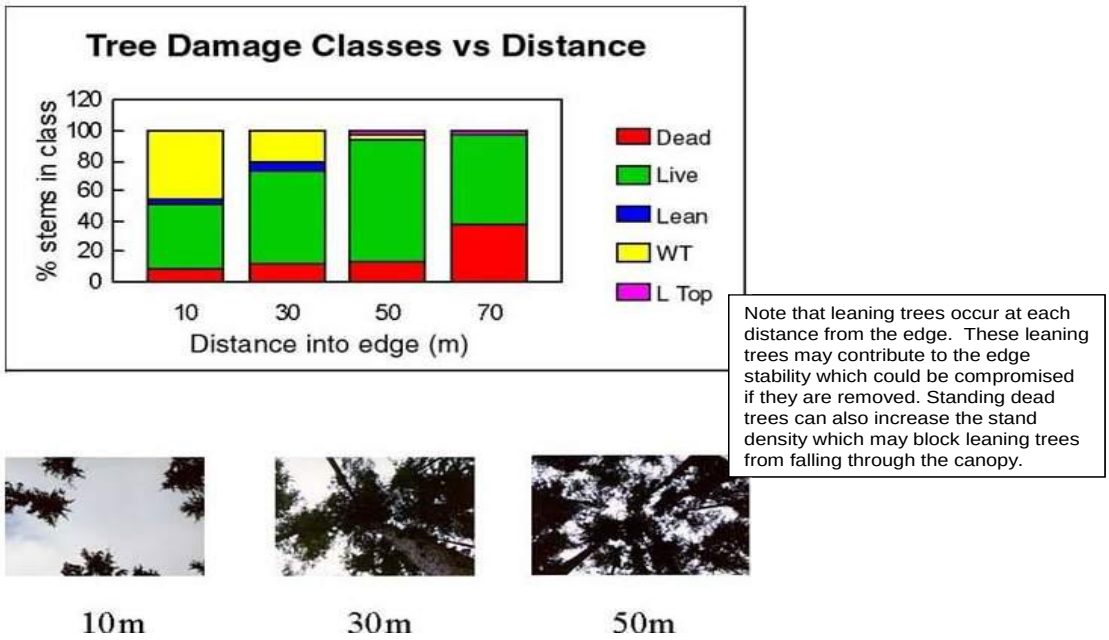


Figure 7-P. Tree damage trends with distance from the edge.

Change Layout - Reduce fetch

Pure Fetch

Pure fetch refers to the distance across an opening where wind can flow unobstructed. Understanding fetch is important in considering treatment hazard relative to topographic exposure. It is the combination of edge orientation to prevailing storm winds and fetch that provides for a high treatment hazard. When topographic exposure is also high these three features start to create concern, which could be significant depending on stand and soil features. Figures 7-Q and 7-R illustrate pure fetch and its effects on newly exposed edges and within-block retention. The concept of fetch is useful to reduce impacts on some edges, with strategically placed retention patches, block orientation, and smaller openings in conjunction with multi-pass silvicultural systems.

VR Fetch

VR Fetch (Variable Retention Fetch) is an approach to measuring fetch in more complex layout designs when pure fetch and its effects are difficult to estimate, or in complex terrain where the direction of the damaging winds is less certain. Figure 7-S illustrates a complex layout with varying levels of within-block retention and demonstrates how VR Fetch is calculated.

VR Fetch calculations can be made for a particular point (plot) of interest that contains forest values which need to be sustained (e.g.,. wildlife trees, CMT's, etc.). Block layouts may then be altered to minimize VR Fetch to reduce the likelihood of windthrow impacting the value of interest. Figure 7-T shows how the proportion of stems damaged increases with VR Fetch.

BMPs for using fetch to reduce windthrow

- ***Consider decreasing fetch to reduce wind damage on vulnerable outer block edges*** – Increased windthrow damage is noted as fetch increases past 50 m, but damage goes up considerably beyond 175 m (Figure 7-U).

  Beyond moving to a multi-pass silvicultural system, the most common approach to adjust fetch, to reduce windloading on a vulnerable boundary, is to change the size or shape of the cutblock while using some patches of internal retention. Be aware of alleyways[5] created in the block that may not be apparent during layout - between retention (VR) patches or along road right-aways. Rollerson et. al. (2009) found no clear trend in damage to outer edges of VR blocks based on the manner in which internal retention was designed. Presumably the way in which VR is designed is just too site specific for such a broad trend to emerge over many blocks, even though it has been noticed in specific situations (see Figure 7-R).

- ***Consider decreasing fetch to reduce wind damage in retention patches and strips*** – Increases in damage are noted as fetch increases beyond 50 m, progressively more up to 400+m (Figure 7-V).

[5] Alleyways - funneling between retention patches within the block – see Figure 7-X for similar considerations and trends with small openings)

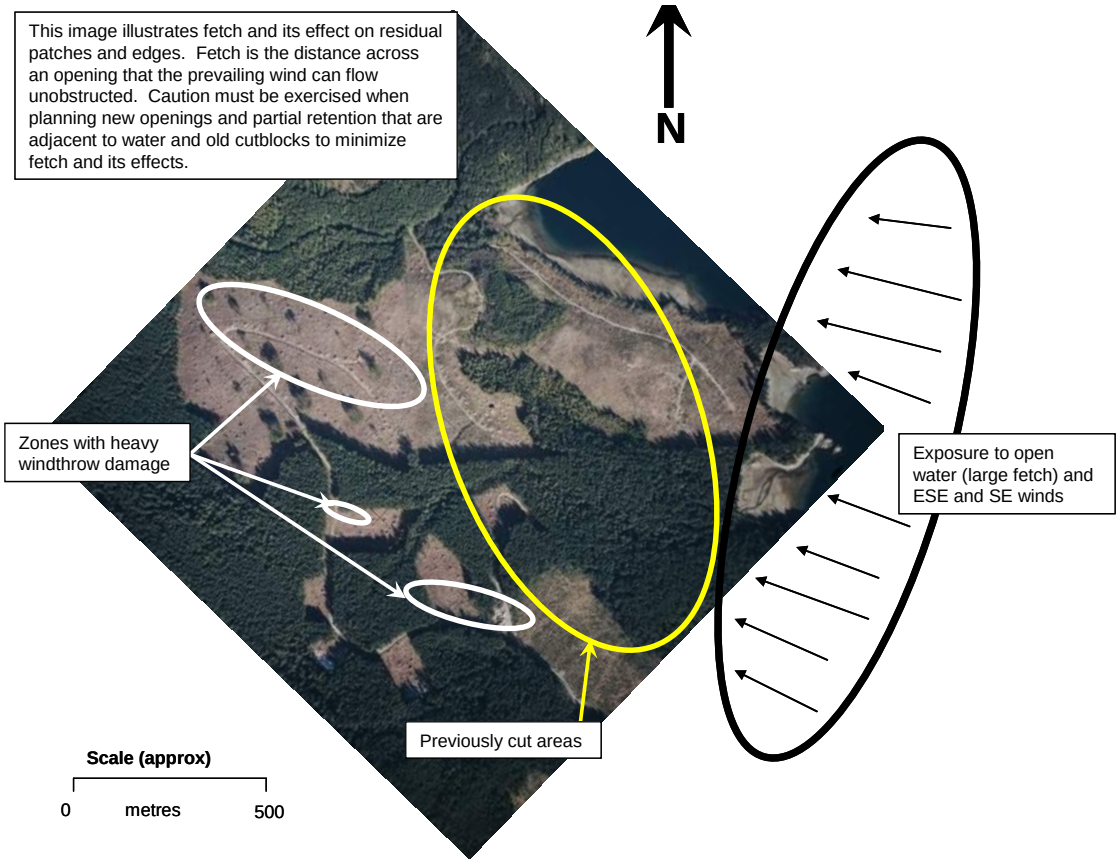


Figure 7-Q. Aerial image of patch cut and aggregate retention treatments at the STEMS II research site in the Sayward Forest on Vancouver Island.

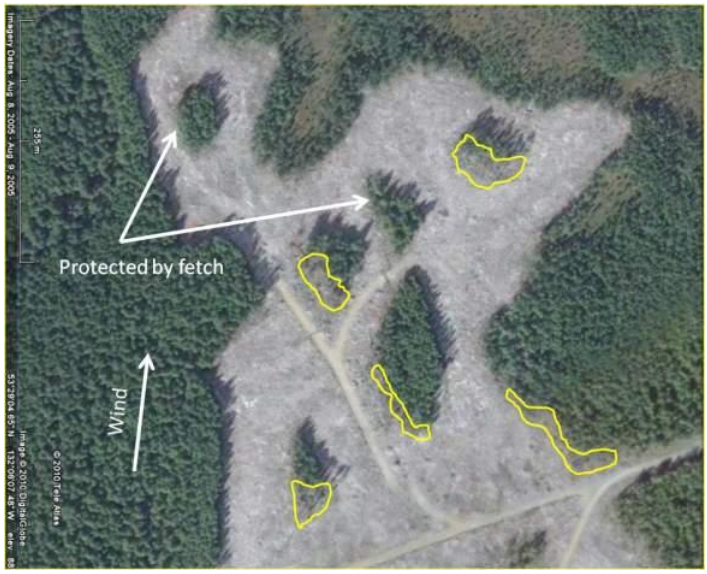
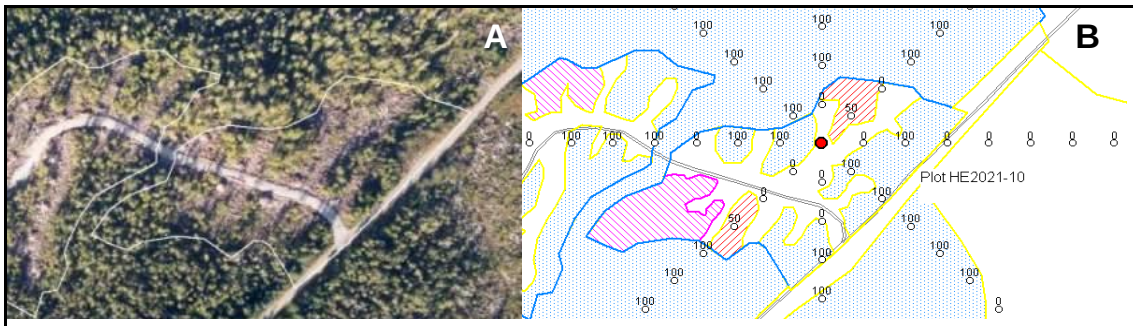


Figure 7-R. GoogleEarthTM image from Haida Gwaii with windthrow circled in yellow. Note the influence of fetch on two patches.



VR Fetch = Σ (Distance × Removal Level (%) for each 30 m section in 8 cardinal directions)

• Note (in Figure B) – Percentages indicate retention level, therefore, removal level equals **1 – (% Retention/100)** in this example

• Assuming retention levels are repeated beyond the edge of the graphic (i.e. 0 repeated east, 100 repeated north, etc.) a sample calculation of VR Fetch follows (starting at the north cardinal angle, working clockwise and radiating outward):

Cardinal Direction	Calculation	VR Fetch (subtotal)
N	1 * 30 + 9 * (0 * 30)	30
NE	0.5 * 30 + 1 * 30 + 8 * (0 * 30)	45
E	1 * 30 + 0 * 30 + 8 * (1 * 30)	270
SE	5 * (0 * 30) + 5 * (1 * 30)	150
S	2 * (1 * 30) + 8 * (0 * 30)	60
SW	2 * (1 * 30) + 0.5 * 30 + 7 * (0 * 30)	75
W	2 * (0 * 30) + 1 * 30 + 3 * (0 * 30) + 4 * (1 * 30)	150
NW	10 * (0 * 30)	0
	TOTAL VR Fetch (Σ subtotals)	**780**

Figure 7-S. Definition and sample calculation of VR Fetch (For more information on this approach see Scott 2005).

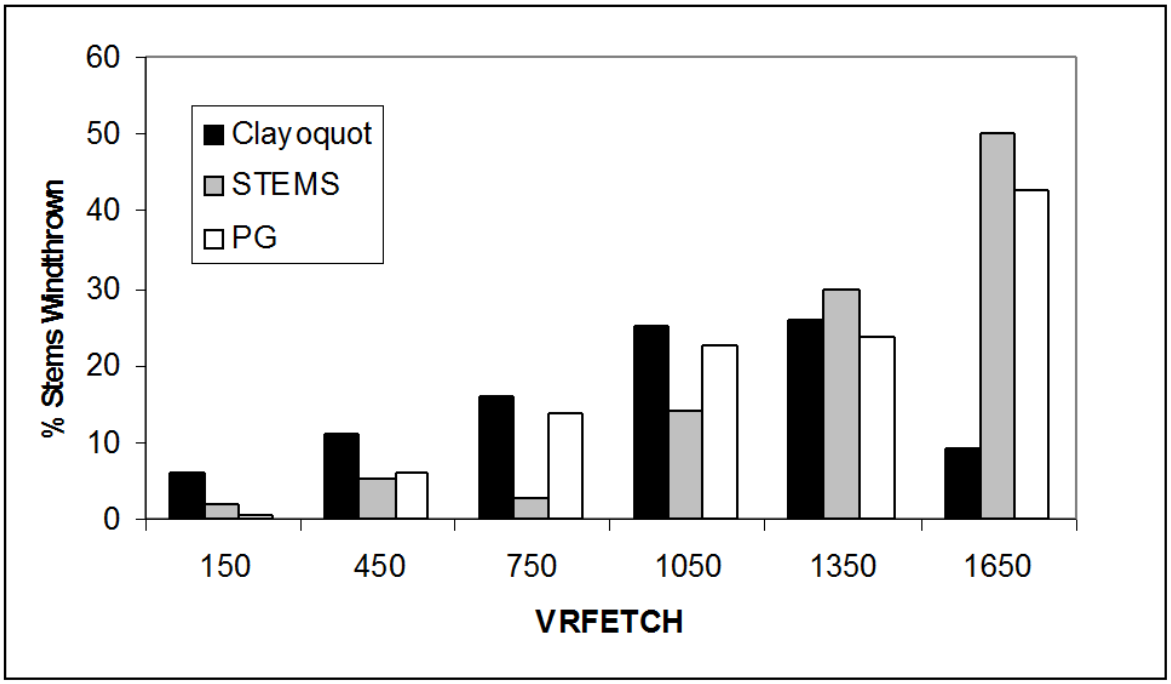


Figure 7-T. Relationship between the proportion windthrown stems and VR Fetch (Scott 2005).

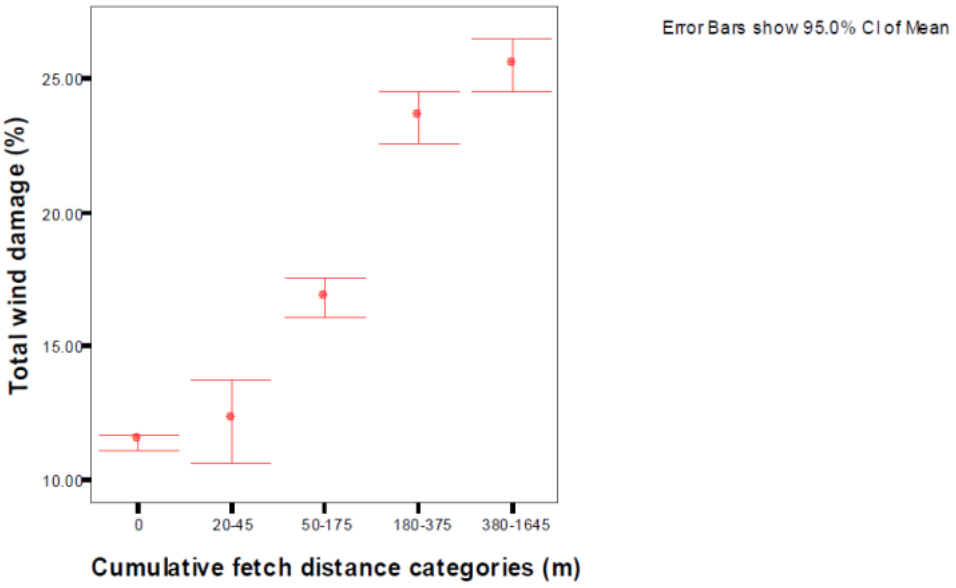


Figure 7-U. Distribution of wind damage on outer cutblock edges with changes in cumulative fetch category (Rollerson et. al. 2009). Note this graph averages data across the entire coast and Vancouver Island. Geographic differences will occur.

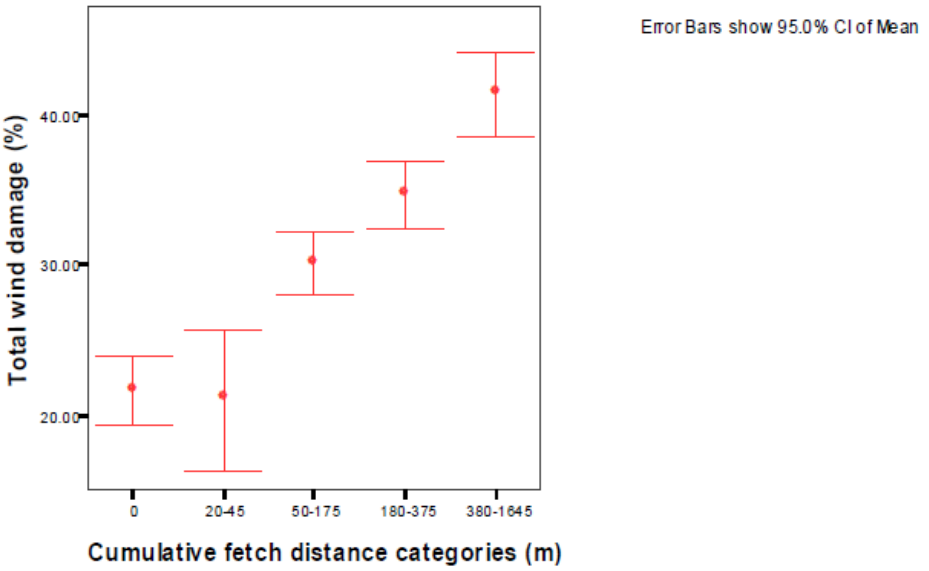


Figure 7-V Distribution of damage in internally-retained strips with changes in cumulative fetch category (Rollerson et. al. 2009), again with data averaged across the coast.

Change Approach to Layout – Prescribe a Multi-pass Silvicultural System

Multi-pass silvicultural systems are a useful alternative to one-pass clearcutting or retention systems when trying to address windthrow concerns. They are however not for the faint of heart. They require a comprehensive understanding of local autecology, stand dynamics, and ecological processes. They also require a long term vision for stand structure, sound long-term well-integrated planning and the ability to innovate with harvesting approaches in unique situations. For more detailed information on these systems, and silvicultural systems in general, see: *The Provincial Silvicultural Systems Handbook (2003)* – http://www.for.gov.bc.ca/HFP/publications/00085/SilvSystemsHdbk-web.pdf

BMPs for multi-pass silvicultural systems to reduce windthrow

- ***Use caution where narrow strips can funnel winds*** – Strips with long edges parallel to wind (or widths perpendicular to the wind direction) can funnel winds with resulting increased wind loading. Funneling damage may result when such strips are greater than one-half tree lengths, but less than about 2.5 tree lengths (Figure 7-X).
- ***Consider fetch across strip and group openings*** – parallel to the wind, consider reducing the fetch to below 5 tree lengths, and perhaps more, if consequences are high.

  Substantial reductions in wind speeds occur below about 3 tree lengths (Figure 7-Y). These data also assume flat terrain, therefore layout should be calibrated with the local site and stand conditions. If prevailing storm winds occur in more than one direction, consider prescribing smaller openings (as in a group selection) which limit fetch in all directions (Figure 7-Z).
- ***Consider multi-pass silvicultural systems with narrow strips or small groups progressing into the wind*** – Opting for small strips or group openings over multiple

passes leaves much of the stand in an unharvested condition with mutual protection between trees intact[6].

In all cases the intent is to remove strips progressively over time into the wind to gradually expose windward edges, allowing some time for acclimation of stems on the most exposed edges (Figure 7-AA & BB). Note that many decisions, other than windthrow, must be considered for such a system, e.g., harvesting costs, regeneration, growth, and impacts of other damaging agents. In some cases, such a prescription may be difficult to adapt to a particular landscape.

Also note that progressive expansion of small group openings into the wind will be more challenging than with strips. Often, openings are accessed on the ground via skid-trails to minimize additive open space over time with wider haul roads (Figure 7-Z).

- ***Be willing to innovate with suitable caution*** – Because every situation is unique in its integration of biophysical characteristics and management objectives, it is useful to try new ideas. They should always be tested on a small scale first, with modifications gradually over time to determine effectiveness.

  For Example – A wind-funneling concern associated with a strip shelterwood or strip selection system may prompt ideas to break up the wind flow along the strips (Figure 7-CC). Such approaches may also help address visual management or other concerns. However, they should be attempted on a small scale first to test the theoretical value to reduce windthrow.

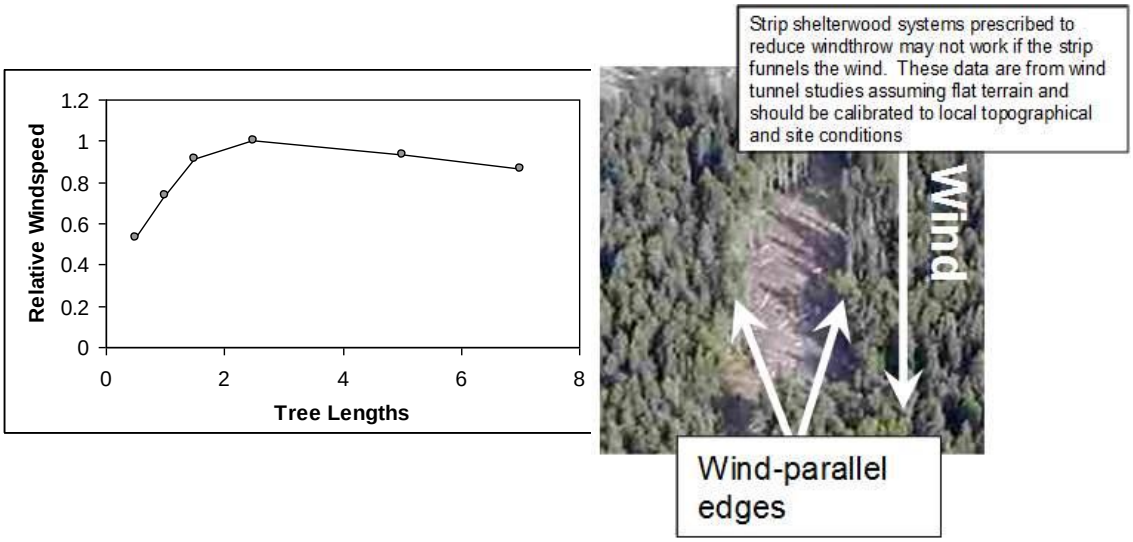


Figure 7-X. Influence of strip width, perpendicular to wind, on relative wind speed within the opening (Novak 2000).

[6] Multi-pass strip systems, either strip shelterwoods, or strip selection were developed in Europe almost 200 year ago. In France these systems are known as "coupe de bandes", in Germany, as "saumschlagbetrieb", and in Spain as "cortas por fajas".

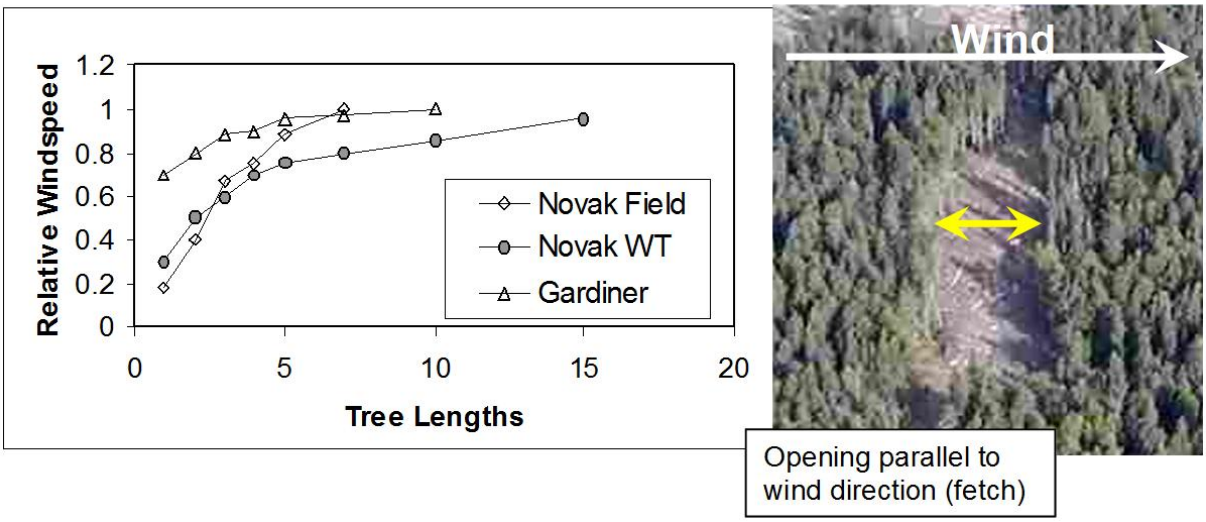
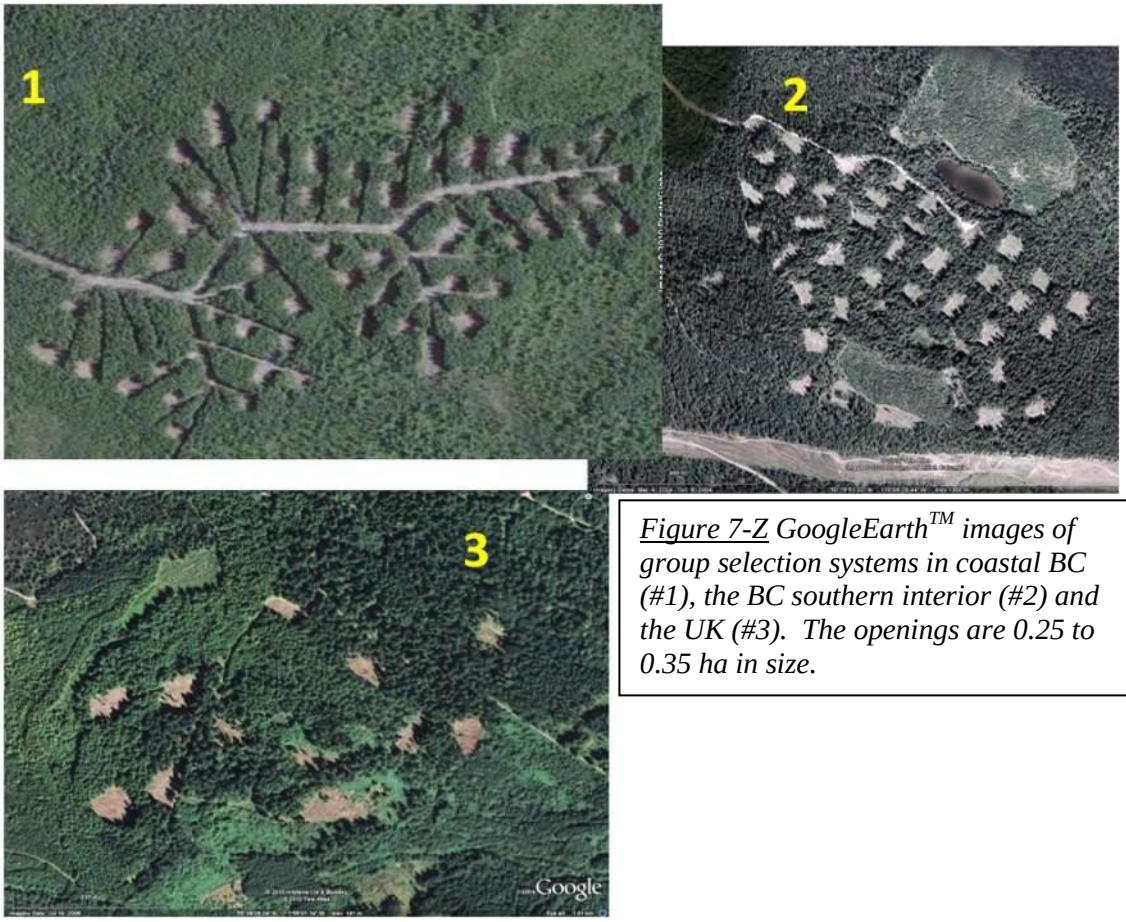


Figure7-Y. Relationship between windspeed (relative to the above canopy windspeed) and gap size parallel to the wind direction (Novak 2000).



<u>Figure 7-Z</u> GoogleEarth™ images of group selection systems in coastal BC (#1), the BC southern interior (#2) and the UK (#3). The openings are 0.25 to 0.35 ha in size.

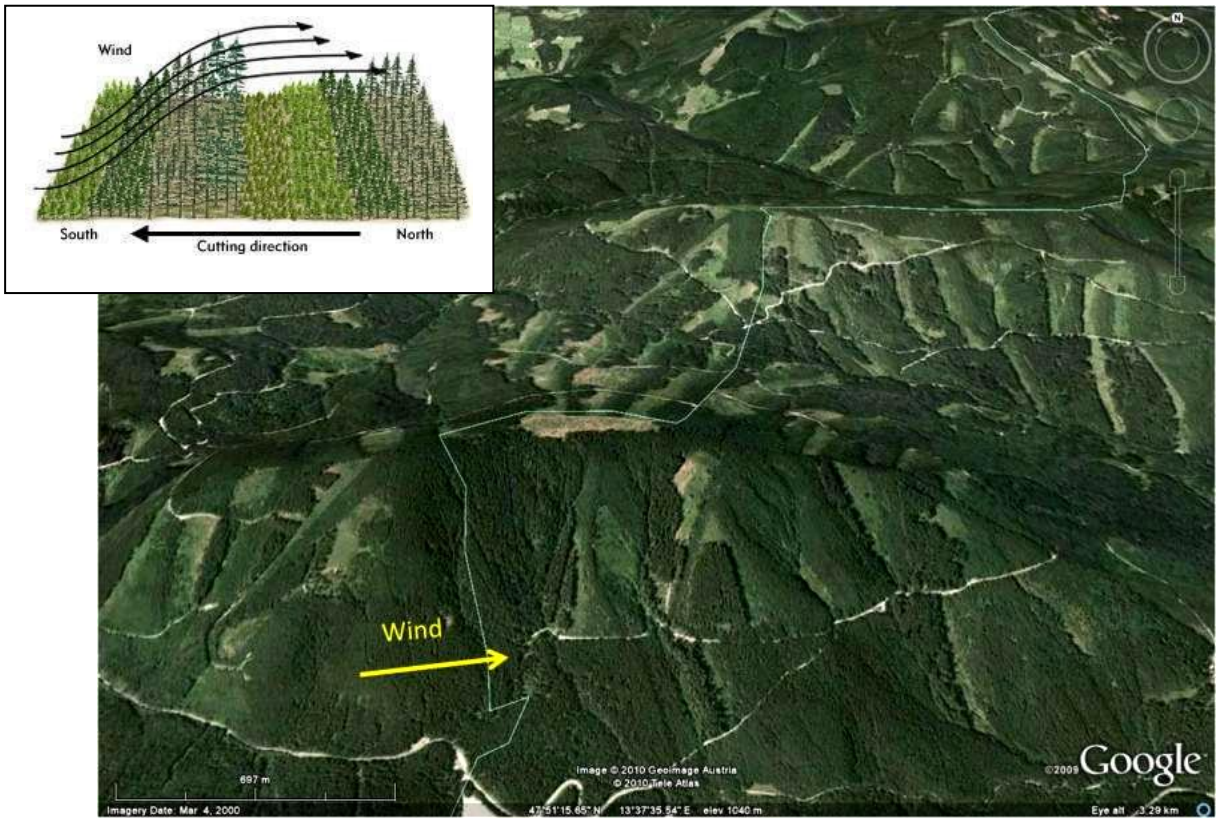


Figure 7-AA. Widespread use of strip-removal silvicultural systems in a wind-prone area in Northern Austria. The systems used here have been used over many passes developing a robust stand structure for future entries as in the graphical representation in the top left corner. Note the general distance between the latest entries and the length of the strips. These systems are used extensively in parts of Austria, Germany, Slovakia and the Czech Republic.

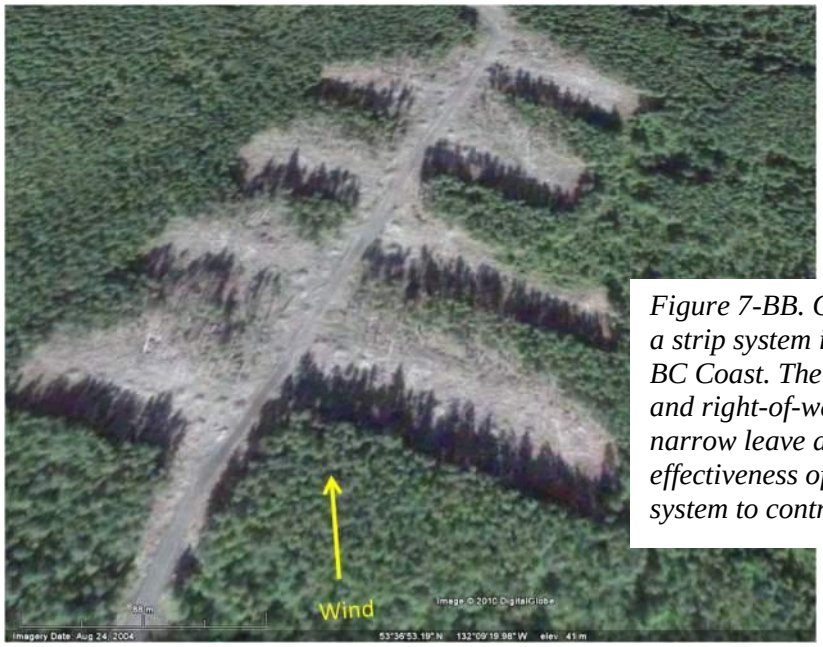


Figure 7-BB. GoogleEarth™ image of a strip system in dense hemlock on the BC Coast. The location of the road and right-of-way, together with narrow leave areas reduce the effectiveness of a multi-pass strip system to control windthrow.

Figure 7-CC. Wavy irregular strip patterns used in the West Kootenays to reduce sight lines for hunters may have potential to reduce windthrow where wind runs parallel to strips, by reducing wind penetration into the strips and subsequent funneling. However, if winds round off the "teeth" in this pattern it could compromise the original intent for non-timber values. Also, harvesting in subsequent passes, could be challenging.

Windfirming Treatments

The decision to treat edges or individual trees depends on a number of factors related the likelihood of windthrow exceeding the threshold set for maintaining the values on the site of interest. Windfirming is sometimes considered the most practical and perhaps cost-efficient option to protect forest values inside the forest edge. This is only true if treatments are

carefully chosen and correctly applied. Figures 7-DD to 7-GG provide an overview of the common forms of windfirming treatments. To be effective these treatments must be conducted prior to the onset of winter storms (late October), either preharvest or post-harvesting.

OVERVIEW OF TREATMENTS

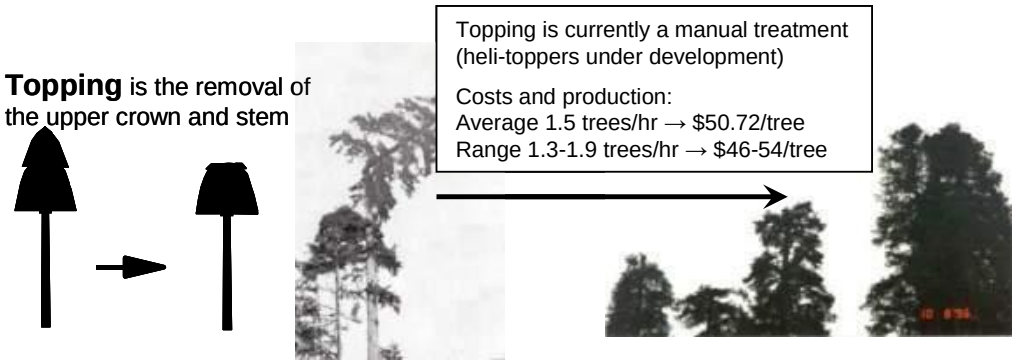


Figure 7-DD. Description of topping and associated methods and costs.

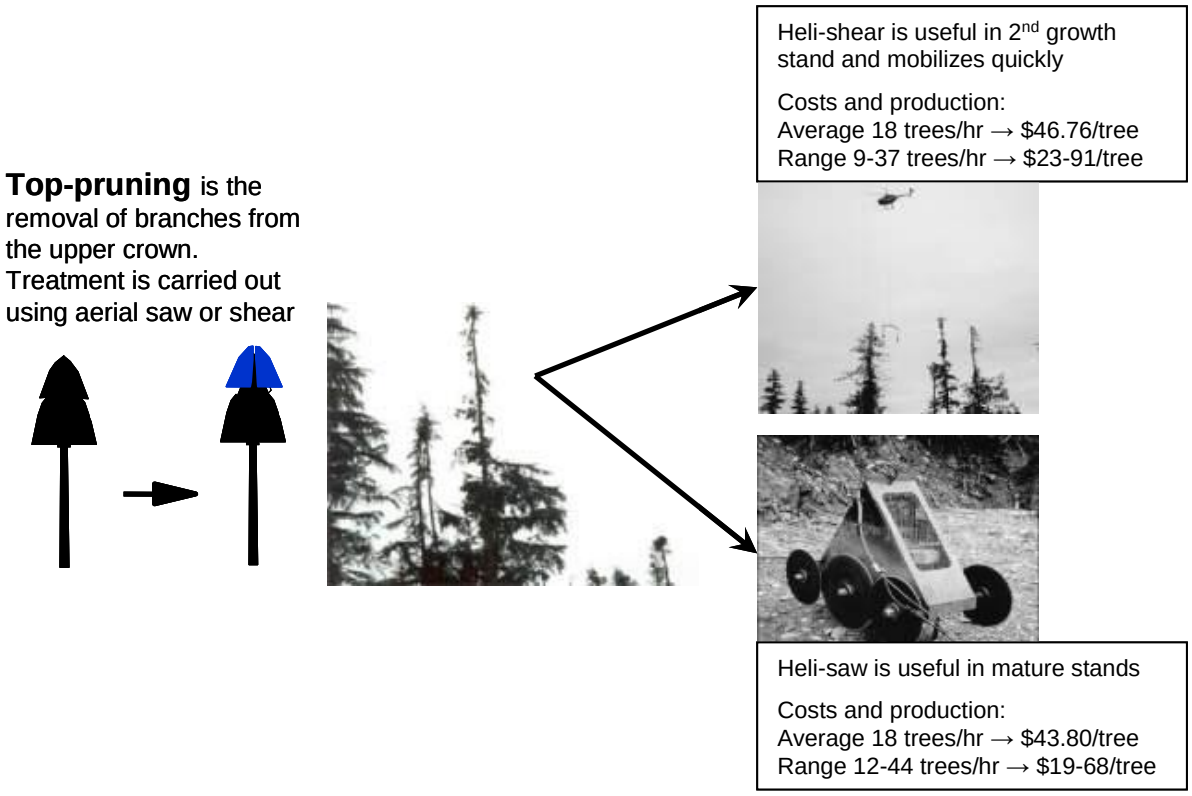


Figure 7-EE. Description of top-pruning and associated methods and costs.

Spiral-pruning is the removal of branches throughout the crown

Spiral pruning is a manual treatment made more efficient if climbers can swing tree-to-tree (i.e. closely spaced)

Costs and production:
Average 1.5 trees/hr → $50.72/tree
Range 1.3-1.9 trees/hr → $46-54/tree

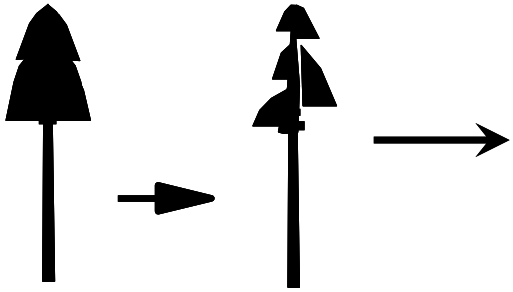


Figure 7-FF. Description and approximate costs of spiral pruning.

Edge feathering is intended to mimic partial damage along edges. Vulnerable trees (i.e. slender trees, co-dominants, low live crown ratios) are harvested at the edge before (it is assumed) they will blow down. It is best prescribed for multi-storied stands.

Figure 7-GG. Illustration and explanation of edge feathering treatment. Multi-storied stands (where dominance is well-expressed) are the most suitable. The edge is thinned by removing susceptible trees 15-30 m into the stand. Avoid high likelihood stands – feathering could make windthrow worse.

BMPs for Topping and Pruning on Edges

Crown pruning and/or topping can be an effective method to reduce crown loading on individual trees (Boswell 1997, Rowan et.al. 2003) - (Figure 7-HH). The principle of such crown treatments is to reduce the sail area of the crown (Figures 7-DD to FF).

General:

- ***Complete topping and pruning before first winter winds hit new harvesting edge*** – either treat the edge before harvesting, or schedule treatments so that they are completed by the end of September in the year of harvesting, otherwise damaging winds are likely to occur before the prescription can be implemented
- ***Consider topping and pruning in <u>moderate</u> situations*** – where negative consequences are significant.

  Avoid over-prescribing these treatments. They are expensive and so should be reserved to situations of concern where they are suitable. The benefits are questionable when treating an edge that is expected to have moderate amounts of windthrow (25-30% in the first tree length) with no consequences for non-timber values and mostly low value timber being damaged by the wind. Where likelihood of windthrow is high, often trees beyond the treated edge will blowdown due to the increased wind penetration into the edge.
- ***Remove only one third (33%) of the live crown*** – This will avoid an excess amount of crown removal which may cause tree mortality. One third removal (whether from topping or pruning) will generally reduce windloading on the crown by 50%.

  NOTE: Dense stands with minimal live crown are poor candidates for these treatments because little crown can be treated while remaining within this guideline. Often these stands exhibit high levels of post treatment mortality in the trees that were treated.
- ***Avoid treatment of larger trees that are not likely to be damaged (if left untreated)*** – It is important to consider what you are trying to achieve with the crown treatments. Often treatments that are deemed a success simply reflect treated trees that were not susceptible to wind damage to begin with (See Section 2 – windthrow concepts - for a discussion regarding individual trees and characteristics that resist wind).

  Firstly, such a treatment is a needless cost. Secondly, if larger trees that are not likely to be damaged are treated, the wind may penetrate deeper into the stand than before. This could have profound implications if such penetration encourages vulnerable trees deeper in the stand to strike a feature of concern or impact an important forest value.
- ***Treat for a minimum of one-half to one tree length into the stand -*** for a general reduction in windthrow on the edge. Treating only the front row of trees is of little value.

  Pruning can increase retention of standing live trees and reduce windthrow with distance from the edge. At the leading edge most susceptible trees should be treated (depending on consequences). As treatment progresses deeper into the edge, the proportion of treated trees can be reduced, but consider the post treatment wind penetration (Figure 7-II).
- ***Consider that untreated exposed trees may still be vulnerable*** – It may be challenging or impossible to treat all trees within a strip along a vulnerable edge.

Rowan et. al. (2003), found that pruning or topping treatments reduced the amount of wind damage in treated edge segments. Yet Rollerson et.el. (2009) reported little reduction in damage. The reason for the divergent finds may be due to misapplication of the treatment. For example - if only scattered larger dominants trees are treated, windthrow will likely occur as it normally does in the untreated codominants and intermediates exposed on the edge.

- ***Consider crown modification for trees specifically identified that could strike a feature of concern*** - These situations may occur near a culturally modified tree (CMT), an active nest for a rare or regionally important species, or another feature with similar consequences. While treatment of such trees may prevent direct damage, further treatments may be necessary if an undisturbed zone is needed around the feature.

  Prevailing storm wind directions will be important to consider, as in all windfirming treatments. By reducing the sail area on the trees most likely to cause damage, this approach may be the most risk-averse action to address windthrow concerns, where direct damage to the feature is the only concern.

- ***Consider spiral pruning trees, rather than topping*** - if visual quality is a concern and/or there is a desire to maintain the quality, health and longevity of the treated trees. Spiral pruning will reduce sail area and retain the aesthetic character of the trees.

  Tree climbers will be required for this work, as with topping. If the stands have a closed canopy, they may be able to transfer aerially from tree to tree which will reduce costs.

- ***Consider crown shearing/sawing (i.e. helicopter) in stands difficult to access with climbers*** - especially where it is difficult for climbers to transfer aerially and/or a large amount of work must be completed within a narrow time window, making it challenging for climbers.

  By using a helicopter this work can be done quickly, often relatively cost-effectively. However, where climbers can transfer aerially from tree-to-tree costs pruning or topping costs with climbers may be competitive.

- ***Avoid pruning one side of the crown in shearing operations*** - This will shift the gravitational balance of the tree possibly making it less stable (i.e. Figure 7-JJ).

BMPs for Feathering on Edges

Feathering is questionable as an effective treatment to avoid windthrow. At best, it should be used with caution because situations where it can be effective are rare and it has the potential to exacerbate windthrow (both amount and penetration) where it is incorrectly applied. Most often feathering is used as an excuse to remove some valuable timber on an edge, possibly leading to a more susceptible edge.

Consider:

- ***AVOID feathering on edges with a high windthrow likelihood*** – Feathering in such situations is likely to make windthrow worse.

- ***Feathering should only be used where you can predict with confidence the trees that will likely blow down*** - and therefore could be removed beforehand. In this way, feathering is a proactive salvage strategy.

  Note: Feathering should not be used on edges with highly uniform timber, where more susceptible trees are difficult if not impossible to discern. These unsuitable stands are

often one-story, single species and reasonably dense. More suitable stands generally have dominance well expressed with a mix of dominant, codominant and intermediate trees.

Because feathering should generally remove the more slender co-dominants, the economics of the treatment are often questionable

- ***Consider increased wind penetration with feathering*** - While feathering may reduce windthrow at the edge, it may increase with distance from the edge and potentially impact features of concern within the stand (Figure 7-KK).

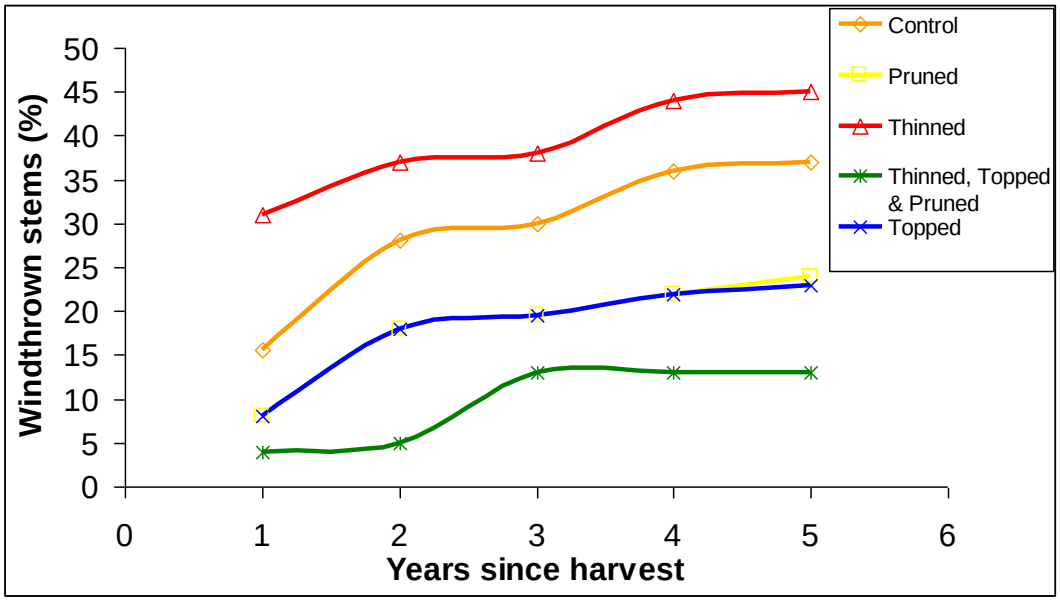


Figure 7-HH. Effects of crown treatments on the proportion of windthrow damage (Rowan and Mitchell 2005). Note that the "pruned" trend line may not be evident as it mostly follows and is obscured by the "topped" line.

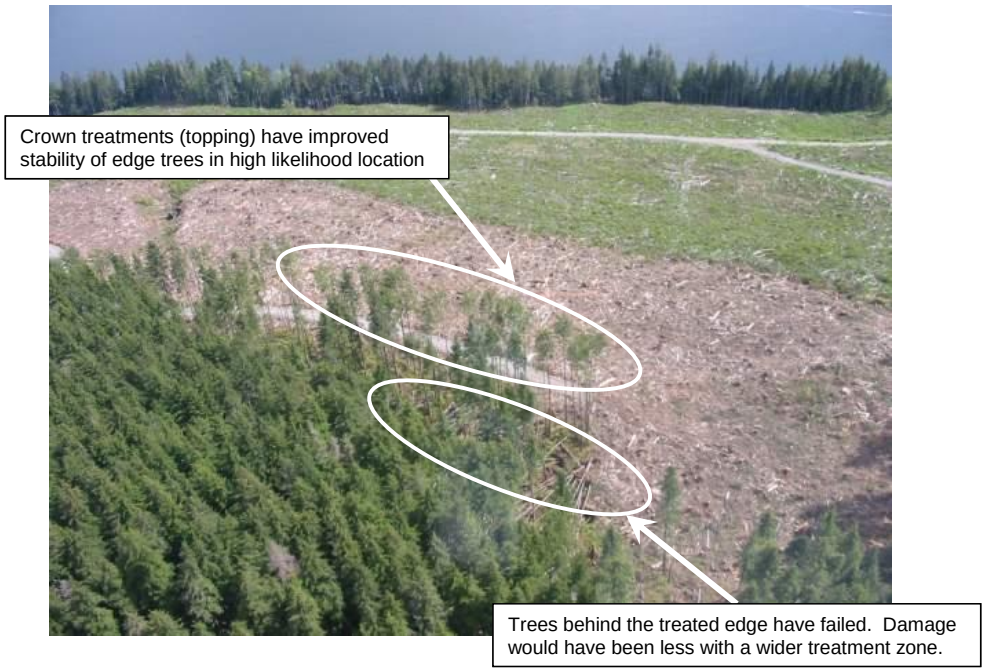


Figure 7-II. Potential effects of edge windfirming treatments.

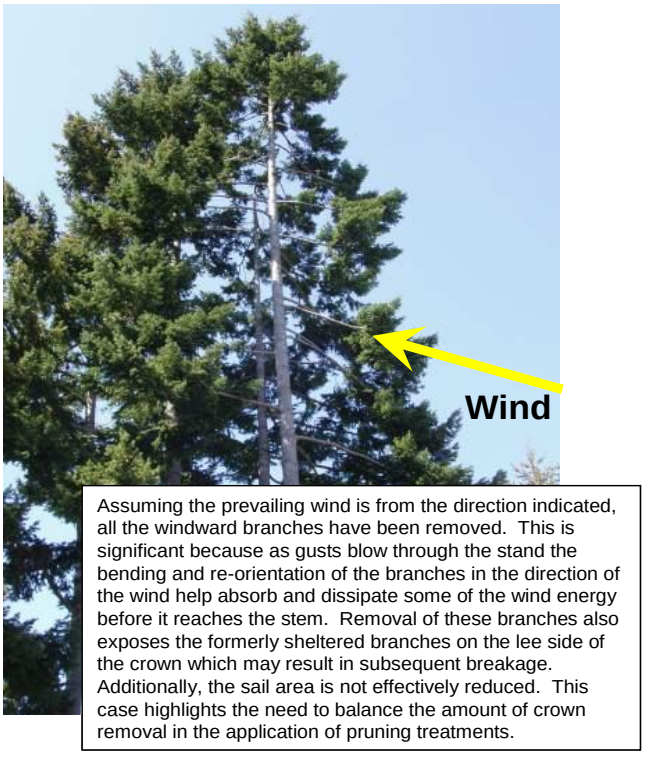


Figure 7-JJ. Example of lop-sided crown pruning treatment which may increase windthrow susceptibility.

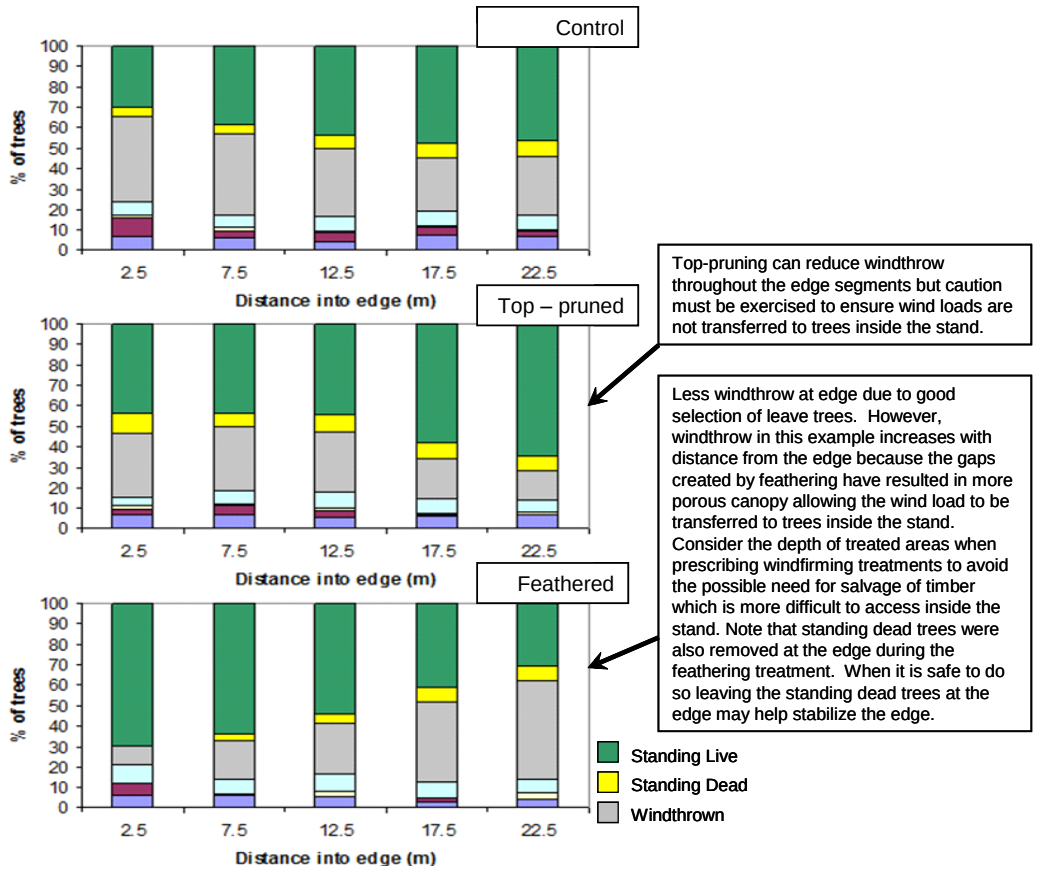


Figure 7-KK. Comparison of the effects of edge treatments with distance from the edge.

OPTIONS FOR UNIFORM PARTIAL CUTTING[7] (other than planning salvage)

Background

When uniform partial cutting is used it is important to be aware that the leave trees have acclimated to the protection of their neighbours (more or less). This protection comes in the form of crown collisions to dissipate the wind energy. The denser the stand, the more individual trees rely on protecting neighbors for wind resistance. Trees in dense stands will also favour height growth over diameter growth due to competition which results in shorter live crowns and greater height to diameter ratios.

Once neighbouring trees are removed through partial-cutting, growing space and wind penetration increases. Therefore, trees require some time to acclimate to the new conditions. Crown growth will eventually increase to exploit the new growing space, however this may take some time. Increased sway in the wind will stimulate trees to increase diameter growth mostly in the lower portion of the stem, thereby increasing taper (Figure 7-LL). If trees can continue to acclimatize in this manner without being blown over, they will become more windfirm. Note that during this time, height growth may actually be suppressed (site

[7] Thinning, dispersed retention, uniform seedtree systems, uniform shelterwoods, or single-tree selection systems

dependant). Also, the expanding crown mass will shift down slightly to improve wind resistance.

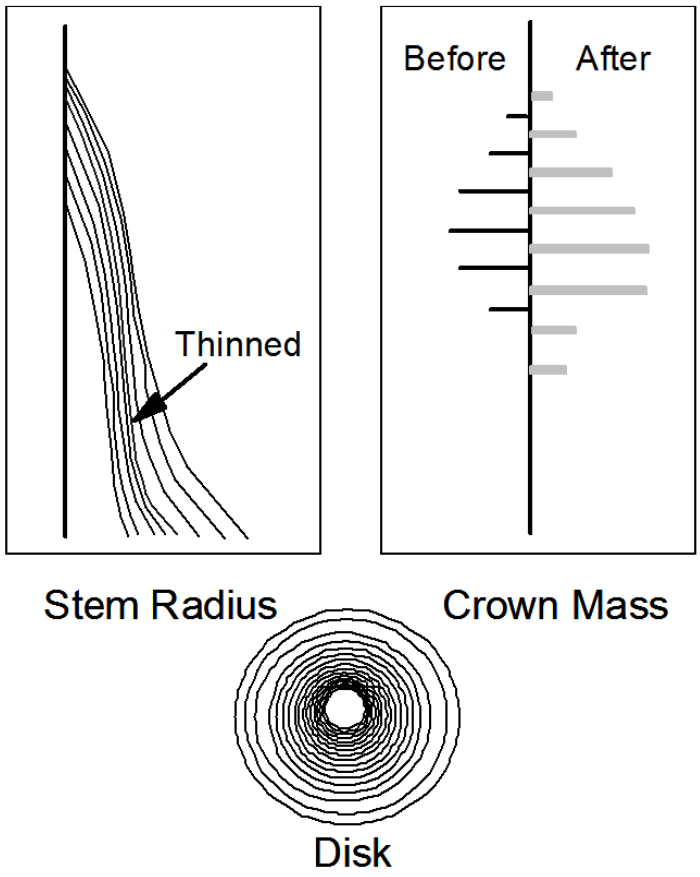


Figure 7-LL. Stem and crown growth before and after thinning treatment.

Modify leave tree parameters

BMPs for Changing leave tree criteria

- ***Favour trees with the lowest height to diameter ratio (Figure 7-MM)*** - Generally trees with a height:diameter ratio less than 60 show the highest degree of windfirmness, with those over 70 being much more susceptible. See Section 2 (Windthrow Concepts) for more information.
- ***Consider clumps of leave trees*** - If wind resistant clumps can be identified.

  Especially where stands developed naturally, often clumps of trees developed together as a unit to resist wind. These are best left as intact units or clumps.
- ***Trees with the lowest live crown ratio tend to be the most susceptible to windthrow (Figure7-NN)*** - While windthrow decreases with increasing live crown ratio, consider that larger crowns have a much greater sail area resulting in much higher wind loads (i.e. drag force is approximately proportional to the square of wind speed).

This does not mean that trees with high live crown ratios should not be selected but consider they may require crown treatments depending on the degree of exposure (see following section on windfirming). Consider the nature of the crown as many trees with a high live crown ratio may be questionable to treat. Older trees may have a high percentage of live crown that is tattered and open, allowing for less drag. Hemlock crowns tend to create more drag force than western redcedar (See: Section 2 - Windthrow Concepts).

BMPs for changing density of uniformly dispersed leave trees

- ***Consider increasing the density of leave trees*** - minimizing gaps and significant space between crowns may help reduce the amount of wind penetration into the stand, and provide for tree-to-tree damping. Consider that as density decreases the above canopy wind speeds drop closer to the ground and expose residual trees to higher wind loads (Figure 7-OO & PP).

  NOTE - This option may only be possible for commercial thinning operations. Dispersed retention entries intended to create space for regeneration will likely require considerable open space. Yet, preparatory thinnings may be used in appropriate stands to gradually open them up and allow trees to acclimatize to increased windloading over time – thus "preparing" the stand for a dispersed retention regeneration entry (Figure 7-QQ). This approach is only appropriate where leave trees can respond to such treatments and suitable acclimation will occur.

- ***Consider decreasing the density opting for a less uniform, even clumpy distribution*** – where wind-acclimated dominant trees can be selected as the leave trees and uniform spacing is less important. This may be a better option for a harvesting entry that is to encourage regeneration and growth (Figure 7-RR).

- ***Use caution when thinning trees within riparian strips or moisture receiving sites*** - especially when they are adjacent to openings to minimize the effects of increased loads on residual trees.

BMPs for Windfirming – topping or pruning in uniform partial cutting

Selection of windfirming treatments in uniform retention will depend on the amount and size of trees which need to be treated. Review the recommendations in the previous section on windfirming plus the following considerations which are more specific to uniform retention.

- ***Consider pruning over topping where the leave trees are intended for a visual management objective*** - Topped trees in a uniform partial-cut will look odd, and from a distance may not provide for the visual buffer envisioned.

- ***Target only those trees that need to be treated*** - These treatments could be especially costly (on a tree-by-tree basis) as pruned or topped trees in an open dispersed partial-cut usually must be climbed, significantly increasing costs over similar treatments in stand edges where climbers can conduct aerial transfers from tree to tree.

  Slender trees with small live crowns are poor candidates for windfirming treatments because the crown removal may significantly reduce their growth and even cause mortality. Pruning or topping is probably best targeted only at vulnerable leave trees with long live crowns to reduce the newly exposed sail area.

Change general silvicultural system design

This option should be seriously considered if there is a widespread concern for windthrow in your leave-trees. Consider both your approach to the silvicultural system and block design. This will depend on your objectives and the opportunities the stand provides for making these adjustments. Basically your options are:

- Smaller openings with less fetch, possibly with multiple passes.
- Patch/strip (group) retention.
- Combinations of the above, possibly still with some dispersed retention.

NOTE – See the considerations under Options for Clearcut and Patch/Strip Retention Edges for a more detailed discussion of these options.

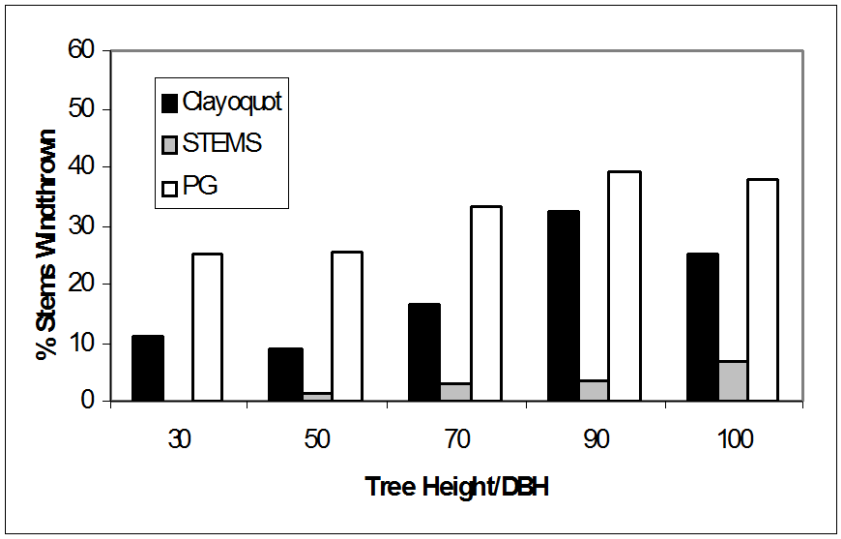


Figure 7-MM. Windthrow trends with height to diameter ratio in three separate studies (Scott 2005).

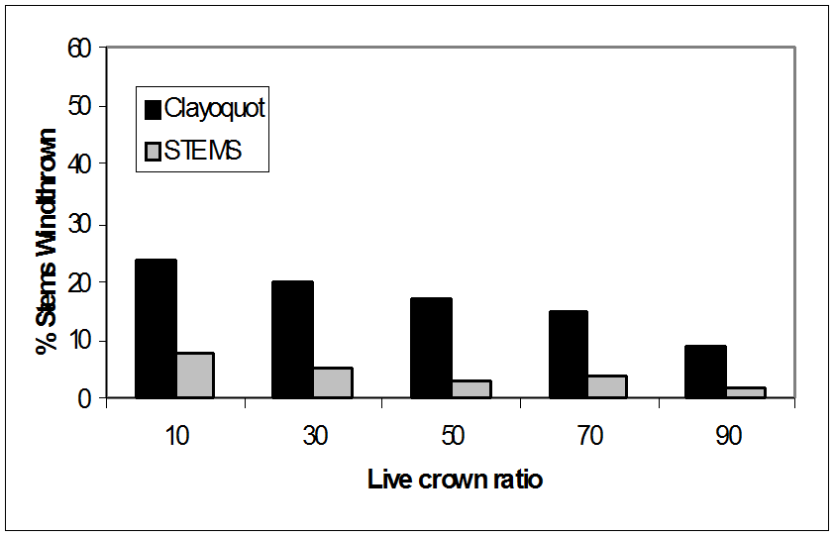
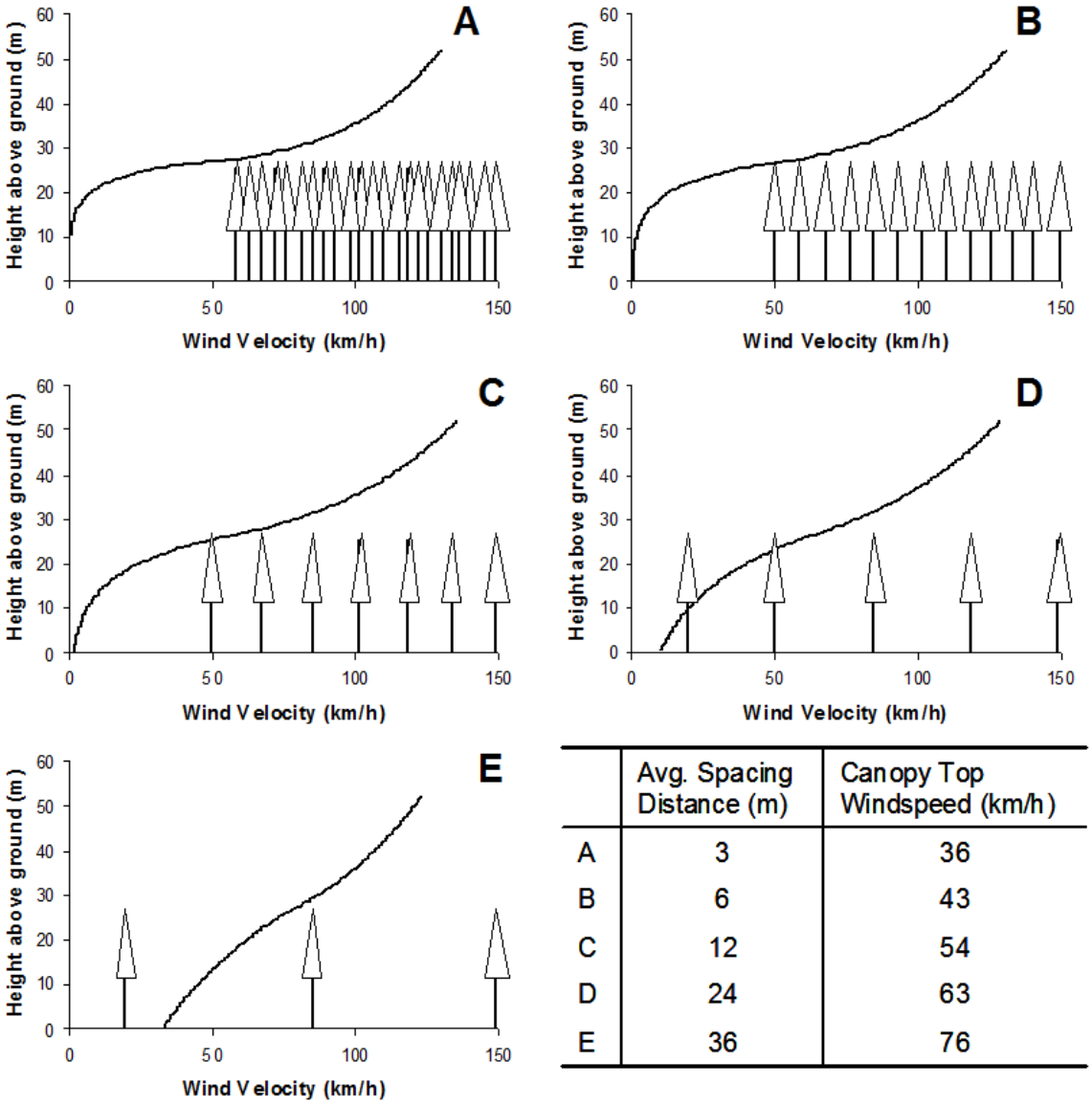


Figure 7-NN. Windthrow trends with live crown ratio (Scott 2005).



	Avg. Spacing Distance (m)	Canopy Top Windspeed (km/h)
A	3	36
B	6	43
C	12	54
D	24	63
E	36	76

Figure 7-OO. Vertical wind speed profile in a 26m tall stand simulated over at a range of spacing distances with an above canopy wind speed (10m above the canopy) of 100 km/h. While these functions are based on wind flows through field experiments and model forests in a wind tunnel, the simulations illustrate well how the vertical wind speed profile drops into the stand with decreasing density.

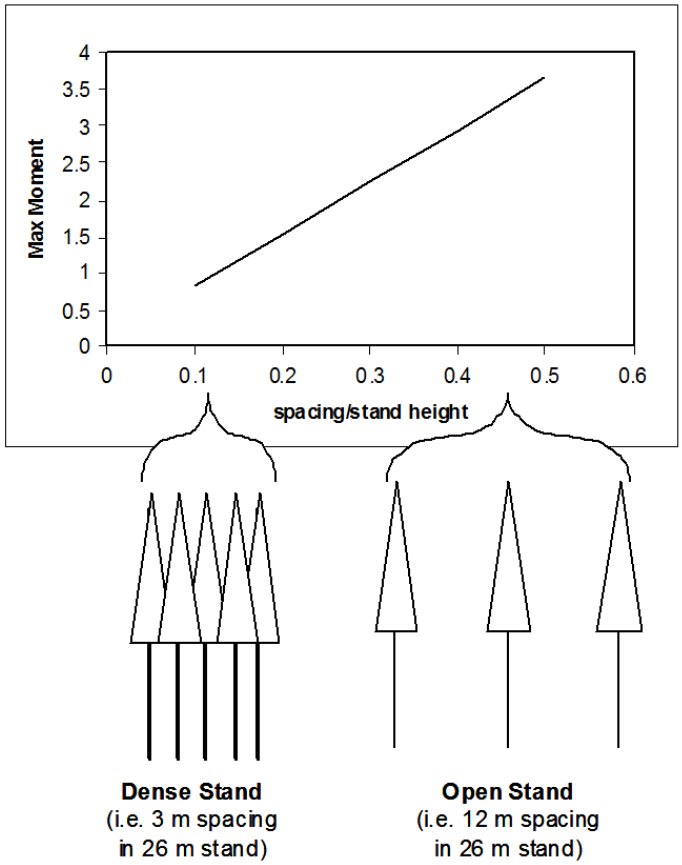


Figure 7-PP. Effects of increased spacing distances on normalized (to 0.14 spacing factor) maximum turning moment - maximum torque to overturn the trees from wind-derived sway. (Gardiner 1997).

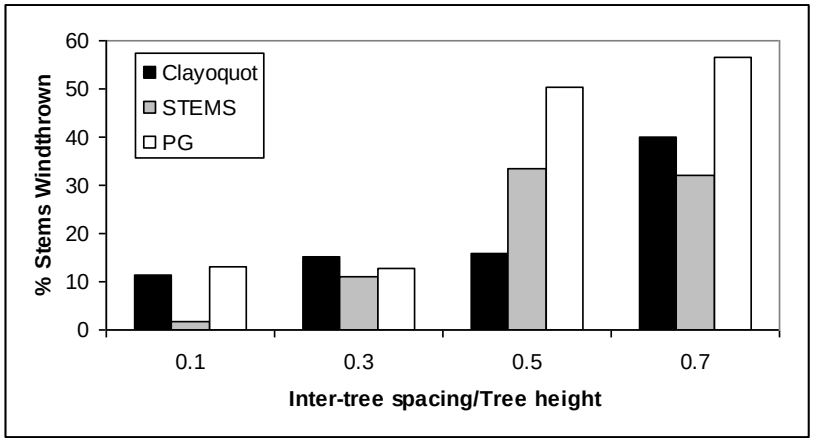


Figure 7-QQ. Impact of spacing factor on windthrow on three BC sites (Scott 2005). Clayoquot had typical West Coast old growth timber in high-wind stand on the West Coast of Vancouver Island. STEMS is a Douglas-fir second growth study area near Campbell River. PG examined lodgepole pine stands south of Prince George.

Figure 7-QQ. Preparatory commercial thinnings in even-aged second growth Douglas-fir / Western Larch stands in central Idaho. The intent is to harvest these stands with an open seed tree system (perhaps with some long term dispersed retention for habitat).

Figure 7-RR. Decreased, less uniform spacing in dispersed retention in a Douglas-fir stand on Vancouver Island allows for selection mostly of larger dominant trees and veterans as leave trees.

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8. Windthrow Monitoring

CONTENTS

Overview 2

Objectives for a Monitoring Program 2

Cutblock Recordkeeping to Facilitate Windthrow Monitoring 4

Landscape Level Monitoring of Windthrow Occurrence 5

OBJECTIVE 1 - To highlight landscape level trends. 5

Sampling Design for Stand Level Monitoring 5

OBJECTIVE 2: To improve and refine the mechanics of windthrow risk assessments. 5

OBJECTIVE 3: To determine if windthrow risk assessments are providing desired outcomes*:* 5

Monitoring Variables for Stand Level Monitoring 7

Amount and type of windthrow: 7

Monitoring of assessed hazard and likelihood parameters: 8

Monitoring of consequences for value objectives. 8

Monitoring Recommendations 9

Feedback from Stand Level Monitoring 9

Exit Meeting 9

Summary Reports 9

Optional if funding is available – a field review with field staff: 9

Appendix 8-1 11

Example retention rankings based on value for biodiversity *11*

Appendix 8-2 13

Use a windrose approach to map out windthrow 13

Overview

Goals and Objectives for a Monitoring Program

The general goal of a windthrow monitoring program is:

- *To learn from past windthrow management activities to facilitate continuous improvement over time.*

To achieve this goal, windthrow monitoring includes a number of potential objectives:

1. To support localized landscape level probability mapping by tracking the significant occurrence of windthrow in the operating area over time to highlight potential problem areas, susceptible stand types and prevailing directions of damaging winds to aid in development planning.
2. To determine if the assessment of windthrow risk[1] and subsequent linkage to layout design and prescription development is providing the desired outcomes.
3. To improve and refine the mechanics of windthrow risk assessment, which will ultimately improve outcomes.
4. To better understand the success of windfirming and other measures to limit windthrow.

1. To highlight landscape level trends to complement probability mapping:

Building on the broad landscape level insights from the Business Area probability maps to map windthrow occurrence over time will help facilitate improved approaches to silvicultural system and block location, orientation and sequencing across landscapes. The probability mapping may initially help to identify landscapes where windthrow is perceived as an overwhelming challenge for layout and prescriptions. Mapping windthrow and salvage locations over time along with the orientation of the damage helps identify locally windthrow prone areas/features and dominant wind directions. This added information will help to design broad strategies for harvesting, silvicultural systems, retention and reserves over time.

While probability mapping will be useful to start development of these strategies, not all of the business areas have such mapping. Also, landscape monitoring of windthrow occurrence will gauge the success of such broad approaches and may provide insights to refine them.

2. To improve and refine field windthrow risk assessments

It is important to use monitoring over time to continually improve the application of the windthrow risk assessment and the associated skills of layout and prescription staff. If these mechanics are improved so that windthrow risk and all the associated hazards and thresholds are better estimated, then future impacts on value objectives may be avoided. It is therefore desirable to improve the skills and judgments of assessors before impacts on values occur.

[1] Reference to "windthrow risk assessment" is intended to include the full package of measurements, assessments, estimates and predictions to determine biophysical hazard for windthrow, likelihood of windthrow and ultimately, windthrow risk.

Primarily, this monitoring objective is achieved by validation or refinement of predicted estimates of windthrow likelihood and associated thresholds (penetration and amounts) in specific stands, landscape settings, and layout configurations. Such monitoring should be conducted over a range of situations and circumstances, and should therefore likely not be limited to those with concerns about impacts on value objectives.

At times, monitoring may be focused mostly on improvement of assessments, because few situations are being encountered where value objectives appear compromised. Regardless, monitoring should always include a review of the estimated consequences and thresholds, which may have been over-estimated for the particular situations encountered, incurring unnecessary costs in staff time, treatments or reserved timber. Such monitoring requires significant expertise and experience with windthrow hazard and risk assessment and management.

3. To determine if windthrow risk assessments are providing desired outcomes:

First it is important to determine if desired outcomes are being attained by exploring the impacts on key values and associated objectives in spite of windthrow assessment and management efforts. Where it is clear that desired outcomes are not being attained, the monitoring will initiate an exploration of the questions associated with the problem(s). This may be a relatively simple or considerably complex investigation. The range of questions that may be associated with windthrow-compromised value objectives include:

a. Was the initial assessment of biophysical hazard and likelihood correct?

b. How close was the estimate of windthrow penetration and amount to that which actually occurred? Were larger than expected trees, or different species damaged by wind?

c. Was the prescription followed, or windfirming treatments correctly applied?

d. Were the consequences of windthrow under, or over estimated, and/or threshold values set exceedingly high?

e. Related – Are the consequences of windthrow understood well enough to set reasonable thresholds for windthrow?

If there is little or no impact on management values, there may appear to be little need to follow up on the questions listed above. However, this conclusion is misleading. Compromised values due to windthrow[2] may only be obvious occasionally – especially where consequences are being over-estimated and thresholds set exceedingly high. Yet, monitoring is still worthwhile.

A related continuous improvement question that may be worth spending time on is whether or not the consequences of windthrow are understood well enough to enable assessors to adequately set thresholds for windthrow. For values that frequently emerge across a landscape, this question may be worthwhile pursuing with the appropriate specialist(s). For example - coarse filter conservation objectives using retention to provide for structural diversity is particularly challenging for establishment of windthrow thresholds. A focus on windthrow at a small scale may be misleading. First, at the stand level, it may be more important to collect information on the trees left standing to determine impact (Appendix 8-

[2] expressed as actual windthrow found in monitoring exceeding preharvest threshold values (for penetration and amount).

1). However stand level impacts should be put into context with higher scales of coarse filter management before being judged as a "potential impact" or "trend of concern".

Therefore, it may be useful to have some specialists involved in helping to provide some guidance for establishing stand level thresholds for windthrow over time, and for long-term monitoring of trends.

4. To better understand the success of windfirming and other measures.

Windfirming treatments can be costly. It is therefore useful when monitoring to specifically evaluate results of such treatments, interpret effectiveness and make recommendations. It is useful to identify treatments that provide unacceptable results, evaluate the failure and provide recommendations. However it may be challenging without a well-chosen untreated control area to link success to the treatment. Windfirming conducted where it is not required may have the appearance of a successful treatment.

Therefore, it is important that monitoring include considerable expertise and experience. This will provide the most useful interpretations and recommendations to effectively improve windfirming over time.

Summary

Monitoring is an essential component for continuous improvement. It requires a well thought out procedure clearly tied to objectives for management, allowing for feedback to those who were responsible for the original prescriptions and implementation.

As can be seen from the identified objectives above, it is not only windthrow, the amount or type that is of interest, it is often whether the amount of windthrow was limited adequately so the objectives for identified values were not compromised. A determination of a compromised objective will vary by situation and could require input from a range of specialists. Clearly, monitoring may require assessment of more than simply trees on the ground. Therefore a number of suggestions are provided to address the above objectives – beginning with recordkeeping.

Cutblock Recordkeeping to Facilitate Windthrow Monitoring

1. At the cutting permit stage, highlight key windthrow assessment information in the corporate database, including:
    a. Maximum (highest) consequences ranking on the block.
    b. Maximum biophysical hazard for the block.
    c. Maximum windthrow likelihood ranking on the block.
    d. Maximum windthrow risk on the block.

    Note: The intent is to be able to characterize the block as a whole with four metrics related to windthrow hazard and risk.
2. Store results of field windthrow risk assessments for all edge/strata within each cutblock where it can easily be accessed over time.

Landscape Level Monitoring of Windthrow Occurrence

OBJECTIVE 1 - To highlight landscape level trends.

This objective for monitoring at the landscape level will support and augment the UBC probability mapping by providing more detailed information to planners within geographic units.

Suggested steps to address this objective:

Because this objective is focused on the landscape scale, it can mostly be satisfied using an office based tracking of cutblocks over time, greatly facilitated where aerial photography is continuously updated. While this information will be useful to address objective 1, it will also be used to help address objectives 2 and 3.

1. Track significant windthrow on all harvested cutblocks over time. The detection of windthrow is best incorporated in standard operating procedures associated with post harvesting activities at least 2-3 winter storm seasons post-harvest. This may be achieved from several sources:
    a. Photographs and field notes taken by staff conducting other post-harvest fieldwork in the cutblock.
    b. Satellite or ortho-photo imagery that was taken at least two years since the completion of harvest.
    c. Visual observations and photographs taken when flying over, or driving through a cutblock. Annual scheduled flyovers may be necessary where windthrow could not be recorded by other means.

    NOTE: As a minimum such information needs to be geo-referenced (with a GPS unit if necessary). As well a compass bearing should be noted to orient the photographic image.
2. This information should be entered into the corporate database for each block. As well, the location of windthrow should be recorded on a GIS overlay and clearly identified as an edge segment or dispersed retention stratum. Images of the windthrow need to be organized and stored with other cutblock information for ease of future reference.

Sampling Design for Stand Level Monitoring

OBJECTIVE 2: To improve and refine the mechanics of windthrow risk assessments.

OBJECTIVE 3: To determine if windthrow risk assessments are providing desired outcomes*:*

Suggested steps to address these objectives:

This monitoring will be field-based, including observations and measurements to validate initial assessment rankings and thresholds. It should likely be conducted every 2-3 years initially to ensure learning and improvement occurs. Gradually over time this may be extended to every 6 years or more, depending on the significance of windthrow in the Operational Unit and the general experience and knowledge of the staff. In areas with a high

staff turnover and highly significant windthrow, monitoring may need to continue at relatively frequent intervals.

1. The sampling population:

Assumptions – Because the general goal is to maximize learning from past windthrow management activities, it is most useful to focus on cutblocks where management of windthrow was, or may be relevant. Relevance can be detected by assessed consequences and/or detected occurrence of windthrow since harvest.

Use the following rules to identify the population of cutblocks which are relevant for windthrow monitoring:

a. Identify all cutblocks in the corporate database that have experienced at least 2 winters of storms.

b. From the cublocks identified in (a), list all blocks with both:

   i. Significant windthrow since harvest (see objective 1 above), and

   ii. At least one windthrow assessment with a maximum consequences ranking of moderate or higher.

   This will help isolate most, but not all blocks where value objectives may have been compromised.

c. Add to the list all other blocks having a maximum preharvest windthrow consequence ranking of high or very high. This will capture blocks with highly susceptible values but no significant windthrow noted since harvest. For these blocks it is possible that undetected levels of windthrow may have caused undetected consequences.

2. Sample Size

Assumptions: A large enough sample should be included to cover the range of windthrow management situations encountered in the operational unit so that conclusions regarding trends may be drawn with a reasonable amount of confidence.

In Operational Units where windthrow is a significant concern over the entire Unit, consider sampling a minimum of 15-20% of the cutblocks harvested 2-3 years ago ((minimum 20 blocks). In operational units where windthrow is not a significant concern, a lower level of monitoring should be considered.

3. Choosing the sample cutblocks:

Use the following screening rules to construct the sample from the sample population:

a. Choose all blocks with a maximum consequence ranking of very high or high.

b. Unless the minimum sample size has already been exceeded, use a random number generator to randomly pick cutblocks with a moderate maximum consequence ranking until the minimum sample size is reached.

4. Planning the edges/strata to examine within sample cutblocks:

<u>Assumption</u> – We are interested in a range of assessed conditions for windthrow, especially where windthrow has actually occurred. It is useful however to check the assessment in areas of concern with little windthrow to ensure windthrow and impacts are not being over-estimated. Where windthrow is not assessed (assume consequences and/or treatment risk were determined to be low) it is only worthwhile to monitor if significant windthrow has occurred - to ensure that assessment of consequences was correct.

Use the following rules to plan monitoring activities on the cutblocks:

a. Examine all edges/strata with a high to very high consequence rating regardless of the amount of windthrow noted since harvesting.

b. Examine all edges with some form of crown modification.

c. Examine all other edges/strata showing significant windthrow (either at the time of monitoring, or recorded previously) regardless of consequence ranking (if any[3]).

d. Examine more edges/dispersed strata if necessary to a total of 20, for the moderate consequence ranking. Use a random number generator to randomly choose them across the sample cutblocks.

e. Examine more edges/dispersed strata if necessary to a total of 10, for the low consequence category. Use a random number generator to randomly choose them across the sample cutblocks.

Monitoring Variables for Stand Level Monitoring

Examinations on individual edges/strata will require measurements, knowledgeable estimates, interpretations, and recommendations. While measurements may be relatively simple, considerable expertise, judgment and experience will be required for quality feedback. It will therefore be necessary to use assessment teams with considerable experience and expertise in windthrow assessments.

Amount and type of windthrow:

1. Compare actual windthrow to that predicted in the preharvest assessment. It will be necessary to first gather pertinent information from the BCTS preharvest windthrow risk assessment field forms 2 and 3. It may also be necessary to review other pertinent information such as higher level plans, assessments by qualified professionals, and other information pertinent to the block.

[3] Some edges or dispersed retention strata may not have had a windthrow assessment if the assessor did not consider it necessary, due to an anticipated low treatment hazard and consequence ranking.

Variable to measure	Original estimate or assessed value preharvest	Monitored value
a. Penetration (max)	Predicted	Measured to the furthest windthrown rootball. The actual range is also helpful.
b. Amount of windthrow in an identified zone	Predicted	Measured

2. Additional information should be collected to describe the windthrow - estimating the relative range of species, heights, diameters and direction of damaging winds (opposite to the direction of windthrow roots to top). See Appendix 8-2 for an example method to capture wind direction and frequency of blowdown.

Monitoring of assessed hazard and likelihood parameters:

Problems in predicting the penetration or amount of windthrow may originate with the preharvest predictions. At the monitoring stage, assessors have the benefit of actual outcomes to confirm monitoring estimates.

The preharvest assessment of hazards and likelihood should therefore be evaluated and compared against those estimated at the time of monitoring. These hazards and likelihoods include: topographic hazard; stand hazard; soil hazard; biophysical hazard; treatment hazard and windthrow likelihood ranking.

Where the monitoring estimates disagree with preharvest predictions, these should be highlighted and discussed with suggested reasons for possible over or under estimates of hazard and likelihood.

Monitoring of consequences for value objectives.

1. The following preharvest predictions should be compared to that found when monitoring:

Variable to measure	Original estimate or assessed value preharvest	Monitored value
c. Consequence Ranking (record value and associated attributes of concern)	Estimated	Estimated
d. Established Thresholds: Penetration (if applicable): Amount in an identified area (% basal area):	Estimated	Exceeded (yes or no) and by how much? Also comment on appropriateness of the thresholds (if possible)

2. Examine the area impacted by windthrow, making notes of obvious consequences for established values, and questions for follow-up regarding observed impacts and consequences. Note that in some cases consequence or impact may be relatively obvious, such as windthrow damage to a feature. However, the connection between windthrow damage and consequences is often subtle.

   While it is useful to know if windthrow is exceeding thresholds set in the preharvest assessment based on consequences, it is also useful to examine if the thresholds were appropriate given the consequences. It may not be possible to address this question at the windthrow monitoring phase where impacts on values or consequences are not obvious or easily measured. Instead it may be necessary at this point to recommend that specialists become involved to help determine impacts.

   A rating system, such as the example provided in Appendix 8-1 could be developed by specialists prior to the monitoring to help assess consequences where some common values of interest are likely to be encountered often. It may be useful to engage these specialists to help initially provide guidance for thresholds set in preharvest assessments.

Monitoring Recommendations

Lastly, for every edge/stratum examined, recommendations should be designed regarding what should have been done differently, including improvements to: general assessment procedures, establishment of thresholds; layout and prescribed treatments.

Feedback from Stand Level Monitoring

Exit Meeting

After monitoring in an operating unit, an exit meeting should be held for all layout personnel for the operating area. If possible this should be a one day indoor session where data are presented by block showing the results of the windthrow assessment and resultant windthrow and impacts on the identified values. PowerPoint slides by cutblock can be used with a similar format to present the information and provide discussion and learning points. These would also include recommendations of what should have been done differently where relevant.

Summary Reports

Provide a report for each Operational Unit that summarizes the windthrow monitoring findings based on the findings on each cutblock. The report should summarize key data, as well as interpretations to provide a complete picture of the quality of preharvest assessments, outcomes of assessments and associated layout and prescriptions, and unexpected consequences. Recommendations for improvement should be summarized as well.

Optional if funding is available – a field review with field staff:

Priorize blocks to visit to highlight:

1. Successes – layout that worked, windthrow was kept below identified thresholds and the integrity of the objectives is maintained (consequences avoided, regret minimized).

2. Issue blocks – windthrow compromised the objectives, consequences were not avoided, what went wrong? What could have been done differently?

3. For a one day field trip, 3 to 5 sites can be visited depending upon logistics.

Appendix 8-1

Example retention rankings based on value for biodiversity[4]

For each Group or Segment - start with the initial rankings add points according to conditions up to a max total of 5. Final group rankings will range from Excellent (5), to Good (4-4.5), to Acceptable (3-3.5), to Poor (1.5-2.5) to Unacceptable (0-1).

IF - There is no standing retention (i.e., the entire patch was blown down) – (0)

IF - Standing retention is dominated (most of basal area) by small 0 – 25 cm dbh trees with low vigor. (1 point to start)

a) If retention has moderate to high vigor – add 1 point

b) If windthrow is > or equal to 50% (basal area) - subtract ½ pt

c) If there are scattered dead snags (40 cm+) trees with a significant presence - Add ½ point

d) If retention is anchored on a riparian feature, a rocky outcrop with unique vegetation, a special habitat (bear den, nesting habitat etc), or any other uncommon biological feature - Add 1 point

e) If an intact understory is present, complete with intact forest floor, herbs and shrubs and/or understory trees - Add ½ point.

f) If patch size was designed as > 0.30 ha – Add ½ pt

(Unless the shape is long and narrow perpendicular to the wind)

g) If patch size was designed as < 0.20 ha or as a long narrow strip – Subtract ½ pt

[4] This is provided as an example; specific approaches to address local objectives may vary and require a different assessment procedure. Specialist input is recommended.

IF – Standing Retention is dominated (most of the basal area) by trees ≥25 cm. (2.5 points to start)

h) If most trees have low vigor - Subtract 1 point

i) If windthrow is > or equal to 50% (basal area) - subtract 1 pt.

j) If BA is dominated by trees 35 –55 cm dbh - Add ½ point

k) If BA is dominated by trees 55-75 dbh class - Add 1 point

l) If BA is dominated by trees 80 cm+ dbh class - Add 1 ½ points

(If one or more of these trees are > 150 cm dbh – add an additional ½ point)

m) If very large (80 cm+) trees do not dominate but are scattered with a significant presence - Add ½ point.

n) If 50%+ of the live trees (by basal area) have old growth features – dead top / limbs, some rot, lichen on branches etc - Add ½ point

o) If there are scattered dead snags (40 cm+) trees with a significant presence - Add ½ point

p) If retention is anchored on a riparian feature, a rocky outcrop with unique vegetation, a special habitat (bear den, nesting habitat etc), or any other uncommon biological feature - Add 1 point

q) If an intact understory is present, complete with intact forest floor, herbs and shrubs and/or understory trees - Add ½ point.

r) If patch size was designed as > 0.30 ha – Add ½ pt

(Unless the shape is long and narrow perpendicular to the wind)

s) If patch size was designed as < 0.20 ha or as a long narrow strip – Subtract ½ pt

Appendix 8-2

Use a windrose approach to map out windthrow

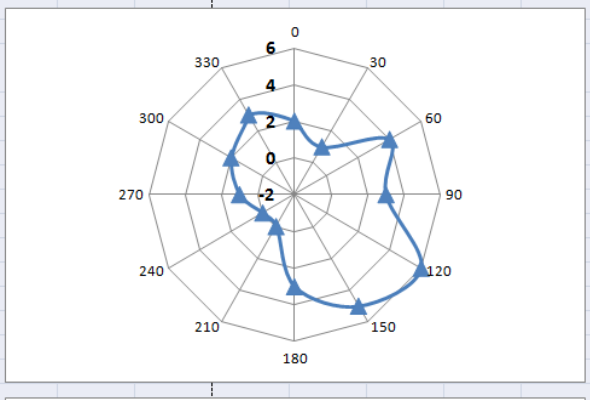
Methods (procedure to create chart in Excel)

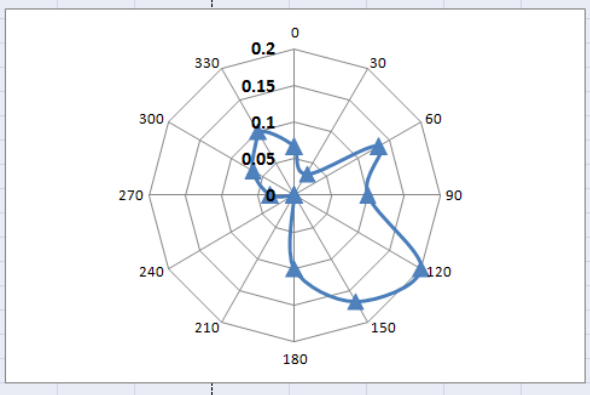
- Record direction of fall (i.e. direction of damaging wind) for sample of trees
- Establish damage direction classes
- Record frequency in each class
- Calculate proportion of damage in each class
- Insert radar chart
- Select Class Midpoint for axis labels and Frequency or Proportion for series

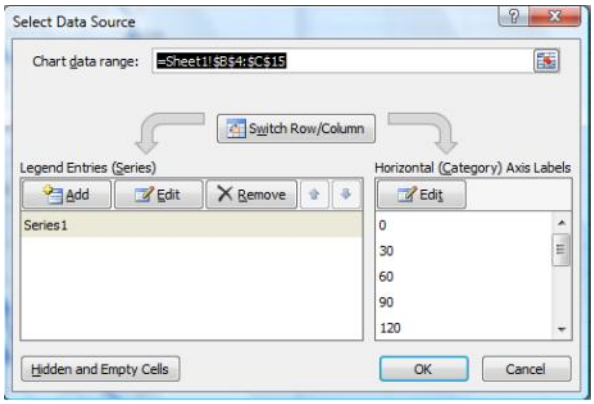
Example:

Microsoft Excel - RadarPlot.xlsx

	A	B	C	D
3	Direction of Fall Class	Direction of Fall Mid-point	Frequency	Proportion
4	346 - 015	0	2	0.066666667
5	016 - 045	30	1	0.033333333
6	046 - 075	60	4	0.133333333
7	076 - 105	90	3	0.1
8	106 - 135	120	6	0.2
9	136 - 165	150	5	0.166666667
10	166 - 195	180	3	0.1
11	196 - 225	210	0	0
12	226 - 255	240	0	0
13	256 - 285	270	1	0.033333333
14	286 - 315	300	2	0.066666667
15	316 - 345	330	3	0.1
16			30	







Advantages/Disadvantages

- Advantage(s): acquire highly localized data on damaging wind directions and is a good system to record the types of trees being damaged
- Disadvantage(s): Any estimates of wind velocities which caused damage are imprecise, damage may have occurred from more than one windthrow event.