WINDTHROW MANAGEMENT MANUAL for Coastal British Columbia

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

BCTS Chinook and Strait of Georgia Business Areas

Client: BC TIMBER SALES
Strait of Georgia Business Area
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Updated May, 2022

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

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NOTE TO THOSE USING THIS MANUAL:

This manual represents the best currently available information for the British Columbian Coast regarding the mechanics, prediction, and management of windthrow in forestry operations. It brings together numerous tools and guidelines in one package and explains them based on 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. It was originally developed by the authors in 2010 and updated by Ken Byrne and Ken Zielke in 2022.

Success with windthrow management will only be achieved by using the tools provided here, along with the windthrow probability mapping produced for BCTS (Mitchell and Lanquaye-Opoku 2009), 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 idea for this manual was originally conceived by Enrique Sanchez, BCTS, Chinook Business Area and Dr. Stephen Mitchell of the University of British Columbia. Funding initially was provided by the BCTS Chinook and Strait of Georgia Business areas. Paul Dagg of BCTS (Port Alberni) provided thoughtful guidance and leadership for the 2022 update and funding was provided by BCTS Strait of Georgia Business Area.

The authors are uniquely indebted to Dr. Mitchell. It was his research and work in British Columbia and with the authors over the past 17 years that laid the foundation for this manual. During this time, Dr. Mitchell led the design of the windthrow risk assessment procedure and the exploration of windthrow concepts and management. Our experiences in the field, designing prescriptions and layout, training and monitoring, all benefited from his insights and feedback. The authors would also like to thank Dr. Mitchell for his suggestions and reviews of material throughout the development of the manual.

The authors also thank the BCTS staff and contractors who helped us to understand issues specific to the Strait of Georgia and Chinook business areas, and BCTS requirements to address windthrow. These people included: Paul Dagg (BCTS), Bryce Young (BCTS) and all the participants in the 2022 workshops from BCTS and Meridian Forest Services Ltd, as well as those who contributed in 2010 including: 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.)

1. Table of Contents

1. How to Use this Manual

Overview

Windthrow is a common concern on the BC Coast for management. 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 first provincial approach to windthrow hazard and risk assessment developed by Dr. Mitchell of the University of BC was recently modified to reflect more recent data and knowledge (Mitchell and Zielke 2006). At that time field cards and training materials were produced that did not receive wide distribution. This manual was produced to bring together: the recent approach to windthrow hazard and risk assessment; up-to-date research results on the coast, and the current thinking on windthrow monitoring, salvage and other management strategies.

Those who would find this manual useful

The manual is designed primarily 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 by Dr. Mitchell to model windthrow across BCTS Business Areas and other parts of the coast, as well as other relevant data and trends relevant to Coastal BC. 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 updated Coastal Windthrow 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 tolerance levels or thresholds provide a basis for comparison when likelihood of windthrow is determined for a particular situation such as an edge segment. Again, the Windthrow 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

Mitchell, S.J. 1998. A diagnostic framework for windthrow risk estimation. For. Chron. 74:100-105. Also see http://faculty.forestry.ubc.ca/mitchell/publications/stevespub.htm

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

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

2 OVERVIEW OF WINDTHROW MANAGEMENT CONCEPTS – Including key definitions

Contents

Overview

Introduction

Windthrow results from the interaction of tree, stand and landscape level factors and is influenced by forest management and block layout decisions. These factors integrate in different ways on different sites and in different geographic areas. Generalizations regarding one factor or another should be considered in the context of other factors. Therefore, a good understanding of the conceptual basis for windthrow is necessary.

The following section, is based on Mitchell and Zielke (2006)[1] 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:

- *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. The likelihood of endemic windthrow occurring can be predicted. Note – endemic windthrow is highly variable, influenced by broad geography and a number of site, stand and harvesting/treatement specific factors (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 generally cause more stem breakage (Figure B). The likelihood of catastrophic windthrow cannot be predicted for these extreme wind events.

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

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.

The patterns of catastrophic damage reflect undulating cells or waves of gusts and eddies that move across the landscape when winds reach very high speeds. Damage is often random and unpredictable on the landscape and at the stand level. Exposed edges in one location may be less susceptible than intact stands elsewhere. Ridges, valley-bottoms and midslopes may or may not be affected within the same area. Some stands may have narrow bands of damage while others have broad swaths of damage. Heavy damage may be found adjacent to undamaged timber – for no apparent reason.

Windthrow Hazard definitions

- *Biophysical Hazard* - is the intrinsic stability of the stand in its pre-harvest 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.

- *Harvesting Hazard* - is the way in which a particular harvesting design increases or decreases the windloading or wind resistance of trees. A simple example of harvesting hazard is the exposure of new edges (Figure 7-C). Harvesting 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 Harvesting 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.

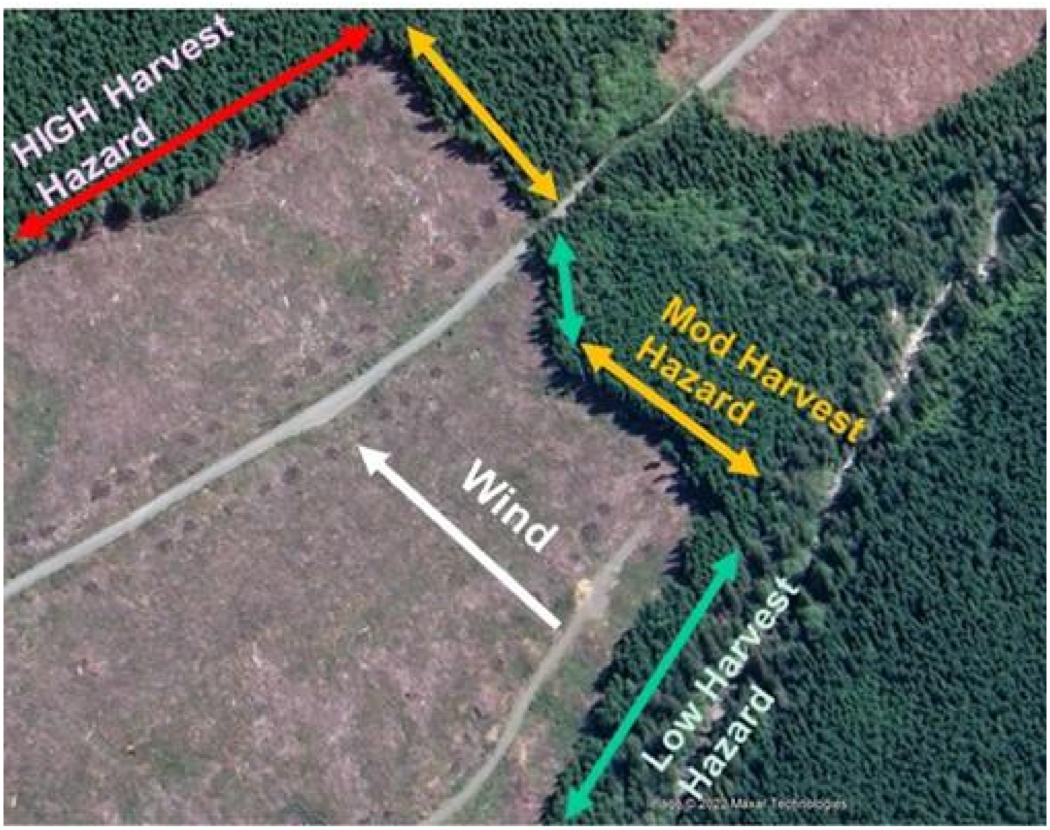

Figure 7-C. A simple example of harvesting hazard. Where: harvesting maximizes windloading the hazard is high; where harvesting minimizes windloading, hazard is low; and where it is something in between (as in a parallel boundary), hazard is moderate.

Understanding Climate, Weather and Wind

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

To better predict and understand windthrow hazard and risk it is useful to assess typical weather and specific wind patterns. There is much literature on this subject and the equations which calculate surface, upper level and atmospheric winds are very complex. This is why meteorologists use the largest and fastest computers to help predict the weather. However, one need not be a meteorologist to understand prevailing weather patterns in their working area. The following is a glimpse at 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. Wind warnings are issued with the forecast of these wind speeds.

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 (cyclones) from the Pacific Ocean across North America. 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. The reason for these surface wind patterns is that, like any fluid, air moves from high pressure systems (anti-cyclones) 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). The direction of the surface wind runs roughly perpendicular across the isobars with a slight shift to the right due to the earth's rotation. The steeper pressure gradient (i.e. isobars which are close together) the stronger the wind will be. Therefore, a deep low pressure system followed or preceded by a very strong high pressure system will result very strong surface winds which flow across the isobars from the high to the low pressure area.

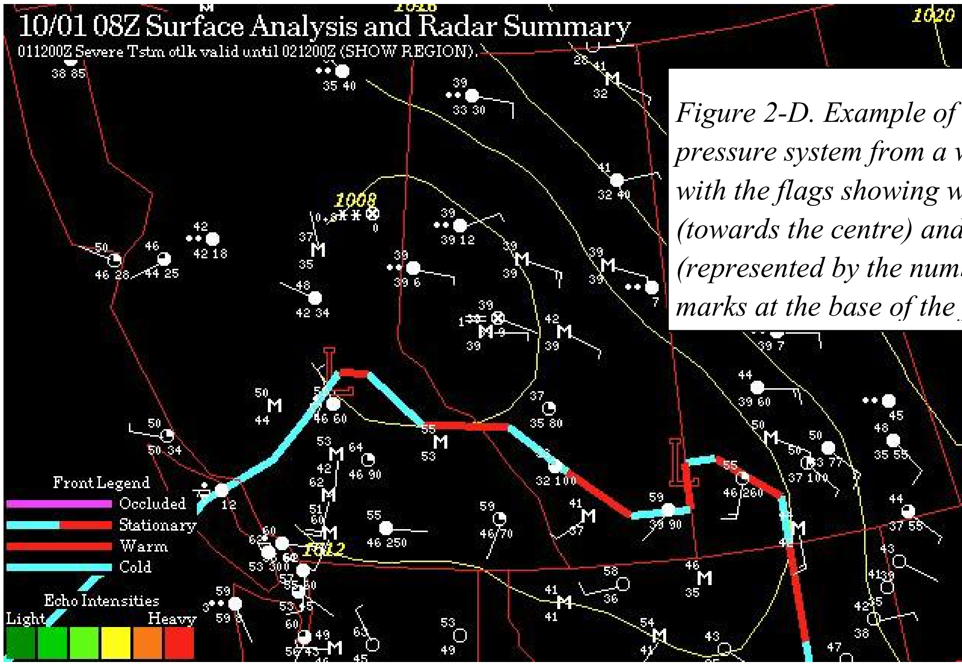

Figure 2-D. Example of a low pressure system from a weather map with the flags showing wind direction (towards the centre) and wind speed (represented by the number hash marks at the base of the flag).

The other large scale weather systems which can cause stand damaging winds are arctic ridges of high pressure (Figure 2-E). These systems move south over the interior of BC and outward along the coast. Strong outflow winds through major valleys are associated with these winter systems.

It is important to understand the frequency and magnitude of high and low pressure zones in your area. It is also important to understand the frequency and magnitude of small scale local wind patterns.

Most of 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 anomalies (both speed and direction) occur when the winds from these systems are modified by topography.

Smaller short-lived systems such as downbursts and outflows from thunderstorm cells also cause significant local damage. These cells generate strong local winds away from and in advance of the centre of the storm front. 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.

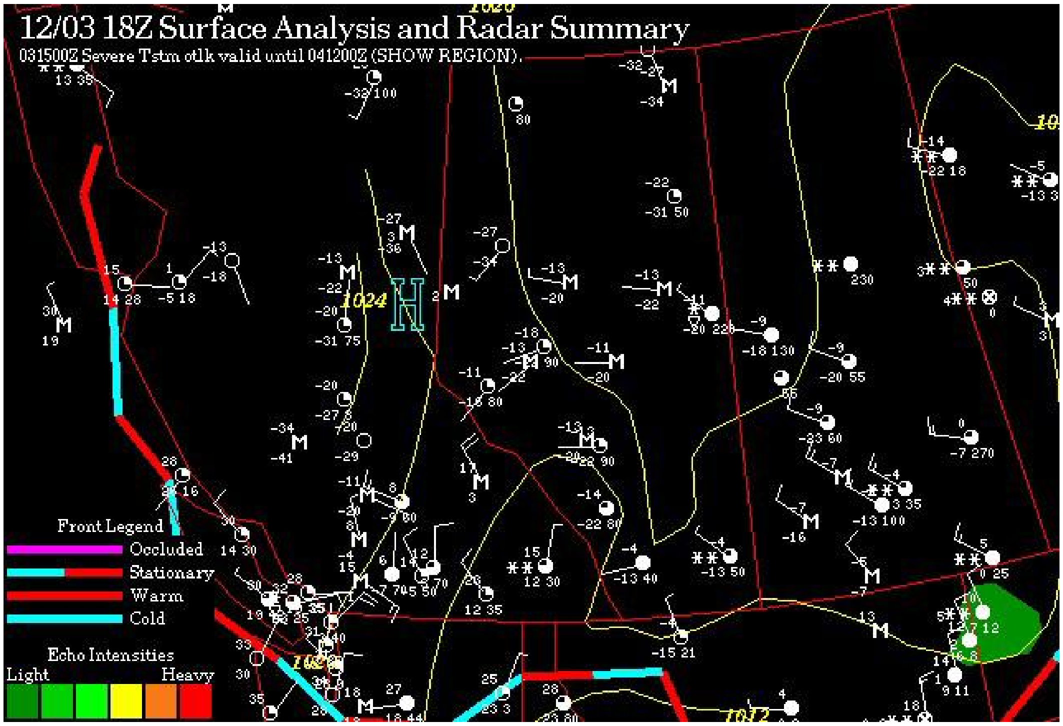

Figure 2-E. Example of a high pressure system from a weather map with the flags showing wind directions radiating out from the centre.

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

Windthrow Hazards - Topographic Exposure.

General weather patterns drive wind development, however, wind is modified by local terrain and topography which create many local anomalies related to wind speed and direction.

Some areas will have direct exposure to the wind while others will be sheltered resulting in less wind in the local area than the average over the landscape.   Other winds will be accelerated by topographic conditions, for example, funneling through valley gaps and compression 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.

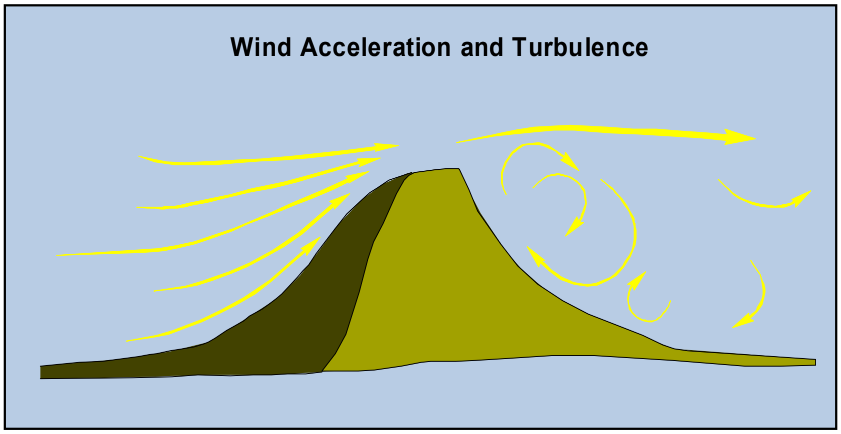

Figure 2-H. Impact of topography on wind.

Wind speed and direction is modified by topography and 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).

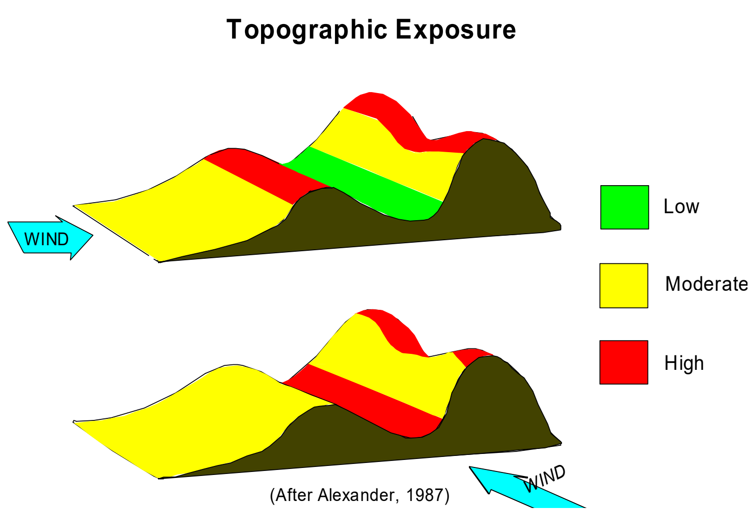

Figure 2-I, Impact of Topography on wind, Topographic Exposure.

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.

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Fig 2-K - A vulnerable edge due to funneling of wind through a small notch or saddle. Note – funneling can also be caused by harvesting 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 harvesting.

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 free at the top. The crown of the tree is like a sail. Wind acting on the crown creates a 'drag force'. This drag force is multiplied by the lever arm to produce a turning moment around the point of attachment (stem base).

Because trees are flexible, the crown can move. 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. Tree stems acclimate to this stress by devoting more resources to diameter growth. (see Height to Diameter ratio 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 (Figure 2-L). This is especially common in dense stands where the trees are devoting more resources to height growth to survive competition.

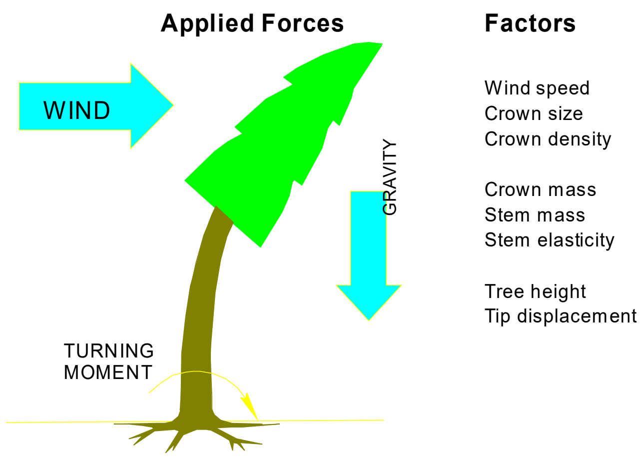

Figure 2-L. Effects of wind on trees.

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?

Trees vs. Stands

Trees grown in the open adapt to higher wind loads as they grow (large diameter, high degree of taper and large spreading roots) becoming 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.

Intact stands are often less prone to windthrow than recently exposed individual trees. 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 primary diagnostic question for windthrow stand hazard is based on individual tree 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 harvesting 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. 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. It is the ratio of height in metres divided by the diameter in metres. For example, a tree of 35 m with a diameter of 50 cm (0.5 m) has a height to diameter ratio of 70. Trees with a low height to diameter ratio (< 60) are much less likely to blow down than slender trees with a high ratio (Figure 2-P).

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 stabilize quickly with minimal penetration of windthrow into the edge (Figure 2-Q).

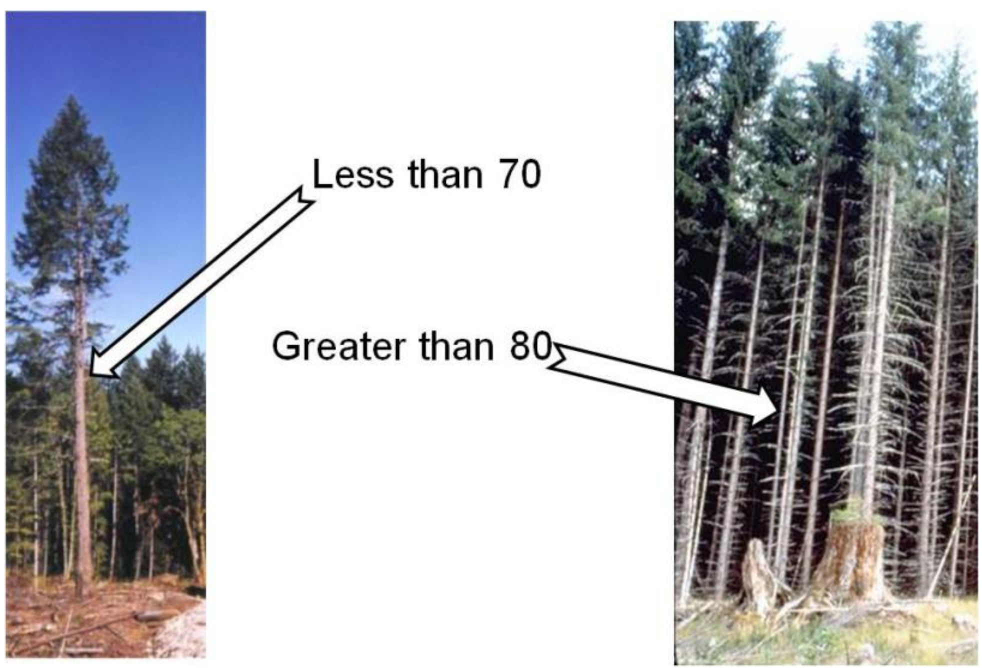

Figure 2-P. Using Height to Diameter ratio to help assess stand hazard. The tree on the left has a Ht/Diam ratio approaching 30, and the trees on the right closer to 100.

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

Species Considerations

Some species have more resistance to windthrow than others. However, generalizations about species susceptibility and resistance must be viewed with caution when considering stands on the landscape – other factors are often more important to consider.

For Example:

- 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 redcedar are often highly tapered with sparse crowns (often with a dead top) reducing drag forces even further on larger trees. However, slender redcedar in dense second growth stands may still incur a high degree of windthrow in some situations. Additionally thrifty mature redcedar with dense full crowns may have enough sail area in certain situations to make them susceptible to windthrow when exposed.
- Hemlock is perhaps the most commonly windthrown species on the Coast. This trend is likely influenced by the fact that hemlock 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.
- Douglas-fir is generally considered relatively resistant to windthrow. 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 may be more to do with site and stand effects than species.

- 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.

It is best to become familiar with the species composition of windthrow in various situations in your local area – close to your proposed cutblock. 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. Therefore, rooting is another important consideration in assessing the Biophysical Hazard. Figure O 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)?

The answer to the question addresses the influence that the soil or rooting medium contributes to the overall biophysical hazard for windthrow. A key consideration are the restrictions to rooting. 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-R).

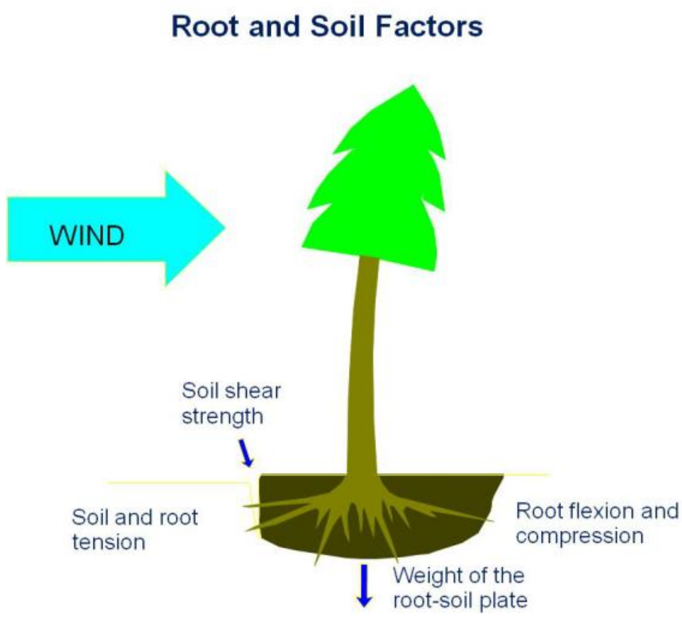

Figure 2-R – components of the Soil Hazard rating.

It is important to make observations about the rooting habit of the trees – not just the soil. Road cuts or where windthrow has occurred in similar situations in older adjacent blocks are excellent places to make these kind of observations. Flat plate-like root systems are very restricted (Figure 2-S), 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-T).

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, 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.

A confusing fact is that deeply rooted stands often show high levels of windthrow. However, where these stands occur on rich, well-drained soils with adequate or abundant moisture, they are tall, dense and even-aged. These stand characteristics when combined with topographic exposure increase the biophysical hazard for windthrow. Soil influences become more dominant where both topographic exposure and stand hazards are relatively neutral or moderate. It is in these instances where changes in soil characteristics can significantly influence the windthrow hazard.

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

Figure 2-T. 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.

Questions

Isn't windthrow too unpredictable to manage?

This is only true if you are not familiar with how it works. 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 all developed with a high degree of sheltering and support from neighbours and are highly 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 very small amounts of windthrow may occur over a 10 year period 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 year after harvest (trees are exposed to new conditions that they may not be adapted to, susceptible trees are sorted out quickly).

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 hazard rating is outside of normal (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.

3. BACKGROUND: Coastal Windthrow Damage Trends

CONTENTS

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

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%[1] 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 over more than 30% of the area of the segment. Using these data, windthrow as a general damage concern can be compared across various geographic area 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. Western Vancouver Island (Port Alberni to Bamfield) ranks second in the level of damage, although it was significantly lower than Haida Gwaii. Elevated levels of damage in West Island 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. Northern 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.

Chilliwack and Squamish have the lowest levels of damage on the coast reflecting their complex terrain, and relative proximity to Pacific storms -a significant distance inland from the outer coast and the Strait of Georgia. The authors speculate that the Sunshine Coast likely ranks somewhere between North Island and Chilliwack.

[1] 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.

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[2].

Geographic Area	Proportion of edge segments with (x% canopy loss) – (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%		6,715
4. Chilliwack	7%	0.3%		6000
5. 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 windthrow hazard and likelihood assessments. The local wind regime and topographic exposure generally are the driving factors mostly influencing 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).*

It is strongly urged that the information and data that follows should be viewed with caution when drawing conclusions for specific geographic locations. Broad geographic trends regarding hazard and windthrow likelihood cannot be arbitrarily applied to individual stands. Broad trends that show a strong correlation to a marked increase in damage with some variables may show such damage levels only on 30-40% of susceptible edges, meaning a great number of similar edges are less

[2] See references above for sources of data.

vulnerable. These data are averaged over large areas. As well, different studies quantify damage differently. 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[3]

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. A significant proportion of area that is uniform and relatively flat also provides little shelter here from such wind regimes.

It is well known that topographic attributes (along with boundary orientation) strongly influence windthrow. Therefore, inland areas with highly complex geography (such as West Vancouver Island, North Vancouver Island, Chilliwack or Squamish) show less consistent patterns with topography over the whole area, than does Haida Gwaii. This does not mean that topographic influences are not important. It means that topographic influences are highly variable and are best examined at finer scales for patterns. As well, the interaction between stand attributes, site fertility and topographic attributes can compensate – for example – often in Chilliwack shorter older (therefore more open) stands are found in windier, continuously exposed, higher elevations positions, while taller, slender, more vulnerable, second growth stands are found in the valleys.

Note that in the Chilliwack operating area, and possibly in 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, 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.

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

In all areas more windthrow was noted with cublocks located on north rather than south hillslope aspects, being somewhat counter-intuitive, considering prevailing winds. However, it is presumed that on south slopes stands may be more open, perhaps shorter, and likely more acclimated, having developed under the influence of strong prevailing winds. This is a reflection of a general topographic feature, and should not be confused with south-facing cutblock boundary edges, which shows the highest proportion of damage in all study areas (relative to other cutblock edge orientations).

Species Composition in Local Stands[4]

In Haida Gwaii, 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[5]. However, 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. In Chilliwack, unlike the other operational areas, there is 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 Plains, which are 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. When windthrow penetrated 50 m from the block edge, hemlock stands were damaged more frequently than other species. Basically, 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.

Note that Rollerson et al. (2009) when studying cutblocks across the coast found external edges on average to have more total wind damage when dominated by hemlock, red alder and amabilis fir, while edges 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.

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

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

Influence of Stand Height and Site Productivity[6]

Across all areas the most vulnerable stands are relatively tall (i.e., about 35 m in height), with much less damage to shorter stands (i.e., closer to 15 m). Stands taller than 35 m may be less vulnerable because they are older, perhaps less dense and slender, and may be in more sheltered geographic positions. The slenderness coefficient (height to diameter ratio) shows a strong correlation for windthrow damage with a value of 60 being a good threshold. The data indicates much more damage with height:diameter ratios of greater than 60 and significantly less damage as values drop below 60.

More damage was found on somewhat richer sites (SI_{50}> 20) in Haida Gwaii, reflecting a general trend found on Vancouver Island and supporting the trend of more windthrow with taller stands. However, moderate site indices in Chilliwack were more important for damage, while in Squamish site indices below 20 showed increased damage. Productivity gradients are greater in Haida Gwai. As well, with the exception of the Hecate Lowlands, the majority of stands being harvested in Haida Gwaii are old or mature, having have more complex structure than the second growth stands that dominate in the Squamish and Chilliwack valley bottoms and mid-slopes.

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 as they are the most exposed to winter storms with southerly winds (SE-SW). Openings with larger fetch result in increased damage. Generally narrower (<20 m) internal retention strips experience more damage, as do boundaries located on the slope break into gullies (compared to those set back in upland terrain).

[6] 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	**SOURCE**

30% of the area of the segment.	
• > 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)
• Below SI 20 – MORE DAMAGE (6-10%) • Above 20 – 2-4% • This is likely because the low site index sites are at higher	**BCTS Squamish** (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**
elevations and have greater wind exposure.	
• 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.

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, slender second growth stands generally found on such sites.

Layout Design Attributes

Boundary orientation (along with topographic attributes) generally more strongly influences windthrow than stand 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 – trees on the other side are exposed to large increases in wind loading and damage progresses down the lee slope (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
- 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.

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

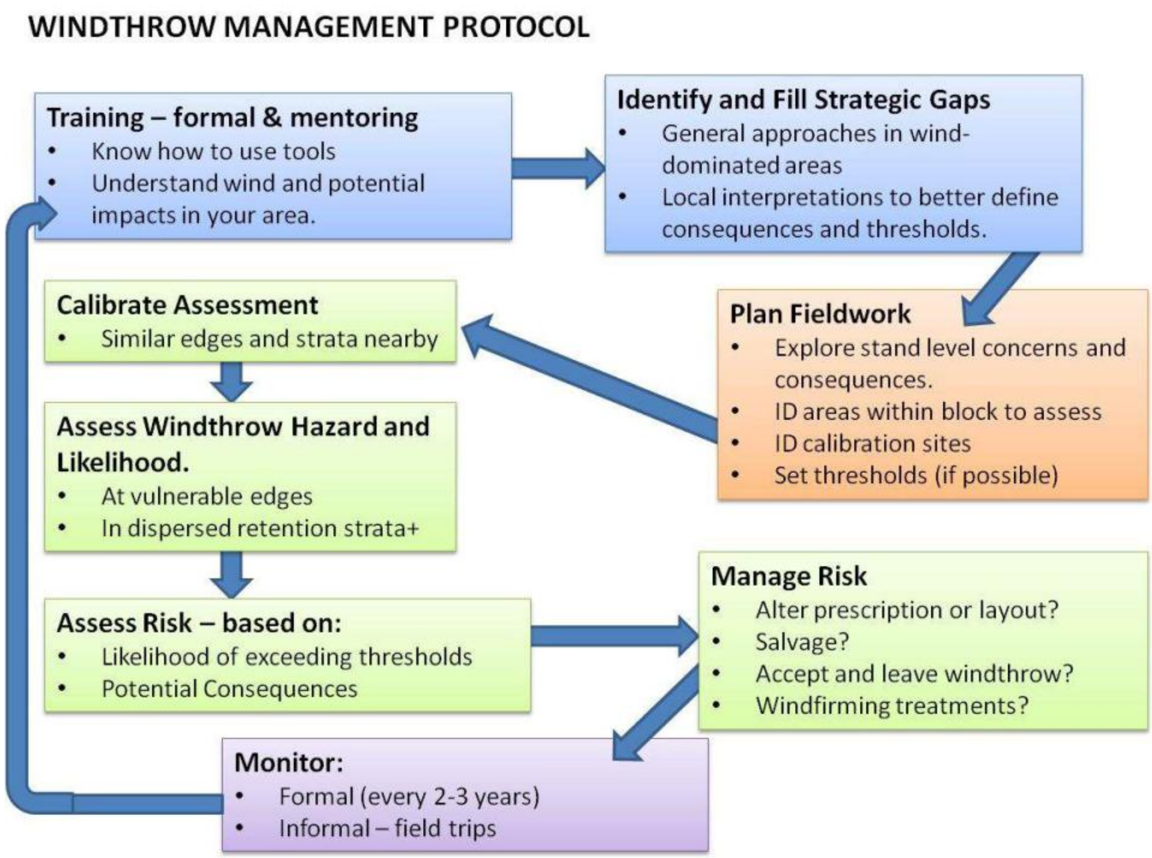
CONTENTS

Overview

Windthrow management is a multi-scale challenge. Windthrow is generally triggered by stand level harvesting activities. The risk to management (windthrow risk) is tied back to planning values and objectives at the management unit scale through consequences. Biophysical hazard, windthrow likelihood, and windthrow risk all gain important context at the landscape 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 valuable feedback to those who are trying to predict and manage for windthrow.

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 to reasonably 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.

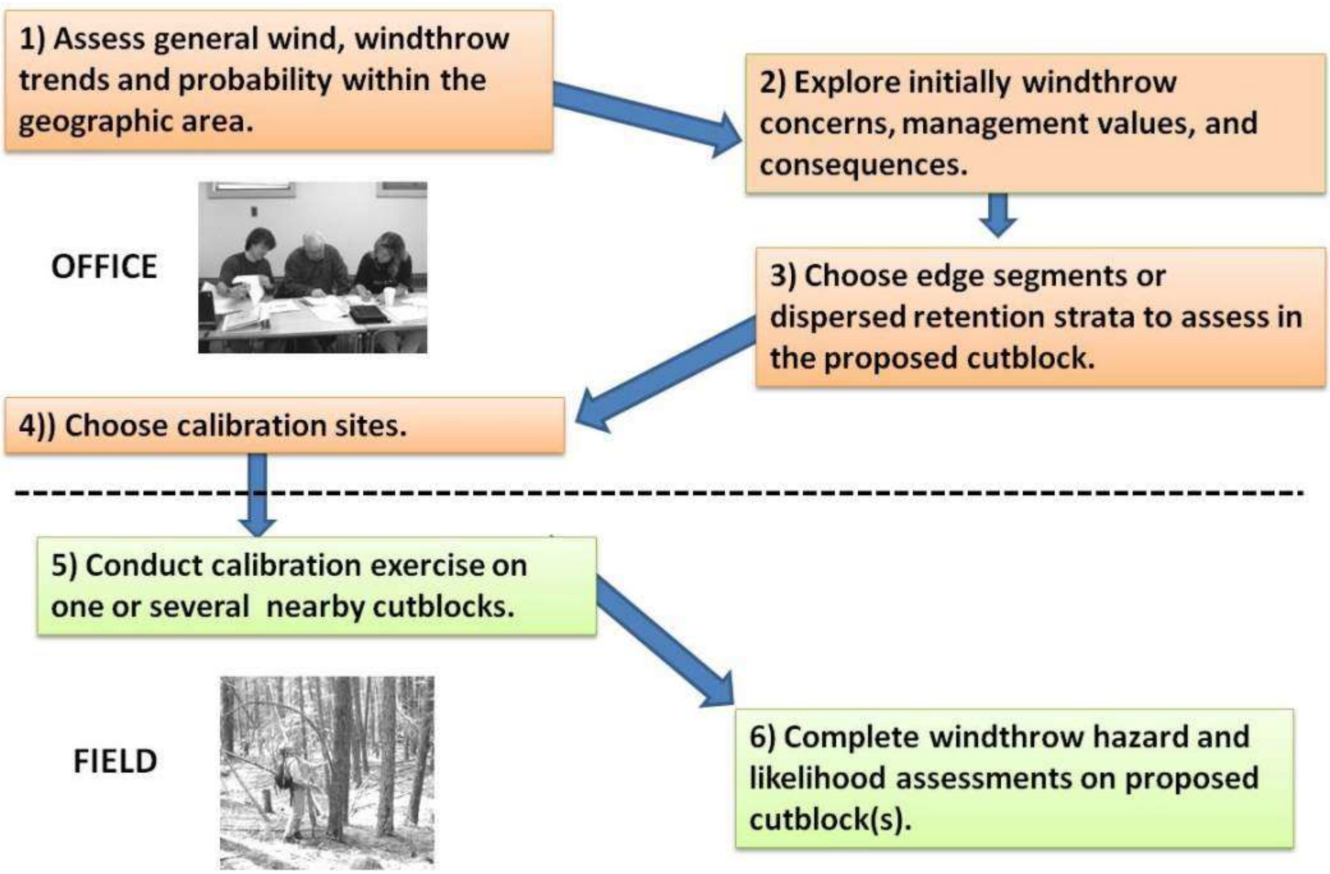
5 Assessment of Windthrow Hazard and Likelihood

CONTENTS

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

DIAGNOSITIC QUESTION1: Are you in a windy area?

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

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.

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)

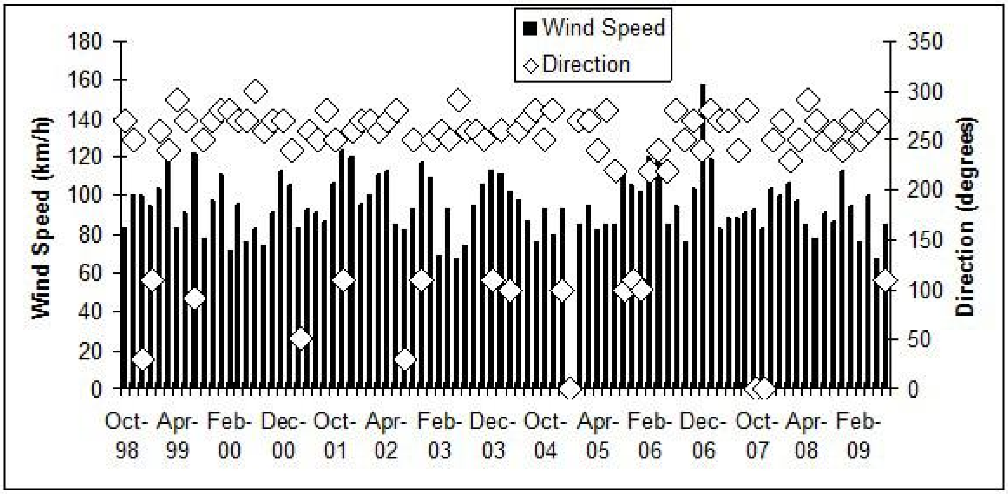


Figure 5-A Wind data for Race Rocks light station near Victoria, BC (peak monthly velocities/directions Oct. – May)

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.

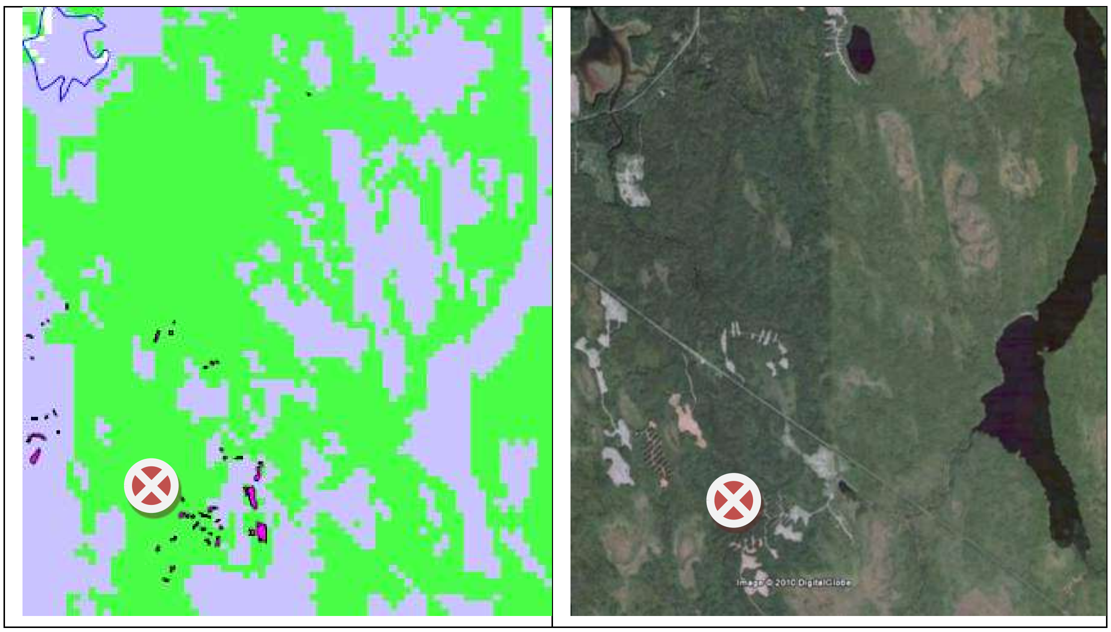


Figure 5-B A small portion of the probability map (left) for Haida Gwaii (just east of Port Clement), showing a hypothetical proposed block location (X). The corresponding location is also shown on a GoogleEarth™ image (right). The green in the probability map indicates a probability of 0.15 – 0.30 (wtt3020) – 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, 15 to 30 times out of 100. Actual windthrow may be considerably more (occasionally), and 70% of the time - less. Note the blue on the map indicates area other than mature forest - marsh, bog, open water, young or stunted stands. The pink patches are mapped windthrow used in the modeling.

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 harvesting situations, 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 imagery 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 topographic position and exposure to endemic 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.

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

- Try to surface additional clues for 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).

Step Two – Explore Potential Windthrow Concerns Prior to Fieldwork.

DIAGNOSITIC 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 tolerance limits or thresholds of acceptable windthrow for edges and portions of the proposed block where concerns are present. An alternative approach is to determine the target structure you wish to maintain regardless of windthrow.

PROCEDURE

Consider harvesting hazards

- Consider how your proposed harvesting will add a 'harvesting hazard' to the cutblock area.
- Using the general knowledge you gained of local wind patterns, identify areas with a moderate to high harvesting 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 layout features or modifications:
    - Opening size, shape and removal sequence.
    - Intentions for leave tree percentage, species and crown class (if known yet).

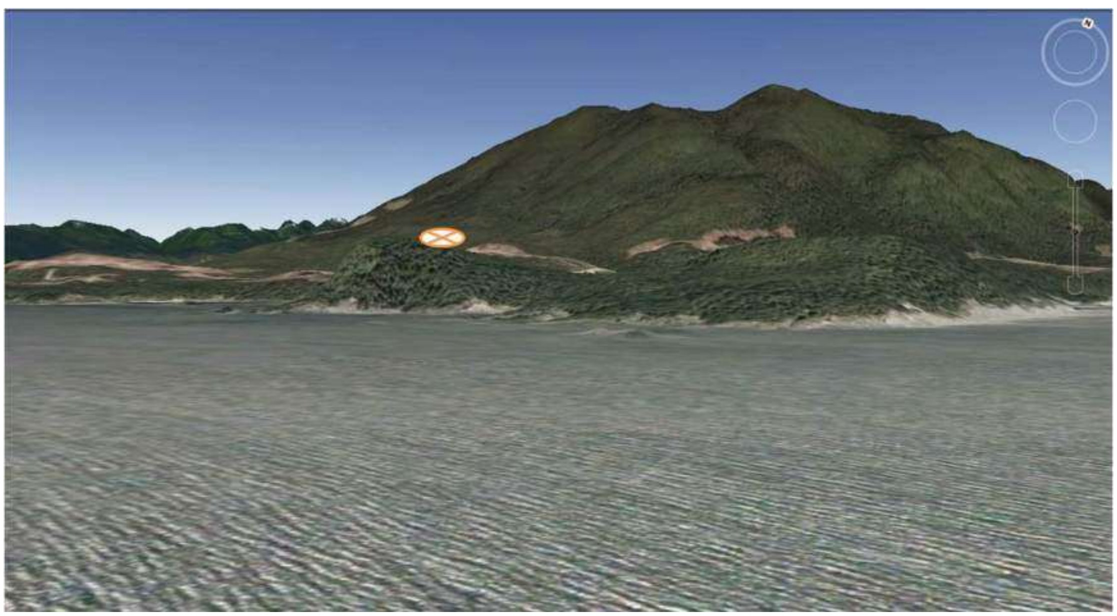


Figure 5-D Use of GoogleEarth™ to explore potential exposure of a prospective block location (X) to prevailing storm winds, the example provided above is on the West Coast of Vancouver Island. The view is from the sound toward the cutblock from the southeast (the direction of the prevailing storms).

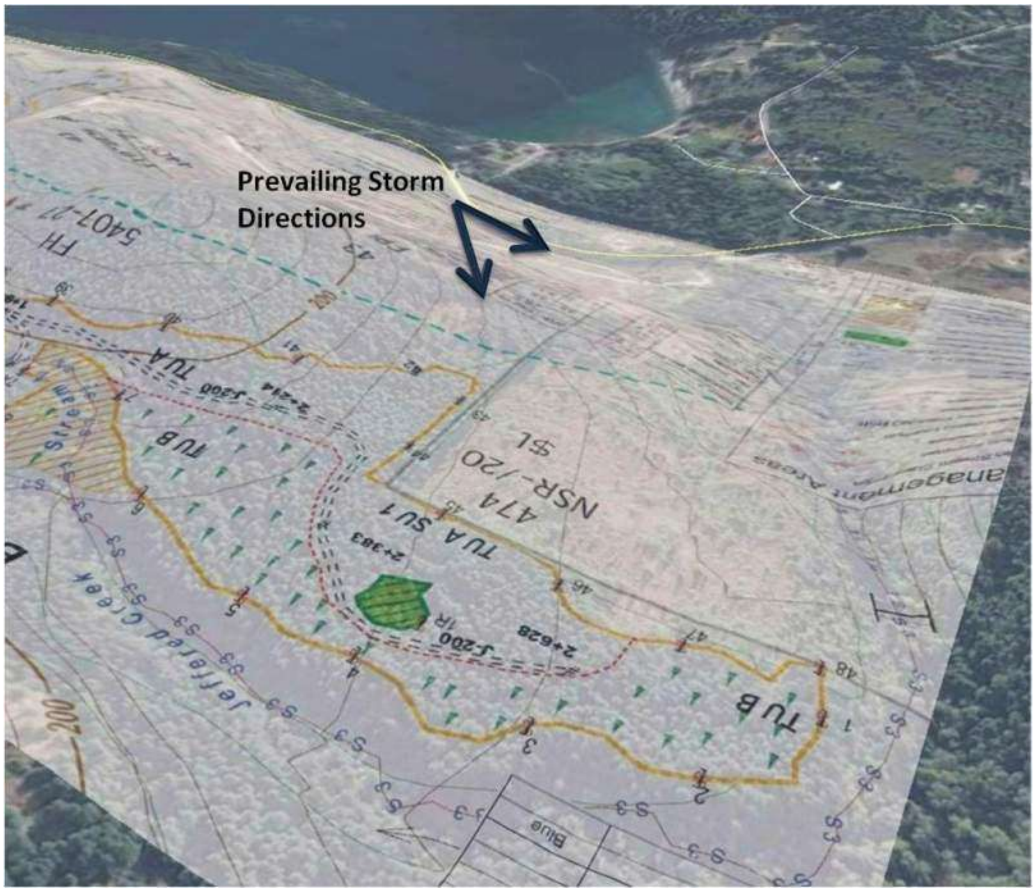


Figure 5-E Use of the overlay feature in GoogleEarth™ to explore exposure of planned boundaries to prevailing storm winds, by overlaying the block map as an image.

Determine Initial Consequences (ALSO REFER TO: 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 and so on.
- On the cutblock harvest plan map or Site Plan map, 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 and so on.). Also, identify external boundary edge segments that are adjacent to key management features or area of management concern.
- Identify potential value objectives that denote a target condition on the cutblock – such as a Visual Quality Objective or a retention system for stand level biodiversity.

In these cases, consideration of windthrow in patches, strips and edges will be important to maintain an overall condition on the cutblock.

- 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

DIAGNOSITIC 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. Be aware that many edges with a moderate-high likelihood of windthrow often have some concern for timber.

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 on a map and/or air photo.

- NOTE: At this point windthrow risk (based on likelihood of windthrow and consequences) has not been assessed. However, based on knowledge of local winds,

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

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.
- 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.

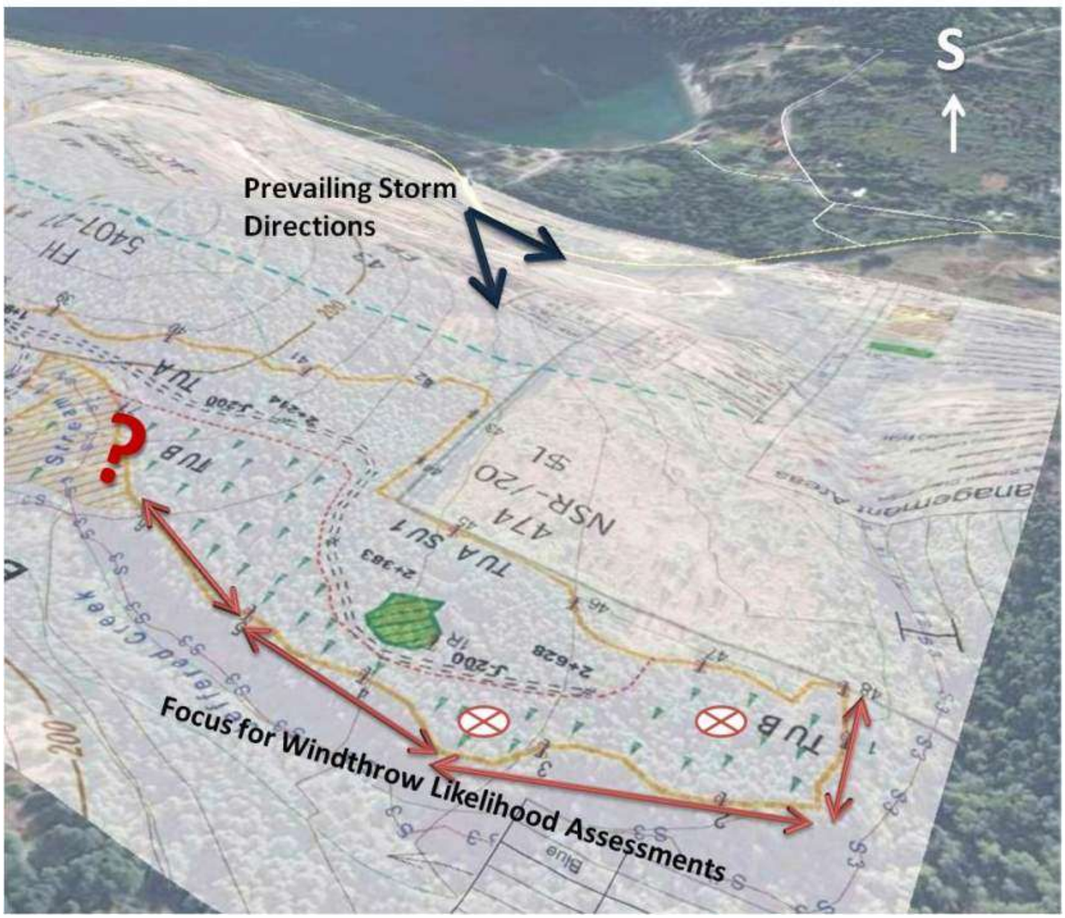


Figure 5-F. Choosing key edge segments for windthrow hazard and likelihood assessments on the proposed cutblock. Edge segments are indicated with the double-headed red arrows, while dispersed retention assessment points are indicated with the circled X's. The "?"indicates a possible assessment that should 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 harvesting hazard).
- Focusing on edges that have similar characteristics as the edges of concern on the proposed cutblock.
- 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 harvesting 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 Coastal Windthrow Form 2 as in Step 6.
- That information is then transferred onto the 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 boundary that has damage levels typical of what you have observed in imagery for the area, with a similar treatment hazard to boundaries of concern in your proposed cutblock(s).
2. Transfer the results of this assessment into the table below for reference.

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

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

CALIBRATION – of windthrow likelihood classification

3. *R*ecord observed damage on the calibration boundary assessed as per above (#1 and #2).

Estimates of Actual Windthrow Damage – to help refine predictions

Measured windthrow penetration into edge (where applicable)	Average (m)		Range (min to max)	
Estimated windthrow throughout the penetration (or a specified) zone: ____________	Average % of total m^2/ha		10% Range (e.g. 30-40 m^2/ha)	

Actual Damage Calibration Categories - to calibrate windthrow likelihood class (See next page)

Basal Area (m^2/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	

4. 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 Windthrow Calibration Field Card.

b. *Record the observed damage on the calibration boundary:*

- Make observations of the windthrow and take some rough notes on the number and sizes of trees you see down in a certain area and compare that to what is still standing in the same area. You can walk in and around the windthrow zone on the existing boundary, but this can be time consuming and challenging – these are difficult place to walk in. Another option is to use a drone to take photos and video that you can analyse in the office.

- You will need to record:
  - Penetration – average and range.
  - Amount of windthrow throughout either a penetration zone or other specified zone – estimated % and 10% range (i.e. 20-30%, 40-50% etc.). If there is a clear zone of windthrow penetration, use the penetration zone. If there is not a clear zone of penetration specify the area or zone you are describing. For example, the windthrow may have occurred throughout a retention patch, strip or reserve and the best way to describe it is a proportion of the whole patch or strip.
  - Estimated windthrow in tree-length categories to help calibrate assessment.
- Note - the use of basal area (m2) for percentage of windthrow is roughly equivalent to a proportional volume estimate. Do not estimate proportion by stems/ha. Ocular estimates are fine.

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.

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 presents a concern, or 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 overall 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 located on the landscape, 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 harvesting hazard (based on the proposed layout) to rank the likelihood of windthrow occurring on the edge segment or for internal dispersed retention.
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).

BC Coastal Windthrow Likelihood Assessment FORM 2 – Side A (May, 2022)

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

TOPOGRAPHIC EXPOSURE TO WIND:

DIAGNOSTIC QUESTION 1: Are prevailing peak storm wind speeds accelerated by terrain constrictions, OR is storm wind reduced by sheltering influences?

CONSIDERATIONS – Topo Exposure increases with:
- Proximity to ridge crest or upper slope shoulders.
- Location on valley floor and lower side walls for storm winds parallel to valleys.
- Valley gaps, constrictions or ridge saddles where storm winds are funnelled.
- Presence of tree-level indicators – flagging (asymmetry) of tree crowns.

CONSIDERATIONS – Topo Exposure decreases with:
- Proximity to lower slopes and sheltered from storm winds.
- Shelter from ridges, hills, knobs and other topographic features large enough to deflect storm winds over the stand edge.

Note – If a leeward slope off a ridge is steep, damaging turbulent winds may continue down the back side.

Top. Ex Hazard Class:	☐ **Very High** (highly accelerated)	☐ **High** (significant acceleration)	☐ **Moderate** (neither acceleration nor shelter)	☐ **Low** (significant wind shelter)[1]	☐ **Very Low** (highly sheltered)

***DIAGNOSTIC QUESTION 2:* Is this a windy region? If so, increase Topo. Exposure hazard by one class**

CONSIDERATIONS – Consider peak regional storm winds and:
- Proximity to large open water - the open ocean, large inlet, strait or lake (if peak storm winds run parallel to the lake, strait or inlet). Consider prevailing peak storm wind direction and sheltering features (question 1)
- If it is a dominant ridge/peak – well above neighbouring ridges and peaks for kilometres in the direction of prevailing storm winds.

STAND STABILITY

DIAGNOSTIC QUESTION 1. Are trees poorly acclimated to wind loading?

STAND CONSIDERATIONS - Acclimation decreases with the following (the opposite indicates increasing acclimation):
- High stand densities – Individual trees rely on long term shelter of neighbouring trees.
- Tall stands - on highly productive sites.
- Most trees are slender - Small live crowns and low degree of taper – ht. to dbh ratio closer to 100 than 50 - with 100 being very slender.
- High degree of defect/decay – heartrot, stem defect, root disease.
- **NOTE:** Tall, slender, dense stands with trees that fall through the canopy to the ground default to 'high'.

TREE-LEVEL INDICATOR OF ACCLIMATION:
- Relatively thick stems with long (deep) live crowns.
- High degree of taper – height to diameter ratio -less than 60.
- Open crowns with sparse foliage or flagging (most foliage on leeward side)
- Short dense stands where windblown trees lean into the stand but do not fall to the ground.

Stand Hazard Class:	☐ **High** (No acclimation)	☐ **Moderate** (neutral - balance of acclimated and non-acclimated trees)	☐ **Low** (Acclimated)	☐ **Very Low** (Highly Acclimated and wind modified)

BC Coastal Windthrow Likelihood Assessment FORM 2 – Side B (May 2022)

SOIL ANCHORAGE

DIAGNOSTIC QUESTION 1. Is root anchorage weakened by an impeding layer, low strength soil, or poor drainage?

CONSIDERATIONS - Weakened anchorage contributes to instability with:
- Poor drainage and soil depth restrict rooting in draws and gullies.
- Conspicuous pockets of higher productivity (seepage over basal till or bedrock; saturated or seasonally saturated riparian soils).
- Smooth rock outcrops or bedrock that roots cannot penetrate (no cracks and fissures).
- Where upturned 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.
- Low soil strength – pure sands or silts with few coarse fragments etc.

Soil Hazard Class:	☐ **High** (weak)	☐ **Moderate** (average)[2]	☐ **Low** (strongly anchored)

HARVESTING HAZARD

DIAGNOSTIC QUESTION. Will the proposed harvesting strategy substantially increase windloading and/or reduce support of trees either along the stand edge or retained as dispersed trees in the block?

NOTE: Consider the interaction of both #1 and #2 – see the windthrow manual.

1. WIND LOADING CONSIDERATIONS - Post harvest wind loading increases on newly exposed edges with:
   - Exposure of boundary edges to damaging storm winds – moving from lee-facing edges (least exposed), to parallel edges (moderate exposure), to perpendicular edges (most exposed).
   - Fetch length - wind loading increases linearly as distance across an opening toward prevailing storm winds increases from 0 to 5 tree lengths with no further increases after 10 tree lengths.
   - Funnelling due to treed boundary shape – concentrates wind and further increase wind loading.
2. ALSO CONSIDER INTER-TREE SUPPORT REDUCTION (between adjacent trees). Hazard increases:
   - With increasing tree removal in partial-cutting (dispersed retention or thinned areas).
   - As reserve strips or patches become narrower or smaller (where wind can blow through them).

Harv Haz.Class	☐ **Very High**	☐ **High**	☐ **Moderate**	☐ **Low**	☐ **Very Low**

WINDTHROW LIKELIHOOD EVALUATION - score

Add Topographic, Stand and Soil Hazards to get Biophysical Hazard; then add Harvesting Hazard to Biophysical Hazard to get Windthrow Likelihood. Adjust if similar calibration sites are significantly different.

	Very High	High	Moderate	Low	Very Low	
Topographic Hazard	4	3	2	1	0	
Stand Hazard		3	2	1	0	
Soil Hazard		2	1	0		
Biophysical Hazard	8+	6-7	4-5	<4	0	
Harvesting Hazard	7	6	4	2	0	
Windthrow Likelihood	14+	12-13	10-11	6-9	<6	
Adjust with calibration						

PROCEDURE – On each edge (or area) of interest in the proposed cutblock or on a calibration edge:

a. Assess Topographic Exposure Hazard to Wind:

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

TOPOGRAPHIC EXPOSURE TO WIND:

DIAGNOSTIC QUESTION 1: Are prevailing peak storm wind speeds accelerated by terrain constrictions, OR is storm wind reduced by sheltering influences?

CONSIDERATIONS – Topo Exposure increases with:

- Proximity to ridge crest or upper slope shoulders.
- Location on valley floor and lower side walls for storm winds parallel to valleys.
- Valley gaps, constrictions or ridge saddles where storm winds are funnelled.
- Presence of tree-level indicators – flagging (asymmetry) of tree crowns.

CONSIDERATIONS – Topo Exposure decreases with:

- Proximity to lower slopes and sheltered from storm winds.
- Shelter from ridges, hills, knobs and other topographic features large enough to deflect storm winds over the stand edge.

Note – If a leeward slope off a ridge is steep, damaging turbulent winds may continue down the back side.

Top. Ex Hazard Class:	☐ **Very High** (highly accelerated)	☐ **High** (significant acceleration)	☐ **Moderate** (neither acceleration nor shelter)	☐ **Low** (significant wind shelter)[1]	☐ **Very Low** (highly sheltered)

DIAGNOSTIC QUESTION 2: **Is this a windy region? If so, increase Topo. Exposure hazard by one class**

CONSIDERATIONS – Consider peak regional storm winds and:

- Proximity to large open water - the open ocean, large inlet, strait or lake (if peak storm winds run parallel to the lake, strait or inlet). Consider prevailing peak storm wind direction and sheltering features (question 1)
- If it is a dominant ridge/peak – well above neighbouring ridges and peaks for kilometres in the direction of prevailing storm winds.

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, is good imagery. GoogleEarth™ imagery can be very helpful. It will be difficult to make observations regarding topographic exposure inside the stand at the preharvest stage.
- Consider exposure and sheltering aspects together - Note that the left side of the card lists considerations that increase the exposure of the area to prevailing damaging storm winds. The right side of the card describes potential sheltering factors that will reduce the exposure to damaging storm winds. Consider these carefully – are winds being accelerated due to terrain or sheltered due to terrain? (from prevailing storm winds).
- Be careful here. Sheltered does not mean the area never has wind. It is the prevailing peak storm winds we are most concerned about, which on the Coast generally occur in the winter months, most often in November and December. Many sheltered areas will still typically experience mid-day thermal winds up and down the valley during the summer. Also, even during peak winter storms,

sheltered areas do not exist in a vacuum, wind will still be moving but much less that those areas exposed to the peak storm winds.

- If an area neither experiences acceleration of, or shelter from, peak storm winds, it is neutral or has a moderate hazard. That is, this area reflects the average nature of the peak storm winds, providing a moderate topographic exposure hazard.
- There is a second diagnostic question used here. Is this area windy? That is, is this an unusually windy area for the Coast, due to its proximity to the open Ocean (think West Coast of Vancouver Island or the Holberg area). You may also be in a large inlet or strait where the peak prevailing storm winds run parallel with the valley and experience acceleration off the water. If the proposed harvesting area is close to one of these situations, increase the Topographic Exposure hazard, determined for diagnostic question #1 by one ranking.
- For more information on the significance of these factors – see Section 2 (Windthrow Concepts).

b. Assess Stand Stability Hazard to Wind:

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

<table>
<tr><th colspan="5">STAND STABILITY</th></tr>
<tr><td colspan="5">DIAGNOSTIC QUESTION 1. Are trees poorly acclimated to wind loading?</td></tr>
<tr><td colspan="3">STAND CONSIDERATIONS - Acclimation decreases with the following (the opposite indicates increasing acclimation):
• High stand densities – Individual trees rely on long term shelter of neighbouring trees.
• Tall stands - on highly productive sites.
• Most trees are slender - Small live crowns and low degree of taper – ht. to dbh ratio closer to 100 than 50 - with 100 being very slender.
• High degree of defect/decay – heartrot, stem defect, root disease.
• NOTE: Tall, slender, dense stands with trees that fall through the canopy to the ground default to ‘high’.</td><td colspan="2">TREE-LEVEL INDICATOR OF ACCLIMATION:
• Relatively thick stems with long (deep) live crowns.
• High degree of taper – height to diameter ratio -less than 60.
• Open crowns with sparse foliage or flagging (most foliage on leeward side)
• Short dense stands where windblown trees lean into the stand but do not fall to the ground.</td></tr>
<tr><td>Stand Hazard Class:</td><td>☐ High
(No acclimation)</td><td>☐ Moderate (neutral - balance of acclimated and non-acclimated trees)</td><td>☐ Low
(Acclimated)</td><td>☐ Very Low
(Highly Acclimated and wind modified)</td></tr>
</table>

Considerations

- The card is set up to encourage you to consider the characteristics that indicate decreased stand acclimation to windloading and those that indicate increased acclimation.

  Two important things to Note:

  - Tall slender dense stands (often western hemlock or Douglas-fir second growth in coastal BC) where trees fall through the canopy to the ground will default to a 'high' stand hazard. These are the most challenging stand types on the Coast.
  - Dense stands (could be any species, including hemlock or Douglas-fir) that are short such that trees tend to lean into the stand behind it rather than fall through to the ground – are fairly well-acclimated to windloading. This is in spite of the fact that the leaning stems may be quite noticeable as damage. Highly exposed edges of these stand types tend to acclimate quickly with little windthrow penetration. Stand hazard in these cases are 'Low.'

- 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 if widespread throughout the stand. Not all these considerations will be fully explained 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 note it is not considered on the card. It is only one factor to consider and could be misleading. 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.
- See Section 2 (Windthrow Concepts) for more information.

c. Assess Soil Anchorage Hazard to Wind:

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

SOIL ANCHORAGE			
DIAGNOSTIC QUESTION 1. Is root anchorage weakened by an impeding layer, low strength soil, or poor drainage?			
CONSIDERATIONS - Weakened anchorage contributes to instability with: • Poor drainage and soil depth restrict rooting in draws and gullies. • Conspicuous pockets of higher productivity (seepage over basal till or bedrock; saturated or seasonally saturated riparian soils). • Smooth rock outcrops or bedrock that roots cannot penetrate (no cracks and fissures). • Where upturned 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. • Low soil strength – pure sands or silts with few coarse fragments etc.			
Soil Hazard Class:	☐ **High** (weak)	☐ **Moderate** (average) [2]	☐ **Low** (strongly anchored)

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 AN EXCEPTION - 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 Harvesting Hazard for Wind:

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

HARVESTING HAZARD

DIAGNOSTIC QUESTION. Will the proposed harvesting strategy substantially increase windloading and/or reduce support of trees either along the stand edge or retained as dispersed trees in the block?

NOTE: Consider the interaction of both #1 and #2 – see the windthrow manual.

1. WIND LOADING CONSIDERATIONS - Post harvest wind loading increases on newly exposed edges with:
   - Exposure of boundary edges to damaging storm winds – moving from lee-facing edges (least exposed), to parallel edges (moderate exposure), to perpendicular edges (most exposed).
   - Fetch length - wind loading increases linearly as distance across an opening toward prevailing storm winds increases from 0 to 5 tree lengths with no further increases after 10 tree lengths.
   - Funnelling due to treed boundary shape – concentrates wind and further increase wind loading.
2. ALSO CONSIDER INTER-TREE SUPPORT REDUCTION (between adjacent trees). Hazard increases:
   - With increasing tree removal in partial-cutting (dispersed retention or thinned areas).
   - As reserve strips or patches become narrower or smaller (where wind can blow through them).

Harv Haz.Class	☐ **Very High**	☐ **High**	☐ **Moderate**	☐ **Low**	☐ **Very Low**

Considerations

- On Windthrow Field Form 2, the harvesting hazard ranges from very low to very high depending on how and where harvesting will be applied (e.g., from a single tree removed to a large opening with a large fetch created).
- There are two factors working together for harvesting hazard – increased windloading on individual trees due to harvesting and decreased inter-tree support for trees due to harvesting. The two work together to give an indication of how likely windthrow will be on the edge or within a dispersed retention stratum, (i.e., the likelihood of windthrow).
- FIRST - Consider boundary orientation and fetch - Exposure of edges depends on the horizontal distance into prevailing peak 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 harvesting-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 harvesting hazard, as the actual fetch is much greater than five tree lengths.
  - Note – A fetch of 10 tree lengths (200-400 m) and a boundary perpendicular to the prevailing storm winds will bring the harvesting hazard up to 'High,' while a parallel edge with the same fetch will be 'Moderate.'
- NEXT – Consider inter-tree support reduction by the proposed harvesting – For partial cut harvesting this may be the primary factor driving the harvesting

hazard. In such cases, consider how open the stand will be after harvesting and the lack of adjacent trees to support individuals left standing. If the thinned or dispersed retention area has an exposed edge, then also think about the windloading considerations (#1).

  - If a small retention patch, less than 0.25 ha, is being used or a narrow retention strip (as a riparian or other reserve), which will allow the wind to blow right through it, consider inter-tree support (#2) along with windloading (#1). In this way, if windloading gives you a moderate hazard, a narrow strip could make it a high hazard, or if your windloading provides you with a high hazard, a small patch might make it very high.

- Note – For inter-tree support, the concern is for silvicultural systems (seed tree, shelterwoods, selection, dispersed retention) and intermediate harvesting entries such as commercial thinning. The more open, the greater the harvesting hazard.
- Note - Strips or patches that are one tree-length or less in width can substantially increase windthrow, depending on the windloading. If the exposure and additional windloading is sufficient that the wind profile is expected to penetrate right through the strip or patch, then harvesting hazard will increase. Each tree will feel the maximum drag force from every peak storm, with little support from its neighbours.
- 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).

e. Determining Biophysical Hazard for Wind: Using a Windthrow Form 2 – Side B (completed with an example scenario below)

WINDTHROW LIKELIHOOD EVALUATION - score

Add Topographic, Stand and Soil Hazards to get Biophysical Hazard; then add Harvesting Hazard to Biophysical Hazard to get Windthrow Likelihood. Adjust if similar calibration sites are significantly different.

	Very High	High	Moderate	Low	Very Low
Topographic Hazard	4	3	2	1	0
Stand Hazard		3	2	1	0
Soil Hazard		2	1	0	
Biophysical Hazard	**8+**	**6-7**	**4-5**	**<4**	**0**
Harvesting Hazard	7	6	4	2	0
Windthrow Likelihood	**14+**	**12-13**	**10-11**	**6-9**	**<6**
Adjust with calibration					

Considerations

- Biophysical Hazard - 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.

f. *Determining Windthrow Likelihood:*

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

WINDTHROW LIKELIHOOD EVALUATION - score

Add Topographic, Stand and Soil Hazards to get Biophysical Hazard; then add Harvesting Hazard to Biophysical Hazard to get Windthrow Likelihood. Adjust if similar calibration sites are significantly different.

	Very High	High	Moderate	Low	Very Low	
Topographic Hazard	4	3	2	1	0	
Stand Hazard		3	2	1	0	
Soil Hazard		2	1	0		
Biophysical Hazard	**8+**	**6-7**	**4-5**	**<4**	**0**	
Harvesting Hazard	7	6	4	2	0	
Windthrow Likelihood	**14+**	**12-13**	**10-11**	**6-9**	**<6**	
Adjust with calibration						

Considerations

- Windthrow Likelihood - Following with the same example from the previous page, the harvesting 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.
- Adjusting from calibration edges (See below) – Your calibration edges, if they truly are representative of the stand edge you are assessing in your proposed

harvest block are the most reliable data for predicting the windthrow likelihood. If the calibration edge is telling you that you are scoring one of the component hazards too low, modify as below. You need to consider your calibration edge(s) carefully when making this adjustment. It is helpful if you also explore which hazard you might be under-estimating or over-estimating – for other assessments in the cutblock.

WINDTHROW LIKELIHOOD EVALUATION - score						
Add Topographic, Stand and Soil Hazards to get Biophysical Hazard; then add Harvesting Hazard to Biophysical Hazard to get Windthrow Likelihood. Adjust if similar calibration sites are significantly different.						
	Very High	**High**	**Moderate**	**Low**	***Very Low***	
Topographic Hazard	*4*	*3*	*2*	*1*	***0***	
Stand Hazard		*3*	*2*	*1*	***0***	
Soil Hazard		*2*	*1*	*0*		
Biophysical Hazard	***8+***	***6-7***	***4-5***	**<4**	***0***	
Harvesting Hazard	*7*	*6*	*4*	*2*	***0***	
Windthrow Likelihood	***14+***	***12-13***	***10-11***	**6-9**	**<6**	
Adjust with calibration		12				

g. Determine Consequences and Windthrow Risk

- See Section 6 – Determination of Windthrow Risk.

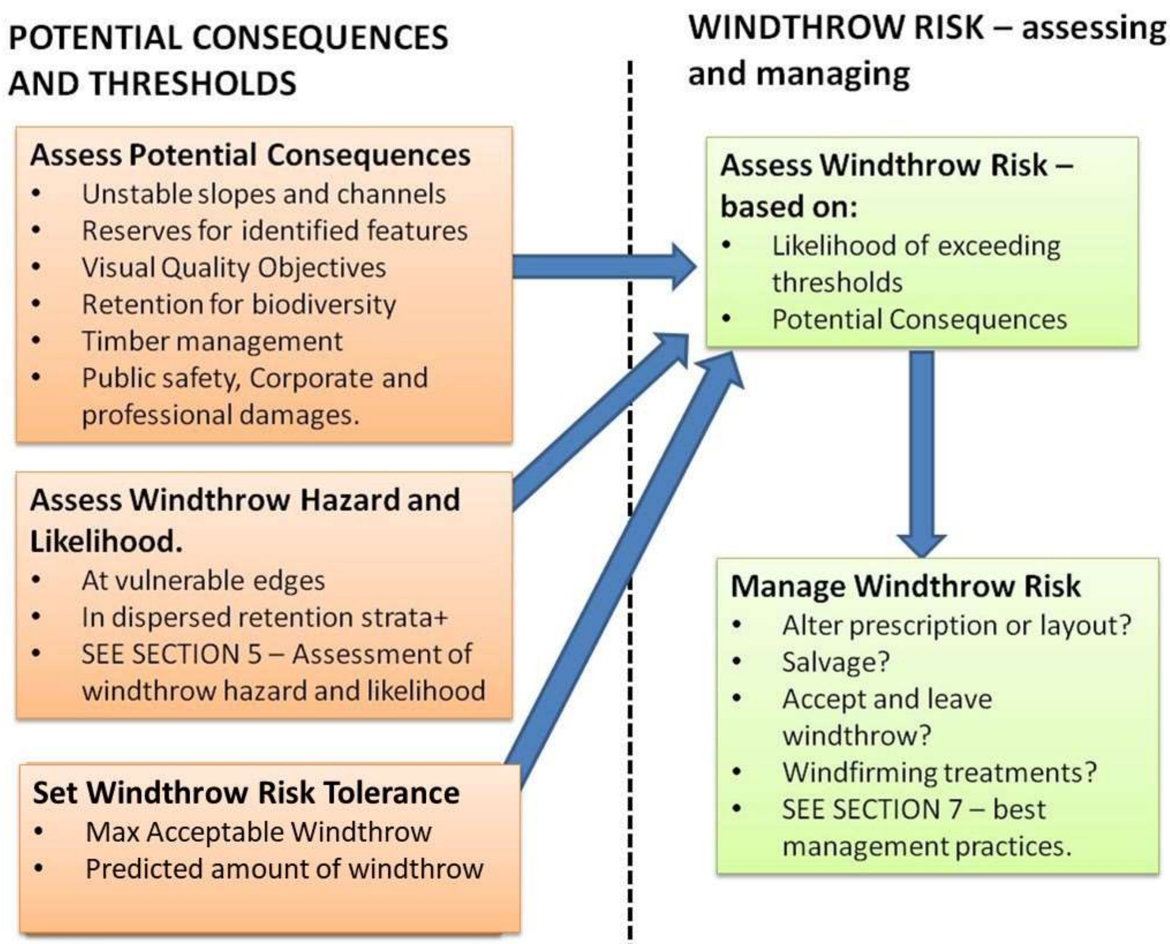
6. Determining Windthrow Risk

CONTENT

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).

Some consequence rankings can be ranked corporately

- The organization should go through the list of potential value-features or conditions that could be encountered on the cutblock and determine if a standard ranking can be assigned as a default, or whether it must be determined on the ground. If ground assessments are required, the specialists and others who should be involved should be identified and how they should be involved described.

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 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.

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

- 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).

===

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:

1. 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:

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

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

Consider:

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

Reserves for an Identified Feature (continued)

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

Consider:

8. Direct impacts – windthrow directly damages the feature – (e.g. the tree with the feature falls; a tree falls on or against the feature).
9. 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:

10. Visual landscape goals.
11. 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:

12. Viewpoints – viewing distance, and angle of viewing.
13. Visual absorption capacity – the ability for the landscape matrix to absorb the windthrow disturbance.
14. 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?

15. Consider - Time to visually effective green up.

Retention for Biodiversity:

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

Consider:

16. If the retention will be left for the entire rotation or most of it – then long term (which increases its importance for biodiversity).
17. 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:

18. 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?
19. Is it a patch of special or unique habitat? If so, go to “identified features” previous.
20. 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)

<u>DIAGNOSTIC QUESTION 3</u> – Is there a legal requirement for this retention?

Consider:

21. Legal objectives for retention targets?
22. Legal targets for ecosystem representation?
23. 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)*

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

Consider:

24. 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.
25. Is there a potential for windthrow to encourage further losses to standing timber – as with Douglas-fir bark beetles?
26. Is there a general strategy for timber salvage? If so, what are the requirements or guidance for salvaging?

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

Consider:

27. 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).
28. Logistics associated with the harvesting equipment to be used and terrain considerations.
29. Access to the windthrow without significantly damaging planted trees and other values.
30. 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)

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

<u>Guidance:</u>

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:

31. Ability to move the boundary to make it less vulnerable.
32. Ability to alter retention, for example leave specific tree species, sizes or patch/clump/strip sizes and locations.
33. The ability to affect fetch distances (while still able to meet all objectives).
34. 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.

35. 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:

36. Significant fine under land management legislation.
37. A lawsuit.
38. Significant damage to the corporate image that could strongly influence future business ventures, or harvesting opportunities.
39. 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:

1. A lawsuit.
2. Significant damage to professional credibility that could significantly impact future professional relationships.

Building Thresholds or Tolerance limits:

- 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).

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 rough 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 WINDTHROW RISK TOLERANCE

Set Windthrow Risk Tolerance

- Max Acceptable Windthrow
- Predicted amount of windthrow

Windthrow impacts on non-timber or timber values can be significant. Where the only concern is loss of timber, salvage may be an option. Normally, little can be done to ameliorate damage to non-timber values, 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]. It is useful to set windthrow tolerance thresholds to understand the amount of windthrow that can be tolerated.

Loss of timber value is probably the most common windthrow concern on most edges. However, the tolerance for windthrow can be much higher if the only value of concern is timber. This will depend on the timber values present and whether forest health concerns exist (generally due to bark beetles). In many cases, a concern for timber values can be addressed after windthrow occurs - through salvaging.

Windthrow Tolerance (expressed as a threshold):

A. Maximum Acceptable % Windthrow in a described area or zone

TOLERANCE QUESTION A: Based on the consequences of windthrow, associated consequences and the nature of the feature, patch, strip, reserve or edge, how much windthrow would be acceptable – In a core area around a feature of concern? Or generally in a patch?

Associated questions:

1. Is the only value timber? If so, how much windthrow could occur to allow for a salvage opportunity? Consider species, grades and potential forest health issues.
2. Are you trying to protect a feature – such as (but not limited to) a CMT, bear den, alluvial fan, unstable gully, fish habitat? If so, is there a core reserve area on, or immediately surrounding this feature that warrants little or zero windthrow (beyond what is natural)?
    - If no core area – indicate with NA
3. What is the amount of windthrow that could be tolerated in a zone beyond a core area, or in an entire patch? If so, what would that maximum acceptable limit be, as a proportion of the basal area or volume that could be lost to windthrow?

Also consider:

- How many standing trees are required to ensure proper function for the value of concern, or to protect a feature? 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.
- Does this zone have a limit, or is it essentially the entire patch/strip?

[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.

Tolerance levels may be set corporately:

Some tolerance levels for windthrow may be set by the organization rather than relying on layout crews to guess at these tolerance levels individually onsite. For some value features local site level considerations will still need to be made, but Standard Operating Procedures can be designed to help crews in this regard.

When setting a tolerance level, consider:

1. There are two ways to set tolerances. Think about which works best in different scenarios – you can specify how much windthrow you can tolerate, or you can specify what you want to see standing after 3 seasons. Either way, that should direct folks on the ground as to what type of buffer and practices to design to achieve those results.
2. Some features or values may be assigned a default zero tolerance for windthrow due to harvesting, but this will need to be confirmed by the organization. This might include public safety and infrastructure, perhaps some streams in a community watershed. For streams in a community watershed, it will depend on the size, location and capacity of the stream to transport sediment and other potential sensitivities – there should be a discussion with a hydrologist.
3. For some features an organization may be able to set standard windthrow tolerances or thresholds that will apply to most field situations, after consulting a specialist. These may include: streams (depending on the type), streams with sensitive hydrogeomorphic features, unstable terrain, cultural features, karst, bear dens and other similar features. You might allow for a potential change in the application of a corporate standard with the site-specific involvement of a specialist.
4. For some value-features the organization might be able to set a standard tolerance relatively easily – Stand level biodiversity patches for example.
5. For some value-features thresholds will have to set on a cutblock-by-cutblock basis. The organization should have a protocol for those who need to set these – for example – VQOs are highly dependent on the block location, or internal retention patches to maintain forest influence in a retention silvicultural system.

EXAMPLE1 : Setting thresholds for acceptable windthrow:

COMPARISON OF PREDICTED WINDTHROW TO MAX TOLERANCE:			
PREDICTED WINDTHROW – from hazard and likelihood assessment – FORM 2			
Predicted edge penetration (m):	20 m	Predicted % windthrow in an identified zone (%):	25% in a 20 m penetration zone
MAXIMUM WINDTHROW TOLERANCE (Limit or Threshold) – The target maximum acceptable amount of windthrow based on consequences and considerations from the Manual. Note - *Use NA if none apply.*			
TO PROTECT a mapped feature:	NA – no feature – just a retention patch		
TO SUSTAIN the general condition of a patch or reserve:	50% windthrow throughout the patch		

Comments:

The patch is second growth left for biodiversity objectives to recruit old growth attributes over time. Windthrow may increase the habitat variability and promote old growth attributes if it stays within the tolerance thresholds.

SEE – The photograph below.

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.

EXAMPLE 2: Setting thresholds for acceptable windthrow:

COMPARISON OF PREDICTED WINDTHROW TO MAX TOLERANCE:			
PREDICTED WINDTHROW – from hazard and likelihood assessment – FORM 2			
Predicted edge penetration (m):	25 m	Predicted % windthrow in an identified zone (%):	50% in a 25 m penetration zone
MAXIMUM WINDTHROW TOLERANCE (Limit or Threshold) – The target maximum acceptable amount of windthrow based on consequences and considerations from the Manual. Note - *Use NA if none apply.*			
TO PROTECT a mapped feature:	• 0% (zero, beyond natural levels) within the S5 gully. • 5% in a 10 m zone from the edge of the gully		
TO SUSTAIN the general condition of a patch or reserve:	NA		
Comments: Where the boundary is currently located on the edge of the gully, there is a high likelihood of significant windthrow throughout the gully with a moderate likelihood of initiating a significant debris flow, which has a moderate likelihood of introducing significant sediment into fish habitat 1000 m downslope (D. Irt Peng-Geotech).			

Relationship to Windthrow Risk

Estimated likelihood of exceeding windthrow Tolerance				High
WINDTHROW RISK ASSESSMENT				
DIAGNOSTIC QUESTION: What is the potential impact of windthrow, considering the likelihood that the tolerance for windthrow is exceeded and 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)
Comments and Recommendations: Risk is High to Very High based on identified Very High consequences and a high likelihood of exceeding the tolerance. Move the edge of boundary out 35 m from the S5 gully and consider windfirming treatments 15-20 m into the edge.				

2. Windthrow Risk

ASSESSING WINDTHROW RISK

Assess Windthrow Risk – based on:

- Likelihood of exceeding windthrow tolerance
- Potential consequences

Windthrow risk reflects the risk to management associated with the layout design, considering the likelihood of windthrow against the tolerance for windthrow, which is 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 tolerance for acceptable windthrow, set as a threshold.

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 threshold for acceptable windthrow - in terms of the amount of windthrow as a proportion of the basal area on a feature, around a feature, in a reserve or buffer or in a zone extending into a stand from the timber edge.

The following categories are used to assess considering likelihood and your windthrow tolerance (thresholds) for potential consequences:

Nil - Predicted windthrow is far below the tolerance

Low - Predicted windthrow is below but not far below the tolerance and, it is expected that windthrow will likely remain below the tolerance.

Mod - Predicted windthrow is close to the tolerance limit (either side) and it is equally likely to be exceeded as it is not to be exceeded.

High - Predicted windthrow significantly exceeds the tolerance but substantial intact timber is expected to remain around feature or in the patch/strip.

Very High - Predicted windthrow exceeds the thresholds so much that most trees in and around the feature or in the patch/strip are expected to be blown down.

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:

Estimated likelihood of exceeding windthrow Tolerance				High
WINDTHROW RISK ASSESSMENT				
DIAGNOSTIC QUESTION: What is the potential impact of windthrow, considering the likelihood that the tolerance for windthrow is exceeded and 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)
Comments and Recommendations: Risk is High to Very High based on identified Very High consequences and a high likelihood of exceeding the tolerance. Move the edge of boundary out 35 m from the S5 gully and consider windfirming treatments 15-20 m into the edge.				

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

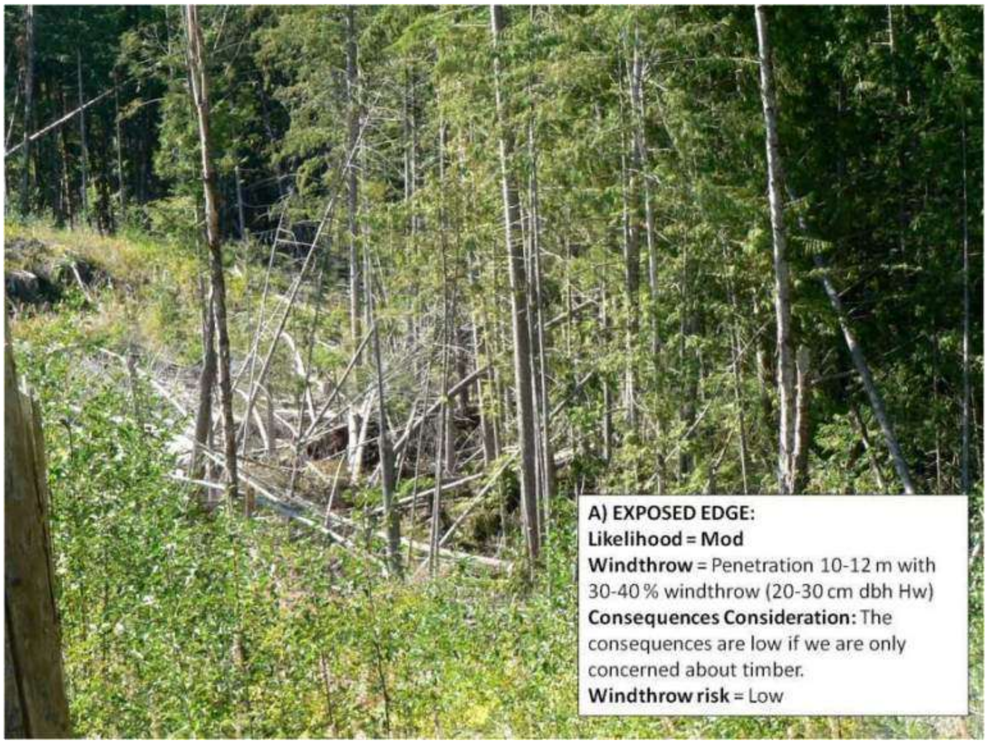
The following examples were chosen to provide an illustration of a range of coastal situations that may be encountered with various combinations of windthrow likelihood, consequences and resultant windthrow risk. Note that *likelihood* is the *likelihood of windthrow occurring*, not the likelihood *to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

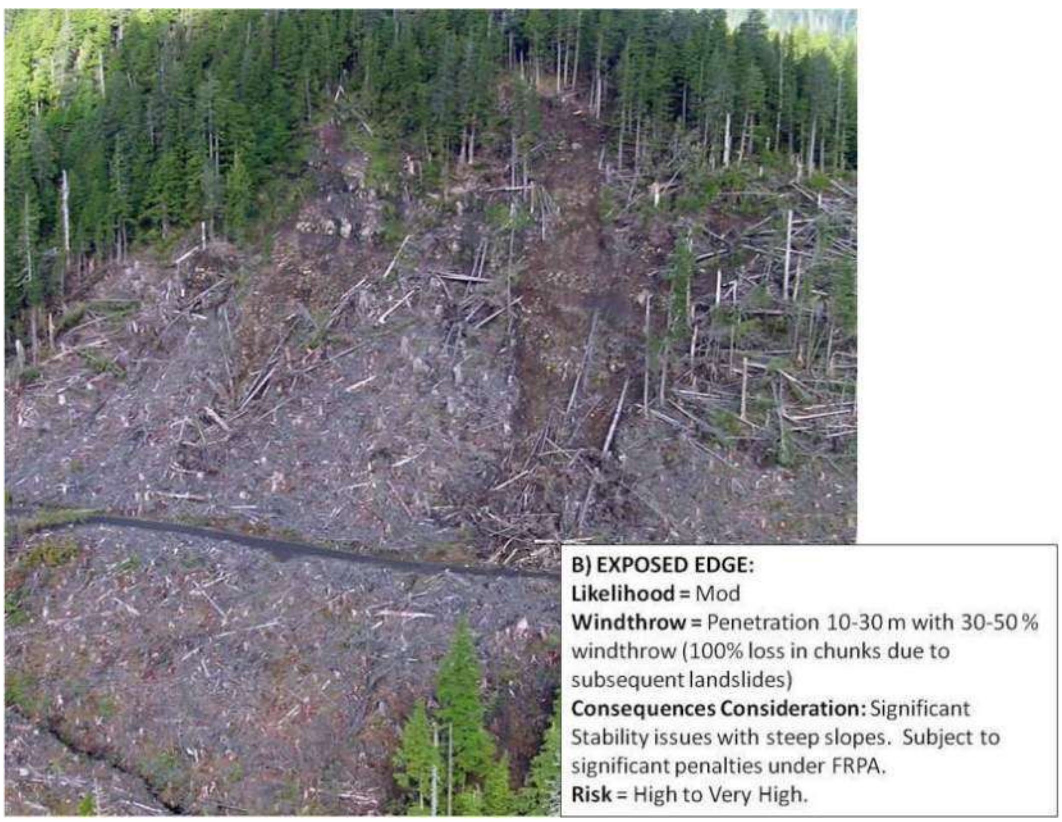
The photographs illustrate actual windthrow to provide a more explicit representation of what to expect for certain windthrow likelihood scenarios. For this reason the windthrow penetration and amount (as a % of total volume or basal area) are reported under *windthrow* rather than *likelihood*, except 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.

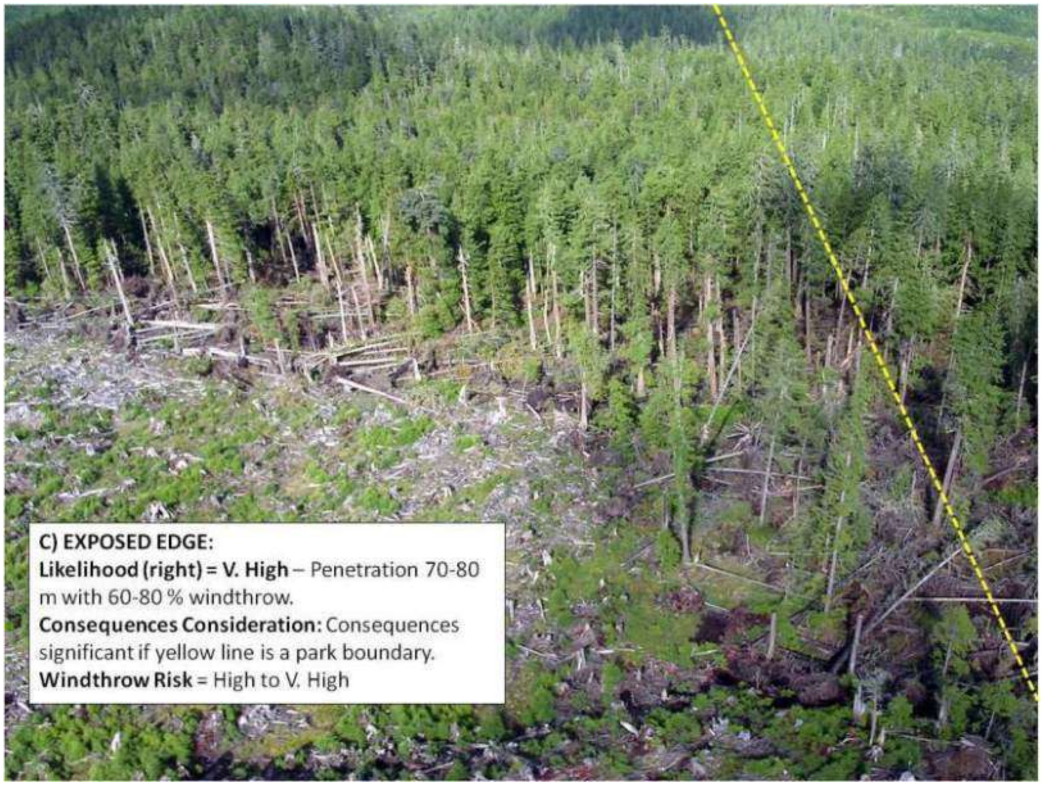
Intent

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.

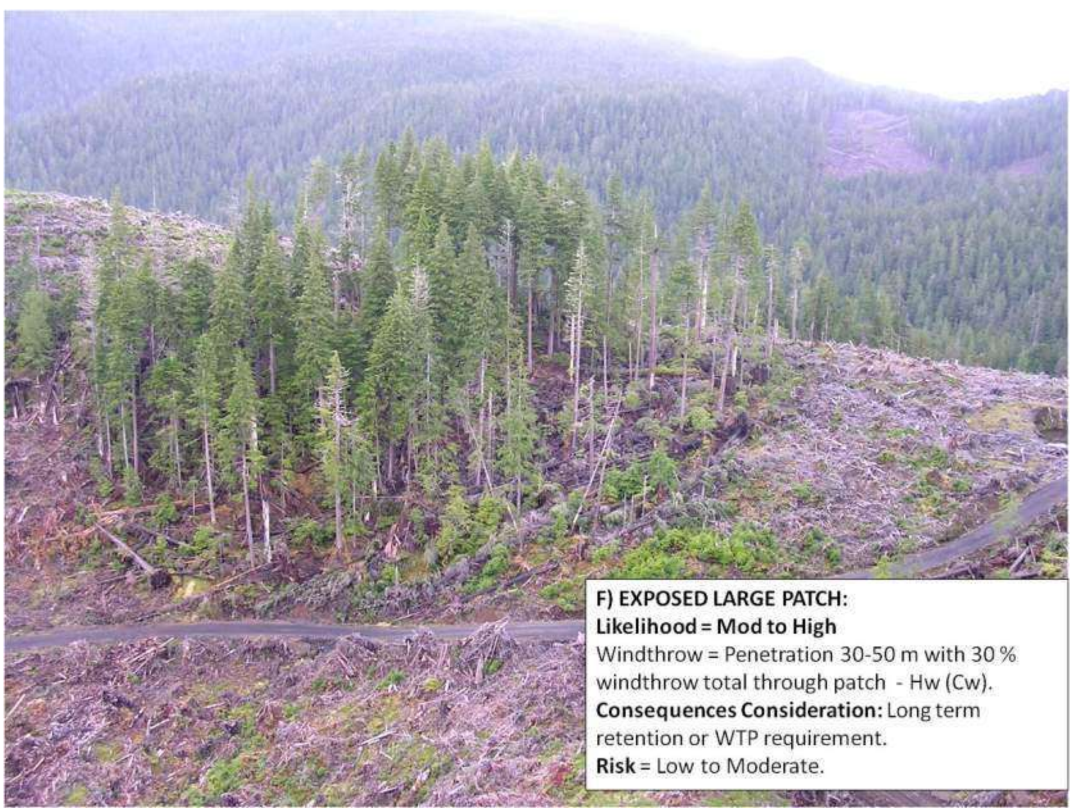

A) EXPOSED EDGE:
Likelihood = Mod
Windthrow = Penetration 10-12 m with 30-40 % windthrow (20-30 cm dbh Hw)
Consequences Consideration: The consequences are low if we are only concerned about timber.
Windthrow risk = Low

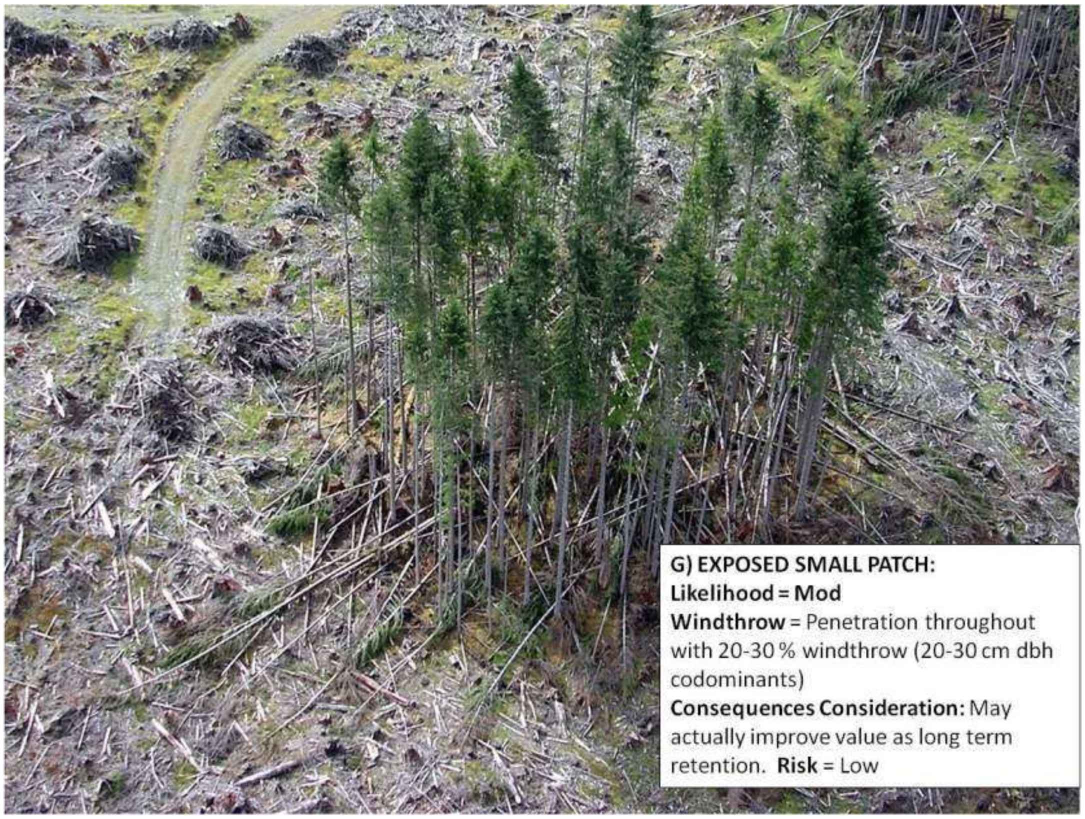

B) EXPOSED EDGE:
Likelihood = Mod
Windthrow = Penetration 10-30 m with 30-50 % windthrow (100% loss in chunks due to subsequent landslides)
Consequences Consideration: Significant Stability issues with steep slopes. Subject to significant penalties under FRPA.
Risk = High to Very High.


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


Break into escarpment
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

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 two stages:

1. 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).
2. 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 perspectives on windthrow likelihood and risk for those developing prescriptions, then guides practitioners through the most current BMP options and their applications.

A Perspective on Windthrow Likelihood Scenarios for Prescribers

Much of the time, the combination of biophysical hazard and initial layout results in a moderate likelihood of windthrow. Appropriate responses to moderate likelihood scenarios can be challenging since they vary widely, depending upon the consequences.
(See Diagnostic Questions to Evaluate Dynamich Nature of Windthrow Likelihood)

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 practice. These are the scenarios where a certain level of windthrow is both likely and acceptable, based on few or no consequences.*

Moderate windthrow likelihood scenarios require careful consideration to be technically sound and cost effective. This is especially true where a poorly thought-out block layout, stand treatment or 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.

==

Diagnostic Questions – Evaluate Dynamic Nature of Windthrow Likelihood

Assess Wind Exposure:

DIAGNOSTIC QUESTION 1 - Is the site a windy area?

Guidance:

You may need to check nearest weather station records or consult local professionals working in the area.

Consider:

1. The wind exposure in the following circumstances:
    - i. Leeward side of topographic obstruction that is not a steep ridge. **(LOW EXPOSURE)**
    - ii. Clear unobstructed view in the direction of regular occurring storm winds. **(HIGH EXPOSURE)**
    - iii. Valley oriented in the direction of regular occurring storm winds. **(HIGH EXPOSURE)**
    - iv. Adjacency to natural openings (e.g. shorelines, bogs, grasslands). **(HIGH EXPOSURE)**
    - v. Variations in the extremes described in ***1i – 1iv*** above (e.g. partial obstruction, less-frequent storm wind directions, distance from natural openings, valley orientations that deviate from storm wind directions). **(MODERATE EXPOSURE GRADIENTS)**

Harvesting effects on Wind Exposure and Windthrow Likelihood:

DIAGNOSTIC QUESTION 2 - How does the creation of new edges change the wind exposure and windthrow likelihood?

Guidance:

Stand alterations and edge modifications may alter wind patterns and increase exposure (especially **MODERATE EXPOSURE GRADIENTS**) of non-acclimatized residual trees/stands.

Consider:

2. A new edge in ***1i*** above will not increase exposure and result in **LOW WINDTHROW LIKELIHOOD**.
3. New edges in ***1ii – 1iv*** do not change exposure and result in **HIGH WINDTHROW LIKELIHOOD**.
4. Existing edges in ***1ii – 1iv*** are usually acclimatized to exposure and result in **LOW WINDTHROW LIKELIHOOD**. *Note – These can be maintained as downwind "anchors" during layout of new openings.*
5. New edges in ***1v*** above nearly always increase within the gradients of **MODERATE EXPOSURE** or from **MODERATE** to **HIGH EXPOSURE**.
    - i. Openings that clear obstructions in the direction of regular occurring storm winds will increase exposure (fetch) for residual trees and result in **HIGHER WINDTHROW LIKELIHOOD**.
    - ii. Narrow openings in the direction of regular occurring storm winds will create a "valley" in the stand and increase funneling resulting in a **HIGHER WINDTHROW LIKELIHOOD**.
    - iii. Within block retention (patches/individual trees) changes or creates new partial obstructions which can maintain or increase wind exposure. *Note – within block retention can protect newly created block edges that have high values associated with them.*
6. The multitude of variations of **MODERATE WIND EXPOSURE** in ***1v*** above combined with the wide range of potential practices in ***5i – 5iii*** require that best management practices focus on **MODERATE WINDTHROW LIKELIHOOD** scenarios.

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

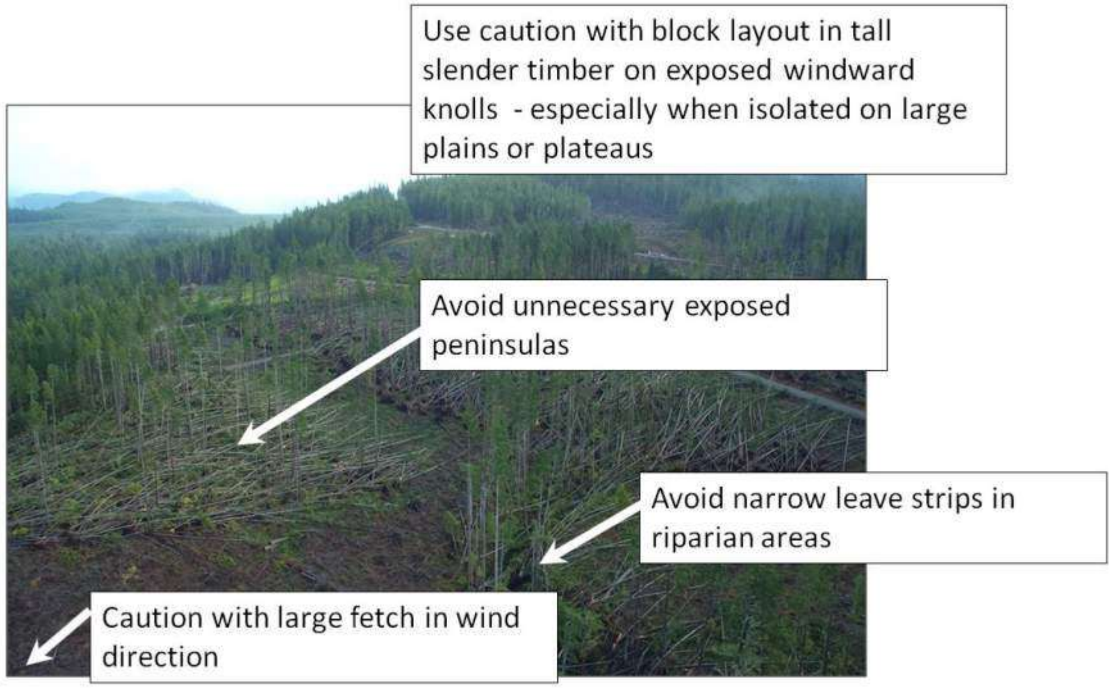


Figure 7-A. Several BMPs for tall slender timber.

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

Figure 7-C. 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 practices, unless a small amount of windthrow may occur which carries high consequences (Figures _7-D,E,F). These scenarios may in fact present opportunities to "anchor" windfirm" boundaries for harvesting on the wind-exposed side of the opening.

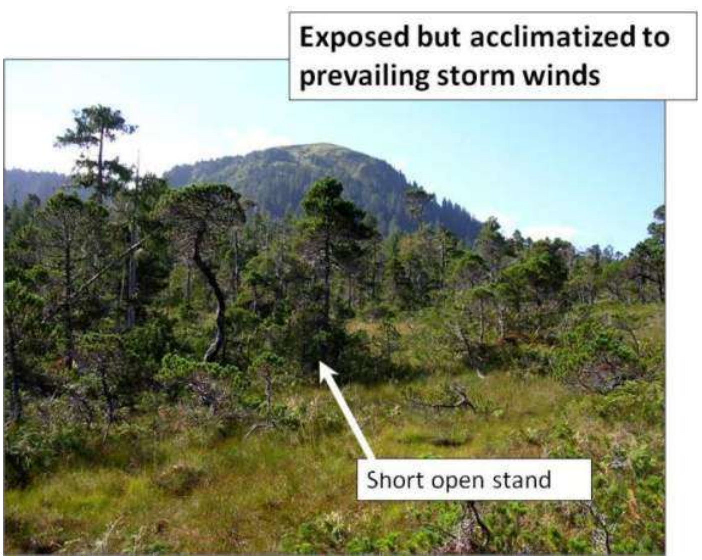


Figure 7-D. Windfirm forest edge on exposed upper elevation bog.

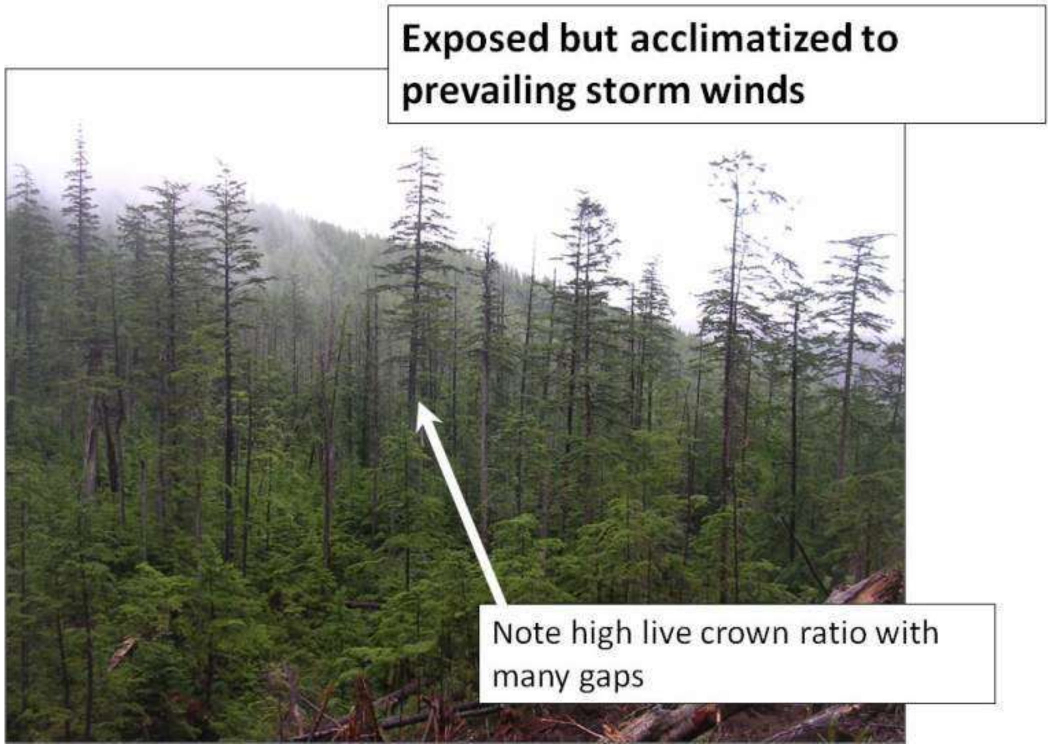


Figure 7-E. Highly exposed, wind-tattered and acclimated stand.

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

Prescription 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, then thresholds for windthrow are not applicable and no practice or harvest modifications are 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.

PRACTICE 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

PRACTICE 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*** – if salvaging is conducted in this way, you can expect the same windthrow to result that occurred on the initial edge.
- ***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 (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 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.
- ***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-G).

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

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

Rollerson et. al. (2009) recommends 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-H). 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-D).
- ***Consider that one-sided riparian reserve strips with lee or parallel edges[3] will have fewer concerns where consequences are high*** (Figure 7-I) - Using a two-edged riparian reserve strip often ensures that one edge will be more exposed to the prevailing wind direction The trends shown in Figure 7-I 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-J) 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-K).

  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-K 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.

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[3] Relative to the prevailing storm winds.

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-L). 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-D to 7-F.
- **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.

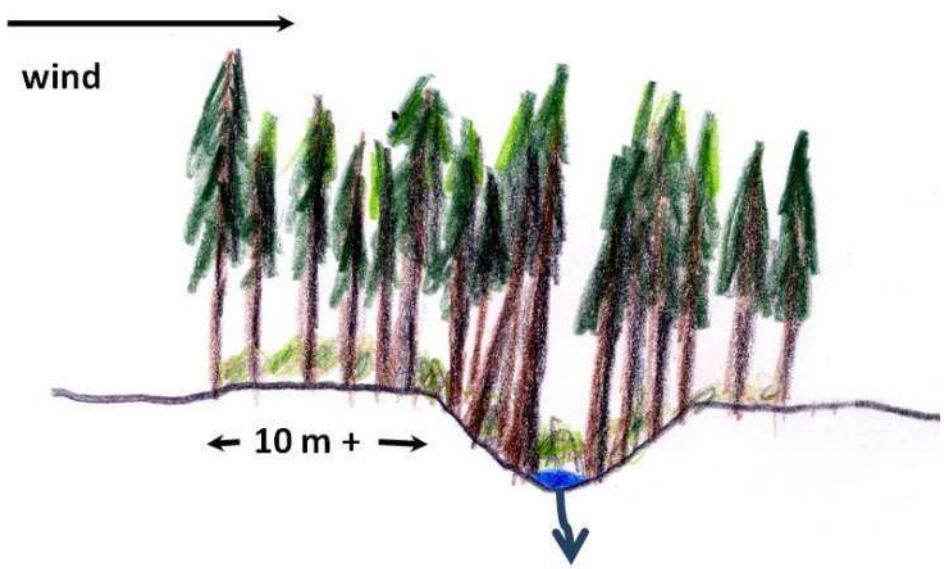


Figure 7-G. An illustration of a reasonable setback to avoid windthrow penetration into less stable riparian gullies or swales.

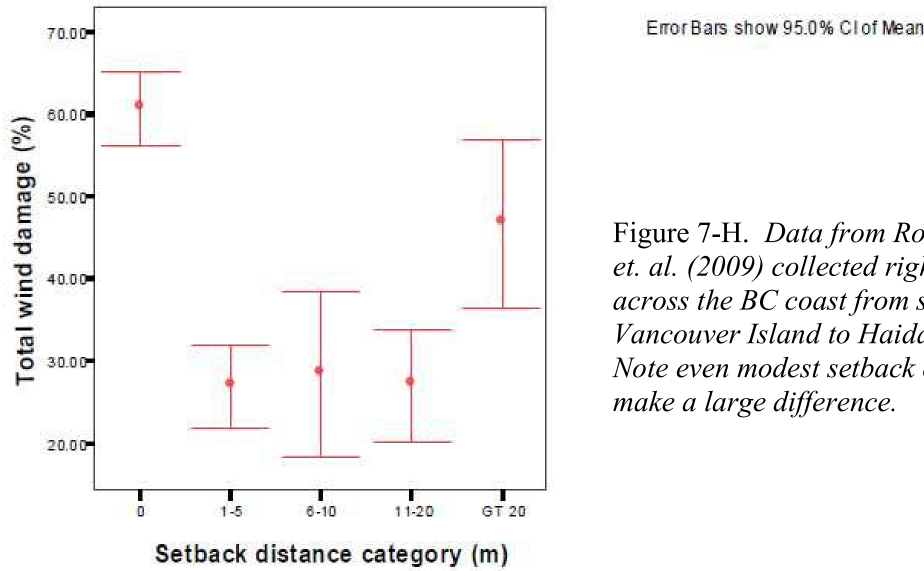


Figure 7-H. *Data from Rollerson et. al. (2009) collected right across the BC coast from southern Vancouver Island to Haida Gwaii. Note even modest setback can make a large difference.*

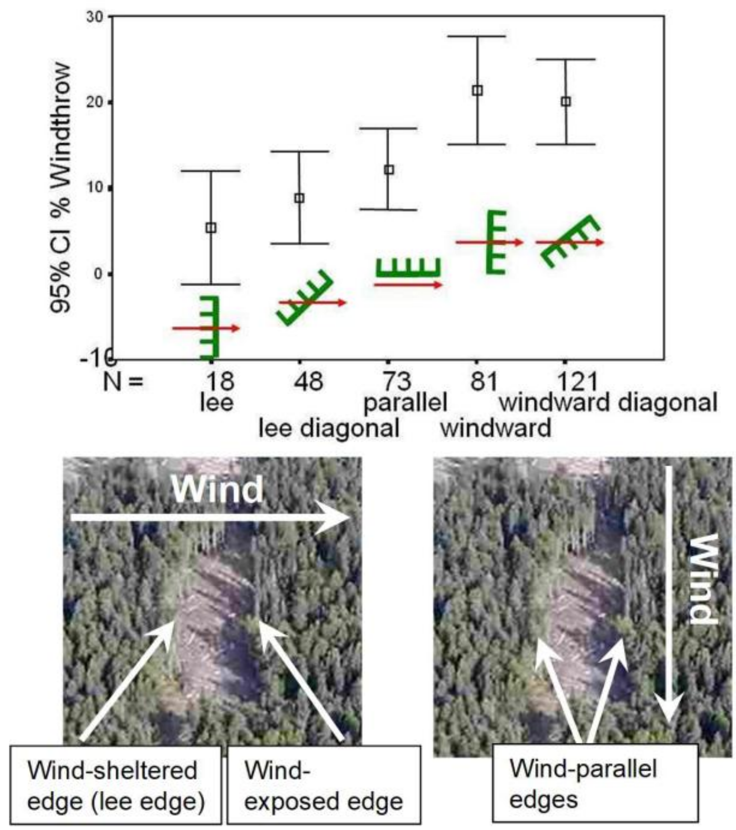


Figure 7-I. Boundary orientation relative to the wind direction and its effects on percent windthrow (Rollerson and McGourlick 2001).

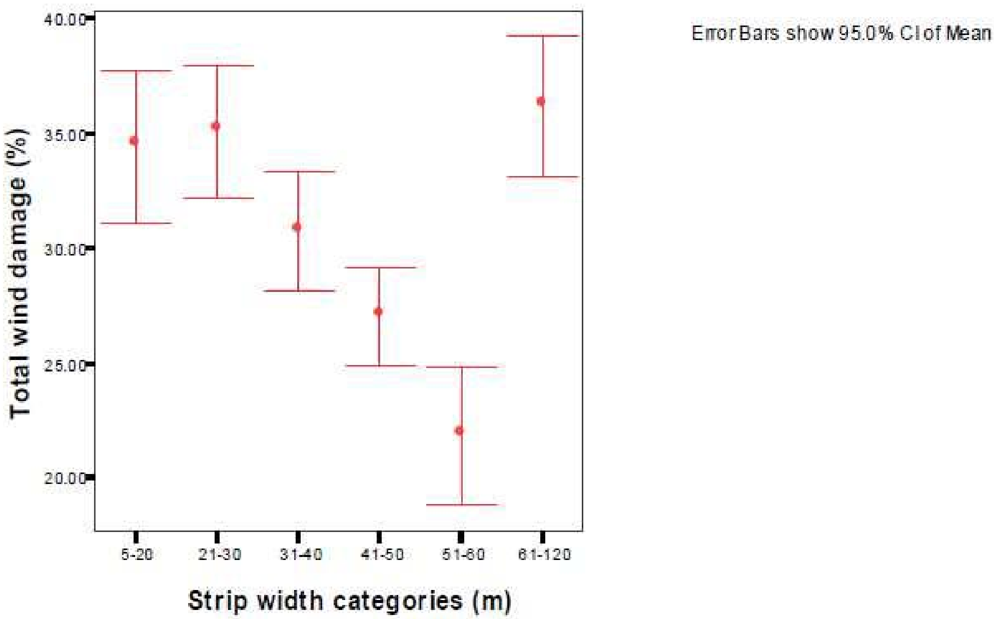


Figure 7-J. Data from Rollerson et. al. (2009) collected across the BC coast from Vancouver Island to Haida Gwaii.

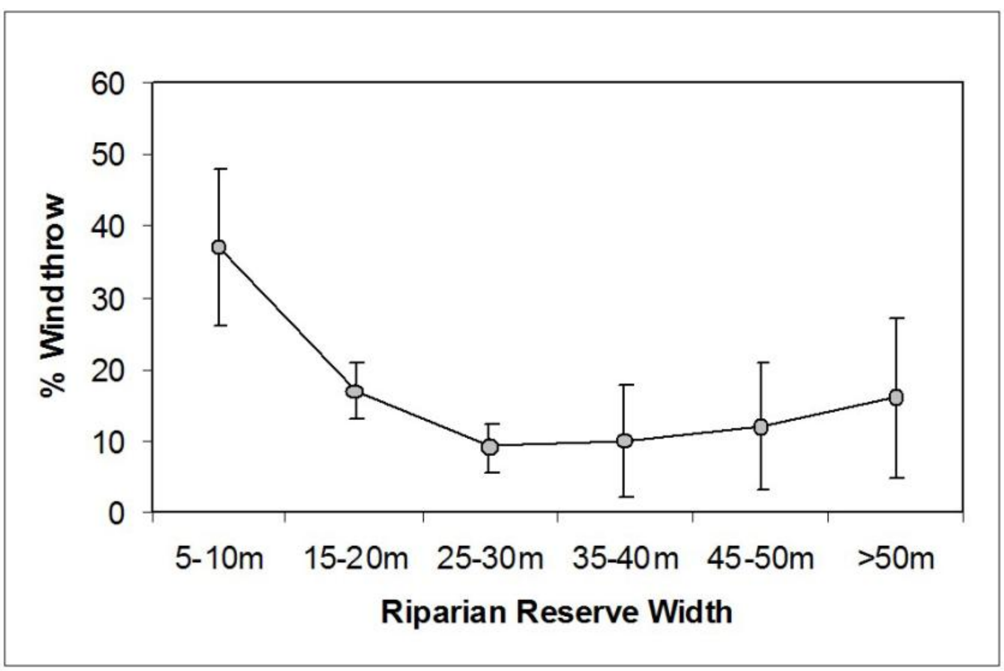


Figure 7-K. Relationship between riparian reserve width and windthrow damage (Rollerson and McGourlick 2001). Note – there were fewer larger reserve widths sampled in this study (i.e. > 35 m) contributing to the larger error bars.

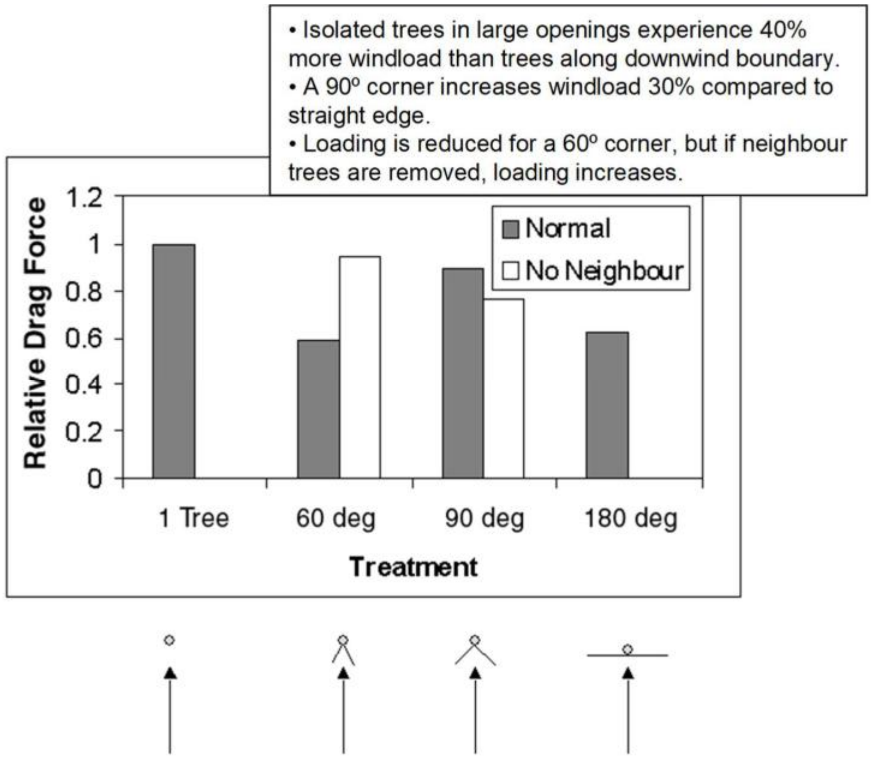


Figure 7-L. Relationship between relative drag force and wind-exposed edge shapes at the downwind side of a large opening (Novak 2000).

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.

  Rollerson et al. (2009) studied windthrow in variable retention blocks across the Coast from Haida Gwaii to Southern Vancouver Island. They found no trend of less wind damage in patch size up to one hectare, with damage ranging from 45% in Haida Gwaii to 16% in Powell River (Figure 7-M).

- ***In addition to increasing patch size, consider locating and orienting the patch to protect a feature (where relevant)*** (Figure 7-N) - 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-O). 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).

- ***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

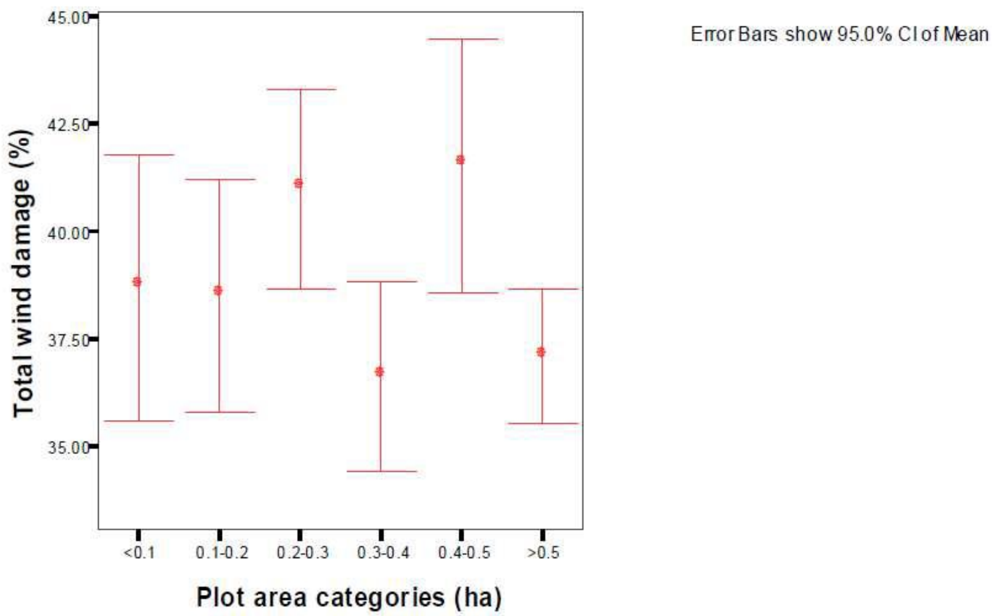


Figure 7-M *Data from Rollerson et. al. (2009) collected across the BC coast from southern Vancouver Island to Haida Gwaii showing no significant trend for patch size and wind damage. However, regional influences may be significant.*

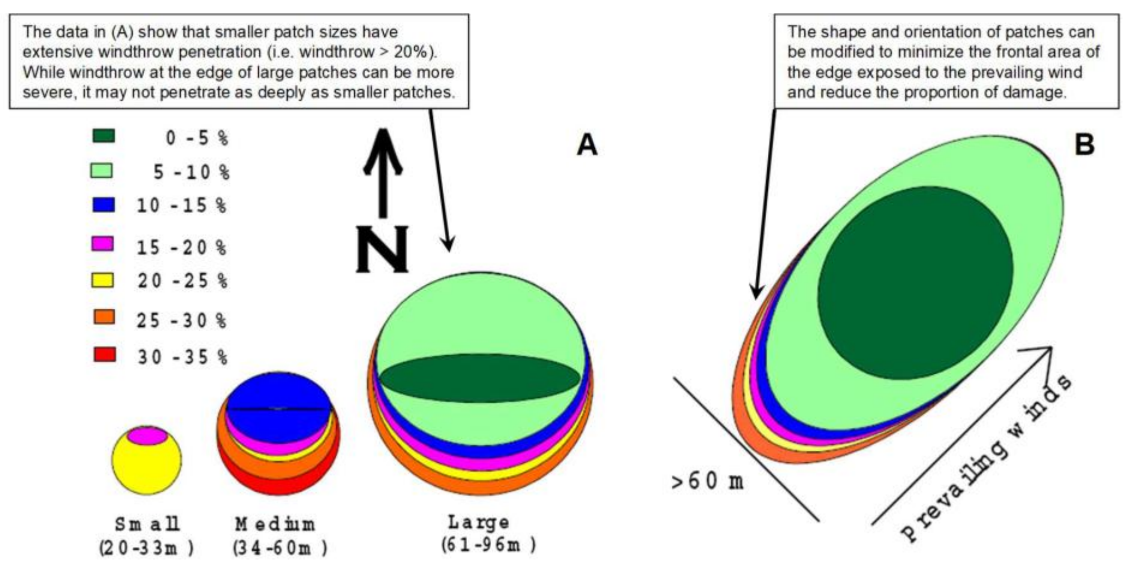


Figure 7-N. *Effects of patch size and patch orientation to the wind direction on windthrow penetration (Burton 2001).*

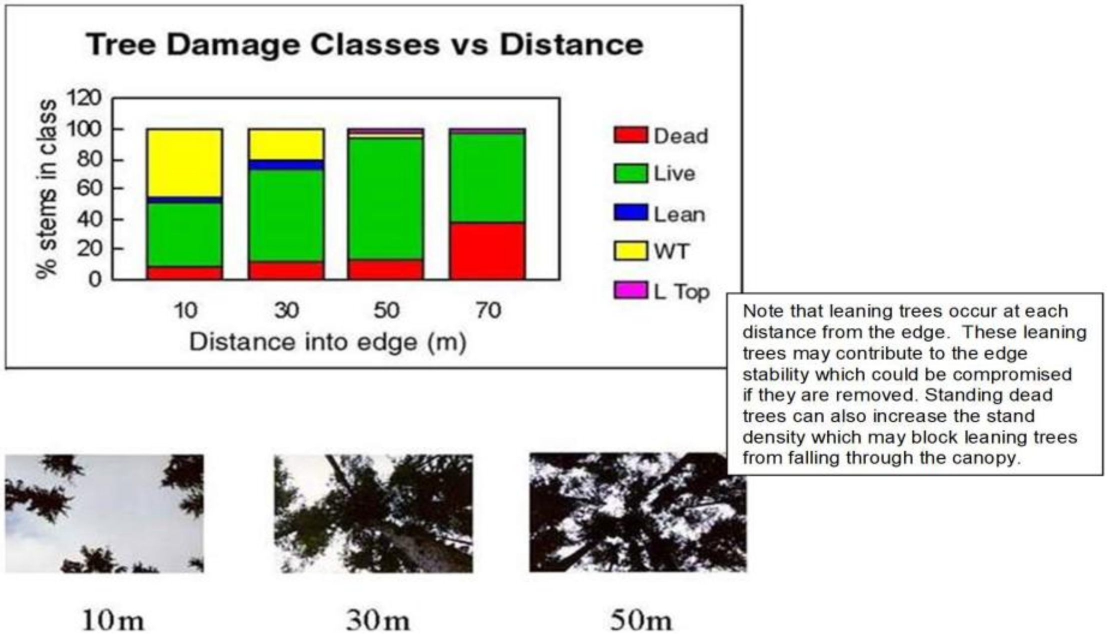


Figure 7-O. Tree damage trends with distance from the edge.

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 harvesting hazard relative to topographic exposure. It is the combination of edge orientation to prevailing storm winds and fetch that provides for a high harvesting 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-P and 7-Q 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-R illustrates a complex layout with varying levels of within-block retention and demonstrates how VR Fetch is calculated.

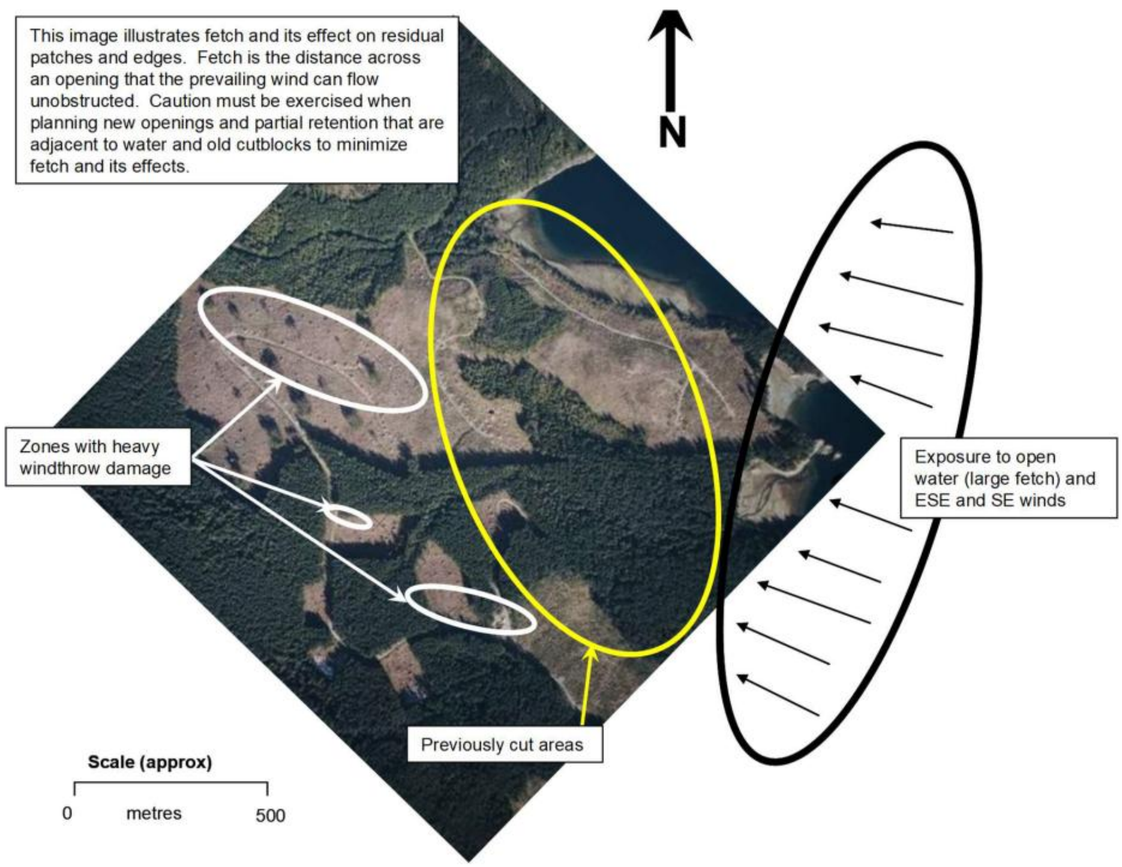
VR Fetch calculations can be made for a particular point (plot) of interest that contains forest values which need to be sustained (e.g.,. wildlife trees, CMT's, etc.). Block layouts may then be altered to minimize VR Fetch to reduce the likelihood of windthrow impacting the value of interest. Figure 7-S shows how the proportion of stems damaged increases with VR Fetch (Note – sample size for VR Fetch = 1650 in Clayoquot was very small).

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-T).

  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-Q).

- ***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-U).



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

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

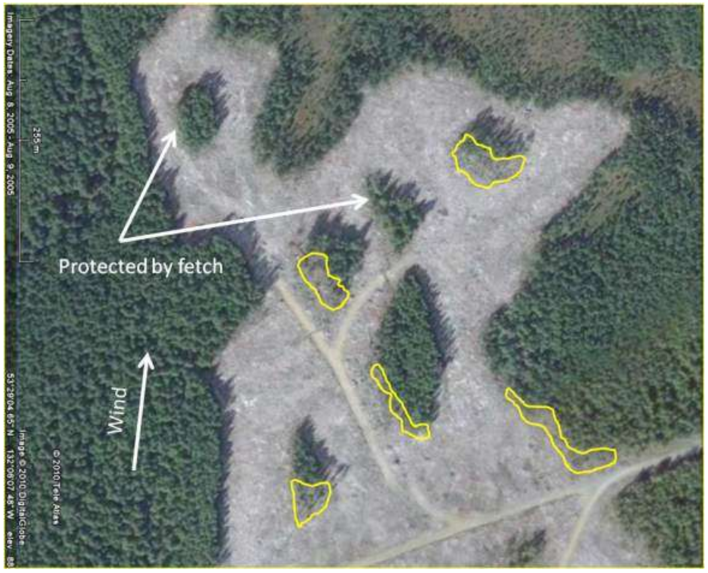
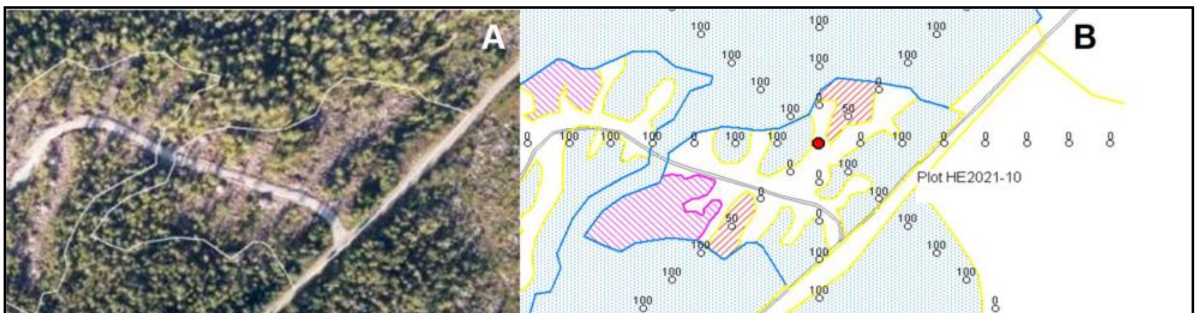


Figure 7-Q. GoogleEarthTM image from Haida Gwaii with windthrow circled in yellow. Note the influence of fetch on two patches.



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

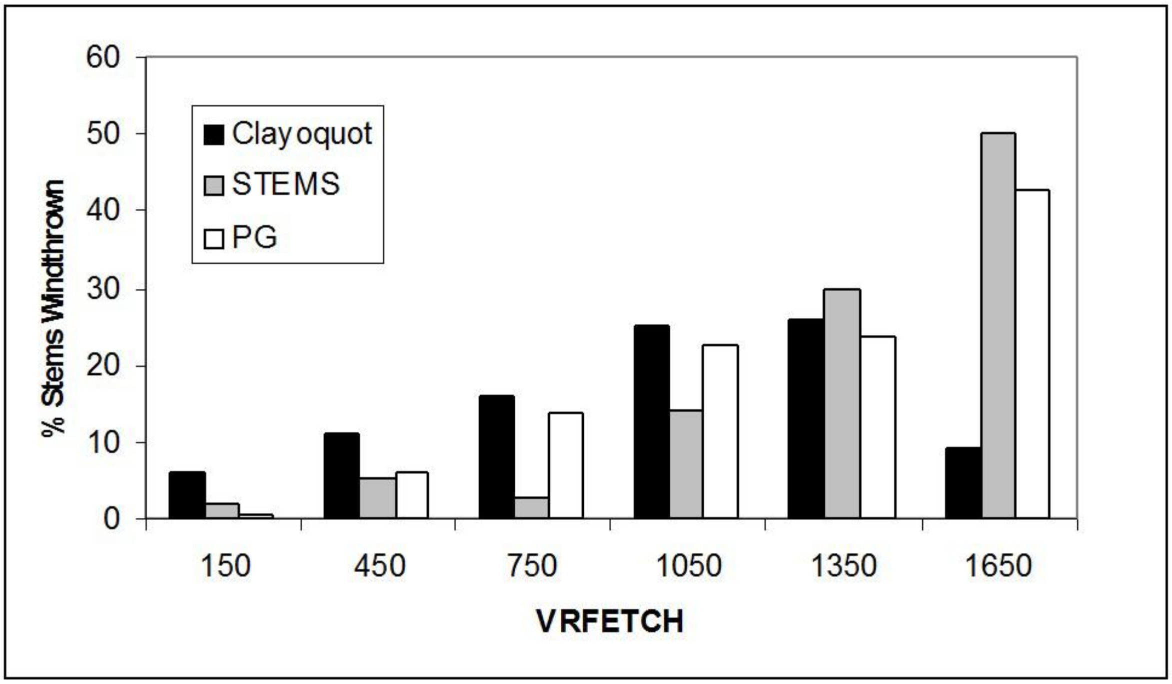


Figure 7-S. Relationship between the proportion windthrown stems and VR Fetch (Scott 2005).

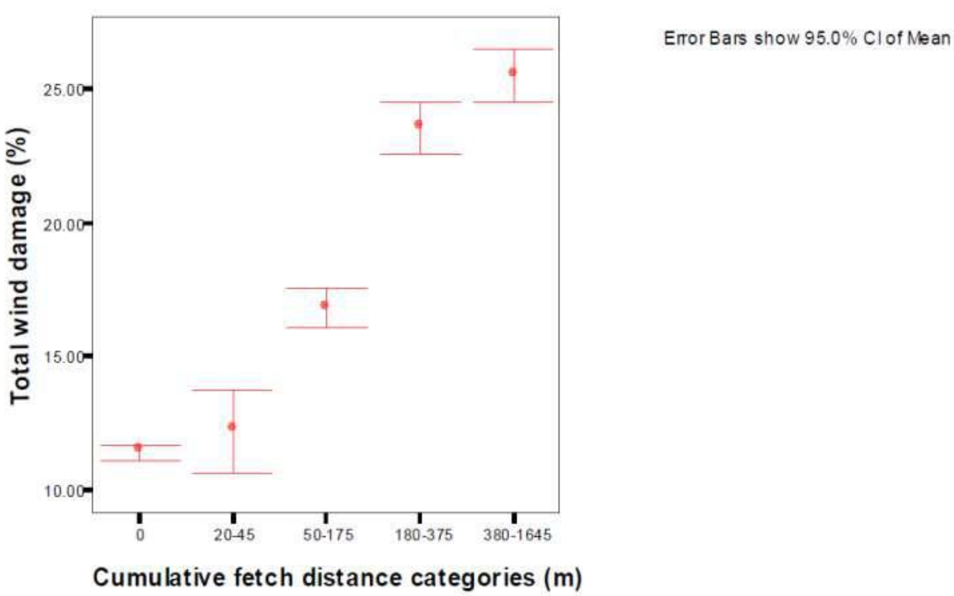


Figure 7-T.. Distribution of wind damage on outer cutblock edges with changes in cumulative fetch category (Rollerson et. al. 2009). Note this graph averages data across the entire coast and Vancouver Island. Geographic differences will occur.

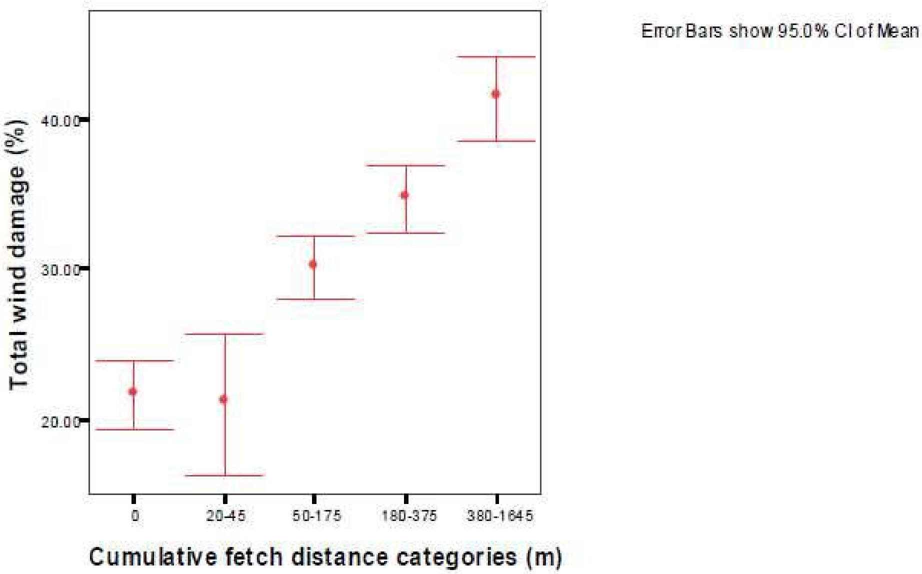


Figure 7-U Distribution of damage in internally-retained strips with changes in cumulative fetch category (Rollerson et. al. 2009), again with data averaged across the coast.

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-V).
- ***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.

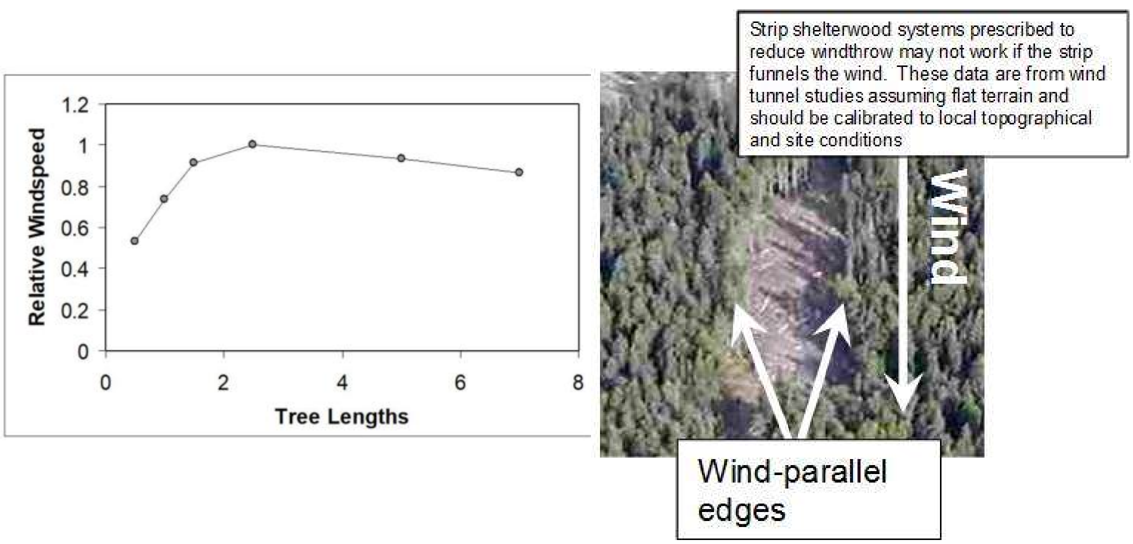
  Substantial reductions in wind speeds occur below about 3 tree lengths (Figure 7-W). These data also assume flat terrain, therefore layout should be calibrated with the local site and stand conditions. If prevailing storm winds occur in more than one direction, consider prescribing smaller openings (as in a group selection) which limit fetch in all directions (Figure 7-X).

- ***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-Y & Z). 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.

- ***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-AA). 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.



[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".

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

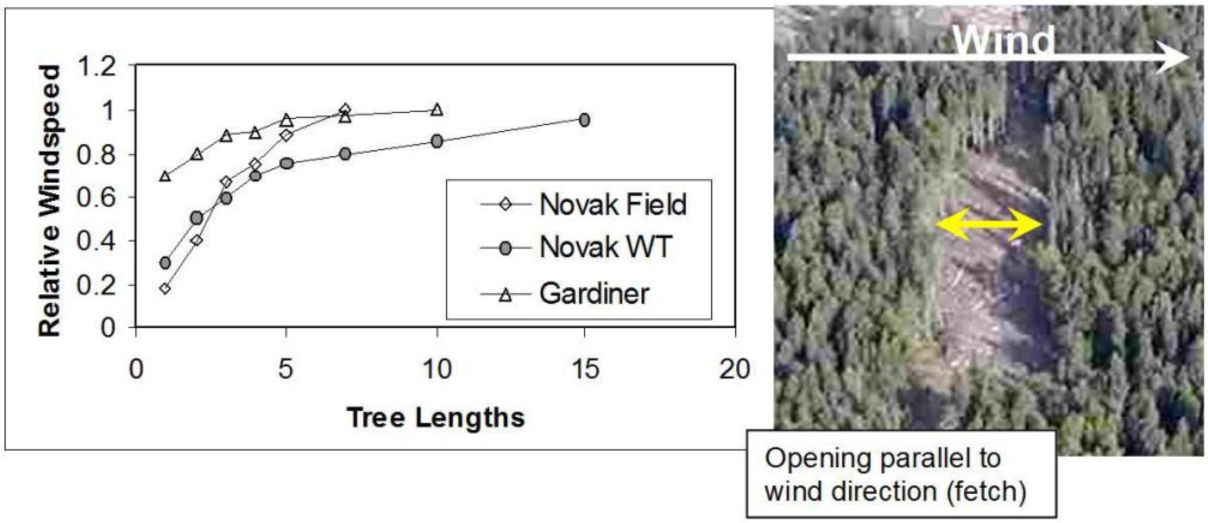
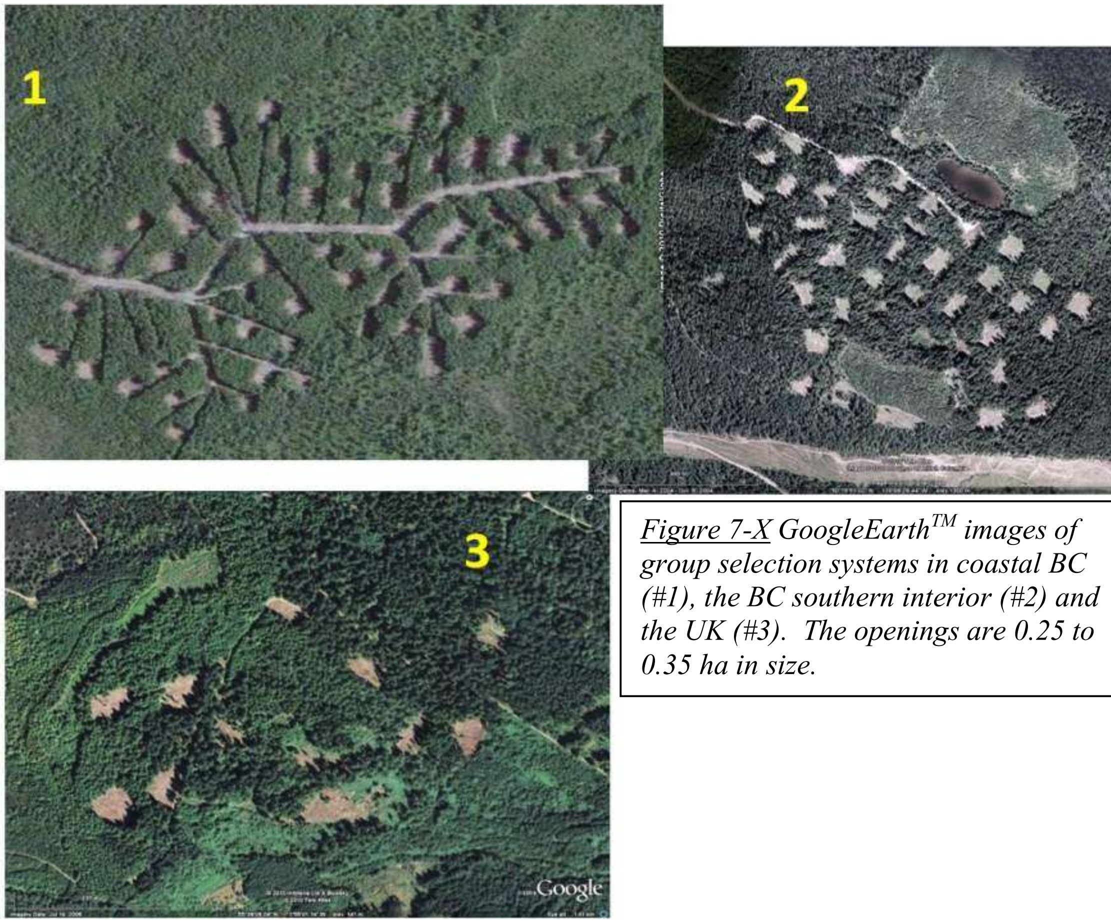


Figure7-W. Relationship between windspeed (relative to the above canopy windspeed) and gap size parallel to the wind direction (Novak 2000).



<u>Figure 7-X</u> GoogleEarth^{TM} 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.

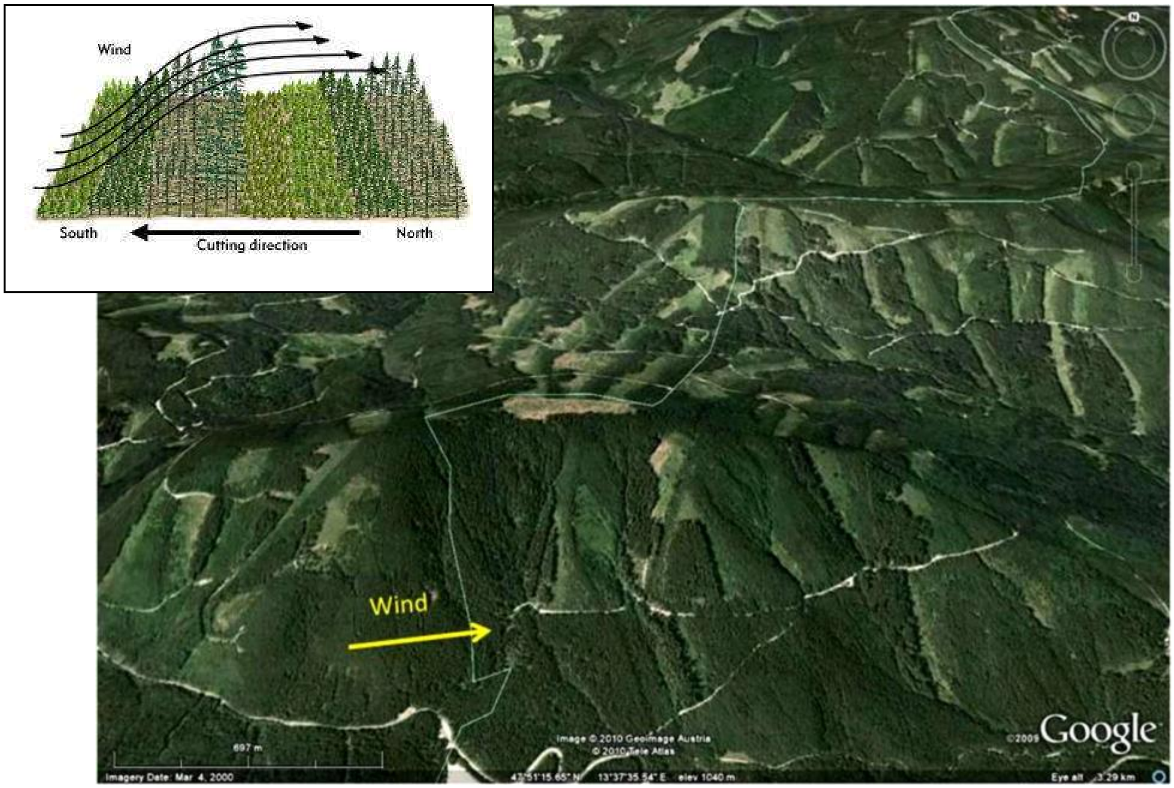


Figure 7-Y. Widespread use of strip-removal silvicultural systems in a wind-prone area in Northern Austria. The systems used here have been used over many passes developing a robust stand structure for future entries as in the graphical representation in the top left corner. Note the general distance 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.

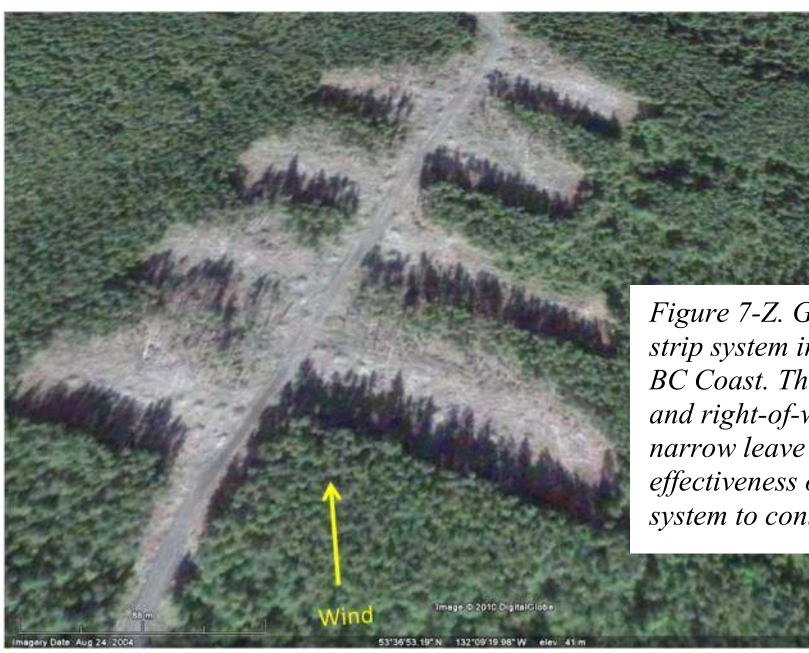


Figure 7-Z. GoogleEarth™ image of a strip system in dense hemlock on the BC Coast. The location of the road and right-of-way, together with narrow leave areas reduce the effectiveness of a multi-pass strip system to control windthrow.

Figure 7-AA. 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-BB to 7-EE 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 WINDFIRMING TREATMENTS

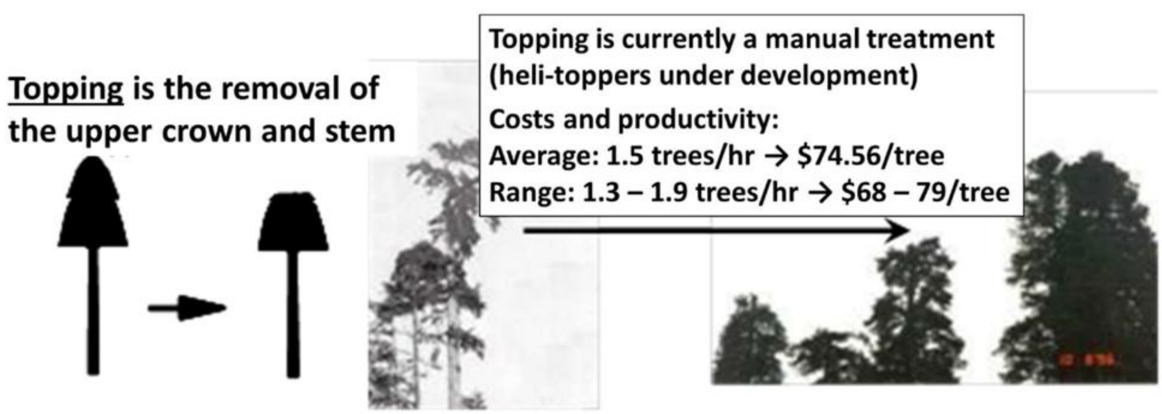


Figure 7-BB. Description of topping and associated methods and costs.

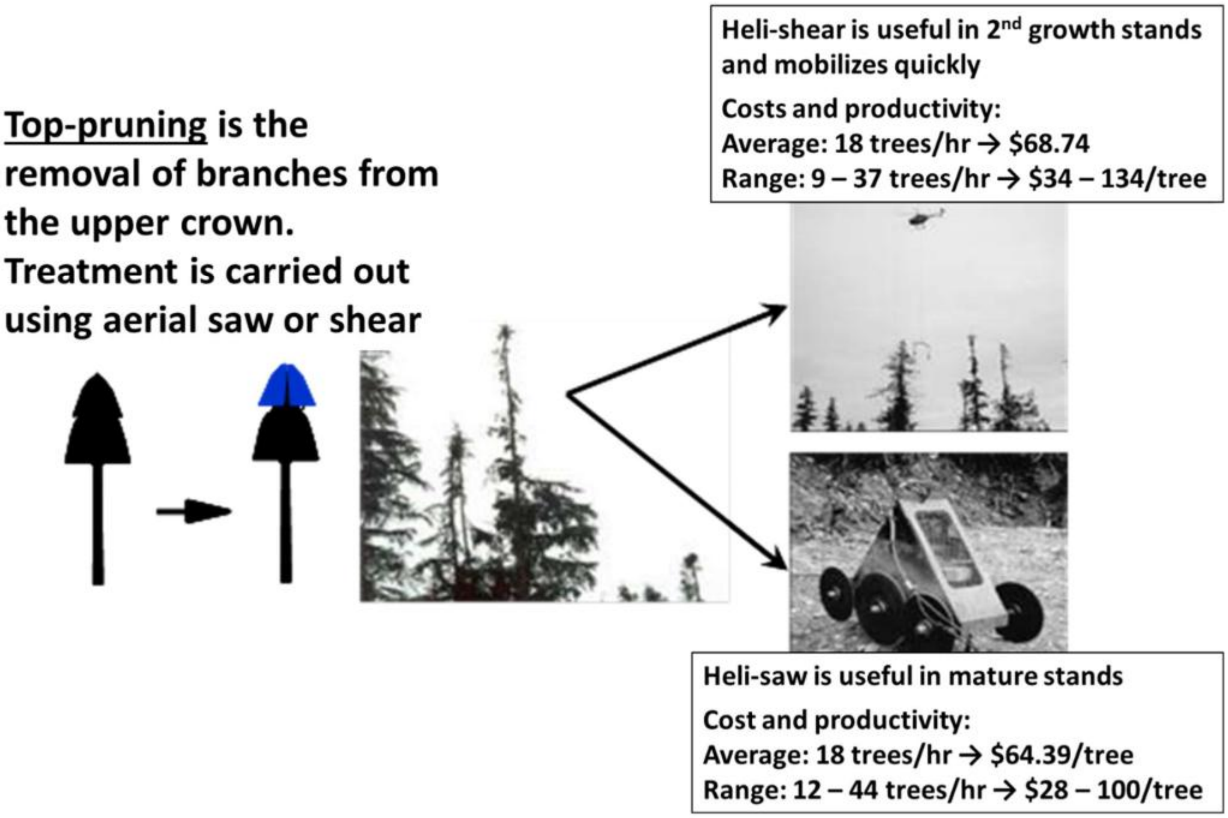


Figure 7-CC. Description of top-pruning and associated methods and costs.

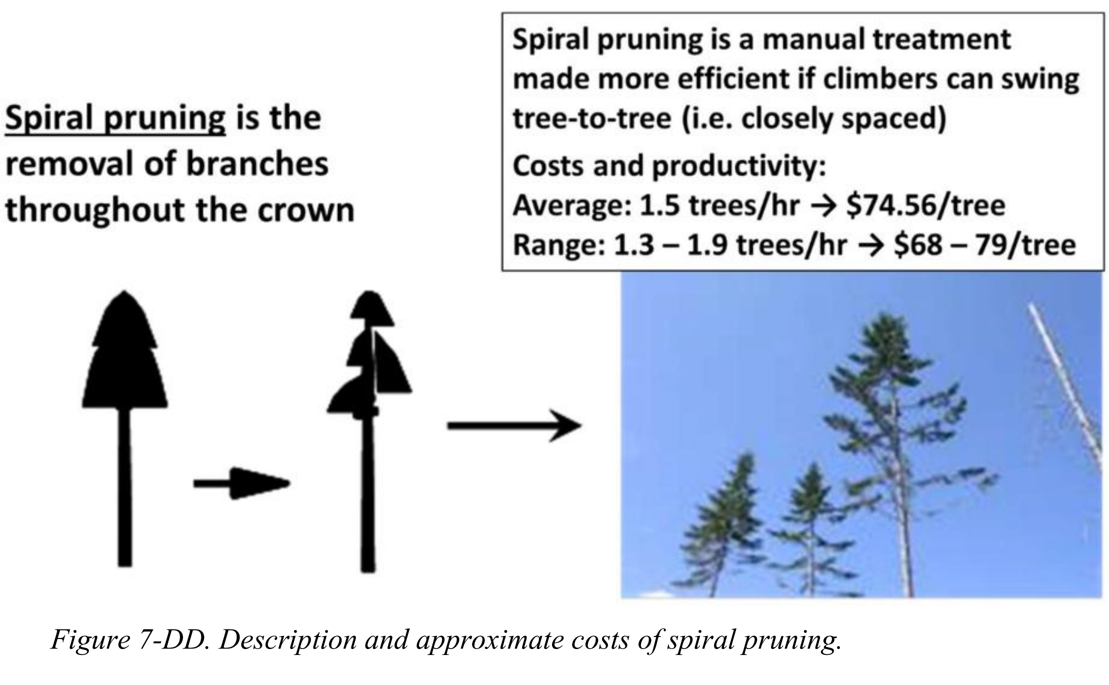


Figure 7-DD. Description and approximate costs of spiral pruning.

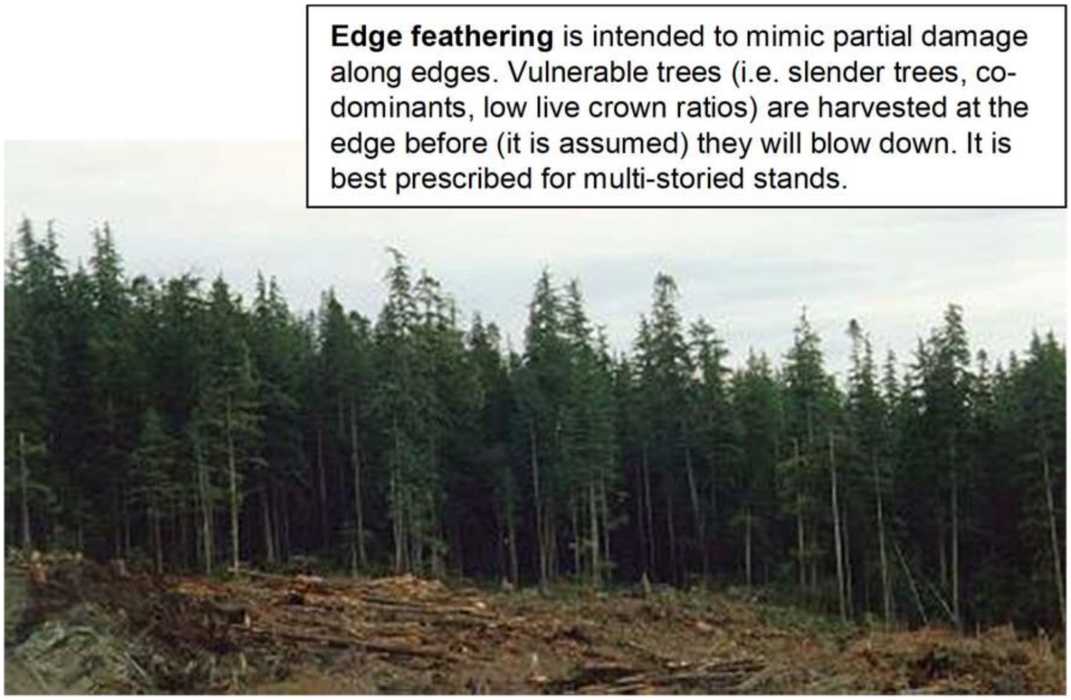


Figure 7-EE. Illustration and explanation of edge feathering treatment. Multi-storied stands (where dominance is well-expressed) are the most suitable. The edge is thinned by removing susceptible trees 15-30 m into the stand. Avoid high likelihood stands – feathering could make windthrow worse.

BMPs for Topping and Pruning on Edges

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

General:

- ***Consider topping and pruning in <u>moderate to high likelihood</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.

- ***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.

  Rollerson et. al. (2009), when monitoring variable retention cutblocks, did not find any indication that pruning or topping treatments were reducing the amount of wind damage in treated edge segments. A common challenge for these treatments is - 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. If wind damage in these lower canopy classes is a concern, and salvage is not an option, these trees could be removed at the time of harvesting in a feathering operation (see BMPs for feathering).

- ***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-HH).

BMPs for Feathering on Edges

Feathering 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.

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-II).

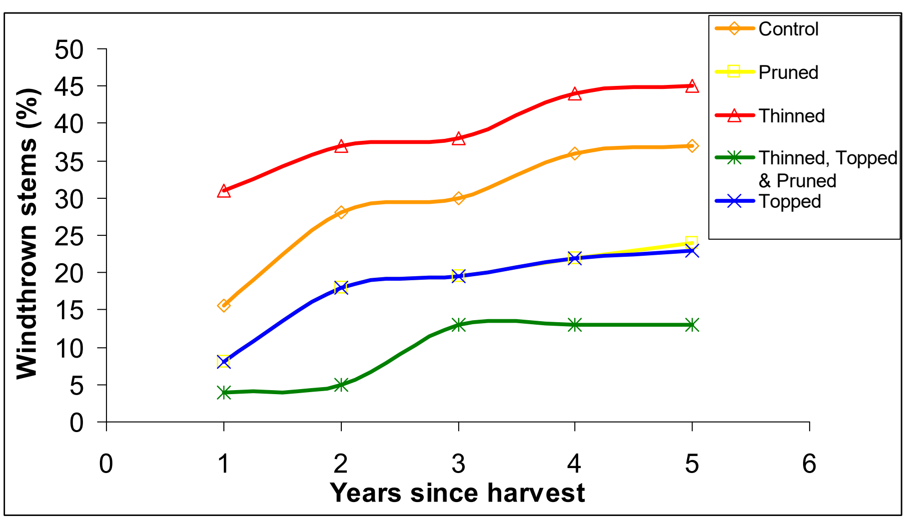


Figure 7-FF. Effects of crown treatments on the proportion of windthrow damage. Note that the "pruned"trend line may not be evident as it mostly follows and is obscured by the "topped" line.

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

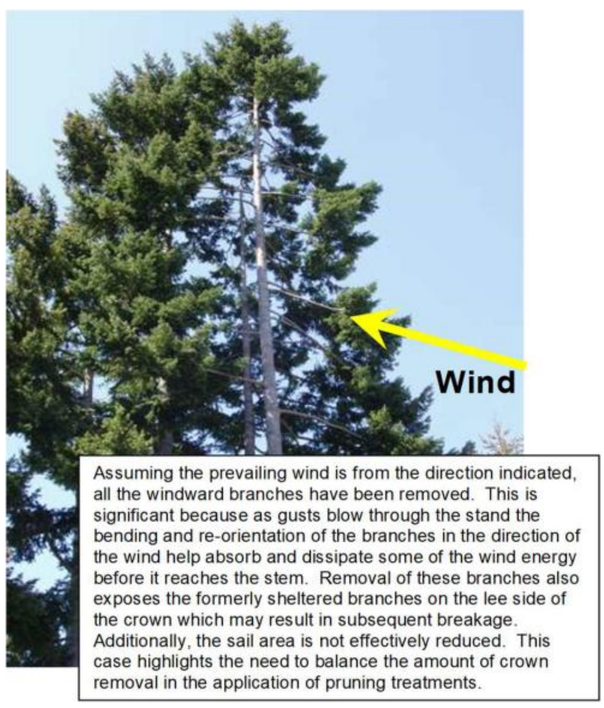


Figure 7-HH. Example of lop-sided crown pruning treatment which may increase windthrow susceptibility.

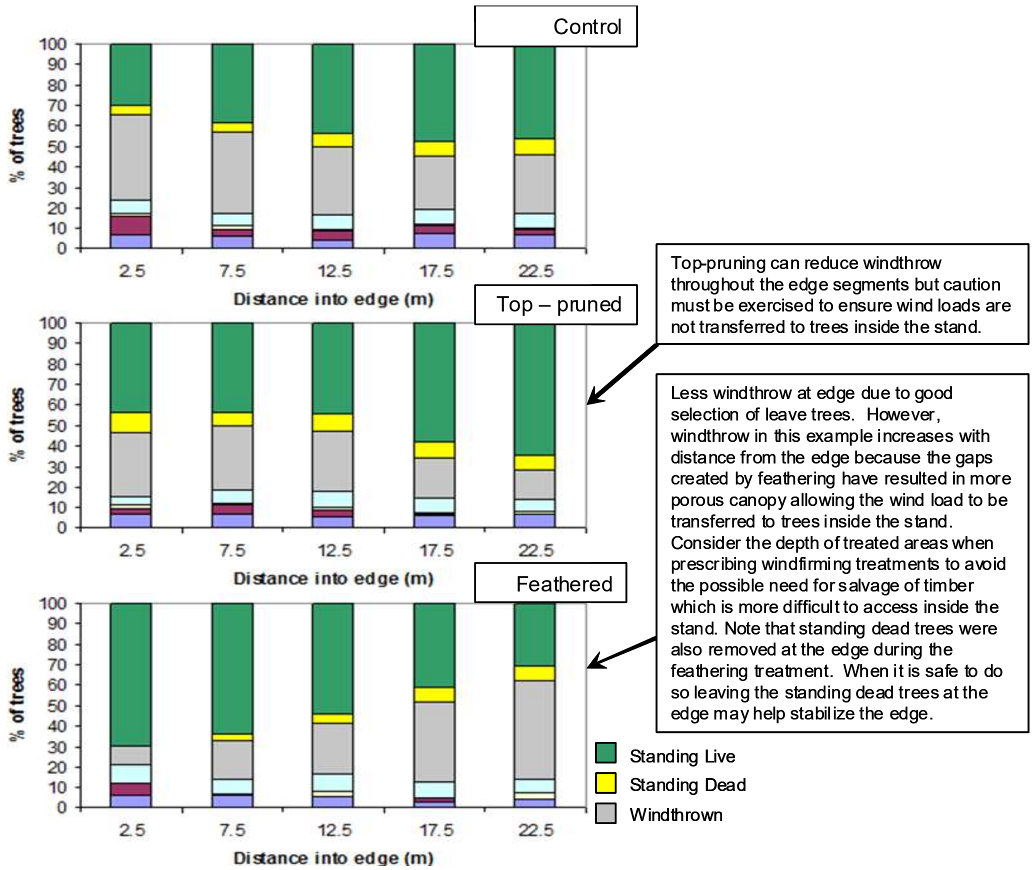


Figure 7-II. Comparison of the effects of edge treatments with distance from the edge.

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-JJ). 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.

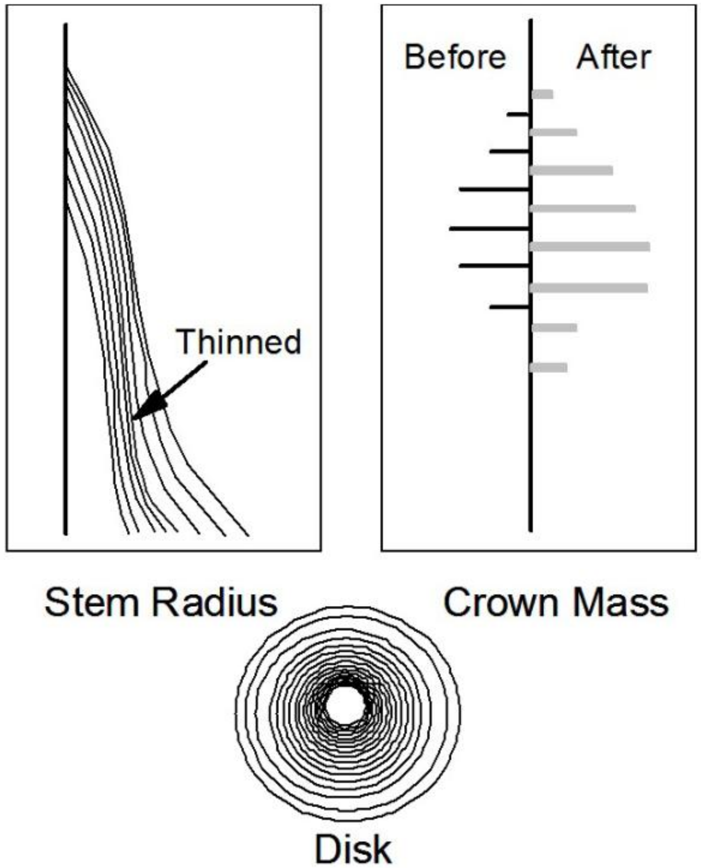


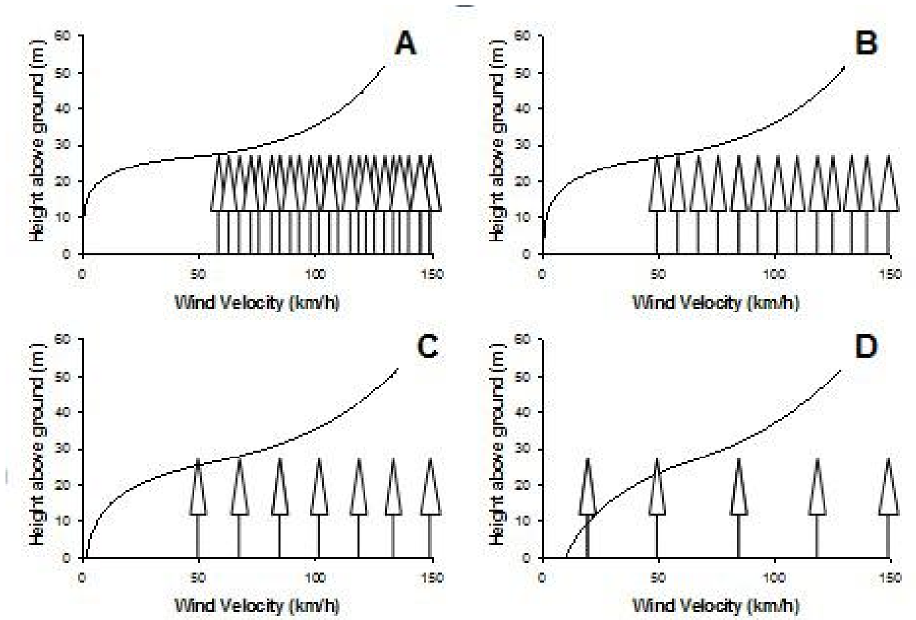
Figure 7-JJ. Stem and crown growth before and after thinning treatment.

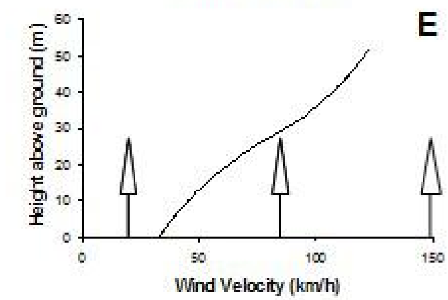
Thinning and fire fuel loading treatment and layout considerations

As the average spacing between trees changes with thinning, the vertical wind speed profile changes within the canopy. Wind tunnel studies demonstrate how the above canopy wind speed profile drops lower into the canopy as spacing increases (Figures KK and LL).

Figure JJ shows how the tree adapts lower stem growth to this new wind exposure post-thinning, however, this takes time and newly exposed trees can be vulnerable for the first few years after treatment. Steps that can mitigate windthrow risk in thinned stands include:

- ***Retention of untreated buffer around thinned areas if the edge is vulnerable.***
- ***Thin from below to retain dominant trees that are more acclimatized to higher wind speeds.***
- ***Avoid orienting trails in the damaging wind directions.***
- ***Use specialized equipment (harvesters/forwarders) to reduce trail width and residual damage.***





	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-KK. 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.

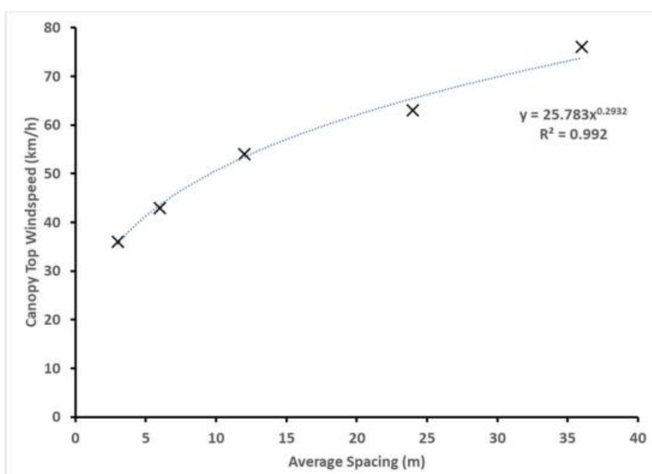


Figure LL. Canopy top windspeed with increased spacing (based on Figure KK).

Modify leave tree parameters

BMPs for Changing leave tree criteria

- ***Favour trees with the lowest height to diameter ratio (Figure 7-LL)*** - 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-MM) -*** 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.

  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-OO). This approach is only appropriate where leave trees can respond to such treatments and suitable acclimation will occur.
- ***Consider orientation of trails relative to damaging wind directions –*** if possible orient trails perpendicular to the direction of known storm wind directions. Note that this is not always possible on steeper slopes that require harvesting equipment to move up and down the hill for safety and to reduce trail width. Undulating trails will also reduce the amount of funneling and wind penetration into the thinned stands (Figure PP).
- ***Consider use of untreated buffer around thinned area if edge is exposed to damaging winds (Figure QQ).***

- ***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.

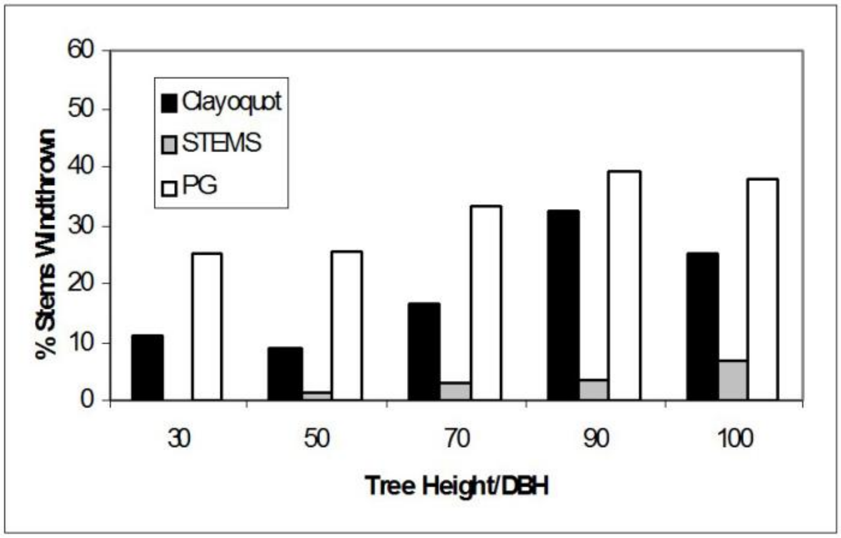


Figure 7-MM. Windthrow trends with height to diameter ratio in three separate studies (Scott 2005).

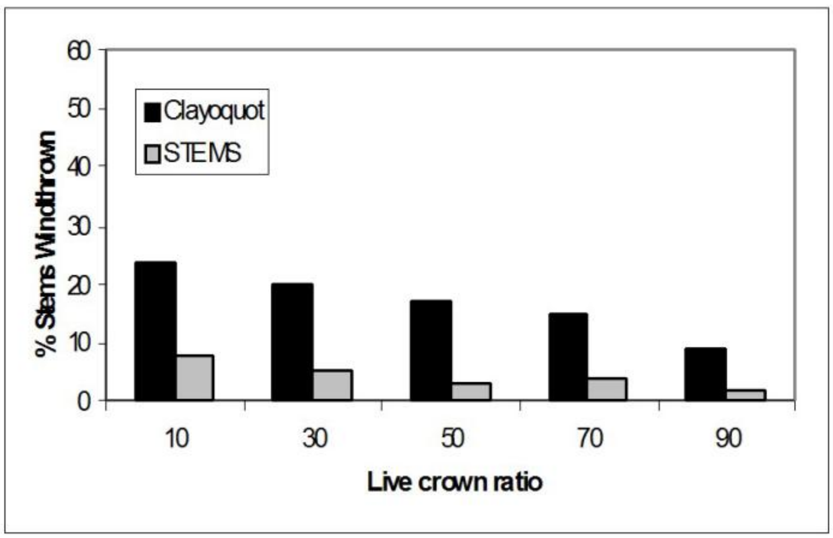


Figure 7-NN. Windthrow trends with live crown ratio (Scott 2005).

Figure 7-OO. 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-PP. Undulate trails to mitigate funneling and wind penetration into thinned stands.

Figure 7-QQ. Maintain buffer for exposed edges of treatment areas and avoid orienting trails in direction of damaging winds.

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

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 of Best Management Practices 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 support 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. Yet, in these wind-challenged landscapes it is useful to contemplate 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 the mechanics of 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.

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.

[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.

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 because it establishes systematic data collection which can be used to increase knowledge of windthrow dynamics. This increased knowledge can then be applied to improve future assessments and track longitudinal data which can be helpful to assess factors such as changes in climate, weather patterns and site and stand dynamics.

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 8-1). 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".

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

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 and plays a significant role in maintaining Best Management Practices. 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. The use of drones in forestry have become standard practice and greatly reduce the time and cost of windthrow monitoring. The high-quality imagery from drone mosaics are spatially referenced and easily integrated into GIS databases. In 2022, FPInnovations held an exclusive webinar to its members on automated interactive tools for post-harvest inventory and compliance using drone imagery, for tracking and reporting in part the status of dispersed logging residues (FPResidue) with no or limited field assessment required with the process. These interactive tools could perhaps also be used for tracking windthrow.

    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:

Assumption – 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 the harvesting hazard was 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 (greater than 20 percent) 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

[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 harvesting hazard and consequence ranking.

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.

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 (% basal area) 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 estimating the penetration or amount of windthrow may originate with the preharvest estimates. At the monitoring stage, assessors have the benefit of actual results 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; harvesting hazard and windthrow likelihood ranking.

Where the monitoring estimates disagree with preharvest estimates, 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 estimates 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 and/or orthomosaic imagery from drones 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:

Prioritize 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.

APPENDICES

Appendix 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 2

Use a windrose approach to map out windthrow

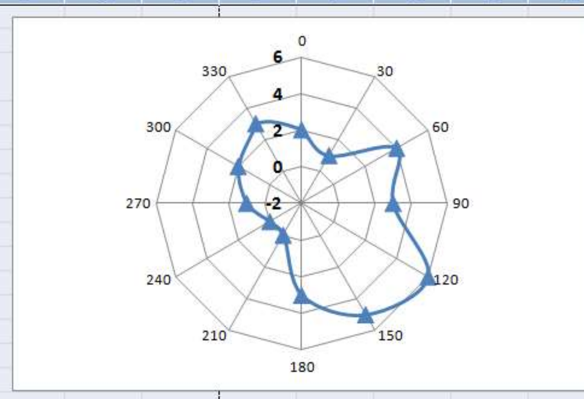
Methods (procedure to create chart in Excel)

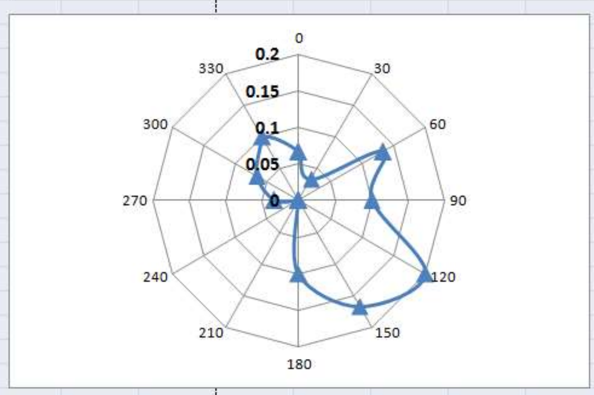
- Record direction of fall (i.e. direction of damaging wind) for sample of trees
- Establish damage direction classes
- Record frequency in each class
- Calculate proportion of damage in each class
- Insert radar chart
- Select Class Midpoint for axis labels and Frequency or Proportion for series

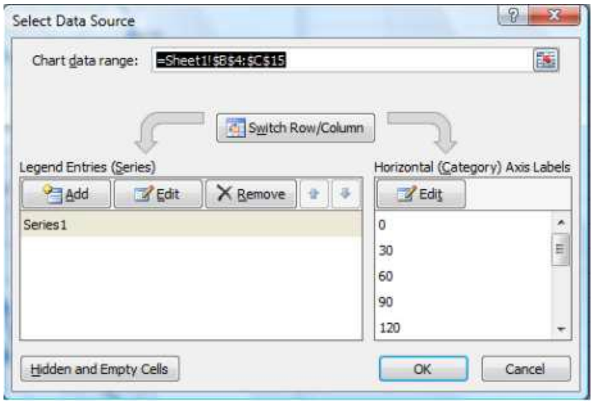
Example:

Microsoft Excel - RadarPlot.xlsx

Direction of Fall Class	Direction of Fall Mid-point	Frequency	Proportion
346 - 015	0	2	0.066666667
016 - 045	30	1	0.033333333
046 - 075	60	4	0.133333333
076 - 105	90	3	0.1
106 - 135	120	6	0.2
136 - 165	150	5	0.166666667
166 - 195	180	3	0.1
196 - 225	210	0	0
226 - 255	240	0	0
256 - 285	270	1	0.033333333
286 - 315	300	2	0.066666667
316 - 345	330	3	0.1
		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.

Appendix 3 – Coastal Windthrow Field Forms

BC Coastal Windthrow Assessment Reference FORM A – Side 1

Definitions
• 'Biophysical Hazard' is the combination of the 'Topographic', 'Soils', and 'Stand Hazard' components. It represents the intrinsic windloading and wind stability of trees on the site prior to treatment. • 'Harvesting Hazard' is the way in which harvesting layout increases or decreases the windloading on trees or their inter-tree support. (For example, boundaries that run at right angles to damaging wind direction at the downwind end of a clearcut are high-hazard treatments.) • 'Windthrow Likelihood' is the expected level of windthrow and is the combination of Biophysical Hazard and Treatment Hazard. • 'Windthrow Consequence' is the probable level of impact on specific management objectives and values if the expected level of windthrow occurs. It is based on the diagnostic questions for windthrow consequence (See Field Form 4 – side B). If wind damage conflicts with your management objectives, the impact is negative. The level of acceptable windthrow in a given management scenario should be included in your management plans and prescriptions. • 'Windthrow Risk' is the potential for a negative consequence from windthrow caused by endemic winds. It is the combination of Windthrow Likelihood and Consequence. • 'Endemic' winds are peak winds expected to recur every 1-3 years in a given location, as distinct from 'Catastrophic' winds, which recur very infrequently (typically > 20 years between events). If a portion of your operating area shows a pattern of repeated edge windthrow or salvage over a period of several years, you have a problem of endemic windthrow.
Assessment Steps
Office 1. Observe windthrow patterns at the landscape and stand level to determine orientation and recurrence of damaging winds. Use probability maps, GoogleEarth™ and other tools to help. 2. Determine initial potential consequences on the proposed block based on relevant plans and the rough paper plan for layout (based on recce information). Check SOPs for pre-established windthrow tolerance levels for some values. 3. Choose nearby previously-harvested blocks with edges or retention strata that have similar situations for windthrow as the proposed block (if possible). 4. Determine the boundaries or portions of the proposed block where you should focus your assessment efforts. **Field** 5. With the nearby selected harvested blocks, calibrate the assessment on a High Harvest Hazard boundary (use BCTS calibration Form 1), then compare expected damage for the estimated Windthrow Likelihood class with the observed damage and adjust the component Biophysical Hazard classes if necessary. 6. i) Assess Harvest Hazard for boundary segments of interest (due to potential windthrow risk). ii) Assess Biophysical Hazard components for boundary segments of interest. iii) Integrate Biophysical Hazard components using the Field Form #2 Matrix. iv) Integrate Biophysical Hazard with Harvesting Hazard to estimate Windthrow Likelihood. 7. Consider the consequences for boundary segments of interest, set windthrow tolerance levels, and compare to the level of damage expected for the Windthrow Likelihood class you have estimated. 8. If the level of expected damage and consequences exceed the tolerance, prescribe actions. 9. Set up a feedback loop where damage, assessment predictions, and actions are monitored to enable improved windthrow prediction and management in your area. 10. Pay particular attention to which boundaries are damaged and damage orientations as this will help you develop maps of local damaging wind orientations.

BC Coastal Windthrow Assessment Reference FORM A – Side 2

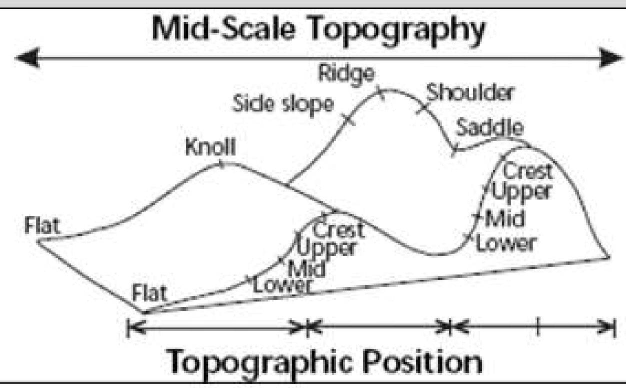
Windthrow Likelihood Class	Expected Damage Caused by Endemic Winds
Very Low	Little or no damage along recent cutblock edges or in recent partial cuts.
Low	Less than 10% of trees uprooted or snapped along recent cutblock edges. Less than 5% in recent partial cuts.
Moderate	Partial damage along recent cutblock edges. Between 10 and 70 percent of the trees are uprooted or snapped within the first tree length in from the edge. Between 5 and 30% of trees damaged within recent partial cuts.
High	Heavy damage along recent cutblock edges. More than 70% of the trees within the first tree length damaged. Between 30 and 70% of trees damaged within recent partial cuts.
Very high	Very severe damage along recent cutblock edges. More than 70% of the trees damaged in both the first and second tree lengths into the edge. More than 70% of trees damaged in recent partial cuts.

Notes on Field Cards

The field cards can be filled out for each clearcut edge segment or partial cut portion, or simply use these cards as a checklist.

- In the boxes for assessing Topography, Soil, and Stand exposure hazard, the focus is on considerations relating to key diagnostic questions. The relationship between indicators and hazard class will vary from place to place so common sense and local experience (brought together by the Diagnostic Questions) should be used in estimating the component Biophysical Hazards.
- The calibration step is important in refining the Biophysical Hazard classification. The logic underlying the assessment framework is as follows. Where site conditions and management actions in an area proposed for treatment are similar to those of an area treated in the past, a similar pattern of damage is expected.
- A more detailed discussion of the assessment framework can be found in '*The Coastal Windthrow Manual (2022)*.

Topographic Terms



BC 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 boundary that has damage levels typical of what you have observed in imagery for the area, with a similar treatment hazard to boundaries of concern in your proposed cutblock(s).
2. Transfer the results of this assessment into the table below for reference.

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

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

CALIBRATION – of windthrow likelihood classification

3. *R*ecord observed damage on the calibration boundary assessed as per above (#1 and #2).

Estimates of Actual Windthrow Damage – to help refine predictions

Measured windthrow penetration into edge (where applicable)	Average (m)		Range (min to max)	
Estimated windthrow throughout the penetration (or a specified) zone: ______________	Average % of total m²/ha		10% Range (e.g. 30-40 m²/ha)	

Actual Damage Calibration Categories - to calibrate windthrow likelihood class (See next page)

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	

4. 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.

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.

5. Use the adjusted interpretations and ratings for classifying Soils, Topography and Stand Hazards for proposed cutblocks.
6. 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.

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.

BC Coastal Windthrow Likelihood Assessment FORM 2 – Side A (May, 2022)

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

TOPOGRAPHIC EXPOSURE TO WIND:

DIAGNOSTIC QUESTION 1: Are prevailing peak storm wind speeds accelerated by terrain constrictions, OR is storm wind reduced by sheltering influences?

CONSIDERATIONS – Topo Exposure increases with:

- Proximity to ridge crest or upper slope shoulders.
- Location on valley floor and lower side walls for storm winds parallel to valleys.
- Valley gaps, constrictions or ridge saddles where storm winds are funnelled.
- Presence of tree-level indicators – flagging (asymmetry) of tree crowns.

CONSIDERATIONS – Topo Exposure decreases with:

- Proximity to lower slopes and sheltered from storm winds.
- Shelter from ridges, hills, knobs and other topographic features large enough to deflect storm winds over the stand edge.

Note – If a leeward slope off a ridge is steep, damaging turbulent winds may continue down the back side.

Top. Ex Hazard Class:	☐ **Very High** (highly accelerated)	☐ **High** (significant acceleration)	☐ **Moderate** (neither acceleration nor shelter)	☐ **Low** (significant wind shelter)[1]	☐ **Very Low** (highly sheltered)

DIAGNOSTIC QUESTION 2: **Is this a windy region? If so, increase Topo. Exposure hazard by one class**

CONSIDERATIONS – Consider peak regional storm winds and:

- Proximity to large open water - the open ocean, large inlet, strait or lake (if peak storm winds run parallel to the lake, strait or inlet). Consider prevailing peak storm wind direction and sheltering features (question 1)
- If it is a dominant ridge/peak – well above neighbouring ridges and peaks for kilometres in the direction of prevailing storm winds.

STAND STABILITY

DIAGNOSTIC QUESTION 1. Are trees poorly acclimated to wind loading?

STAND CONSIDERATIONS - Acclimation decreases with the following (the opposite indicates increasing acclimation):

- High stand densities – Individual trees rely on long term shelter of neighbouring trees.
- Tall stands - on highly productive sites.
- Most trees are slender - Small live crowns and low degree of taper – ht. to dbh ratio closer to 100 than 50 - with 100 being very slender.
- High degree of defect/decay – heartrot, stem defect, root disease.
- **NOTE:** Tall, slender, dense stands with trees that fall through the canopy to the ground default to 'high'.

TREE-LEVEL INDICATOR OF ACCLIMATION:

- Relatively thick stems with long (deep) live crowns.
- High degree of taper – height to diameter ratio -less than 60.
- Open crowns with sparse foliage or flagging (most foliage on leeward side)
- Short dense stands where windblown trees lean into the stand but do not fall to the ground.

Stand Hazard Class:	☐ **High** (No acclimation)	☐ **Moderate** (neutral - balance of acclimated and non-acclimated trees)	☐ **Low** (Acclimated)	☐ **Very Low** (Highly Acclimated and wind modified)

BC Coastal Windthrow Likelihood Assessment FORM 2 – Side A (May, 2022)

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

TOPOGRAPHIC EXPOSURE TO WIND:

DIAGNOSTIC QUESTION 1: Are prevailing peak storm wind speeds accelerated by terrain constrictions, OR is storm wind reduced by sheltering influences?

CONSIDERATIONS – Topo Exposure increases with:	CONSIDERATIONS – Topo Exposure decreases with:
• Proximity to ridge crest or upper slope shoulders. • Location on valley floor and lower side walls for storm winds parallel to valleys. • Valley gaps, constrictions or ridge saddles where storm winds are funnelled. • Presence of tree-level indicators – flagging (asymmetry) of tree crowns.	• Proximity to lower slopes and sheltered from storm winds. • Shelter from ridges, hills, knobs and other topographic features large enough to deflect storm winds over the stand edge. Note – If a leeward slope off a ridge is steep, damaging turbulent winds may continue down the back side.

Top. Ex Hazard Class:	☐ **Very High** (highly accelerated)	☐ **High** (significant acceleration)	☐ **Moderate** (neither acceleration nor shelter)	☐ **Low** (significant wind shelter)[1]	☐ **Very Low** (highly sheltered)

DIAGNOSTIC QUESTION 2: **Is this a windy region? If so, increase Topo. Exposure hazard by one class**

CONSIDERATIONS – Consider peak regional storm winds and:

- Proximity to large open water - the open ocean, large inlet, strait or lake (if peak storm winds run parallel to the lake, strait or inlet). Consider prevailing peak storm wind direction and sheltering features (question 1)
- If it is a dominant ridge/peak – well above neighbouring ridges and peaks for kilometres in the direction of prevailing storm winds.

STAND STABILITY

DIAGNOSTIC QUESTION 1. Are trees poorly acclimated to wind loading?

STAND CONSIDERATIONS - Acclimation decreases with the following (the opposite indicates increasing acclimation):	TREE-LEVEL INDICATOR OF ACCLIMATION:
• High stand densities – Individual trees rely on long term shelter of neighbouring trees. • Tall stands - on highly productive sites. • Most trees are slender - Small live crowns and low degree of taper – ht. to dbh ratio closer to 100 than 50 - with 100 being very slender. • High degree of defect/decay – heartrot, stem defect, root disease. • **NOTE:** Tall, slender, dense stands with trees that fall through the canopy to the ground default to 'high'.	• Relatively thick stems with long (deep) live crowns. • High degree of taper – height to diameter ratio -less than 60. • Open crowns with sparse foliage or flagging (most foliage on leeward side) • Short dense stands where windblown trees lean into the stand but do not fall to the ground.

Stand Hazard Class:	☐ **High** (No acclimation)	☐ **Moderate** (neutral - balance of acclimated and non-acclimated trees)	☐ **Low** (Acclimated)	☐ **Very Low** (Highly Acclimated and wind modified)

[1] Sheltered doesn't mean 'no wind.' It means shelter from the peak force of prevailing storm winds. Anywhere on the landscape, air is going to move during storms.

SOIL ANCHORAGE

DIAGNOSTIC QUESTION 1. Is root anchorage weakened by an impeding layer, low strength soil, or poor drainage?

CONSIDERATIONS - Weakened anchorage contributes to instability with:

- Poor drainage and soil depth restrict rooting in draws and gullies.
- Conspicuous pockets of higher productivity (seepage over basal till or bedrock; saturated or seasonally saturated riparian soils).
- Smooth rock outcrops or bedrock that roots cannot penetrate (no cracks and fissures).
- Where upturned 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.
- Low soil strength – pure sands or silts, organics or wet clays with few coarse fragments etc.

Soil Hazard Class:	☐ **High** (weak)	☐ **Moderate** (average)[2]	☐ **Low** (strongly anchored)

HARVESTING HAZARD

DIAGNOSTIC QUESTION. Will the proposed harvesting strategy substantially increase windloading and/or reduce support of trees either along the stand edge or retained as dispersed trees in the block?

NOTE: Consider the interaction of both #1 and #2 – see the windthrow manual.

1. WIND LOADING CONSIDERATIONS - Post harvest wind loading increases on newly exposed edges with:
   - Exposure of boundary edges to damaging storm winds – moving from lee-facing edges (least exposed), to parallel edges (moderate exposure), to perpendicular wind-facing edges (most exposed).
   - Fetch length - wind loading increases linearly to 75% of full load at 5 tree lengths with further load increases to 100% of full load due to fetch in openings >10 tree lengths toward prevailing storm winds.
   - Funnelling due to treed boundary shape – concentrates wind and further increase wind loading.
2. ALSO CONSIDER INTER-TREE SUPPORT REDUCTION (between adjacent trees). Hazard increases:
   - With increasing tree removal in partial-cutting (dispersed retention or thinned areas).
   - As reserve strips or patches become narrower or smaller (where wind can blow through them).

Harv Haz.Class	☐ **Very High**	☐ **High**	☐ **Moderate**	☐ **Low**	☐ **Very Low**

WINDTHROW LIKELIHOOD EVALUATION - score

Add Topographic, Stand and Soil Hazards to get Biophysical Hazard; then add Harvesting Hazard to Biophysical Hazard to get Windthrow Likelihood. Adjust if similar calibration sites are significantly different.

	Very High	High	Moderate	Low	Very Low	
Topographic Hazard	*4*	*3*	*2*	*1*	***0***	
Stand Hazard		*3*	*2*	*1*	***0***	
Soil Hazard		*2*	*1*	*0*		
Biophysical Hazard	***8+***	***6-7***	***4-5***	***<4***	***0***	
Harvesting Hazard	*7*	*6*	*4*	*2*	***0***	
Windthrow Likelihood	***14+***	***12-13***	***10-11***	**6-9**	***<6***	
Adjust with calibration						

[2] Average – Neither weakly anchored, nor strongly anchored.

BC Coastal Windthrow Consequences and Risk FORM 3 – Side A

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

Description of Management Values / Concerns:	
Slopes, gullies or streambanks with instabilities[1]	
Reserves for an identified feature.	
Visual landscape quality objectives.	
Retention for biodiversity	
Timber management objectives	
Public safety and corporate or professional damages	

SUMMARY OF CONSEQUENCES:

1. Refer to the Diagnostic Questions in the Windthrow Management Manual for your management values/concerns. Note: this can be done prior to layout.

Sensitivity Ranking	Rank as - Nil, Low, Mod, High, Very High (use highest ranking score)

Relevant Values / Management Concerns	Answers to Diagnostic Questions			RANK	
	#1	#2	#3	#	Category
Slopes or banks with instabilities.					
Reserves for an identified feature.					
Visual landscape quality objectives.					
Retention for biodiversity.					
Timber management objectives.					
Public safety and corporate or professional damages.					

Comments:

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

COMPARISON OF PREDICTED WINDTHROW TO MAX TOLERANCE:			
PREDICTED WINDTHROW – from hazard and likelihood assessment – FORM 2			
Predicted edge penetration (m):		Predicted % windthrow in an identified zone (%):	
MAXIMUM WINDTHROW TOLERANCE (Limit or Threshold) – The target maximum acceptable amount of windthrow based on consequences and considerations from the Manual. Note - *Use NA if none apply.*			
TO PROTECT a mapped feature:			
TO SUSTAIN the general condition of a patch or reserve:			
Comments:			

LIKELIHOOD OF EXCEEDING MAX WINDTHROW TOLERANCE:		
Nil	-	Predicted windthrow is far below the tolerance
Low	-	Predicted windthrow is below but not far below the tolerance and, it is expected that windthrow will likely remain below the tolerance.
Mod	-	Predicted windthrow is close to the tolerance limit (either side) and it is equally likely to be exceeded as it is not to be exceeded.
High	-	Predicted windthrow significantly exceeds the tolerance but substantial intact timber is expected to remain around feature or in the patch/strip.
Very High	-	Predicted windthrow exceeds the thresholds so much that most trees in and around the feature or in the patch/strip are expected to be blown down.
Estimated likelihood of exceeding windthrow Tolerance		

WINDTHROW RISK ASSESSMENT				
DIAGNOSTIC QUESTION: What is the overall risk, considering the likelihood of exceeding the tolerance and the consequences for management values, safety, liabilities and other management concerns? [2]				
Risk =	☐ **Very High** (very negative)	☐ **High** (negative)	☐ **Moderate** (slightly negative)	☐ **Low** (minimal to no consequences)
Comments and Recommendations:				

[2] If the consequence is Very High and the Likelihood of Exceeding Thresholds is Low or even Nil, review the accuracy of the likelihood assessment for potential error and check the degree of that uncertainty.

BC Coastal Windthrow Recommended Prescription FORM 4 – Side A

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

FIELD RECOMMENDATIONS FOR TREATMENT MODIFICATIONS	
FOR CLEARCUT AND PATCH/STRIP RETENTION EDGES:	
General: ☐ No treatment modifications prescribed ☐ Allow windthrow – plan salvage	Specific Comments
Layout changes – either: ☐ Adjust boundary or boundaries ☐ Larger/wider patches or strips. ☐ Reduce fetch. ☐ Change to a multi-pass silvicultural system.	
Windfirming treatments – either: ☐ Top or prune. ☐ Feather. ☐ Feather and top/prune.	
FOR UNIFORM PARTIAL CUTTING (thinning, dispersed retention, or seed tree, shelterwood, selection silvicultural systems):	
General: ☐ No treatment modifications prescribed. ☐ Allow windthrow – plan salvage.	Specific Comments
Modify leave tree parameters: ☐ Change leave tree criteria. ☐ Change density of dispersed leave trees. ☐ Windfirm - top or prune.	
Change layout design to alter approach to silvicultural system considering instead: ☐ Several small clearcuts. ☐ Patch/strip retention. ☐ Multi-pass group/strip removal systems.	

BC Coastal Windthrow Recommended Treatment FORM 4 – Side A

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

FIELD RECOMMENDATIONS FOR TREATMENT MODIFICATIONS	
FOR CLEARCUT AND PATCH/STRIP RETENTION EDGES:	
General: ☐ No treatment modifications prescribed ☐ Allow windthrow – plan salvage	Specific Comments
Layout changes – either: ☐ Adjust boundary or boundaries ☐ Larger/wider patches or strips. ☐ Reduce fetch. ☐ Change to a multi-pass silvicultural system.	
Windfirming treatments – either: ☐ Top or prune. ☐ Feather. ☐ Feather and top/prune.	
FOR UNIFORM PARTIAL CUTTING (thinning, dispersed retention, or seed tree, shelterwood, selection silvicultural systems):	
General: ☐ No treatment modifications prescribed. ☐ Allow windthrow – plan salvage.	Specific Comments
Modify leave tree parameters: ☐ Change leave tree criteria. ☐ Change density of dispersed leave trees. ☐ Windfirm - top or prune.	
Change layout design to alter approach to silvicultural system considering instead: ☐ Several small clearcuts. ☐ Patch/strip retention. ☐ Multi-pass group/strip removal systems.	

BC Coastal Windthrow Consequences Reference FORM 4 – Side B

DIAGNOSTIC QUESTIONS – Use to Rank Potential Consequences
Gullies, escarpments, and slopes with questionable stability, or banks of active fluvial streams
1. What is the potential for windthrow to have a significant impact on the slope, gully, escarpment, bank? • *Consider potential for initiation of mass-wasting or debris flows (Geotech input?)* • *Also consider downstream or other indirect impacts from such events.*
Reserves for an identified feature
1. What is the sensitive feature? • *E.g., cultural (First Nations, other), habitat, recreational, private ownership?* 2. How important is the feature at this location? • *Rarity, significance, value?* 3. How might windthrow damage or impair the feature? • *Consider both direct (to the feature) and indirect (around the feature).*
Visual landscape quality objectives
1. How important is the viewscape in which the block is embedded? 2. Does windthrow have a strong potential to significantly impact visual quality objectives? • *Consider viewpoints, visual absorption capacity, features to be hidden such as roadcuts.* 3. How long might windthrow affect visual quality objectives?
Retention for biodiversity
1. Is the retention intended to be long term or short term? 2. What function does the retention serve? • *E.g., remnant old growth patch, connectivity function, special or unique habitat, vertical habitat diversity?* 3. Is there a legal requirement for this retention? If so, what is it? • *E.g., riparian reserve, red-listed ecosystem, protected habitat, or part of a legal requirement for representation or retention (if so, can other areas be substituted)?*
Timber management objectives
1. How much timber value could potentially be lost to windthrow in the proposed block? • *Amount, tree species, sizes and potential grades? Also consider indirect losses – bark beetles?* 2. If anticipated windthrow occurs, how easy would it be to successfully salvage? 3. Can an alternative approach be used that will cost-effectively reduce timber losses to windthrow? • *E.g., moving the edge, alter criteria for leave trees, change fetch distances, conduct crown treatments?*
Public safety and corporate or professional damages
1. Is there a potential for a significant safety issue to arise for the public (i.e., windthrow on trails or other frequently used areas)? 2. Is there a potential for the following to happen to BCTS – lawsuits, significant damage to corporate image or stakeholder relationships that could impact future planning, management and harvesting. 3. Is there a potential for the following to happen to professionals involved in this block – lawsuits, significant damage to professional credibility or professional relationships.