

Identifying the determinants of windthrow damage in wildlife tree patches in the Boreal White and Black Spruce biogeoclimatic zone of northeastern British Columbia

Scott Maxwell¹, D. Scott Green², and William Zhang³

Abstract

Leaving wildlife tree patches (WTPs) has become a common strategy employed to maintain biodiversity among managed forest ecosystems in British Columbia. High levels of wind damage have been observed in many of these reserves owing to the increased wind loading after harvesting. The ensuing damage disrupts forest management plans and reduces the value of WTPs. The objective of this study was to identify the primary determinants of windthrow in WTPs in the boreal forest of northeastern British Columbia and to suggest management strategies to minimize wind-related damage. Line transects oriented parallel and perpendicular to prevailing and dominant winds across 13 WTP reserves were used to quantify wind-related damage and factors that may contribute to windthrow incidence. The occurrence of windthrow corresponded with the exposure of WTP edges to high velocity winds; common, but lower-velocity winds resulted in little windthrow damage. Edaphic, site, and forest-stand factors appeared to have little influence on the incidence of windthrow in this study as compared to exposure to strong winds. The study suggests that forest managers can reduce the incidence of windthrow in WTPs in the boreal forests of northeastern British Columbia by: (1) creating patches that are elliptically shaped with the long axis in the direction of the dominant winds; (2) reducing wind exposure of susceptible edges; and (3) increasing the size of WTPs.

KEYWORDS: *Boreal White and Black Spruce (BWBS), northeastern British Columbia, wildlife tree patch, windthrow.*

Contact Information

- 1 Forest Technician, 725–27th Avenue South, Cranbrook, BC V1C 3J6. Email: scottdmaxwell@gmail.com
- 2 Associate Professor, University of Northern British Columbia, 3333 University Way, Prince George, BC V2N 4Z9. Email: greens@unbc.ca
- 3 Statistical Consultant, University of Northern British Columbia, 3333 University Way, Prince George, BC V2N 4Z9. Email: wzhang@unbc.ca

Introduction

In an effort to protect biodiversity in managed forests, the British Columbia *Forest and Range Practices Act* currently requires the retention of wildlife trees during harvesting operations (British Columbia Forest Information 2005). Wildlife tree retention is frequently accomplished by leaving reserves of standing timber known as wildlife tree patches (WTP) in cutblocks during forest harvesting. These patches enhance structural and biological diversity within large harvested areas (Burton 2001), and provide or maintain habitat for various species of vertebrates, birds, and fish (Keisker 2000). Furthermore, WTPs contribute biomass for future downed woody debris, create aesthetic breaks to meet visual quality objectives, and establish protection buffers for streams (Bradford et al. 2003).

Wildlife tree patches frequently incur wind damage for several years following establishment, thereby significantly eroding their ecological benefits, creating forest health concerns, increasing fuel loading, and limiting the movement of wildlife (Mitchell 1995a). The “hard” edges created between newly harvested areas and WTPs (Murcia 1995) amplify windthrow vulnerability as compared to nearby contiguous forest settings (Burton 2001). Factors contributing to windthrow have been identified and include wind patterns, soil conditions, and tree- and stand-level characteristics (Stathers et al. 1994).

High-velocity and turbulent winds exert strong physical loads on tree stems, branches, foliage, and root systems (Gardiner 1995; Mattheck et al. 1995; Milne 1995). By opening up closed forests, exposed WTP edges are subjected to stronger, more turbulent winds at or near the ground surface (Chen et al. 1995; Flesch and Wilson 1999; Lee 2000; Venäläinen et al. 2004). While tree damage can occur at wind speeds of 50 km/h, most trees will be damaged by winds greater than 100 km/h (Stathers et al. 1994).

Regional meteorological conditions largely determine prevailing wind directions (those that occur most frequently) and dominant wind directions (those that blow with the most effect) (Clark 1998). These two wind directions may or may not be the same at a given location. Topographic characteristics such as slope, aspect, steepness, and slope height may affect wind exposure, direction, speed, and turbulence, and the role of wind conditions in causing windthrow

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may vary regionally with topographic conditions. Tree susceptibility to wind damage may also be a function of edaphic factors that limit rooting depth (poor soil drainage and shallow soil) and/or root development (soil structure, density, and texture) (Day 1950; Stathers et al. 1994). Consequently, windthrow characteristics and best management practices are region-specific, given the complexity of interactions between local climate and other relevant factors.

Open-grown trees develop traits that enhance wind-firmness, such as increased stem, branch, and foliage strength and elasticity, and more developed root systems relative to crown size (Steinblums et al. 1984; Stathers et al. 1994; Telewski 1995). These traits are not usually well developed in recently exposed trees along WTP edges. Stand-level traits, such as stem density and crown position in newly created WTPs, may also affect the relative wind-firmness of trees (Stathers et al. 1994); for example, high-density WTPs will presumably exhibit lower resistance to wind-induced damage because of the protected conditions of the pre-harvest trees.

Previous studies have examined windthrow characteristics and determinants in different regions of British Columbia (Mitchell 1995a; Burton 2001; DeLong et al. 2001), but the windthrow patterns in the boreal forests remain unexamined. The objective of this study was to identify the dominant factor(s) related to windthrow damage in exposed WTPs in the Boreal White and Black Spruce (BWBS) biogeoclimatic zone (Pojar and Meidinger 1991) of northeastern British Columbia. Based on the study findings, several recommendations are offered to better manage the risk of windthrow in wildlife reserves created in the BWBS of northeastern British Columbia.

Methods

Study site

The study area was located within a 16 km radius of Tumbler Ridge, BC (55°22' N, 123°45' W) in the eastern foothills of the northern Rocky Mountains. All WTPs were located in the BWBS zone, primarily within the wet cool (wk1) and the moist warm (mw1) subzones (Pojar and Meidinger 1991). To find suitable sample WTPs, we visited every cutblock created during the mid- to late-1990s within a 50 km radius of Tumbler Ridge. Of 35 WTPs examined, only 13 were suitable for the study based on the following selection criteria.

1. Each WTP must exhibit significant exposure to wind to permit the examination of potential windthrow impacts, and
2. Each WTP must have been established at least 5 years before the study. Eleven of the 13 WTPs were in separate cutblocks, and two WTPs were in the same cutblock, but met the selection criteria.

Significant exposure to wind was defined as an unforested clearing exceeding 70 m between the WTP edge and the unharvested forest in all directions, which has been found to be a threshold of windthrow incidence in some studies (DeLong et al. 2001). The minimum age criteria was chosen based on past studies that found most wind-related damage in WTPs occurred within 5 years following harvest, with the exception of cases of extreme wind events (Mitchell et al. 2001; Ruel et al. 2001). In this study, all sample reserves had been established 6–12 years before the study.

Field measurements

All sampling occurred during September and October 2003. In each study WTP, two parallel line transects (5 m wide and about 50 m apart) were established in each of four directions at 90° angles from a baseline bearing of 200° magnetic, which was the direction of prevailing and dominant winds in the study area (Figure 1). No transect was less than 50 m from changes in edge orientation to minimize any confounding impacts due to wind exposure. Along each transect, trees greater than 10 cm diameter at breast height (DBH) were examined for tree species, distance from the respective WTP edge, and windthrown condition (standing versus windthrown) to a distance of 30 m from the edge. These data were grouped into three distance categories (0–10, 11–20, and 21–30 m from the WTP edge) to characterize

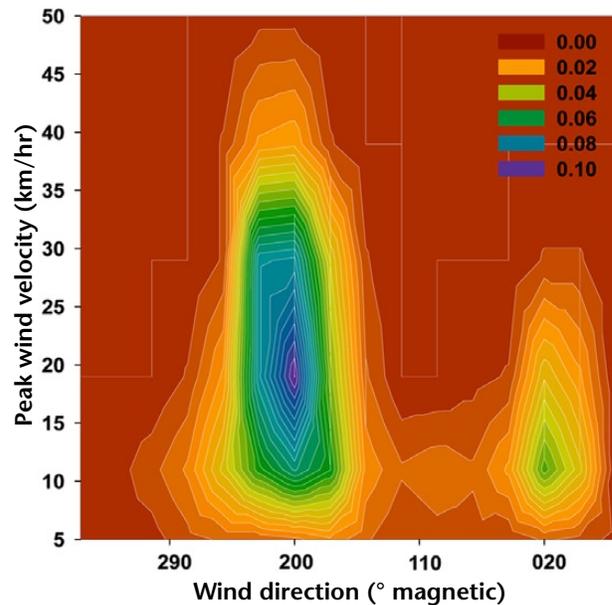


FIGURE 1. Peak wind velocities as a function of orientation in the study area. The colour key indicates the incidence of wind up to a given velocity across the range of magnetic directions. Wind data were collected at a weather station located within the study area from May 1976 to December 1978 (Quintette Coal Limited 1982), and the general patterns were confirmed using recent data from the closest Environment Canada (2005) monitoring station.

spatial patterns of windthrow in study WTPs. Each qualifying tree was categorized by DBH class (10–20, 20–40, and over 40 cm). For windthrown trees, the type of damage was recorded (stem breakage or uprooting). Tree species included (by abundance) *Pinus contorta* var. *latifolia* (lodgepole pine), *Picea mariana* (black spruce), *Picea glauca* × *engelmannii* (hybrid white spruce), *Populus tremuloides* (trembling aspen), *Abies lasiocarpa* (subalpine fir), and *Populus trichocarpa* (black cottonwood), which are all common tree species in the BWBS zone of northeastern British Columbia.

To further clarify the dynamics of windthrow in WTPs, we examined edaphic, site, and stand-level characteristics found to be important in other windthrow studies. Soil pits were excavated at 5, 15, and 25 m along each WTP line transect. These excavations were used to estimate soil texture (percent coarse fragments) and rooting depth for each WTP transect direction and distance category. Slope steepness and tree stem densities were also estimated for each WTP transect direction and

distance category. Slope steepness was visually estimated using a clinometer, and tree stem densities were measured in 5.64 m fixed-radius plots.

The directions of the prevailing and dominant winds were determined using meteorological data collected within the study area by Quintette Coal Limited (1982) at 55°08' N, 120°54' W (Figure 1). While these site-specific data did not span the period covered by the blowdown assessment in this study, the data were consistent with long-term wind data collected from 1971 to 2000 by Environment Canada (2005) at the nearest recording station at Fort St. John (56°14' N, 120°44' W). In other words, the site-specific data were representative of typical conditions.

Statistical analyses

All analyses were conducted using the SAS statistical package, version 8.2 (SAS Institute Inc. 2003). A logistic model was used to analyze the dichotomous response variable (standing tree versus windthrown tree) in this study. We used the model

$$\text{Logit}(\text{tree}) = \alpha + \beta \times \text{POS} + \text{error} \quad [1]$$

where: *tree* = 0 denoted a standing tree, and *tree* = 1 denoted a windthrown tree (broken stem or uprooted). The derived variable, tree position (*POS*), represented 12 combinations of the three distance categories, 0–10, 11–20, and 21–30 m from WTP edges, and the four

transect directions or WTP edge orientations, 20°, 110°, 200°, and 290° (Table 1).

Since *POS* 1 (0–10 m from the WTP edge with the WTP edge oriented 20°) had the lowest probability of windthrow damage (Table 1; Figure 2), it was used as a

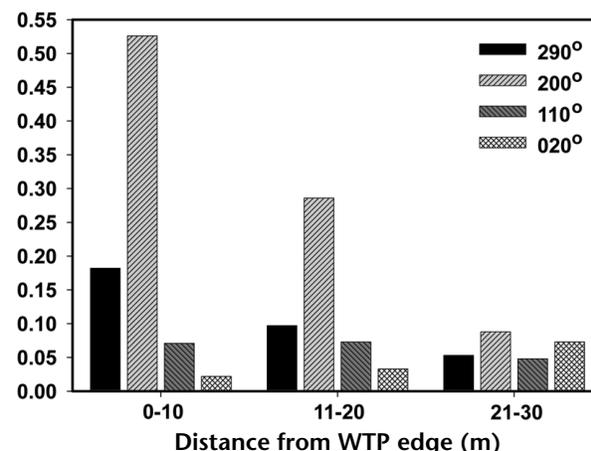


FIGURE 2. The probability of windthrow in study plots as a function of distance from WTP edge and magnetic orientation of the WTP edge. Probabilities were calculated across distance categories of 0–10, 11–20, and 21–30 m from WTP edge using a logistic model. The magnetic orientations of WTP edges are indicated in the legend.

TABLE 1. The effect of tree position on the number of standing and windthrown trees and the probability of windthrow (with 95% confidence intervals).

Tree position (POS)	Orientation of WTP edge (° magnetic)	Distance from WTP edge (m)	No. of standing trees	No. of windthrown trees	Windthrow probability	95% confidence intervals
1	20	0–10	91	2	0.022	0.005–0.082
2		11–20	89	3	0.033	0.005–0.171
3		21–30	89	7	0.073	0.016–0.280
4	110	0–10	117	9	0.071	0.016–0.267
5		11–20	102	8	0.073	0.016–0.275
6		21–30	120	6	0.048	0.010–0.202
7	200	0–10	45	50	0.526 ^a	0.205–0.827
8		11–20	55	22	0.286 ^a	0.083–0.639
9		21–30	93	9	0.088	0.020–0.315
10	290	0–10	81	18	0.182 ^a	0.048–0.497
11		11–20	102	11	0.097 ^a	0.023–0.333
12		21–30	107	6	0.053	0.011–0.222

^a The probability of windthrow was significantly different from that of the baseline ($\alpha = 0.05$), *POS* 1, which had the lowest incidence of windthrown trees.

baseline to compare the probability of windthrow for all other tree positions. To test the goodness-of-fit of the logistic model, we computed the area of Receiver Operating Characteristic (ROC), which measured the model's ability to discriminate between standing trees and windthrown trees. The computed ROC (0.77) indicated acceptable discrimination of windthrow incidence in the model.

One-way analysis of variance (ANOVA) and correlation analyses were used to compare the incidence of wind-related damage with edaphic, site, and stand characteristics (soil texture, rooting depth, slope steepness, and tree stem density). As windthrow damage was minimal beyond 20 m from the WTP edge for any orientation, we limited our analyses to 0–10 m and 11–20 m from the WTP edge.

Results

Windthrow patterns

The logistic model indicated that tree position (*POS*) had a highly significant effect on the number of windthrown trees (Chi-Square = 143.9, *df* = 11, *P* < 0.0001). Consequently, windthrow probabilities for *POS* 2–12 were compared with *POS* 1, which had the lowest probability of windthrow damage (Table 1; Figure 2). Significantly higher probabilities of windthrow were found at 0–10 m and 11–20 m for WTP edges oriented at 200° and 290° magnetic; in other words, *POS* 7, *POS* 8, *POS* 10, and *POS* 11 (Table 1). Beyond 20 m from WTP edges for any orientation (*POS* 2, *POS* 3, *POS* 4, *POS* 5, *POS* 6, *POS* 9, and *POS* 12), the probabilities of windthrow were not significantly different from *POS* 1.

Wind characteristics

Prevailing and dominant winds at the study site originated from the southwest, with a secondary, lower-velocity wind that originated from the northeast (Figure 1). Winds from south to southwesterly directions occurred about 75% of the time, reaching velocities of 50 km/h during the wind-measurement period. Winds from northeasterly directions occurred about 20% of the time, but velocities never exceeded 30 km/h during the measurement period. Winds from other directions were uncommon and gentle.

Determinants of windthrow

Windthrow incidence 0–10 m and 11–20 m from WTP edges was not related to any of the measured edaphic factors (soil texture and rooting depth), site factors (slope steepness), or stand characteristics (tree stem

density), although all factors varied considerably among study WTPs. Coarse soil fragments were generally small to medium in size, and their abundance ranged from 0 to 60% (mean = $16.2 \pm 4.2\%$ [standard error]) of the soil volume. Average rooting depth varied by 10–50 cm (mean = 23.1 ± 2.6 cm). Slope steepness varied by 0–15% (mean = $6.4 \pm 1.2\%$), and tree stem densities ranged from 361 to 1275 stems per hectare (mean = 734.7 ± 72.3 stems per hectare).

The type of wind damage, uprooting or snapping, tends to reflect the health of the individual tree, with uprooting generally indicating a healthy tree and snapping indicating an unhealthy tree (Mattheck et al. 1995). Approximately 85% of windthrown trees were uprooted in this study, and signs of root rot were not evident in the area, suggesting that forest health was not a key factor leading to windthrow. Additionally, tree species composition and stem diameter distributions of windthrown trees did not vary significantly among sampling plots. These results did not support the importance of individual tree characteristics in determining windthrow incidence.

Without WTP-specific wind data, relationships between windthrow and wind patterns could not be formally tested across sample WTPs. However, the probability of windthrow in the study area strongly corresponded to the historical incidence of high-velocity winds originating primarily from the southwest (Figures 1 and 2). Furthermore, the lowest probability of windthrow corresponded with lower-velocity winds originating from the northeast.

Discussion and management implications

Past studies have shown that the orientation of newly exposed edges relative to high-velocity winds is frequently associated with greater windthrow frequency (Mitchell 1995b; Ruel 1995), thus supporting the primary findings of this study. However, these studies also showed that soils, tree species, tree density, and topography were important contributors to windthrow incidence, which conflicts with the findings of this study.

Our results suggest that dominant winds were the primary cause of windthrow in WTPs in the BWBS zone of northeastern British Columbia, and other factors, which have been shown to be important contributors to windthrow in other regions, were not detectable as causal factors in windthrow dynamics in this study area. Consequently, the extent of WTP edge exposure to the prevailing and dominant winds may largely reflect the

risk of windthrow in the BWBS zone of northeastern British Columbia, assuming that poor stand health is not a factor. Furthermore, there appears to be a wind velocity threshold in the study area associated with blowdown damage, which is independent of wind frequency. For instance, the prevailing wind from the northeast, which was characterized by fairly frequent but low-velocity winds, was correlated with the lowest incidence of windthrow.

Further study is needed to confirm these findings and to better characterize the scope of management application and transferability. Windthrow dynamics appear to vary among ecological and topographical zones and may even vary among similar zones. For example, Burton (2001) examined windthrow in the Sub-Boreal Spruce zone, which is adjacent to the BWBS. While he found correlations between windthrow and wind patterns that were similar to our study, we found considerably higher windthrow damage on the leading edge, which further highlights the importance of WTP orientation in the boreal zone. Soil conditions may be another important determinant of windthrow dynamics and merit further investigation.

The lack of prescriptive guidelines in regards to the size, shape, and location of WTPs in British Columbia's managed forests provides managers with a range of design options. Based on the results of this study, three design strategies are suggested to minimize WTP windthrow in British Columbia's boreal forests by reducing edge exposure to dominant winds. While these management recommendations may be generally useful in managing WTP windthrow damage in any environment, they may be particularly useful in conditions where wind direction and velocity are the primary factors related to windthrow, as appears to be the case on sites adjacent to Tumbler Ridge, BC.

1. Create WTP shapes that reduce exposure to dominant winds

Creating "egg" or elliptical-shaped WTPs with the long axis in the direction of the dominant winds minimizes windthrow (Burton 2001) and maximizes the amount of forest interior in the WTP, which tends to be the most valuable portion of the WTP for wildlife habitat (Everett and Otter 2004).

2. Use WTP location within cutblocks to reduce exposure to dominant winds

Reducing the wind exposure along the most susceptible edges of WTPs (i.e., edges facing dominant winds) should be an effective means of minimizing the impact of strong winds. DeLong et

Creating "egg" or elliptical-shaped WTPs with the long axis in the direction of the dominant winds minimizes windthrow and maximizes the amount of forest interior in the WTP.

al. (2001) provided evidence that WTPs further than 70 m from a continuous forest edge had significantly higher levels of windthrow damage (Chen et al. 1995; Flesch and Wilson 1999; Lee 2000; Burton 2001; Venäläinen et al. 2004). Moreover, forest reserves closer to the cutblock edge are more valuable to forest-dwelling birds who will not generally venture more than 80–100 m from the forest edge into the cutblock (Everett and Otter 2004).

3. Increase average WTP size to reduce overall windthrow

Windthrow damage dissipates rapidly further into the forest from the edge, even on exposures facing strong prevailing winds (Figures 1 and 2). By increasing the size of WTPs, the exposed edge per area of WTPs will be reduced (Burton 2001). Also, larger reserves tend to be more valuable to wildlife because of the increase in forest interior (Everett and Otter 2004).

Conclusions

Two commonly used windthrow assessment procedures incorporate numerous factors to assess the relative windfirmness of forests based on the areas, conditions, and forest types for which the procedures were developed (Miller 1985; Mitchell 1995a). The findings from the current study suggest that a more straightforward approach may enhance the management of windthrow risk in WTPs in areas where dominant winds are relatively unidirectional. In such cases, useful management tools that require few input variables might be developed, and detailed stand assessments would likely add little to the predictive capacity of these simpler windthrow models. On the other hand, the management strategies suggested here are likely not applicable in areas with more complex wind patterns. Where dominant winds come from multiple directions or where topographical features create complex wind patterns, windthrow is probably a consequence of interactions among numerous factors.

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Test Your Knowledge . . .

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How well can you recall some of the main messages in the preceding Research Report?

Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. What was determined to be the leading cause of windthrow in WTPs in the Tumbler Ridge area?
 - A) Stand health problems, particularly root rot
 - B) Stand age and species composition
 - C) Dominant, prevailing winds
 - D) Soil texture

2. Which of the following statements are true?
 - A) The *Forest and Range Practices Act* requires the retention of wildlife trees during harvesting operations
 - B) Wind damage in WTPs has been shown to enhance ecological benefits by improving wildlife habitat
 - C) Guidelines regarding the retention of wildlife trees are highly prescriptive, limiting the management options in forestry harvesting operations
 - D) All of the above
 - E) A and C only

3. What strategies are recommended to limit windthrow in a healthy WTP in the BWBS?
 - A) Creating patches that are elliptically shaped with the long axis in the direction of the dominant winds
 - B) Reducing wind exposure of susceptible edges
 - C) Increasing the size of WTPs
 - D) All of the above
 - E) A and B only

ANSWERS

1. C 2. A 3. D