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Quantifying Extreme Winds - Experiments Aimed at Reducing Wind Damage to Released White spruce Understories

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Quantifying Extreme Winds in Experiments Aimed at Reducing Wind Damage to Released White Spruce Understories

Progress Report

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31 December 1996

SUMMARY

Forest management trials in the boreal mixedwoods near Manning, Alberta, are examining felling practises that, at the time of hardwood (aspen) overstory harvest, preserve the spruce understory. A principal concern is the post-harvest windthrow of the previously-sheltered spruce. This project was undertaken to improve the understanding of wind climatology, and aid in the identification of successful harvest designs. This report details our progress.

One study objective is to measure the extreme winds encountered on-site of the management trials, and determine how they compare with the long-term climatology. ***We found that wind conditions from October 93 - November 96 appeared "average" for speed and direction, with a maximum wind of 80.6 kilometres per hour (kph).*** There were no unusual catastrophic winds. The on-site winds were similar to those measured at the Manning airport, suggesting that records from Peace River and High Level can provide a reasonable estimate of winds at the site for periods when we did not take measurements. This also indicates that for planning in other locations, nearby weather records can be used to estimate the wind climatology.

Our second objective was to examine how cutblock designs affect the wind and windthrow potential of "released" spruce. During 1994-95 we measured the wind and turbulence within a 150 m wide cutblock, and in 1996 we made measurements in a 40 m wide cutblock. ***Significant wind sheltering occurred in both cutblocks.*** The greatest sheltering occurring with winds oriented across the narrow width of the cutblock, where wind speeds in the two cutblocks were less that 50% of that in a large clearing. This confirms a north-south cutblock orientation in northern Alberta (because maximum winds come from a westerly direction). ***The narrow cutblock provided more effective wind shelter than the wide cutblock.*** The maximum wind speed in the narrow cutblock was half that in the wide cutblock.

Using a simple engineering model of tree response to the wind, we can predict the wind-induced strain on a "representative" spruce at different cutblock locations. We found that although tree strain would be reduced in both cutblocks, the narrow cutblock would be more effective in reducing strain. We can estimate, for example, that *if* an average wind speed of 40 kph (with gusts to 85 kph) is the threshold for windthrow in large clearings, the threshold in the 150 m wide cutblock would be 44 kph (at the downwind edge), and 60 kph in the 40 m wide cutblock (downwind edge, 97 kph on the upwind edge).

Our measurements also show that wind-induced tree strain pattern can be predicted from simple wind statistics. It should then be possible to use wind flow models (mathematical equations describing how the wind varies as it "moves" within the forest) to predict the windthrow potential for any cutblock design. An example of the usefulness of such a model is trying to determine how wide a forest border should be to ensure effective sheltering in a cutblock. ***Our current priority is the development of a wind flow model.*** Our preliminary attempts to create an accurate model have had mixed results.

A. BACKGROUND

Within the next 60 to 80 years, spruce that has developed under the protection of hardwoods will be the main source of spruce timber in boreal mixedwoods. However, much of the inventoried hardwood stands are scheduled for harvest using conventional methods, which destroy the spruce understory. An effort is being made to develop procedures to protect the associated spruce understory during this harvest. A difficulty is that even if the understory survives the hardwood harvest, it is susceptible to wind damage. Project 8032, "Harvesting options to favour immature white spruce and aspen regeneration in boreal mixedwoods", is a joint project[1] to test harvest methods that may reduce wind damage in the "released" spruce understory. The study site is located northwest of Manning, Alberta. Conventional logging equipment is used, but with innovative approaches to cutblock design, including different cut widths, and different harvest levels.

Critical to the assessment of these new harvest methodologies is an understanding of wind climatology at the study site. In particular it is necessary to know: i) the extreme wind characteristics encountered during the lifetime of Project 8032; and ii), the effect of the different cutblock designs on wind flow, and windthrow potential. We are finishing the third year of a four-year study that attempts to answer these questions.

B. PROJECT OBJECTIVES

1) *The measurement and interpretation of wind extremes at the site of management trials, for aiding in the assessment of cutblock designs for protecting immature spruce from post-harvest wind damage.* Long term wind measurements are being made at two locations: adjacent to the project site, and at the Manning, Alberta, airport. This use of two sites allows us to relate winds observed during the study period to the long-term climatology as found at nearby weather stations (e.g., was the study period unusual?), and assess the spatial representativeness of the winds measured at weather stations in climatological networks (e.g., do observations from Peace River accurately portray winds at the site?).

2) *A better understanding of the wind variation within different cutblock designs, and its impact on windthrow.* It is likely that different cutblock designs will induce different wind patterns, resulting in differences in wind shelter effectiveness. It is not readily apparent what these differences will be. Our approach will have two parts. First, detailed measurements will be made across two cutblocks of Project 8032, to understand the windthrow potential in these cutblocks. Since measuring the winds within other cutblock designs is not feasible, one needs a mathematical model of wind flow to guess what the windthrow potential is in other cutblock designs. We have begun to formulate such a model.

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[1] Includes Forestry Canada, Forest Engineering Research Institute of Canada, Daishowa-Marubeni International, and Alberta Environmental Protection.

C. WORK PROGRESS AS OF 31 DECEMBER, 1996

1. Continued routine wind measurements

Routine wind observations are made from a 15 m high tower at a large clearing adjacent to the site of Project 8032, and from a tower at the Manning, Alberta airport. The following are recorded: maximum wind speed (and direction) for each hour; average hourly wind speeds; and for each day, the maximum wind from eight directions of the compass. Continuous observations have been collected since 8 October, 1993.

2. Completed wind measurements across 150 m wide cutblock

Seven 10 m high towers mounted with wind measurement equipment were placed across a 150 m wide cutblock (see Figure 1). These towers were erected in September 1994 in the Project 8032 cutblock designated F-6-3, D1. Hourly wind measurements were made at each tower using sensitive cup anemometers. Turbulence measurements were made during high wind events using three 3-D propeller anemometers (a "datalogger" was programed to turn on the anemometers during high westerly winds). During these windy periods, the motion of two trees was measured using tilt sensors (a total of six trees were measured during the experiment). Measurements were made from the fall of 1994 through the fall of 1995. The towers were dismantled in October, 1996.

3. Completed wind measurements across 40 m wide cutblock

The seven wind towers were relocated across a 40 m wide cutblock, to duplicate the observations made in the 150 m cutblock (see Figure 1). These towers were erected in October 1996 in the cutblock designated F-6-1, C1. Wind, turbulence, and tree motion measurements were made during October - November 1996.

4. Preliminary development of a wind flow model

We have completed most of the work on a computer wind flow "model". The model is based on mathematical equations that describe the transport and extraction of wind energy in the forest and atmosphere. We use a two-dimensional model (vertical and alongwind directions) to simulate conditions when the wind direction is across cutblocks (we assume complete symmetry in the across wind direction - along the long cutblock edge). Currently the model is operational, and arbitrary cutblock designs can be examined, but we are not yet convinced of its accuracy: model comparisons with our measurements in the 150 m wide cutblock are good, but the agreement is poor in the 40 m wide cutblock. We are optimistic that by incorporating a more realistic treatment of atmospheric physics, we can improve model accuracy.

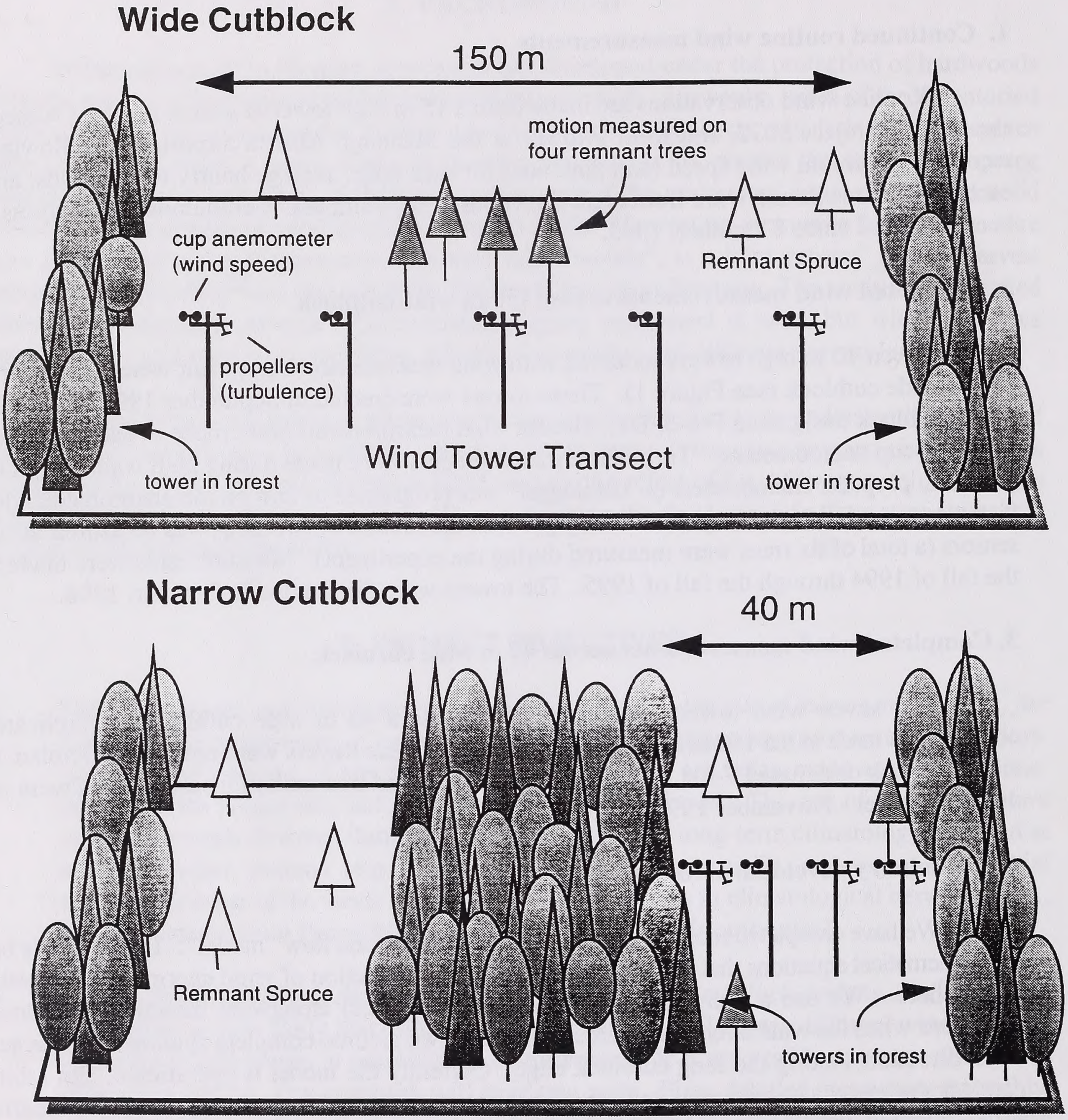

Figure 1. Illustration of cutblock wind experiments at the site of Project 8032. Wind measurements were made in transects across a wide cutblock (150 m width) and a narrow cutblock (40 m width). Wind was measured from 10 m towers using cup anemometers and propeller anemometers. Tree motion was measured for selected spruce.

D. RESULTS AS OF DECEMBER 1996

1. Wind Extremes: October 93 to November 96

The maximum daily wind speeds at the project site from October 93 - November 96 are shown in Figure 2. During the 1148 days in this period, 24 days had winds above 60 kilometres per hour (kph), and on seven days exceeding 70 kph. These days are listed in Table 1. The greatest wind speeds occurred from the SW-W-NW direction. The maximum wind speed recorded at the trial site was 80.6 kph, recorded at on 14 November, 1993. Climatologically we would classify this as important event, but not catastrophic, given the following wind statistics for the region[2]:

Location	2 Yr. Return Period (Annual)	5 Yr. Return Period (Annual)
High Level	79 kph	91 kph
Peace River	85 kph	92 kph

This means that on "average" a wind gust of 79 kph is expected every two years in High Level. Therefore, the 80.6 kph wind at the site can be expected roughly every other year.

2. Comparison of gusts at the project site and the Manning airport

Slightly higher wind speeds were recorded at the Manning airport than at the project site. During the observation period, the airport reported 29 days with winds over 60 kph (Table 1), and 13 days where the wind exceeded 70 kph. The largest wind speeds at the airport also tended to have a SW-W-NW direction. The maximum speed recorded at the airport was about 15 kph higher than that recorded at the experimental site: 96.5 kph on 14 November, 1993. This is a very strong gust given the climatology described above: we would classify this as roughly a one in ten year event.

When the daily maximum winds at the airport site are plotted against those at the project site (Figure 3), we see relatively good agreement between the two. Although there is a good deal of scatter in the points, the observations generally fall about the 1:1 line, particularly at higher speeds. We considered the agreement to be surprisingly good, given that the two sites are approximately 30 km apart, and the terrain differs between the two (flat grass/farmland at Manning, rolling forest at the project site). One conclusion we can draw is that the weather systems that result in strong winds are of large scale and generally affect both the airport and the project site (the major exceptions were a handful of summer events, where high winds at the airport were likely due to small scale thunderstorms that did not affect the project site). This suggests that records from Peace River and High Level can provide a reasonable estimate of winds at the site for periods where we have not made

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[2](from Flesch and Wilson, 1993: Extreme value analysis of wind gusts in Alberta, Canada-Alberta Partnership Agreement in Forestry Report No. 107)

measurements. This also indicates that for planning in other locations, nearby weather records can be used to estimate the wind climatology.

Table 1. Dates when the wind exceeded 60 kph at either the project site or the Manning airport during the period October 93 through November 96.

Date	Project Site		Manning Airport	
	Wind Speed (kph)	Wind Dir	Wind Speed (kph)	Wind Dir
93/10/26	63.9	SW	73.7	W
93/11/14	80.8	W	96.7	W
93/11/19	61.0	W	74.1	SW
93/11/20	44.8	N	72.7	SW
93/12/11	44.5	W	64.9	W
93/12/19	58.2	NW	60.7	NW
93/12/20	74.1	NW	77.3	NW
94/3/1	62.1	W	65.3	W
94/3/5	63.5	W	57.9	SW
94/3/13	73.0	SW	78.0	W
94/3/25	61.0	NW	71.3	NW
94/3/27	66.0	NW	49.0	NW
94/4/12	60.0	W	53.3	SW
94/4/13	53.6	W	64.5	W
94/4/15	67.4	W	67.4	W
94/5/6	72.7	W	70.2	W
94/5/7	61.0	W	69.2	NW
94/5/27	60.7	SW	65.6	SW
94/6/24	72.3	SW	53.3	NW

Date	Project Site		Manning Airport	
	Wind Speed (kph)	Wind Dir	Wind Speed (kph)	Wind Dir
94/7/13	44.8	NW	91.0	NW
94/8/14	23.7	NE	69.2	W
94/9/15	70.2	SW	64.5	SW
94/9/22	73.0	W	82.2	SW
94/12/22	59.8	SW	63.5	SW
95/2/8	72.9	W	69.3	NW
95/2/9	54.5	W	63.3	NW
95/6/25	60.0	W	52.2	W
95/9/11	64.5	W	61.2	W
96/3/16	69.0	N	58.9	NW
96/3/26	60.5	N	58.2	NW
96/4/7	69.3	N	86.4	SW
96/6/17	66.1	SW	59.3	SW
96/6/19	50.6	NW	64.2	NW
96/6/20	59.3	NW	72.0	N
96/6/27	36.0	SE	65.6	SW
96/7/15	40.0	SW	75.9	W
96/10/12	59.6	W	62.8	W

3. Cutblock winds

Our measurements across the wide cutblock (150 m width) and narrow cutblock (40 m width) show that significant wind "sheltering" occurs within the cutblocks. During windy periods, the maximum wind speed in the two cutblocks was 7 - 68% of that measured simultaneously in an adjacent large clearing (approximately 1 km in width). Several *preliminary* conclusions can be drawn about winds in the cutblocks:

i) *Wind sheltering in a long and narrow rectangular cutblock is greatest when the wind is oriented across the narrow width of the cutblock, as opposed to along its length.* In the wide

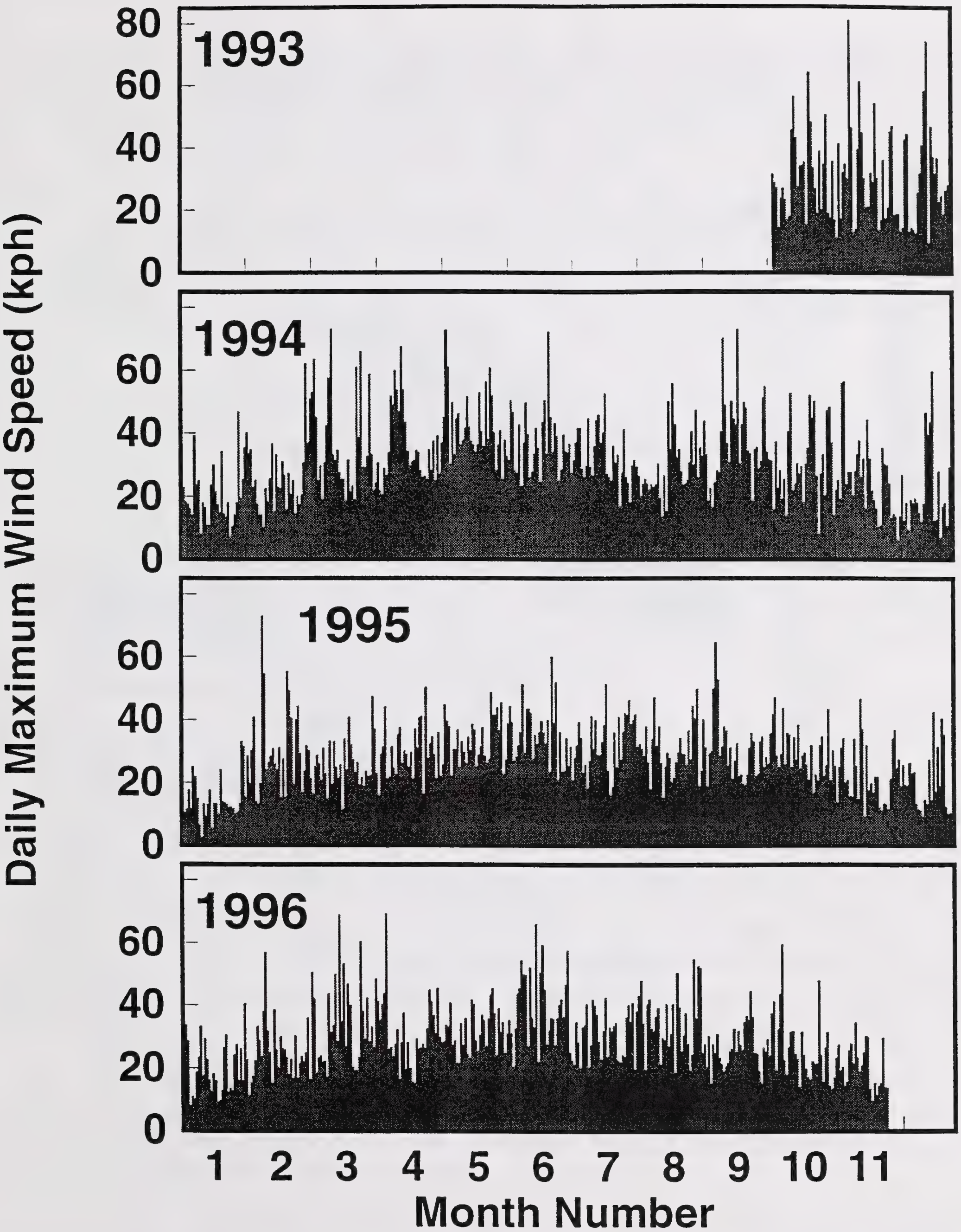

Figure 2. Daily maximum wind speeds recorded in a large clearing at project site northwest of Manning, Alberta, from October 1993 through November 1996.

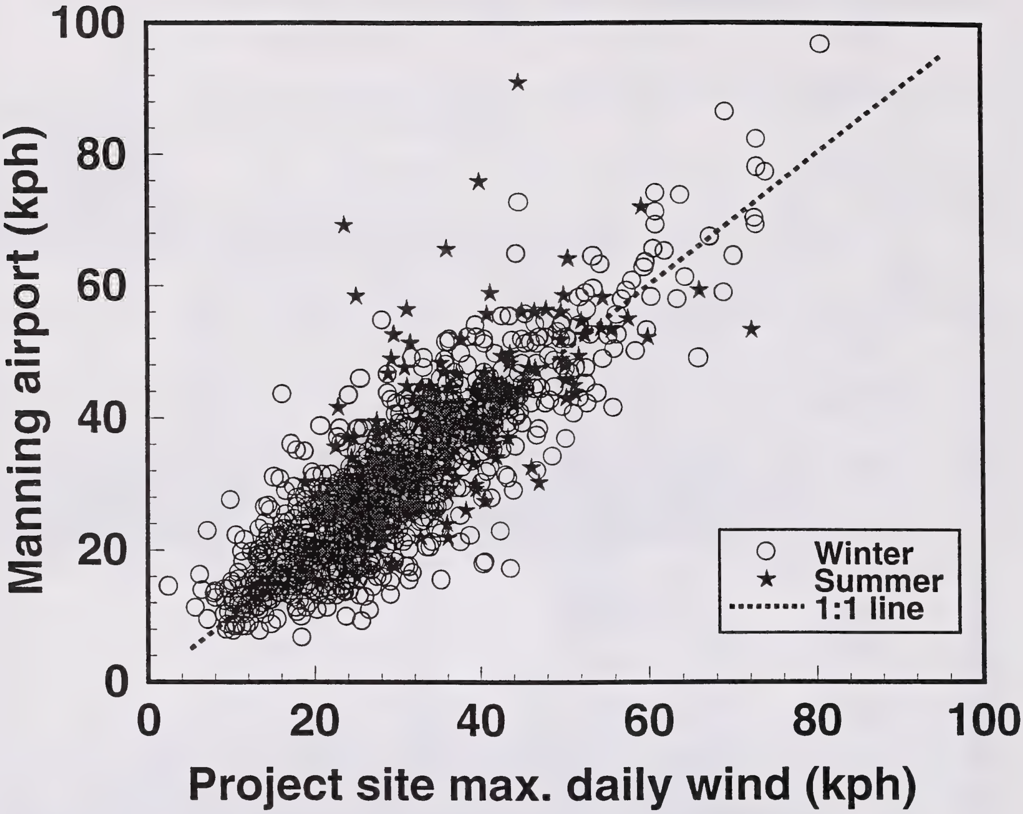

Figure 3. Comparison of the maximum daily wind speed recorded at the project site with that recorded at the Manning airport for the same day. The two sites are separated by approximately 30 km. The data have been grouped into two seasons: summer (June-Sept.), and winter (rest of year).

cutblock for example, wind speeds ranged from 23-51% of the clearing wind speed when winds were oriented across the cutblock, and from 47-53% when winds were oriented along the cutblock (Figure 4). These results confirm earlier assumptions that cutblocks should be oriented perpendicular to the expected maximum winds.

ii) *The greatest wind sheltering occurs on the upwind edge of a cutblock.* The lowest wind speeds and turbulence levels in both cutblocks were found at the tower closest to the upwind edge (Figure 4). In this "quiet" zone, wind speeds were 10-25% of the clearing values. In both the wide and narrow cutblocks, the average wind speed doubled in moving from the upwind to the downwind cutblock edge.

iii) *Wind sheltering increases with decreasing cutblock width (if forest strips of significant width border the cutblock).* When the wind direction was across the cutblock, wind speeds ranged from 23-51% of the clearing speed in the wide cutblock, but were only 10-22% in the narrow cutblock (Figure 4). The enhanced sheltering of the narrow cutblock also occurred when the wind was oriented down the length of the cutblock, where the largest wind speed was still only 36% of the clearing speed.

iv) *The greatest sheltering occurs during summer.* In the wide cutblock we found a further wind speed reduction of 5-10% in the summer, which we attribute to the leaves being out on the hardwoods, increasing the "drag" of the forest.

4. Predicting windthrow potential in the study cutblocks

An assumption in our work is that the key factor in the *spatial variation* of windthrow susceptibility in cutblocks (over the short term, at this site) is wind forcing, rather than any systematic variation in soil conditions, rooting depth, tree health, etc. Nevertheless, to examine the potential for windthrow fully, it is not enough to know only the wind force variation. It is necessary to consider the interaction between the wind force and tree motion (strain). We have chosen to examine this relationship for a "representative"released spruce -- 12-15 m tall, 20 cm trunk diameter at a 1 m height.

Our procedure for quantifying the interaction between wind and tree strain has been to: 1) measure tree motion and wind velocities (turbulence measurements) concurrently during windy periods; 2) determine the appropriate mathematical model for the tree response to wind forcing; and 3) combining turbulence measurements at different cutblock locations and the tree model, predict the strain on our representative tree (if it were at those locations).

The key to this analysis is an accurate mathematical model of tree motion. Our measurements have shown that trees act as a 2^{nd} order vibrating system (like a bending beam), with a characteristic natural frequency and damping coefficient: a sample of six "representative" trees averaged 0.40 Hz and 0.075, respectively. We chose to adopt a vibrating model of tree motion, which allows for tree

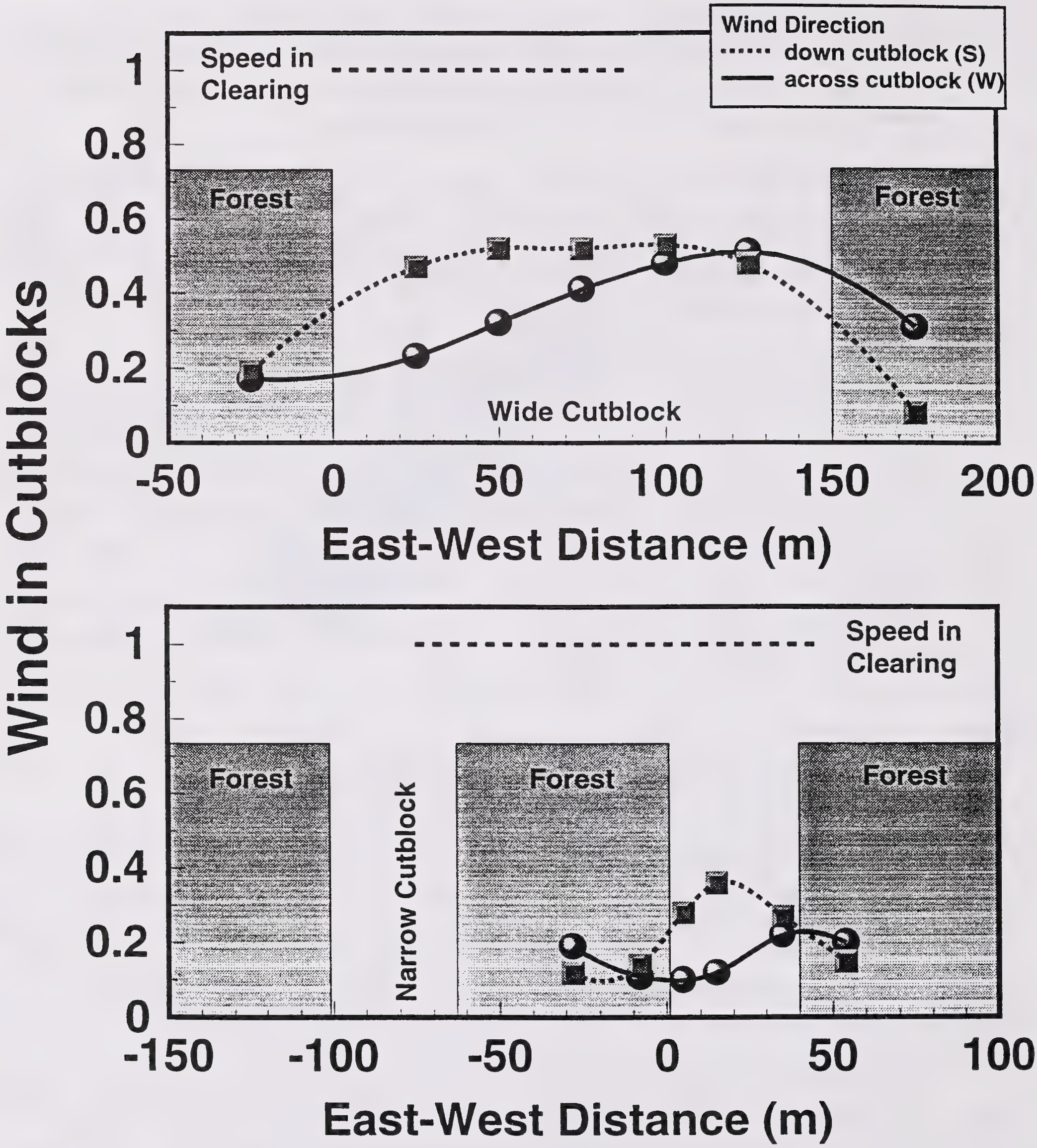

Figure 4. Wind speed in wide and narrow cutblocks when the wind was oriented across the cutblock width and down the cutblock length. Wind speeds were measured at 10 m height, and referenced to the wind speed measured simultaneously in a large clearing adjacent to the cutblocks.

displacement (strain) to be "uncoupled" from the wind, as when we observe tree swaying near its natural frequency of the tree. As well, there is the possibility of a damaging amplification of strain if the turbulence varies with a frequency near the natural frequency of the tree.

Having determined a mathematical model relating tree displacement to wind velocity, we can predict the wind-induced strain pattern of our representative "released" spruce in the cutblocks. Summarizing some *preliminary* conclusions/speculations (for the case where the wind is directed across the cutblock):

i) *The wind-induced strain on a tree within a cutblock will be less than in a large clearing.* For instance, the predicted maximum strain in the 150 m wide cutblock varied from 33-85% of the maximum strain predicted in the adjacent large clearing. Before this study, it seemed possible that enhanced turbulence at some cutblock locations could lead to greater tree strain than would occur in a large clearing. We have not seen any indication that this occurs.

ii) *Tree strain increases in moving from the upwind to the downwind edge of the cutblock.* This is not surprising given the wind speed reductions. In both the narrow and wide cutblocks, we predicted an almost threefold increase in maximum strain moving from the upwind to the downwind edge (Figure 5).

iii) *Tree strain decreases as the cutblock width decreases.* We predicted a lower level of strain in the narrow cutblock compared with the wide cutblock (Figure 5). In the narrow cutblock, the maximum strain is approximately half of that in the wide cutblock. We can estimate, for example, that *if* an average wind speed of 40 kph (with gusts to 85 kph) is the threshold for windthrow in large clearings, the threshold in the 150 m wide cutblock would be 44 kph (on downwind edge), and 60 kph in the 40 m wide cutblock (on downwind edge -- 97 kph on upwind edge).

iv) *Tree strain is relatively insensitive to dynamic characteristics of the "representative" spruce.* This has three important implications. First, that our results are probably not sensitive to our selection of trees to be instrumented. Secondly, there does not seem to be much chance that trees with the "right" dynamic characteristics would be "excited" by the turbulence within cutblocks (there is not enough turbulent wind energy near the tree natural frequencies). Finally, because a complicated dynamic interaction of the wind force and tree motion (e.g., resonance) is relatively unimportant, simple wind statistics can be used to predict windthrow potential. Our goal, in evaluating other cutblock designs, is therefore to determine these statistics.

5. Predicting windthrow potential in other cutblocks -- developing a wind flow model

The results described above improve our understanding of windthrow within the study cutblocks. Nevertheless, we have only measured the winds in those two cutblocks, and while we can extrapolate our results somewhat to consider windthrow in other cutblocks, there are some questions

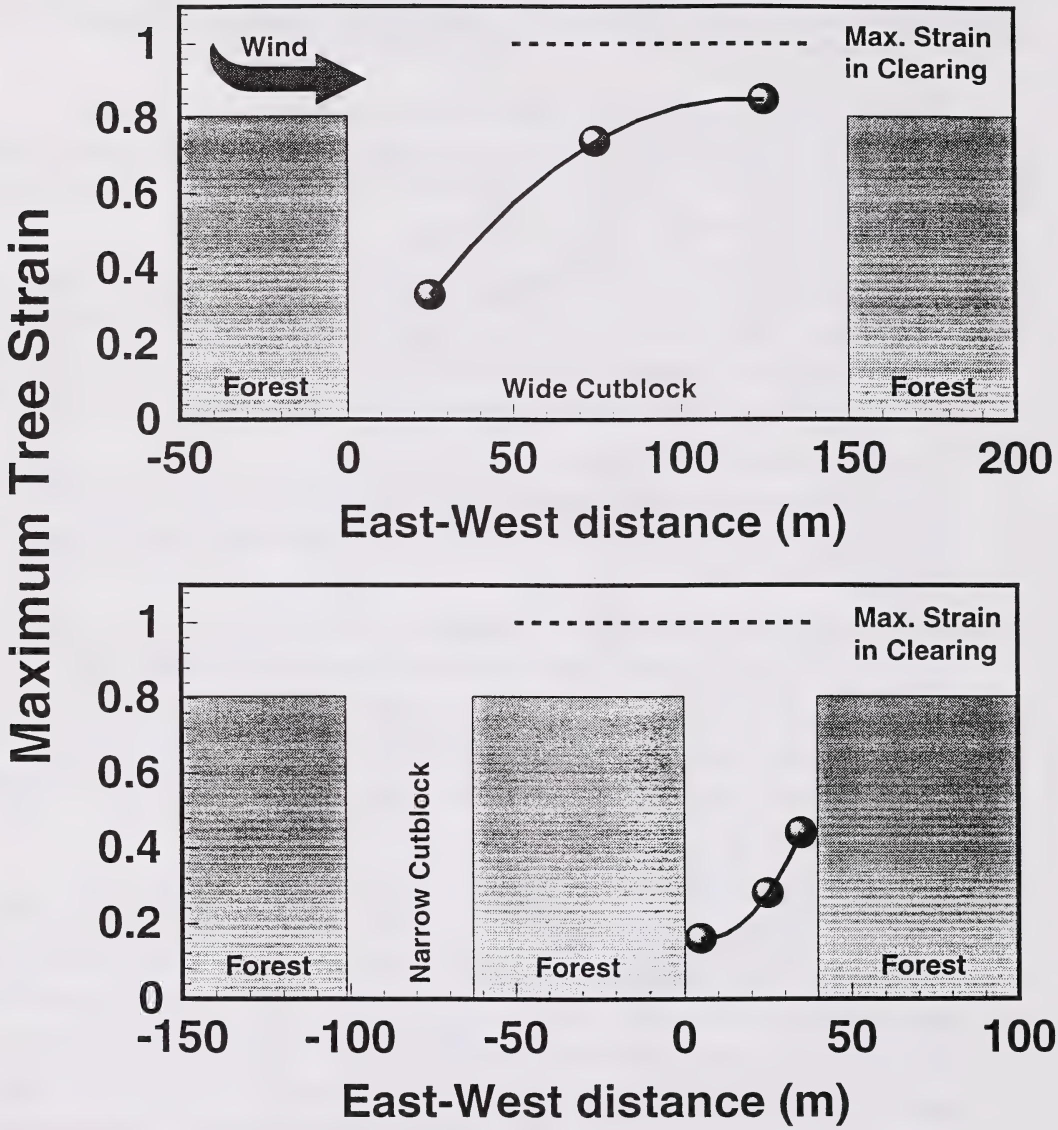

Figure 5. Predictions of maximum tree strain for a "representative" released spruce in the wide cutblock (150 m width) and narrow cutblock (150 m width), when winds are oriented across the cutblock width. Maximum strain is referenced to that predicted for the same tree in a large clearing adjacent to the cutblocks. Strain predictions are determined by applying a mathematical model of tree motion with turbulence measurements made in the cutblocks and in the clearing.

we cannot answer. Although we feel confident that narrower cutblocks will reduce the windthrow potential, our results do not tell us how wide the forest borders must be, or the effect of the density of trees outside the cutblock, or how the density of remnant trees inside the cutblock effects the wind. To investigate these questions, and to simulate the effect of any possible cutblock design, we are "building" a wind flow model to predict the windthrow potential in arbitrary cutblock designs. This is possible because we found that tree motion was insensitive to tree dynamic characteristics, so that the wind-induced strain on a tree can be predicted from the simple wind statistics that a wind flow model calculates: e.g., the mean, standard deviation, and skewness of the wind velocity.

We have completed most of the work on a computer wind flow "model", based on mathematical equations that describe the transport and extraction of wind energy in the forest and atmosphere. We use a two-dimensional model (vertical and alongwind directions) to simulate conditions when the wind direction is across cutblocks (we assume complete symmetry in the across wind direction - along the long cutblock edge). Currently the model is operational, and arbitrary cutblock designs can be examined, but preliminary results have been mixed. Figure 6 gives an example of model wind speed predictions in a series of wide (150m) and narrow (40 m) cutblocks. The model accurately duplicates the rise and fall of wind speed across the forest-cutblock series, and the greater wind speed reduction in the narrow cutblocks compared with the wider cutblocks. It is encouraging that in the wide cutblocks, the predictions of wind speed are in good agreement measurements. However, in the narrow cutblocks the magnitude and pattern of wind speed across the cutblock are not well duplicated. Model improvement is the current priority of our study. We are optimistic that by incorporating a more realistic treatment of atmospheric physics, we can improve model accuracy.

In our two-dimensional modelling, we can only address the case where the wind blows directly across the cutblock. Sabbatical visitor Dr. Andree Tuzet (Inst. Nat. Res. Agronomique, Paris) has, over the past year, generalised the wind flow model to three dimensions. While Dr. Tuzet's long term goal is to measure and interpret the micrometeorology of ***sparse canopies*** (which occupy an appreciable part of the earth's surface), Dr. Tuzet is presently carrying out simulations of our Manning observations during *oblique* winds.

E. PLANS FOR FURTHER INVESTIGATION

1) Long term wind observations will continue to be made at the site of Project 8032 and at the Manning airport. The wind data will be analyzed yearly, and the results of the analysis will be available to the participants of Project 8032.

2) Work will continue on the improvement of our two-dimensional wind flow computer model, with the goal to be good agreement between the model predictions and our earlier measurements in the 150 and 40 m wide cutblocks.

3) As part of our effort to improve model accuracy, we hope to return to the 40 m wide cutblock location to make new measurements (May, 97). We have recently acquired more

accurate and sophisticated sonic anemometers. We hope that a set of strategic observations will "fill-in" some holes in our understanding, and lead to a more accurate model.

4) Once we are satisfied with the accuracy of our 2-D flow model, we will focus on the prediction of winds within different cutblocks. Using these predictions, and our understanding of windthrow, we will then predict the windthrow protection provided by different cutblock designs.

5) We are currently collaborating with a French scientist (Dr. Andree Tuzet), who has extended our model to three-dimensions. We will be attempting to use that model to investigate questions related to more complex spatial situations. For instance, if a cutblock is very long and narrow, and the wind blows down its length, can there be a wind acceleration in the cutblock? Dr. Tuzet has visited the Manning site, and will be returning to Edmonton in February 97 for further collaboration.

ACKNOWLEDGEMENTS:

We are grateful for the help of Terry Thomson in carrying out our field work, and Dr. Stan Navratil and Lorne Brace for their help in initiating the project. Thanks also to J.P. Bielech and Clarence at Manning Diversified for helping us stay clear of chainsaws.

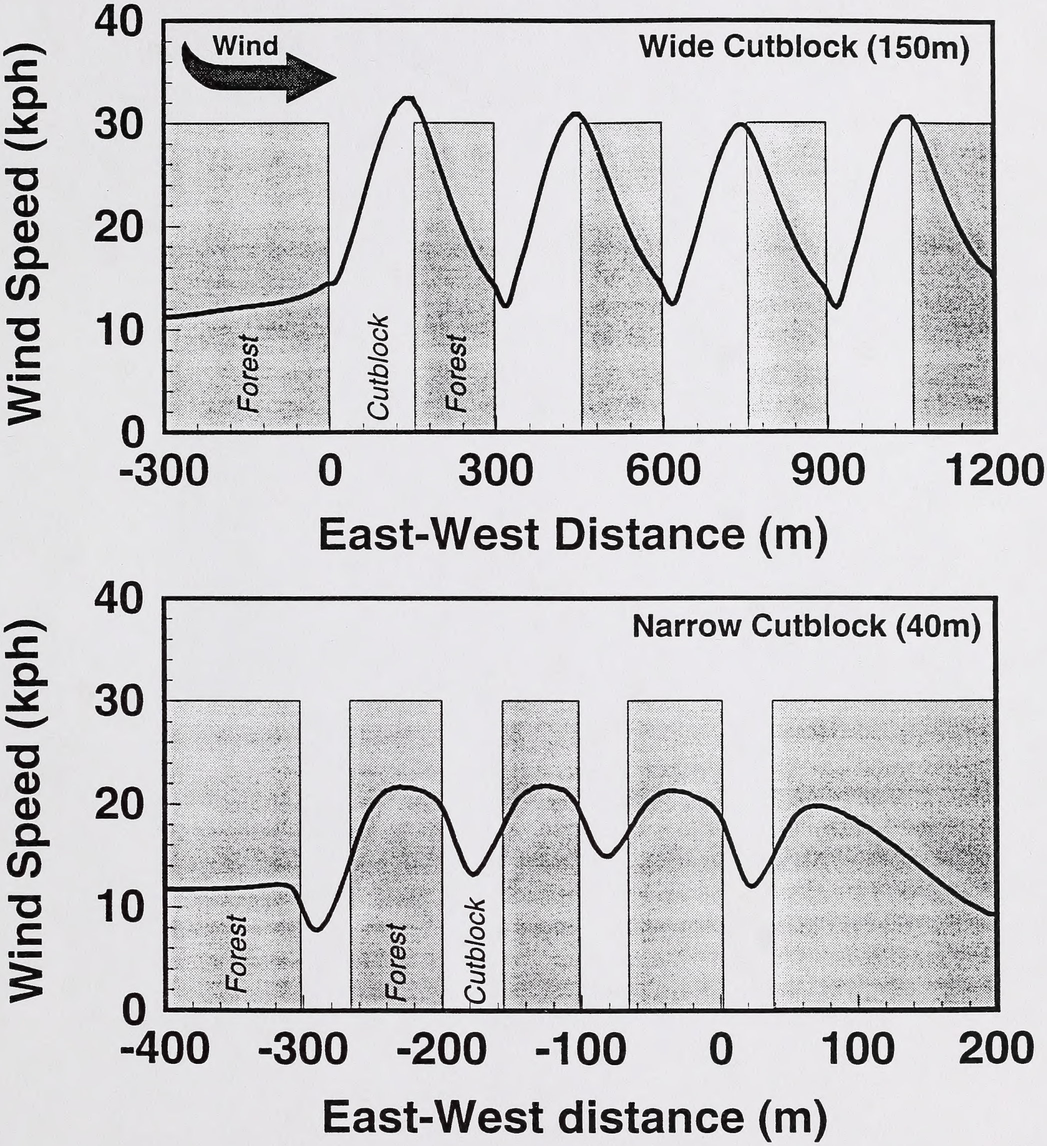

Figure 6. Example of computer model predictions of wind speed (at a height of 10 m) across a series of wide (150 m width) and narrow (40 m width) cutblocks. These cutblocks are similar in geometry to those in Project 8032.