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Using TIPSY to Evaluate Windthrow Effects on Regeneration in Variable Retention Harvests

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Abstract

The Table Interpolation Program for Stand Yields (TIPSY) enables forest managers and timber supply analysts to explore the impacts of variable retention. TIPSY variable retention adjustment factors (VRAFS) are calculated based on the level and pattern of both group and dispersed tree retention using four primary variables from the retained stand: percent crown cover, average group or crown size, initial edge length (perimeter), and top height. Windthrow losses in the years shortly after harvest can now be estimated using two methods; empirical regression equations that predict windthrow effects, or specifying expected windthrow losses for a given location. VRAFS reduce post-harvest regenerated yields on a per-hectare basis over the entire cutblock as a function of the area occupied by retained trees. Windthrow losses will reduce the crown cover retained and therefore increase the growing space and future yields for the regeneration.

Introduction

The variable retention (VR) approach to harvesting is an adaptive management strategy intended to promote conservation, ecosystem function, and biological diversity. This approach retains structural diversity (e.g., trees of varying sizes, snags, down woody debris, etc.) from the original stand after harvest to maintain some of the original forest attributes (Mitchell and Beese 2002; Beese et al. 2003). The harvested portion of the stand is then regenerated or replanted following ecological site-specific prescriptions.

The Tree and Stand Simulator (TASS) (Mitchell 1969, 1975) is a spatially explicit individual tree model that provides key growth and yield estimates for the managed forests of British Columbia. TASS provides the database for the Table Interpolation Program for Stand Yield (TIPSY) (Mitchell et al. 2000) that is used in every timber supply review in the province. TIPSY was expanded in 2003/04 to include factors that reduce regenerated yields for aggregated and dispersed patterns for VR harvesting systems (Di Lucca 2004; Di Lucca et al. 2004).

VR adjustment factors (VRAFS) in TIPSY represent the ratio of merchantable volume for the regenerated or planted trees after VR harvesting to the volume after a traditional clearcut given different harvesting ages, site

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indices, and retention levels. For example, TIPSY indicated that, relative to the clearcut base case, leaving about 15 dispersed trees per hectare within openings could reduce harvest volumes by about 3% in the medium term, and 8% in the long term at the TSA level in the Fraser Timber Supply Area (B.C. Ministry of Forests 2003). However, these estimates did not account for the impact of windthrow, which often follows VR harvesting.

Windthrow disrupts planning, can affect small streams, and increases logging costs (Stathers et al. 1994; Mitchell 1995). Estimating the impacts of windthrow on the regenerated stand volume is critical in the development of a VR cutblock management plan. Windthrow losses vary with geographic location and post-harvest exposure of trees to wind. Early silvicultural systems experiments with dispersed retention experienced 20% (D'Anjou 2002; Scott 2005) to 50% (de Montigny 2004) loss of the retained trees. Reported windthrow losses in aggregated group retention are lower but still range from 10 to 25% of the residual trees (Scott and Beasley 2001; de Montigny 2004; Scott and Mitchell 2005). Loss of retained trees to windthrow will affect the growth and yield projections for the regeneration. Our goal is to quantify these effects in our simulations of VR in TIPSY.

This report describes how TIPSY can be used to predict the regenerated volume impacts of windthrow after VR harvesting for use in yield tables applied to cutblocks, polygons, or timber supply analysis units. This collaborative work by the Research Branch of the B.C. Ministry of Forests and Range, the Faculty of Forestry of the University of British Columbia, and the United Kingdom Forestry Commission was funded by the B.C. Forest Investment Account, Forest Science Program.

Windthrow Prediction Background

The occurrence and severity of windthrow depends on the interaction between climate, stand and soil conditions, tree characteristics, site quality, and topographic factors. The resulting damage can be in a form of stem failure, root failure, and uprooting (Mergen 1954; Somerville 1980; Stathers et al. 1994; Moore 2003). Windthrow management in British Columbia typically involves risk assessment using qualitative approaches to identify the factors that predispose a stand to windthrow. An example is the windthrow hazard classification system developed by Mitchell (1998) that forms the basis for the BCMOFR 712 Windthrow Assessment field cards.

Mechanistic modelling estimates tree resistance and drag, based on tree winching and wind tunnel studies, respectively. The results of these studies are synthesized to predict critical above-canopy windspeeds that cause tree loss. These predictions provide peak wind return periods, which are estimated by topographic windspeed models to determine when and where windthrow will occur (e.g., ForestGALES in Gardiner et al. 2000; Ruel et al. 2000). Mechanistic models have been used to predict windthrow in uniform plantation forests in Great Britain and Finland, and in balsam fir (*Abies balsamea* (L.) Mill.) stands in Quebec. However, the variability in tree attributes, stand structure, and composition in British Columbia stands, combined with the lack of windspeed data for remote areas, limits the use of these models for local conditions. The mechanistic model ForestGALES is currently being configured to use tree-list input from TASS and British Columbia wind data, and will be complete by the end of 2008.

Empirical models use regression equations based on field data to predict windthrow probability as a function of site, stand, and/or tree attributes. These equations can be fit for tree-level or stand-level outcomes. Empirical modelling is suitable for stands with complex and variable composition, and where soils and geography are heterogeneous. Geographic Information Systems (GISs) and TIPSY have been used in the development of some of these models.

The probability of windthrow loss in partial cuts is known to reflect stand, neighbourhood, and tree-level attributes, and is strongly influenced by the effect of harvest design on wind exposure within the stand, also known as "fetch" (Scott and Mitchell 2005).

Steve Mitchell (UBC) and his students have used aerial photos of stand edges and stand-level GIS data to fit empirical windthrow risk models for five coastal and three interior British Columbia locations (Mitchell et al. 2001; Lanquaye and Mitchell 2005). These risk models use logistic regression equations to predict the probability of windthrow occurring within 25- by 25-m edge segments around the cutblock boundary. For this project, the probability is modified based on the number and pattern of trees retained and sample data collected from:

- GIS stand/forest cover information (i.e., stand height, ecosystem, soils, time since harvest, management history, etc.)
- Mean annual wind speed obtained from B.C. Hydro data at 1 km grid resolution
- Topographic variables, including exposure indices derived from Digital Elevation Models (DEMs)

The portability of these local risk models to other locations was tested and produced good windthrow risk predictions after calibration. Generic coastal, interior, and provincial models with good fits to independent data were also generated (Lanquaye and Mitchell 2005). To integrate the model predictions into TIPSY it is therefore necessary to convert the predicted windthrow probability loss to estimate the retained crown cover loss after VR harvesting.

TIPSY Windthrow VRAF Development and Use

To recap, the VRAF will be affected by three components: 1) the withdrawal of retained tree areas from future timber production, 2) the competitive influence (i.e., shading, etc.) of retained trees on the adjacent regenerating portions of the cutblock, and 3) the reduction of the retained trees due to windthrow.

TIPSY's VRAF model requires four primary input variables that describe the retained trees at the time of VR harvest: 1) percentage of total residual crown cover across the opening, 2) average group size or average crown size for individuals, 3) initial edge length (perimeter) of groups or individuals, and 4) top height. Retained crown cover is derived from ground surveys or post-harvest aerial photos for group retention. TIPSY can also predict edge length and crown cover from retained basal area, a common measure of dispersed retention (Di Lucca et al. 2004).

Within TIPSY the form of the windthrow probability logistic model for a given location is:

$$P_i = \frac{\exp(\text{logit}_i)}{\exp(1 + \text{logit}_i)}$$

Where P_i is the probability of damage in boundary segment (25- by 25-m) "i," and the logit values are given by:

$$\log it_i = b0 + b1 \times \text{var}1 + b2 \times \text{var}2 \cdots + bk \times \text{var}\,k$$

Where var1 to var k are a series of independent variables described in Table 1. The mean values and parameter estimates for these variables are included in TIPSY as defaults, and described in Lanquaye and Mitchell (2005).

TIPSY accepts input values for the variables listed in Table 1 to estimate the effects of windthrow on the regenerated portion of the cutblock. The user selects a model for the desired location, and the program will incorporate the estimated default values accordingly. Alternatively, the user can partially modify these values for sensitivity analysis or can specify an expected windthrow loss to reflect a different stand condition.

TIPSY VRAFs represent the reduction in post-harvest regenerated yields on a per-hectare basis over an entire VR cutblock as a function of the retained area(s) or trees removed from timber production. Windthrow losses will reduce the percentage of crown cover, the average group size or crown size, and the initial length of edge per hectare retained. This will decrease the VRAF and therefore increase both the available growing space and the expected yields for the regeneration. The computed VRAF at age 100 is displayed in TIPSY's Stand Description, and the VRAF values at any given age are available through the Custom Table.

After analyzing the database and deriving the models, it is expected that windthrow losses will increase with:

- topographic exposure
- elevation
- mean wind speed
- site index and stand height
- slenderness, high height diameter (H/D) ratios
- time since harvest
- opening size and boundary exposure
- density and stand uniformity
- decreasing retention levels
- smaller retention groups and dispersed trees
- narrower rectangular retention strips

Users should be aware that, as with any predictive model, there are

TABLE 1 *Summary of independent variables for stand-level models*

Variable	Description	Units
Bearing	Bearing (cosine) at right angles to boundary inward towards block	°
Mean wind speed	Mean wind speed from B.C. Hydro data (2001)	m/s
Directional exposure	Number of segment exposed directions out of eight cardinal directions	#
Topex 2000	Topographic exposure to distance: sum of maximum angle to ground within 2 km for each of eight cardinal directions	°
Elevation	Ground elevation from 100 m DEM	m
Time since harvest	Years since harvest of adjacent opening	years
Stand top height	Stand top height from forest cover layer	m
Crown cover loss	Mean proportion of crown cover loss within the segments at a given location	%
Area loss	Mean proportion of area loss within the segments at a given location	%

important modelling assumptions that affect the accuracy of projections and their interpretation. The windthrow models are empirical, and, consequently, work best for situations very similar to those for which the model was fit. These models reflect the average outcome for stand edges or trees with particular sets of attributes. They incorporate damage that occurs within 10 years of harvesting and therefore reflect endemic windthrow from routinely occurring peak winds rather than catastrophic windthrow. Harvesting strategies are evolving, and the stand-level windthrow models are based primarily on clearcut systems. Additional tree- and stand-level datasets are needed to fully develop and test models suitable for the full range of VR scenarios. Windthrow predictions should be used for evaluating potential outcomes with the recognition that actual local windthrow may vary substantially from the prediction.

The operational version of TASS used to generate the TIPSY database assumes that the sun is always directly overhead and that shorter trees will not survive within the vertical canopy shadow of taller trees. TIPSY VRAFS remove the crown area of retained trees after windthrow. Users who consider this effect too extreme may wish to reduce the crown area accordingly (for dispersed retention in particular).

TIPSY VRAFS are appropriate for single-species forests and assume that the retained stand is of the same species as the regenerated stand. The VRAF in mixed-species stands is calculated for each species, and the resulting single-species yields are prorated according to the species composition of the stand. The windthrow models do not differentiate between species.

An Example Using TIPSY

We want to remove 60% of the area of an existing 70-year-old cutblock of coastal Douglas-fir (site index 30) located in the North Island Timberland (NIT) (Sayward/Tsitika/Eve River). The cutblock prescription includes the retention of the remaining 40% of the stand to meet VR objectives. The retained area is aggregated into groups with an average size of 3000 m^2 and with a top height of 31.4 m at the time of harvest (Figure 1). If there is an expectation that the retained area will be reduced due to windthrow, TIPSY will calculate the windthrow probability loss using the default mean values for the North Island Timberland (NIT), as shown in Figure 2. We assumed that the windthrow damage occurs before the harvested portion of the cutblock is replanted.

Given these inputs, TIPSY predicts that the retained crown cover is reduced from 40 to 37.8%, the edge from 483 to 465 m/ha, and the VRAFS at age 100 from 0.46 to 0.49 after windthrow losses are calculated (Figure 2). Figure 3 depicts the merchantable volume curves generated by TIPSY comparing a VR harvest without and with windthrow. TIPSY predicted that windthrow loss would increase the planting area by 5%, which would increase the regenerated yields at age 100 by 6% (or 22 m^3). Similar yield tables are often used in timber supply analysis and silvicultural planning.

The application of VRAF does not eliminate the need for operational adjustment factors such as OAF1 to reflect small stocking gaps (e.g., wet areas, rock outcrops, etc.) or OAF2 to reflect an expected increase in forest health losses due to VR (e.g., root rot or mistletoe). No changes were made to OAF1 and OAF2 default values of 15 and 5%, respectively, in this example.

Management Implications

Windthrow can cause significant yield reductions, especially in partially cut stands. Forest managers need to develop management plans that account for expected levels of windthrow and the resulting impacts to growth and yield. Stand growth models combined with empirical windthrow risk models allow predictions of stands that are representative of British Columbia conditions and managed under a variety of scenarios.

When creating management plans for VR harvesting systems, keep in mind that windthrow risk increases as retention levels decrease, and areas of high wind hazard and exposure will have higher levels of damage.

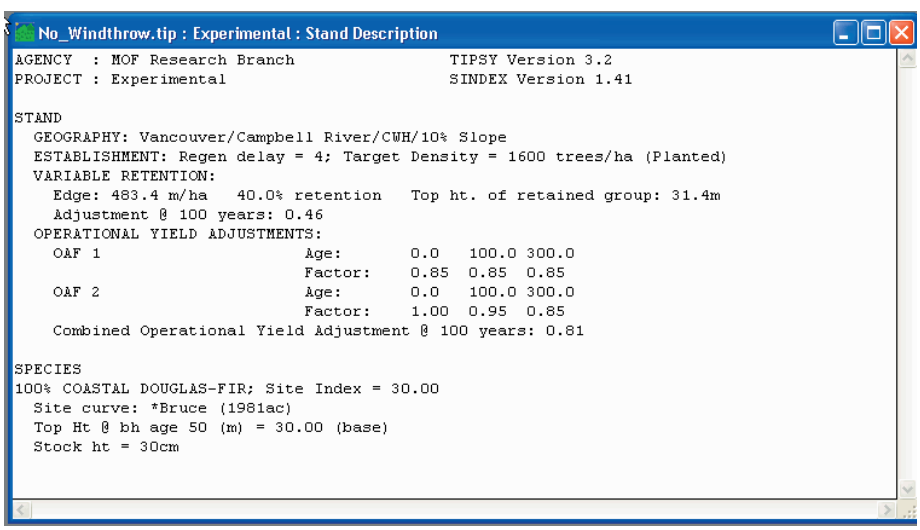

FIGURE 1 *TIPSY's stand description information.*

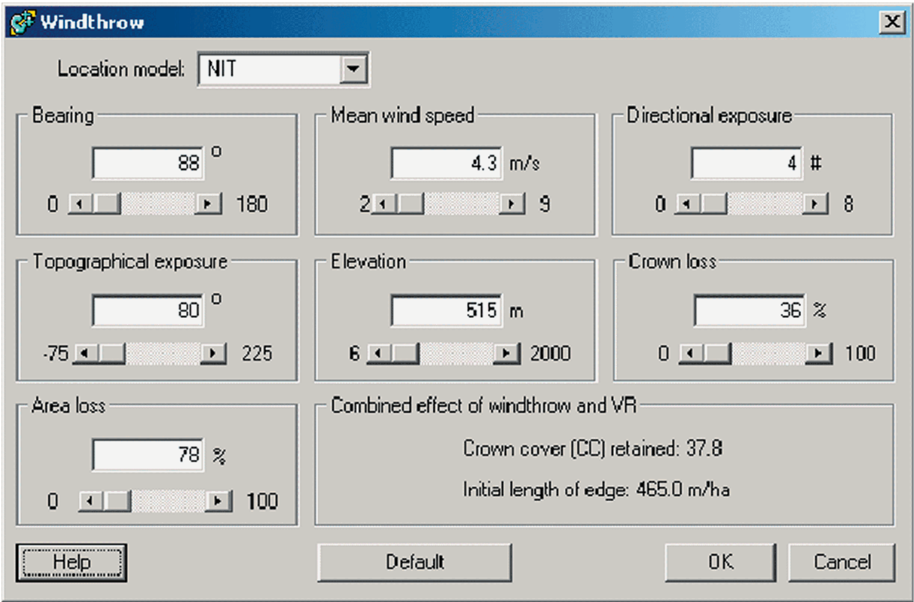

FIGURE 2 *TIPSY's windthrow input screen.*

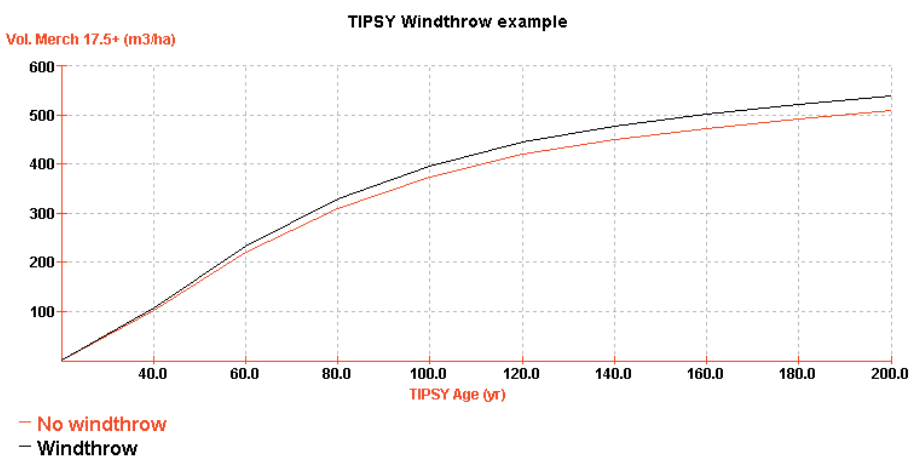

FIGURE 3 *TIPSY-generated merchantable volume 17.5+ (m^3/ha) curves, comparing a clear-cut scenario with the VR example with and without windthrow.*

Where probable windthrow impacts exceed acceptable levels, modifications should be considered for retention levels, cutblock boundary location, boundary design, and retention tree characteristics (e.g., topping or pruning). Windthrow losses in aggregated retention systems can be reduced by increasing the size of the retained groups, and by selecting more stable group shapes (e.g., square or circular instead of rectangular narrow strips). Windthrow damage in dispersed retention systems can be reduced by selecting strongly tapered and flat-topped trees, and in combination with aggregated retention where possible. Modifications such as topping or pruning for windfirmness are not yet incorporated in the TIPSY calculations.

TIPSY Distribution and User Support

TIPSY is distributed and supported by the Research Branch, B.C. Ministry of Forests and Range <http://www.for.gov.bc.ca/hre/software/>. Users are encouraged to consult TIPSY's online documentation and Help function, which provide answers to many common questions. Software additional support information is available on the Research Branch Growth and Yield Modelling web site <http://www.for.gov.bc.ca/hre/gymodels/>.

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