WINDTHROW ALONG ELECTRICAL DISTRIBUTION LINES IN A RURAL SETTING

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Abstract. A blowdown survey was conducted along electrical distribution lines in a rural setting in order to identify the most important variables in estimating blowdown hazard. The variables usually involved in such an estimation did not prove very powerful in explaining blowdown density. In fact, blowdown was more related to the vegetation characteristics, namely size, species and vigour. This can be explained by an overriding effect of those characteristics in poorly managed stands that can be overmature and of low vigour. Specific studies are then needed to include those variables in blowdown hazard assessment.

Windthrow is a complex phenomenon, resulting from interactions between numerous factors, either man-made or natural. Among the factors most often cited are: wind exposure, soil properties, stand and individual tree characteristics (10). Windthrow can have a significant impact on the reliability of the power distribution network. In fact tree fall was directly responsible for 34% of the power interruptions that occured from 1988 to 1992 in the study area.

When faced with the the risk of windthrow, many attitudes can be taken. One can consider it as a fatality against which nothing can be done. This seems justified in the case of extremely severe storms that destroy almost anything. An example of such a storm is the tornado that hit Maskinonge in Quebec. There, pylons from a main power line (230-315 KV) were locally thrown over. However, the endemic damage, related to less severe but more frequent storms, is insiduous and can be of great significance. This is the type of damage for which a hazard estimation seems possible.

Systems have been proposed to assess windthrow hazard. Some are solely based on the effect of soil properties on rooting depth and efficiency, others consider wind exposure and some use only stand characteristics. One system that looks appealing is in use in Great Britain (6). It considers wind exposure and soil properties and provides management guidelines regarding the height at which a stand is likely to become affected by windthrow. However, none of these systems has yet been tested in Quebec's conditions.

In Quebec, power distribution lines meet extremely various ecological and ownership conditions. They often run through private, poorly managed stands. By studying a particular network where blowdown losses are known to occur, we can determine the primary factors that eventually could be included in a hazard rating system.

Methods

The study area lies 120 km northwest of Montreal (Quebec) and covers approximately 95 km2 (Figure 1). Winds over 40 km/h (25 mph) mostly come from the west (60 %) or the northwest (30%). Surface deposits are mostly glacial tills or fluvio-glacial deposits underlain by precambrian, igneous bedrock. Lacustrines deposits are also found in some places.

The study area is part of the sugar maple-yellow birch-basswood climax zone. The forest is composed of sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*) with occurence of yellow birch (*Betula alleghaniensis*), white ash (*Fraxinus americana*) and basswood (*Tilia americana*). Balsam fir (*Abies balsamea*) and white spruce (*Picea glauca*) are found on well-drained as well as imperfectly drained soils. Pionier stands

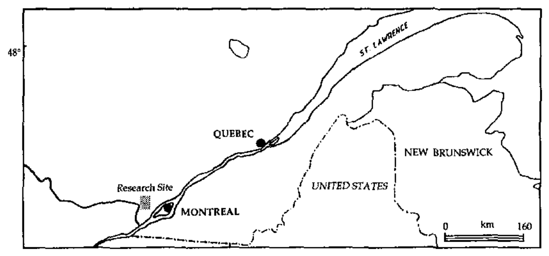

Figure 1. Location of the research site.

of quaking aspen (*Populus tremuloides*), bigtooth aspen (*Populus grandidentata*) and paper birch (*Betula papyrifera*) are also frequent. The lowest elevations have been converted to agriculture, a large part having since been abandoned. Stands are generally on private land mostly used for recreation and are generally not managed for wood production. Stand vigour is often poor.

The blowdown survey was conducted in stands whose height exceeded that of the electrical conductors. Seventy-nine plots were laid out on the 70 km of lines present on the pilot area. Plots were rectangular (5m x 20m), parallel to the electrical line. Blowdown trees, located outside the plot but in the same stand, were also measured. Blowdown trees were retained only if their appearance indicated a relatively recent occurrence of windthrow (leaves or needles still attached, upturned rootball intact, firm bark).

Data gathered at each station included:

- data relative to the electrical network: location and orientation;
- ecological data: slope, aspect, wind exposure, surface deposit, drainage, soil type;
- data on the blowdown: distance from the network, orientation, type of wind damage, species, height and diameter at breast height, occurence of physical or decay indicating defects;
- stand data: species, height, diameter at breast height, stem inclination and the occurrence of physical or decay indicating defects.

Wind exposure was estimated by calculating a TOPEX (TOPographic EXposure) value (6,7). The angles of elevation to the visible skyline were measured with a compass and an optical clinometer at the eight major points of the compass. The sum of the eight angles constitutes the TOPEX value. TOPEX values were then grouped into five classes, from severely exposed (TOPEX: 0-10) to very sheltered (TOPEX greater than 100).

External defects can indicate the presence of internal decay or can correspond to a point of poorer mechanical resistance. Among the main indicators of decay the following were selected: conks, frost cracks, stem wounds, low forks, broken tops, cankers.

The slenderness ratio (height/diameter) has been suggested as an index of stand resistance (3). It accounts for the fact that slender stems of a given height are less resistant to breakage and possible uprooting. The spacing factor could also be useful for estimating stand stability. This factor estimates the average distance between trees in relation to the stand height (2).

$$S(\%) = \frac{10746}{H^{*}N^{.5}}$$

where H=dominant stand height
N=stand density (stems/ha)

Plots were first grouped into three blowdown density classes designed to sort out the 25% most affected and the 25% least affected stands . Statistical analysis of categorical data (ecological data and TOPEX class) was conducted with log-linear models. A comparison of field-estimated TOPEX and map-estimated TOPEX was made with regression analysis. Analysis of stand data was made with stepwise discriminant analysis using blowdown density class as the classification variable. The analysis of tree-level factors was made in two steps. First, univariate statistics were computed to characterize the windthrown trees. Secondly, a comparison of living and downed trees was made by contigency tables and log-linear models for defects and inclination, and by "t" test for diameter and height.

In addition to the field survey, a study of aerial photographs was conducted to better understand wind exposure in the eastern part of the study area (2 km^2). Photographs at the scale 1/5000, taken during the leafless season, were used. They enabled the delineation of blowdown density class, blowdown location and direction.

Results and Discussion

The analysis of the field survey reveals some similarities between the apparent direction of the damaging winds, as inferred from the direction of fallen trees, and the occurence of strong winds recorded at the nearest meteorological station, located 25 km from the study area (Figure 2). Fall direction was generally in an eastern direction, indicating westerly damaging winds. This is in relative agreement with the occurrence of windspeeds over 40 km/h. This result would sug-

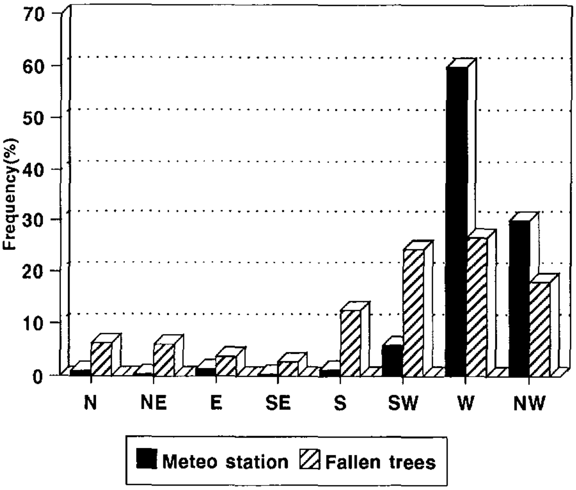

Figure 2. Frequency directions of windspeeds over 40 km/h recorded at the nearest meteorological station and of actual winds that caused blowdown, as inferred from fallen trees.

gest that meteorological station data could provide a rough estimate of the direction of potentially damaging winds over an area. However, significant differences (p<.005) were observed between both frequency distributions. These differences are probably related to the effect of topography on wind behaviour (4).

No effect of slope angle or topographic position on blowdown density was found. To further investigate the impact of topography on wind, it was necessary to resort to the aerial photographs. Figure 3 shows these results. A dominant easterly fall direction emerges, but with strong variations, this direction becoming northerly or north-easterly in the Lac-des-Seize-Iles area. Many high density zones were mapped, one such zone occurring east of Lac-des-Pins. This zone is associated with a funnelling effect at the end of the lake, further emphasized by the presence of a steep slope. It is well known that wind speed increases when flowing over an obstacle (4). On the western side of Lac-des-Seize-Iles, an intermediate concentration of blowdown (point A) can be seen where fall direction is northerly, parallel to the lake long axis. This agrees with the general observation that, in rugged topography, wind tends to follow the valleys (8). On top of Montagne-de-la-Croix, an area (point B) with no preferential fall direction is seen. This could correspond to an increase in turbulence behind an exposed crest (4). These results suggest that, even though potentially damaging wind direction can be roughly estimated by data from meteorological stations, reliable prediction at a local level would require a better understanding of the effect of topography on wind direction and strength.

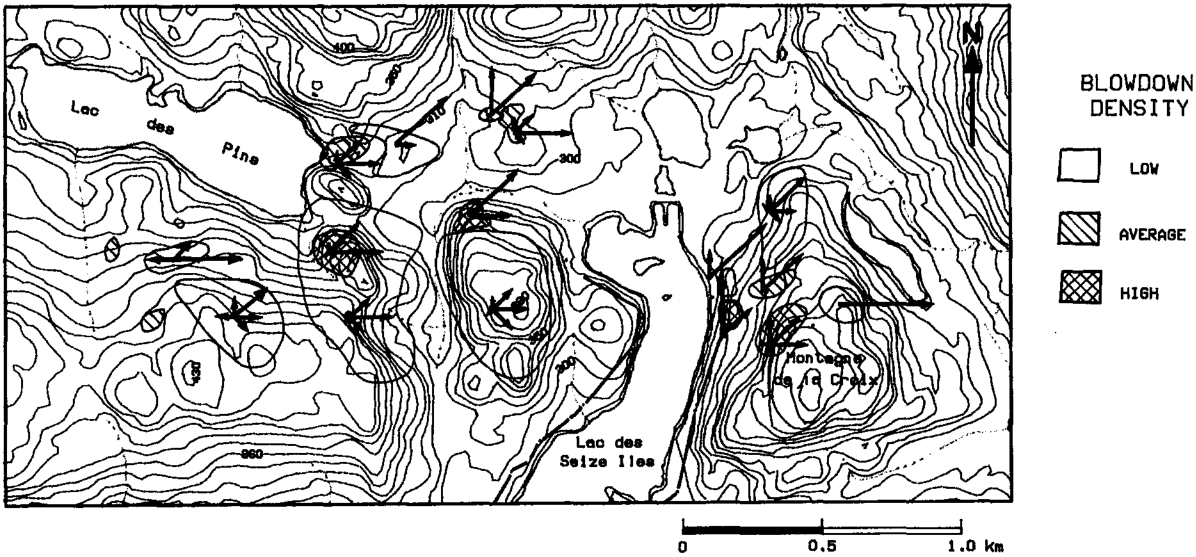

Figure 3. Localization of blowdown from aerial photographs. Arrows are proportional to the frequency of treefall in each diréstion.

Field TOPEX assessments have often been difficult to make with adequate accuracy due to the obstruction of the skyline by the stand. An alternative solution, the assessment by topographic maps, was then used. Even though a correlation exists between both approaches, it only explains 48% of the variance when trying to estimate field-measured TOPEX from the one measured on maps. Moreover, a bias was observed, field values being higher than map computed values. This indicates that an overestimation of the TOPEX value can occur when the skyline is obstructed by the surrounding forest and the observer tends to use the tree tops at a certain distance to estimate the skyline angle. When such conditions prevail, one must be very careful in estimating TOPEX in the field. No effect of TOPEX could be detected on windthrow density class. This variable provides an estimate of the topographic shelter but does not account for local variations in wind behaviour such as those described from the aerial photographs (7). For example, in Figure 3, points A and C have similar TOPEX values, being quantified as moderately exposed. However, blowdown density is completely different. If we use the direction of fallen trees as an indicator of the potentially damaging winds, then point C appears to benefit from the shelter of a small hill against the southerly winds while point A is more exposed to those winds. Thus, a better estimation of wind exposure would be possible by integrating the effect of topography on the direction and strength of the potentially damaging winds.

In the analysis of the effect of soil variables, namely surface deposit and drainage, no significant effect on blowdown density was found. It is generally recognized that poorly drained soils restrict rooting depth and hence are associated with a greater risk of blowdown (11). However, the soils studied here are generally well to moderately well drained and those conditions should be conducive to the establishment of a proper root system. Surface deposit also did not have an effect on blowdown density even though shallow soils were present. Shallow till over bedrock would usually be expected to present a greater amount of windthrow than deeper tills but no difference was found. However, we should not conclude that there was an absence of effect since, in this study, the effect of stand and tree variables might be overriding that of soil properties.

The analysis of stand data did not show an effect of dominant height, of cover type (softwoods vs hardwoods), of spacing and slenderness ratio. However, a relationship was seen between the proportion of living trees bearing at least one physical or pathological defect and the blowdown density. The classification criterion derived from the discriminant analysis is effective in classifying stands where damages are high but tend to overestimate it in the less damaged stands. This can be explained by the fact that, even though a stand can be quite defective, damages are likely to remain low if it is not exposed to wind. In general, stands had more than 50% of the stems bearing one or more defect. This probably explains why very few effects could be detected for the variables traditionnally retained when trying to rate blowdown hazard.

The study of blowdown at the tree-level enables us to compare living trees with fallen trees in the same ecological and wind exposure conditions. This comparison provides us with clues for the treatment of individual trees in a given stand and gives us an insight into the factors likely to affect stand vulnerability.

Four species accounted for 84% of the dead trees sampled. These were: balsam fir, aspen (bigtooth and quaking) and sugar maple. Other species were of relatively minor importance. The species frequency of dead trees differs significantly from that of living trees (Figure 4). Balsam fir comprised 49% of the total number of dead stems and 32% of the living stems. Sugar maple compiised 3% of the dead stems and 13% of the living stems. This seems to demonstrate a differential vulnerability of those species to windthrow. An effect of cover type was not seen in the preceeding analysis of stand-level factors probably because many other factors also varied concurrently. We nevertheless can expect sugar maple stands to be less vulnerable and balsam fir stands to be more vulnerable. Sugar maple is generally believed to be a deeper rooting species and less prone to decay than balsam fir (5).

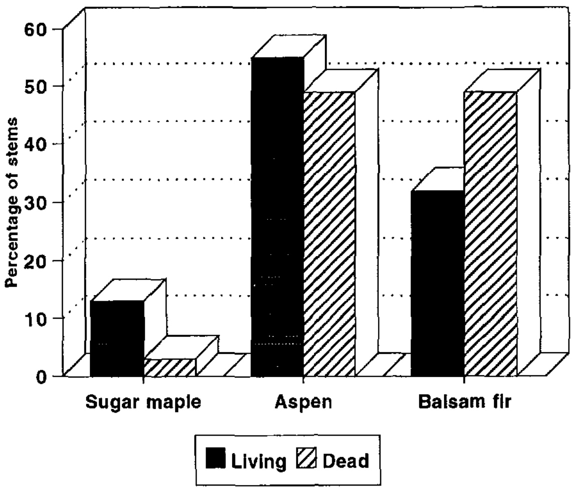

Figure 4. Species frequency in living and dead trees.

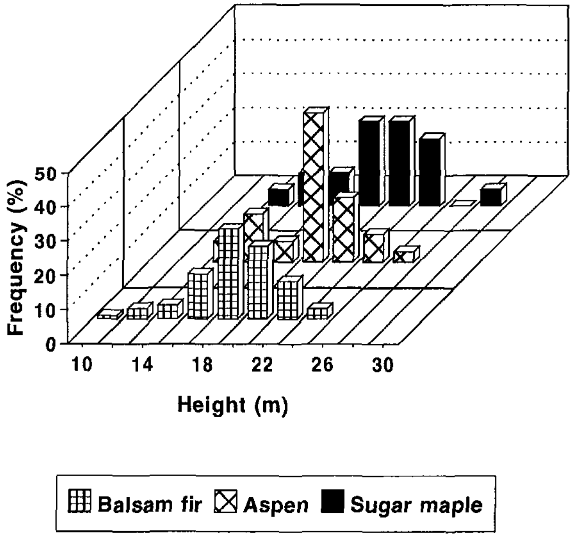

Figure 5. Height distribution by species in fallen trees.

Univariate statistics of fallen trees were compiled to characterize this population. In this case study, which should be viewed as a first step, the median was chosen to represent a certain critical height or diameter. Figure 5 shows the frequency distribution of height by species and Figure 6 displays the same information about diameter. Median values are presented in Table 1. Balsam fir becomes very affected by blowdown when it reaches 18 m while this occurs around 20 or 22 m for the other species. The height of fallen balsam fir and sugar maple trees is significantly greater than that of living trees (Table 2). This was not the case with aspen since some stands, with very tall trees, were found in sheltered situations. The results for the two former species indicate that stand height should be considered as a good indicator of windthrow hazard. The effect of tree diameter follows the same trend and the same conclusions can be drawn (Figure 6 and Table 2).

The increase of blowdown with stand height is a well-known pnenomenon related to an increase in the length of the levering arm on which the wind is acting (10). A greater stress is then imposed on roots. The effect of diameter could also come from the correlation between diameter and height. Stem diameter could then be used as a surrogate for height in field estimations since it is more easily measured. However, height and diameter also increase with age and stand vigour is likely to deteriorate after a certain critical age. Thus, median heights of fallen trees are not reached before 55 years for balsam fir and blowdown losses induced by decay increase rapidly beyond 60 to 70 years for that species. Decay occurrence would then appear critical in the blowdown process for balsam fir (12).

Some defects are known to reduce the stem resistance or to indicate internal decay. For this particular analysis, only stem or stump breakage were considered since these defects do not indicate a weakness in the root system that could lead

Table 1. Median values for height and diameter of fallen trees

Species	Height	Diameter
Balsam fir	18.0	21.0
Aspen	20.0	25.0
Sugar maple	20.5	33.0

Table 2. Average height and diameter of living and dead trees.

Species	Height		Diameter	
	Living	Dead	Living	Dead
Balsam fir	16.4	17.7	20.0	22.4
Aspen	20.9	19.3	14.1	25.9
Sugar maple	17.8	20.4	21.4	32.7

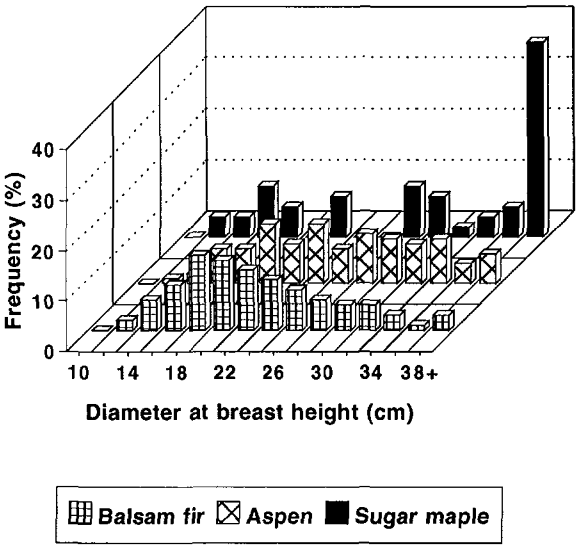

Figure 6. Diameter distribution by species in fallen trees.

to uprooting but rather a stem weakness. The analysis revealed that some of these defects were significantly more abundant on broken trees. Thus, forks were present on 38% of the broken sugar maple trees in comparison with an occurrence of 7% on standing trees and conks were present on 26% of dead aspen stems compared with 4% on the living trees. No defect was found in greater numbers on broken balsam fir.

It is often difficult to assess the presence of decay from external indicators (1). Balsam fir is rated particularly vulnerable to decay; butt decay often entering through the root system. This explains why, for this species, decay is often found with no external evidence (1). Stand age would appear to be critical for balsam fir. For trembling aspen, decay also increases steadily with age. The most important causal agent, Fomes igniarius, is able to develop fruiting bodies on living trees. Their presence could then be used as an indicator of moderate to large amount of advanced decay (1). This would explain our result for that species. For sugar maple, forks can represent a point of poorer mechanical resistance rather than an indicator of decay. Furthermore, there is a tendency to underestimate the incidence of defects on fallen trees since one cannot look at defects on the side of the stem lying on the ground. Thus, the impact of these defects is underestimated, with the exception of forks that remain easily noticed.

Stem inclination towards the electrical line would contribute to a greater amount of damage by increasing both the risk of blowdown and the risk that an eventual blowdown hits the line. The tendency to lean towards the electrical network varies with species; aspen is a light demander, being more prone and balsam fir, less. Thus, 24% of the living aspen trees were leaning moderately to severely towards the line, compared with 9% for balsam fir. This reflects a phototropic reaction occurring when the incidence of light is from only one direction.

This study enables us to prepare some guidelines on estimating the risks of power failures caused by blowdown. First of all, we should be looking at the actual risk of blowdown, not only the potential risk. In fact, most available blowdown hazard rating systems rely heavily on site conditions and wind exposure. Critical vegetation variables, which were the most important in this study, are usually not considered. A greater refinement of wind exposure rating would also be needed since no effect of TOPEX was seen and it was demonstrated that this variable did not account properly for some topographic features. Furthermore, critical wind direction would be needed to assess the risk that a falling tree hits the power distribution network.

An approach developed for recreation sites would appear particularly relevant to the electrical distribution network context. This approach considers three risks (9):

- risk of occurrence of strong winds in a given year;
- risk of falling for a specific tree, considering species and vigour;
- risk that the falling tree causes damages.

Those three risk ratings are multiplied to obtain a rating of damage probability. Then, this risk is multiplied by the value of the infrastructure destroyed to obtain the amount of probable damages. In our specific context, the number of clients potentially affected could be used instead of dollar values. The need for wind direction data is further stressed by this approach.

Conclusion

This study has shown the need for specific blowdown studies along power distribution lines. Indeed, variables traditionnally retained in assessing windthrow in managed stands performed very poorly in our study. More important was the condition of the present vegetation. A windthrow hazard rating tool would definitely be useful to those in charge of stand treatment along those lines. However, a decision support system, considering windthrow hazard, in conjunction with the risk of damaging the line and the potential number of clients affected, would be more appropriate.

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Résumé. Une étude sur la chute des arbres par le vent fut menée le long d'une ligne électrique de distribution dans une zone rurale afin d'identifier les variables majeures nécessaires pour l'estimation des risques de chute. Les variables habituellement employées pour ce genre d'estimation ne s'avérèrent pas très puissantes. En réalité, la chute par le vent était beaucoup plus attribuable aux caractéristiques de la végétation, à savoir la dimension, l'espèce et l'état de santé. Ceci peut être expliqué par un effet prépondérant de ces caractéristiques sur des zones mal gérées où les arbres peuvent être à l'état de sénescence ou bien en mauvaise condition de santé. Des études spécifiques sont dès lors nécessaires pour inclure ces variables dans l'évaluation des risques de chute.

Zusammenfassung. Entlang der elektrischen Stromversorgung in einer ländlichen Siedlung wurde eine Untersuchung über Windwurf durchgeführt, um die wichtigsten Variablen bei der Einschätzung der Windwurfgefahr zu identifizieren. Die Variablen, die gewöhnlich bei einer solchen Schätzung berücksichtigt wurden, haben sich als nicht aussagenkräftig erwiesen. Tatsächlich steht der Windwurf eher in Zusammenhang mit den vegetativen Charakteristiken, nämlich größe, Art und Lebenskraft. Das erklärt sich durch die überragende Wirkung jener Charakteristiken in kümmerlich gepflegten Beständen, die überreif sind mit geringer Lebenskräft Spezifische Studien sind erforderlich, um solche Variablen in die Untersuchung von Windwurfgefährdung miteinzubleziehen.