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AN IMPROVED UNDERSTANDING OF WINDTHROW – MOVING FROM HAZARD TOWARDS RISK, by Chris Quine

Abstract

The threat of windthrow has been an important influence on the management of Britain's upland forests. Choice of afforestation site, thinning practice, and felling age have all been determined using some assessment of the threat of wind damage, generally through use of the windthrow hazard classification. This Note summarises recent changes in thinking on the factors affecting windthrow, particularly in respect of variability in wind climate and the potential for adaptive growth of trees. A conceptual model is proposed which treats windthrow as a risk rather than an inevitable hazard, and which therefore necessitates flexibility in forest planning. Until such a risk classification is produced, the continued use of the hazard classification is recommended subject to a number of caveats.

Introduction

1. The windthrow hazard classification (Booth, 1977; Miller, 1985) was created to summarise existing research and to guide the selection of areas where thinning should be avoided. The classification has provided a valuable tool for forest management and a method for comparison of hazard between forests. The need to forecast production and returns on investment meant that initial estimates of **critical height** (at which windthrow is predicted to start) were supplemented by estimates of **terminal height** (at which windthrow is predicted to reach levels requiring clearfelling). Terminal heights have been influential in determining harvesting programmes and in shaping forest design plans.

2. Recent changes to the windiness scores have improved the objectivity of the method (Quine and White, 1993) and by reducing the area of the highest hazard class (hazard class 6) have gone some way to meeting criticism that the predictions of the system were pessimistic. However, a number of recent findings indicate that the classification could be improved further. This Note explains the significance of these findings for the existing classification, and outlines how a new classification will be developed.

Recent advances in understanding

3. Recent evidence from windthrow monitoring areas (Quine and Reynard, 1990), and severe storms in south-east England, Wales, and north-east Scotland have emphasised the fact that the wind climate is very variable both in space and time. British foresters have often distinguished between endemic and catastrophic damage – the former being due to normal winter gales, and the latter resulting from severe storms. Although such definitions are a convenient way of describing the scale of the management problem, they are inappropriate as climatic definitions. Annual maximum wind speeds clearly vary rather than fall into two distinct bands (Figure 1). This implies that the amount of windthrow will also vary from year to year, even when the most severe ('catastrophic') storms are disregarded.

4. There is a very marked non-linear change in recurrence with increasing maximum wind speed (Figure 2). Therefore changes in management practice (e.g. adopting no-thin or early thin regimes instead of normal or delayed thinning) which result in a small shift in the wind speed necessary to blow over trees in the stand can have a dramatic effect on the frequency of damage.

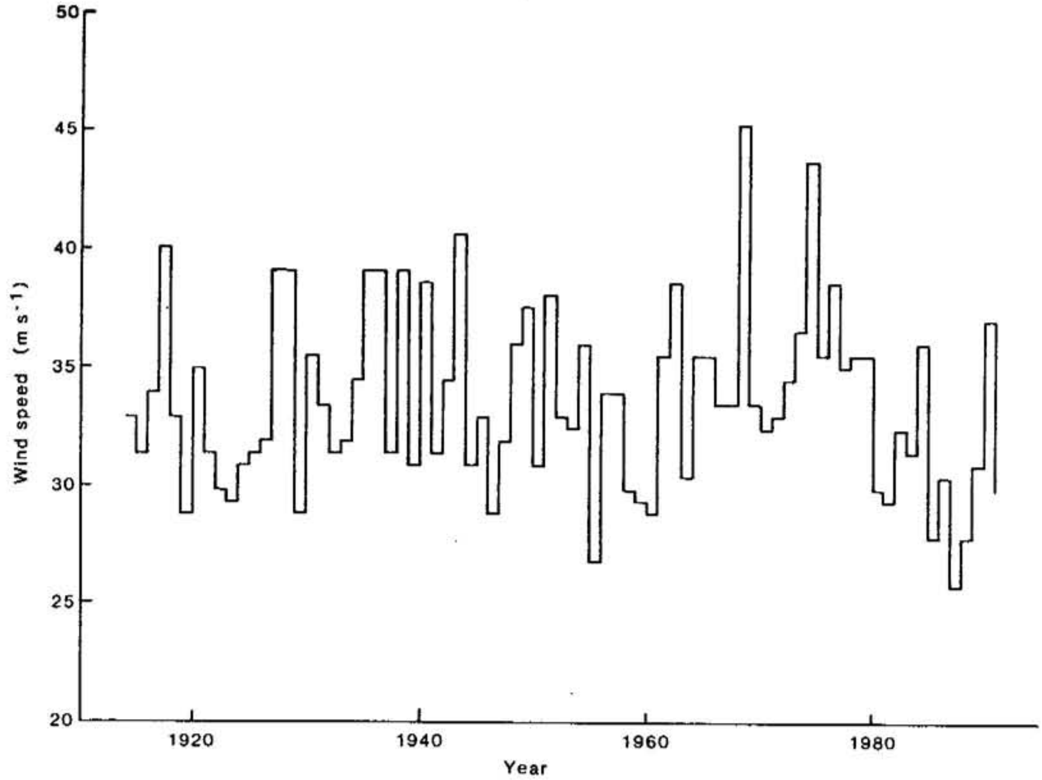

Figure 1 Annual maximum gust (m s^{-1}) recorded at Eskdalemuir Meteorological Office observatory for the period 1914-1991. The period mean was 33 m s^{-1}. (Source: Quine, in press).

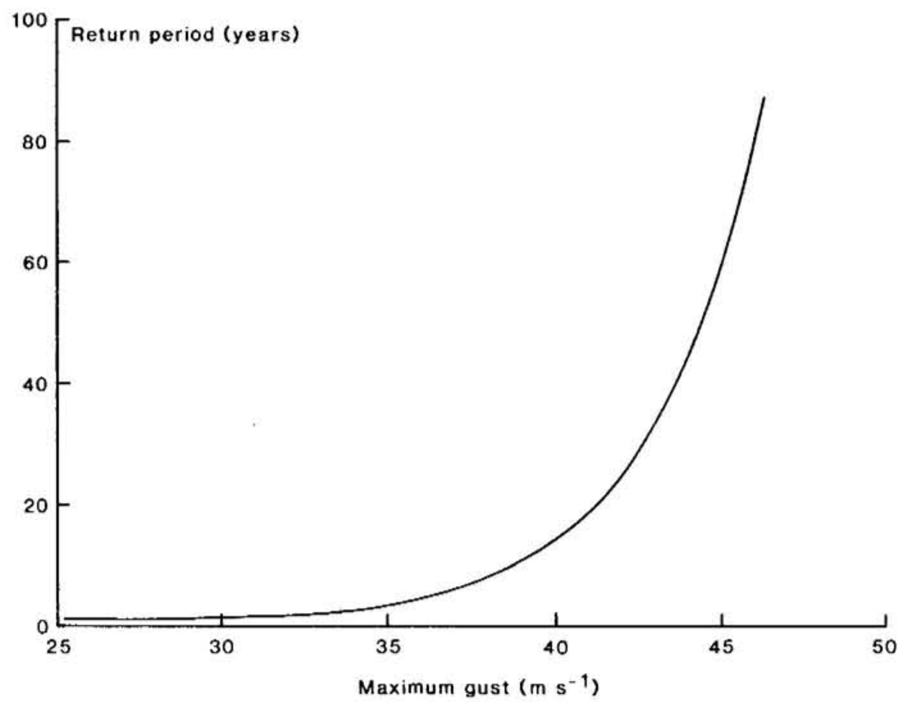

Figure 2 Relationship between wind speed (maximum gust) and recurrence (expressed as return period, i.e. average interval in years between exceedances) for the Eskdalemuir Meteorological Office observatory. The return periods were calculated using annual maximum gusts from 1958-1991. (After Quine, in press).

5. Observations from windthrow monitoring areas in typical upland forests have shown that conifer stands of less than rotation age are not damaged by normal winter storms (i.e. wind speeds with an annual recurrence). Windthrow will only occur in normal winter storms in exceptional situations where trees are exposed at felling margins, or have been subjected to a very heavy thinning. More substantial storms are required to damage unthinned plantations, and to extend that damage. For example, there are windthrown gaps in monitoring areas which have not spread for eight years (Quine, in press).

6. There is increasing evidence that adaptive growth can play a major part in mediating the effects of strong winds (Mattheck, 1991). Tree response to wind loading can result in increased stem and structural root growth. This means that the wind speed required to blow a tree over may not necessarily decrease continually as the tree grows, and that recovery after thinning may be sufficient to render a thinned crop as stable as an equivalent unthinned crop.

Rethinking the windthrow model

7. This evidence has led to a revision of the way we think of windthrow. The factors controlling the stability of trees in strong winds can be divided broadly into those which influence the threshold wind speed required to blow over or snap the trees on a site, and those which determine the probability of that wind speed being experienced on that site.

8. The vulnerability of a tree (threshold wind speed required to blow over or snap a particular tree) has three components (Quine, in press) (Figure 3). These components are termed persistent, progressive and episodic, and as their combined contribution to vulnerability increases the threshold wind speed will decline. The site contribution (due to the soil and its modification by site preparation) changes little over the life of a tree and is therefore a **persistent** component of vulnerability. The **progressive** component reflects the way a tree grows (i.e. development in diameter, crown and root form) which results in changes in vulnerability. It might be anticipated that the older the stand, the larger will be the progressive component and hence the lower the threshold wind speed. However, observations of old stands and the potential for adaptive growth suggest that such a decline in the threshold wind speed due to the progressive component may not be continuous but may reach a certain point beyond which there is little change. Finally, events that contribute to vulnerability for a period, from hours to years, (e.g. removal of neighbours in thinning, loading of crown by wet snow, soil saturation, the presence or absence of leaves in deciduous trees) constitute an **episodic** component.

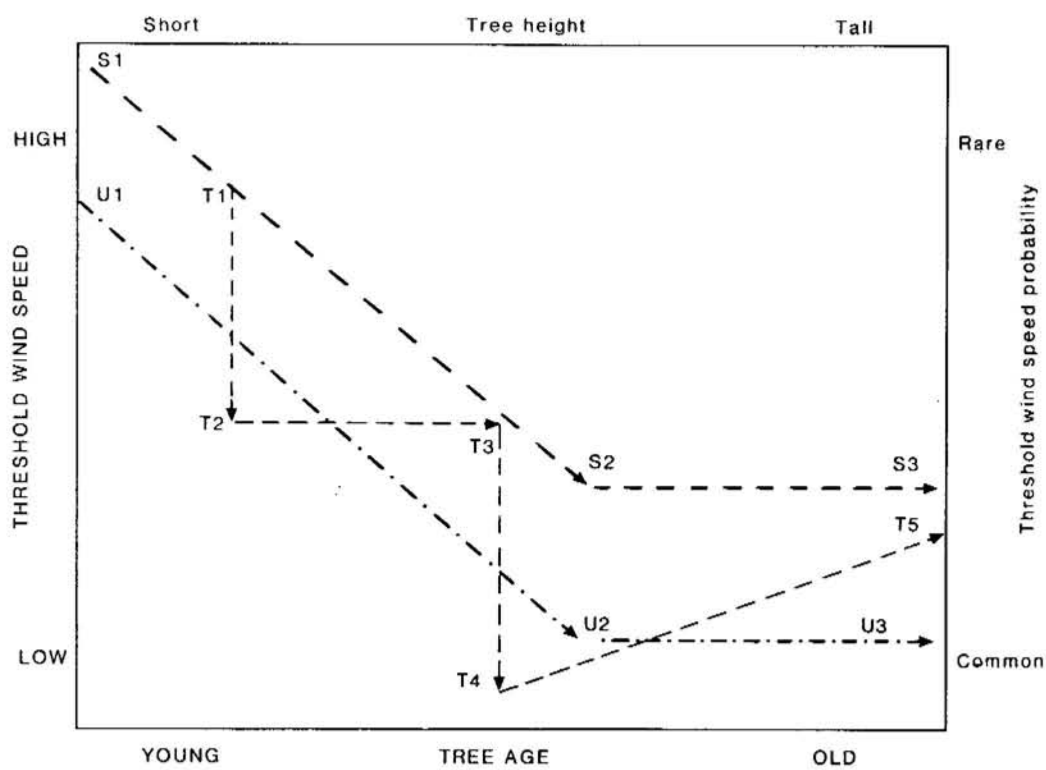

Figure 3 The change in tree vulnerability with time expressed as three components – persistent, progressive, and episodic. S1-U1 represents the difference in persistent vulnerability between a stable and unstable soil. S1-S2 and U1-U2 represent the change in progressive vulnerability due to the growth of the tree, and S2-S3 and U2-U3 a period when progressive change levels off. T1-T2 represents and episodic change in vulnerability induced by thinning, and T2-T3 the recovery period after thinning. (After Quine, in press).

9. Vulnerability varies over time among trees in a stand due to the particular combination of persistent, progressive and episodic components. The strength of the wind experienced by a tree, and hence the probability of the critical wind speed being exceeded, will depend upon its regional location, the surrounding topography, the presence of upwind stands, and the position of the tree within a stand.

10. The current windthrow hazard classification includes an estimate of persistent vulnerability in the form of a soil score. The progressive component arising from tree growth is represented by a continual linear decline in threshold wind speed until the stand becomes vulnerable to the endemic wind speed. The endemic wind speed is represented by a windiness score that varies spatially but does not vary with time thus reflecting the supposed 'normal winter storms' (Figure 4a). Thinning is assumed to cause a permanent shift in the path of progressive vulnerability, rather than to be episodic in effect. The result is a deterministic model that, for a particular management regime (e.g. no thin), provides a single outcome for each hazard class, even though the hazard class may be determined by different combinations of vulnerability and wind climate.

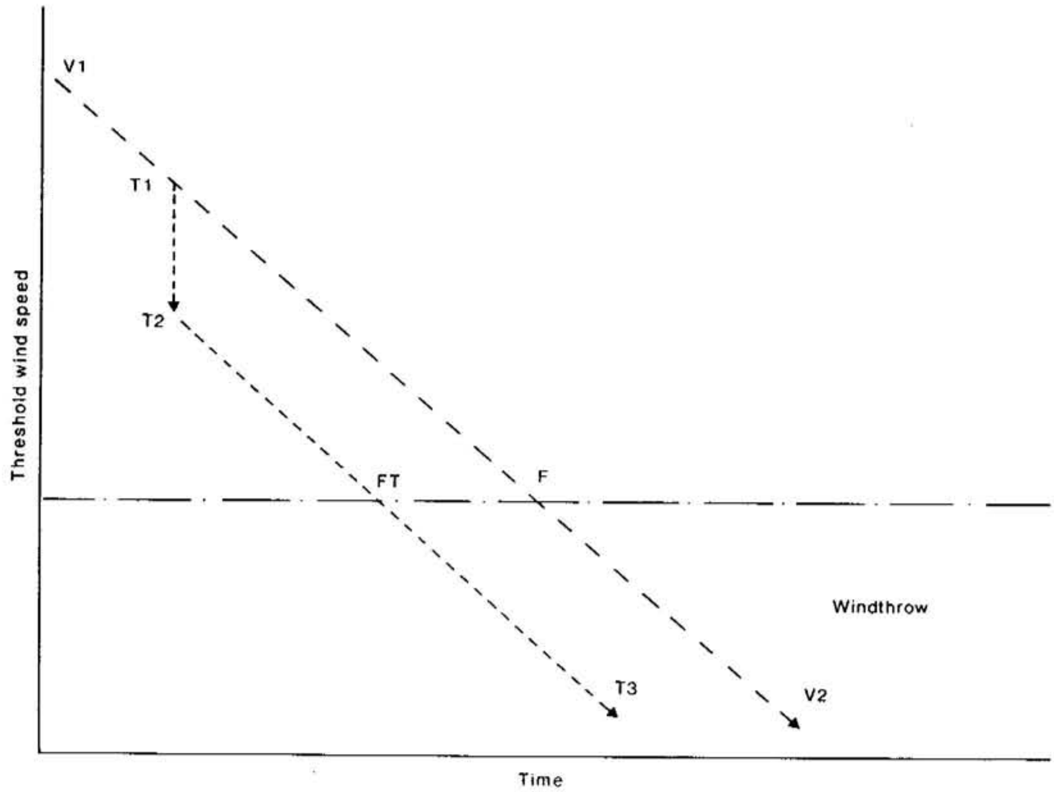

Figure 4a The components of vulnerability (Figure 3) as represented in the windthrow hazard classification. V1 is determined by the persistent vulnerability (ie soil score) and V1-V2 is a linear decline in threshold wind speed (progressive vulnerability) for an unthinned stand. The dot–dash horizontal line is the endemic wind speed. F identifies the point of first damage after which damage occurs regularly. T1-T2 represents a thinning and the subsequent progressive vulnerability path T2-T3 gives an earlier time of first damage (FT) than for the equivalent unthinned stand (F). (After Quine, in press).

11. The classification would predict more accurately if it incorporated changes in the rate of progressive vulnerability with time, an episodic component to vulnerability, and variability in wind speed (Figure 4b). A risk classification would be formed by quantifying the variability in wind speed in the form of probability of occurrence or exceedance of a given value. The classification would then assess the likelihood (i.e. risk) rather than the inevitability of damage (i.e. hazard). Such changes would emphasise the variable nature of the onset and progression of windthrow. Thus, there is a small chance that stands which are unstable because of site or thinning practice will not be damaged, and conversely there is a small chance that very stable stands will be damaged. This would emphasise the need for maintaining an element of flexibility in forest plans.

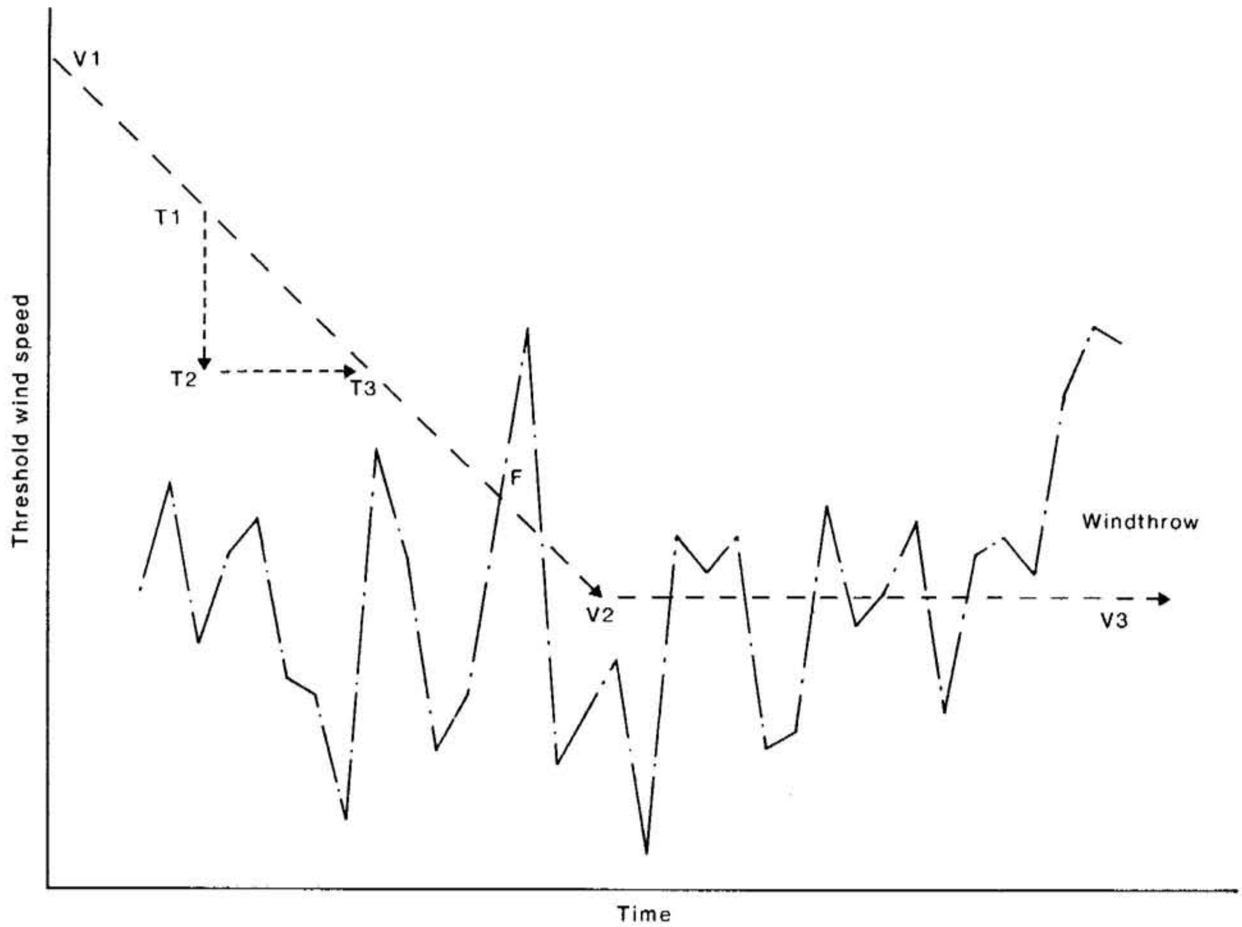

Figure 4b A more realistic version of Figure 3 that includes a varying wind climate, changes in the rate of progressive vulnerability, and episodic vulnerability. V1-V2 represents a linear decline in threshold wind speed followed by a levelling off V2-V3. The dot–dash line represents the time-series of wind speed. F identifies the first damage, and subsequent damage occurs only when the time-series line exceeds V1-V3. T1-T2 represents a change in vulnerability due to thinning and T2-T3 the subsequent recovery; in this instance the thinning does not result in an earlier time of first or subsequent damage. (After Quine, in press).

12. Until a risk model is constructed, use of the present hazard classification is recommended to provide an objective basis for comparison and a structure for decision making. Derivation of windiness scores from digital terrain models has provided the opportunity to apply the classification consistently and accurately across large areas of upland Britain (Quine and Bell, 1994). Terminal heights published previously (Miller and Quine, 1991) should be used but with caution. They are intended as a guide for production forecasting purposes and for application at the forest level.

13. For operational planning within forests the predictions must be checked on the ground and note taken of other factors (as yet unaccounted for in the classification) that may influence windthrow such as type of ground preparation, state of drains, presence of existing windthrow (Coutts *et al.*, in press). At the individual compartment scale the occurrence of windthrow may vary markedly from that predicted. The potential for departure from prediction is greatest in the stabler stands because these require rare wind speeds to cause damage, or unusual episodes to lower the threshold wind speed. Unstable stands are damaged by wind speeds which occur more frequently and the timing of damage is therefore more certain. Thinning will make a stand more vulnerable to windthrow. However, the degree and period of increased vulnerability will depend upon the pattern, yield and machinery used. Canopy recovery after thinning without intervening wind damage will produce a stand no more vulnerable than if it were unthinned. Conversely, inappropriate thinning or wind damage soon after thinning can prolong the canopy recovery period and render the stand more vulnerable.

Developing a risk classification

14. Perception of risk is heavily influenced by personal experience. The extreme variability in wind climate means that short-term experience of wind damage may be misleading. This highlights the need for an objective system of estimating risk. There is limited potential to improve the existing classification; recent changes (Quine and White, 1993) have improved the objectivity but there is no simple way of extending the system to include further advances without resorting to subjective weighting of factors.

15. It is planned to develop a new risk classification along the lines outlined above. This new model will be based on a mechanical treatment of the tree (Gardiner, 1992), and will derive the wind speed needed to damage the tree from calculation of the resistive and applied moments. The probability of that wind speed occurring will then be calculated. The model will be based on a geographic information system (GIS) to facilitate its application to forest management.

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