HMSO £1·75 net

Forestry Commission Leaflet 85

Windthrow Hazard Classification

K F Miller

CONTENTS

FRONT COVER Windthrow in Sitka spruce (top height 11 m) on a surface water gley soil, windthrow hazard classification 5. *(36716)*

WINDTHROW HAZARD CLASSIFICATION

K F Miller
Silviculture (North) Branch,
Forestry Commission

Introduction

Windthrow in conifer plantations has become an increasingly serious problem in many parts of the United Kingdom. Much of the large-scale afforestation undertaken during the past 30 years is located on exposed upland areas in the north and west of the country, where the soils often have impeded drainage and other characteristics which restrict the development of windfirm root systems. As the trees grow taller, they become increasingly susceptible to windthrow, which frequently begins well before plantations have reached the economically desirable rotation age, and the yield of valuable large-diameter timber may be considerably reduced. Effective planning of timber harvesting and marketing, and the selection of appropriate silvicultural techniques must take into account the possibility of windthrow damage. It is therefore highly desirable to have a means of predicting the likelihood of such damage.

Two main categories of windthrow damage can be recognised:

1. *Catastrophic windthrow* arises as a result of storm conditions of unusual severity. These severe storms have long recurrence periods, and on average affect some part of the United Kingdom about once in every 15 years. The extremely high wind speeds involved can cause serious damage to plantations on both unstable and windfirm sites, and the degree of damage is influenced more by wind speed, wind direction and local topographic features than by soil conditions or silvicultural practices. Catastrophic damage produces serious harvesting problems in affected forest areas, often exacerbated by a substantial proportion of trees being broken rather than uprooted. Recent examples of extensive catastrophic storm damage occurred during January 1968 in parts of west and central Scotland (Holtam, 1971), and during January 1976 in a narrow band through Wales, central England and East Anglia. It is not possible to predict where future catastrophic damage will occur, and in general it is not possible to mitigate significantly the effects of such storms by silvicultural means, other than by increasing the diversity of stand ages and heights within a forest and so reducing the proportion of the total forest area at risk at any one time.

2. *Endemic windthrow* is of greater economic importance than catastrophic windthrow, and arises as a result of normal winter gales with a relatively moderate mean speed of approximately 20 m s^{-1} (45 mph) gusting to 30 m s^{-1} (67 mph). Most upland forest areas experience gales of this type several times per year, and a common result is the occurrence of fresh wind damage in the less stable parts of semi-mature plantations. Very little stem breakage occurs, uprooting of trees on wetter soils being the predominant effect. Damage is often sporadic, but is influenced strongly by site conditions and silvicultural practice. This offers a means of predicting the occurrence of endemic windthrow damage, as well as the prospect of selecting silvicultural treatments likely to delay or restrict the incidence and extent of such damage.

Examination of the relationship between site factors and the incidence of endemic windthrow led in 1977 to the development of a broad windthrow hazard classification for coniferous forests in Britain (Booth, 1977). This was based on the assessment and quantification by scoring of four major site factors in forest areas. The method was first described in Forestry Commission Research Information Note 22/77/SILN and was subsequently published as Appendix A of Forestry Commission Leaflet 77 (Hamilton, 1980). The practical value of the classification as a management aid has been clearly demonstrated by experience gained since its introduction. It has now been possible to revise and refine the method, for improved reliability of results, through a continued programme of observations and surveys in upland forests. The purpose of this leaflet is to describe the basis for the revised classification and the method of assessment involved, and to make the classification readily available to forest managers.

It is well established that plantations become increasingly susceptible to windthrow with increasing stand height, and the top height of the stand when windthrow damage begins is termed the *critical height*. The onset of windthrow in any stand is arbitrarily defined as the time when 3 per cent of the living stems have been windthrown. Damage may arise as scattered individuals or as small groups of trees. Following initial windthrow, damage generally spreads progressively within the stand over a period of years, either as additional individual stem blowdown, or as extension of windblown pockets. When this progression of damage within the stand reaches 40 per cent, the stand top height at this stage is termed the *terminal height*, and under normal circumstances clear felling is desirable to enable recovery of the full productive capacity of the site.

Definitions

Before considering the basis of classification, it is necessary to define the following terms:

WINDTHROW HAZARD – the susceptibility of a forest stand to windthrow during normal winter gales.

WINDTHROW RISK – the probability of endemic windthrow developing in a forest area at any given time, or during a given period.

ONSET OF WINDTHROW – when more than 3 per cent of the living trees in a stand are windthrown.

TOP HEIGHT – mean height of the 100 trees of largest diameter at breast height per hectare.

CRITICAL HEIGHT – top height of the stand at the onset of windthrow.

TERMINAL HEIGHT – top height of the stand when windthrow has affected 40 per cent of the trees.

Factors influencing windthrow

Windthrow in forests involves complex aero-mechanical interactions between turbulent wind passing over the forest and the dynamic response of the stand, comprising trees of various shapes and sizes anchored imperfectly by the roots and soil. It is impossible to predict the location, severity and duration of potentially damaging gales with any accuracy, and the great variation in soils, topography and forest structure increases the difficulty of windthrow prediction. It is thus not possible to quantify these interactions with precision, although current experimental work is designed to clarify the relative importance of the factors involved. Empirical observations have shown that windthrow hazard is closely related to the following site features, which can be objectively quantified to some extent.

1. Windiness of regional climate

From long-term meteorological records, it is known that the north and west of Britain experience strong winds more frequently, and at greater strength than other parts of the country. In addition, coastal areas are also associated with more frequent gales than inland areas. Using a combination of exposure flag survey data and published meteorological data on extreme winds (Hardman *et al.*, 1973), it has been possible to zone the country according to the incidence and severity of strong wind conditions (Figure 1). These wind zones illustrate the increased exposure of the north-west and of coastal areas. The wind zone boundaries have been produced from detailed analysis of data from over 400 exposure flag sites, and the division into wind zones is based on the rate at which flag attrition rises with increasing elevation (Miller and Hunt, in press). Considerable interpolation has been necessary to define the

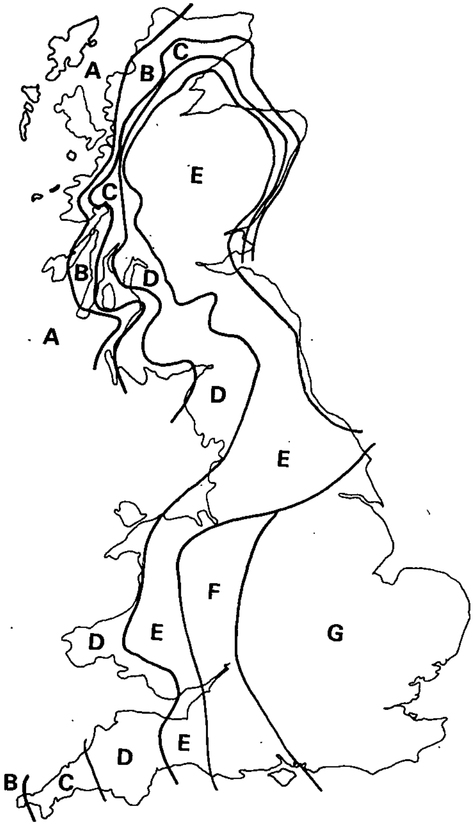

Figure 1. Wind zonation of Great Britain, based on a combination of wind speed data and exposure flag surveys. (Equal gradations of wind exposure from high –A to low –G).

boundaries shown, and they must be regarded as approximations. Where extensive forest areas lie close to, or straddle, a wind zone boundary it may be desirable for management reasons to undertake special exposure flag surveys to enable more accurate definition of that boundary. Typical surveys would involve the deployment of five to ten exposure flags over a period of 3 years.

2. Elevation

Mean wind speed increases with elevation, as does gale frequency, and forests at higher elevation are therefore generally more prone to wind damage than lowland sites within any geographic area. Rainfall also increases, leading to wetter soil conditions with a lowering of the rooting capacity and a possible reduction in soil sheer-strength at higher elevation. These effects are not linear, and for a similar elevation increment there is a more rapid rise in the incidence of wind damage at higher than at lower elevations.

3. Topography

The effects of increasing elevation on the wind exposure of a site are modified by the influence of surrounding topography (Hütte, 1968). The sheltering effect of adjacent high ground can be particularly important in reducing local wind speeds, and a low elevation site with no adjacent high ground may be associated with high wind exposure. The incidence of windthrow is also related to topographic shelter. The influence of topography on site exposure is complex, with the generation of lee slope turbulence, valley funnelling and along-slope acceleration of wind often being of local importance. However, as a general principle it is possible to describe the relative exposure of a site by determining the degree of shelter provided by adjacent topographic features.

A simple, objective characterisation of the topographic shelter of a site can be obtained by *topex* assessment (Malcolm and Studholme, 1972; Pyatt, 1977). This involves measurement on site of the angle of inclination to the horizon, at the eight major compass points. By summing the eight angular measurements a topex value for the assessment site is obtained. Experience has shown this topex value to be a useful relative indicator of general site exposure. Topex assessments are of course best carried out in clear weather, using a prismatic compass to determine the sighting alignment, and an optical clinometer to measure the skyline angles. For extensive areas with considerable variation in terrain, it is important to cover a full range of elevation and aspect, using a sampling system. In practice, topex assessments are often combined with soil surveys.

4. Soil conditions

The incidence of endemic windthrow in conifer plantations is related to the effectiveness of root anchorage, and the greatest proportion of damage is by uprooting. The degree to which the tree root system can resist the leverage and overturning forces of the tree stem under wind loading is related to root morphology and soil sheer strength. Root morphology is strongly affected by soil type, with the depth and strength of structural roots being influenced by soil moisture and aeration, and by physical conditions within the soil profile. Soil sheer strength is also related to soil type, with soil moisture status being particularly important. The method of site preparation used for the establishment of plantations also influences root architecture and soil strength, with consequent effects on plantation stability later in the rotation.

Because of the complexity of variation in root architecture and soil physical conditions it is necessary to adopt a simplified approach, which relates gross root development and soil strength to soil type alone. It is then possible to estimate the relative stability of stands established on different soil types. Where soils within a forest have been mapped as complexes, the elements can be assessed separately, and the overall stability rating of the soil complex determined by weighting according to the proportions of the component soils.

Assessment of windthrow hazard

The windthrow hazard class of a site is derived from scoring assessments of the four site factors

Figure 2. Typical wind damage pattern in Sitka spruce following systematic thinning. Kielder Forest (Northumberland), windthrow hazard classification 5. *(36717)*

wind zone, elevation, exposure (topex) and soil as described below. The total score for the four factors indicates the hazard class.

1. Wind zone

The relevant wind zone for a forest area is determined from the wind zonation map for Britain (Figure 1). The appropriate score for wind zone is then obtained from Table 1.

Table 1 Wind zone scores

Wind zone	A	B	C	D	E	F	G
Score	13.0	11.0	9.5	7.5	2.5	0.5	0

For sites lying close to a wind zone boundary it is acceptable to modify the score by interpolation, increasing or decreasing by up to 50 per cent of the difference between it and the nearest adjacent score.

2. Elevation

The elevation above sea level of the assessment site is best determined from published Ordnance Survey maps. If the area under survey is extensive, and the actual assessment point cannot be accurately identified on a map, use of a barometric altimeter on the site may be helpful. The score for the relevant elevation band is then noted from Table 2.

Table 2 Elevation scores

Elevation (m)	Score
541+	10
466-540	9
406-465	8
361-405	7
316-360	6
286-315	5
256-285	4
226-255	3
191-225	2
141-190	1
61-140	0.5
0-60	0

3. Topex

The degree of exposure as influenced by topographic features surrounding the site is assessed by topex survey in the field, or by reference to topex maps if these are available. The score for total topex value is obtained from Table 3.

Table 3 Topex scores

Topex (total °)	Score
0-9	10
10-15	9
16-17	8
18-19	7
20-22	6
23-24	5
25-27	4
28-40	3
41-70	2
71-100	1
101+	0

Alternatively, where topex-based exposure maps have already been prepared scores can be obtained from Table 4.

Table 4 Topex map zone scores

	Topex total	Score
Severely exposed	(0–10)	10
Very exposed	(11–30)	7
Moderately exposed	(31–60)	3
Moderately sheltered	(61–100)	1
Very sheltered	(100+)	0

In the absence of topex data or exposure maps, it is possible to assess subjectively the influence of local topography on site exposure using five exposure classes shown in Table 4.

4. Soil

The information available on soils and their rooting capacity differs widely between forest areas, and affects the way in which the scoring for soil conditions can be done.

Where detailed soil information is not available, or where observations of root development on blown trees enable an objective assessment of the restriction to root development, scores are obtained from Table 5.

Table 5 Soil scores based on root development and broad soil groups

Root development	Soil group	Score
Unrestricted rooting in excess of 45 cm	Brown earths, podzols, intergrades to ironpan	0
Restricted rooting but some structural root penetration in excess of 25 cm	Deep peats, loamy gleys	5
Very restricted rooting under 25 cm deep	Peaty gleys, surface water gleys, shallow indurated soils, waterlogged soils	10

If more precise information on soils is available (e.g. from detailed soil maps or from soil surveys carried out as part of windthrow hazard assessment), the soil scoring system described in Appendix 1 can be adopted. The soil types are fully defined by Pyatt (1982).

5. Derivation of windthrow hazard class

The scores for wind zone, elevation, topex and soil are added to give a total score for windthrow hazard. The appropriate windthrow hazard class for the site is obtained from Table 6.

Table 6 Windthrow hazard classes

Windthrow hazard score range	Windthrow hazard class
Up to 8.0	1
8.0–13.5	2
14.0–19.0	3
19.5–24.5	4
25.0–30.0	5
Over 30.5	6

Field assessment and mapping of windthrow hazard classes

It is recommended that the windthrow hazard classification of forest areas be recorded on 1 : 10 000 or similar scale maps, as this has proved the most useful method and is compatible with normal forest soil mapping. The preparation of windthrow hazard maps is normally divided into two related stages:

1. Field survey for data collection.
2. Data compilation and map production.

If detailed soil maps are not available, the field survey will normally collect data for both soil and topex. Wind zone and elevation data are available from existing maps. The intensity of field sampling for both topex and soil data is mainly determined by the site variation. Slope and vegetation changes are a useful guide for soil sampling. The selection of locations for topex measurement will depend partly on the coverage of ground for soil survey, but should approximate to a grid sampling system, with sampling points never more than 500m apart. An example of a typical windthrow hazard map is shown in Figure 3 in the Appendix.

Management applications of windthrow hazard classification

The value of the windthrow hazard classification to forest managers lies primarily in the field of production planning, by assisting decisions on the location and extent of future thinning and felling operations. In upland forests subject to high risk of premature windthrow, an important management objective will be to achieve the maximum possible crop rotation length on susceptible parts of the forest, thus increasing the yield of higher value sawlogs from these stands. It is often the case that a relatively small increase in rotation length can substantially

Table 7 Critical heights for different windthrow hazard classes

Windthrow hazard class	Critical height (m)		
	for unthinned stands	for selectively thinned stands	for systematically thinned stands
1	28.0	25.0	25.0
2	25.0	22.0	22.0
3	22.0	19.0	18.0
4	19.0	16.0	14.5
5	16.0	13.0	11.5
6	13.0	10.0	9.0

improve the value of a stand at time of clear felling, due to an increase in average tree size.

The six windthrow hazard classes are associated with a range of critical heights at which the onset of windthrow can be expected. The average critical heights for three generalised thinning regimes shown in Table 7 have been estimated from survey data for Sitka spruce plantations.

It is now well established that thinning operations in spruce stands on sites susceptible to premature windthrow are frequently associated with the rapid initiation of high levels of damage. The advantage of non-thin management in delaying the onset of windthrow is clearly indicated in Table 7.

By combining local estimates of the rate of spread following onset of wind damage with the critical heights indicated for windthrow hazard class, it may be possible to estimate local terminal heights and adjust regional felling, harvesting and marketing plans accordingly. Surveys of windthrown spruce stands on sites typical of the Scottish-English border area suggest that unthinned stands in windthrow hazard classes 3–6 have average terminal heights approximately 4–5 m greater than predicted critical heights. For systematically thinned stands in these hazard classes, the more rapid spread of windthrow is likely to give terminal heights only 2–3 m above the predicted critical heights, while for selectively thinned stands a difference of 3–4 m is probable.

Because of the early incidence of windthrow and truncated rotation following thinning, plantations in windthrow hazard classes 5 and 6 should normally be excluded from thinning programmes. Particular care should be exercised in the selection of thinning pattern and intensity of thinning in windthrow hazard classes 3 and 4. Delayed and systematic thinning of plantations in these classes can precipitate serious windthrow and reduce rotation length below the economic optimum. Very high volume removal in individual thinning operations can also be seriously detrimental to stability (Hamilton, 1980).

Knowledge of the distribution of windthrow hazard classes for extensive forest areas is therefore crucial in the formulation of regional production forecasts, resource planning and marketing arrangements based on thinning activity. At the individual forest level, windthrow hazard classification is useful in development of local production plans, particularly by facilitating the general division of the forest into areas to be thinned and areas to remain unthinned, thus indicating sections of forest where harvesting activity will be concentrated in the future.

Limitations of windthrow hazard classification

It is important to appreciate that the assessment of windthrow hazard classes by the method described is a practical approximation intended for the broad zonation of forest areas of the order of 500 ha or more in extent. Identification of the windthrow hazard class distribution within any forest area gives a general indication of appropriate silvicultural treatment, but does not provide a satisfactory basis for detailed subcompartment management prescriptions. Windthrow hazard is only one of several factors to be taken into account in the appraisal of silvicultural options. Decisions on whether to thin or to clear fell any individual subcompartment should be based on the actual site and stand conditions, and should take into account any demands and constraints applying to the forest area as a whole. The actual occurrence of wind damage in individual stands may deviate widely from that predicted by the windthrow hazard class, which is concerned with the average windthrow response of a large number of stands.

The windthrow hazard classification was mainly developed from observations of windthrow in spruce stands on gently rolling topography in the Scottish Borders, and the predictive accuracy of the system is high in these conditions. In the more complex topography of north and west Scotland, precision of windthrow prediction is likely to be lower.

An important limitation of the windthrow hazard classification is the fact that it is based on the concept of critical height (i.e. the crop stage at which windthrow begins). Following initial windthrow, damage normally spreads progressively through the stand over a period of years until clear felling is necessary. The rate of spread of windthrow is highly variable, and although terminal heights are of greater importance to forest managers, it is not possible to predict wind damage extension rates with any accuracy. The factors which determine the rate of damage extension appear to be broadly the same as the factors involved in the initiation of windthrow, but they interact in a different way, and include the additional effects of exposed edges in windthrown gaps. Local observation and crop surveys of damaged stands may give some indication of the probable rate of spread of endemic wind damage which can be incorporated with critical height calculations to give local terminal heights and rotation lengths.

It has been observed that the onset of endemic windthrow in some forests is poorly predicted by the windthrow hazard classification. In some cases, these deviations can be remedied by substituting revised wind zones scores, based on a wind zone adjacent to the assessment site. In other cases, the influence of local thinning practices, unusual site preparation methods, or spacing practices may result in wind damage patterns which are not readily predictable using the standard windthrow hazard classification system. In these circumstances, it may be possible to adjust the indicated critical heights for each windthrow hazard class in line with observations of actual critical heights across a range of sampled assessment sites. Managers faced with such problems are advised to contact staff of the Forestry Commission's Research and Development Division for guidance.

Most of the data used in the development of this windthrow hazard classification were obtained from stands which had been established on spread turves or on shallow ploughing. Changes in site preparation methods, and in particular the shift to deeper, single mouldboard spaced furrow ploughing methods at closer spacing, may have a detrimental effect on root architecture (Savill, 1976). Limited observations indicate that site preparation methods have a greater influence on the rate of damage extension than on the initiation of windthrow. Local observation of windthrow in plantations established with different site preparation methods is the most effective method of obtaining information to modify the classification, using adjustment of the soil score to reflect the influence of site preparation. In the absence of local information on the effects of site preparation on windthrow, stands established on gley and peat soil types using deep single mouldboard spaced furrow ploughing should have their critical heights reduced by 1.0 m.

Future refinements of windthrow hazard classification

A current research programme on endemic windthrow is concerned with improving the predictive accuracy of the windthrow hazard classification, particularly in areas of more complex topography and soils. Several forests are monitored regularly by aerial photography and site surveys to check the incidence of new wind damage and rates of damage extension. These surveys will also provide further information on the effects of different site preparation methods, the interactive influence of the timing, pattern and intensity of thinning, and the effects of different spacing and respacing practices.

Research into the influence of wider initial spacing, respacing, precommercial thinning and chemical thinning on stand stability is in progress. By relating canopy structure to turbulent wind conditions it may be possible to define stocking density standards for optimum stability.

In addition, a study of the interactions between airflow and topography, using both topographic models in wind-tunnels and full scale wind recording in complex terrain, may improve windthrow prediction by making it possible to identify specific parts of forest areas which are at particular risk to high windspeeds or potentially damaging turbulence levels. Routine exposure flag surveys for the assessment of elevation limits to plantability continue to provide information necessary to refine wind zone boundaries. Development of alternative site preparation methods such as mound ploughing, mole draining, ridge-replacement ploughing and scarifying is aimed at improving root structure and hence wind stability of future plantations.

APPENDIX

The Forestry Commission soil classification described by Pyatt (1982) is in widespread use in British forestry, and soil scoring for windthrow hazard classification purposes can be based on this system.

It must be emphasised that the more precise the soil assessment, the more reliable the final windthrow hazard class allocated to the site. Tables 8 and 9 give details of the scores appropriate for the main soil types and phases of the Forestry Commission soil classification.

Table 8 Soil scores based on detailed soil types

Soil type	Soil code	Score
Brown earths	1, 1d, 1u, 1z	0
Podzols	3	0
Intergrade and podzolic ironpan soils	4b, 4z	0
Ironpan soils	4	2.5
Ground water gley	5	7.5
Peaty gleys	6	10
Peaty podzolic gley	6z	7.5
Brown gleys, podzolic gleys	7b, 7z	5
Surface water gleys	7	10
Juncus bogs	8a, 8b, 8c, 8d	10*
Molinia bogs	9a, 9b, 9c, 9d, 9e	10*
Sphagnum bogs	10a, 10b	10*
Calluna/Eriophorum/Trichophorum bogs	11a, 11b, 11c, 11d	10*
Eroded bogs	14, 14h, 14w	10*
Mining spoil, stony or coarse textured	2s	0
Mining spoil, shaly or coarse textured	2m	5
Calcareous (rendzina)	12a	5
Calcareous (argillic brown earths)	12b, 12t	0
Brown and podzolic rankers	13b, 13z	7.5–10**
Scree	13s	0–10***
Peaty and gley rankers	13r, 13g, 13p	10
Well drained littoral soils	15s, 15d, 15e	0
Poorly drained littoral soils	15i	2.5
	15g	5
	15w	10

*Depending on rooting depth: If rooting depth 26–45 cm deep, score 7.5, if rooting depth more than 45 cm deep, score 5.

**Depending on rooting depth: If greater than 25 cm, score 7.5.

***Depending on rooting depth: If greater than 75 cm, score 0, if less than 25 cm, score 10.

The soil scores derived from Table 8 can be further refined if accurate information on soil classification is available. Table 9 shows appropriate score adjustments to be applied if soil phases have been identified.

If more than one phase suffix is used to classify the soil type, the modified total score cannot exceed 10. It is important to note that when the basic soil type alone is used (e.g. for broad descriptive purposes) the scores in Table 8 tend to be underestimates, because most phases require increases in scores. For example, the average score for most ironpan soils (soil type 4) is actually closer to 5 rather than 2.5 as shown in Table 8, because the 4p and 4zx phases are much more abundant than type 4 unmodified.

Table 9 Soil score modifications for soil phases

Phase	Score
a	add 5
x	add 5
(x)	add 2.5
g	add 2.5
f	add 2.5
h	add 2.5
p	add 2.5
w	add 2.5
i	subtract 2.5
l	subtract 2.5
c, e, k, s, v	no change

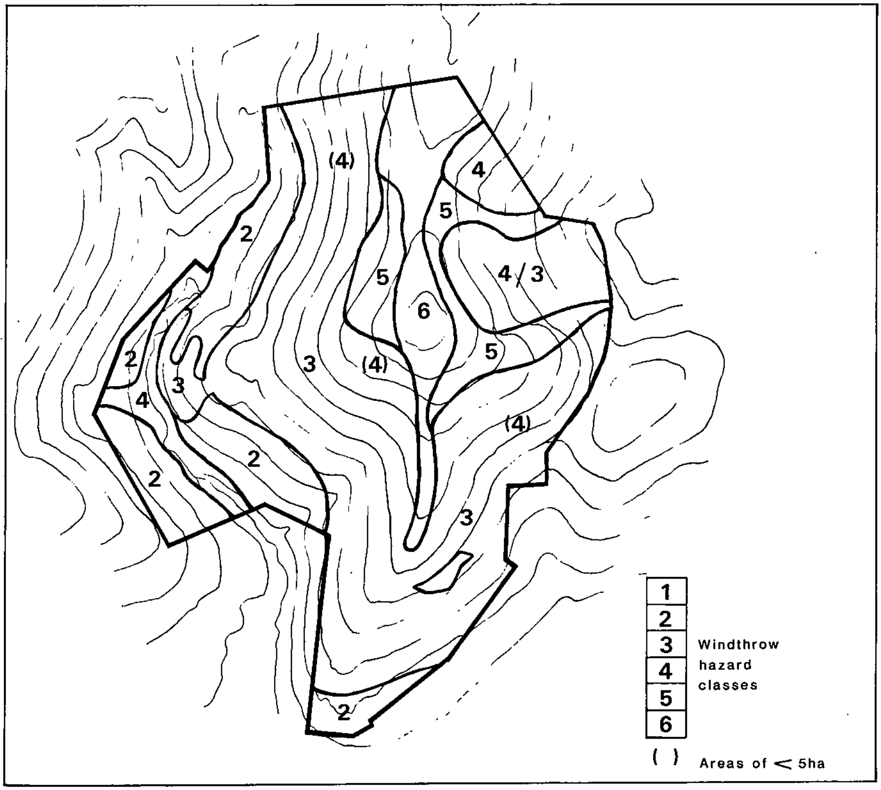

Figure 3. Windthrow hazard map of an upland forest area. Windthrow hazard classes 1 (low) to 6 (high).

ACKNOWLEDGEMENTS

The author expresses thanks to the many people in the Forestry Commission who have been involved in the preparation of this leaflet; in particular Mr T C Booth, who developed the main concepts of windthrow hazard classification, and offered valuable guidance during various stages of drafting. Prior to publication the advice and comments of Dr A J Low, Dr D G Pyatt and Mr D T Seal were very helpful.

REFERENCES

Booth, T.C. (1977). *Windthrow hazard classification.* Forestry Commission Research Information Note 22/77/SILN.

Hamilton, G.J. (1980). *Line thinning.* Forestry Commission Leaflet 77. HMSO, London.

Hardman, C.E., Helliwell, N.C. and Hopkins, J.S. (1973). *Extreme winds over the United Kingdom for periods ending 1971.* Meteorological Office Climatological Memorandum 50A.

Holtam, B.W., (Ed.), (1971). *Windblow of Scottish forests in January 1968.* Forestry Commission Bulletin 45. HMSO, London.

Hütte, P. (1968). Experiments on windflow and wind damage in Germany; site and susceptibility of spruce forests to storm damage. In: Wind effects on the forest, Supplement to *Forestry*, 20-26.

Malcolm, D.C. and Studholme, W.P. (1972). Yield and form in high elevation stands of Sitka spruce and European larch in Scotland. *Scottish Forestry* **26** (4), 298-299.

Miller, K.F. and Hunt, J. Exposure assessment of forest areas. *Forestry* (in press).

Pyatt, D.G. (1977). *Guide to site types in forests of north and mid Wales.* Forestry Commission Forest Record 69. HMSO, London.

Pyatt, D.G. (1982). *Soil classification.* Forestry Commission Research Information Note 68/82/SSN.

Savill, P.S. (1976). Effects of drainage and ploughing on surface water gleys on rooting and windthrow of Sitka spruce in Northern Ireland, *Forestry* **49** (2), 133-141.

Enquiries relating to this publication should be addressed to the Publications Officer, Forestry Commission Research Station, Alice Holt Lodge, Wrecclesham, Farnham, Surrey, GU10 4LH

First published 1985

HER MAJESTY'S STATIONERY OFFICE

Government Bookshops

49 High Holborn, London WC1V 6HB
13a Castle Street, Edinburgh EH2 3AR
Brazennose Street, Manchester M60 8AS
Southey House, Wine Street, Bristol BS1 2BQ
258 Broad Street, Birmingham B1 2HE
80 Chichester Street, Belfast BT1 4JY

Government publications are also available through booksellers

ODC 421:181.232

ISBN 0 11 710047 1

Printed in the UK for HMSO Dd 737994 C25 2/85 2004/3932(8)