Forestry Commission

Designing Forest Edges to Improve Wind Stability

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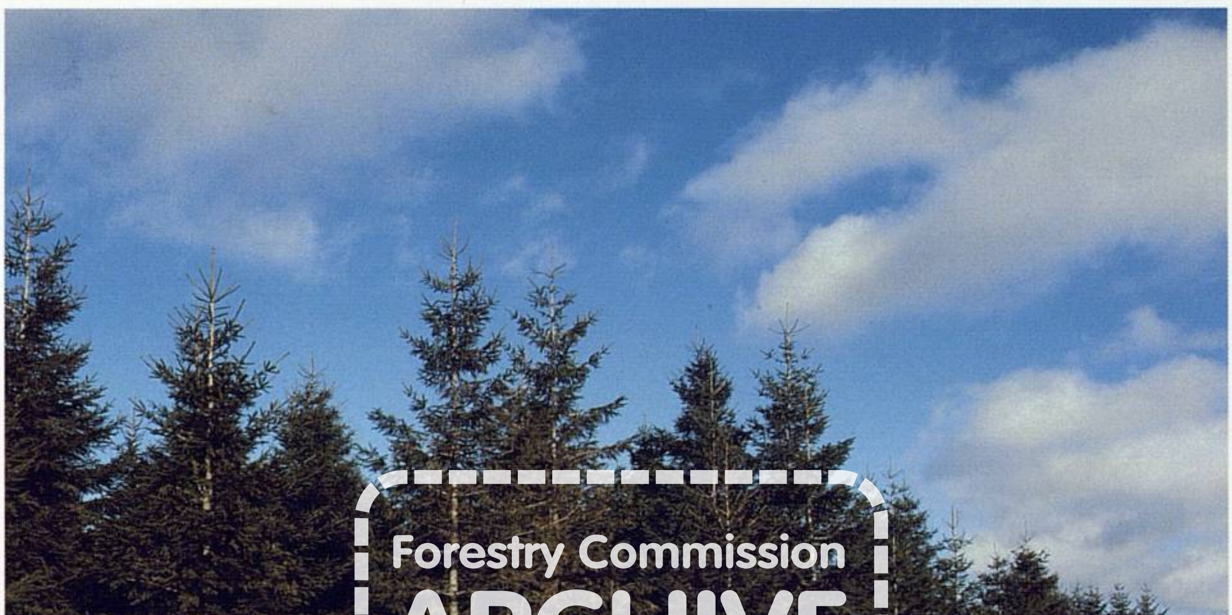

Technical Paper 16

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Designing Forest Edges to Improve Wind Stability

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Summary

Forest edges are important for the stability, visual impact and biodiversity of forests. There is growing interest in the treatment of edges to improve their stability and the diversity of habitats they provide. Wind tunnel measurements suggest that trees at established forest edges are inherently more stable than trees within the forest because their form will have adapted to the increased wind exposure. On the other hand, recently exposed edge trees will be much more vulnerable because of their lack of adaptation. Experiments were carried out in the wind tunnel on five different edge treatments and show that tapered edges and those with a gradation in tree density have potential stability benefits for both new edges and trees inside an established edge. However, a low shrub layer placed just in front of the forest edge increased the wind loading on the edge trees and reduced their stability. Practical methods for creating edges that can improve forest stability and visual appeal are discussed.

Introduction

The edges of forests and stands are important for a number of reasons. They represent:

1. a transition from trees to other vegetation forms;
2. a transition in light intensity;
3. a transition in shelter for animals;
4. an area potentially vulnerable to wind damage; and
5. the most visible aspect of a forest.

Presently there is a need for the forest industry in Great Britain to take a more imaginative approach to edge management, particularly as a method of making forests more visually appealing (Forestry Commission, 1994). Many forests are being restructured to create a greater spread in age classes with a resultant increase in the number of stand edges. Management actions of this type are certain to affect forest stability against wind.

This Paper describes experiments carried out in a wind tunnel to assess the effect of different forms of edge treatment on forest stability and on the airflow and wind loading across the untreated edges of forests of different planting densities. The experiments repeat and extend the earlier wind tunnel measurements of Fraser (1964).

Experimental arrangement

Wind tunnel

Tests were carried out in the Oxford University wind tunnel using 1:75 scale model spruce trees that had been previously used to assess the stability implications of thinning, spacing and clear-felling in commercial forests (Gardiner *et al.*, in press). A full description of the experimental arrangement and of the way in which the wind loading on the model trees was measured can be found in Stacey *et al.* (1994). Comparison of the wind tunnel data with full scale experiments (Stacey *et al.*, 1994) suggests that the wind tunnel simulates conditions in the forest very successfully.

Edge treatments

The model forest was designed to represent a 15 m mean height (h) Sitka spruce forest at a spacing of 1.7 m. The flow in the tunnel was representative of open farmland upwind of the forest edge and a mean wind speed of 30 m s^{-1} (15 knots) at a height of 30 m. Five edge treatments were tested in the wind tunnel and compared with an untreated edge (U1) representing a sharp transition from open ground to forest. The patterns are illustrated in Figure 1. Treatments T½, T1 and S were designed to taper the forest edge and treatments G1 and

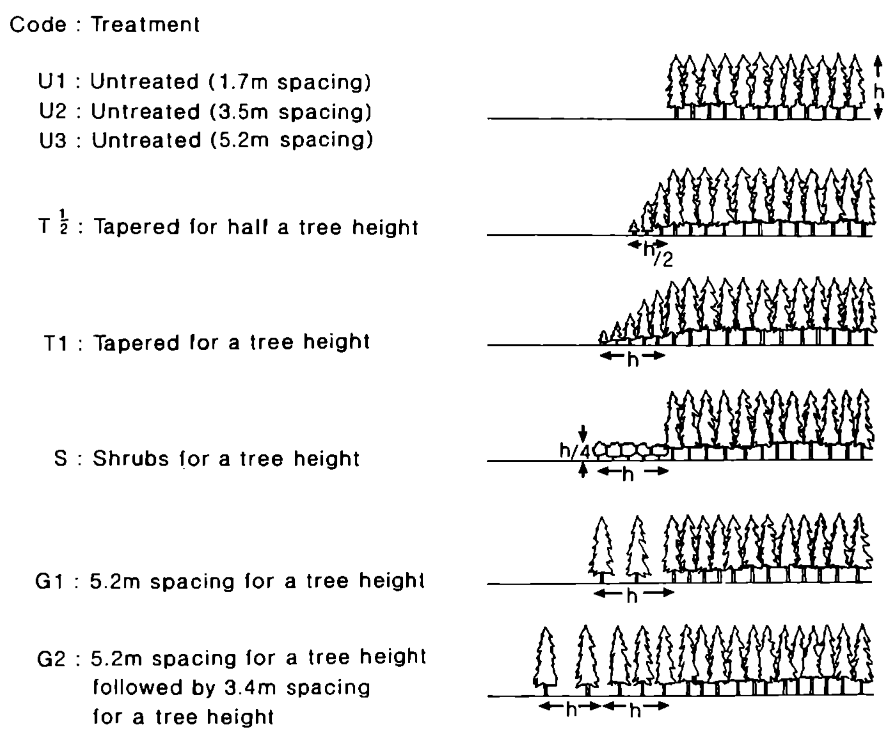

Figure 1 Designs of forest edges tested in the wind tunnel, where h represents mean tree height.

G2 were designed to make a gradual transition from open ground to forest by altering the spatial arrangement of trees. Tapering in treatments T½ and T1 was achieved by shortening the standard 20 cm length model trees, which were then deployed in two bands, one with a width equivalent to half the forest height (½ h) and one with a width equivalent to a full forest height (1 h). The tapering in treatment S, to represent dense shrubs, was achieved by placing a 1 h wide and ¼ h high layer of horsehair in front of the model forest. The first graduated density edge (G1) was constructed by placing a 1 h wide margin of trees at a planting density of 1 in 9 (compared with a normal forest) ahead of the main forest block, whereas the second graduated density edge (G2) used a 1 h wide strip of trees at a density of 1 in 9 followed by a 1 h wide strip of trees at a planting density of 1 in 4. At a standard spacing of 1.7 m between trees this represents a tree spacing of 5.2 m and 3.5 m respectively. Additional tests were carried out on model forests with untreated edges but with spacings equivalent to 3.5 m (U2) and 5.2 m (U3) for comparison with the graduated density edge treatments.

Measurements

Figure 2 illustrates the measurement positions used in the experiments on the treated edges. (Forest edge always refers to the edge of the untreated part of the forest, not the edge of the treatment. The treatment edge is, therefore, in front of the forest edge.) Wind profile measurements were made at three points using a hot-wire anemometer. The points were located ½ h in front of the treatment, above the edge of the normal forest and at 5 h back from the edge. The applied basal bending moments due to the wind were measured at the forest edge and at 5 h back from the edge using a moment balance developed by Oxford University. Both mean moments and extreme bending moments were recorded. For the untreated edges, measurements of wind profile and bending moment were made at much more frequent intervals back from the forest edge.

The applied bending moment represents the torque (force x distance) at the base of the tree created by wind pressure on the canopy. The mean applied bending moment is a measure of the average wind loading to which the tree is subjected. The tree adapts to this mean wind loading by modifying its growth behaviour and stem form (Telewski and Jaffe, 1986) so that more exposed trees are shorter and have more tapered and stronger stems. The extreme applied bending moment is the wind loading that the tree has to resist in order not to overturn or break. If the roots and soil are unable to match the extreme applied bending moment the tree will be uprooted and, if the stress created in the outer fibres of the stem is greater than the modulus of rupture for the wood, the stem will break (Gardiner and Quine, 1994).

In these experiments, unlike a real forest, the shape and height of the model trees was not a function of their distance from the edge. This means that the heights of the model trees close to an edge will be slightly taller than they should be and the applied bending moment will be overestimated. Measurements

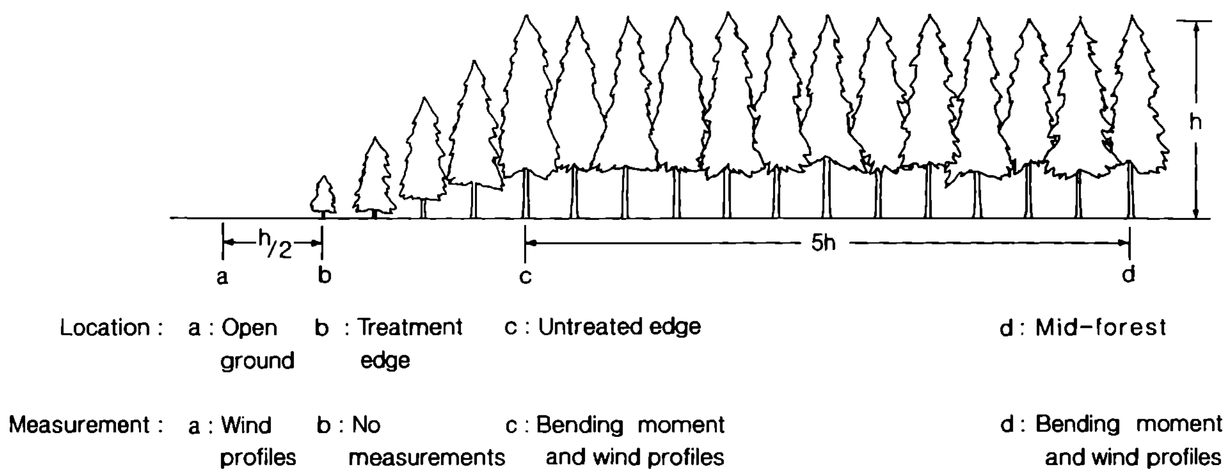

Figure 2 Types and positions of measurements in relation to the treated forest edge.

of tree heights back from a very exposed forest edge in Northumberland suggest that the overestimate will in the worst case be less than 20%.

Results

Untreated edges with different tree spacings

All bending moments are normalised by dividing them by the value of the extreme bending moment at the edge of treatment U1 in order to allow easy comparison with the wind loading on trees at the untreated edge of a normal spruce plantation. Figures 3a and 3b show the change in the mean and extreme bending moments over a distance of five tree heights (5 h) back from the edges of the three model forests with untreated edges but different tree spacings (U1,U2 and U3). The values of mean and extreme bending moments were similar at the edge of all three treatments but back from the edge the reduction was largest and most rapid in the closely spaced treatment (U1). By a distance of 1 h from the

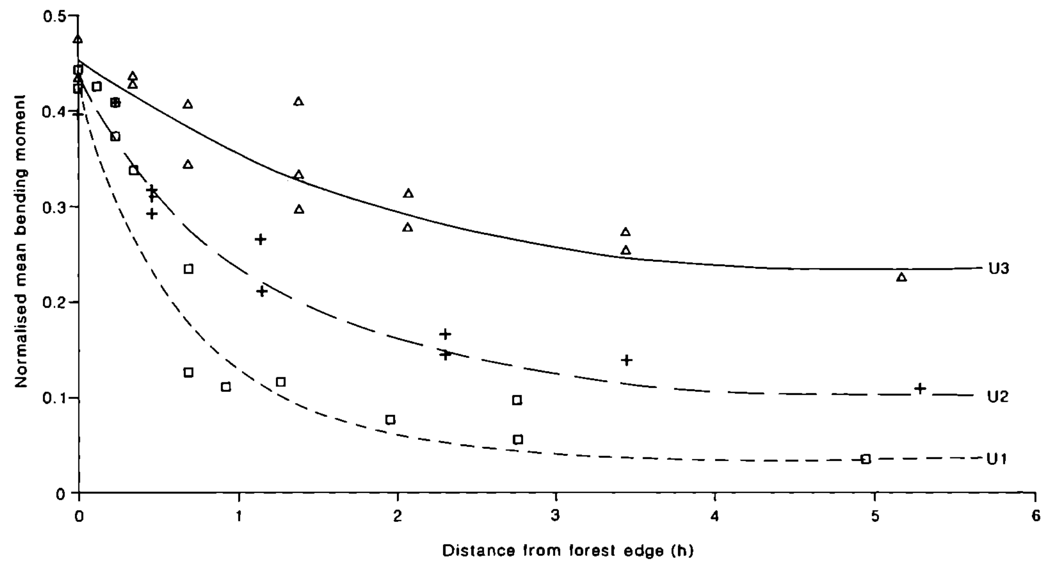

Figure 3a Normalised mean bending moments at different distances (in tree heights) back from the untreated edge of forests with different planting densities (U1 = 1.7 m spacing, U2 = 3.5 m spacing and U3 = 5.2 m spacing). All bending moments are normalised by dividing them by the extreme bending moment at the untreated edge of a forest with standard spacing (U1) to allow easy comparison between treatments.

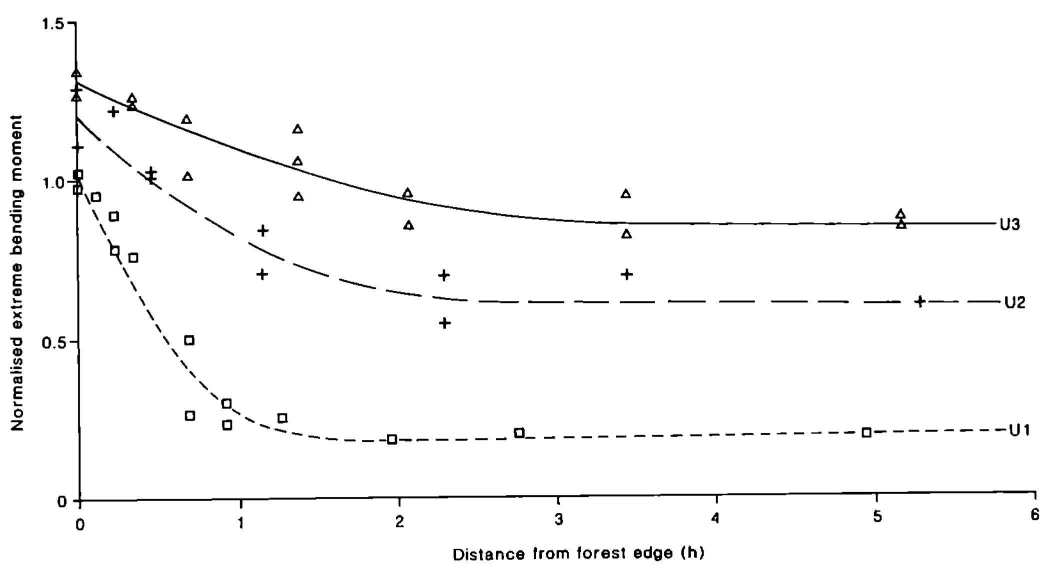

Figure 3b As for Figure 3a but for normalised extreme bending moments. Note change in y axis scale.

edge, the extreme bending moments in treatment U1 reached a constant value, whereas this took a distance of 2 h and 3 h in treatments U2 and U3 respectively.

At the forest edge the ratio between the extreme and mean bending moments (see Table 1) was higher for the more open spacings (U2, U3). From Figures 3a and 3b we can see that the mean bending moments were very similar between the treatments but the extreme bending moments were higher at the wider spacings. This illustrates that, even at the forest edge, trees at the densest spacing (U1) derive some measure of support from their neighbours. Back from the edge the ratio between extreme and mean bending moment increased for all spacings but did so most rapidly for the closest spacing to give values well within the forest (8 h) of 8.6, 6.2 and 5.0 for treatments U1, U2, and U3 respectively. If the extreme bending moment is greater than the maximum resistive moment the tree can provide, the tree will be damaged. However, the maximum resistive moment will be determined by the adaptive growth of the tree in response to the mean bending moment. Therefore, if the trees are not restricted in their ability to adapt to their local wind environment, the ratio of extreme to mean bending moment will be a measure of the trees' vulnerability to damage. This suggests that trees at the edge are less vulnerable to damage than those further into the forest and this difference will be most marked at higher planting densities.

Table 1 Ratio of extreme to mean bending moments as a function of distance from the forest edge

Treatment	*0 h*	*1 h*	*2 h*	*3 h*	*4 h*	*5 h*	*6 h*	*7 h*	*8 h*
U3	3.0	3.0	3.1	3.3	3.5	3.8	4.1	4.4	5.0
U2	2.9	3.4	4.0	4.5	4.9	5.3	5.6	5.9	6.2
U1	2.2	2.3	2.6	3.1	3.8	4.7	5.8	7.1	8.6

Treated edges

In Figures 4a and 4b the mean and extreme bending moments for the edge tree and a tree 5 h back from the edge are displayed for the different edge treatments. All the treatments except for the shrub layer (S) reduced both the extreme and mean moments at the edge. Wind profile measurements above the forest showed a speeding up of the airflow over the edge as the

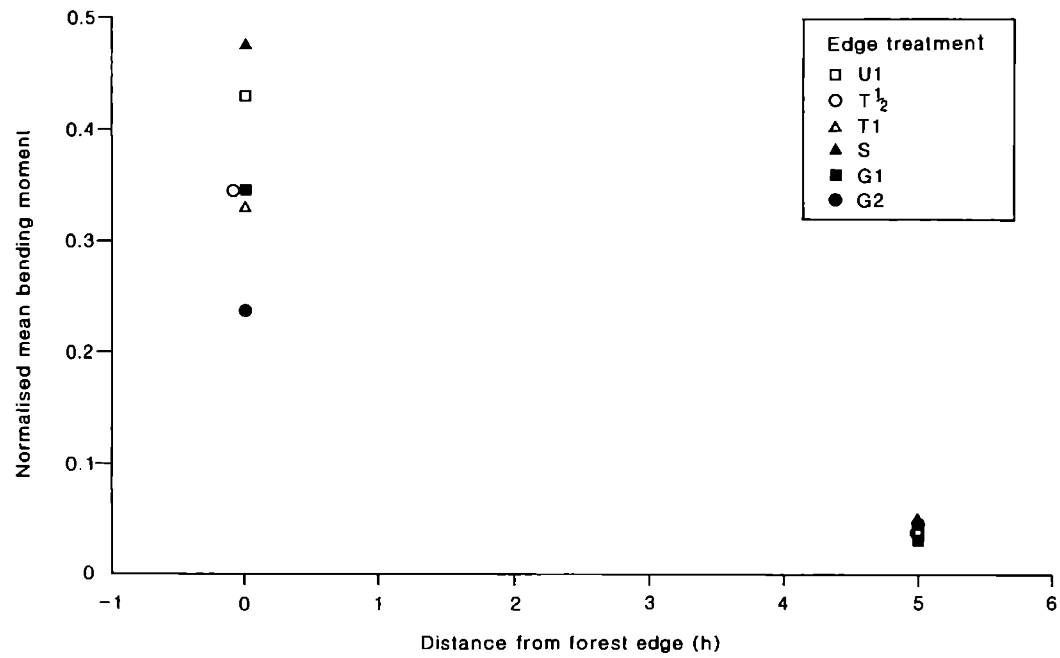

Figure 4a Normalised mean bending moments at the forest edge and 5 tree heights back from the edge for different edge treatments. As in Figures 3a and 3b, all bending moments are normalised by dividing through by the extreme bending moment at the untreated edge of a forest with standard spacing (U1). See Figure 1 for explanation of symbols.

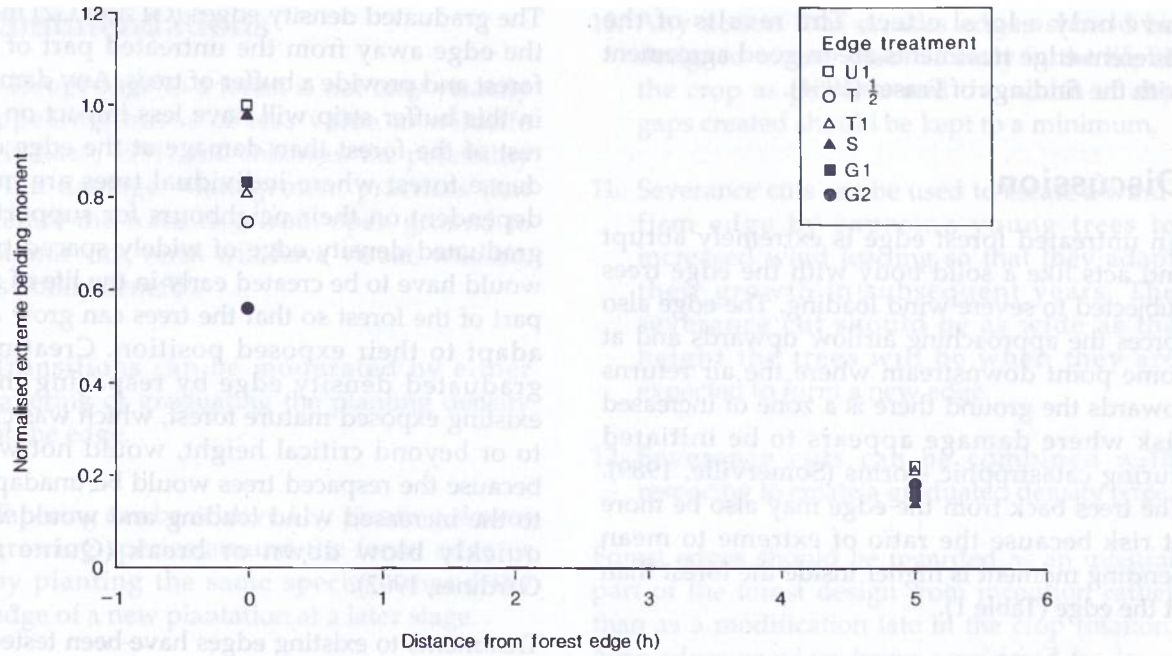

Figure 4b As for Figure 4a but for normalised extreme bending moments. Note change in y axis scale.

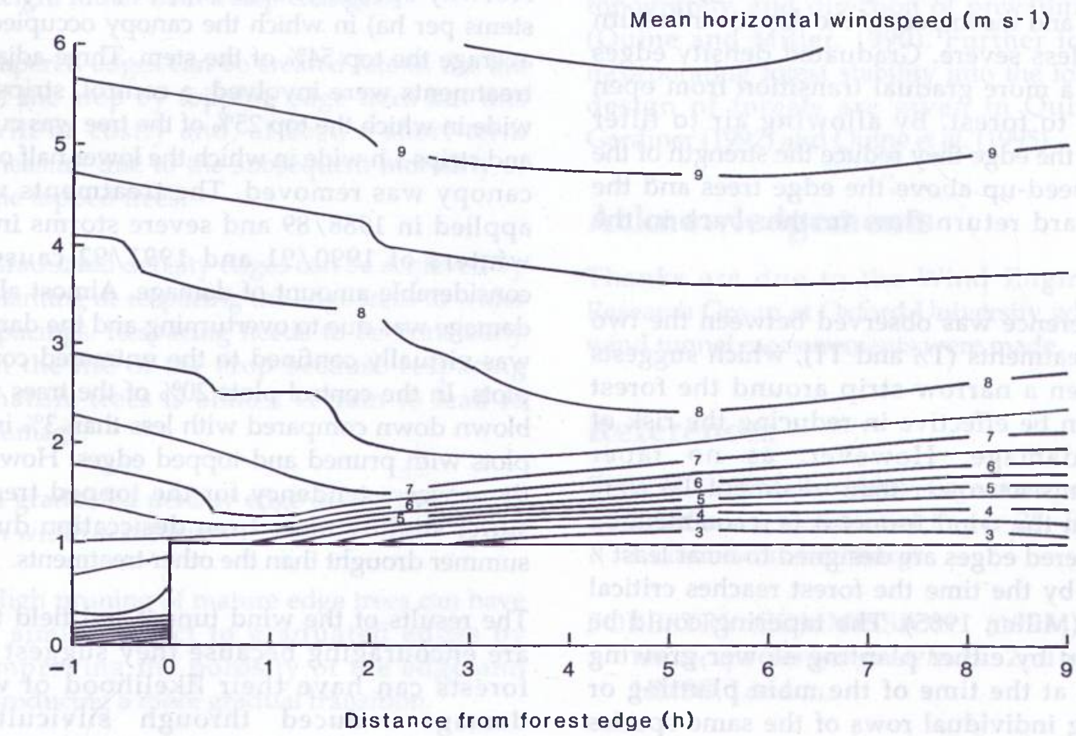

Figure 5 Contours of mean wind speed across an untreated forest edge (U1). Note the increase in wind speed just above the edge trees.

air is squeezed by the presence of the forest (Figure 5). This increases the wind loading on the edge trees and the effect was enhanced when a shrub layer was placed in front of the edge.

The largest reduction in bending moment occurred for graduated treatment G2 which is 2 h wide. There was no difference between the reductions due to the two tapered treatments (T½ and T1) and the 1 h wide graduated treatment (G1). By a distance of 5 h from the edge the differences in bending moment between the different treatments had disappeared, illustrating that the treatments have only a local effect. The results of the different edge treatments are in good agreement with the findings of Fraser (1964).

Discussion

An untreated forest edge is extremely abrupt and acts like a solid body with the edge trees subjected to severe wind loading. The edge also forces the approaching airflow upwards and at some point downstream where the air returns towards the ground there is a zone of increased risk where damage appears to be initiated during catastrophic storms (Somerville, 1989). The trees back from the edge may also be more at risk because the ratio of extreme to mean bending moment is higher inside the forest than at the edge (Table 1).

Any treatment that reduces the abrupt nature of the forest edge is likely to be beneficial. Tapered edges cause the airflow to be directed upwards in a more gentle fashion than an untreated edge so that the wind loading on the edge trees is reduced and the impact of the downward return flow is less severe. Graduated density edges present a more gradual transition from open ground to forest. By allowing air to filter through the edge they reduce the strength of the wind speed-up above the edge trees and the downward return flow further back in the forest.

No difference was observed between the two taper treatments (T½ and T1), which suggests that even a narrow strip around the forest edge can be effective in reducing the risk of wind damage. However, as no taper treatments narrower than treatment T½ were tested in the wind tunnel it is recommended that tapered edges are designed to be at least ½ h wide by the time the forest reaches critical height (Miller, 1985). The tapering could be achieved by either planting slower growing species at the time of the main planting or planting individual rows of the same species in subsequent years. Care needs to be taken that the effect is not to produce a step change in height similar to the shrub layer treatment (S), which will increase the wind loading on the edge trees. However, shrubs and trees used in combination to produce a tapered edge would be beneficial for both stability and wildlife.

The graduated density edges (G1 and G2) move the edge away from the untreated part of the forest and provide a buffer of trees. Any damage in this buffer strip will have less impact on the rest of the forest than damage at the edge of a dense forest where individual trees are more dependent on their neighbours for support. A graduated density edge of widely spaced trees would have to be created early in the life of that part of the forest so that the trees can grow and adapt to their exposed position. Creating a graduated density edge by respacing in an existing exposed mature forest, which was close to or beyond critical height, would not work because the respaced trees would be unadapted to the increased wind loading and would very quickly blow down or break (Quine and Gardiner, 1992).

Treatments to existing edges have been tested in the field by topping (cf. tapering) or high pruning (cf. graduated density) trees. Mattheson (1992) carried out field trials at 14 sites in Jutland, Denmark using middle-aged and old Norway spruce stands (approximately 1000 stems per ha) in which the canopy occupied on average the top 54% of the stem. Three adjacent treatments were involved: a control, strips 1 h wide in which the top 25% of the tree was cut off and strips 1 h wide in which the lower half of the canopy was removed. The treatments were applied in 1988/89 and severe storms in the winters of 1990/91 and 1991/92 caused a considerable amount of damage. Almost all the damage was due to overturning and the damage was virtually confined to the untreated control plots. In the control plots 20% of the trees were blown down compared with less than 3% in the plots with pruned and topped edges. However, there was a tendency for the topped trees to suffer slightly more from desiccation during summer drought than the other treatments.

The results of the wind tunnel and field trials are encouraging because they suggest that forests can have their likelihood of wind damage reduced through silvicultural intervention. In mature forests new edges created by nearby clear felling or road construction can be improved by high pruning or topping. This could be valuable for short-term protection in forest restructuring. When establishing or restructuring forests, long-term protection of edges may be achieved by planning tapered or graduated density edges.

Recommendations

Any abrupt edge to a forest is not only visually unappealing but is of less value to wildlife (Ferris-Kaan, 1991) and enhances the possibility of wind damage. Management practices that moderate the transition from open ground to forest and vice versa will have visual, wildlife, and stability benefits.

1. Transitions can be moderated by either tapering or graduating the planting density at the edge.

2. Tapering can be achieved by planting slower growing species around the forest edge or by planting the same species around the edge of a new plantation at a later stage.

3. The tapered edge should be designed to be at least half a tree height wide when the main crop reaches critical height. Care must be taken to create a smooth transition in height rather than a step change.

4. Tapered edges can be created late in the life of the crop by topping edge trees but this will be costly and, at best, a short-term measure due to the subsequent mortality of the topped trees.

5. Graduated density edges can be achieved by planting or respacing the edge trees to wider spacings. Respacing needs to be done early in the life of the crop because respacing mature trees is almost certain to lead to damage.

6. A graduated density edge of one tree height in width is sufficient .

7. High pruning of mature edge trees can have a similar effect to graduated edges by improving the porosity of the edge and producing a more gradual transition.

8. Edges could combine graduated density and tapering so that tree size and planting density increase into the forest. This would more closely simulate some natural forest edges.

9. New edges created by thinning, clear cutting or road building are more vulnerable than any other part of a forest.

10. Any action that creates edges should be designed to take place as early in the life of the crop as possible and the width of any gaps created should be kept to a minimum.

11. Severance cuts can be used to create a wind-firm edge by exposing young trees to increased wind loading so that they adapt their growth in subsequent years. The severance cut should be as wide as the height the trees will be when they are expected to form a new edge.

12. Severance cuts can be combined with respacing to create a graduated density edge.

Forest edges should be regarded as an integral part of the forest design from inception rather than as a modification late in the crop rotation. New edges or edges being considered for long-term retention should have any potential treatments set alongside other factors affecting stability such as edge shape, soil type, cultivation treatment, slope aspect, local topography, and direction of prevailing wind (Quine and Miller, 1990). Further ideas on incorporating forest stability into the long-term design of forests are given in Quine and Gardiner (1992) and Quine *et al.* (1995).

Acknowledgements

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