Assessment of the Economic Limit of Plantability

P. S. SAVILL[1]

Introduction

ABOUT 40 per cent of the State forest land in Northern Ireland has been classed as climatic or blanket peat. Such peats are found only in inhospitable areas where precipitation is high, usually at least 1,400 mm a year, elevations generally exceed 300 m (Barry, 1969); the areas are very windy. (Mean hourly windspeed at Ballypatrick, Co. Antrim was 11.8 knots in 1972 with 677 hours during the year when the mean speed was in excess of 22 knots (Anon 1973).)

The demarkation line between economically successful and unsuccessful afforestation often lies within the altitudinal range of climatic peats. Much attention has been paid in recent years to try to demarcate this boundary more precisely than by the forester's subjective assessment. Limitations on economic timber production can be caused by two main factors. Firstly, growth may be so slow as to result in unacceptably low returns from the money invested and, secondly windthrow may cause extensive damage very early in the rotation.

Lines and Howell (1963) were among the first to give detailed consideration to the problems of "exposure" on tree growth. They analysed the combined effects of a number of variables, including elevation, rainfall, proximity to the sea and the rate of disintegration of cotton flags, which contribute to the generalised concept of "exposure". This was done on an extensive scale, covering much of Scotland and northern England.

The aim of the work carried out in Northern Ireland was to investigate the effects of "exposure" on the growth of Sitka spruce on a local rather than an extensive scale.

"Exposure" in Relation to Tree Growth

Gloyne (1966) has pointed out that a satisfactory definition of the term "exposure" has not yet been produced. It may well be impossible since the term almost always relates to the response of some physical or biological system to various elements of the atmosphere environment, both acting singly and in different combinations. There is evidence that on certain sites the rate of disintegration (or tatter) of cotton flags may well be governed by that combination of atmospheric influences which inhibits tree growth and in this

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1. Research Officer, Forestry Division, Department of Agriculture, Belfast.

context flags may be better indicators of exposure than would purely wind measuring devices.

Tatter Flags

"Exposure" or "tatter" flags are made of "Madapollam", a specially manufactured cotton cloth, and are 12 inches high and 15 inches long (about 30 cm × 38 cm). The important feature of the cloth is its uniformity. Flags are mounted on steel rods sited at about 1.5 m above the ground and are free to rotate. Over a period of time the free vertical edges of the flags fray and assessments of exposure are made by measuring the area of solid weave lost. Details are given by Lines and Howell (1963). Those elements of the weather with which flags loss is most closely correlated have been discussed by, among others, Gloyne (1966), Rutter (1966, 1968) and Jack and Savill (1973).

Collection of Data

With a few exceptions tatter flags were flown in the year following the planting of trees on an area (P+1) and in the following year (P+2). Precise periods are given in Table 2. They were located in the forest by using a stratified random sampling design in which two flags were placed at random within strata of approximately 4 ha. The strata were subjectively by chosen experienced staff as being areas where exposure would be roughly the same. Altogether exposure, as indicated by flag tatter, has been measured on 276 sampling points at Beaghs Forest, Co. Antrim (in the P59–71 areas) and on 392 points at Ballintempo Forest, Co. Fermanagh (P66–71 areas).

Individual flags were flown for periods of 7 weeks at Beaghs Forest and 6 weeks at Ballintempo and then all replaced by new ones on the same day. After each flag change the area of solid weave lost by tattering was estimated. This was originally done by tracing the area remaining on to squared paper.

Later, Jack (1965) found it could be calculated with a very high degree of precision by using the formula:

$$Y = 1179.4 - 28.2X$$

where Y is the area of flag lost in square cms and X is the length of flag remaining in cm, as measured horizontally from the pole to the centre of the frayed edge.

Jack also demonstrated that provided the period of exposure of a flag does not exceed 7 weeks, then correlations of flag losses remain high between pairs of flags. The rate of tatter of flags which have already been exposed for some weeks is likely to be higher than the rate of tatter of recently exposed flags. It is therefore probable that differences in exposure values for Beaghs and Ballintempo, where flags were exposed for 7 and 6 week periods respectively are small. The longer period used at Beaghs may however result in a slight over estimate of exposure relative to Ballintempo.

The growth of the Sitka spruce trees at some tatter flag points was measured periodically. In an attempt to eliminate the effects of soil differences and those of varying levels of fertiliser application a degree of selection was necessary in deciding at which flag positions growth measurements should be used for analysis since it is now well established that a very important factor influencing tree growth on peat is adequate nutrition (Dickson and Savill 1974). Plots were therefore discarded if the trees were clearly showing symptoms of a nutrient deficiency, which was usually caused by insufficient quantity or uneven spreading of fertilisers at the time of planting. Other plots were discarded if they were on soil types other than oligotrophic peat, except in the P69 area at Beaghs where over half of the plots were on mesotrophic peat. (These peat types are described by Dickson and Savill, 1974.) Thus, except in this one P- year, plots with low tatter values were not associated with depressions in the topography which resulted in more fertile soil conditions. For these reasons several whole P-years had to be rejected from the analyses at Beaghs Forest. At Beaghs, only the 5 tallest trees (out of a plot of 20), representing about the 1,000 tallest per hectare were measured. At Ballintempo all trees in the plot, representing about 2,500/ha were measured. It was found that much better results were obtained at Ballintempo by using all 20 trees in the analyses rather than the 5 tallest.

Analysis and Results

1 *Exposure*

It was soon found that only long-term averages of flag loss were satisfactory to obtain a reasonable estimate of the relative exposure of the site. Table 1 shows how "exposure", expressed as the mean daily flag loss in cm^2, in each 6 week period is correlated with all other periods among 95 flags flown from 1967 to 1969 at Ballintempo. While some correlations are good and all are significant at the 95 per cent probability level or more, none provides as consistently good an estimate of relative exposure as average daily flag loss over the approximate annual periods shown in Table 2, where coefficients of correlation were generally in the order of 0.95 on 11 different P-years. As a result it was decided to use only long-term averages when examining the relationships between exposure and growth. Further details about mean daily flag loss in different P-years are given in Table 2. Column 3 shows that average losses ranged

TABLE 1

CORRELATION MATRIX OF MEAN DAILY FLAG LOSS ON 95 SAMPLING POINTS DURING 1967-68 ON P66 AND P67 AREAS AT BALLINTEMPO

Period

	10.10.67 to 21.11.67	21.11.67 to 2.1.68	2.1.68 to 13.2.68	13.2.68 to 26.3.68	26.3.68 to 7.5.68	7.5.68 to 18.6.68	18.6.68 to 30.7.68	30.7.68 to 10.9.68	10.9.68 to 22.10.68
	1	2	3	4	5	6	7	8	9
1	1.000								
2	.864	1.000							
3	.961	.882	1.000						
4	.889	.849	.911	1.000					
5	.823	.738	.795	.799	1.000				
6	.743	.680	.769	.729	.683	1.000			
7	.379	.301	.353	.351	.300	.274	1.000		
8	.612	.595	.622	.610	.619	.612	.218	1.000	
9	.894	.826	.864	.849	.787	.735	.384	.640	1.000

TABLE 2
SUMMARY OF ANALYSES OF FLAG TATTER DATA AT BEAGHS AND BALLINTEMPO FORESTS

P Year	Period of measurement	Daily flag loss cm² Min	Daily flag loss cm² Mean	Daily flag loss cm² Max	Std error of mean ± cm²	Coeff. of var. %	Consistency of tatter from year to year R	Residual degrees of freedom
BEAGHS FOREST								
1959	13.10.64–27.10.65	2.8	8.3	12.1	0.83	14.2	—	21
1962								
1963	13.10.64–27.10.65	3.1	8.2	10.5	0.85	14.5	0.88***	32
1964	27.10.65–17.10.66	2.4	8.1	11.0	0.90	15.7		
1965	27.10.65–17.10.66	2.0	8.7	11.6	0.96	15.6	0.94***	13
	17.10.66–18. 9.67	2.4	9.4	12.6	1.01	15.2		
1966	17.10.66–18. 9.67	3.3	9.4	12.1	1.47	22.0	0.97***	10
	18. 9.67– 7.10.68	3.0	7.1	8.7	1.04	20.6		
1967	18. 9.67– 7.10.68	5.8	8.3	10.9	0.73	12.3	0.93***	1
	7.10.68– 7.11.69	6.7	9.6	12.3	0.83	12.2		
1968	7.10.68– 7.11.69	2.5	6.0	13.6	0.85	20.0	0.93***	9
	7.11.69– 4.12.70	2.5	6.1	12.6	0.93	21.6		
1969	7.11.69– 4.12.70	3.4	8.9	12.3	1.50	23.7	0.95***	7
	4.12.70– 5.11.71	3.0	7.4	11.2	1.27	24.2		
1970	4.12.70– 5.11.71	4.6	6.8	11.0	0.84	17.4	0.96***	10
	5.11.71– 1.12.72	4.6	7.1	11.1	0.79	15.7		
1971	5.11.71– 1.12.72	2.9	6.2	12.0	1.01	22.9	—	25

Table 2 Continued

BALLINTEMPO FOREST								
1966	10.10.67–22.10.68	3.6	6.2	9.7	0.79	18.1	—	41
1967	10.10.67–22.10.68	3.6	7.6	13.2	0.84	15.6	0.96***	36
	22.10.68– 4.11.69	3.6	6.7	13.4	0.80	16.8		
1968	22.10.68– 4.11.69	3.6	7.0	12.3	0.79	15.8	0.88***	34
	4.11.69–17.11.70	3.9	7.8	12.7	0.66	11.9		
1969	4.11.69–17.11.70	5.0	9.7	15.2	0.78	11.4	0.96***	26
	17.11.70–30.11.71	3.6	6.8	12.7	0.49	10.2		
1970	17.11.70–30.11.71	3.4	4.6	7.2	0.31	9.6	0.94***	29
	30.11.71–12.12.72	3.5	5.5	8.7	0.49	12.7		
1971	30.11.71–12.12.72	3.5	6.4	11.4	0.79	17.3	—	30

Significance at probability levels: NS = not significant, * = 0.05, ** = 0.01, *** = 0.001.

between 4.6 and 9.7 cm^2/day. The minimum loss found in any year was 2.0 cm^2 and the maximum 15.2 cm^2/day. These values compare well with the range found by Lines and Howell (1963). Tatter values in mid-summer are very low, which may partly explain the weak correlations of tatter in period 7 (mid-June to July) with all other periods shown in Table 1.

Tatter flags give only an indication of the *relative* exposure between sampling points. However, because measurements taken in any one P-year overlap in time with those in the previous and following P-years it is possible to predict what tatter values would have been at any point in any of the years sampled. Of course such estimates are liable to increasing amounts of error as time from the datum year increases. In the analyses described below, only actual tatter values were used, not predicted tatter values, except for the data used in preparing Figure 1 where predicted tatter for 1965 was used for the P65 and P69 areas at Beaghs. This was done in order to remove the effect of different levels of exposure in years sampled for P65 and P69.

2 *Relationship between exposure and tree growth*

Acceptable data on the growth of Sitka spruce at a number of tatter points was available for seven P-years at Beaghs and for two P-years at Ballintempo. The number of points from which measurements were taken varied from 8 to 32 in individual P-years. For each P-year linear regressions were calculated using tree height, usually at several ages, as the dependent variable and mean daily flag loss in cm^2 during one of the years sampled as the independent variable.

Out of the seven P-years at Beaghs Forest, significant relationships at the 95 percent probability level or better, between total height and exposure were found in four of them: P60, 61, 65 and 69. The relationship in a fifth P-year (P64) was significant at the 90 per cent probability level. At Ballintempo Forest a significant relationship was found in one of the two P-years.

These regressions are shown in Table 3. Some of them suggest a trend of improving relationships between height and exposure as age increases. Thus in the P60 area at Beaghs, mean height in 1964 (age 5) had a correlation with tatter of —0.59, which improved to —0.82 when mean height in 1973 (age 14) was considered. (This did not happen in the P69 area at Beaghs however.)

The reason for this is that young trees, when newly planted, are of a fairly uniform height. Only over a period of years do the differences due to exposure begin to manifest themselves. Differences

TABLE 3—LINEAR RELATIONSHIPS BETWEEN TOTAL HEIGHT AND EXPOSURE

P Year	Age	Variables: (Y) Tree Height (cm) in	Variables: (X) Tatter (loss in cm²/day)	Regression Coefficient of Y on X	Regression Constant	R between X and Y	Residual df
			BEAGHS FOREST				
60	14	1973	1965	—71.2	813.1	—0.823***	10
	13	1972	,,	—65.0	739.2	—0.830***	,,
	12	1971	,,	—57.3	653.8	—0.844***	,,
	11	1970	,,	—47.5	564.0	—0.830***	,,
	10	1969	,,	—37.5	475.5	—0.797**	,,
	9	1968	,,	—29.3	398.8	—0.776**	,,
	8	1967	,,	—21.2	318.8	—0.738**	,,
	7	1966	,,	—15.2	257.9	—0.715*	,,
	6	1965	,,	— 4.3	205.9	—0.704*	,,
	5	1964	,,	— 2.6	156.5	—0.595*	,,
61	13	1973	1965	—41.5	593.7	—0.767**	9
	12	1972	,,	—38.9	548.1	—0.780**	,,
	11	1971	,,	—35.4	489.3	—0.796**	,,
	10	1970	,,	—31.4	432.4	—0.794**	,,
	9	1969	,,	—24.9	353.0	—0.761*	,,
	8	1968	,,	—19.1	281.2	—0.746*	,,
	7	1967	,,	—14.1	217.5	—0.713*	,,
	6	1966	,,	—13.3	201.8	—0.868**	,,
	5	1965	,,	— 3.7	150.6	—0.894**	,,
65	6	1970	1967	—11.1	234.7	—0.501*	21
69	5	1973	1970	— 9.5	222.8	—0.691**	11
	4	1972	,,	— 7.5	174.3	—0.647*	,,
	3	1971	,,	— 6.4	131.5	—0.738**	,,
	2	1970	,,	— 3.9	87.4	—0.834***	,,
			BALLINTEMPO FOREST				
67	6	1972	1969	— 6.7	195.4	—0.611***	30
	5	1971	,,	— 5.0	141.7	—0.577***	,,
	4	1970	,,	— 3.1	93.7	—0.528**	,,
	3	1969	,,	— 1.9	61.3	—0.511**	,,

in growth are cumulative in terms of total height of the trees and so become more pronounced as the years go by.

Figure 1 illustrates this point more clearly. In it the relationships between the regression coefficients for all P-years in which significant

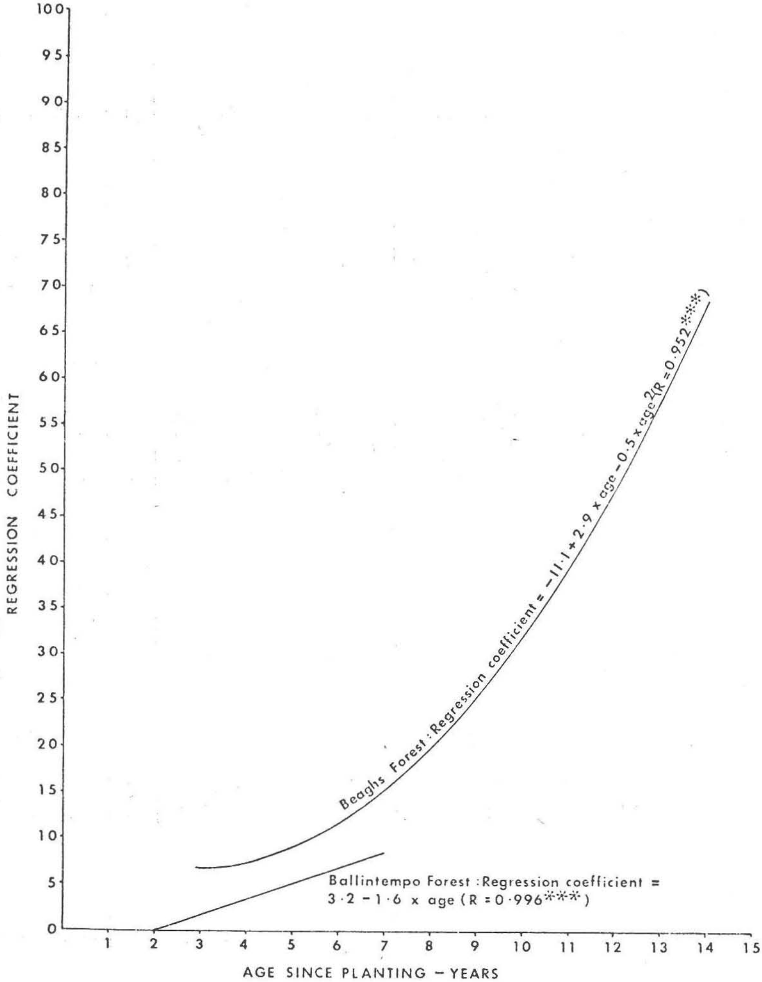

Figure 1: Relationships between regression coefficients from Table 3 and crop age, i.e. reduction in height in cm for each additional 1 cm² flag loss per day.

Note—Estimated coefficients for 1965 tatter values used for P65 P69 areas at Beaghs.

regressions were found, and crop age are shown. These coefficients represent the deduction, in cm, which must be made from the height of a crop for each additional 1 cm^2/day of flag loss. So, at age 6 at Beaghs, about 13 cm must be deducted from the height of the crop for each additional cm^2 of daily flag loss. This increase to 65 cm at age 14.

The apparent difference between the regressions for each forest

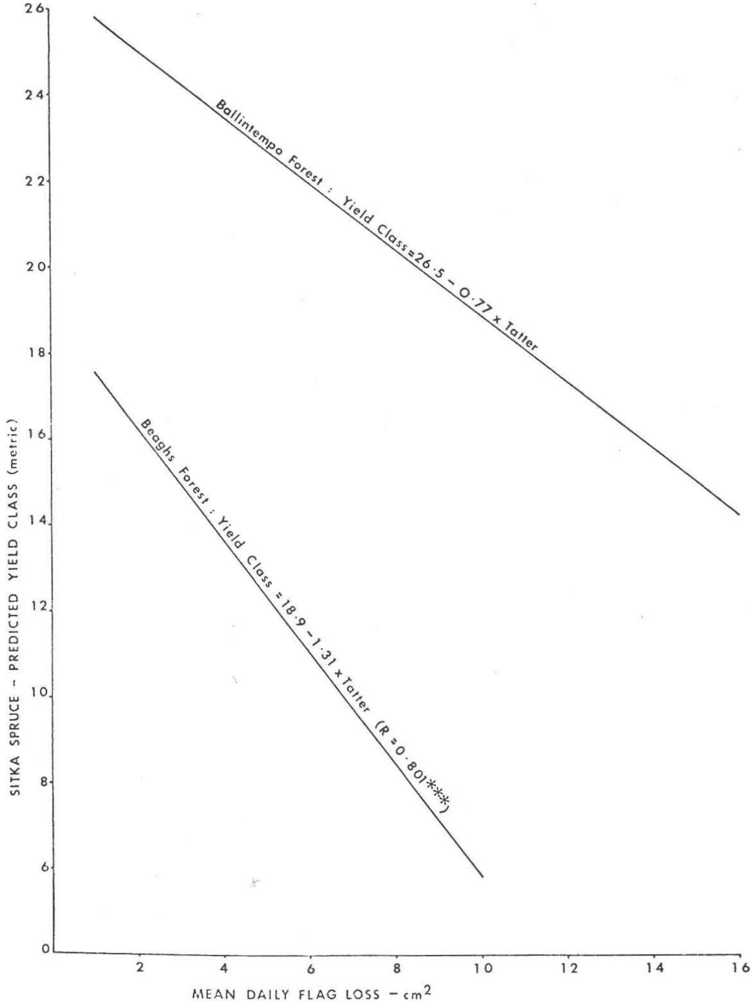

Figure 2: Relationships between predicted yield class and flag tatter.

is partly caused by the fact that the line for Ballintempo is based on measurements of all 20 trees per plot, while at Beaghs only the 5 tallest were measured. There were also large differences in the rate of growth between the two forests and, as can be seen from Table 3, much less data were available for Ballintempo Forest.

These results can be translated into more commonly understood terms if they are expressed as the effect of exposure on predicted yield class. At the particular stage of development, all the crops examined were too young to assign with any certainty to a yield class in the Forestry Commission's tables (Hamilton and Christie, 1971), but at least tentative predictions can be made. The relationships found are shown in Figure 2. In the case of Beaghs Forest the line is based upon the combined data for the two oldest (P60 and P61) areas. The line for Ballintempo is based on the P67 area only.

It will be seen that at Beaghs Forest predicted yield class falls off rapidly with the increasing exposure, from YC15 where mean daily flag loss is 3 cm^2 to YC6 where flag loss is 10 cm^2. The major difference in the case of Ballintempo is that for apparently similar exposure values, crops are about 11 yield classes higher than at Beaghs. This difference in growth rate may be caused at least in part by the influence of slightly different peat types and of the warmer climate in the west which is indicated in meteorological office records. It must also be caused in part by the fact that differences in climate, particularly rainfall (Rutter, 1966) influence the rate of tatter of cotton flags, so that the factors which contribute to a given level of tatter in one place may be quite different from those which contribute to the same level in another. The fact that the P67 area at Ballintempo was fertilised with broadcast rock phosphate, while at Beaghs the fertiliser was basic slag put into the planting hole may also contribute to the difference, but it is commonly observed that even where fertiliser treatments and soils are the same, growth in Ballintempo is invariably better than at Beaghs.

Relationship Between Altitude and "Exposure"

It is well recognised that as elevation above sea level increases, "exposure" also increases. To determine the relationships between the two, the elevations of the tatter flag points on the P60 and P61 areas at Beaghs were estimated by scaling between 100 ft (30 m) contours on 1:10560 ordnance survey maps. This could not be done for Ballintempo because almost all the plots for which growth measurements were available lay on a plateau at about 300 m which made the estimation of elevations from a map impossible. There are sufficient changes in topography however to understand subjectively the differences in rates of tatter.

The relationship at Beaghs where elevations ranged from 250–350 m was:

Flag loss in cm^2/day = —20.5+0.0922×altitude (m)
(R=0.72***)

The correlation coefficient is sufficiently good go indicate that elevation plays a very important part in influencing the rate of flag tatter.

Relationships Between Altitude and Growth of Sitka spruce

Mayhead (1970) has demonstrated relationships between elevation and yield class for different regions in Britain, and has shown that they are not constant. The regions investigated were Forestry Commission Conservancys, each about as big as the whole of Northern Ireland.

On the much more local scale of investigations in Northern Ireland it was possible to eliminate major differences in soil fertility by

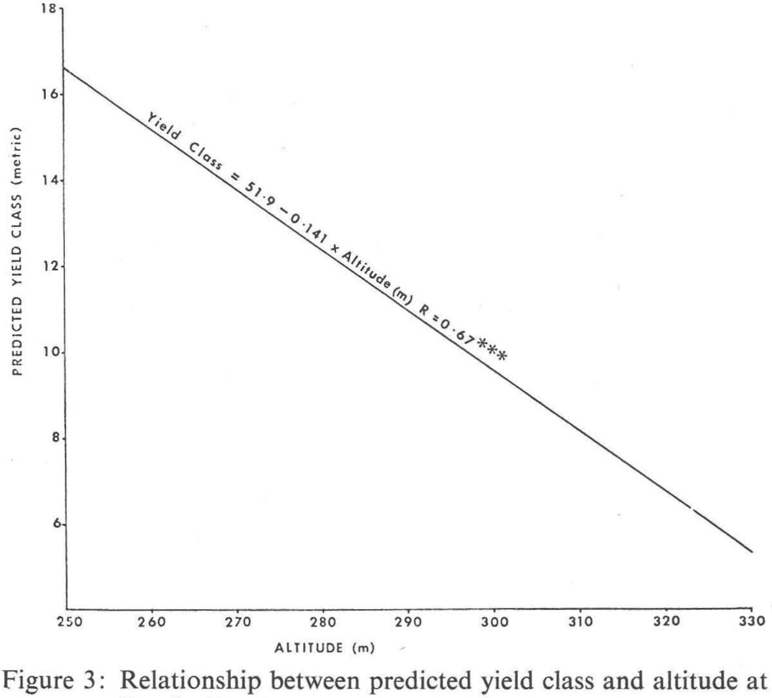

Figure 3: Relationship between predicted yield class and altitude at Beaghs forest.

selection of sampling sites, so the main influences causing differences in growth were likely to be climatic.

Using the same sample plots as were investigated for tatter flag purposes in the P60 and P61 areas at Beaghs, the relationship between yield class and altitude is shown in Figure 3. This relationship is not quite so good as those between crop height and flag tatter shown in Table 3.

Although no regression could be calculated for Ballintempo for the reasons given above, it is certain that if a similar yield class/elevation relationship did exist there it would differ significantly from that at Beaghs, in the same way as the relationships between flag tatter and yield class differed. This is because elevations at both forests were very similar, if not slightly greater at Ballintempo but yield classes at Ballintempo were on average much higher than at Beaghs.

Discussion

Work carried out at Beaghs and Ballintempo Forests has confirmed that the relationships between tree growth, "exposure" and elevation are sufficiently good to be of practical use. However, if a plantable boundary based on predicted yield class is being sought, then this can only be determined for a reasonably localised area. The two forests studied are separated by a distance of 120 km yet differences in response to apparently similar levels of exposure amounted to about 11 yield classes in conditions where soil and elevation did not differ very greatly.

Coefficients of correlation between exposure and yield class, and altitude and yield class were rather variable, and while both could be regarded as being reasonably acceptable for use on a local scale, there is a fairly strong suggestion that exposure expressed as tatter provides the more reliable indicator of growth differences.

While neither method provides a means of explaining anything like the total variability in growth, both explain sufficient of it to make them reasonably acceptable for determining a plantable limit objectively. It is known that correlations with other factors, such as temperature and the supply of nutrients can be found (Malcolm and Freezaillah, 1973).

In the past it has been the normal practice to determine economically plantable boundaries on subjectively assessed altitudinal limits. They are usually modified from place to place by differences in aspect, soil or equally subjective opinions as to the degree of local shelter. It is of interest to note that an isopleth ("contours" of exposure) map of Beaghs forest, produced from tatter flag results agreed remarkably well with one produced by the local forestry staff who assessed relative exposure levels purely from their own knowledge and experience, and without access to tatter flag data.

If this can be done elsewhere, it appears to be necessary only to establish the relationship between exposure and yield class on a small part of an area under consideration and for experienced foresters to decide where similar levels of exposure would be found elsewhere. An acceptable economically plantable limit could probably be produced in this way.

Acknowledgments

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