Spatial Analysis of Forest Growth

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A SPATIAL ANALYSIS OF FOREST GROWTH

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CONTENTS

PREFACE

In this paper forest yields are seen through the eyes of a geographer and other than those of a forester and the treatment is, therefore, slanted towards a spatial viewpoint rather than towards a purely forestry one. The spatial approach is unlike the normal scientific approach in that instead of studying the individual site and ecological factors and attempting to build up a picture from them, it takes as its starting point the *resultant* of all these factors in the form of the yield class system of classifying growth (Hamilton and Christie, 1971). Although it has already been fully discussed and described elsewhere (Johnston and Bradley, 1967) it is worth mentioning that this system classifies growth of tree crops in terms of maximum mean annual volume increment per hectare, irrespective of age of culmination or tree species. The range of yield classes recognised is from 4 m^3/ha to 30 m^3/ha; within a species the number of yield classes varies from three for oak to ten for Sitka spruce. The yield class system is highly flexible. It can be used to compare growth performance both within and between species. It measures both the biological and commercial performance of conifers and broadleaf species in even-aged or uneven-aged, pure or mixed stands. It is thus capable of wide application and presents in an unprecedented way a system by which species performance in Britain can be studied at national, regional or local levels to see what variations exist.

By studying the spatial variation of the yield classes (i.e. the resultant) it is possible to identify the major component factors, having approached this problem from the other end. This approach is complementary to the normal one which works from the specific to the general.

With the exception of Anderson (1930), who mapped quality class zones* in Scotland based mainly upon data from Scots pine, European larch and Norway spruce sample plots, previous spatial work has been confined mainly to detailed micro-studies, and it is debatable whether such highly specific investigations can be fitted together to produce an overall picture. An example of the difficulty of applying specific findings to a more general context is provided by an investigation carried out in Gwydyr Forest in North Wales (Mayhead, 1968). By using the presence, absence or association of plant species to predict site potential for forestry, it was shown that certain species were strongly related to site

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* A system of relative classification relating height to age for individual species.

productivity in two plots of Sitka spruce, but despite the thoroughness and intensity of the study the author concluded -

> 'regression did not suggest whether the vegetation was reflecting the site or merely the crops above it'

Other studies, such as that by Sindon (1965) on the length of rotations, and Andrew (1972) on the growth of two tropical trees, also reinforce the view that micro-site studies need to be supplemented by macro-site studies.

The data used throughout this study were obtained from sub-compartment records prepared by the Forestry Commission for all its English and Welsh forests in 1970. Sub-compartments are the smallest units of management in a forest and are areas of ground which possess sufficiently homogeneous characteristics to enable them to be given a separate identity for management purposes. They are not necessarily permanent and their identity may be lost during the growth of a stand. A number of sub-compartments form a compartment which is the smallest permanent division of Forestry Commission land and is clearly identifiable on the ground by means of mappable features such as rides, streams etc.

When a forest is surveyed the area, species composition, year of planting, (P. year), top height, general yield class, local yield class are recorded for each sub-compartment together with, in some instances, additional site data. This information is subsequently transferred to a stock-map. The sub-compartment records thus provide the basic data for a forest, which can then be aggregated in various ways to form useful summaries for management.

The summary data for Conservancies were used to calculate mean yields at the national level, and those for separate forests were used to calculate weighted mean yield classes for each species in each forest. Areas and yield classes are recorded for both pure and mixed stands but the mixed stands occupy only a negligible proportion of the total.

This is an abridged account of a study (Nicholls, 1978) intended to develop the understanding of spatial variations in the growth of trees and refinement of the analytical techniques used. The results of the yield analysis at the national level are applied on a compartment basis in two study forests in England and Wales.

The purposes of the analyses is to obtain a more precise knowledge of the locations that produce high and low yields for each species; also to ascertain how far this information either confirms or contradicts site selection by means of 'conventional guidelines' published in *Forestry Practice*, Forestry Commission, 1978. An attempt is made to indicate, in a preliminary way, how locational changes in the planting of species for the next rotation can give higher yields per unit of forested area.

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ABBREVIATIONS

Species

SP	Scots pine *(Pinus sylvestris)*
CP	Corsican pine *(Pinus nigra)*
LP	Lodgepole pine *(Pinus contorta)*
SS	Sitka spruce *(Picea sitchensis)*
NS	Norway spruce *(Picea abies)*
EL	European larch *(Larix decidua)*
JL&HL	Japanese and Hybrid larch *(Larix kaempferi & Larix eurolepis)*
DF	Douglas fir *(Pseudotsuga menziesii)*
OC	Other Conifers
Oak	Oak *(Quercus)*
Be	Beech *(Fagus sylvatica)* .
OB	Other Broadleaved species

Conservancies*

NE	North East England
NW	North West England
NWA	North Wales
SWA	South Wales
SW	South West England
SE	South East England
E	East England

* The regions into which the country is divided for forest administration are shown in Figure 7.1 (p.96)

m^3/ha yield in cubic metres per hectare per annum.

ACKNOWLEDGEMENTS

The writer wishes to acknowledge the invaluable help given by the Forestry Commission and especially by:-

Mr J.M. Christie who greatly assisted the author in the understanding of the yield class system, and who undertook the task of condensing Part I of the original thesis into a more rationalised length.

Mr K.W. Wilson for the planning and design of this paper and for his invaluable assistance with the final editing.

Mr K.P. Thallon for providing national data.

Mr W.E. Powell and Mr M.J. Waite (Chief Foresters of St. Gwynno and Mortimer Forests respectively) for compartment data, advice and time spent in the field.

Grateful acknowledgement is made for a University of London Central Research Fund Grant for the purchase of maps and data and for travel on field work. The University of London Computing Centre's advice and facilities greatly assisted the processing of the data. Special thanks are due to Mr J. Gilbert and Mrs A. Daniels.

The completion of this thesis was made possible by a sabbatical year granted by Lanchester Polytechnic, Coventry, which also made available the skilled assistance of the Visual Aids Department for reproducing copies of the numerous plates and figures. The enthusiasm of Messrs M. Barker, E. Partridge, W. Boswell and A. Raynor successfully overcame the technical difficulties of processing and reduction.

Mr B. Caulfield, Principal Lecturer in Statistics, gave valuable advice on statistical techniques.

The writer is immensely indebted to his supervisor, Miss A.M. Coleman, Reader in Geography at Kings College London, for all the time she has willingly spent on this thesis. Her enthusiasm, encouragement and clear direction were tremendously helpful and beneficial.

The author is indebted to the following for their kind permission to use published material in the paper:-

The Institute of British Geographers (for S. Gregory's map of Accumulated Temperature).

The Meteorological Office for the maps of Mean Annual Rainfall, Average Wind Speed, and Minimum Temperatures.

The Royal Meteorological Society (for G.M. How's map of Moisture Regions).

CHAPTER 1

NATIONAL YIELD CHARACTERISTICS

INTRODUCTION

It is the purpose of this chapter to explore the characteristics of the main forests species by comparing their growth rates nationally, in this case, over Forestry Commission woodlands in England and Wales only. This will give a quantitative statement about the national performance of the various species and the mean yield will provide a norm against which spatial variations in yields at the Conservancy, Forest and compartment levels can be discussed in subsequent chapters.

Since the formation of the Forestry Commission in 1919, the species planted have generally been selected on the foresters assessment of site conditions and the need to maximise yield. It must be noted that a number of species used are not native species and, initially, there was limited experience of their performance on many sites, particularly those which were afforested during the post-war period of expansion of the forest estate. The ranked total area of species in 1971 in Figure 1.1 (p.17) form a basis for discussion of frequency distributions of yield variations.

MEAN YIELDS

The mean yields of the species are ranked in decreasing order of magnitude from left to right in Figure 1.2 (p.17) and five groups can be recognised: Douglas fir and Other conifers with mean annual yields of above 13 m^3/ha, Norway spruce, Corsican pine and Sitka spruce with yields of 11.2 - 11.6 m^3/ha, Japanese and Hybrid larch and Scots pine with yields of 9.4 m^3, European larch and Lodgepole pine yielding 7.4 and 6.7 m^3/ha, and the broadleaved species with mean yields of less than 5.7 m^3/ha. The intervals separating the groups are mostly of the order of two cubic metres.

If the species are compared, some interesting contrasts are seen which are for the most part a reflection of site conditions. Douglas fir, with a mean yield of 13.2 m^3 grows 18.6 per cent faster than Sitka spruce and 40.8 per cent faster than Scots pine, the two most extensively planted species. The two spruces have high, and almost equal, yields of 11.6 and 11.2 m^3/ha, while the two larches have rather low yields of 9.4 m^3/ha for JL/HL, and 7.4 m^3/ha for European larch. The pines, by contrast, exhibit wide differences in yield. Corsican pine, with a mean yield of 11.5 m^3/ha is as productive as the spruces, while Scots pine, yielding 9.4 m^3/ha is no more productive than Japanese larch, and Lodgepole pine, at 6.7 m^3/ha is the lowest yielding of all the conifers. On average, Corsican pine grows 23 per cent faster than Scots pine and 73 per cent faster than Lodgepole pine.

The marked variation in species means suggest that if the more productive species could be planted more extensively and the less productive reduced in area, there could be scope for increasing production, provided that better quality sites become available to the Forestry Commission and that this is justified by the demand for the types of timber concerned.

FREQUENCY DISTRIBUTIONS AND SKEWNESS

A more detailed picture of national performance can be obtained by analysing the frequency distributions of yield classes and planted areas shown by the histograms in Figures 1.3 to 1.7 (pp. 18-20). The coefficient of skewness (μ_3) has been devised by the following formula:

$$\mu_3 = \frac{\Sigma f \ (x - \bar{x})^3}{\Sigma f}$$

where μ_3 = the third movement about the mean

Σf = the sum of the frequencies (i.e. the total number of hectares in each yield class).

x = the yield class (m^3/ha/a).

$\bar{x}$ = the mean of all yield classes for a given species (e.g. 9.4 m^3 for JL/HL).

Mode and skewness indicate how far the distributions of yield classes approximate to or depart from the normal distribution. In a normal distribution the mean is exactly equal to the mode and the skewness is zero, indicating that the values are symmetrically disposed about the mean. The more asymmetrical the distribution the greater the displacement of the mode from the mean and the higher the value of the coefficient of skewness. These related characteristics are highly relevant to the comparison of actual and potential yield levels.

Figure 1.8 (p.21) shows that one species is characterised by a negatively skewed distribution. This is the native conifer, Scots pine, about which most is known by foresters, and which has, therefore, not surprisingly been best matched to suitable sites. All the exotic species show positive skewness, and since they are mainly in the first planting generation, it is equally unsurprising that there is room for improvement of yields in the future. What is surprising is that the native broadleaves should also show positive skewness, though they account for only about 6 per cent of Forestry Commission woodland and are retained largely for amenity. Therefore the highly positively skewed distributions are perhaps less significant.

After establishing a qualitative impression of skewness in terms of the positive or negative sign of the coefficient, the following thresholds will be adopted:

+ 0.3 to + 1.0	moderate skewness
+ 1.0 and above	very marked skewness

In nature there are very few perfectly normal distributions and hence low coefficients ranging from -0.2 to +0.2 will be regarded as representing near normal distributions, i.e. species with only mediocre yield achievement. Those with negative coefficients in the moderate range will be considered as good achievers, and those with very marked positive coefficients as poor achievers.

Only the Scots pine can be considered as a relatively good achiever and even this species has a less than moderate coefficient of -0.18. Corsican pine and Japanese and Hybrid larch have very low coefficients, suggesting only mediocre achievement in relation to their potential. As the size of the positive coefficient increases, sites are clearly not producing the optimum. Most broad-leaved species show a marked skewness but in the context of their importance for amenity this is not necessarily very significant.

The relationship of the mode to the mean provides a salutory reminder that the applied interpretation of the skewness coefficient has not yet been thoroughly explored by statisticians, and that not too great an emphasis should be placed upon its quantitative values. In no case has the mean been displaced very far from the mode. In all except two cases the mean falls within the modal class, and in both the exceptions - Sitka spruce and Japanese and Hybrid larch - it falls only just outside it. Since these are both cases in which the exact position of the mode lies to one side of the modal class, the difference between mean and mode is still only about one cubic metre, or half a yield class.

However, if a general increase of one cubic metre could be effected for all British species, this would represent a 10 per cent increase in the annual yield (about 0.2 million m^3 in England and Wales) which would be a very useful supplement to the nation's timber production.

STANDARD DEVIATIONS AND RANGE

A summary of the dispersal of the yield classes is shown in Figure 1.9 (p.21). The range of $\pm$ 1 standard deviation has been inserted as pecked lines. The species are ranked in descending order of mean yield and it will be noted that there is an overall tendency for the standard deviations to decrease in the same ranked order as the means for Other conifers (3.4 m^3) to Oak (1.1 m^3).

The ideal distribution of yields for any given species would be a high mean with a low standard deviation, showing that the yields clustered very close to their highest potential. In general, however, low standard deviations are associated with low means, where the total range of yields is too low to accommodate a wide spread. High-yielding species, by contrast, can always fall below their norms on poor sites, and have plenty of headroom for a wide dispersion of values. Thus the high-yielding conifers (Other conifers, Douglas fir, the two spruces and Corsican pine), have wide dispersions, with more than 3 m^3 above and below the mean included in one standard deviation. The moderate yielders, the larches and Scots pine, have more restricted dispersions of $\pm$ 2.2 to 2.7 cubic metres within one standard deviation, while the low-yielding Lodgepole pine and broadleaves are even more bunched into a dispersion of $\pm$ 1.1 to 1.8.

If the low-yielding tail of a high-yielding species is clipped by turning over the worst sites to another species, this reduces the standard deviation and approximates the frequency distribution to the ideal, tightly bunched, normal curve at a high level. This type of normal curve would represent a high-achieving species as compared with the mediocre achievement associated with ordinary normal curves in the last section.

Scots pine is the only species in which the standard deviation could be reduced by a little clipping of the lower-tail in this way. The others all have upper tails, and there is a need to move the mass of the yields bodily upward through the range.

The extreme range of yields for each species is more individually variable than the standard deviation and unlike the latter does not always decrease in the same order of species as the mean. Table 1 explores this problem further by examining the mean yield and upper extreme yield.

Table 1

Difference between Mean Yield and Upper Extreme Yield (m^3/ha)

Species	*Difference*
Sitka spruce	16.87
Douglas fir	14.79
Other conifers	13.81
Other broadleaved	13.23
Norway spruce	12.42
Corsican pine	10.46
European larch	8.63
Japanese and Hybrid larch	8.63
Scots pine	8.62
Lodgepole pine	8.34
Oak	5.88
Beech	4.28

The rank order of scope for improvement indicated by this method is quite different from that suggested by a consideration of the coefficient of skewness. In fact the rank correlation coefficient between the two approaches is only +0.17 and not significant. Neither approach is more than exploratory and should be regarded as preliminary indications only. With that proviso, it may be mentioned that the following species appear in the upper half of both lists: Sitka and Norway spruces, Douglas fir and Other broadleaved.

CONCLUSION

Yield class data have permitted the quantification and comparison of growth rates in a consistent way, to give national norms against which regional variations can be compared. This wide view must necessarily conceal very large variations but there is already seen to be a difference of 9.0 m^3, or over four yield classes, between the mean yields of the fastest and slowest growing species, Douglas fir and oak. Douglas fir grows 213 per cent faster than oak and 40.6 per cent faster than the indigenous Scots pine, but owing to its site requirements is not planted on a scale commensurate with its high volume production.

Large ranges of growth and relatively low mean yields suggest unrealised potential for increased volume production. Theoretically there ought to be a positive correlation between the yield level of each species and the extent of its planting. The correlation coefficient obtained for all the species under discussion is in fact positive, but at 0.4088 it is not significant and this again suggests the need to investigate possibilities for improvement.

Such questions and problems cannot adequately be answered at the national scale of generalisation and it is necessary to analyse yields in the different conditions found throughout the country. For this purpose the discussion moves on to focus upon yields at three successive levels. The macro-level is represented by Conservancies, the meso-level by forests and the micro-level by compartments.

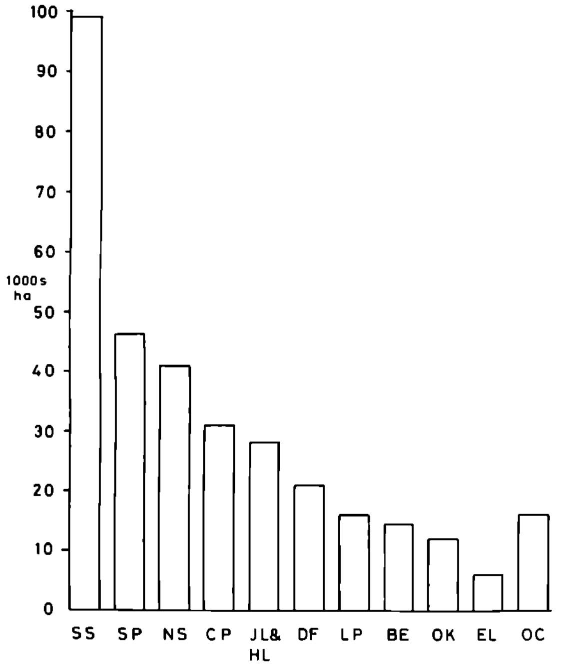


Figure 1.1 Total area by species.

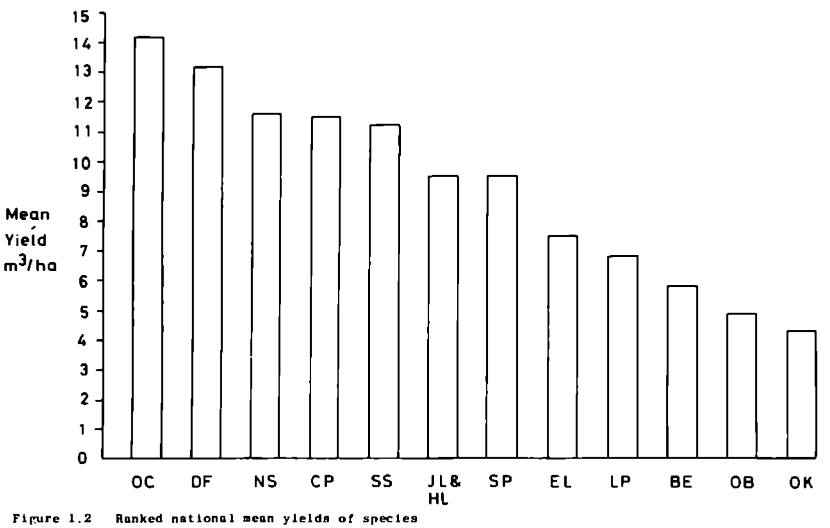


Figure 1.2 Ranked national mean yields of species

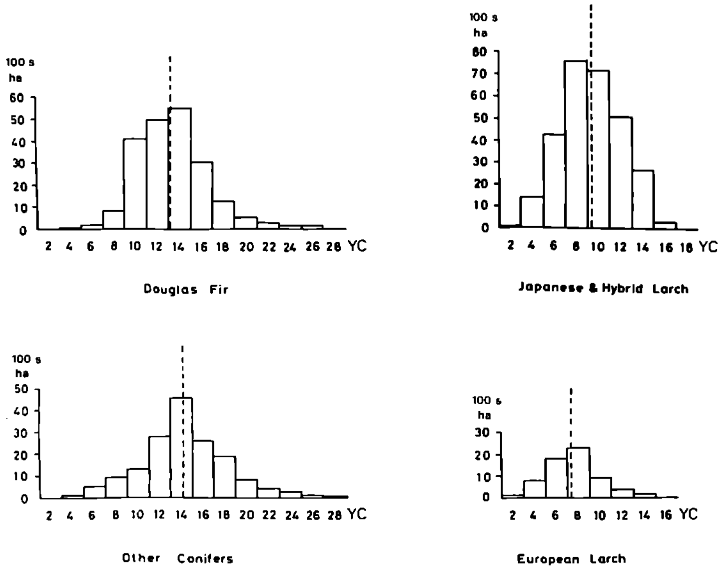
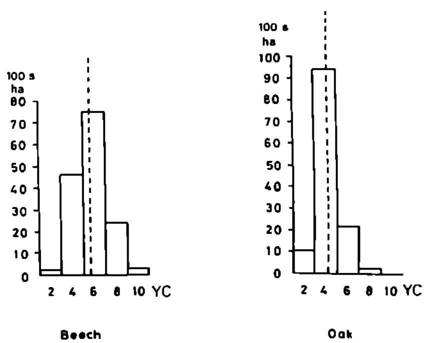


Figure 1.5 Yield class frequencies - European larch, Japanese and Hybrid larch, Douglas fir, Other conifers



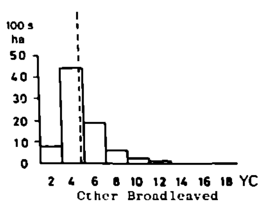


Figure 1.6 Yield class frequencies - Other Broadleaved

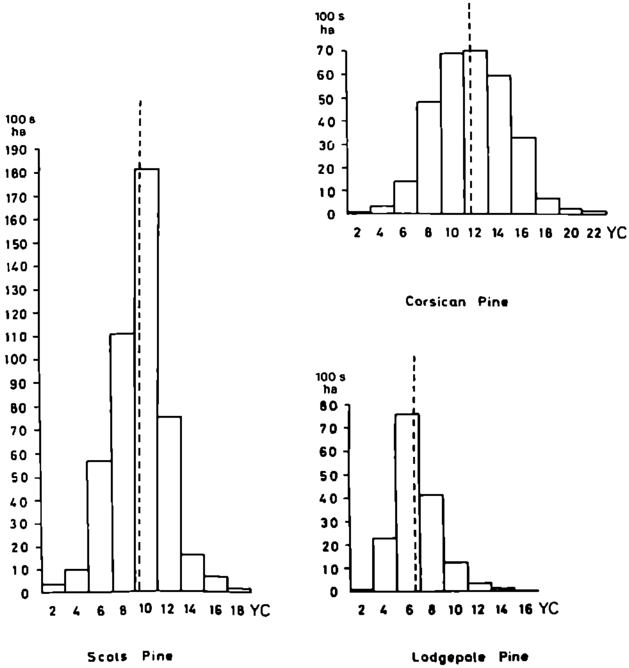


Figure 1.3 Yield class frequencies - Scots pine, Corsican pine, Lodgepole pine.

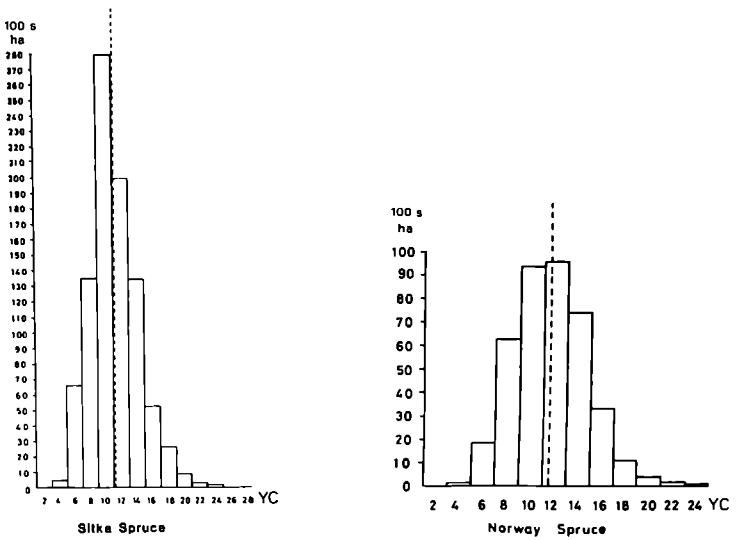


Figure 1.4 Yield class frequencies - Sitka spruce, Norway spruce

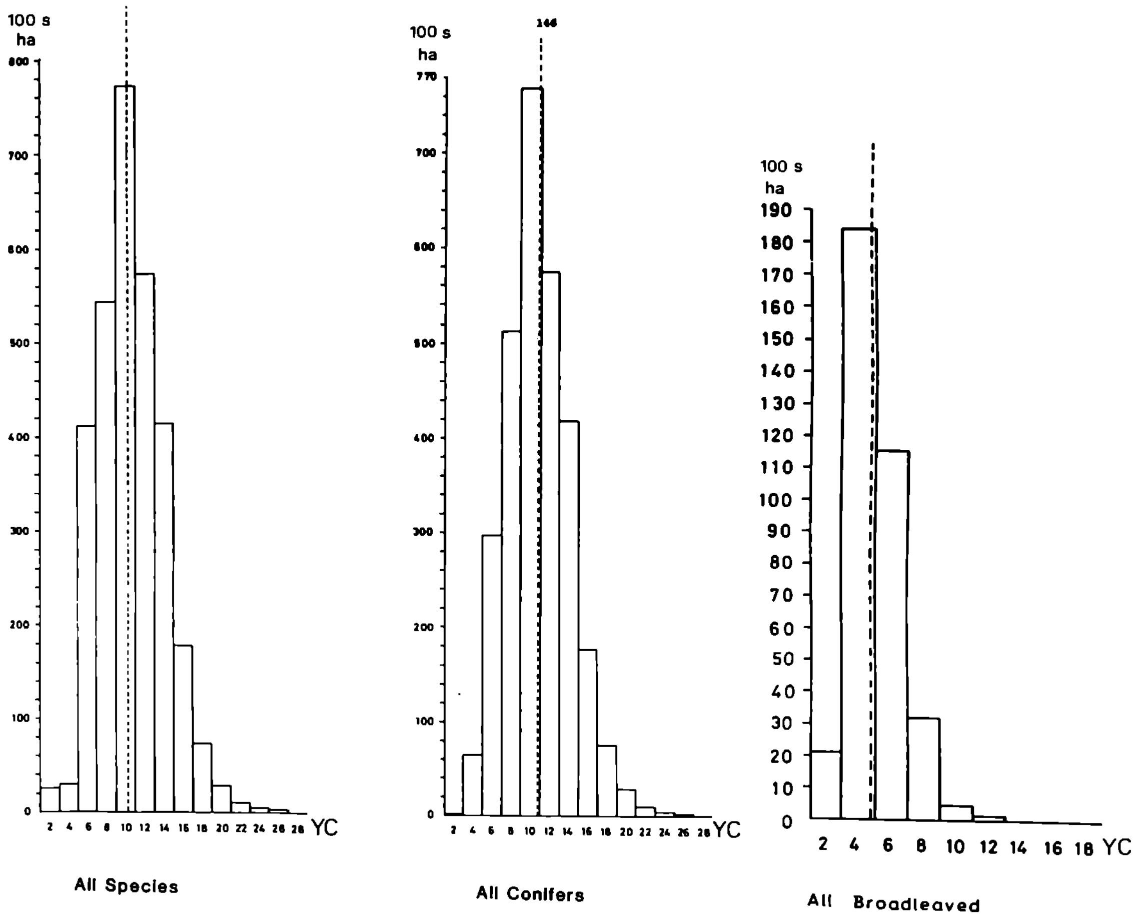


Figure 1.7 Yield class frequencies - All species, Conifers, All Broadleaved

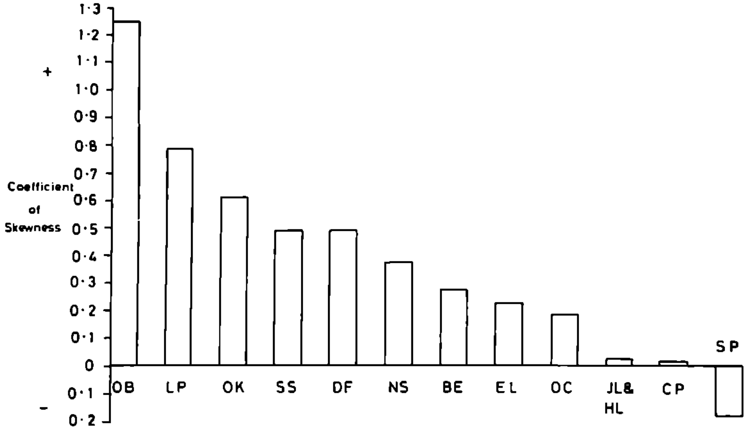


Figure 1.8 Ranked skewness of national frequency distributions

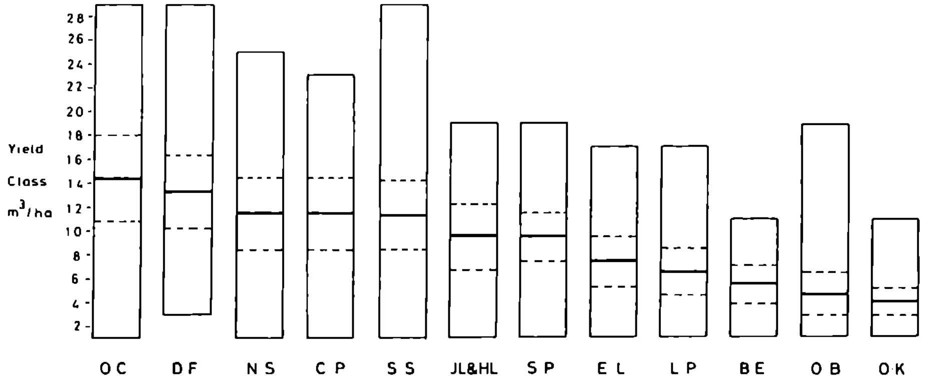


Figure 1.9 Range and standard deviations for individual species and groups

CHAPTER 2

SPATIAL VARIATIONS BY CONSERVANCIES

INTRODUCTION

Although the Conservancies (Figure 7.1, p.97) are not coherent geographical regions and cover a wide variety of sites, climates, and elevations, they offer an opportunity of evaluating species yields at a regional or macro-level. Four methods have been used: maps, frequency distributions, skewness coefficients and dispersion diagrams.

These four methods will be used sequentially for each species or group of species in an attempt to detect the best performances either for species or Conservancies. The conclusions drawn independently from each method will be compared and similarities and contrasts between the species will be noted.

Since three of the methods have already been used in the previous chapter only the use of the maps needs to be explained here. They are used to show the distribution of Conservancy means. Since the Conservancy means are averages of a wide range of means for smaller areas, they tend to cluster fairly closely around the national mean for each species, and only seven yield classes are involved, ranging from 4 to 16 m^3/ha. These can be represented either by colours or, as in Figures 2.1 and 2.2 (pp.27 & 28), by shading.

SPECIES DISTRIBUTION IN THE CONSERVANCIES

Before analysing yield variations by the four methods mentioned above it is instructive to examine the distribution of planted area in the seven Conservancies as they may not follow the national ranking of species. Sitka spruce which is dominant nationally is also dominant in all but the East and South East Conservancies where pines predominate. The Japanese and Hybrid larch group is particularly prominent in South Wales while European larch is sparsely planted in all Conservancies. Douglas fir is present in all Conservancies but is noticeably more abundant in the South West. The broadleaved species are important only in the South West and South East. The South West, and to a lesser extent, South East have the most even quantities of conifers and broadleaved species. The latter Conservancy has the least Forestry Commission woodland, while the North East and the two Welsh Conservancies account for about 55 per cent of all the Commission's productive forest in England and Wales. The uneven proportion and variable amounts of different species in the Conservancies reflect problems of land acquisition, finance, and the need to match species to sites.

Scots pine

The first impression afforded by the map of mean yields for Scots pine (Figure 2.3, p.29) is that all the Conservancies cluster very closely around the national mean of 9.4 which is within the class interval of yield class 10. In the North West, South West, South East and East the yield class is the same as for the national average while the Welsh Conservancies and the North East are in the next lower class. The map suggests that poorer growth may be associated with Conservancies which have a preponderance of higher ground. The North West with its long north-south extent has more lowland than upland, and so its average level of yield adheres to this pattern. The association of poor yields with high ground is consistent with Scots pine's dislike of high rainfall as recognised in the conventional guidelines (Forestry Commission, 1978). Overall, it seems to grow better in the drier lowland zone.

Planting appears to be well related to yield patterns and Figure 2.3 (p.29) shows that Scots pine is generally more concentrated where growth is relatively good, i.e. in the East, North West, and South East. The North East and South West are anomalous since the former, with a larger than average area of Scots pine, has below average yields whereas the South West with average growth was a very small planted area. The smaller areas in Wales seem justified in view of the species' poor performance there.

Figure 2.4 (p.29) shows that the skewness coefficients fit much the same pattern. Although Scots pine has a negative coefficient nationally, only two of the Conservancies have negative skewness, but these are two of the four higher yielding areas, the North West and South East. The North West has a very marked negative coefficient, suggesting a preponderance of planting on good sites. The other two high-yielding Conservancies except the South West, the East and North East have moderate positive coefficients. The only anomaly is the North East where low yields are fairly normally distributed. Here there is no elongated upper tail to give the impression that much better sites exist and could perhaps have been used.

Perhaps a better indication of growth potential is illustrated by means of the range in Figure 2.5 (p.29) which shows that growth rates of up to 18 m^3/ha are possible in the South East and South West. This is 8.6 m^3/ha above the mean.

Although the maximum yield value declines to 16 m^3/ha in the East and to 14 m^3/ha elsewhere the differences between the means and upper range values still demonstrate that there may be some prospects for better yields.

In general, however, Scots pine shows small growth variations in comparison with other species. Its small spatial deviations from the national average would seem to make it a reliable species for minimising poor returns, as might perhaps be expected from the only indigenous conifer. On the other hand, it is a poor species for maximising high returns, a role that is more effectively filled by exotic conifers, e.g. Sitka spruce.

Sitka spruce

This species with a mean yield of 11.2 m^3/ha grows faster than the pines in all Conservancies except for Corsican pine in the North East and South Wales and both Corsican and Scots pine in the North West. The spatial pattern of mean yields (Figure 2.2, p. 28), shows a general northward decline from 14 m^3/ha to 10 m^3/ha, with the exception of South Wales which is anomalously low.

Planted area and yield do not correspond closely. Although good growth in the South West and South East is possible the species is hardly used there (Figure 2.6, p. 30) because of the low rainfall and lack of moist sites. It is almost exclusively confined to the Welsh Conservancies and the North East, i.e. the highland zone where conditions considered unfavourable to Scots pine are more suitable for Sitka spruce.

The abundant use of poor sites is illustrated by Figure 2.7 (p. 30) which shows that there are no negative skewness values for any Conservancy and only in the North East, North Wales and the South West does the distribution of yield classes approach normal. The national skewness coefficient of +0.5 is exceeded by South Wales and the North West, both of which have below average mean yields, and moderate degrees of skewness.

Figure 2.8 (p.30) shows that the range of growth in the Conservancies is clearly greater in the more moist, upland regions especially North Wales with 28 m^3/ha maximum. The smallest range occurs in the East where there is least scope for raising yields at the upper end of the range, but also less risk of very low yields. In the southern Conservancies, where the best growth occurs, the mean is 10 to 12 m^3/ha and large standard deviations of 3.1 and 4.2 m^3/ha indicate the growth potential of southern Conservancies and that on suitable sites good growth is possible.

The yield distribution maps for other species are shown in Figure 2.1 & 2.2 on pp.27 to 28 and inferences may be drawn from them in a similar way.

CONCLUSION

The methods used above to interpret variations in Conservancy yields of Scots pine and Sitka spruce help to clarify a complicated picture and to distinguish critical features relevant to the scope for improvement. By a study of the diagrams for the other species similar features can be distinguished but the picture is as yet only tentative. This is presumably because Conservancy mean values necessarily incorporate values from a wide variety of sites with environmental differences, and incorporate a high degree of generalisation. It is possible to distinguish broad patterns such as the higher yields of Douglas fir in the west and the higher yields of pines in the east of the country, but even though species such as Corsican pine are being concentrated where better growth is possible, it seems likely that forest potential is generally being under-realised in relation to the known growth responses of the species. The discrepancies are most apparent between the North East Conservancy with the largest forest area and the lowest yields and the South West with the least forest and highest yields.

These problems may be summarised further by plotting the Conservancy means in relation to the national mean for each species as in Figure 2.9 (p.31). It is clear that the rank order of Conservancies according to this scheme is (a) South West and South East, (b) South Wales, (c) East and North Wales, (d) the North West and (e) the North East. The North East is below the national average in every case suggesting that environmental rather than genetic causes are responsible.

A further summarising measure can be obtained by correlating Conservancy mean yields and Conservancy planted areas by species to test whether there is a significant relationship between these variables. Table 2, listing the Pearson Correlation Coefficients obtained, shows only four statistically significant values, and furthermore only two of these, Corsican pine and beech, are positively correlated. This indicates that Corsican pine and beech are planted more extensively as mean yield increases and although these relationships have been mentioned above, especially for Corsican pine, the association for beech was less clear. In the case of Lodgepole pine there is an inverse relationship between planted area and yield and is explained by the deliberate choice of this species as a coloniser for poor sites. The high negative value of 0.7787 for 'All conifers' is further but more generalised evidence that forestry is not always being concentrated where better yields are possible, most probably because such land cannot be released to forestry. Apart from Douglas fir and 'Other conifers' all the conifers have negative values whereas, apart from 'Other broadleaved', all the broadleaves have positive values, though none are significant. Ideally all values should be significantly positive indicating that species and site are best matched.

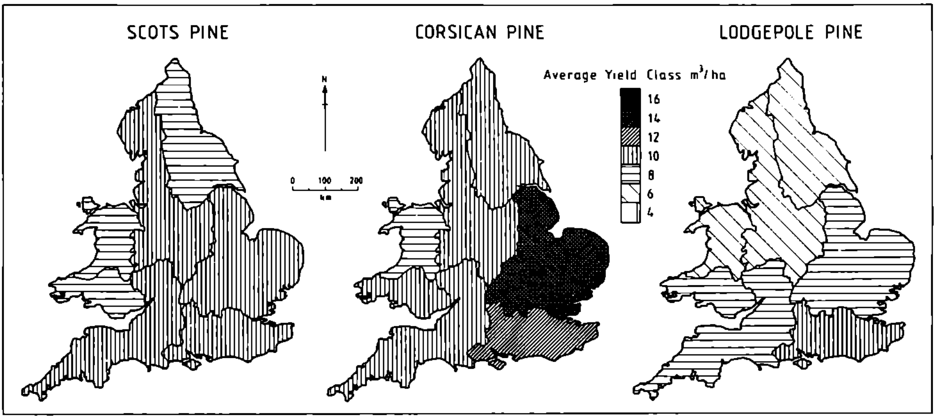
Table 2

Correlation Between Mean Yield and Planted Area

Species/Group	*Correlation coefficient*
Scots pine	- 0.3085
Corsican pine	0.8665*
Lodgepole pine	- 0.7883*
Sitka spruce	- 0.5398
Norway spruce	- 0.3709
European larch	- 0.1496
Japanese and Hybrid larch	- 0.1408
Douglas fir	0.6342
Other conifers	0.3582
All conifers	- 0.7787*
Oak	0.0865
Beech	0.8642*
Other broadleaved	- 0.5355
All broadleaved	0.5343
All species	- 0.2922

* Significant at the 0.05 level

Further analysis of statistical association and significance of the data is necessary and the problem of Conservancy and species mean yields is treated in greater depth in Chapter 3.



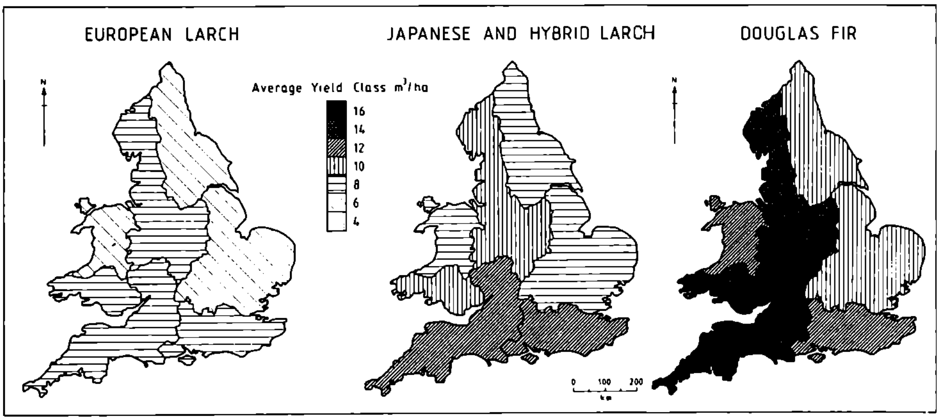


Figure 2.1 Yield maps for Scots pine, Corsican pine, Lodgepole pine, European larch, Japanese & Hybrid larch, Douglas fir

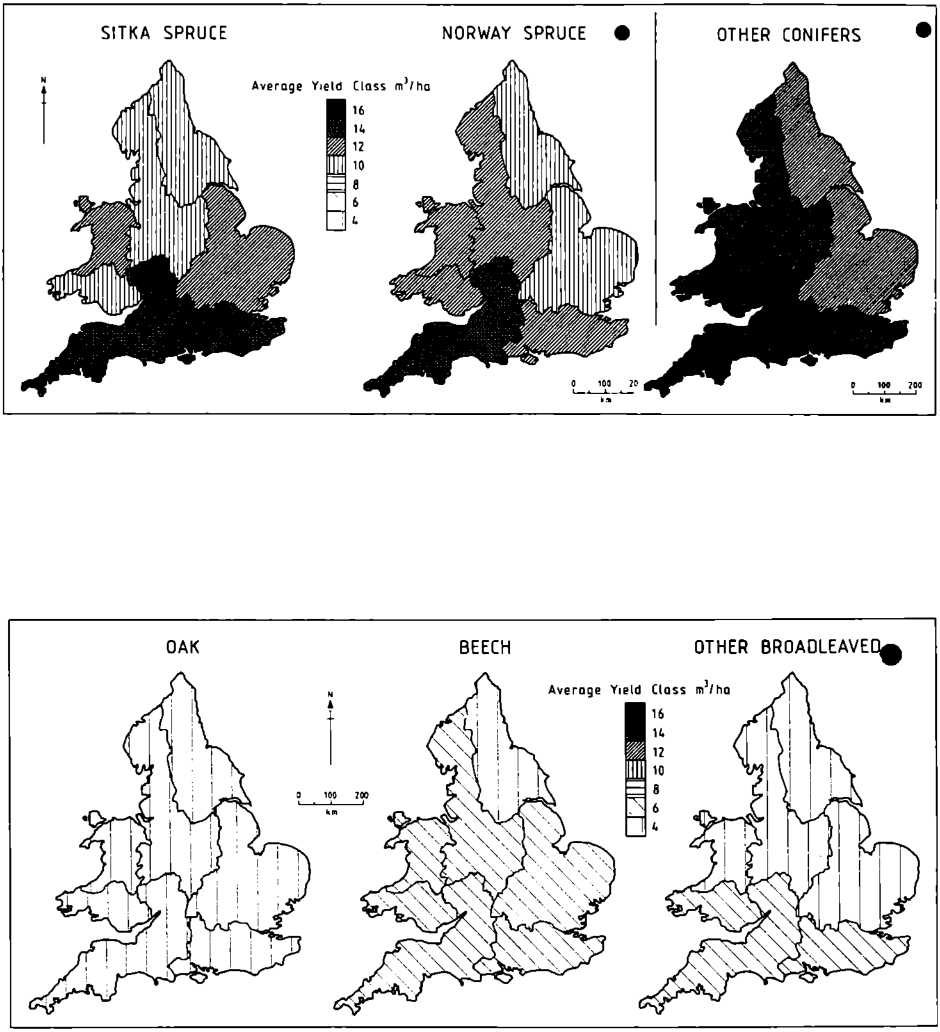


Figure 2.2 Yield maps for Sitka spruce, Norway spruce, Other Conifers, Oak, Beech, Other Broadleaved

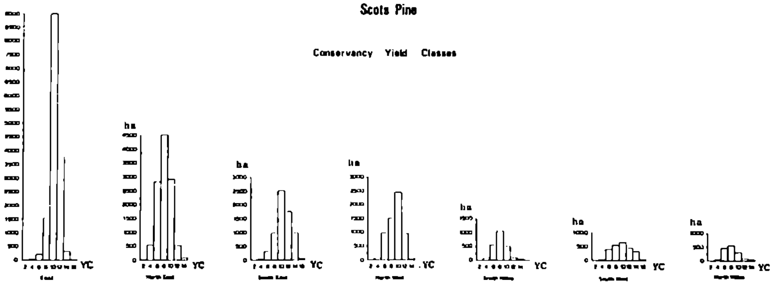


Figure 2.3 Frequency distributions of Scots pine

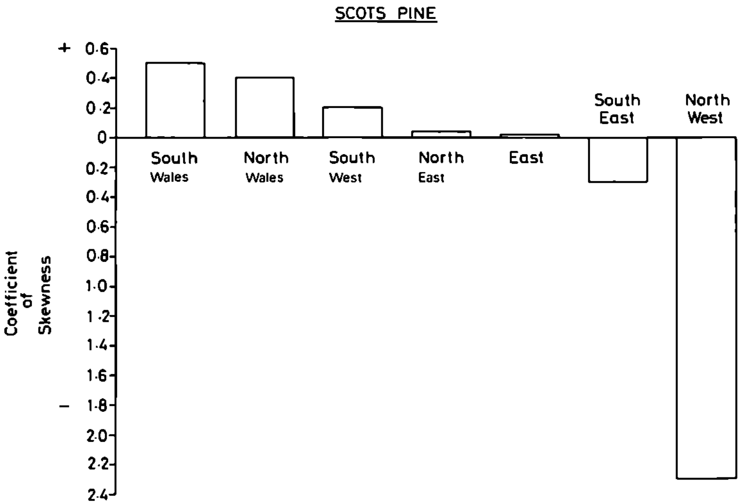


Figure 2.4 Skewness coefficients of Scots pine

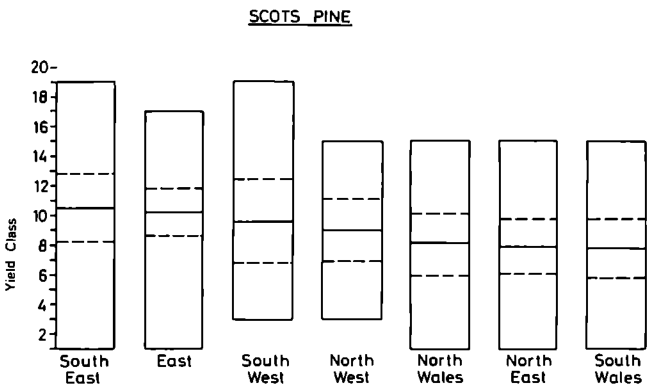


Figure 2.5 Range and standard deviations of Scots pine

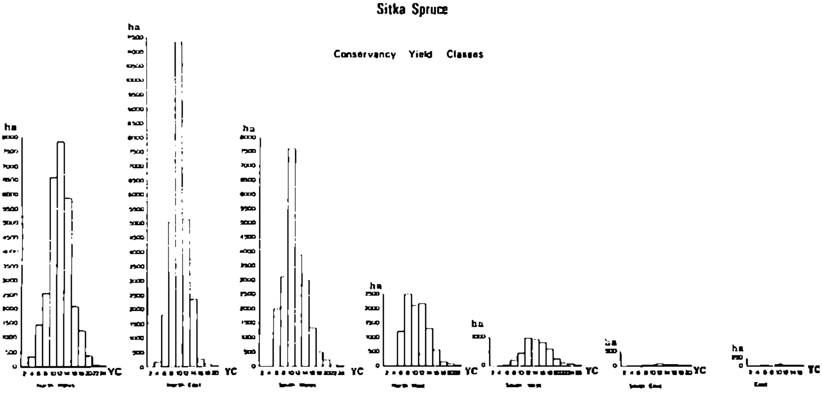


Figure 2.6 Frequency distributions of Sitka spruce

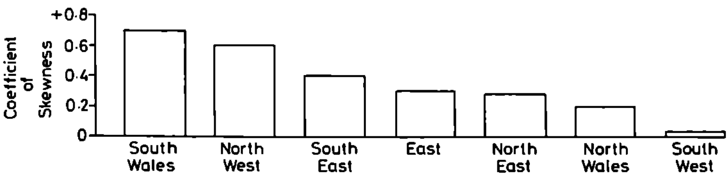


Figure 2.7 Skewness coefficients of Sitka spruce

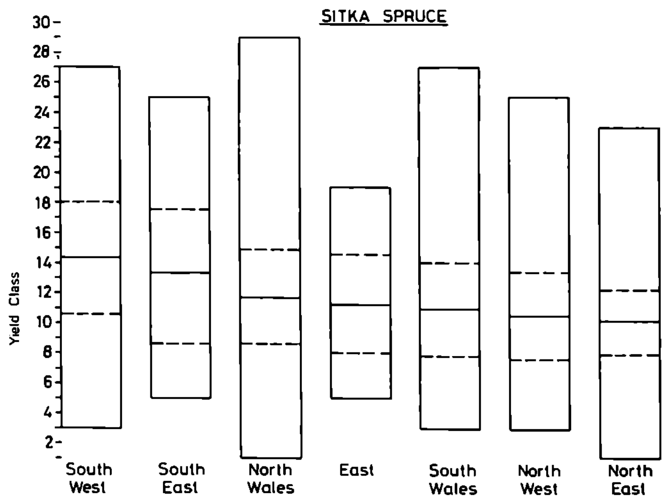


Figure 2.8 Range and standard deviations of Sitka spruce

CONSERVANCY PERFORMANCE IN RELATION TO NATIONAL MEAN YIELDS

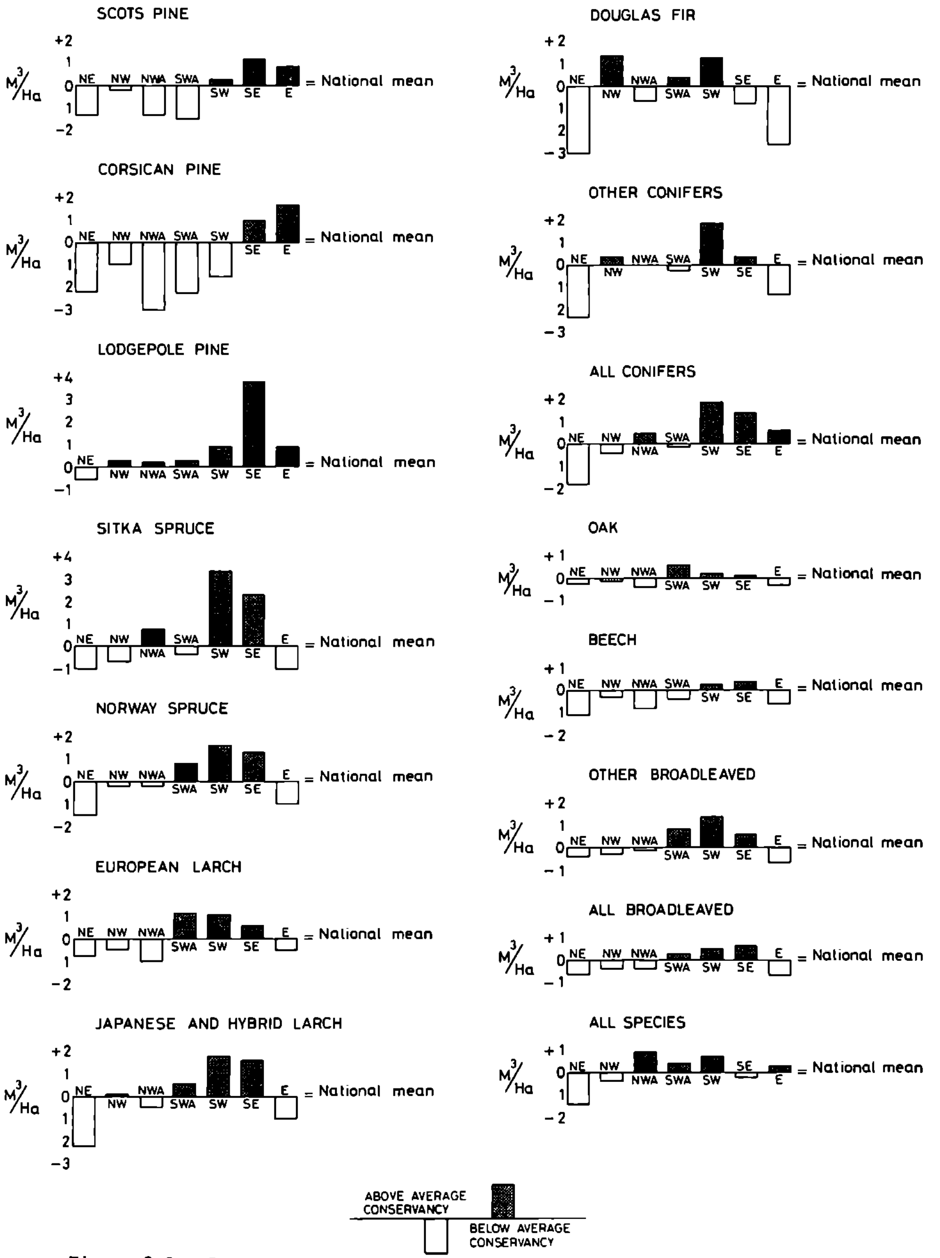


Figure 2.9 Conservancy means in relation to the national means

CHAPTER 3

STATISTICAL ANALYSIS OF VARIATION BY CONSERVANCIES

INTRODUCTION

The preceding chapter was concerned with a description of yield variations by Conservancies, using graphical methods such as maps and diagrams together with descriptive statistics such as means and standard deviations.

This chapter is concerned with the statistical significance of the differences that have been described, and for this purpose use will be made of two types of inferential statistical tests, namely analysis of variance and the Duncan Multiple Range test.

ANALYSIS OF VARIANCE

Since it is desirable to test the difference in yields by species as well as by Conservancies, a two-way analysis of variance was applied, using null hypotheses of no significant difference between yields in respect of both these factors. The mean yields are set out in Table 3 and the results are set out in Table 4.

Table 3

Two-Way Analysis of Variance

Source of Variation	*Degrees of freedom*	*Sum of squares*	*Mean square of the estimate (MSE)*	*F*
Conservancies	6	54.364	9.06	11.92 ***
Species	11	798.595	72.59	95.51 ***
	66	50.48	0.765	
Total	83	903.439		

*** Significant at 0.001 level

The F statistic for the Conservancy effect is 11.92 and as this is greater than the Tabled value of 3.12 which is the critical limit of F with 6 and 66 degrees of freedom at the 0.001 level, the null hypothesis is rejected. There is therefore, a very highly significant difference between Conservancy mean yields. Similarly, since an F value of 95.51 for the species effect is greater than the Tabled value of 2.63 which is the critical limit of F with 11 and 66 degrees of freedom at the 0.001 level, the null hypothesis is rejected and there is also a very highly significant difference between species mean yields.

Table 4

Mean Yields by Species and Conservancies

	Conservancies						
	North East	*North West*	*North Wales*	*South Wales*	*South West*	*South East*	*East*
SP	8.05	9.20	8.12	7.92	9.69	10.57	10.32
CP	9.39	10.52	8.57	9.23	10.01	12.47	13.27
LP	6.17	6.91	6.81	7.00	8.60	10.44	8.52
SS	10.14	10.53	11.89	10.96	14.39	13.48	11.32
NS	10.06	11.52	11.52	12.38	13.21	12.92	10.65
EL	6.63	7.01	6.39	8.53	8.42	7.99	6.98
JL & HL	7.23	9.49	8.86	10.01	11.17	10.99	8.36
DF	10.36	14.56	12.57	13.61	14.53	12.65	10.68
OC	11.94	14.64	14.19	13.96	15.89	14.59	12.91
OK	4.01	4.17	3.88	4.82	4.35	4.25	3.93
BE	4.64	5.35	5.03	5.38	5.95	6.13	5.12
OB	4.34	4.43	4.70	5.54	6.16	5.41	4.21

THE DUNCAN MULTIPLE RANGE TEST

The analysis of variance has shown that there is a significant variation in yields both among Conservancies and also among species, but it does not show which of the species or Conservancies are responsible. It is possible that some are not significantly different from others, and that only a few of the means are responsible for the overall difference. There is a need, therefore, for a statistical test, which will not only give an overall result, as analysis of variance does, but will also indicate whether any group of means differs significantly from other groups of means. This degree of differentiation can be provided by the Duncan Multiple Range test (Miller and Freund, 1965).

This test can be applied to data suitable for one-way analysis of variance, provided that sample sizes are equal, and therefore in this case it must be applied twice, respectively to Conservancy samples and to species samples.

The test compares the range of any set of p means with a corresponding *least significant range,* R_p

R_p is calculated as a product of two expressions:

a) a constant, $\sqrt{\frac{MSE}{n}}$, which is derived from the error MSE in the analysis of variance table, and

b) a variable, r_p, which is derived from the Duncan table for the required significance level by consulting the row for the number of degrees of freedom corresponding to the MSE and the column for the number of means in the range under consideration.

Thus $R_p = \sqrt{\frac{MSE}{n}} \,.\, r_p$, (more usually expressed $S_{\bar{x}} \,.\, r_p$)

Application of the Test to Conservancies

The Conservancy means are ranked in order in Table 5, from which successive sets of p means can be isolated for the purpose of calculating ranges. As p refers here to the number of Conservancies, n refers to the number of species, namely 12, and the value of

$$\sqrt{\frac{MSE}{n}} \text{ is } \sqrt{\frac{0.765}{12}} = 0.252$$

Table 5

Conservancy Means in Ranked Order

Conservancy	NE	NW	SE	E	SWA	SW	NWA
	8.89	9.87	10.04	10.21	10.54	10.84	11.08

The observed range for any set of two, three, four, five, six or seven means is calculated by subtracting the lowest value in the set from the highest. Thus, there is only one possible set of seven means, with a range of 2.19, while there are two possible sets of six means, with a range of 1.95 between the first and sixth, and 1.21 between the second and seventh. The complete list of range values is listed in Table 6.

The corresponding theoretical values, or *least significant ranges,* R_p, are set out in Table 7 using the 0.01 level of significance and 66 degrees of freedom.

Table 6

Observed Range Values for Conservancies

p (No. of means to be compared)	*2*	*3*	*4*	*5*	*6*	*7*
Ranges	1.02	1.25	1.32	1.65	1.95	2.19
	0.17	0.34	0.67	1.07	1.21	
	0.17	0.50	0.80	1.04		
	0.33	0.63	0.87			
	0.30	0.54				
	0.24					

Table 7

Theoretical R_p Values for Ranges of Conservancy Means

p (No. of means to be compared)	*2*	*3*	*4*	*5*	*6*	*7*	
r_p	3.76	3.92	4.03	4.11	4.18	4.23	(Values from Duncan Tables)
r_p x 0.252	0.95	0.99	1.02	1.04	1.05	1.07	(R_p)

The value of R_p in any column represents the critical value for comparing with the ranges of any two, three., four, five, six, or seven sets of means. Where the observed range between means exceedsthe R_p values the differences are significant. Differences which are less than the critical R_p values are therefore not significant.

In relation to the Conservancies it is seen that the observed range between the two extreme means, i.e. those of the North East and North Wales is 2.19 which is greater than the R_p value of 1.07 and therefore significant. From this it is concluded that there is a highly significant difference between the means of the North East and North Wales Conservancies. The same procedure is followed for comparing the range between the lowest mean (North East) and the second highest (South West) and also between the highest and the second lowest (North Wales and North West). The differences respectively 1.95 and 1.21 are both greater than the critical R_p value of 1.05 for comparing six means, and are therefore significant. The table of R_p values is worked through until all observed ranges have been tested. The results are summarised in Table 8 where a line is drawn under any set of adjacent means for which the range is less than the appropriate R_p value, and therefore not significant.

Table 8

Conservancy Groupings

Conservancy	NE	NW	SE	E	SWA	SW	NWA
Mean Yield	8.89	9.87	10.04	10.21	10.54	10.84	11.08

Table 8 shows that Conservancies may now be grouped into two classes between each of which there is a significant difference in mean yield. This significant difference between the Conservancies shows that they fall into two response groups as follows:-

Low Response	*Medium Response*		
NE	NW	SE	E
	SW	SWA	NWA

The low response of the North East Conservancy is not unexpected in view of its observed poor performance shown in Chapter 2, but the medium response group of six Conservancies is surprising in view of the highly variable individual species performance there. The aggregation of the medium response Conservancies is caused by the overall weighted mean incorporating large areas of high volume producing species in Conservancies such as North Wales and by large areas of low volume producing species in Conservancies such as the South East. Thus the weighted All species mean tends to even out the differences that actually exist between Conservancies for individual species except in the case of the North East which is overall significantly different from the other six Conservancies.

The relationship between these two groups and the overall species mean is shown graphically in Figure 3.1 (p.40). Although there is a general upward trend of yields between the North East and North Wales Conservancies the rate of increase varies especially between the North East and the North West Conservancies, and there are marked deviations above and below the mean trend for individual species.

Application of the Test to Species

The Duncan test can now be applied to distinguish significant differences between species means, and to see whether the differences between the five groups previously distinguished by eye (Chapter 2, p.22)are great enough to be statistically significant. The same procedure is applied as for the Conservancy means, and in this case

$$\sqrt{\frac{MSE}{n}} = \sqrt{\frac{0.765}{7}} = 0.331$$

where n is the number of Conservancies.

Thus value r_p from the Duncan table for the 0.01 level and 66 degrees of freedom are multiplied by the constant 0.331 to give the R_p values shown in Table 9.

Table 9

Theoretical R_p Values for Ranges of Species Means

p	2	3	4	5	6	7	8	9	10	11	12
R_p	1.24	1.30	1.33	1.36	1.38	1.40	1.41	1.43	1.44	1.45	1.48

The ranked means of the 12 species have been underlined for groupings over which the range is less than the theoretical value of R_p, i.e. where the differences are not significant at the 0.01 level (Table 10).

Table 10

Species Groupings

Species	*Oak*	*OB*	*BE*	*LP*	*EL*	*SP*	*JL & HL*	*SS*	*CP*	*NS*	*DF*	*OC*
Mean Yield	4.22	4.77	5.72	6.66	7.37	9.35	9.37	11.18	11.54	11.58	13.2	14.19

For the species the Duncan test shows many more significant differences, reducing the range of groupings to pairs or triplets. However, for the five lowest yielding species there are four overlaps and the differences between pairs are very small so it seems reasonable to combine all of these into a single group, instead of two groups as suggested by visual inspection in Chapter 2. The pecked lines mark the divisions between groups of species for which the means are significantly different, giving four distinct yield categories.

Low Yields	*Medium Yields*	*High Yields*	*Very High Yields*
Oak	Scots pine	Norway spruce	Douglas fir
Beech	Japanese and	Corsican pine	Other conifers
Other broadleaved	Hybrid larch	Sitka spruce	
Lodgepole pine			
European larch			

It is clear that the four yield groups are not genetically determined. The Low Yield group includes all the broadleaves together with Lodgepole pine and European larch, while the other two pines fall into the Medium and High Yield groupings respectively. Such a result is not unexpected and all the groups reflect what has been foreshadowed in Chapter 2.

The overall ranked species means and the four groups are depicted graphically in Figure 3.2 (p.41). The dotted lines indicate the groups and the continuous line shows the overall upward trend in yields between the low extreme of Oak and the high extreme of Other conifers. The rate of yield increase between groups is seen to be noticeably steeper than the more even trend of yields within each group. This line in Figure 3.2 (p.41) acts as a reference level against which to compare the species performance for each individual Conservancy. The Conservancies are discussed in the same ranked order as set out on page 34.

Figure 3.3 (p.41) shows that whilst for North East England the trend is consistently below the national mean the performances for the North West, East, South Wales and North Wales Conservancies, with one or two notable exceptions, are very close to the national mean. South East and South West England, however, lie consistently above the datum (Figures 3.4 - 3.9, pp.41-42)

This exercise emphasises the intrinsic importance of Conservancy variations, particularly for individual species and also confirms that certain species appear either highly unsuitable or alternatively, highly appropriate for more specific locations.

The graphs show that yields of the pines especially, Lodgepole pine and Corsican pine, deviate most strongly from the national datum particularly in the East and South Wales. The high-yielding spruces deviate from the national reference level most noticeably in the South West, East and South East Conservancies.

CONCLUSION

Differences between Conservancy mean yields and species mean yields are statistically very highly significant and a more rigorous treatment of the data has helped to confirm earlier observations based upon descriptive statistics and graphical techniques. The Duncan test has made it possible to separate unlike species and unlike Conservancies into distinctive groups. This helps to overcome the problem of interaction between genetic differences in species and diversity of sites. The Duncan test for Conservancy and species means corroborates some of the earlier suggestions in Chapter 2 about their performance. But it is clear that these groupings are not necessarily followed closely either by all the species in the case of the Conservancy groupings, or by all the Conservancies in the case of the species groupings. This suggests that although it is possible to distinguish, differentiate and evaluate yields into basic patterns and groups at Conservancy level, much of the variation can only be observed rather than directly accounted for. It is necessary, therefore, to sharpen the focus and enlarge the scale of analysis by investigating the spatial variation of yields at the forest level, (or meso-level), to see whether forest yields are typical of Conservancy variability and also to relate more detailed growth variations to selected environmental factors which may help to explain growth differences.

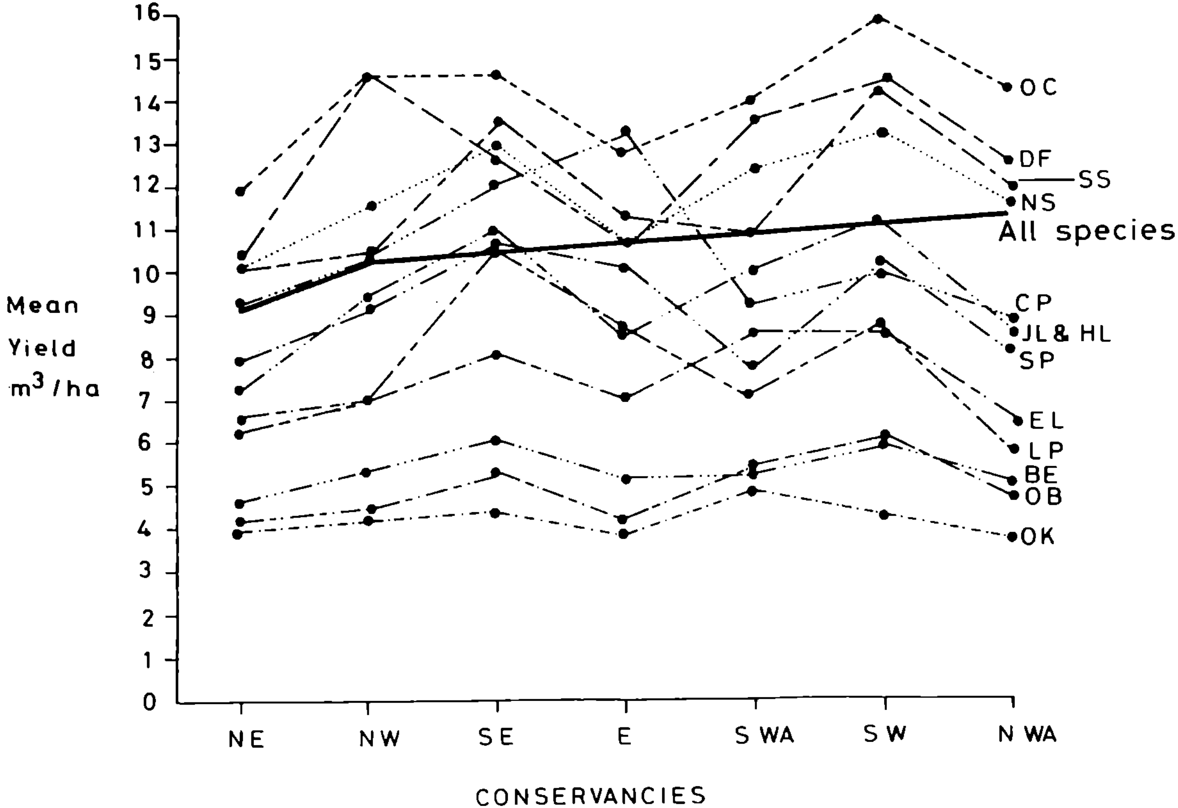


Figure 3.1 Species means in relation to Conservancy ranking

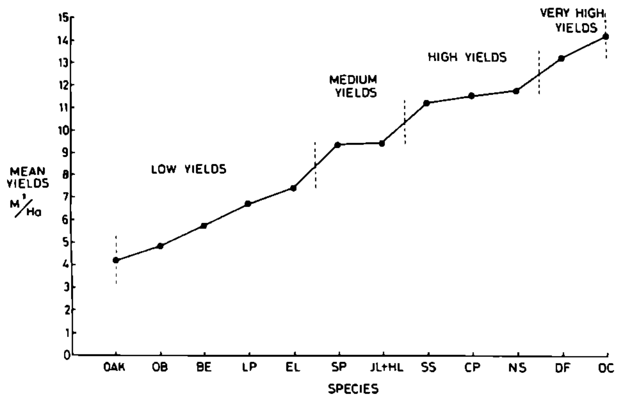


Figure 3.2 Species groupings and overall ranked means

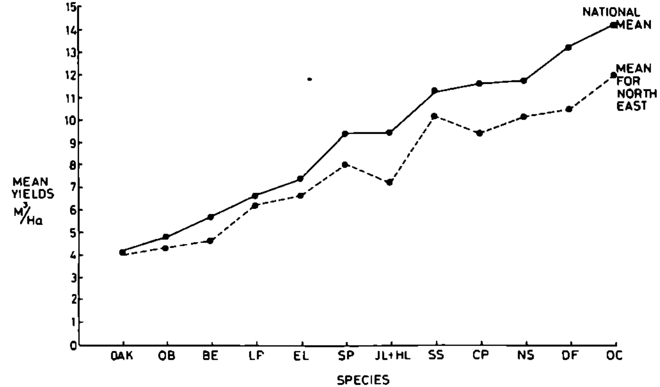


Figure 3.3 Relationship between All species means and the North East Conservancy

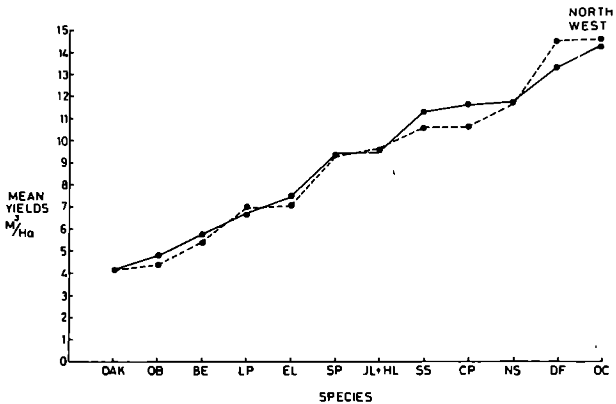


Figure 3.4 Relationship between All species means and the North West Conservancy

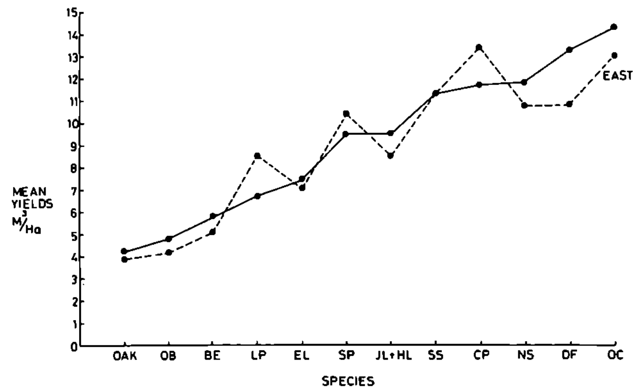


Figure 3.5 Relationship between All species means and the East Conservancy

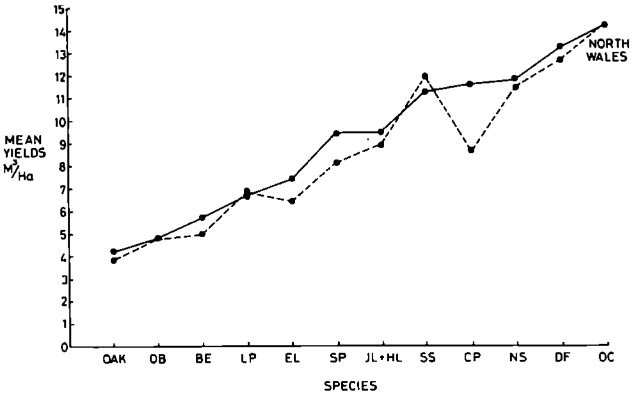


Figure 3.6 Relationship between All species means and the North Wales Conservancy

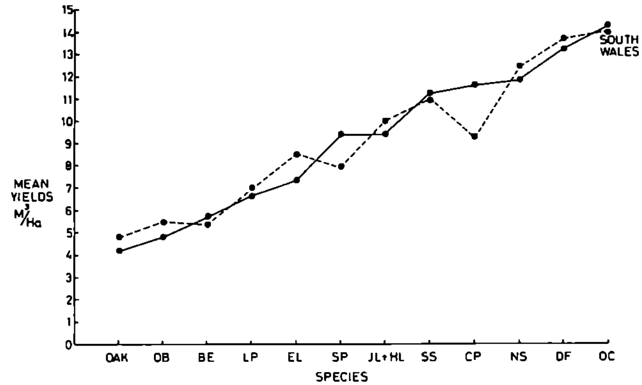


Figure 3.7 Relationship between All species means and the South Wales Conservancy

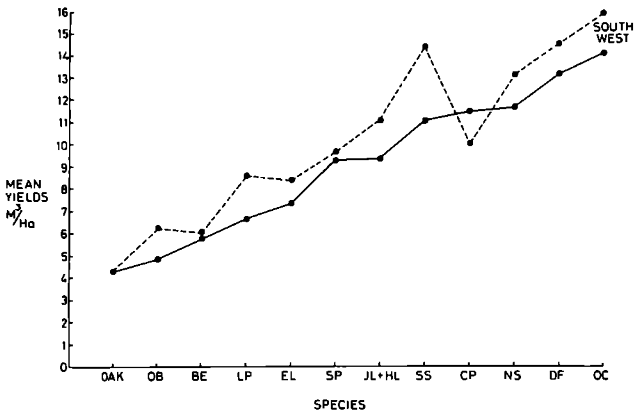


Figure 3.8 Relationship between All species means and the South West Conservancy

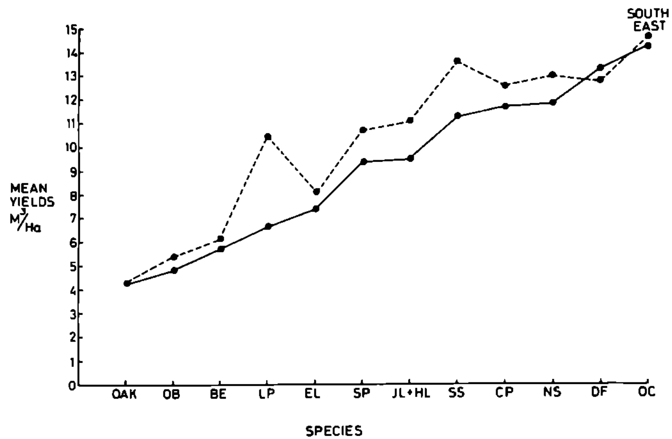


Figure 3.9 Relationship between All species means and the South East Conservancy

CHAPTER 4

VARIATIONS BY FORESTS

INTRODUCTION

Just as the broad national figures conceal spatial variations in yield which are revealed at the Conservancy level, so it may be expected that the Conservancy figures conceal more detailed variations existing between individual forests, and it is the purpose of this chapter to explore this more detailed level, using the forests as units.

THE SELECTION OF FOREST-UNIT LOCATIONS

In 1975 the Forestry Commission reorganised its English and Welsh forests into 208 management units, each of which embraces a number of scattered woodland parcels, which together with the number of forest units in each Conservancy is shown in Table 11.

Table 11

Number of Forest Units and Woodland Blocks

Conservancy	*Forest Units*	*Woodlands*
North East	54	214
North West	36	400
North Wales	23	667
South Wales	29	499
South West	30	350
South East	20	315
East	16	440
Totals	208	2885

NB. It should be noted that the forest units are constantly being amalgamated and that these figures refer to 1975 data only.

These figures reflect the fact that the North East, which has the largest area of forest, consists of a relatively few, contiguous units in contrast to the extremely fragmented nature of forests in Wales, although in the latter the forest units are closer together.

The 2885 blocks of woodland represent the actual sites on which the trees grow but such a large number of blocks is difficult to handle and almost impossible to map clearly at an appropriate scale. Moreover, yield class data for the forests apply only to the 208 units since the measurements are aggregated from samples spread through the blocks.

As a first approach to the mapping problem, it was necessary to decide where to locate the yield class value in relation to a given forest unit. In the case of a large, contiguous or a small, compactly clustered forest unit, the yield class value can be located at the centre of that unit. But in the case of forest units with widely scattered parcels it would be more meaningful to relate the yield class value to each separate block of woodland. As a compromise between detail of location and manageability of data points, it was decided to identify the major outlying blocks and treat them as separate entities. This gave a total of 367 data points which, it was felt, adequately represented the forest distribution.

COMPUTER MAPPING OF FOREST YIELDS

For this purpose smoothed isarithmic mapping is desirable and since the large volume of data and their complexity require computer methods, the versatile SYMAP Contour program was chosen as the most suitable and practical solution to the problem.

Contour SYMAPS are used to describe continuously varying data from observations made at discrete locations and thus fall into the class of isogram maps. The isogram, or contour, is constructed by passing lines through points of estimated equal value. The estimate is calculated on the basis of the information that is available on a grid of known points which may be either regularly or irregularly spaced. Values for unknown points are interpolated on the basis of a consistent mathematical criterion and SYMAP interpolates or extrapolates in the following manner. A grid of cells of a specified size is imposed by the computer upon the map to be created. The cells are usually the size and shape of a single printing character in the line printer of a computer. Certain cells contain the real spatial location of the known data points which are then printed in the appropriate class shading. The values of all other cells must be interpolated or extrapolated. The calculation is made on the basis of the nearest four to ten known cells, the exact number depending upon their density and distribution. The values calculated for the unknown cells are weighted in proportion to the inverse square of the straight line distance from the known cells. The weighted values are then adjusted on the basis of the spatial directions of the known cells and also to allow for the local trend of the surface. The resultant number field acts as a continuous surface and may be considered the 'most probable' surface based on the given information and certain mathematical constraints. At the time of printing, the values in the cells are replaced by appropriate printing symbols, and the contour or isogram is then defined as the linear junction between two areas of symbols which represent adjacent values in the range (Rosing and Wood, 1971).

It is evident, therefore, that the contour method is preferable for the present purpose, as it fulfils the objective of providing a continuous surface of variation based upon the 367 irregularly spaced data points.

The standard contour package was used for the forest SYMAPS together with a number of Electives, or options which increase the program's flexibility and enhance the finished appearance of the maps.

Yield classes are distinguished by a series of levels printed in appropriate unit characters. The yield class containing the national mean for each species has been underlined in the SYMAPS. The mean yields for the forest data points are adjusted so that the SYMAPS correspond to the established yield class system. It should be noted however, that while the contours are located at conventional values separating yield classes, the specific symbols used for given class values may vary from map to map. This results from the fact that the yield class key for each species is based upon the range of mean forest yields for that species only. Line printer symbols are not comparable for different species unless they have the same range of forest yields, e.g. Scots pine and Lodgepole pine, but not Lodgepole pine and Sitka spruce, which have different ranges. By allowing the computer to use the full range of symbols irrespective of the quantitative range of the species yields, the maps convey the variations with more graphic impact. Each individual species SYMAP shows the fastest growth most prominently since the densest line-printer characters are assigned to the maximum yield class for each species. Large blank areas on the SYMAPS show that the species is absent.

Contour SYMAPS have been produced for all the main forest species, and it is now proposed to evaluate the variability and their relationship to macro-factors such as geology and climate.

ANALYSIS OF SYMAPS

The contour SYMAPS reveal much more detail of yield variations than the shaded Conservancy maps in Chapter 2, and it is clear that the yield pattern revealed by forest data is far more complex, especially in the case of the conifers. This complexity is not unexpected but needs explaining at some length, particularly in relation to climate and geology. These variables may be related to the yield patterns by superimposing transparent overlays of selected indices to see whether certain macro-factors appear to be operating at this level of analysis. Clearly this sort of exercise is descriptive in nature but the main objective is to observe the *locational coincidence* of macro-factors and species yields. The macro-factors used are as follows:

Solid geology.

Average annual rainfall 1901-1930. (Figure 4.9)

Approximate average number of days with gale, 1918-1937.

Average wind speed (m.p.h.) 1926-1940. (Figure 4.10)

Average dates of first screen frost 1911-1940.

Average dates of last screen frost 1911-1940.

Range of average Monthly Temperatures 1901-1930.

Average Annual Frequency of Days with a minimum Temperature of $0^{o}C$ or less 1913-40. (Figure 4.11)

Mean Annual Accumulated Temperatures 1881-1915, degrees F. (Gregory, 1954). (Figure 4.12)

Moisture Regions (Howe, 1956). (Figure 4.13)

Discussion in subsequent paragraphs is related to the zones shown on the maps. The climatic variables other than Gregory (1954) and Howe (1956) were taken from the Climatological Atlas of the British Isles (1952). Although these data refer to varied time periods they are the only information available at this scale. There is no scope for selecting one time range in preference to another. Most of the periods fall at least partly within the life-span of the Forestry Commission when the crops that provided the yield-class data were growing.

It should be stressed that any locational coincidence of these variables with forest yields does not necessarily indicate a causal relationship but any such coincidences ought to be noted and might possibly suggest scope for further work.

The SYMAPS show not only discrete growth variations but also a 'most probable' surface of yields which emphasizes broad regional trends or yield gradients that often divide the country into distinctive halves. This is particularly so for *Scots pine, Corsican pine, the Larches and Douglas fir.* In some instances, e.g. Scots pine, the country is neatly divided along the classical Exe-Tees line, but in other cases, e.g. Japanese and Hybrid larch, it is divided along a line coincident with a Mersey-Thames axis. Average yields appear to be consistently higher in the South West Peninsula and parts of Wales and usually below average in the north and north east of England. These general statements need further elaboration.

Figure 4.1 (p. 53) for the indigenous Scots pine shows that the country is divided into two well defined yield sections along a line roughly coincident with the Exe-Tees axis between Highland and Lowland Britain. North and west of this line below average yields occur on the older rocks such as the Pre-Cambrian, and Palaeozoic up to the late Carboniferous, whereas south and east of this line and particularly on the Cretaceous series, yields are above average. Corsican pine Figure 4.2 (p. 53) follows a similar but more interrupted pattern. Even though Corsican pine is one of the fastest-growing commercially used species it is clearly not uniformly good everywhere. Figure 4.2 (p. 53) shows that compared with Scots pine yields fall off more abruptly especially in Cornwall, Wales, the north west and north east of England. The best areas for Scots pine and Corsican pine are around York, East Anglia, the south east of England, Hampshire, Gloucestershire and parts of Devon.

The coincidence of average and above average yields with the younger rocks and lower elevations is reinforced by their relationship with mean annual rainfall. Yields of both pine species are high where rainfall does not exceed 40 ins, and reach 14 m^3/ha and more where rainfall falls below 30 ins.

These concentrations of above average yields for Scots and Corsican pine are further related to areas where mean annual accumulated temperatures exceed 2,500 day degrees F, where wind speeds do not on average exceed 12.5 m.p.h. and where the last screen frosts occur before May 15th.

The pattern of Lodgepole pine yields (Figure 4.3, p. 54) is less distinct because it is not grown in large parts of the Midlands, East Anglia and the south, and this absence results in corresponding blank areas on the SYMAP. Figure 4.3 (p. 54) shows that yields of up to 14 m^3/ha are possible in north

Norfolk, which suggests that this species may have the same maximum potential as Scots pine. Apart from north Norfolk, above average growth is most evident in Highland Britain especially where the rainfall exceeds 40 in. annually. This incidence of high yields in the more exposed, wetter, colder areas contrasts strongly with the other pines. Yields do not necessarily fall off with decline in values of mean annual accumulated temperatures, nor do they fall where wind speeds rise above 10 m.p.h. and thus it grows faster than the other pines in the Perhumid zone (Howe, 1956).

These results suggest that climatic factors are important and that the pines respond differently to these factors. Lodgepole pine seems to be far more versatile in that above average growth rates occur in both very dry lowland and very wet upland zones.

Three important fast-growing species, Sitka spruce, Norway spruce and Douglas fir (Figures, 4.4, 4.5 and 4.6, pp.54-55) show yield patterns that contrast strongly with the pine yields, especially Scots and Corsican pine. Faster growth is concentrated especially in the south-western region of the country, whereas generally poorer yields are found in the east. Sitka spruce, the most abundant conifer, is clearly concentrated in areas with above 30 in. annual rainfall and Figure 4.4 (p.54) shows that it is not planted in large areas in the drier parts of the country. In contrast, Norway spruce (Figure 4.5 p.55) and Douglas fir (Figure 4.6, p.55) are more evenly planted and fewer blank areas occur on the maps. All three species grow fastest where rainfall rises above 40 in. and particularly high yields of 18 m^3/ha occur at locations within the area enclosed by the 50 in. isohyet.

Yields of these species are noticeably higher in zones (Figure 4.12, p.60) where the accumulated temperature reaches 2000 to 3000 day degrees F, especially for the spruces. Average and below average growth, 12 m^3/ha and below, coincide with the lower value of 1000 to 2000 day degrees F in northern England, the Pennines and the Lake District. In relation to moisture (Figure 4.13, p.61) both spruces yield best in the Perhumid and Humid moisture regions, A_1 and B_1 apart from the Pennines and Lake District. The best growth of Sitka spruce is found in the Humid and Moist Subhumid zones B_1 and C_2 in Somerset and Shropshire and in the C_2 zone in Kent. It is particularly noticeable that for Sitka spruce the Dry Subhumid zone, C_1, coincides with areas of below average yields of 5 to 10 m^3/ha in Lincolnshire and Cambridgeshire.

Yield variations, however, do not seem related to wind speeds or gale frequencies except that in the case of Sitka spruce yields increase up to 20 days with gales but fall off in Wales where the number of gale days rises to 30. This suggests that although Sitka spruce tolerates exposure, excessive windiness may well reduce overall yields. However, there is no clear visual relationship on the map between Sitka spruce yields and wind factors in north-east England, Cumbria, and Lancashire where yields tend to be below average throughout.

The spruces and Douglas fir show a closer relationship with frost. Douglas fir grows better where the first screen frosts are as late as November and December and the last screen frosts as early as March and April. For Sitka spruce, first screen frosts in late November and December coincide with high yield areas in north Devon, Somerset and Cornwall and below average yields are found in the Lake District and northern England where the first frosts occur in October and early November. Norway spruce tolerates somewhat earlier frosts especially in Wales, south-west and south-east England and grows well even if first frost dates are as early as October and November. In general however, it seems that early autumn frosts depress yields below the average.

Thus these three fast-growing species are seen to produce optimum growth in areas with over 40 in. annual rainfall, where accumulated temperatures are above 2000 day degrees and where the first frosts occur late in the year. This may account for the fact that the highest yielding areas are confined specifically to the South West Peninsula and Welsh borders.

Comparison of Figures 4.4, 4.5 and 4.6 (pp.54-55) also reveals that growth peaks of 16 m^3/ha and 18 m^3/ha occur in association with the Old Red Sandstone series, especially in Devon. For Sitka spruce and Douglas fir excellent growth is also found on the Millstone Grit and Culm Measures in Shropshire and southern Powys. Norway spruce also grows well on similar formations in the latter area and in Dyfed. In contrast to these high yields on acid rocks below average yields are found on the calcareous formations, especially the Chalk and Carboniferous series in south Wales, the Pennines, and the south east of England. This suggests that less alkaline and more water-retentive soils are clearly conducive to better growth for the major conifers.

The importance of the South West Peninsula in British forestry is further supported by the SYMAPS of larch yields. Figures 4.7 and 4.8 (pp. 56) show that above average yields of over 10 m^3/ha occur south of a line joining the

Mersey and Thames. In the case of European larch, yields at this level also extend into East Anglia and south-east Lincolnshire. The SYMAP therefore shows that a substantial proportion of the country has a higher potential for European larch then for Japanese and Hybrid larch, which is contrary to much of the preceding evidence on the relative productivity of the two species. This suggests that the species may be commonly planted in less favourable locations which depress its actual performance. This conclusion has already been foreshadowed by the large disparity between the mean and maximum yields.

In relation to rock type, yields of 14 m^3/ha occur in association with the Old Red Sandstone formations, and the Millstone Grit and Culm Measures especially in Devon, Dyfed, south Wales and also on the Cretaceous series in Wiltshire.

Above average yields for both larches are located where the annual rainfall rises above 40 inches. This is especially true for Japanese and Hybrid larch in most of the counties in southern England and south Wales. Yields of European larch appear to decline where windspeeds exceed 12.5 m.p.h. Good growth appears also to be associated with last screen frosts as early as March and April, especially in eastern England, the south east, south Devon and western Dyfed. For Japanese and Hybrid larch low yields occur in areas where minimum temperatures of $0^{o}C$ or less are experienced on over 50 days of the year. High accumulated temperatures and high yields also appear to be associated, since growth peaks of both the larches occur in the zone of 2000 to 3000 day degrees F. An exception is poorer growth of European larch in the exposed coastal zones of Wales and Cornwall where high accumulated temperature values are also found. For both larches good growth coincides with the Humid B_1, B_2 and Moist subhumid C_2 moisture regions but not in very moist or very dry areas. Yield variations of the larches would seem to indicate that frost factors, warmth and a rainfall of between 30 and 40 in., and even somewhat higher are conducive to faster growth rates.

Contour SYMAPS provide a convenient summary of species yield trends and regional variations and it is already clear that identifiable spatial patterns are often repeated. This suggests that certain areas of the country are frequently unsuitable for the best growth, whereas other regions produce faster growth rates irrespective of species. Furthermore, several variables such as high accumulated temperatures, rainfall values and geological strata have been shown to coincide approximately with species yield variations. It is therefore necessary to note those regions of the country which, irrespective of species,

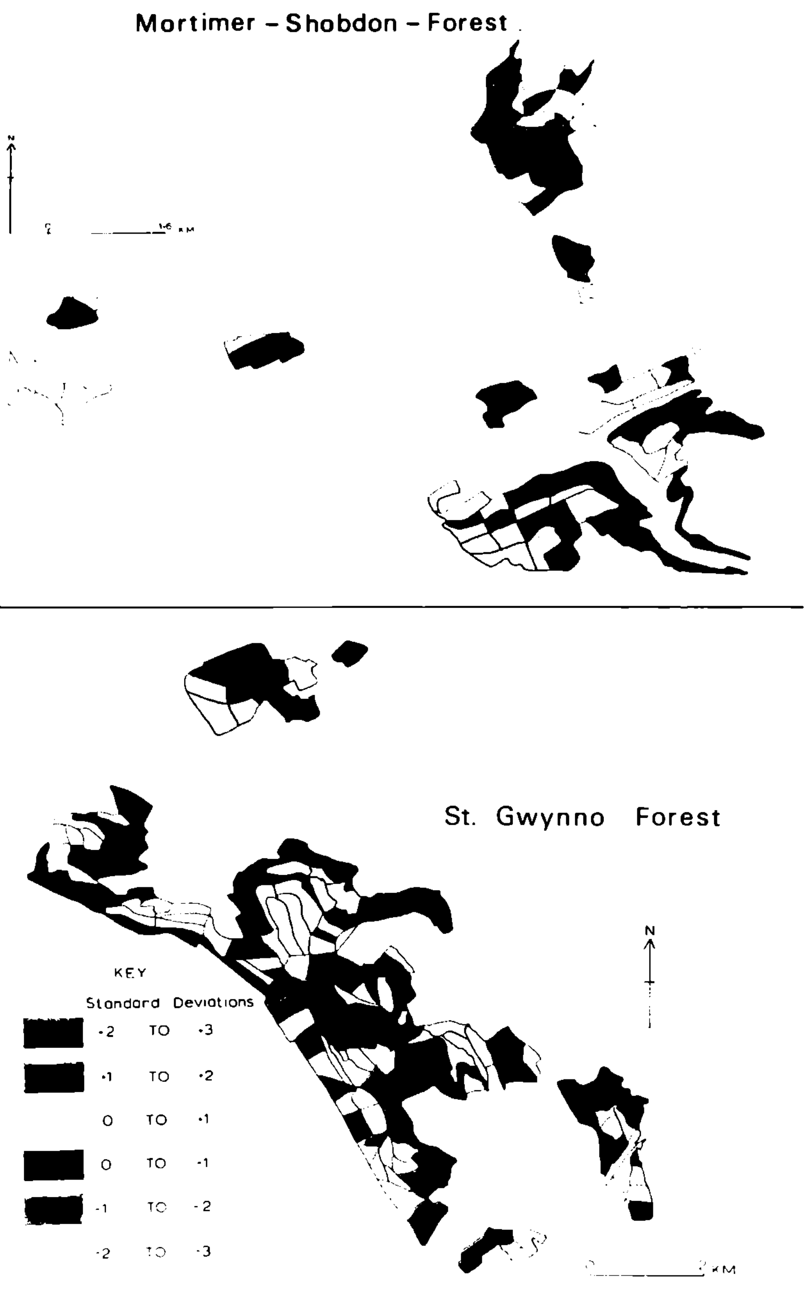


PLATE 1. Deviation of compartment yields from national mean in St. Gwynno and Mortimer (Shobdon) Forests.

Colour Key to Recommendation Diagrams

Standard Deviations in Yield

+2 to +3

+1 to +2

0 to +1

0 to -1

-1 to -2

-2 to -3

• Dominant species

Blank areas = Species not grown

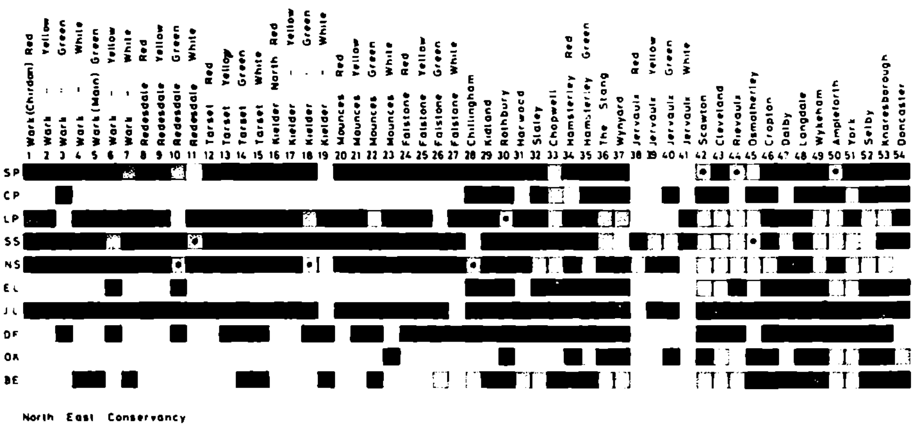


PLATE 2. Key and recommendation diagram for the North East Conservancy

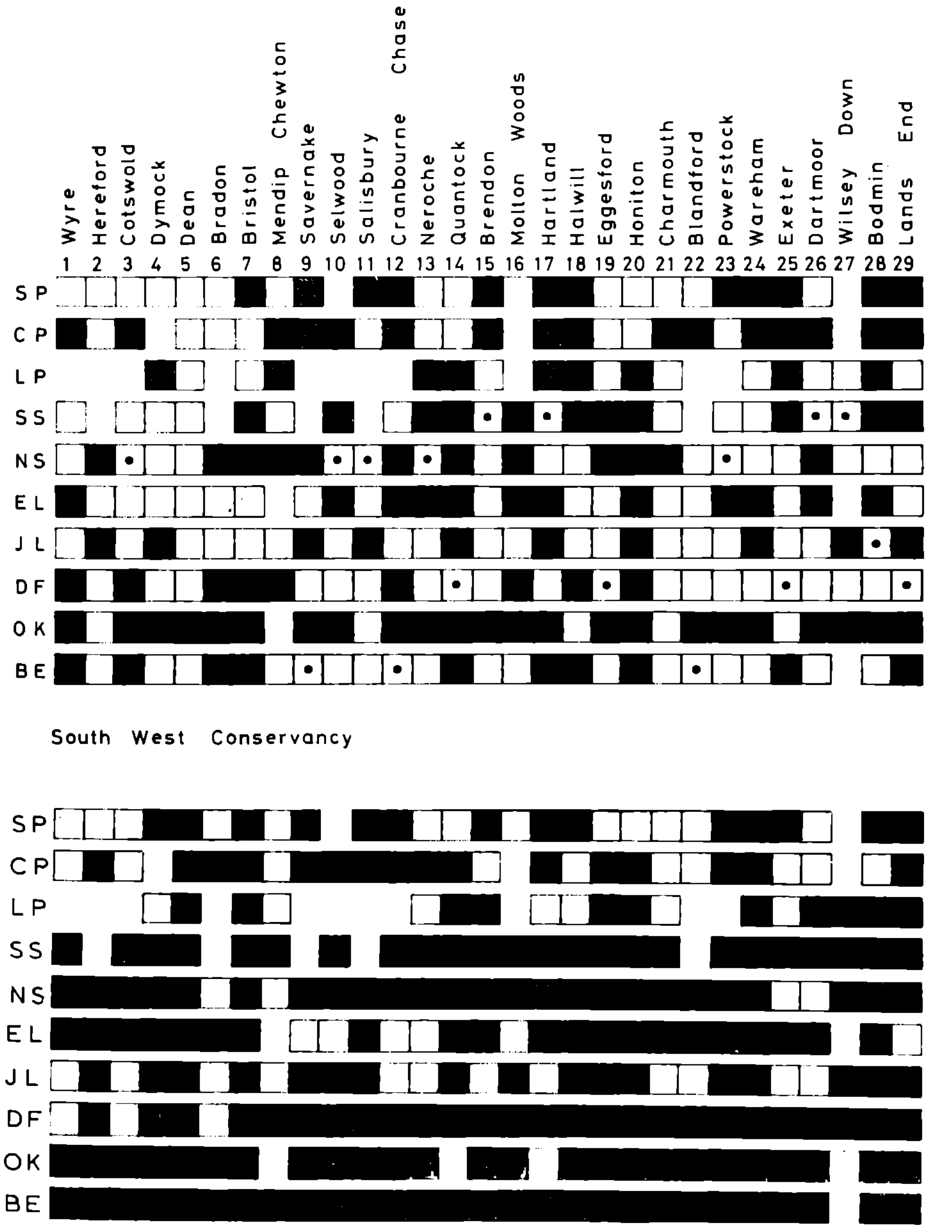


PLATE 3. Recommendation diagrams for the South West Conservancy

PLATE 4. Recommendation diagrams for NW(E), N(W), S(W), SE(E) and E(E) Conservancies.

constantly produce very fast or very slow growth, and to see which macro-factors of meso-factors coincide with these regions. If the high-yielding patches of 18, 16 and 14 m^3/ha and the low-yielding patches of 6, 4 and 2 m^3/ha are isolated from the SYMAPS certain generalisations can be made as have been summarised in Table 12.

Table 12

Relationship Between High and Low Yield Areas and Macro-factors

Yield Class *m^3/ha*	*Geology*	*Mean ann. rainfall inches*	*Temp. range* *^oC*	*No. of days 0^oC or less*	*Accumulated temp. ^oF*	*Moisture regions*
High Yield						
18	Old Red Sandstone	50+	<11	50	2000-2500	A - B_2
16	Old Red Sandstone	40+	9-11	10-25	2500-3000	A - B_1
14	Old Red Sandstone	30+	11	>50	2500-3000	A - B
Low Yield						
6	Carbonifer-ous Pre-Cambrian	40+	10-12	25-100	500-2500	A - C_2
4	Carbonifer-ous Silurian Ordovician	30+	10-12	50-100	1000-2500	A - C_2
2	Cretaceous Carbonifer-ous	<30	11	50-100	1000-2500	A - C_2

Table 12 represents a somewhat more quantitative and precise statement about growth factors but it is only a first attempt and more work is necessary before more authoritative statements can be made. If these lines of enquiry were pursued they could possibly yield an improved means of locating planting in areas of optimum characteristics.

CONCLUSION

The value of the forest level of analysis lies in the increased detail which can be consistently displayed by SYMAP, revealing complex yield variations and trends. These are usually gradual suggesting that climatic factors are possibly responsible, and this has been demonstrated by superimposing climatic variables over the yield distributions. Such a repeated coincidence of relationships indicates that it is now possible to specify location and suggest certain quantitative thresholds as a basis for planting. This sort of recommendation is an advance on the conventional guidelines approach since it should be theoretically possible, therefore, to reduce forest rotation periods by proposing that, for instance, Scots and Corsican pine be grown in areas where the annual rainfall does not rise above 30 in., or that spruces should be concentrated where annual rainfall exceeds 40 inches. Furthermore, the coincidence and obvious overlapping of yield areas of 16 and particularly of 14 m^3/ha in the same localities indicates that these regions are intrinsically highly productive for several species and must, therefore, represent some of the prime timber-producing sites in the country. They afford a potential opportunity to increase production by concentrating planting programmes in such areas rather than the more negative, less productive areas of the Pennines and northern England.

This approach does not, however, assess statistical significance for the relationships. In Chapter 5 yields are correlated specifically with some of the observed variables, in order to see how valid are these suggested relationships.

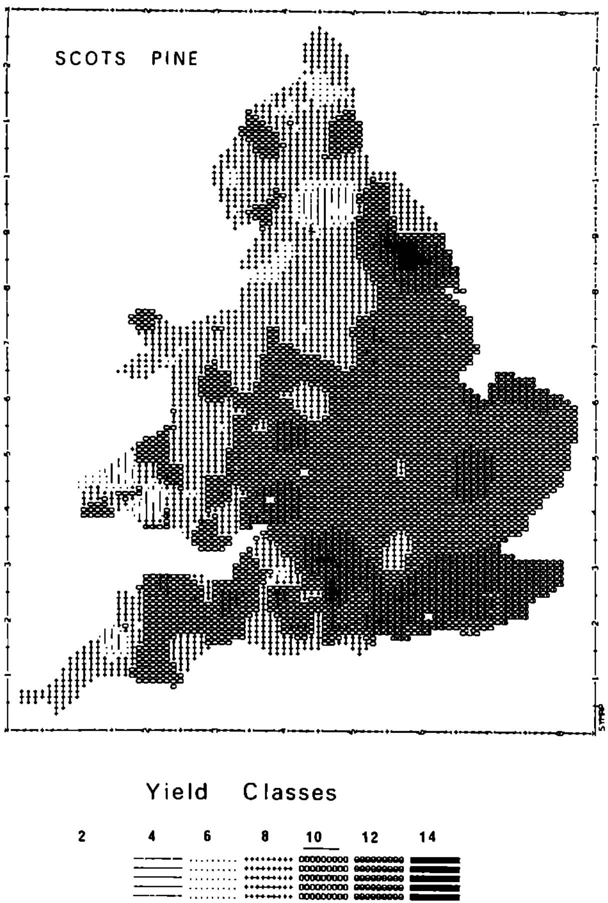


Figure 4.1 SYMAP of Scots pine yields

Figure 4.2 SYMAP of Corsican pine yields

Figure 4.3 SYMAP of Lodgepole pine yields

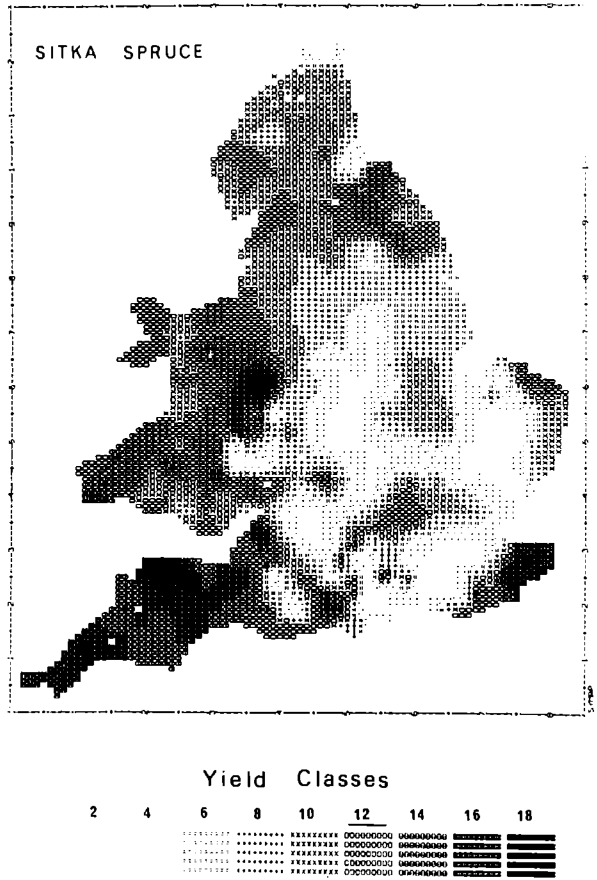


Figure 4.4 SYMAP of Sitka spruce yields

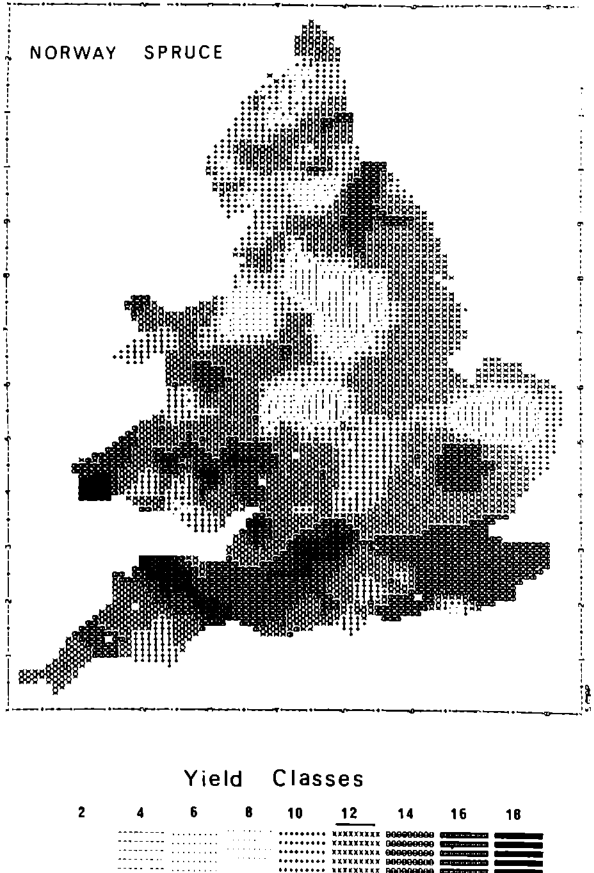


Figure 4.5 SYMAP of Norway spruce yields

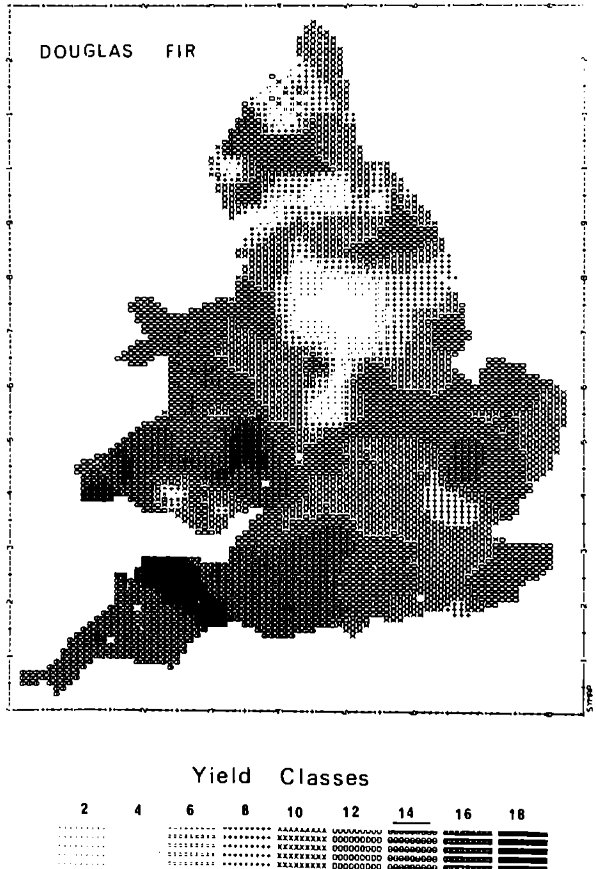


Figure 4.6 SYMAP of Douglas fir yields

Figure 4.7 SYMAP of European larch yields

Figure 4.8 SYMAP of Japanese and Hybrid larch yields

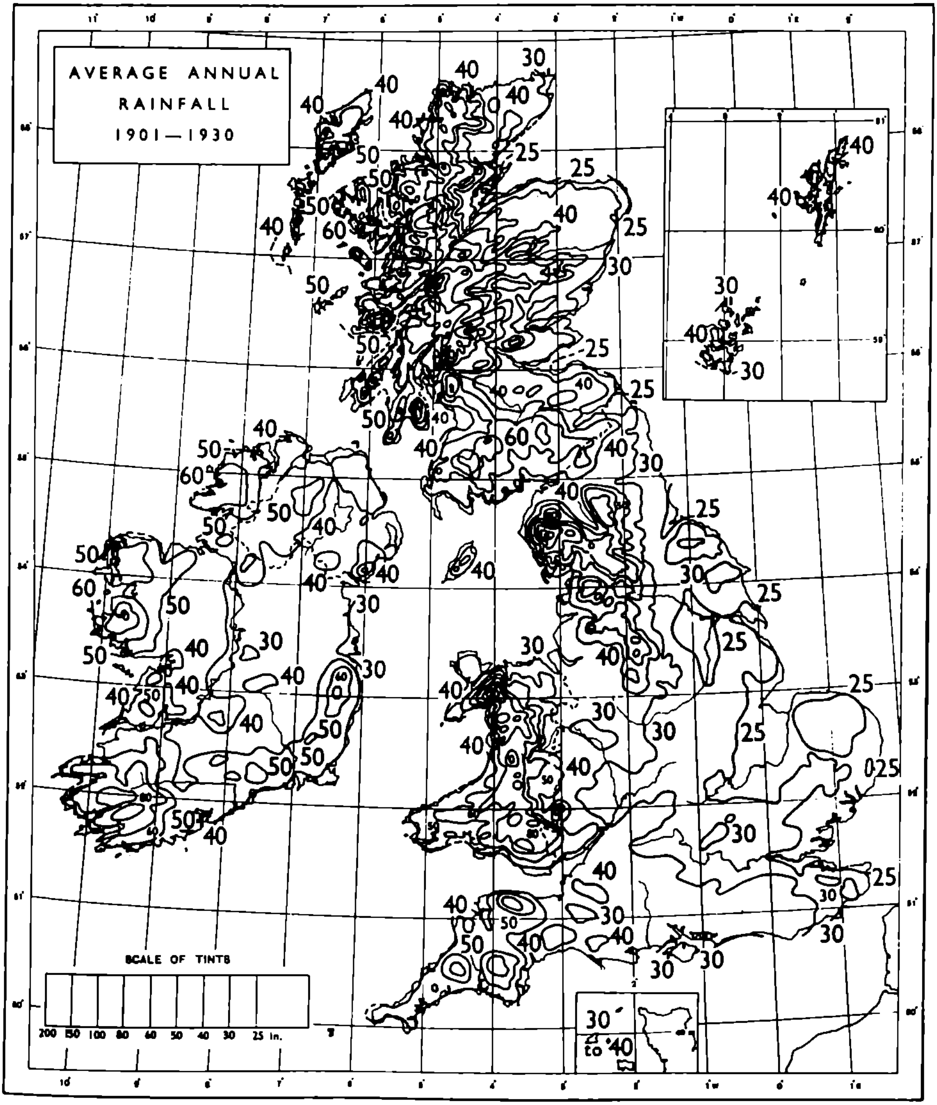


Figure 4.9 Average rainfall 1901-1930

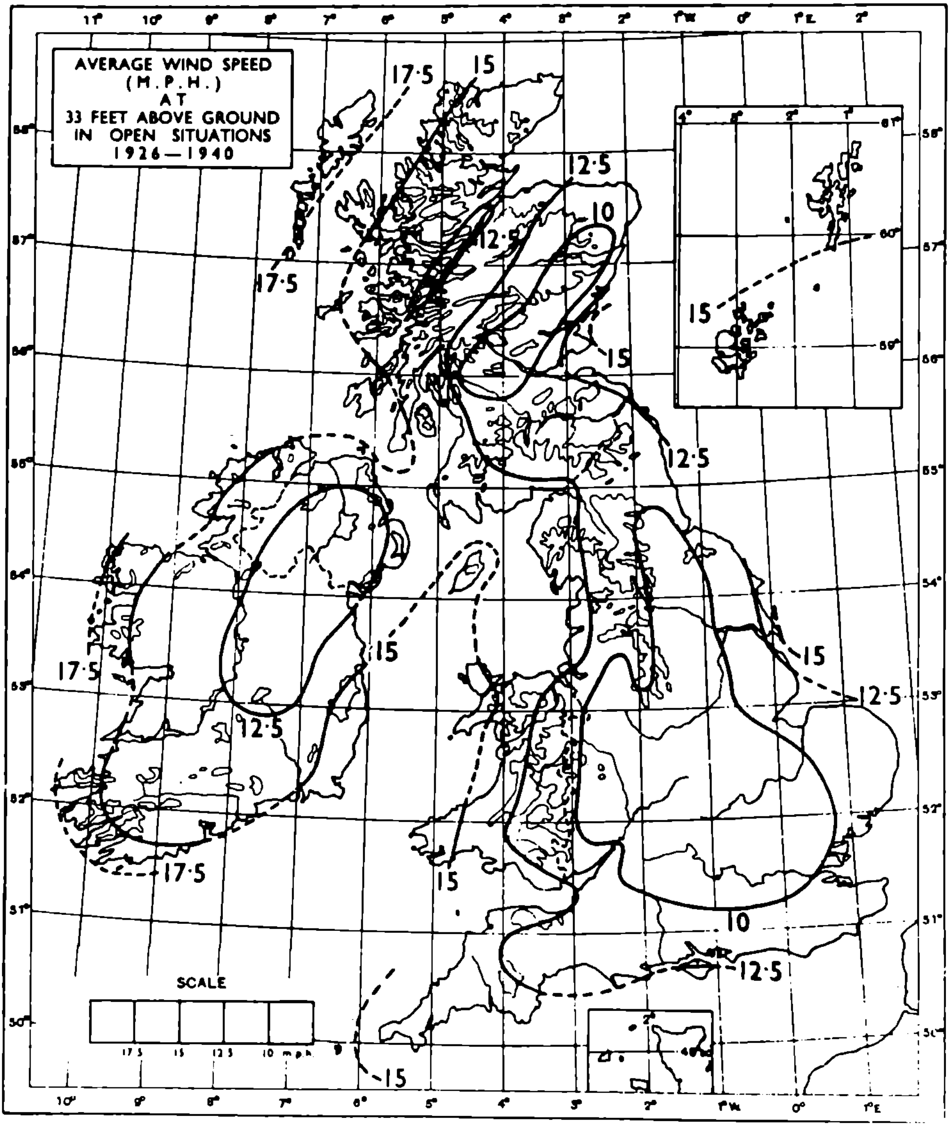


Figure 4.10 Average wind speed (m.p.h.) at 33 feet above ground in open situations 1926 - 1940

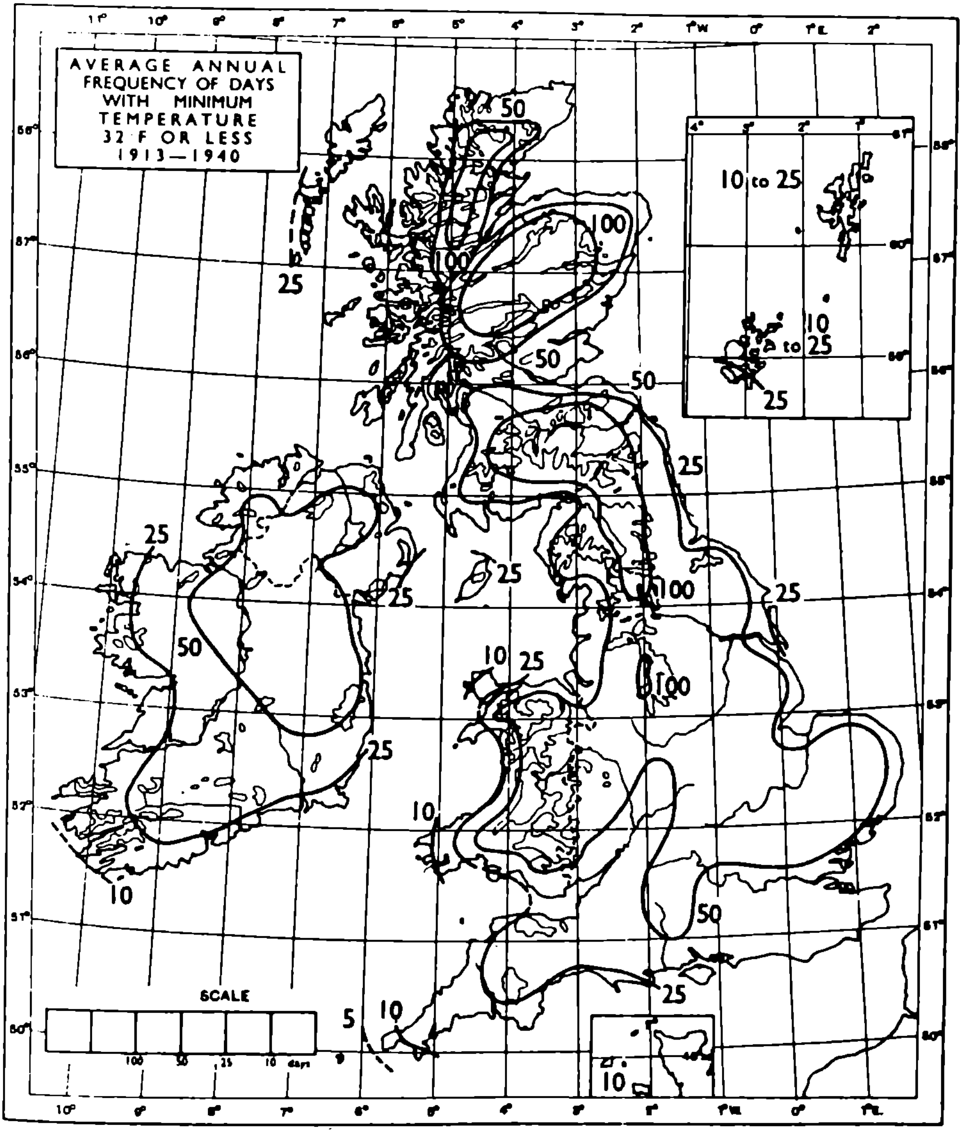


Figure 4.11 Average annual frequency of days with minimum temperature of 32^{0}F or less 1913 - 1940

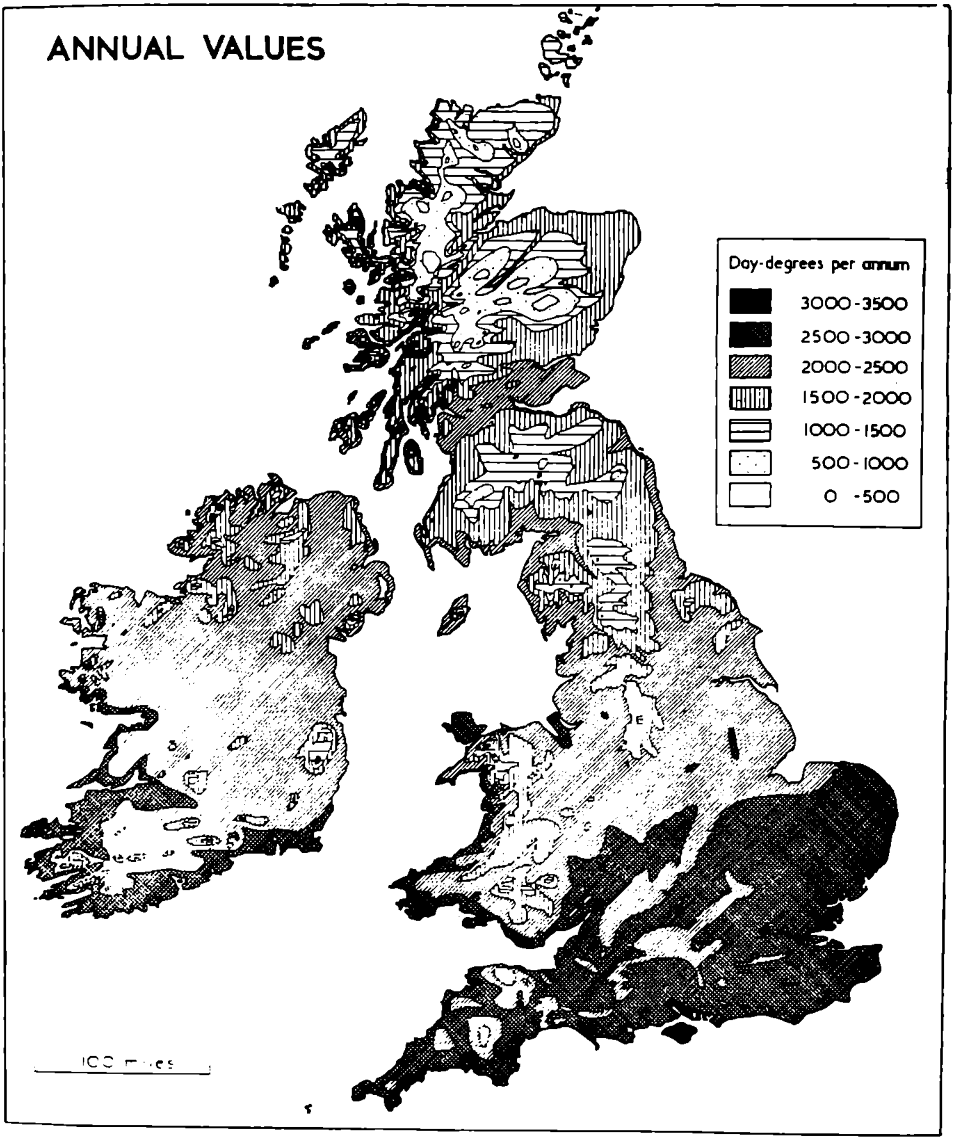


Figure 4.12 Mean annual accumulated temperatures in the British Isles 1881 - 1915

	Climatic Type	*Moisture Index*
A	Perhumid	100 and above
B_4	Humid	80 – 100
B_3	Humid	60 – 80
B_2	Humid	40 – 60
B_1	Humid	20 – 40
C_2	Moist subhumid	0 – 20
C_1	Dry subhumid	–20 – 0
D	Semi-arid	–40 – –20
E	Arid	–60 – –40

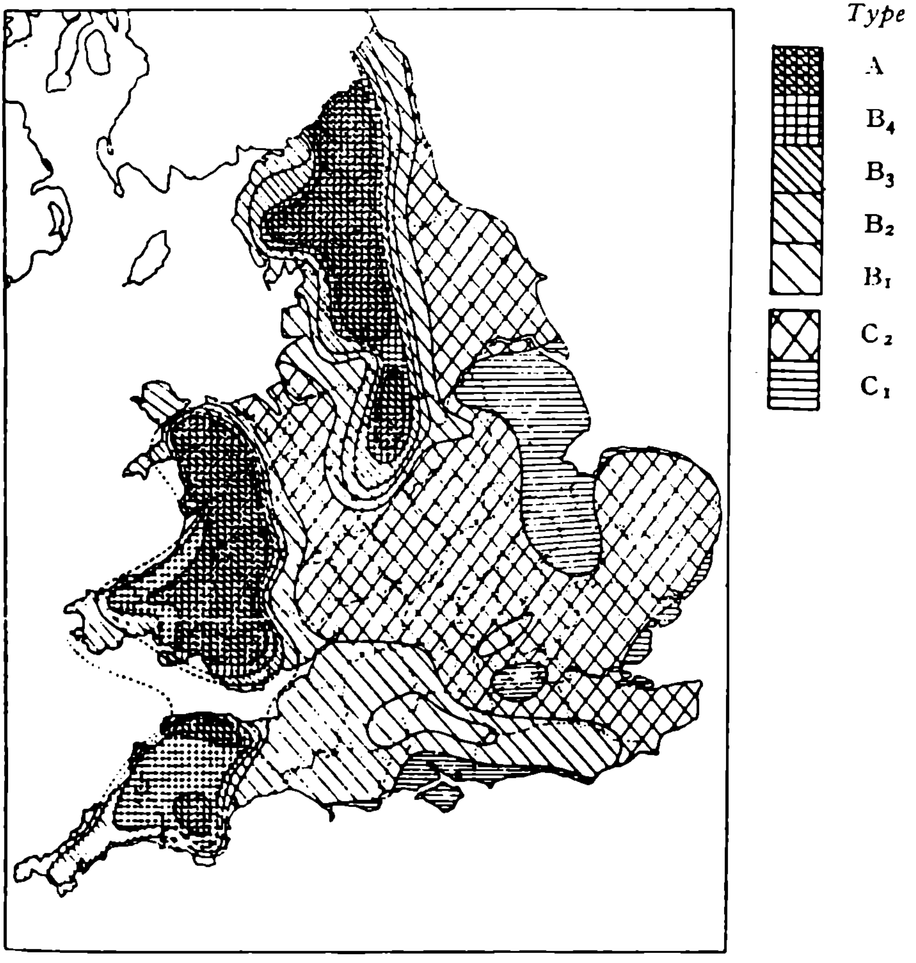


Figure 4.13 Moisture regions in England and Wales (Howe, 1956)

CHAPTER 5

STATISTICAL ANALYSIS OF VARIATIONS BY FORESTS

INTRODUCTION

The SYMAPS reveal clear patterns of yield variability based upon the mean yields of the individual forests and permit broad correlations of yields with macro-factors such as geology and climate but they do not explain the variations. The present chapter, therefore, aims to extend the analysis of forest yields a stage further by ascertaining the statistical significance of yield variations and their statistical relationship to two macro-factors: elevation and rainfall.

ANALYSIS OF VARIANCE

The variation in the mean yields between Conservancies was discussed in Chapter 2, and it is now necessary to see whether the forests within the Conservancies also exhibit significant yield variations.

A two-way analysis of variance was conducted on a random sample of six forests in each Conservancy to test the null hypotheses of no significant differences between species and forest means. Only the eight conifers and two broadleaved species were considered in this case. A random sample was necessary in order to obtain an equal number of observations in each Conservancy. The 42 forest means selected from the total population of 208 forests are shown in Table 13. The standard error of the overall mean is 0.04 and the standard deviation is 0.19. These are small values and may be considered a sufficient justification for the chosen sample.

Before conducting the analysis of variance test it was necessary to inspect the mean yield values in the 42 randomly selected forests because, in some instances, particular species are absent and there are, consequently, missing values. In order to provide a consistent test it was decided to insert a calculated mean value for the absent species. This value is calculated as the mid-point between the column mean (for the same species) and the row mean (for the same forest) within each Conservancy. It should also be noted that in the analysis of variance the F ratios are based upon the number of degrees of freedom obtained by subtracting the number of inserted values from the total degrees of freedom for each Conservancy. Thus it will be seen from the two-way analysis in Table 14 that the residual and total degrees of freedom vary by Conservancy according to the number of inserted values used.

Table 13

Mean Yields (m^3/ha) of Six Randomly Selected Forests in Each Conservancy

Conservancy	*Forest*	*Species* SP	CP	LP	SS	NS	EL	JL/HL	DF	OAK	BE
NE	Don	8.5	10.0	6.0	7.4	(8.5)	4.6	6.9	(8.5)	4.3	4.3
	Cropton	8.0	11.2	6.0	10.0	13.9	6.6	6.0	11.7	4.0	4.5
	Chopwell	10.0	11.9	8.0	10.0	13.1	5.0	8.0	9.1	4.0	5.4
	Mounces (White)	6.0	(8.1)	5.1	8.9	8.0	(6.0)	4.0	(8.4)	4.0	(5.6)
	Rothbury	7.4	7.0	7.0	10.0	10.0	6.2	6.8	10.8	4.0	5.0
	Redesdale (White)	4.8	(8.4)	4.0	11.3	8.0	(6.2)	6.0	(8.6)	(5.4)	(5.8)
NW	Mortimer (Shobdon)	10.0	12.0	(9.9)	18.9	11.2	8.2	10.9	15.7	4.0	6.8
	Walcot	9.2	12.0	(9.5)	16.9	12.2	8.2	9.1	12.0	6.0	6.8
	Launde	10.0	10.0	(8.3)	(10.8)	9.4	8.0	8.0	(11.1)	3.7	4.0
	Mortimer (Bucknell)	10.4	12.0	10.0	13.2	11.9	7.9	9.9	16.0	4.0	6.0
	Bagot	10.6	10.0	9.4	(11.4)	11.0	6.6	9.0	14.0	4.0	5.0
	Matlock	8.1	8.0	7.0	6.0	6.0	5.2	6.2	(10.6)	6.0	6.0
NWA	Ystwyth	8.7	9.2	7.0	11.1	9.9	6.8	7.1	13.1	4.0	5.2
	Clocaenog	7.8	7.2	6.0	12.3	11.0	6.0	7.0	12.2	4.0	6.0
	Penllyn	7.7	6.0	7.0	12.9	12.2	6.3	8.7	12.0	6.0	6.3
	Rheidol	9.0	9.0	7.7	10.1	10.1	(7.6)	8.9	11.0	4.0	4.0
	Ceri	7.0	6.7	5.2	12.9	11.0	6.9	8.0	10.0	4.0	4.0
	Newborough	9.3	8.9	7.0	12.8	13.0	(7.8)	9.7	11.8	5.1	4.8
SWA	Coed Taff Fawr	9.4	(10.3)	8.1	14.1	15.0	(9.1)	9.9	14.0	6.0	7.0
	Coed y Rhaidor	7.6	8.0	7.9	10.9	9.9	(6.6)	9.0	12.5	3.4	2.0
	Brechfa	8.4	10.0	8.7	11.9	12.0	5.1	11.0	14.5	5.0	5.0
	Cymer	6.0	7.2	5.0	7.0	7.1	8.0	6.9	10.0	5.4	4.6
	Tintern	10.5	11.0	7.0	13.9	13.9	7.5	11.0	13.9	5.0	6.6
	Coed Abertawe	11.0	12.0	14.8	13.0	13.8	8.0	11.0	14.0	4.0	6.0

Table 13 contd...

Mean Yields (m^3/ha) of Six Randomly Selected Forests in Each Conservancy

Conservancy	*Forest*	*Species* SP	CP	LP	SS	NS	EL	JL/HL	DF	OAK	BE
SW	Dartmoor	10.0	9.8	7.8	14.0	10.0	6.4	11.2	13.8	4.0	5.9
	Hereford	10.6	14.0	(9.6)	(13.6)	15.0	7.5	8.6	15.4	5.1	6.0
	Brendon	11.0	(11.8)	(10.5)	18.0	16.0	10.0	12.0	18.0	4.0	6.0
	Halwill	9.0	9.0	10.0	15.0	12.0	8.0	12.0	13.0	4.5	5.3
	Cotswold	10.5	10.0	(9.4)	14.0	13.0	7.6	10.3	11.0	7.0	5.4
	Dean	11.6	14.0	8.0	12.9	13.0	9.0	12.0	14.8	4.0	6.0
SE	Queen Elizabeth	11.3	17.8	10.0	(11.3)	9.4	8.3	13.0	12.5	4.8	6.0
	Alice Holt	13.0	14.1	10.0	12.0	9.8	7.4	12.0	13.6	4.0	6.9
	Micheldever	12.0	12.2	(9.7)	(11.2)	12.5	8.5	11.9	12.0	4.4	6.7
	Wight	7.4	12.8	(8.4)	(8.3)	9.8	5.0	8.5	10.0	4.0	5.0
	Abinger	11.8	13.0	8.0	(11.2)	14.3	9.3	11.0	11.0	4.0	6.3
	Bedgebury	12.6	14.6	8.0	16.0	13.7	8.0	11.4	11.3	4.7	6.5
E	Wymersley	8.2	10.7	(10.4)	6.0	8.8	4.0	(7.2)	8.0	4.0	4.0
	Bernwood B.	10.0	10.0	(10.5)	(8.8)	(8.8)	9.8	7.3	9.8	4.0	4.0
	Kesteven	10.0	9.9	(11.3)	10.0	11.7	6.4	8.0	10.0	5.4	5.2
	Chilterns	9.1	10.0	(11.4)	12.0	11.6	8.0	9.0	10.0	4.7	4.0
	Bernwood O.	10.0	12.0	(10.8)	(9.1)	9.0	6.0	6.0	8.0	3.4	5.0
	Wensum	12.0	13.1	14.0	14.8	12.0	8.0	7.9	11.7	4.0	5.0

N.B. Values in brackets ( ) indicate inserted values (See page 62)

Table 14

Two-way Analysis of Variance

Conservancy	*Source*	*Degree of freedom*	*Sum of squares*	*Mean square*	*Freedom Ratios (F)*
NE	Species	9	252.58	28.06	10.92**
	Forest	5	34.09	6.82	2.65
	Residual	31	79.77	2.57	
	Total	45	366.44		
NW	Species	9	417.98	46.44	15.43**
	Forest	5	102.81	20.56	6.83**
	Residual	38	114.23	3.01	
	Total	52	635.02		
NWA	Species	9	380.46	42.27	44.03**
	Forest	5	12.25	2.45	2.55
	Residual	43	41.28	0.96	
	Total	57	433.99		
SWA	Species	9	418.30	46.48	19.21**
	Forest	5	124.44	24.89	10.29**
	Residual	42	101.67	2.42	
	Total	56	644.41		
SW	Species	9	611.44	67.94	30.60**
	Forest	5	36.74	7.35	3.31
	Residual	40	88.91	2.22	
	Total	54	737.09		
SE	Species	9	469.28	52.14	24.83**
	Forest	5	58.44	11.69	5.57**
	Residual	40	84.03	2.10	
	Total	54	611.75		
E	Species	9	361.16	40.13	21.58**
	Forest	5	55.95	11.12	5.98**
	Residual	36	66.85	1.56	
	Total	50	483.96		

** Significant at the 0.01 level

The F ratios were found to be significant at the 0.01 level for all the species means in each Conservancy indicating that the differences between species are not due to chance. Thus the null hypothesis of no significant differences between species means was rejected. In the case of the second null hypothesis, concerning the difference between forest yields, only four of the seven Conservancies revealed significant variations at the 0.01 level, namely the North West, South Wales, South East and East Conservancies. In these cases, the null hypothesis can be rejected. The variation in forest yields in the other Conservancies, North East, North Wales, and South West are not significant, indicating that the null hypothesis cannot be rejected in these Conservancies and that the forests are performing fairly evenly. This confirms some of the visual impressions given by the SYMAPS which revealed that yields in the South West forests were consistently high, those in North Wales, consistently average, and those in the North East, consistently low, irrespective of species.

This test helps to clarify the picture of forest yields within the Conservancies. It does not explain why the yields vary but it provides a basis for the study of causal relationships.

RELATIONSHIPS BETWEEN YIELDS AND ELEVATION AND RAINFALL

It was decided to select indices applicable to all 208 forests which were not only important to growth but which could also be obtained for each forest. This severely restricted the choice to elevation and rainfall, since, unfortunately, other equally, and possibly more relevant, variables such as frost incidence, accumulated temperatures, windspeeds or soil depths, cannot be obtained consistently at this level of analysis. Elevation and rainfall can be relatively easily determined from published maps, and it is already known that both factors strongly influence growth. Elevation also influences a number of other variables such as mean annual rainfall, temperature, and exposure. Mean annual rainfall although possibly less meaningful than rainfall during the growing season is the second macro-factor that can be obtained consistently. The determination of these two factors in relation to the forest units is discussed below.

Determination of Elevation and Rainfall Values

A single elevation value for each forest was calculated by taking the mean of the highest and lowest elevations for each separate unit of forest larger than 65 hectares and then finding the overall mean of these means.

Rainfall values for each forest unit were derived from the 10 mile Mean Annual Rainfall map 1916-1950 (O.S. 1967), over which the Forestry Commission's 10 mile map of forest areas could easily be superimposed. Mean rainfall values were obtained for each forest in the same way as elevation means.

The purpose of this section is merely to gain a first approximation to the relationship between yields and the two macro-factors. These figures for elevation and rainfall are generalisations but fully weighted means would be beyond the scope of this study. If the results prove significant they could justify more detailed research at a later date.

Regression Analysis

Simple linear regressions for yield/elevation and yield/rainfall have been obtained by means of Statistical Package for the Social Sciences Scattergram program. The results are summarised in Tables 15-19.

For elevation, all correlation coefficients at national level are negative and seven are highly significant indicating that decreasing yields are associated with increasing elevation. This is particularly so for the pines which have the largest negative coefficients. On the other hand, yields of Sitka spruce, Douglas fir and Oak are not significantly associated with increasing elevation. This is not surprising for Sitka spruce, but it is more surprising for Douglas fir and Oak, neither of which are tolerant of elevation.

In the case of yield/rainfall correlation coefficients the picture differs. Unlike the consistently negative response of yields to elevation, rainfall can exert either a positive or a negative effect. All six of the negative correlations are significant, but only one of the four positive correlations. The latter is Douglas fir, which does better in higher rainfall areas.

The ranked correlation coefficients for elevation and rainfall demonstrate the important negative effect of both factors on yields, especially in the case of the pines. The magnitude of the r values is also explored in this table by means of ranking the coefficients for the two factors. Clearly the ranking is the same for Scots and Corsican pine, European larch and Douglas fir, and is very close for the spruces and beech. This suggests that both factors have a very similar effect, exerting a negative effect upon growth in most cases. The only significant exception is Douglas fir.

Table 15

National Correlation Coefficients and Their Rank

Species	*Elevation*	*Rank*	*Rainfall*	*Rank*
SP	-0.49 **	2	-0.35 **	2
CP	-0.55 **	1	-0.45 **	1
LP	-0.46 **	3	-0.17 **	5
SS	-0.08 NS	9	0.03 NS	8
NS	-0.21 **	6	0.01 NS	7
EL	-0.25 **	4	-0.18 **	4
JL&HL	-0.24 **	5	0.09 SS	9
DF	-0.03 NS	10	0.21 **	10
OAK	-0.09 NS	8	-0.19 **	3
BE	-0.19 **	7	-0.16 **	6

** Significant at 0.01 level

NS Not Significant

Table 16

Conservancy Correlation Coefficients - Yield/Elevation

Species	*NE*	*NW*	*NWA*	*SWA*	*SW*	*SE*	*E*
	Conservancies						
SP	-0.35**	-0.60**	-0.18	-0.41*	0.23	0.46*	-0.51*
CP	-0.41*	-0.12	-0.04	-0.43*	0.06	0.13	-0.34
LP	-0.55*	-0.27	-0.09	-0.37*	0.02	0.07	0.42
SS	0.01	-0.06	-0.10	-0.11	-0.01	0.26	0.11
NS	-0.41**	0.25	-0.37	-0.11	-0.35	0.29	0.09
EL	-0.26	-0.11	0.31	-0.39	0.25	0.17	-0.41
JL&HL	-0.14	-0.05	-0.16	-0.29	0.11	0.17	-0.12
DF	0.05	0.25	-0.23	-0.43*	0.16	0.09	-0.05
OAK	0.14	0.14	0.13	-0.15	-0.22	0.05	-0.01
BE	-0.34*	0.11	0.19	-0.11	0.15	0.18	-0.24

** Significant at 0.01 level

* Significant at 0.05 level

Table 17

Conservancy Correlation Coefficients - Yield/Rainfall

Species	*NE*	*NW*	*NWA*	*SWA*	*SW*	*SE*	*E*
	Conservancies						
SP	-0.29*	-0.65**	-0.53*	-0.26	-0.34	0.27	-0.29
CP	-0.24	-0.25	-0.48*	-0.30	-0.36	0.27	-0.34
LP	-0.58**	-0.37*	-0.27	-0.03	-0.15	0.11	0.47
SS	-0.23	-0.31	-0.48*	0.03	0.26	0.43	0.25
NS	-0.37**	0.02	-0.04	-0.07	-0.25	-0.31	0.03
EL	-0.47*	-0.18	0.01	-0.31	-0.11	-0.06	0.08
JL&HL	-0.33*	-0.06	0.20	-0.24	-0.09	0.44*	0.12
DF	-0.05	-0.02	0.26	-0.21	0.29	0.22	-0.03
OAK	0.05	-0.05	-0.34	-0.16	-0.36*	-0.16	0.05
BE	-0.43*	-0.45*	0.14	-0.16	-0.06	-0.06	-0.39

** Significant at 0.01 level

* Significant at 0.05 level

Table 18

Significant Linear Correlation Coefficients (r) and Polynomials (P) for Yield/Elevation

Species	*Conservancies*														*National*	
	NE		NW		NWA		SWA		SW		SE		E			
	r	P	r	P	r	P	r	P	r	P	r	P	r	P	r	P
SP	-0.35**	3**	-0.60**	5*			-0.41*				-0.46*		-0.51*			
CP	-0.41*						-0.43*									
LP	-0.55**						-0.37*									
SS																3**
NS	-0.41**															
EL				3*				2*								
JL&HL																
DF		2*					-0.43*									
OAK		3*				2**										
BE	-0.34*	3**														

** Significant at 0.01 level

* Significant at 0.05 level

Table 19

Significant Linear Correlation Coefficients (r) and Polynomials (P) for Yield/Rainfall

Species	*Conservancies*														*National*	
	NE		NW		NWA		SWA		SW		SE		E			
	r	P	r	P	r	P	r	P	r	P	r	P	r	P	r	P
SP	-0.29*		-0.65**		-0.53**			2*		2**						
CP	-0.58**				-0.48*							2*				
LP			-0.37*													3**
SS		3*			-0.48*											5*
NS	-0.37**									4**						
EL	-0.47*															
JL&HL	0.33*										0.44*					
DF																
OAK									-0.36*							
BE	0.43*		-0.45*													

** Significant at 0.01 level

* Significant at 0.05 level

Since the relationships are complex and not entirely explained by linear regression curvilinear regressions were fitted to the data. In some instances a significant fit was obtained where nothing was obtained by linear regression earlier and vice versa. This possibly indicates the influence of outlying points in some areas and there is, therefore, a need for more refined data before firmer conclusions can be drawn. However, the significant regressions are shown graphically in Figures 5.1 - 5.10 (pp. 75-77).

These graphs may help to clarify the problem of the interaction between yields and elevation and rainfall, and although much more precise data are necessary there are indications that species yields, based on silvicultural evidence, may well follow the predictions given in the conventional guidelines in Bulletin 14. Nevertheless, it would be interesting to be able to refine these statements and to see at which thresholds of elevation and rainfall yields begin to change.

Since elevation and rainfall clearly interact it is necessary to examine the combined effect of these two variables in order to determine the amount of explained variation which these factors contribute to yield variations. For this purpose multiple regression is used.

Table 20 shows the multiple correlation values for the national situation, the F levels, degree of significance, and the amount of explained variation which clearly varies widely among species. The fact that the two variables jointly account for over one-fifth and one-seventh of the yield variations of the pines and Japanese and Hybrid larch respectively, reinforces earlier statements in Chapter 4 about their yields being affected by elevation and rainfall. For the remaining species the amount of explained variation is much smaller and there are clearly other factors much more responsible in these cases. The significant multiple regression values within the Conservancies are shown in Table 21.

Multiple regression is a useful statistical procedure but has only limited application in this context owing to the generalised nature of the data and the fact that only two variables have been used. The fact that there are only twelve significant Conservancy values and that the maximum multiple r value never exceeds 56 per cent indicates that other, and possibly more important, variables affect yield variations and that further studies of more detailed site data could usefully follow the broad view taken above.

Table 20

National Multiple Regression

Values for Elevation Plus Rainfall

Species	*F Value*	*Multiple r*	*Explained Variation per cent*
SP	32.3**	0.49810	24.8
CP	37.6**	0.56918	32.4
LP	22.3**	0.47249	22.3
SS	1.3†	0.12193	1.5
NS	7.6**	0.26795	7.2
EL	5.1**	0.25123	6.3
JL&HL	16.3**	0.37964	14.4
DF	7.6**	0.28280	7.9
OAK	3.1*	0.19588	3.8
BE	3.6*	0.19731	3.8

** Significant at 0.01 level

* Significant at 0.05 level

† Not significant

Table 21

Significant Multiple Regression Values

(Elevation plus Rainfall) for Conservancies

Conservancy	*Species*	*F value*	*Multiple r*	*Explained Variation per cent*
NE	SP	3.4*	0.35936	12.9
NE	CP	4.2*	0.40776	16.6
NE	LP	14.6**	0.62815	39.5
NE	NS	5.7**	0.43526	18.9
NE	BE	3.5*	0.43997	19.4
NW	SP	20.7**	0.75083	56.4
NW	BE	5.8**	0.54974	30.2
NWA	SP	4.1*	0.53027	29.2
SWA	LP	4.6*	0.50974	25.9
SWA	CP	4.9*	0.42797	18.3
SW	SP	5.4*	0.55563	30.8
E	EL	6.1*	0.70941	50.3

** Significant at 0.01 level

* Significant at 0.05 level

CONCLUSION

The application of statistical tests and methods helps to add precision to the suggestions made in earlier chapters in an attempt to ascertain the causes of yield variations. Thus, for seven species, increasing elevation is nationally significant, especially for the pines. Increasing rainfall, by contrast, may not reduce yields as much as elevation for most species since yields and rainfall are less often negatively correlated. The fact that there are more negative correlations in northern or upland Conservancies suggests that irrespective of species these are areas where poor performance is more likely in higher elevation and rainfall zones. This conclusion is indicated in Table 22.

Table 22

The Number of Significant Negative Correlation Coefficients by Conservancy

Conservancy	*Negative Coefficients (Yields by Elevation or Rainfall)*
North East	11
North West	3
North Wales	3
South Wales	4
South West	1
East	1
South East	-

These values confirm what has been suggested by the SYMAP analysis in Chapter 4, and indicate that in order to maximise growth potential in these upland Conservancies careful attention must be paid to elevation and rainfall factors. This is especially relevant in relation to projected forestry expansion which is more likely to occur in these Conservancies than in the lowland areas.

The Forestry Commission, however, are concerned with factors other than rainfall and elevation and it is now appropriate to move from the meso-scale to the micro-scale in order to see how species perform, not only in relation to these factors but also to other factors such as slope, soil and wind. This is done by examining species responses in the individual compartments of two selected forests.

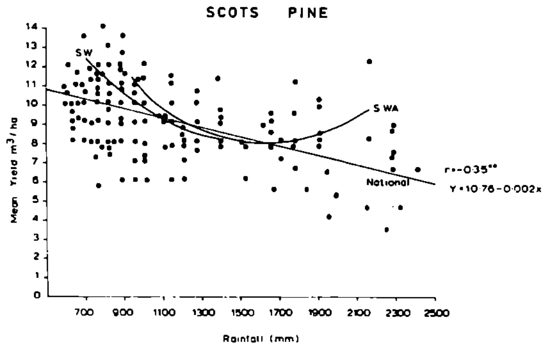


Figure 5.1 Yield/rainfall scattergram and regression lines for Scots pine

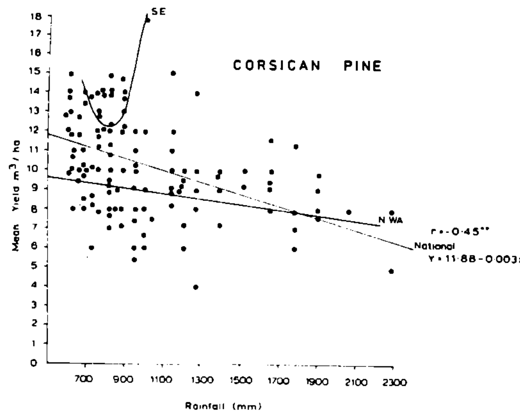


Figure 5.2 Yield/rainfall scattergram and regression lines for Corsican pine

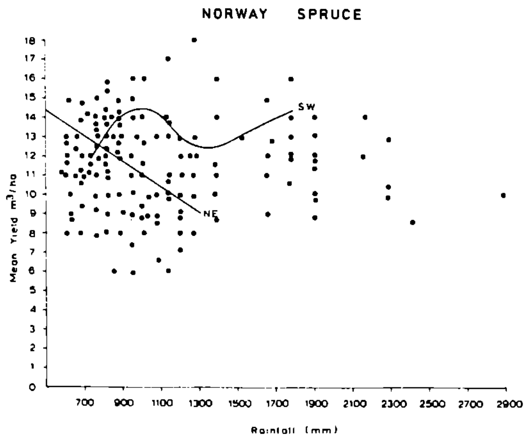


Figure 5.3 Yield/rainfall scattergram and regression lines for Norway spruce

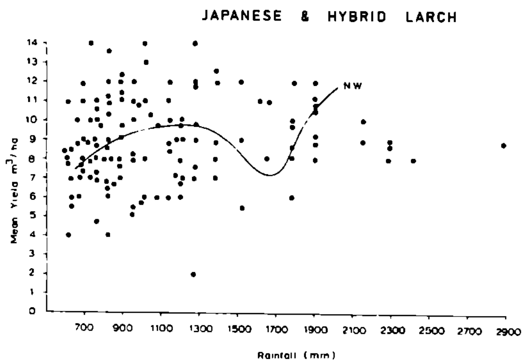


Figure 5.4 Yield/rainfall scattergram and regression line for Japanese and Hybrid larch

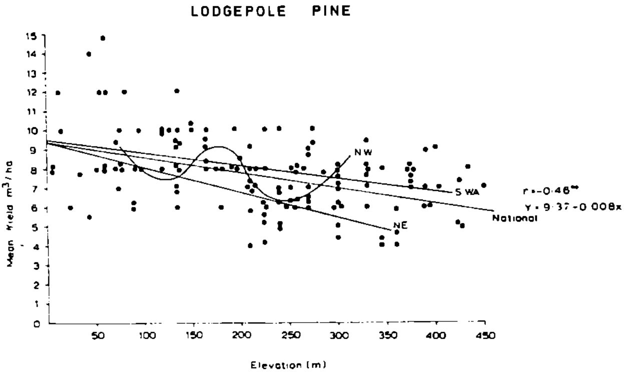


Figure 5.5 Yield/elevation scattergram and regression lines for Lodgepole pine

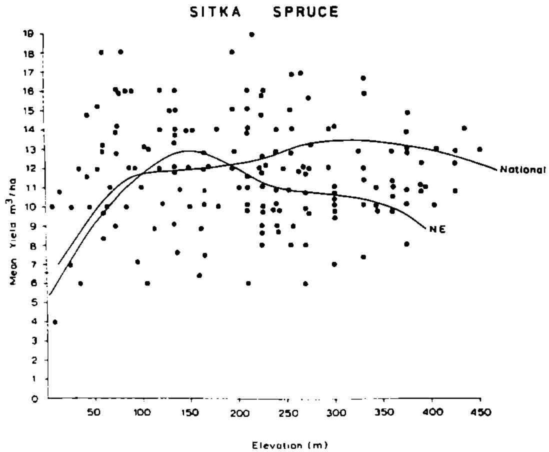


Figure 5.6 Yield/elevation scattergram and regression lines for Sitka spruce

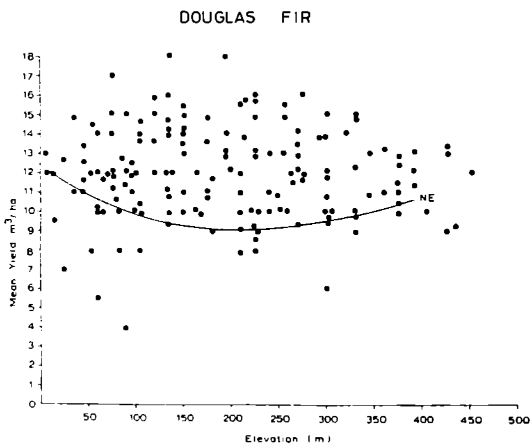


Figure 5.7 Yield/elevation scattergram and regression line for Douglas fir

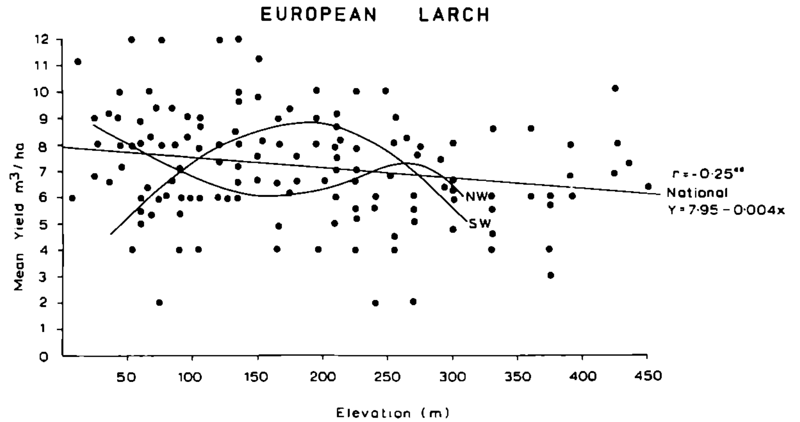


Figure 5.8 Yield/elevation scattergram and regression lines for European larch

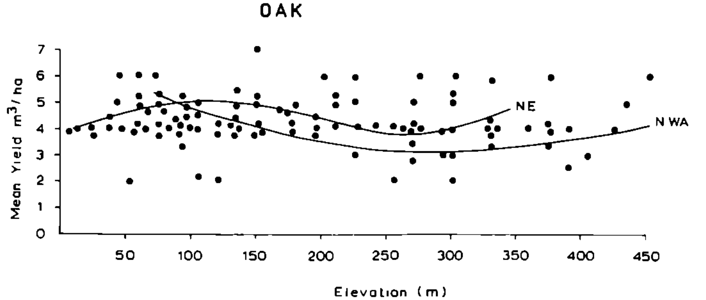


Figure 5.9 Yield/elevation scattergram and regression lines for Oak

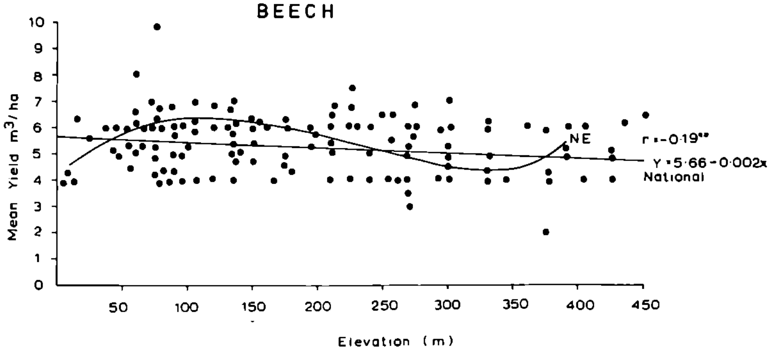


Figure 5.10 Yield/elevation scattergram and regression lines for Beech

CHAPTER 6

GROWTH IN A FOREST

INTRODUCTION

The main purpose of this chapter is to follow the macro-level and meso-level discussion by a more detailed examination at the micro-level found within a forest. The broad findings made earlier will be related to the more detailed spatial context at sub-compartment level and also extended to more specific variables. The forest, and especially the compartment, are the basic management units and it was felt that this examination would be incomplete without some analysis of growth at this level.

Two forests have been chosen for this purpose, St Gwynno Forest, in the South Wales Conservancy and Mortimer Forest, in the North West Conservancy. St Gwynno Forest was selected because it is an average yielding forest with characteristics not atypical of many of the Commission's poorer sites. Mortimer Forest was chosen because of its overall high yields already observed in Chapter 4; it was felt that this high potential should be investigated further. Figures 6.1 and 6.2 (pp. 86/7) show the location and topography of St Gwynno and Mortimer Forests.

It is desirable to develop explanation of yields beyond that which has already been afforded by the generalised variables of elevation and rainfall. Unfortunately, climatic variables are not available at the compartment level nor are all the variables consistently available for both forests. For each forest subcompartment species, stocked area, yield class, aspect, exposure (Topex value at St Gwynno), elevation and slope were recorded for analysis.

A set of histograms (Figures 6.3 and 6.4, pp. 88-90) has been constructed to show the yield frequencies and means of major species in each forest in relation to the selected variables. Each one is calibrated in percentage terms and the assemblage of graphs provides a synoptic view of compartment yields in the context of the different variables. These graphs are discussed below.

In Figure 6.4 (p.88-9) for St Gwynno Forest, the three elevation categories of 250m, 350m and 450m represent fixed altitudinal bands but despite this it is clear that increasing elevation causes the mean to shift leftwards to lower values for all four species. This is especially apparent in the case of Scots pine where the mean shifts a whole yield class from 10 m^3 at 250m to 8 m^3 at 450m. This shift to lower values also affects the mean of supposedly elevation-tolerant species such as Sitka spruce.

Figure 6.4 (p.90) which shows a similar set of histograms for Mortimer Forest (Ludlow and Shobdon blocks combined) contrasts with the set for St Gwynno Forest in that there are six species and four variables. Of the variables only aspect and elevation are comparable with those of St Gwynno.

The first variable, elevation, was determined by grouping the wide range of mean compartment elevations into four bands for the convenience of the graph. The three other variables, exposure, aspect and slope were extracted from the compartment records.

Overall, it is clear from the histogram that the mean of the spruces is more affected by the four variables than the means of the other species. However, in general, the means are reduced with increasing elevation especially in the case of Norway spruce, although Sitka spruce shows a slight increase above 300m, demonstrating once again its elevation-tolerant nature.

The histograms provide a first approach to the complex array of data but they do not of themselves offer explanations of yield variations. Instead, they indicate a series of clues to possible factors worth investigating in detail. This investigation would be best handled by regression analysis but unfortunately most of the variables are ordinal in type and do not lend themselves to this sort of test. This means that the only possible correlates are yields with elevation and mean soil depth in St Gwynno and elevation and mean slope in Mortimer.

Regression

Elevation is not a new variable but its values by compartments are more precise than those calculated by forests in Chapter 5. The significant correlation coefficients for yield/elevation for the major species in the two forests are shown in Table 23 where national and Conservancy coefficients for relevant species are compared.

There are only three significant results for the two forests and nowhere is more than 15 per cent of the variation within the forest explained by elevation. Only the compartment coefficient for Douglas fir is an improvement on the Conservancy and national values in contrast to the coefficients for Scots pine in Mortimer and Japanese and Hybrid larch in St Gwynno, which are less significant than both the national and Conservancy values and explain less of the variation.

Table 23

Yield/Elevation Coefficients

Species	*National by Forests*	*Conservancy by Forests*	*Forest by Compartment*	*Explained Variation Forest by Compartment (per cent)*
		SWA	St Gwynno	
JL&HL	-0.24**	-0.29†	-0.21*	4.4
		NW	Mortimer	
SP	-0.49**	-0.60**	-0.39*	15.2
DF	-0.03†	-0.25†	-0.27**	7.3

** Significant at 0.01 level

* Significant at 0.05 level

† Not significant

Correlation coefficients for yield/mean soil depth in St Gwynno Forest are significant for three species (Table 24).

Table 24

Yield/Mean Soil Depth - St Gwynno Forest

Species	*Coefficient*	*Explained Variation (per cent)*
JL&HL	-0.26**	6.8
NS	-0.25*	5.0
SS	-0.22*	4.8

** Significant at 0.01 level

* Significant at 0.05 level

These values suggest that there is a significant association between falling yields and increasing soil depth from its minimum of 15 cm. This could be a reflection of poorer drainage or rocking problems on waterlogged, spongy soils. At this stage, however, it is not possible to be specific about causes as such.

Mean slope in Mortimer Forest can be tested in the same way and Table 25 shows the linear correlation coefficients of yield/slope in this forest.

Table 25

Yield/Slope Coefficients - Mortimer Forest

Species	*Coefficient*	*Explained Variation (per cent)*
BE	+0.65*	42.3
JL&HL	-0.29**	8.4

** Significant at 0.01 level

* Significant at 0.05 level

Although only two species show significant correlation the slope variable adds a new dimension to the analysis since it has not previously been demonstrated that slope is associated with yield variations. It will be noted that both positive and negative slope coefficients occur. Thus increasing yields of beech are associated with increased slope angle whereas yields of Japanese and Hybrid larch decline as slope increases. This problem could well be examined in more depth.

Although there are combinations of only two variables in each forest it is worth investigating the combined effect of these variables on yields. Table 26 shows the results of a multiple regression test involving combination of the variables elevation and mean soil depth.

Table 26

Multiple Regression Values for Soil Depth and Elevation

St Gwynno Forest

Species	*Overall F Value*	*Explained Variation (per cent)*
SS	3.6*	5.9
JL&HL	5.34*	9.0

* Significant at 0.05 level

Only two results are significant at the 0.05 level and nowhere is more than 9 per cent of the variation explained. The generally very low level of explained variation for the spruces and larches suggest that other variables may be more important in determining compartment yields.

For Mortimer Forest the results of the combined variables, mean slope and elevation, on yields is shown in Table 27.

Table 27

Multiple Regression Values for Slope Angle and Elevation

Mortimer Forest

Species	*Overall F Value*	*Explained Variation (per cent)*
SP	3.47*	22.5
JL&HL	6.32**	12.2
DF	4.14*	7.6
BE	4.5*	45.0

** Significant at 0.01 level

* Significant at 0.05 level

The lack of precise interval data for the remaining compartment variables precludes the further use of regression and it is now necessary to view the problem by mapping compartment yields.

Mapping Compartment Yields

In the absence of further statistical data there is another approach in the compartment yield class figures themselves which are the *resultant* of all the operative factors whether known or unknown.

In this method, the yield of the dominant species in each compartment is expressed by its standard deviation from a mean, i.e. one of three class intervals of 1 standard deviation either side of the mean, and each interval distinguished by a colour. A series of three maps was made to show the standard deviation of the compartment yield from the forest, Conservancy and national means. Plate 1 (Centre p.) shows the spatial variation from the national mean in St Gwynno and Mortimer (Shobdon) Forests, the tabular summaries of the variations being given in Tables 28 and 29.

St. Gwynno Forest

Compartments in which there are no species at all are shown in black to avoid confusion with the white category for -2 to -3 standard deviations. The overall relative increase in compartment yields from Forest to Conservancy to national reference levels is clearly evident. In most instances, individual compartments show that their performance is comparatively good by Conservancy standards and even better by national standards. This is not necessarily true for all compartments as some remain above average or below average at all three levels of reference.

Table 28

St Gwynno Forest - Summary of Compartment Yields

Number of Compartments

Standard Deviations	*Deviation from Forest Mean*	*Per cent*	*Deviation from Conservancy Mean*	*Per cent*	*Deviation from National Mean*	*Per cent*
+2 to +3	1		4		4	
+1 to +2	14		21		33	
0 to +1	34		67		65	
Sub Total	49	28.2	92	52.8	102	58.6
0 to -1	91		64		62	
-1 to -2	25		12		8	
-2 to -3	9		6		2	
	125	71.8	82	47.2	72	41.4
Total	174		174		174	

Of the 102 compartments which have yields above average in all three contexts 87 compartments were over +1 standard deviation from the mean. This result confirms the suitability of the species, the spruces mainly, for the sites on which they had been planted.

It is significant that of the 72 compartments with below national average growth, more than half carried the larches and could be expected to be more productive under another species, probably the spruces.

There are, clearly, many unanswered questions concerning yields in St Gwynno Forest. However, it is suggested that the techniques adopted provide a framework in which to direct attention to problem areas or particularly good areas. This is not directly evident from the compartment records themselves and shows how mapping can help to organise raw data.

Mortimer Forest

The great complexity and fragmentation of Mortimer Forest compared with St Gwynno prevent so direct an interpretation of compartment variability. The Shobdon section diagram of spatial variation from national means is shown in Plate 1 (centre page).

As at St Gwynno, there is a large cluster of compartments with yield within the standard deviation from the forest means but, in contrast, there is a much better balance of compartments with yield either side of the mean. Compared with Conservancy and national averages the compartment yields are quite favourable.

Table 29

Mortimer (Ludlow and Shobdon) Forest

Summary of Compartment Yields

Standard Deviations	*Deviation from Forest Mean*	*Per cent*	*Deviation from Conservancy Mean*	*Per cent*	*Deviation from National Mean*	*Per cent*
+2 to +3	2		9		7	
+1 to +2	25		58		59	
0 to +1	74		75		94	
Sub Total	101	51.3	142	72.1	160	81.2
0 to -1	76		46		30	
-1 to -2	73		9		7	
-2 to -3	7		-		-	
Sub Total	96	48.7	55	27.9	37	18.8
Total	197		197		197	

CONCLUSION

The main feature of this chapter has been the investigation and development of methods and techniques appropriate to an analysis of compartment yields. Although much of the sub-compartment record data was unsuited to the statistical treatments attempted, it nevertheless could be portrayed in a visual way. This shows that in addition to the established usefulness of these records to the foresters there also exists further potential.

The amount of explained variation at the compartment level is surprisingly low despite the more precise data theoretically available. Thus the relative lack of adequate explanation suggests that the broader explanations at Forest and Conservancy level may be more absolutely important than suspected and may justify the broad view hitherto taken in this paper. Equally it is also likely that other highly specific site factors not yet explored may be causing more of the yield variability in the two forests.

The present work, however, is mainly concerned with attempting to make recommendations on a rather broader basis than the compartment but the methods and techniques developed for the compartment approach could be adopted at the national level. This is undertaken in the following chapter in which a national recommendation scheme based upon forest standard deviations formed the final objective of this study.

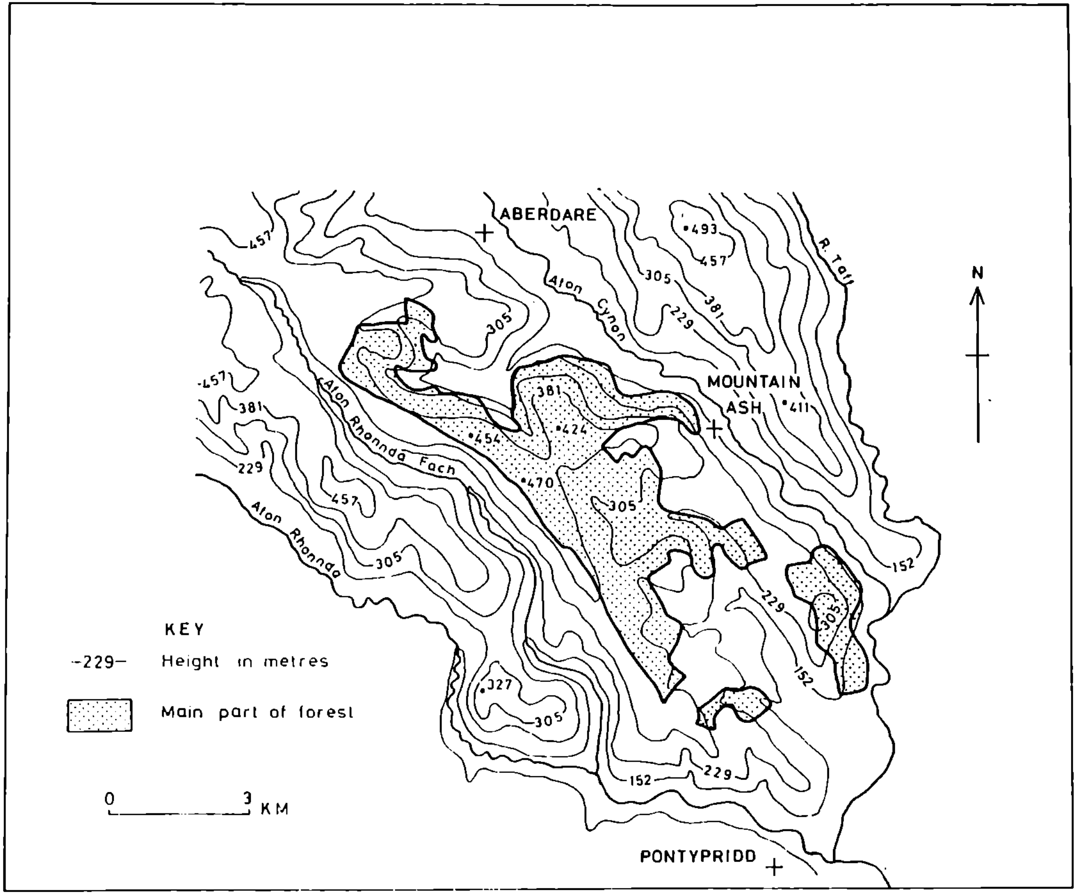


Figure 6.1 St. Gwynno Forest - Relief

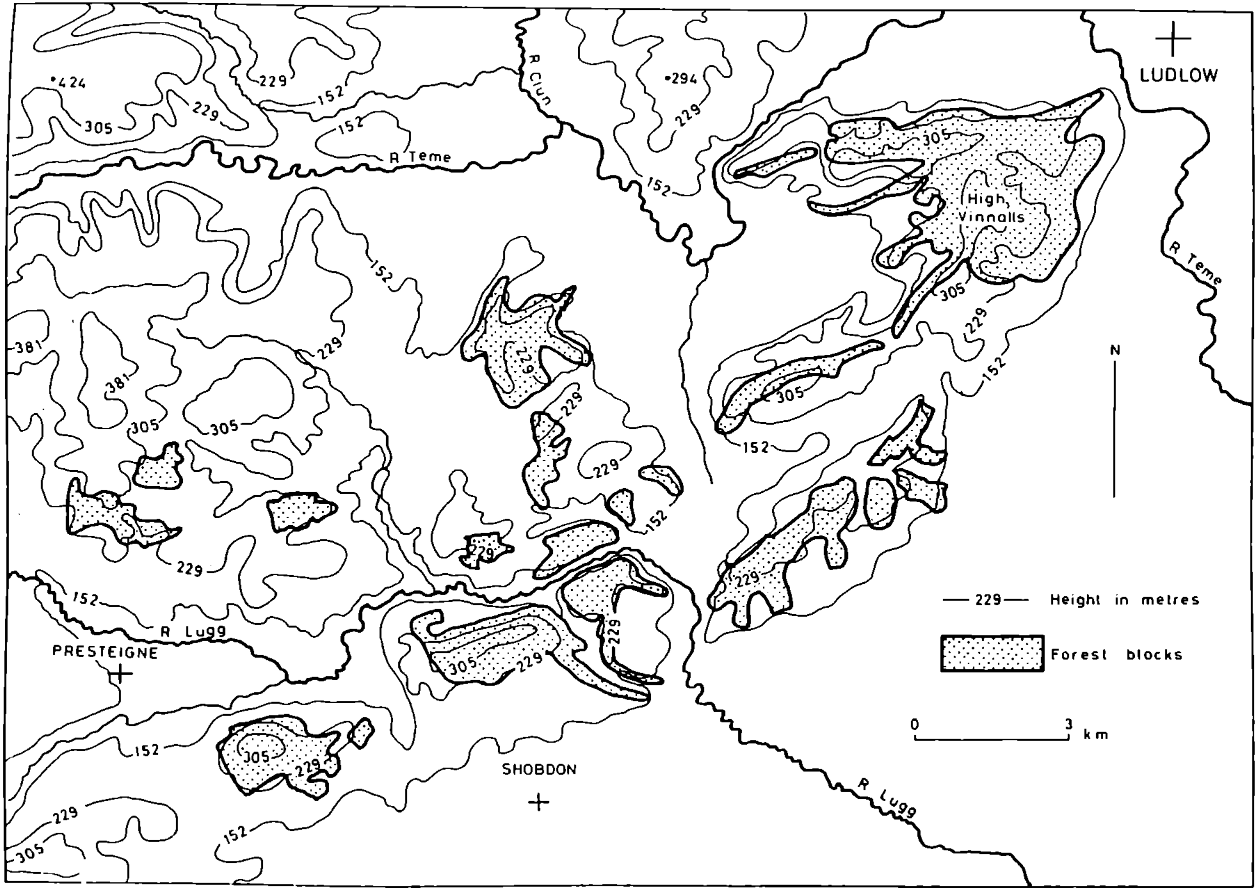


Figure 6.2 Mortimer Forest (Ludlow & Shobdon) - Relief

St. Gwynno Forest

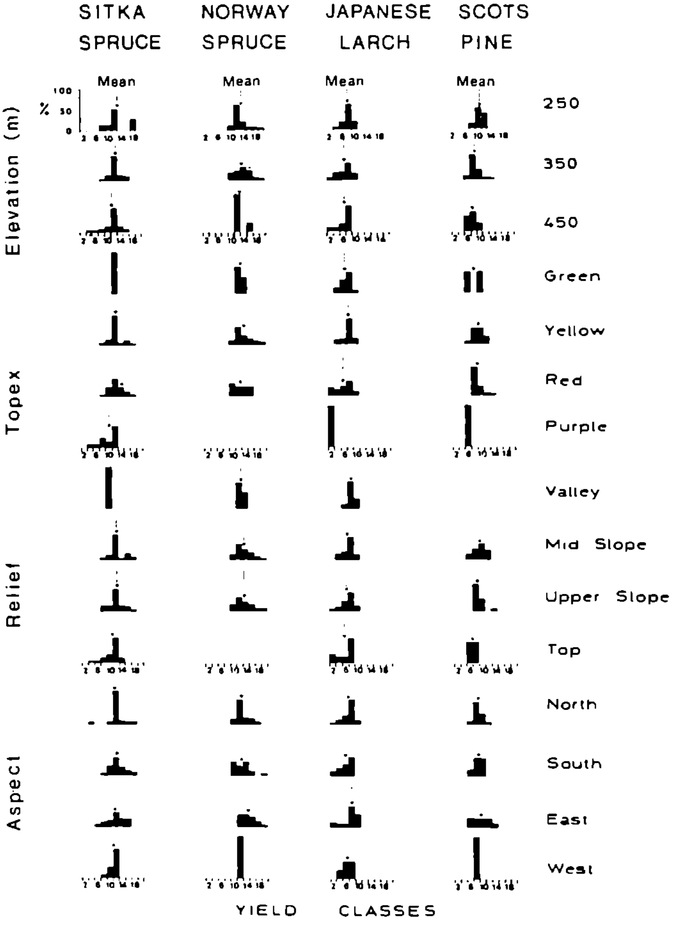
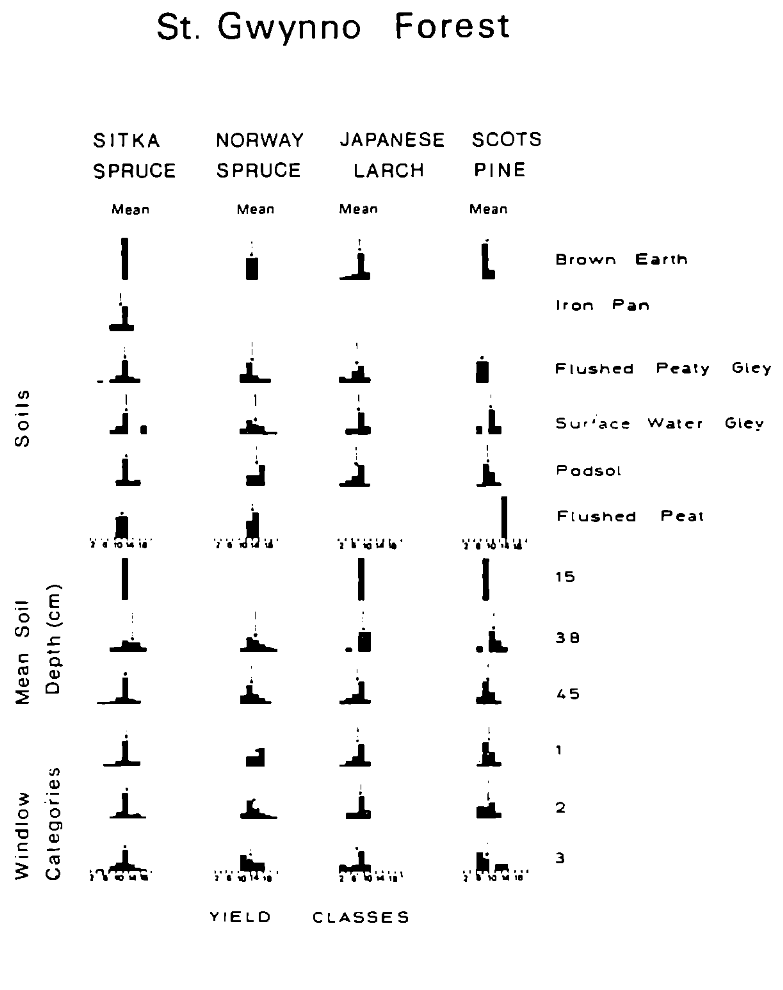


Figure 6.3 Yield frequencies for



site variables in St. Gwynno Forest

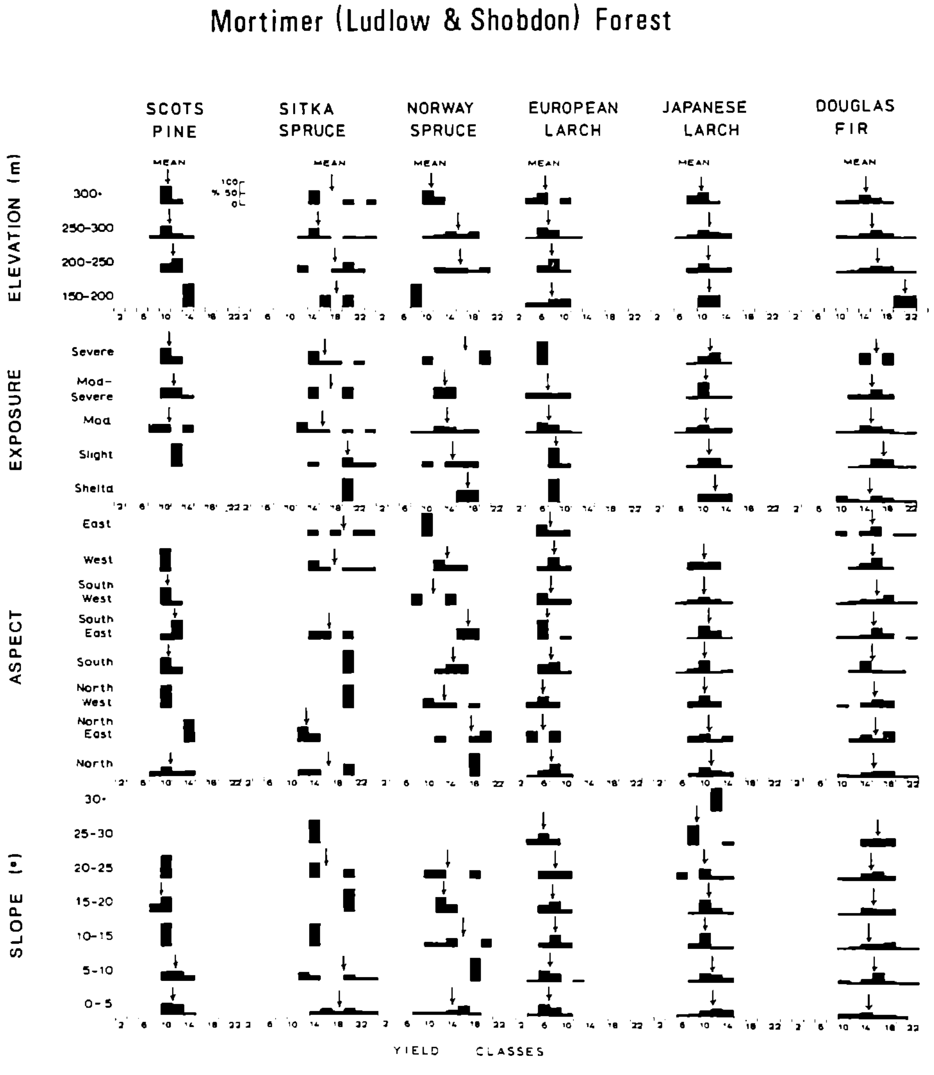


Figure 6.4 Yield frequencies for site variables in Mortimer Forest

CHAPTER 7

RECOMMENDATIONS

INTRODUCTION

It is now appropriate to focus the yield findings into a form which can provide answers to questions only briefly alluded to earlier so that they can serve as a basis for planting recommendations.

The two main questions that need to be answered are:

a) Choice of area

For any given species, which are the high-yielding areas that should be selected for planting and which areas should be avoided to minimize poor performance ?

b) Choice of species

Given an area of land which would be the best species to choose or the ones to avoid; what is the range of alternative species ?

Diagrams have been devised to attempt to answer these questions. They are termed recommendation diagrams and take the form of a set of Conservancy matrices. For each Conservancy the ten species are represented by ten rows and the individual forests are arranged by columns in a north-south sequence from left to right. The forests are numbered from 1 to n in each Conservancy for the purpose of reference to a location map (Figure 7.1, p.97). In North-East Conservancy the colour suffixes to forest names relate to an earlier attempt to identify exposure zones and do not relate to the system of colours used in this paper. Recommendation diagrams are compiled to show units of standard deviation in the same manner as in the maps of compartment yields in Chapter 6. Additional features of the matrix diagrams include the use of unframed blank areas to show that a given species is absent, and the superimposition of a black dot on any cell for which the species is both above average in yield and preponderant in area. The dot is a visual indication of a successful choice of species. The key to the recommendation diagrams is shown in Plate 2 (centre).

THE USE OF THE DIAGRAMS

The North East and South West Conservancies will be taken to illustrate the use of the diagrams and the findings for the other Conservancies will be summarised in turn.

The purple and dark blue cells indicate areas and species with well above average growth. In the North East Conservancy there are seven of these (Plate 2, (centre), Scots pine in York Forest, Lodgepole pine in Chillingham, Jervaulx (White) and York Forests, Norway spruce in Ampleforth Forest, Japanese and Hybrid larch in Jervaulx (Green) Forest, and Oak in the Stang Forest. In only two of these cases are the favoured species preponderant in area, and so there appears to be a case for recommending an increase in the area of the other five.

This short list of seven locations exhausts all the cases where any species in any forest is growing more than one standard deviation above its national average. This restricts the first round of recommendations to a very few areas and for most of the forests it would seem better, at first sight, to grow the various species in other Conservancies where there are more locations yielding more than one standard deviation above the national average. However, since the Forestry Commission owns a great deal of land in the North East Conservancy and must grow some species there, it is necessary to turn to question (b), i.e. given an area of land, which is the best species to grow? Plate 2 (centre) can answer this question only in part. For example, in Wark (Chirdon) Red, Lodgepole pine performs best in relation to its national average while Japanese and Hybrid larch perform worse in relation to their national average. However, the larches are actually producing more timber per hectare than Lodgepole pine because their national averages are so much higher. It is, therefore, necessary to introduce a different type of recommendation diagram which is designed to answer question (b) by relating all production figures to a single national mean for all species combined, rather than to the varying means for individual species. This second technique is illustrated for the South West Conservancy since previous findings suggest that this Conservancy is potentially one of the most productive for a wide range of species.

Plate 3 (centre) shows two matrices for the South West Conservancy. The upper matrix is based upon the national means of individual species as in Plates 2&4 (centre)whereas the lower matrix is based upon the combined national mean of all species. The colour system remains constant; only the reference level changes. When related to an overall national norm some species such as Douglas fir are performing even better whereas oak and beech are performing even worse. If,therefore, question (b) is being asked the lower diagram suggests that, for example, in Wyre Forest spruces are best, in Hereford Forest Norway spruce and Douglas fir are best, and in Savernake Forest, Corsican pine and

Douglas fir are best. By contrast, if it is required to increase the area of a *given* species, (question (a)), then the upper matrix in Plate 3 (centre) shows that, for example, Scots pine could be increased in area in Salisbury Forest, Sitka spruce in Bristol Forest, and European larch in Hartland and Honiton Forests. By contrast, the poor performance of European larch in Wyre Forest, Scots pine in Bristol Forest or Japanese and Hybrid larch in Lands End Forest,in both diagrams clearly indicates which species and areas should be avoided if yields are to be maximised. In practice, decisions would be made by combining the results of these two questions in relation to each type of recommendation diagram.

Within the confines of this study it was not possible to undertake the production of both types of recommendations diagram. Preference has been given to the type which answers question (a), for the following reasons. At present the Forestry Commission is mainly concerned with volume production and therefore with question (b). As Britain grows only 8 per cent of its requirements the balance is imported and, therefore, most home-grown timber can find a market. If, in the future, it becomes necessary to be more self-sufficient in forest products there will arise a need to balance the type of timber produced according to demand and question (a) choice of area to suit constraints in the choice of species, will become a more important question. As this has received less attention hitherto, it has been given preference here. A second reason for considering areas related to a variety of species is the ecological need for species variety which has been sacrificed by emphasis upon a very few high volume producing species. It is worth stressing again that effecting a general increase by one yield class nationally, would give a ten per cent increase in production without any change in land area.

CONSERVANCY SUMMARIES

Recommendation diagrams for the other 5 Conservancies are shown in Plate 4 and brief summaries of their implications are given below, as well as further discussion of the diagrams for North East Conservancy (Plate 2) and South West Conservancy (Plate 3).

North East Conservancy

The main task in the North East Conservancy is minimizing areas with below average performances. It would probably be ecologically undesirable to restrict species to those few capable of reaching above the national average but the aim could be to replace everything performing worse than the dark brown cells. Regression upward towards the national mean yield for species seems a desirable objective in the North East Conservancy.

North West Conservancy

The dominance of browns and yellows offers a cautionary warning against indiscriminate new plantings but it does indicate that there is usually at least one species with above average yields in a forest and a greater extension of such crops could help to achieve a higher volume production in future.

North Wales Conservancy

Forests with the best alternative choices between species with above average yields are those of Newborough, Dyfnant and Radnor. Elsewhere the choice is severely limited and forestry in this Conservancy could be faced with a monoculture of the spruces, with a need to plant less productive species, and especially Lodgepole pine, for reasons of variety.

South Wales Conservancy

Compared with the three previous Conservancies the greater range of alternatives in South Wales is clearly apparent from Plate 2 (centre). There are 28 forests (11% of the total cells) in which species yields range from +1 to +3 standard deviations above average, yet there are no locations where the preponderant species yields from +2 to +3 standard deviations above average (purple squares) and only three cases where the preponderant species yield between +1 and +2 standard deviations (dark blue squares). These latter are Sitka spruce in Taf Fechan Forest and Japanese and Hybrid larch in Cilgwyn Forest and Slebech Forest. These facts testify to a considerable scope for raising future yields. For example, a better use of land and a quicker rotation should be possible by increasing the area of Sitka spruce in Taf Fechan Forest, planting more Norway spruce in Slebech Forest or Scots pine in the Rhondda Forest.

Although the yields of pines in South Wales rise above average in more cases than in North Wales, Plate 4 (centre) shows that an expansion in the area of these species is less to be recommended than Japanese and Hybrid larch. The importance of Japanese and Hybrid larch is partly recognised, so that it already occupies the preponderant area in four of its 16 above-average cells. Plate 4 (centre) also demonstrates that forests such as Teifi, Cilgwyn, Talybont, Slebech, Llandowror and Coed Taf Fawr, have between seven and eight species from which to choose to obtain above average yields.

South West Conservancy

The upper recommendation diagram (Plate 3) shows that there is enormous scope for increasing the areas of higher yielding species, not only at the expense of those that yield below average, but also, if required, in place of those that yield only slightly above average. For example, Scots pine would be a highly suitable dominant crop in Savernake or Salisbury Forests, Sitka spruce in Molton Woods, European larch in Hartland and Honiton Forests, or Oak in Cotswold Forest. The high yields of Douglas fir in Molton Woods and Honiton Forest are already acknowledged in the preponderance of this species there. The forester clearly has a diversity of species with above average yields and future planting could be a rich mixture of alternatives.

South East Conservancy

The free choice of species with above average yields for future planting in the South East is marred only by the poor performance of Douglas fir and the low yields at Friston and the Isle of Wight Forests. There are 25 cells (8.3% of the total) in which yields range from +1 to +3 standard deviations and 128 cells (71.9% of the total) which are above average.

East Conservancy

All forests except Wymersley (Yardley) have at least one species from which above average yields may be obtained and although the recommendation diagram for the East Conservancy compares with that for the North Wales Conservancy in terms of restricted species choice, there are comparatively more opportunities to increase volume production.

CONCLUSION

The Conventional Guidelines for species selection have been a first approximation, but yield class offers a more positive and precise method by which future replanting could be achieved with a rather more scientific match of species to area. In this way higher production should be possible even if there is no increase in total forest area.

The recommendation diagrams show that there are clearly a number of alternatives for raising forest productivity. These alternatives vary according to spatial location, and forests in southerly areas generally enjoy a wider range of species choice than do forests in the north or east of the country. All the seven Conservancy recommendation diagrams show a distinct 'blue' shift to higher yields in the south of most Conservancies and also in forests in the south of the country. The marked increase of blues and purple in the south and south west is possibly due to strong climatic influences, and the SYMAPS have already

(Chapter 4) alluded to this trend. Conversely the increase in browns and yellows in upland and northerly locations reflects more adverse conditions. Whatever the causes the diagrams offer actual blueprints from which certain aspects of future forestry operations might be planned. Ideally, foresters would avoid all cases where below average yields prevail but in many cases, such as the North East Conservancy, the task is to minimise a preponderance of cases that are greatly below average by concentrating on expanding the area where a species yields from -1 to 0 standard deviations.

The recommendation diagrams depict Conservancies in a different light from that previously discussed in the paper. Some Conservancies such as North Wales and the East could be termed '*species specific*' in that replanting for above average yields is restricted predominantly to the spruces and Scots and Corsican pine respectively. Other Conservancies such as the North East and North West emerge as highly '*forest specific*' since most species yield well in particular locations and not in others. The remaining Conservancies (South East, South West and South Wales) are '*forest and species flexible*' because of the large range of alternative species and forests in which above average growth is possible. These latter Conservancies represent some of the most valuable and important land for future forestry and their potential ought to be more fully realised in replanting programmes.

It is suggested that these approaches contribute additional methods of planning forestry by using simple techniques to identify which sites and species offer maximum potential. There is now no need to rely upon a 'fashions in planting' approach; the use of yield class data could offer a more convenient and sophisticated method of site assessment relevant not only to contemporary forest 'accounting' but also to future management objectives.

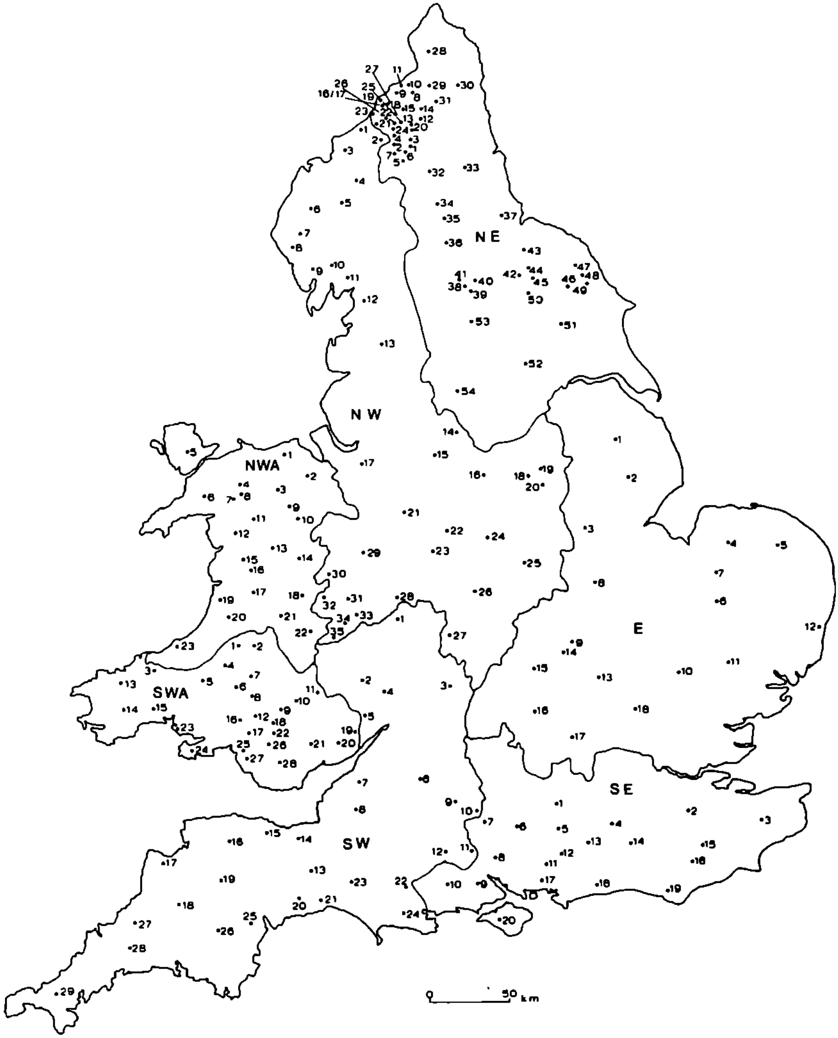


Figure 7.1 Map showing Forestry Commission Conservancies and forest locations

Occasional Paper No.12. Price £5.00

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

ODC 27 : 101

ISBN 0 85538 098 5

Printed by MCR Offset Ltd, Colliers Wood, London.