

Chapter (non-refereed)

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Tree physiology and the influence of the physical environment

10. SITE FACTORS INFLUENCING THE GROWTH OF STANDS OF SCOTS PINE IN GREAT BRITAIN

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With the realisation that supplies of fossil fuels are not limitless, it becomes increasingly important to understand the factors that control growth and transform solar energy, moisture and nutrients into wood, possibly a continuously renewable fuel. For this purpose, and hoping that it would be possible to devise ways of increasing "efficiency", possibly by changing silvicultural practices, a study was made of the growth of Scots pine, *Pinus sylvestris*, analysing the relations between growth and site variables by using principal component analyses and orthogonalized regressions.

Comparable studies have already been made of Sitka spruce by Mayhead and Broad (1978) and Malcolm (1976); of Sitka spruce, Douglas fir and Japanese larch by Page (1970). These workers, like students working with Scots pine in the Soils Department of the University of Aberdeen, found that elevation was of major importance. However, in analyses of Corsican pine, *Pinus nigra* var. *maritima*, Fourt *et al.* (1971) found that evapotranspiration during summer was the dominant factor, although, in their analyses, this factor incorporates (confounds) the effects of altitude at least to some extent. In the study made by Fourt *et al.*, growth of Corsican pine was found also to be significantly related to soil chemical and physical characteristics but these characteristics were not of primary importance. Because these studies were made of different tree species growing in restricted parts of the UK, it was decided to extend the approach to sites throughout the country. Would principal component analyses and orthogonalized regressions be as effectively discriminating when applied to stands distributed throughout the UK? As it has been widely planted, with Forestry Commission sample plots distributed in most of the afforested parts of the UK, it was decided to assess the growth of Scots pine.

1. Methods

During the summer of 1975, 101 variables, arranged in 11 groups (White, in prep.), were recorded at each of 73 sites (Figure 24):

1.1 Dependent variable

Size and age of *P. sylvestris*. Because stands of *P. sylvestris* can progress from one yield class to another within the span of a rotation, this fairly coarse dependent variable was replaced by 'Y', a term expressing the relation between actual growth and that predicted from the relation between \log_e Top Height (m) and \log_e Age (yrs):—

$$\log_e (\text{Top Height} - 10.0) = 0.584 \log_e (\text{Age} - 27.0) + 0.285 \quad 1)$$

where Top Height = mean height of the 100 largest trees ha^{-1} as assessed from diameters measured 1.3 m above ground.

1.2 Regressor variables

- a) Geographical—latitude and longitude
- b) Topographical—elevation, slope and aspect
- c) Competition—type and intensity of thinning
- d) Total soil depth
- e) Physical properties of top 5 cm of soil
- f) Physical properties of soil 5-25 cm below ground level
- g) Chemical properties of top 5 cm of soil
- h) Chemical properties of soil 5-25 cm below ground level

NB The physical and chemical soil variables were similar to those assessed in other studies with the addition of extra variables coping with the estimation of soil phosphorus.

- i) Monoterpenes—Because trees from different seed-lots grow differently, an attempt was made to identify genetical affinities by assessing the balance of monoterpenes, a supposedly distinctive and unvarying marker, in resin taken from needles.
- j) Climate—temperatures, rainfall, visibility, indices of wind direction and snow depth were calculated from equations given by White (1979), knowing latitude, altitude and other map readable site characteristics.

Although it was deemed necessary to include a large number (101) of site variables to ensure that

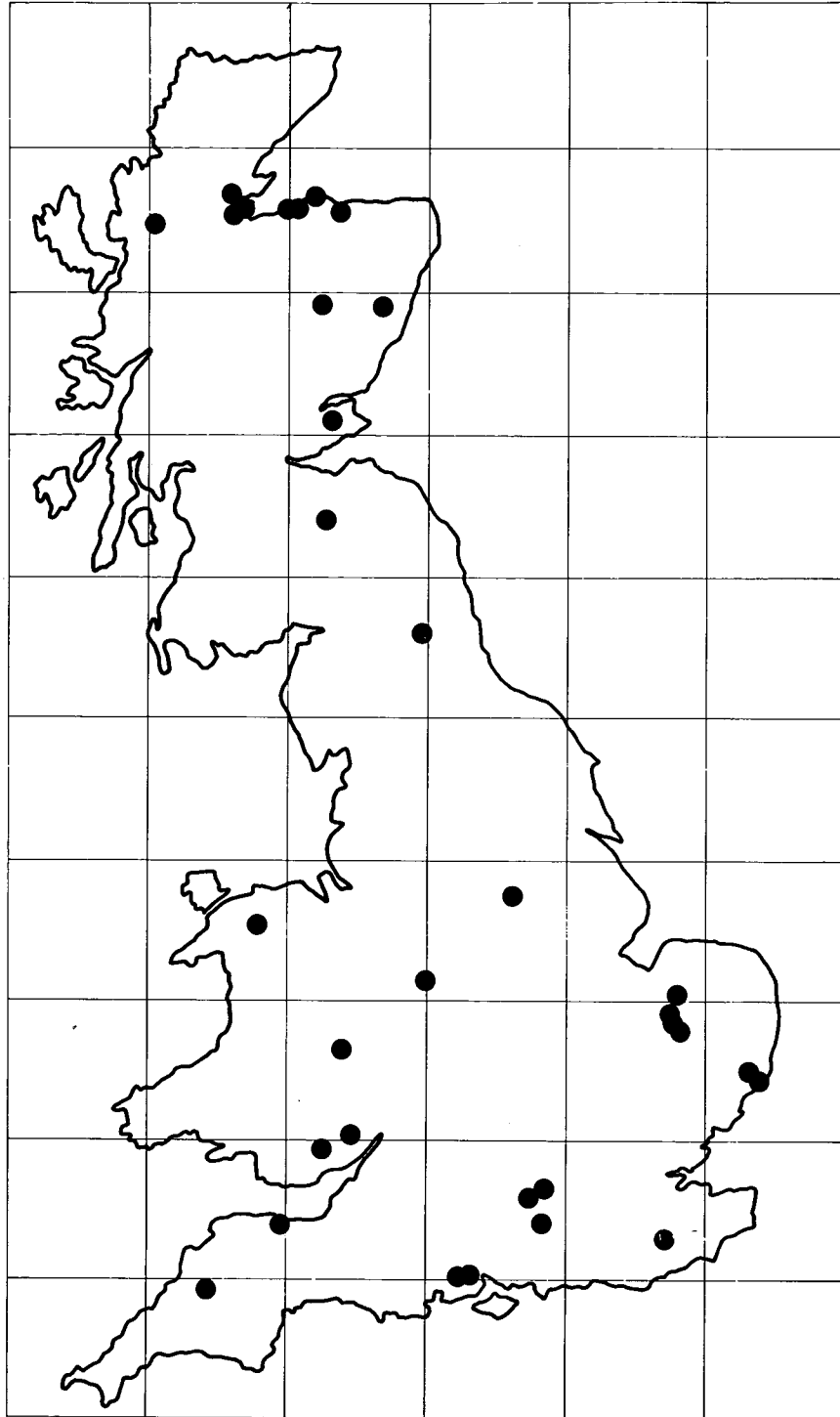


Fig.24 Map showing the distribution in England, Scotland and Wales of Forestry Commission Scots pine sample plots studied during 1975.

important factors were not overlooked, it was equally important to effect simplification as soon as possible. This was done by principal component analyses (PCA) applied to 3 sets of site variables including chemical and physical soil variables expressed in:

- (i) quantities per unit soil weight
- (ii) quantities per unit soil volume allowing for stones and bulk density
- and (iii) quantities per profile as for (ii) but allowing for depth

After calculating orthogonalized regressions, it was found that tree growth was more closely related, as judged by the amount of associated variation, to soil variables, including nutrients, expressed per unit soil volume than to the other 2 data sets. By setting aside data sets (i) and (iii) the dependence of tree growth, designated 'Y', was estimated by a complex of step-up multiple regressions on regressor variables starting with those selected by PCA (See method B4 of Jolliffe (1972) (Figure 25). As a result, 2 equations were obtained. In one, growth of Scots pine was related to 7 regressor variables, each of which accounted for a statistically significant amount of variation and in the other to 17 variables, the 7 plus 10 others which together minimized the standard deviation from the regression (Snedecor & Cochran, 1967).

2. Results

The 7 statistically significant variables were:

Variable	Cumulative percentages of variation explained
Mean summer solar radiation from July to September, measured at ground level	30.1
Silt, % vol, in top 5 cm of soil	35.5
Stones, % vol, in soil 5-25 cm below ground level	42.4
Moisture content of soil, 5-25 cm below ground level (% vol of air dry soil)	47.3
Index of mean wind direction July-Sept (degrees)	51.3
Log _e of the water holding capacity of top 5 cm of soil (% vol)	53.6
Distance from sea x slope to west (km), an index of 'exposure'	56.8

The additional 10 variables to minimize the standard deviation of the regression included "expressions" of soil phosphorus, including isotopically exchange-

able phosphorus, topography and additional aspects of soil texture and water holding capacity.

Not surprisingly, growth of Scots pine was closely and directly related to solar radiation (energy), a factor not previously identified in other research no doubt because of the unavailability of solar radiation maps first made available by the Meteorological Office in 1976. However, there were distinct differences in different parts of the country with variations in amounts of solar radiation being relatively unimportant within the north-east region of Scotland, Wales and south-west England, and south-east England including East Anglia.

After solar radiation, the next most generally important factors were those concerned with soil physical properties, growth being directly related to water holding capacity and increasing concentrations of silt and stones, and amounts of moisture (Figure 26).

In the north of Britain, growth was related to the shape of the contours, passing through the sample plots, from which effects on shelter and percolation down slopes were inferred, whereas in the south, summer soil moisture at 5-25 cm below ground level was an important factor. In the south-west a significant relation with monoterpenes suggests that the growth of Scots pine varied considerably with origin, an effect not noticed elsewhere.

3. Discussion

Because different research workers have used distinctive variables, many of which integrate the effects of a variety of associated factors, it would be unwise to overemphasize differences between the results of their analyses. However, in the present analyses, done for most of the UK and in which estimates of solar radiation were included, elevation did not prove to be a statistically significant factor affecting the growth of Scots pine. However, in analyses made of Scots pine in a restricted part of the Scottish uplands, students at Aberdeen University found, without the inclusion of solar radiation data, that elevation was of major importance, an observation which is not in conflict with the results given in this paper. In additional analyses restricted to the north-east, amounts of solar radiation were found to be independent of elevation and in this circumstance a topographical variable relating forests to either valleys or hill-tops was of significance in addition to soil depth and mean wind speed during April-June.

Although the opening and closing of Sitka spruce stomata are critically related to changes in atmospheric saturation vapour deficits (Watt *et al.*, 1976; Jarvis & Stewart, 1979), macroscopic growth was

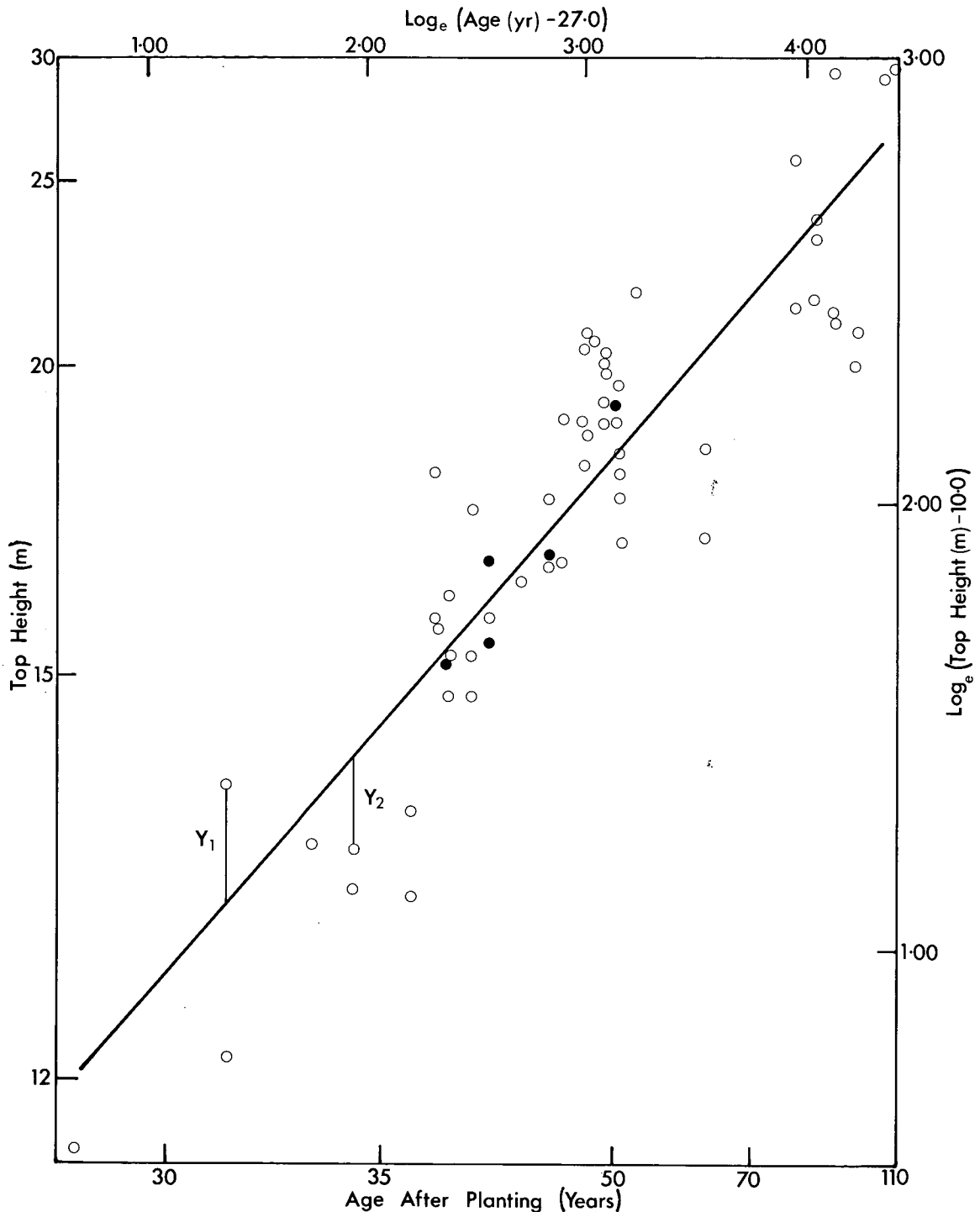


Fig. 25 Relation between (i) top height (m) and (ii) age, in years after planting, of Scots pine grown in sample plots at many different locations in the UK. The lines Y_1 and Y_2 indicate the deviations between actual and predicted heights of stands of trees about 31 and 34 years old respectively.

less stringently related to available soil moisture (Malcolm, 1976) than might have been expected. On the other hand, the guard cells of Scots pine stomata seem less sensitive to stress than those of Sitka spruce yet there was a strongly positive relation between the growth of the former and amounts of soil moisture.

Although growth differences in different parts of the UK were not attributable in the present analysis

to temperature variations—in the north-east of Scotland, the predicted quarterly mean air temperatures were strongly and negatively correlated with altitude—they were in an analysis restricted to trees in the northern Pennines (White, 1974). Here, Scots pine was particularly responsive to soil temperatures from May to early August. Although the relation between predicted air temperatures (April-June) (T_2) and growth (Y) in the analysis described in this paper was inexact it

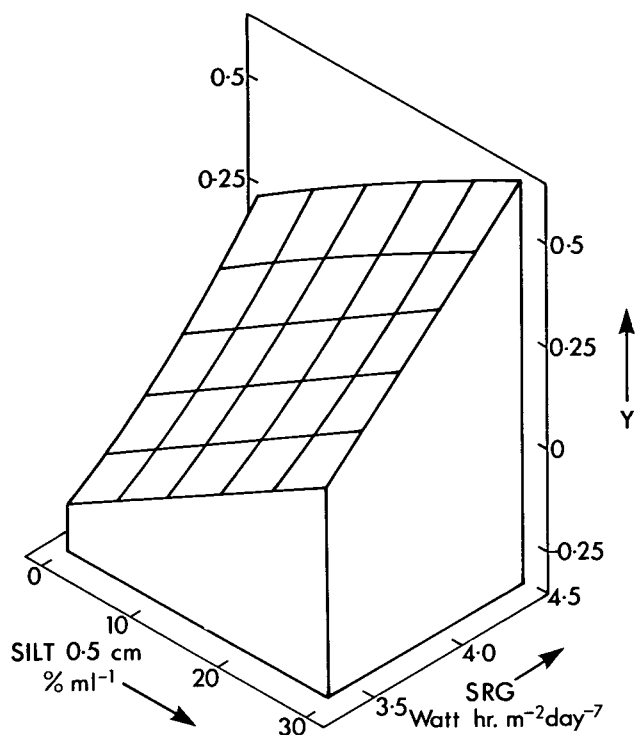


Fig. 26 Relation between predicted height growth rate of Scots pine (expressed as deviations from equation 1) (Y), and (i) concentrations ($\% \text{ ml}^{-1}$) of silt in the top 5 cm of soil, and (ii) the mean incoming solar radiation at ground level (SRG) from July to August ($\text{Watt hr. m}^{-2} \text{ day}^{-1}$).

was nevertheless statistically significant at $p=0.01$:

$$Y = 0.766 T_2 - 0.824 \quad 2)$$

This equation suggests that a climatic deterioration of 1°C from the April-June mean would be associated with a top height decrease in trees, 50 years old, of 0.6 m from 18.3 to 17.7 m. This loss of height would be reflected in a 7.3% decrease in accumulated volume growth (Hamilton & Christie, 1971).

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