Climate and Leader Length Variation

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Summary

Fluctuations in annual leader growth were observed in several stands. These are shown to be related to summations of air temperature squared in both the current and previous growing season for pine stands, and to that in the previous growing season only, for spruce stands. A method of adjusting observed leader length to compensate for the effect of climate is demonstrated. The usefulness of this method for assessing fertiliser response or possible damage due to pests and diseases is discussed.

Introduction

In 1980 widespread dieback of several species of pine, particularly Scots and some provenances of Lodgepole, led to a pathology investigation. During this it was noted that leader lengths in many pines had decreased markedly since 1977. Was this due to disease onset or sub-optimal climatic conditions?

It was noted that fluctuations in leader lengths in both pines and spruces were generally synchronised which suggested that climatic conditions and not disease were responsible for the observed leader length reductions prior to dieback. Assuming that the fluctuations were totally the result of climatic variations, major troughs or peaks could be expected to be related to major fluctuations in rainfall or temperature, these factors having been well documented in the literature as being of primary importance. For example Mork (1960) related shoot growth of Norway spruce to temperature and rainfall in the current year while Juntilla (1986) reported that temperature during bud formation in Scots pine was positively correlated with stem length in the following year.

A common method of quantifying the effect of temperature is through the concept of growing degree days whereby daily temperatures are accumulated and correlated with shoot growth. For example Owens *et al* (1977) showed that shoot elongations in white spruce and red pine were correlated more with growing degree days than calendar days. In these accumulations of temperature a threshold value of 5°C is commonly used. This has biological justification as many growth processes such as conifer seed germination show virtually no growth activity below 5°C. Furthermore, Emmingham (1977) demonstrated that Lodgepole pine buds only begin to swell when soil temperatures reach 5°C while Lavender *et al* (1973) noted a similar phenomenon with the bud break of Douglas fir seedlings. Wommack (1964) also showed that 5°C was optimum for the dormancy bud chilling requirement for Douglas fir. Perala (1985) used the method of growing degree days to predict red pine shoot growth while Beckwith and Kemp (1984) predicted shoot growth for Douglas and grand firs, although with a different relationship for the two species. In attempting to quantify the production of Sitka spruce in Northern Britain Worrell and Malcolm (1990) calculated temperature indices based on accumulated temperatures above 5.6°C. Norton (1984) showed that a strong correlation between temperature and growth in Nothofagus could be obtained by considering temperatures during the austral summer months (December-March) only.

While most of the references mentioned concentrate on establishing a relationship between temperature and growth, none attempt to adjust the annual growth observed over a number of years to allow examinations of the underlying pattern of growth in response to, for example, applied fertiliser or management regime. Thus the work in this paper was carried out with two objectives:

1. to establish whether leader length fluctuations were related to climate in Northern Ireland and, if so

2. to devise a procedure for adjusting observed leader length to compensate for fluctuations in climate.

Data sets

The data set for this study consisted of annual leader length measurements from 5 stands located at two sites as follows:

Species	Site	P Year	Measurement period	Code
Lodgepole pine	Beaghs	1964	1969-1980	LP64/1
Sitka spruce	Beaghs	1964	1964-1978	SS64
Logdepole pine	Ballintempo	1964	1964-1979	LP64/2
Sitka spruce	Ballintempo	1966	1966-1980	SS66
Sitka spruce	Ballintempo	1967	1967-1978	SS67

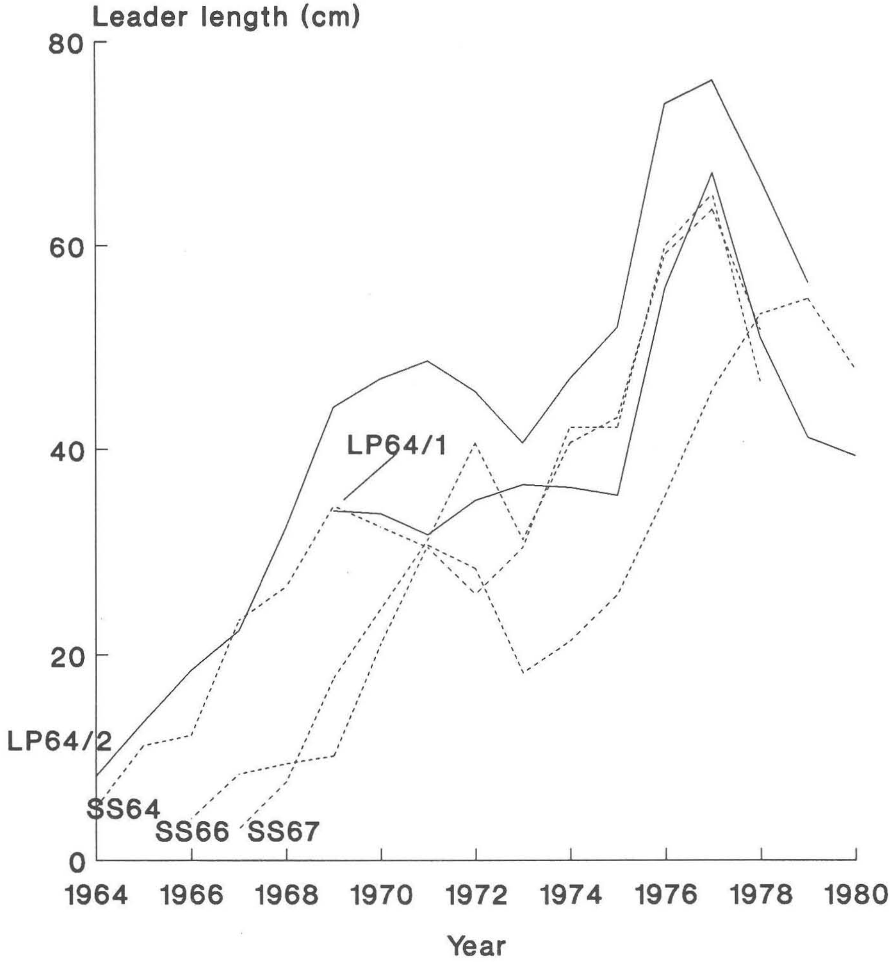

Figure 1: Changes in leader length of 2 Lodgepole pine (solid line) and 3 Sitka spruce (dashed line) stands.

Measurements were made by forest mensuration officers during the dormant season (November-March) in provenance or fertiliser trials and annual means calculated based on a minimum of 64 trees. Mean monthly temperature and total monthly rainfall data were available for the two forests for the relevant years from the Northern Ireland Meteorological Office. Beaghs Forest is in the north-east (Long 6°12′W, Lat 55°05′N) and Ballintempo in the south-west (Long 7°53′W, Lat 54°21′N) of Northern Ireland with the latter having on average a 1°C temperature advantage. Both sites are on high elevation (Beaghs 310m, Ballintempo 340m) oligotrophic blanket peat.

Preliminary Analysis

A graph of annual leader length against year (Figure 1) shows the fluctuations noted in the introduction with a distinct peak in 1977 for 4 of the 5 stands followed by a sharp decline to 1980.

Before investigating these fluctuations further, it should be noted that the rate of growth of trees on a particular site primarily depends both on the age of the trees and the quality of the site. It is thus necessary to take account of these factors when assessing the effect of climate on growth over the range of sites and ages in the data set. This was achieved by calculating the average leader length over all stands at each age and expressing the annual growth of each individual stand of trees as a difference from this average, thus a stand with better than average growth at a particular age had a positive difference while one with a poorer than average growth had a negative difference. Adjusted temperatures and rainfalls were calculated in a similar fashion for each stand and month as the difference between the actual values and the corresponding average over all stands and years.

The preliminary graphical investigation first used summations of mean monthly temperatures and then summations above threshold values of 4, 5 or 6°C. Summations of rainfalls for the year were also made. This study demonstrated that, while rainfall showed no discernible pattern, temperature above the 5°C threshold accounted for some leader length variations but not their magnitude or exact position. The relationship was improved by also taking account of the corresponding summation of monthly temperatures for the previous year. However while there was reasonable agreement between the patterns of summated temperature and growth it was found that extreme growth fluctuations were consistently underestimated. The situation was found to be improved by squaring the mean monthly temperatures after subtracting 5° and before summation thus giving greater emphasis to more extreme temperature conditions. Finally, in an attempt to combine the effects of temperature in the current and previous

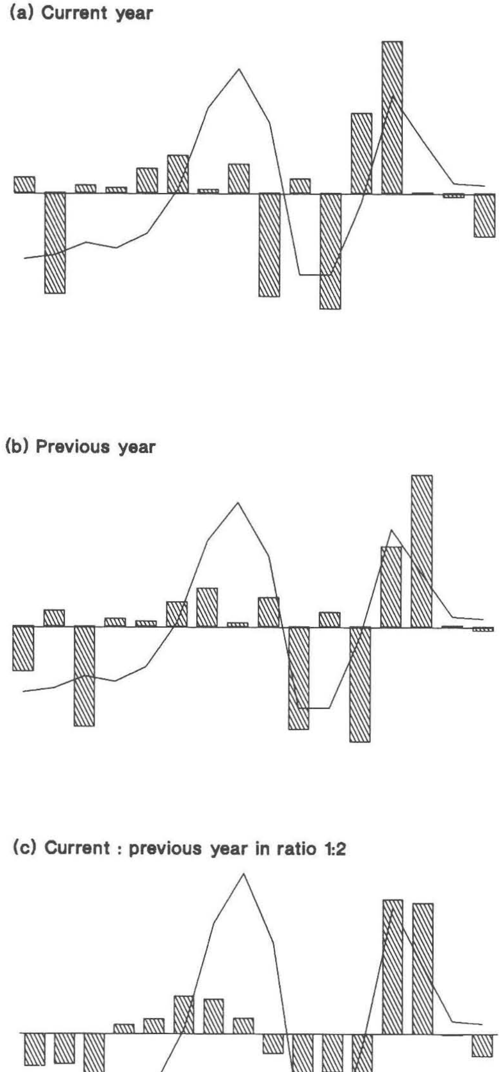

Figure 2: Relationship between adjusted leader lengths (shaded bars) and summations of adjusted monthly temperatures (solid line) for LP64/2.

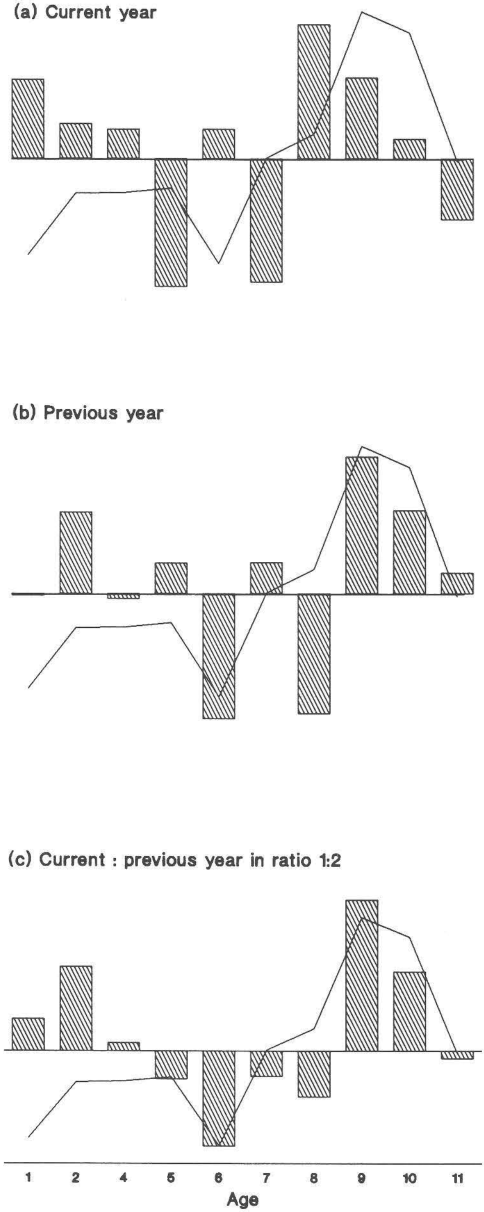

Figure 3: Relationship between adjusted leader lengths (shaded bars) and summations of adjusted monthly temperatures (solid line) for SS67.

years, various weighting combinations were applied to values from these two years.

Graphs showing the relationship between adjusted leader lengths and summated temperatures are shown in Figures 2 and 3 for the LP64/2 and SS67 stands respectively. From Figure 2 it can be seen that the periods of above average growth observed between ages 6 to 8 and 13 to 14 coincide with above average temperature conditions while the period of below average growth observed between ages 10 to 11 coincides with below average temperature conditions. A similar pattern is observed in Figure 3 for the below average growth at age 6 and the above average growth at ages 9 and 10. In the case of the two pine stands it was noted that the best agreement was with a 1:2 weighted combination of the current to previous years' temperatures while for the three spruce stands, the best agreement was with the previous year's temperature with the effect of the current year being less apparent. Thus the final formula produced for pine stands by this graphical approach was:

1/3 (mean monthly temperature – 5)^2 for current year
+ 2/3 (mean monthly temperature – 5)^2 for previous year

Statistical Analysis

In order to statistically test the hypothesis that leader growth fluctuation could be largely explained by annual fluctuations in growing season temperatures, it was assumed that leader length growth in young stands would, under normal temperature conditions, show a smooth asymptotic increase with age. This is justified by previous work on modelling top height growth of Sitka spruce, Kilpatrick and Savill (1981), which had incorporated data from stands from 5 years of age. Typical curves for a high, medium and low site quality stand are shown in Figure 4 from where the asymptotic nature of the curves for annual increment can be seen. Any deviations from these smooth curves should then be due to factors other than the age of the trees and the quality of the stand.

Accordingly smooth curves were fitted to each of the stands and differences between the observed and smoothed leader lengths were calculated. These differences were then correlated against various alternative summations of the monthly temperatures. These included summations of temperatures and squared temperatures both with and without first subtracting 5°. Additionally the summations were examined over a range of time periods within each year. Regression analysis was used to select the summation method giving the best correlation with the leader length differences and to determine the significance of the effects.

It was found that the best correlation was obtained with:

x_1 = sum of squared temperatures in July, August and September for current growing season and

x_2 = corresponding value for previous growing season.

The inclusion of extra months gave no significant improvement over the summation involving only the months of July, August and September while the effect of first subtracting 5° was also found to be unimportant.

The results for goodness of fit are summarised in Table 1. For the two pine stands inclusion of both x_1 and x_2 significantly explained more of the variation in leader length growth than the smooth curve alone, while for the spruce stands, inclusion of x_1 made no significant improvement but x_2 did, although at a reduced level of significance for 2 of the 3 stands. In a further analysis the regression coefficients for x_1 and x_2 for each stand were compared. This indicated that the coefficients differed between species i.e pines and spruces, but were the same for stands of the same species. The regression coefficients are shown in Table 1. For pines, the coefficients for both x_1 and x_2 were significant and were in the ratio of 3:5 for temperatures in the current and previous year. For spruce stands, the coefficient for x_1 was not significant. Over all 5 stands, the inclusion of x_1 and x_2 (or x_2 alone for Sitka) increased the proportion of the variation in leader length growth explained from 0.832 to 0.914.

Table 1: Regression analysis of leader length data.

			Regression coefficients	
Stand	R_1^2	R_2^2	x_1	x_2
LP64/1	0.33	0.73	0.0893 +	0.1565 **
LP64/2	0.86	0.98	0.0742 **	0.1005 ***
Pines	0.77	0.92	0.0757 ***	0.1177 ***
SS64	0.83	0.90		0.0630 +
SS66	0.87	0.90		0.0517 +
SS67	0.92	0.97		0.0755 **
Spruces	0.87	0.91		0.0624 ***

Note:
$R_1{}^2$ = proportion of variation explained by the smooth asymptotic curve and
$R_2{}^2$ = corresponding value with x_1 and x_2 included.

Significance of regression coefficients
+ P<0.10, **P<0.01, ***P<0.001

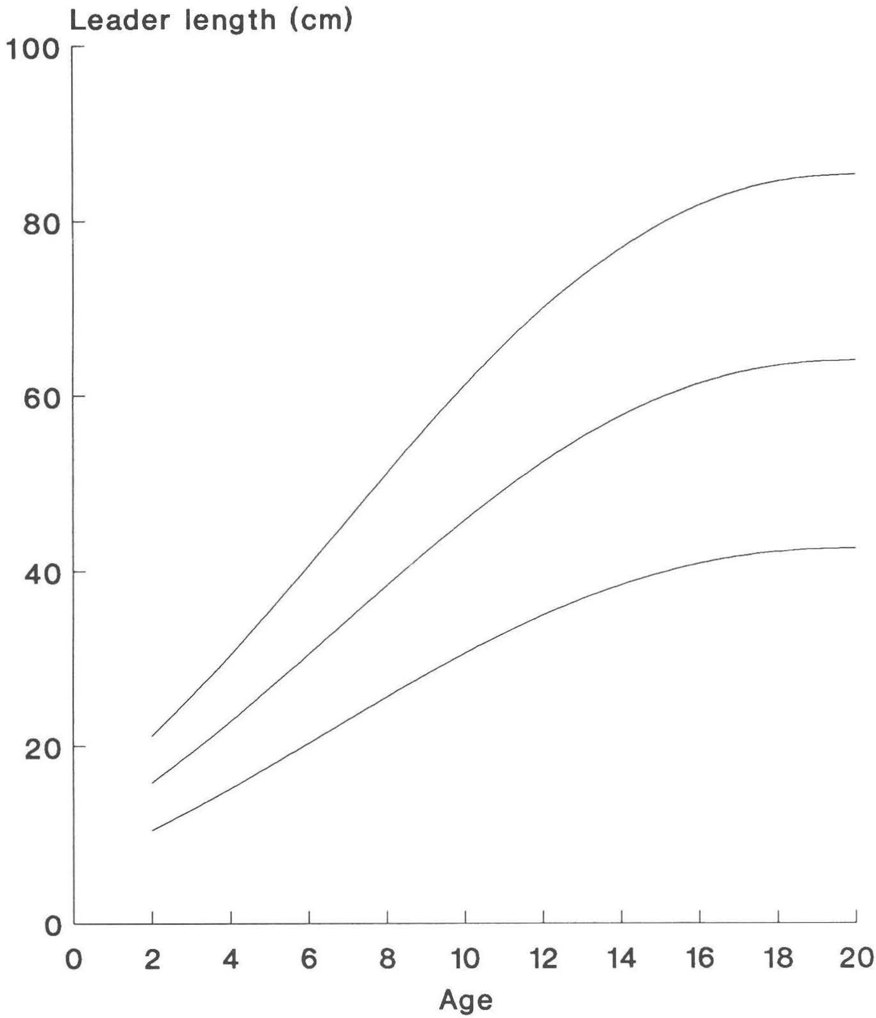

Figure 4: Theoretical development of leader length with age for examples of a high, medium and low quality stand.

Adjustment of observed leader lengths for effect of temperature

In order to apply the statistically derived formula to adjust the observed leader lengths for temperature, average monthly temperatures were calculated over the 2 sites and the 20 years. The summated squared temperatures for individual years and sites were then expressed as a difference from the corresponding summation based on the squared average temperatures. Leader lengths were then adjusted up or down pro rata depending on whether this difference was negative or positive respectively. For example the adjusted leader length for LP64/1 in 1976 is given by:

$$73.9 - 0.0757^{*}\,(625.6\text{-}504.8) - 0.1177^{*}\,(568.8\text{-}504.8) = 57.2$$

where

73.9 = observed leader length for LP64/1 in 1976

625.6 = sum of squared July, August and September temperatures for site in 1976,

568.8 = similar value for 1975,

504.8 = similar value using average temperatures over all years

and 0.0757 and 0.1177 are the regression coefficients from Table 1.

This adjustment removed the vast majority of leader length fluctuations in the data sets. Comparisons of actual and adjusted leader lengths for LP64/2 and SS67 are shown in Figures 5 and 6 respectively. From time of planting the adjusted leader lengths demonstrated a steady increase in length with only occasional peaks and troughs which were not synchronised in time with temperature but were explainable by, for example, fertiliser applications. Troughs particularly with spruce leaders corresponded to one extremely severe frost known to have caused widespread damage in the southern half of the province and also to years following well documented heavy spruce aphid attacks.

Further validation of the evolved formula appeared to be obtained by applying it to other forest plots in these two similar blanket bog but widely spaced forests, Beaghs in the north and Ballintempo in the south. This showed, for example, that an observed 16.4% better growth over a 14 year period in a large Lodgepole pine provenance trial (P64 comprising 9 provenances) corresponded to a calculated 19% better temperature climate during that period. In another similar trial a 20.1% better growth over 6 years corresponded to a 24.1% better temperature climate. In this same trial 3 years leader growth was 17.5% better at Ballintempo and the temperature climate was 13.9% better. Similarly in 1969 mean leader length was 30% better at Ballintempo and climate 29.1% better. Thus the evolved formula appeared to have potential usefulness in helping to explain growth variations between sites as well as between good and bad years.

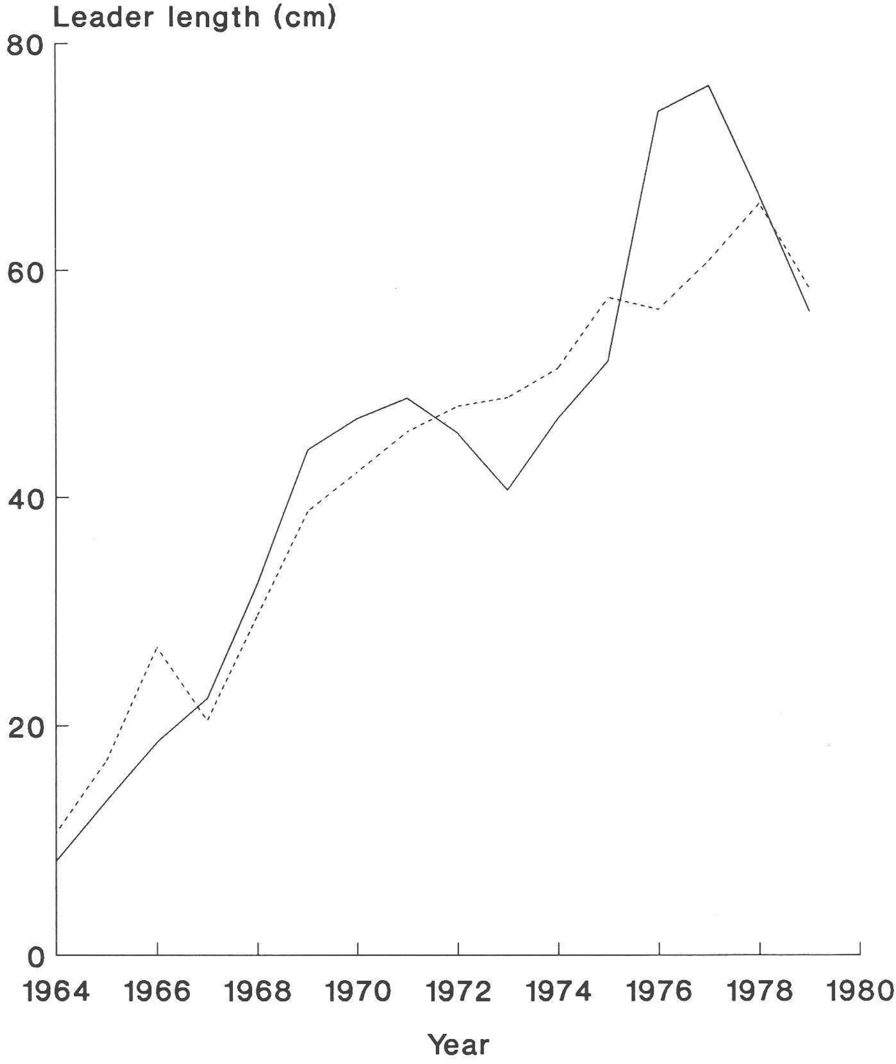

Figure 5: Comparison of actual (solid line) and temperature adjusted (dashed line) leader lengths for LP64/2.

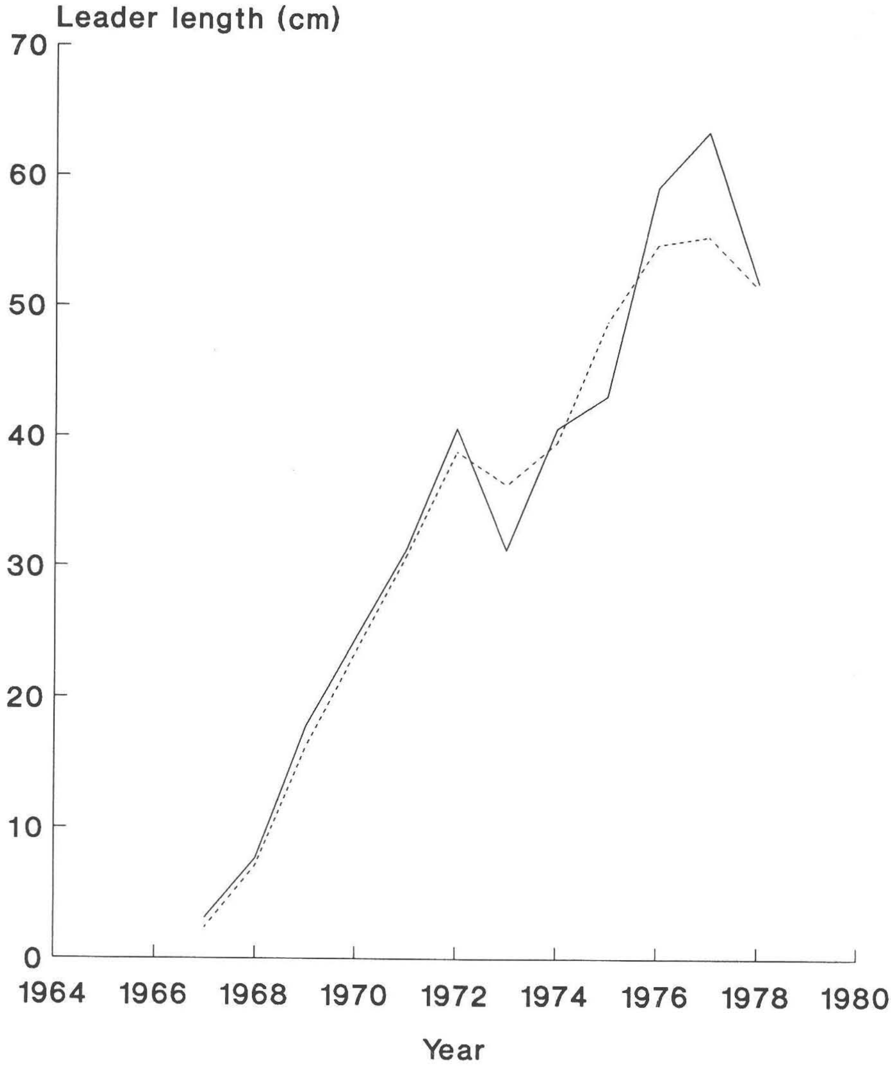

Figure 6: Comparison of actual (solid line) and temperature adjusted (dashed line) leader lengths for SS67.

Discussion

In this study both the empirical graphical and the more rigorous statistical approaches have shown that growth is influenced by climate. There is a clear effect due to temperature summations in a combination of both the current and the previous season for pines, while for spruces, only the temperature summation in the previous season is statistically important. The two approaches gave similar results despite the fact that the empirical approach used summations over all 12 months of squared temperatures after first subtracting 5° in contrast to the statistical approach which used summations over July, August and September without the 5° adjustment. This apparent discrepancy can be explained by noting that, as these are the 3 warmest months, their squared temperatures would tend to dominate the summation over all 12 months and the effect of first subtracting 5° is to further decrease the contribution of temperatures in the cooler months. Biologically the importance of the temperatures in the summer months of the previous year is explained by the fact that at that time the needle initials on the shoot are laid down for the following year.

It has been shown that it is possible to quantify the influence of temperature on growth and hence adjust measured leader length or top height growth to compensate for the effect of climate. It is important in applying this technique generally that the adjustment regression coefficients should be consistent over different sites and this proved to be the case where the coefficients for the 2 pine stands were similar as were those for the 3 spruce stands. Thus this technique may prove useful in a manner similar to that advocated by Woollons and Whyte (1988) to obtain better precision in forest fertiliser experiments by calculating, for example, the true response to fertilisation in experiments where often the true effect might have been masked by climate. Differences in growth due to the altitude or latitude effect on temperature could also be predicted. Effects on growth of insect or disease attack might be more accurately calculated. Indeed queries concerning the latter were the impetus for the initiation of this work.

The discovery that temperature alone influenced growth and that rainfall was not important, was in contrast to the work of Mork (1960), and suggests that, at least on most peat sites in Northern Ireland, moisture is not a limiting factor. This is supported by the observation that even in drought years the peat on these oligotrophic sites does not dry out to more than a few centimetres below the surface. It is recognised that although air temperature alone was considered (because of its convenience and availability) it does not eliminate the possibility that either soil temperature or amount of incident sunshine might be more biologically important. However both could be assumed to be broadly related to air temperature summations and in the case of sunshine measurements, the importance of skyshine could be underestimated.

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