DENDROCLIMATOLOGY OF ELM IN LONDON

DONALD W. BRETT

Botany Department,
Bedford College, University of London

ABSTRACT

A pilot investigation of 11 trees from London parks has shown that elm (*Ulmus*) is suitable for dendrochronology and dendroclimatological analysis. Ten trees are shown to crossdate well and form the basis of a London group elm chronology for the years 1900-1971; chronologies derived from fewer trees cover the period 1840-1971. Correlations with monthly climatic variables and seasonal rainfall and soil moisture totals are described. Response functions for the relationship between the London elm chronology and precipitation and temperature recorded at Kew demonstrate the direct relationship between ring width and precipitation during the growing season and during the previous autumn and early winter (September to December), an inverse relationship to rainfall the previous summer; above average temperature during the previous autumn leads to above average ring width but there is an inverse relation between ring width and temperature during March and April at the commencement of the growing season.

Une étude pilote portant sur onze ormes provenant des parcs de Londres a montré que cette espèce étrait utilisable pour des études dendrochronologiques et dendroclimatiques. Dix arbres se synchronisent bien et forment la base d'une chronologie de l'orme à Londres, de 1900 à 1971; quelques arbres formet une chronologie de 1840 à 1971. Des corrélations calculées avec les variables climatiques mensuelles, les précipitations saisonnières et l'humidité total du sol sont dècrites. Les fonctions réponses obtenues pour la chronologie londonieene de l'orme, à partir des précipitations et des températures relevés à Kew démontrent qu'il y a une relation directe entre l'épaisseur des cernes et les précipitations durant la saison de croissance et pendant l'automne et le début de l'hiver précédent (septembre à décembre); il existe une relation inverse avec la pluviosité de l'été précédent. Des températures supérieures à la moyenne, au cours de l'automne précédent, conduisent à des épaisseurs de cernes dépassant la moyenne; par contre il y a une relation inverse entre cette épaisseur et la température de mars à avril, au commencement de la saison de croissance.

Eine erste Untersuchung an 11 Ulmen in Londoner Parks hat ergeben, daß diese Baumart für dendrochronologische und dendroklimatologische Analysen geeignet ist. Zehn Bäume waren gut synchronisierbar und bilden Grundlage für eine Londoner Ulmen-Chronologie für die Zeit von 1900 bis 1971; die Jahrringfolgen einiger Bäume überspannen die Periode von 1840 bis 1971. Die Korrelationen mit den Monatswerten von Klimavariablen und den Summen der Jahreszeitlichen Niederschläge und der Bodenfeuchtigkeit werden beschrieben. Die Reaktionsmuster (response functions) für die Beziehung zwischen der Londoner Ulmen-Chronologie und den in Kew registrierten Niederschlags-und Temperaturwerten zeigen eine direkte Abhängigkeit von Jahrringbreite und Niederschlag während der Vegetationsperiode und im vorherigen Herbst und frühen Winter (September bis Dezember) sowie eine umgekehrte Beziehung zum Niederschlag des vorigen Sommers. Überdurchschnittliche Temperaturen im vorherigen Herbst führen zu überdurchschnittlichen Jahrringbreiten; es besteht aber eine negative Beziehung zwischen Ringbreite und Temperature im März und April zu Beginn der Vegetationsperiode.

INTRODUCTION

The English elms are not long-lived trees and are, therefore, unlikely to compete with oak as the basis of a long tree-ring record from which to infer past climate. They have, nevertheless, several claims to our interest. Only one of the British species of *Ulmus*, *U. glabra* Huds., appears to be a native woodland tree. Most of the other species and varieties have been traditionally cultivated in hedgerows along field boundaries where they were either deliberately planted or allowed to grow from sucker shoots (Pollard, Hooper, and Moore 1974); a detailed account of the methods of propagation and cultivation of elm trees is to be found in editions of John Evelyn's "Sylva". Their long cultivation since Roman times at least has resulted in the establishment of many local clones and has led to taxonomic complexity (Richens 1955). These varieties rarely, if ever, produce fertile seed and have been propagated vegetatively for as long as historical records exist although some of the older varieties probably originated as hybrids. Existing trees of the common field elms, *U. carpinifolia* Gled. and *U. procera* Salisb., and most parkland varieties are threatened with destruction as a result of the outbreak of Dutch elm disease. Some of the oldest trees felled in the south of England are about 250 years old; 150 years seems to be a more common old-age for large English elms and they are not uncommonly blown down in gales at this stage of life. Some of the trees used in the present study were blown down in February 1973, others were felled because they were dying of Dutch elm disease.

The present article gives an account of some results from a pilot investigation of 11 elm trees grown in parks in the London area. These consisted of five trees from Regent's Park, two from Bushy Park, one from Kensington Gardens, and three from Brompton Cemetery. These locations are shown in Figure 1. The three Brompton trees were about 90 years old; the rest about 160 years.

SAMPLING AND MEASUREMENT

Cross sections were cut from the felled trees and two or four radial blocks sawn out after marking some distinct check rings around the circuit to facilitate crossdating between the radii. When only two radii were sampled (Regent's Park trees) these were taken opposite one another, otherwise four radii at right angles to one another were sampled. Ring widths were measured parallel to the rays to 0.05 mm using a stereozoom binocular microscope with eyepiece graticule. Generally a 20X magnification was sufficient: The zoom optics were useful when wide rings were encountered. Occasionally it was necessary to examine thin sections of small regions at higher magnification because the rings were very narrow with no latewood present. Other difficulties were presented by the oblique grain, sometimes accompanied by small sparse earlywood vessels, which results in a near-radial view of the wood appearing on the cross section surface.

TREE-RING ANALYSIS

The analytical methods used in this study are essentially those developed at the Laboratory of Tree-Ring Research, Tucson, and described most recently by Fritts (1976) who gives references to the relevant original articles. A preliminary listing and plotting computer program was used to calculate mean ring widths, mean sensitivity and running means, and to plot on microfilm the ring widths, 20-year running means, and regression lines. A least-squares curve fitting program (NAG library) was used to fit a curve approximating the growth function to each radius series of ring widths in order to the convert the ring measurements to standardized indices. Initial estimates for the parameters were made from the microfilm plots. In most cases the fitted curve was specified by the equation:

$$Y = ae^{-bx} + k$$

which accounts for the marked reduction in ring width over the earlier years of the tree's growth, but in a few cases a linear regression was fitted with no restriction on slope.

All subsequent statistical analyses of the ring-width index chronologies and correlations with climatic variables made use of the Rothamsted GENSTAT statistical programs. The program for response function analysis is written in GENSTAT; the microfilm plots use DIMFILM.

CLIMATIC DATA

Weather data used in this study include the mean monthly temperature and total monthly rainfall recorded at Kew, Surrey (Figure 1). Monthly values of potential evapotranspiration representative of Kew (Wales-Smith 1973) were used to compute a month-end water balance to provide additional moisture variables for correlation with the tree data. Soil moisture depletion and recharge were calculated using the models for clay and loam soils described by Zahner (1967). Although these models were developed with forest soil conditions in mind they provided realistic water balance series with field capacity set in these trials at seven inches (178 mm) for the clay model and eight inches (203 mm) for the loam model. Several components of the water

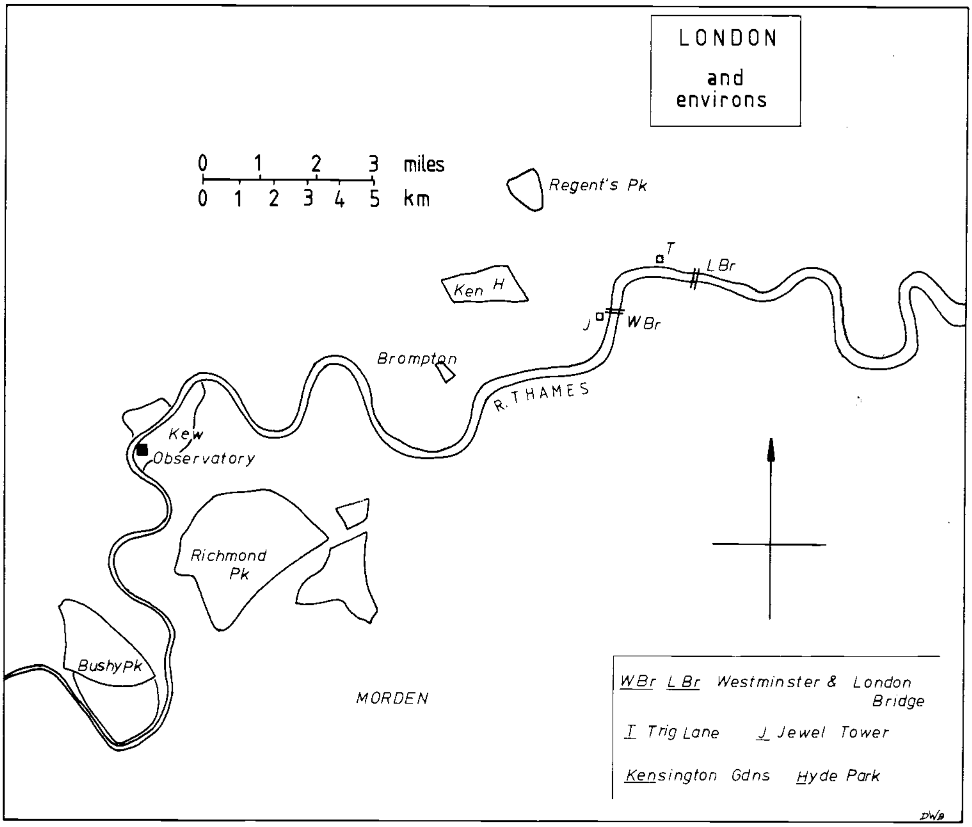

Figure 1. Map showing the location of sites.

balance were derived from these calculations but only the soil moisture for the loam balance will be discussed in this paper. Wigley and Atkinson (1977) have estimated the mean soil moisture deficit for the 'growing season' (May-August) using the monthly Kew data and the Penman - Meteorological Office model. Their account of soil moisture is closely similar to that derived in the present study: for the correlation between the May-August soil moisture from the loam model and Wigley's mean May-August SMD, $r = 0.98$ (1901-1970).

STATISTICAL ANALYSIS

The tree from Kensington Gardens is not included in the present account. However, its inclusion in trial mean chronologies (e.g. the mean "A" in Brett 1978) made little difference to correlations with climatic variables. The total sample of 10 trees has proved adequate for the present purposes; the trees obviously represent a small region, but were not 'selected' in any way for this work apart from the omission noted above. There are three sites represented so it is necessary to consider differences between them.

The two trees from Bushy Park show high correlation between their chronologies: $r = 0.53$. when two radii were averaged, 0.75 when four radii were used. Likewise the three trees from Brompton Cemetery gave higher correlations between their four-radius tree chronologies ($r = 0.54$ average) than between their two-radius chronologies ($r = 0.38$ average). Correlations between the five two- radius tree chronologies of the Regent's Park trees average at $r = 0.39$. These results refer to the interval 1900-1971 (70 degrees of freedom for the correlation). It seems clear that the use of four radii in the small samples provides significantly more information common to the trees of a particular site: it may be reasoned that site means based on four-radius sampling will contain more local site information and therefore give lower correlation with other site chronologies. There is no clear indication at present that this is so but it is suggested by the correlations between the Bushy site and Brompton site: $r = 0.23$ (two-radius mean), and .19 (four-radius mean). The growth rings of elm have a high circuit variability and this is reflected in a low average correlation of radii between trees. I have for this reason used tree means based on all available radii to construct the group chronology.

Some general statistics for the London elms are given in Table 1. Details are given for the two sites, Regent's Park and Brompton Cemetery and the chronologies for these are plotted in Figure 2. The Bushy Park site chronology is very similar to the Regent's Park site chronology (correlation is high, $r = 0.7$). The plots of the Regent's Park and Brompton site means in Figure 2 obviously show much similarity too, but correlation between them is much lower ($r = 0.35$). The Brompton site also has a much lower serial correlation (Table 1). Although these differences are confounded with the age difference between the Brompton trees and the others the differences between the chronologies do not appear to be due to the age of the trees: further differences in the correlation with climatic variables will be discussed in the following sections.

Table 1. Sample and chronology statistics for London elm.

Number of sites	3		
Number of trees	10		
Number of radii	30		
Years of analysis	72		
Interval of analysis	1900 to 1971		
Mean ring width	2.68 mm		
Analysis of variance:			
Percent variance; Years	20.4		
Percent variance; Trees. Years	19.5		
Percent variance; Residual	60.1		
Standard error; Years	0.109		
Cross correlation:			
Mean correlation of radii within trees	r = 0.43		
Mean correlation of radii between trees	0.22		
Mean correlation between trees	0.35		
Chronology statistics:	mean sens.	st. dev.	1st serial
Regent's Park (5 trees)			
1840 - 1970	0.20	0.30	0.66
1900 - 1970	0.20	0.33	0.71
Brompton Cemetery (3 trees)			
1900 - 1970	0.22	0.27	0.41
London group (10 trees)			
1900 - 1970	0.18	0.27	0.64

CORRELATION WITH CLIMATE

Correlation and multiple regression analysis of the London elm chronology in relation to rainfall has been discussed elsewhere (Brett 1978). The coefficients for simple linear correlations with precipitation, temperature, potential evapotranspiration, and estimated soil moisture are presented in Figure 3. The correlations with precipitation suggest positive relationship between ring width and precipitation of the previous November and the summer months of the growing season, April through August. It is of interest to note that although the correlation for August is about the same as for June, August precipitation does not normally enter the equation in a stepwise multiple regression. Highly significant correlation was found with the accumulated rainfall totals through the summer months, e.g. for the April-August total $r = 0.43$ (DF = 68, 1901-1970). For several decades during the interval studied, i.e. 1340-1970, the correlation is above 0.8 and in the final decade $r = 0.92$ (DF = 8, 1961-1970). Summer rainfall is graphed in Figure 2.

The five-tree Regent's Park chronology gives essentially similar results to those obtained with the total sample of 10 trees except that the correlation with the previous November and current June and August are all about equal. The summer correlations obtained with the group chronology are augmented by the three Brompton trees, the chronology of which alone gives a correlation coefficient of 0.57 with total summer precipitation.

The Brompton chronology also shows higher correlation than the other London trees with April temperature and summer potential evapotranspiration and much higher correlations with soil moisture: for April to August soil moisture $r = 0.61$, and for the May to August mean soil moisture deficit of Wigley and Atkinson (1977) $r = -0.62$; the coefficients are both about 0.25 for the Regent's Park chronology. There is

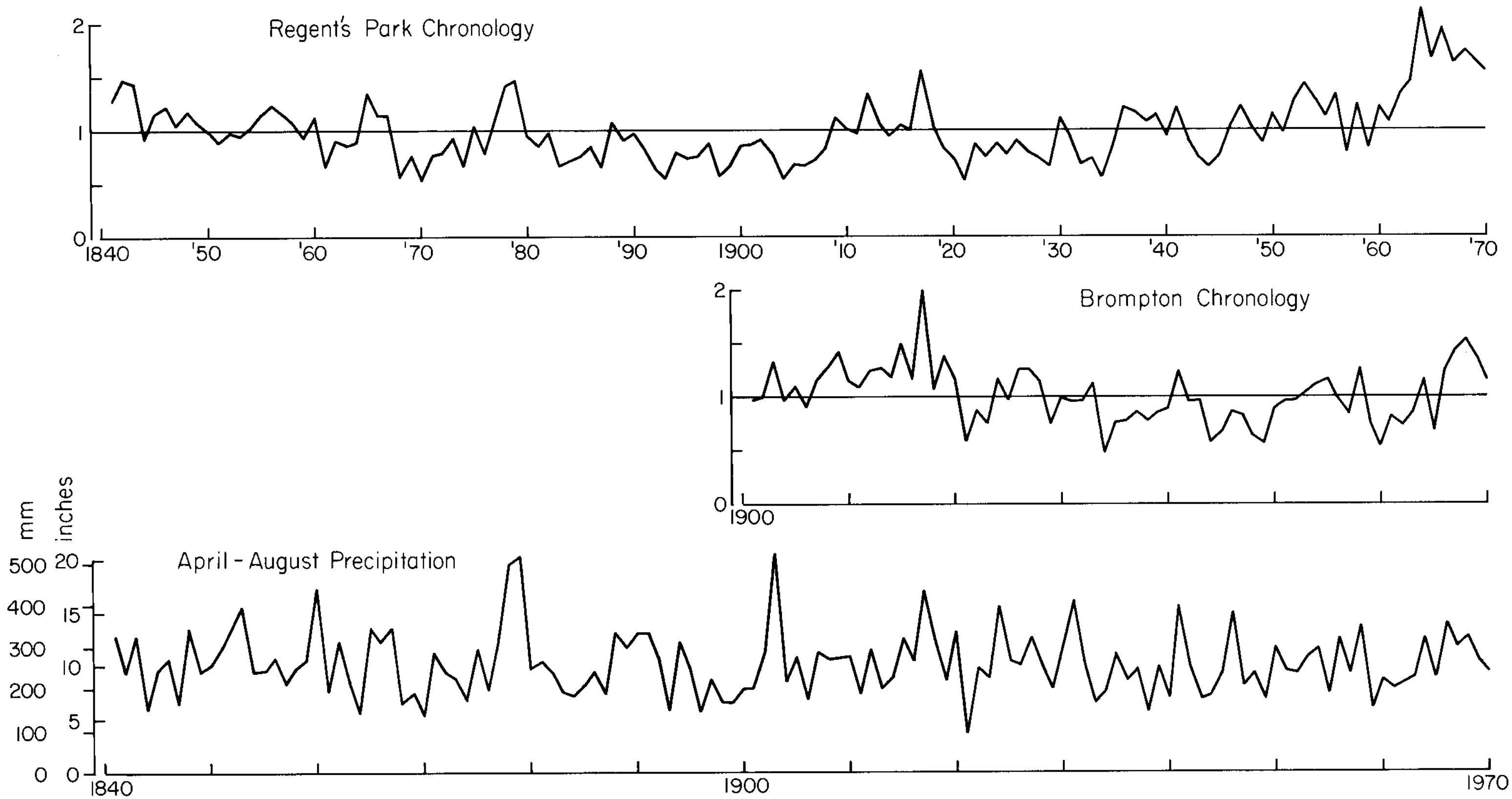

Figure 2. Ring-width indices for the Regent's Park and Brompton Cemetery mean chronologies and the total summer rainfall (April to August) with which they are highly correlated.

no doubt that, while the London elms as a whole show a significant record of moisture stress in their ring widths, the Brompton trees show this to a greater extent than the rest of the sample. This is almost certainly due to soil differences. The subsoil at Regent's Park is mostly clay (although there are, or were, some gravel deposits and the working of these long ago was the origin of the lake) but, according to the gravediggers, there are areas of pure sand at Brompton Cemetery. The more freely draining soil may be expected to lead to greater moisture deficiency during the summer months and to the sort of differences in the correlations observed, including the lower serial correlation.

RESPONSE FUNCTIONS

Response functions for the London elm chronologies have been calculated following the description of the method of Fritts et al. (1971) and some necessary clarification of certain points (Harold Fritts and Barbara Gray, personal communications). Only a brief outline of the program which has been written in GENSTAT by the present author will be given here: For further explanation of the response function analysis and rationale the reference given above and Fritts (1976) should be consulted.

In the GENSTAT program rainfall and temperature data and ring-width indices are normalized by subtracting the mean and dividing by the standard deviation. The normalized climatic data are then subjected to principal components analysis (PCP)

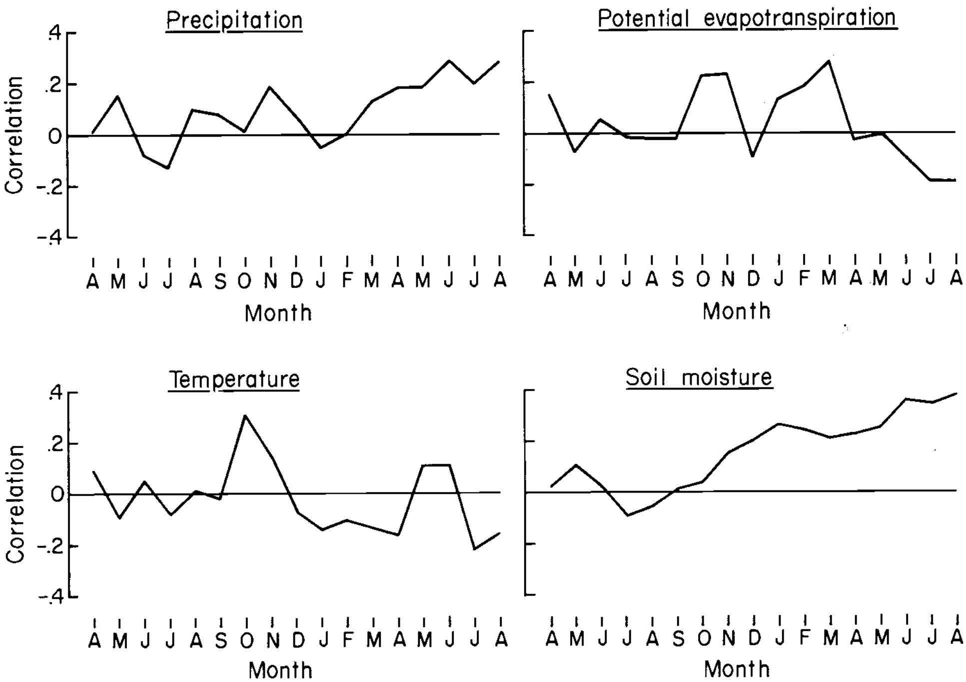

Figure 3. Correlation coefficients for the correlations between the monthly climatic variables indicated and the London elm group chronology (ID 8010). The interval of analysis is 1901-1970 (68 degrees of freedom for the correlation).

and the scores (amplitudes) for the eigenvectors are used, together with normalized indices lagged one, two, and three years, as the independent variables in the stepwise (MINIMISE) regression routine with normalized indices as dependent variable (Y). A parallel regression (FIT) fits the eigenvectors selected at each step of the first regression in order to estimate the variance reduced by the climatic variables alone (i.e. without the allowance for autocorrelation provided by the lagged indices in the stepwise regression). Using the matrix operations facility the eigenvector matrix is premultiplied by the regression coefficients relevant to the scores to obtain the response function for the climatic variables. Standard errors are computed from the variances of the regression coefficients (the diagonal elements of the variance/covariance matrix saved at each step of the regression). The variances are premultiplied by the eigenvector matrix and the result postmultiplied by the transposed eigenvector matrix. The standard errors of the response function are the diagonal elements of the resultant symmetrical matrix.

Response functions for the London group chronology (ID 8010) and the Brompton site (ID 8409) are given in Figures 4 and 5. The results shown are consistent with previous multiple regression analysis of these chronologies. For the response functions illustrated precipitation and temperature from June in the year prior to growth to July in the year concurrent with growth were used. Additional trials showed current August precipitation to be no more important than that of July. Twenty-five of the 28 eigenvectors were entered in the multiple regression. Both examples given refer to the 15th step of the regression when 13 of the eigenvectors and the two vectors for prior growth were in the regression equation.

It will be seen that the Brompton result, although based on only three trees, presents a substantially similar response to climate to that of the group chronology. Because of the lower serial correlation the variance reduced by prior growth is much less at Brompton and with 54.8% of the chronology variance reduced by climate it is clear that these trees have responded very significantly to climatic fluctations.

Apart from an inverse relationship to the precipitation of the previous summer months, the London elm ring widths are directly related to precipitation, and the precipitation of the previous autumn and early winter months is just as important as that received during the growing season. The importance of a mild autumn to prepare the tree for the following growing season is shown by the positive temperature response for October - December, a time when growth has ceased but the leaves are usually still on the trees. The most significant inverse relationship to temperature is found at the very commencement of the growing season, in March and April, when the leaf buds are bursting and the very first earlywood vessels are expanding (mid-to-end of April), and in September of the previous year. At both times high temperatures may well be correlated with dry conditions, but it is possible that wood growth may be reduced if warm early spring conditions lead to rapid shoot growth and leaf expansion.

PROSPECTS

The results of this pilot study demonstrate unequivocally that the science of dendroclimatology has much to contribute to our understanding of tree growth — climate relationships in Britain. Other recent studies have shown that success will not be restricted to the drier southeast corner of the islands (Pilcher 1976; Hughes et al 1978).

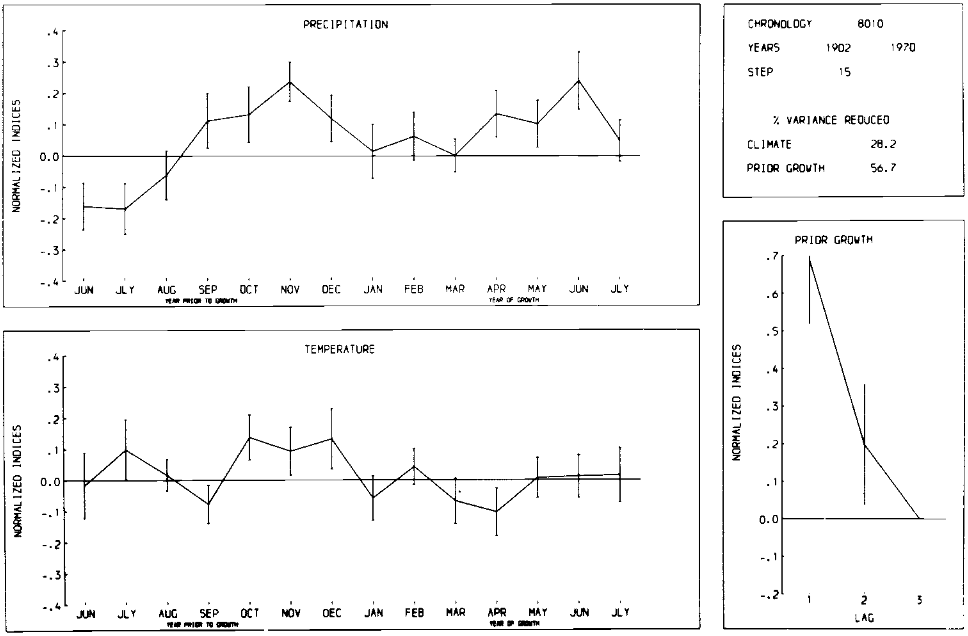

Figure 4. Response function for London elm group chronology based on 10 trees.

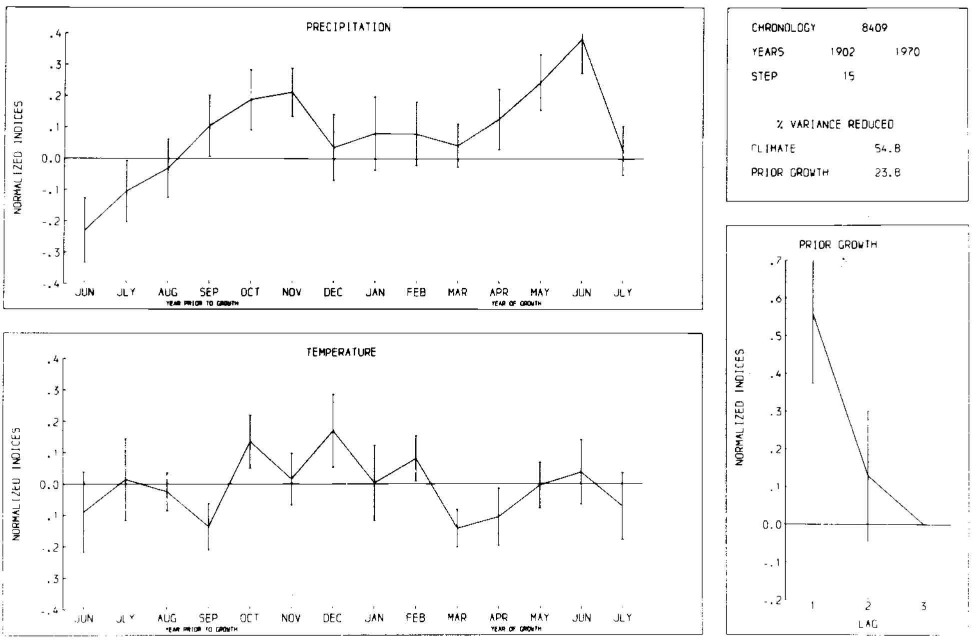

Figure 5. Response function for Brompton Cemetery site mean chronology based on three trees.

Further investigations are in progress using elms for both local analysis (Regent's Park and Morden) and eventually to sample a wider area. A similar study of oaks in the southeast has been started. The possibility of using elm tree rings as a rainfall record has been discussed in another paper (Brett 1978) though we can see from the full response function that there is considerably more climatic information in the ring widths than a record of drought.

Medieval elm piles excavated from near the Jewel Tower, Westminster, and Trig Lane in the City of London (Figure 1) seem to exhibit similar ring-width fluctuations to those of the modern elms. They are mostly of 14th century origin and thus may provide a climatic record for that period. Work on this is continuing and will be reported elsewhere.

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