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DENDROCLIMATIC ANALYSIS OF BUR OAK IN EASTERN NEBRASKA

MERLIN P. LAWSON
RICHARD HEIM, JR.
JOHN A. MANGIMELI
and
GARY MOLES

Geography Department
University of Nebraska
Lincoln, Nebraska

ABSTRACT

Tree-ring samples from bur oak in eastern Nebraska are analyzed and found suitable for dendroclimatic analysis. Four methods of standardization are used to develop four 233-year master chronologies. ANOVA statistics and response functions based on each chronology are examined. Response functions based on both single-station and regional climatic data are analyzed and compared. The information provided by response function analysis varies considerably depending upon choice of standardization option, number of eigenvectors extracted, and generalization of climatic data (station or region). A response function based on the polynomial chronology and 46 years of regional climatic data relates 53.4% of the chronology variance to climate and 70.4% to climate plus prior growth. The bur oak master chronology provides valuable proxy evidence for periods of moisture stress experienced during exploration and settlement of eastern Nebraska.

Des échantillons dendrochronologiques de "Bur Oak" dans le Nebraska Oriental ont été analysés et il apparaît qu'ils conviennent pour des analyses dendroclimatiques. Quatre méthodes de standardisation ont été utilisées pour développer quatre chronologies maîtresses de 233 ans. Les statistiques Anova et les fonctions de réponse basées sur chaque chronologie sont examinées. Des fonctions de réponse basées sur une seule station et sur des valeurs climatiques régionales sont analysées et comparées. Les informations fournies par l'analyse des fonctions de réponse varient considérablement et dépendent du choix de l'option de standardisation, du nombre de vecteurs propres extraits et de la généralisation des données climatiques (station ou région). Une fonction de réponse basée sur une chronologie polynomiale et 46 ans de données climatiques régionales, montrent que 53,4% de la variance de la chronologie peuvent être reliées au climat et 70,4% au climat et à la croissance antérieure. La chronologie maîtresse du "Bur Oak" met en évidence de façon valable les périodes de crises d'humidité subies durant l'exploration et la colonisation du Nebraska Oriental.

Die Jahrringproben von Eichen (Quercus macrocarpa) in Ost-Nebraska werden analysiert und als brauchbar für dendroklimatologische Studien befunden. Dabei werden vier Standardisierungsverfahren zum Aufbau von vier 233-jährigen Chronologien eingesetzt. Zudem werden für jede Chronologie Varianzanalysen und Response-functions berechnet. Die Response-functions, die sowohl auf den Klimadaten von einzelnen Stationen als auch größerer Regionen beruhen, werden miteinander verglichen. Die Befunde aus den Response-function-Berechnungen zeigen beträchtliche Unterschiede und hängen von der Art der Standardisierung, der Zahl der Eigenvektoren und der Verallgemeinerung der Klimadaten (ob Einzelstationen oder Region) ab. Die Response-function, die auf einer mit Hilfe von Polynomialfunktionen standardisierten Chronologie und einer 46-jährigen regionalen Klimareihe beruht, führt 53,4% der Jahrringbreitenstreuung auf das Klima und 70,4% auf Klima plus Vorjahreszuwachs zurück. Die Eichenchronologie gibt einige wertvolle Hinweise auf Perioden von Feuchtigkeitsmangel während der Erkundung und Besiedlung von Ost-Nebraska.

INTRODUCTION

Attempts to reconstruct the climate of the Great Plains have been hindered by limited biogeographical evidence. While in other areas of the United States, tree-ring analysis has proven to be a useful tool in paleoclimatic studies, the scarcity of forested areas in the Plains and Prairie states has restricted the application of dendroclimatic methods (Stockton et al., in press). In Nebraska, only two significant regions of native timber exist: relic stands of ponderosa pine (*Pinus ponderosa*) along escarpments in the Nebraska panhandle and deciduous forests along the Missouri River and its tributaries in extreme eastern Nebraska. Fritts has developed a ponderosa pine chronology for the Pine Ridge area of northwestern Nebraska (Drew 1974). Earlier, Weakly (1937) studied scattered red cedar (*Juniperus virginiana*) in various locations in western Nebraska and correlated ring widths and cross-sectional area with local climatic data (reviewed by Lawson 1976). No dendroclimatic work has been done in the eastern forests of the state, where bur oak (*Quercus macrocarpa*) is the longest-lived species.

The purpose of this study is to determine the suitability of bur oak for dendroclimatic research. Secondary objectives specifically applied to the problems of using bur oak for climatic inference include: 1) a comparison of different methods of standardization of tree-ring series, and 2) an attempt to determine whether data from a single climatic station or averaged regional data provide better interpretation of tree-ring indices.

SPECIES AND SITE DESCRIPTION

Bur oak is a ring-porous angiosperm, with a deep root system and fire-resistant bark. Its tolerance to a wide range of soil and moisture conditions enables bur oak to act as a pioneer species along the eastern edge of the Plains. Because of its drought-resistant nature, we expected the mean sensitivity of bur oak to be low, but we hoped that trees from well-drained sites along the western margin of their range would show sufficient sensitivity for dendroclimatic analysis.

The study site is an area of deciduous forest along the steep loose bluffs of the Missouri River just south of Omaha, Nebraska (Figure 1). The site is within a

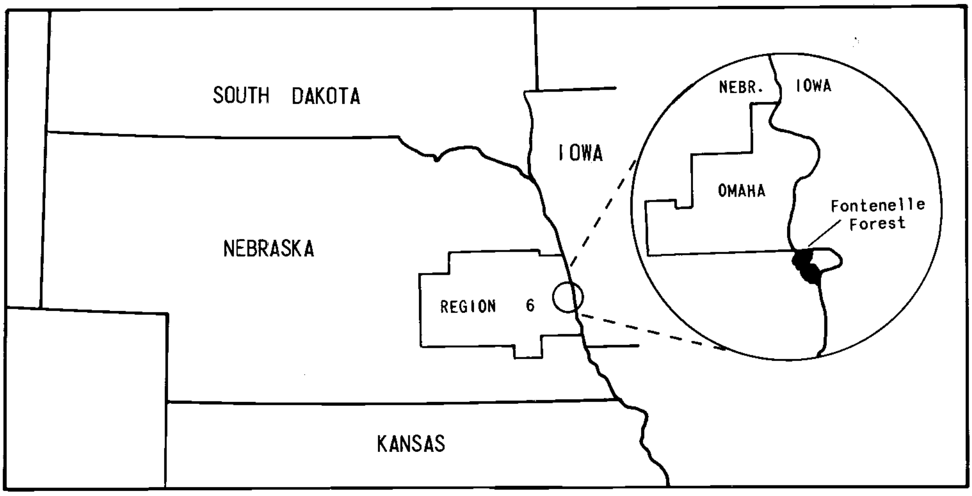

Figure 1. Location of Fontenelle Forest.

privately-owned natural preserve known as Fontenelle Forest, which contains approximately 1300 acres of relatively undisturbed land, most of which is densely forested with oak, hickory, ash, hackberry, basswood and other eastern deciduous trees. The present Fontenelle Forest environment, however, is not necessarily representative of the area during much of its history. Using dendrochronological and historical methods, Garabrandt (1978) discovered that Fontenelle Forest has a complex history due to man's activities in the area. Prior to white settlement of eastern Nebraska, the higher elevations of the Fontenelle Forest area were probably more open than they are at present, with park-like bur oak stands interrupted by grassy areas. Prairie fires occasionally swept into the forest from the west and kept down the understory without significantly damaging the mature, thick-barked oaks. Fire was probably beneficial to the oaks, as it reduced competition and opened areas for oak seedling germination.

With the beginning of white settlement in the 1850s, the forest environment was altered, as parts of the forest underwent logging and grazing, resulting in release growth in many of the uncut saplings. These activities were stopped in 1913 with the creation of the nature preserve. After 1913, however, man's activities outside the forest boundaries continued to affect forest ecology. Plowing and farming of the prairies west of the forest prevented prairie fires from burning the area and allowed a dense undergrowth to spread from protected ravines onto the ridge tops, resulting in increasing interspecific competition for sunlight, water, and minerals. The importance of fire to bur oak ecology is evidenced by the fact that in many parts of the forest no bur oak saplings or young trees less than 120 years old can be found today. Garabrandt (1978: 132-35) fears that bur oak may disappear entirely from the forest as old trees die and no young oaks can penetrate the undergrowth to replace them.

Despite man's activities a few portions of the forest were never logged or so lightly logged that young trees showed no release growth. In one of these areas (approximately 41° 10' North, 95° 54' West, elevation 350 m), 13 large bur oaks were located on well-drained ridge tops.

SAMPLING AND MEASUREMENT

Samples were taken from each of the 13 trees during the summer of 1979. Using a 16-inch Swedish increment boring tool, two samples were obtained from each tree from the directions most suitable for maximum depth of penetration. A third core was taken if either of the initial samples was significantly wide of the pith, but only two cores from each tree were used in statistical analysis. After mounting, the cores were measured under a stereozoom microscope with magnifications ranging from 10.5X to 45X.

The annual rings of the bur oak are not well defined and tend to be obscured by numerous resin ducts and rays. Considerable lateral displacement of the rings from one side of a ray to the other was frequently found, which presented problems in maintaining the chronological sequence. No evidence of missing rings was found; however, one obviously anomolous tree that could not be crossdated with the others was eliminated from statistical analysis.

TREE-RING ANALYSIS

This study utilized computer programs for statistical analysis developed at the

Laboratory of Tree-Ring Research in Tucson, Arizona (Fritts 1976). The program RWLIST was used to list ring-width measurements, calculate mean ring widths and mean sensitivity, and calculate 20-year moving means to aid in deciding a curve-fitting option. All four types of growth curve options commonly used for ring-width standardization were used in this study: a negative exponential curve, a straight line of any slope, a horizontal line through the mean, and a polynomial curve. Fitting each of these four curves to raw ring-width data, the INDXA program produced four standardized indices for each of the 24 cores, calculated cross-correlations, and performed analysis of variance (ANOVA) within each of the four sets of indices. The indices of all 24 cores for each method of standardization were then averaged to produce four master chronologies for the bur oak site (Figure 2).

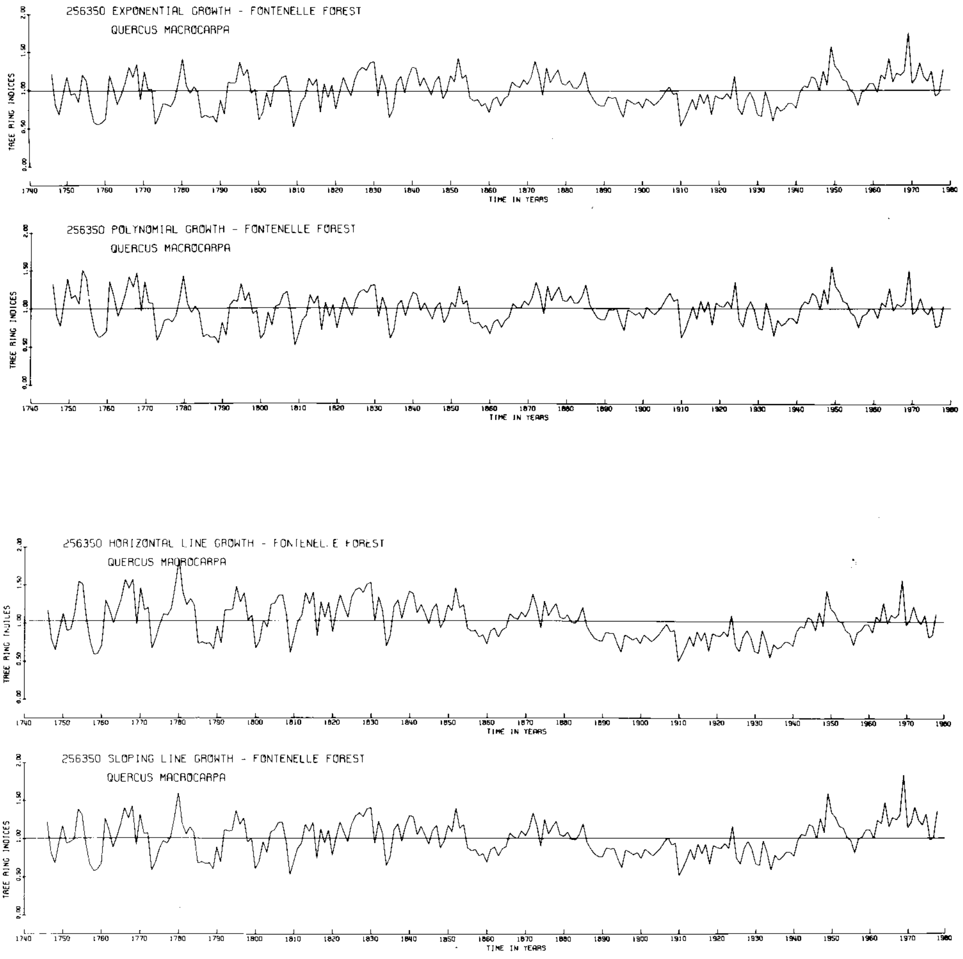

Figure 2. Fontenelle Forest master chronologies standardized by four growth curve options.

Table 1. Chronology and ANOVA statistics.

	CHRONOLOGY SERIES			
Number of trees	12			
Number of radii	24			
Oldest specimen	233 years			
Method of standardization	HL Horizontal Line	SL Sloping Line	PN Polynomial Curve	NE Exponential Curve
Serial correlation	0.63	0.58	0.48	0.56
Mean sensitivity	0.16	0.16	0.16	0.16
Mean Index	1.02	1.00	1.00	0.99
Standard deviation	0.25	0.23	0.20	0.21

	ANOVA SERIES			
Method of standardization	HL	SL	PN	NE
ANOVA period	1840-1978	1840-1978	1840-1978	1840-1978
Serial correlation	0.69	0.65	0.49	0.63
Mean sensitivity	0.17	0.18	0.17	0.18
Percentage variance:				
Years	40.3	45.2	42.5	44.5
Years x Trees	36.2	33.8	28.7	33.5
Years x Trees x Radii	22.7	21.0	28.8	22.1
Cross correlations:				
Within trees	0.76	0.79	0.71	0.78
Between trees	0.41	0.46	0.44	0.46
All series	0.43	0.47	0.45	0.47

The mean, standard deviation, serial correlation and mean sensitivity for each of the four chronologies are listed in Table 1. All have the same mean sensitivity and, as expected, it is low (0.16). Serial correlation is lowest for the chronology standardized by the polynomial curve (PN chronology), which eliminates the most trend, and highest for the chronology standardized by the horizontal line (HL chronology), which does not remove trend.

An ANOVA period of 1840-1978 was selected, which corresponds to the period of growth common to all trees. Both mean sensitivity and serial correlation increased slightly for all four chronologies for the ANOVA period, and cross-correlation statistics for all four chronologies are similar (Table 1). Statistical data is nearly identical for the chronology standardized by the negative exponential curve (NE chronology) and the chronology standardized by the sloping line (SL chronology), as the ANOVA period does not include the initial growth years of most of the trees, and for later years of growth the negative exponential curve closely resembles the sloping line. (If the INDXA program cannot fit a negative exponential curve to a particular core, a straight line of any slope is fitted. A straight line was substituted in 11 of the 24 cores, which helps to explain the similarity between the NE and SL chronologies).

CLIMATIC DATA

Two sources of climatic data were used in this study: the National Weather Service

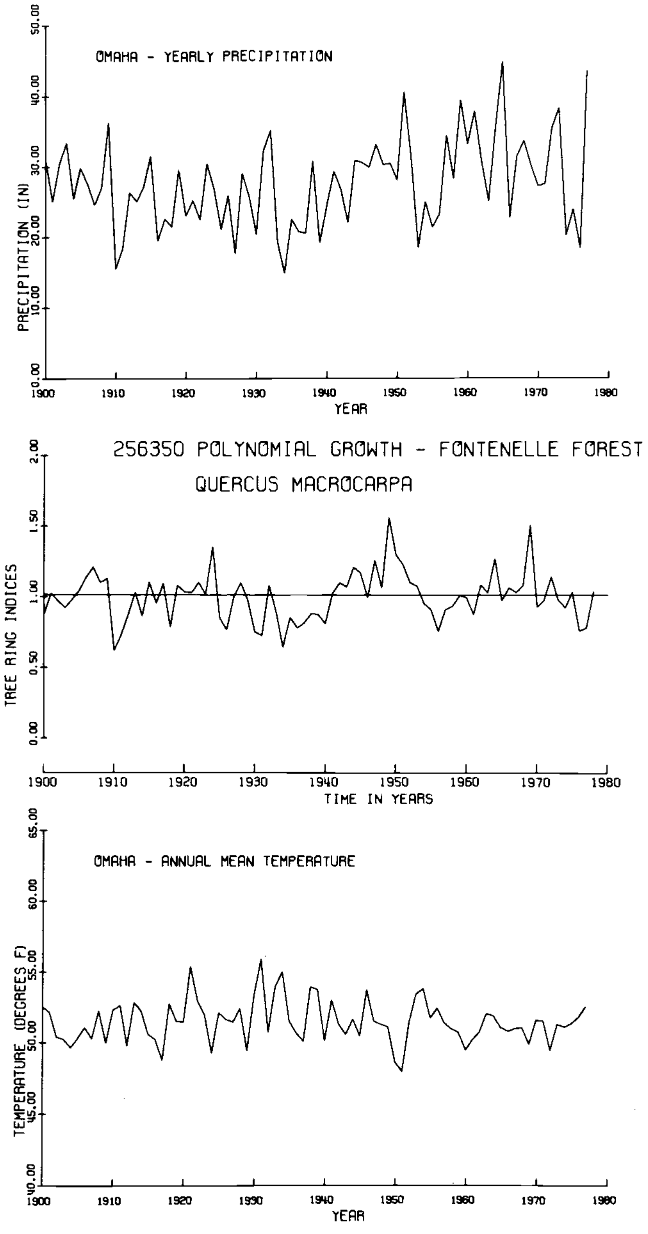

Figure 3. Ring-width index for Fontenelle bur oak as related with yearly precipitation totals and mean annual temperature at Omaha, NE.

station at Omaha (approximately 41° 18' North, 95° 54' West, elevation 299 m), due to its proximity to the bur oak site (13 km) and its relatively long period of record (1900-1977); and the Nebraska East-Central Climatic Division (Region 6), in order to compare response functions based on averaged regional data with those based on single site data. Region 6 is composed of 15 counties in east-central Nebraska (Figure 1), with data available for 1931 to 1976. The Omaha precipitation and temperature data and the PN chronology for 1900-1977 are plotted in Figure 3.

RESPONSE FUNCTIONS

Three different sets of climatic data were employed to develop response functions: Omaha, 1900-77; Omaha, 1931-76; and Region 6, 1931-76. For each set of climatic data, monthly mean temperatures and total monthly precipitation from June prior to current growth season to July of current growth season were selected. The computer program RESPONSE normalized each set of climatic data, extracted eigenvectors, calculated amplitudes, and performed step-wise multiple regression using as predictor variables the amplitudes derived from the 10 most important eigenvectors and three years of prior growth, resulting in regressions of each of the four master chronologies with each of the three sets of climatic data. In addition, each of the four master chronologies was regressed using 20 eigenvectors extracted from Region 6 data (including three years of prior growth). Results from all 16 response functions are presented in Table 2.

Statistics from the NE chronology, the SL chronology, and the HL chronology are similar for each of the four sets of independent variables used and will be discussed as a group. For the Omaha 1900-77 data, the percentage variance explained by climate is low while the percentage variance explained by climate plus prior growth is high. This large difference between total percent variance reduced and that reduced only by climate may indicate a trend induced by non-climatic factors acting on all trees. The response functions based on Omaha 1931-76 data explains considerably more variance due to climate and slightly more total variance. It may be hypothesized that, for bur oak, climate — tree-ring correlations are improved during years of extreme water shortage or extreme temperatures, when macroclimate assumes a relatively greater role than non-climatic factors in determining growth, and that differences in variance explained by climate reflect a greater frequency of extreme fluctuations of precipitation and temperature during the 1931-76 period than during the first 30 years of the century. This hypothesis is supported by the NE chronology ANOVA data for 1900-77 (from 44.5% to 54.8%).

For the NE, SL, and HL chronologies, averaged regional data explains a greater percentage of variance due to climate than does the Omaha single-site data for the same time period, while the Omaha station data explains more total variance. (In his study of numerous arid-site chronologies, Fritts (1974) found that regional data explained slightly more total variance than single-site data.)

Response functions for the NE, HL, and SL chronologies indicate that there is little advantage in the use of 20 eigenvectors rather than 10 eigenvectors in terms of variance reduced by climate (less than 2% increase). There is considerable improvement in the total variance reduced, as more prior-growth variables are used in the 20-eigenvector response functions.

Table 2. Response function results. Step = final step of regression. PCL = percent variance reduced by climate. RR = percent variance reduced by climate plus prior growth.

Climate data	Omaha, 1900-1977 10 eigenvectors			Omaha, 1931-1976 10 eigenvectors			Region 6, 1931-1976 10 eigenvectors			Region 6, 1931-1976 20 eigenvectors		
Chronologies:	Step	PCL	RR	Step	PCL	RR	Step	PCL	RR	Step	PCL	RR
NE	8	30.3	66.9	11	44.6	72.3	9	58.1	64.8	12	60.3	78.1
SL	8	25.7	70.8	13	42.2	74.2	8	55.8	68.4	13	56.2	80.4
HL	8	33.6	65.4	10	48.9	71.3	9	58.7	64.1	11	58.1	77.3
PN	9	43.7	52.9	10	42.3	61.8	8	41.0	51.1	13	53.4	70.4

The response functions based on the PN chronology do not fit the pattern of the other three chronologies. The PN chronology explained less total variance than the other chronologies for each set of climatic predictor variables used and less climatic variance for each of the three sets of predictor variables based on 1931-76 climatic data. The opposite was true, however, for variance reduced by climate using the Omaha 1900-77 data. In the case of the response functions based on the long-term Omaha data, the PN chronology explained considerably more variance due to climate than the other three chronologies, while explaining less total variance. While we do not offer a definitive explanation of this anomaly, one interpretation could be linked to the complex history of Fontenelle Forest and the changing nature of the forest due to the control of fires, which allowed heavy undergrowth to develop between the bur oaks in what was previously a more park-like environment. This gradual development of undergrowth may have resulted in a non-climatic trend in which increasing competition for soil moisture during the period from the late 1850s to the late 1930s limited bur oak growth. Such a trend would account for the low percent variance reduced by climate in the NE, SL, and HL chronologies. The PN chronology, however, would eliminate this trend, resulting in lower total variance reduced but a higher percent variance reduced by climate alone.

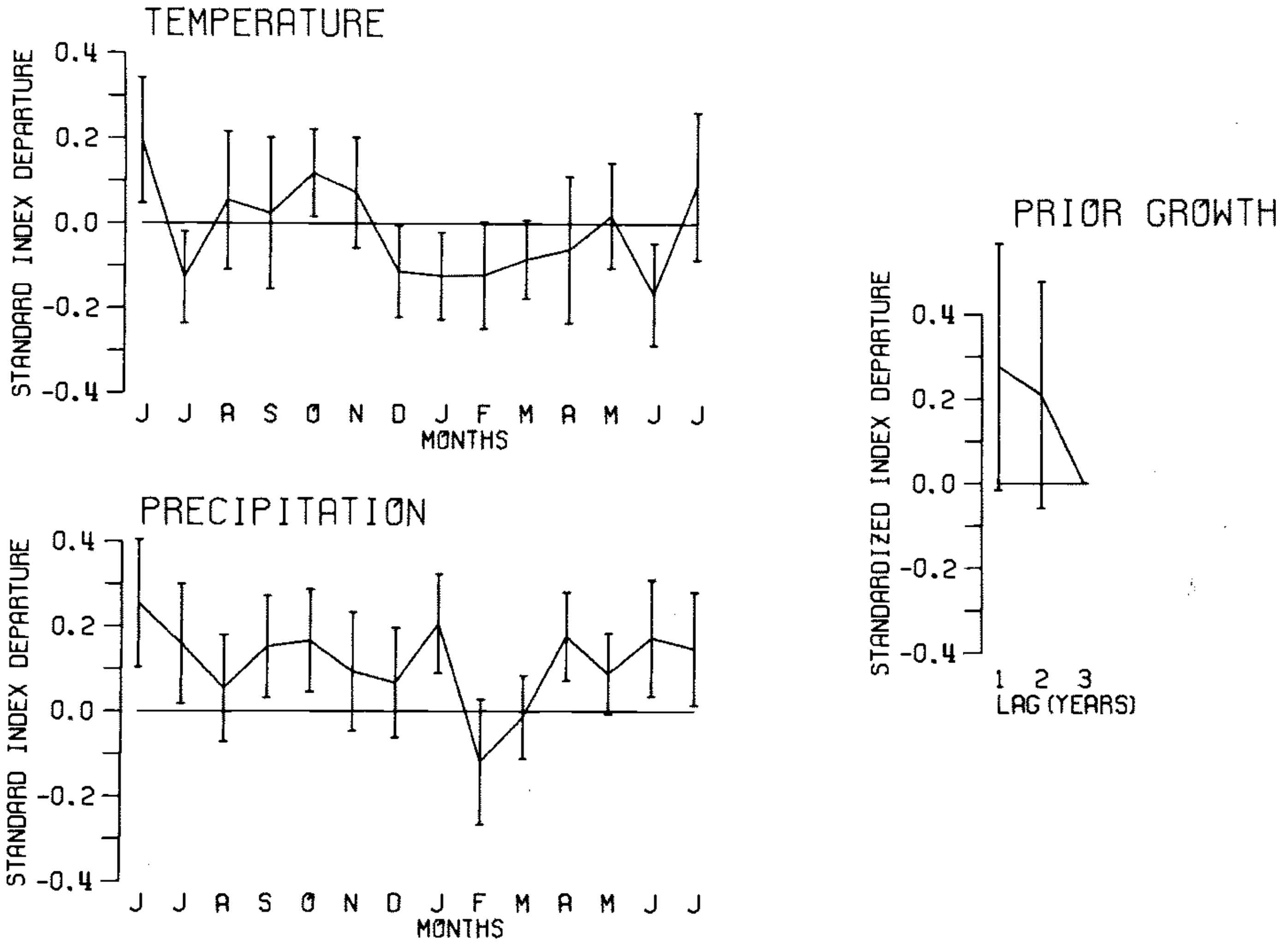

Figure 4. Response function for Fontenelle bur oak chronology standardized by fitting a polynomial curve. Monthly precipitation totals and temperature means from 1931-1976 were computed for the Nebraska East-Central Climatic Division. Twenty principal components of climate and three years of prior growth were entered into the regression model. At step 13 the variance reduced by climate was 53.4% and 70.4% was explained by prior growth plus climate.

During the extremely dry 1930s, fires again burned through Fontenelle Forest and cleared out much of the understory (Garabrandt 1978). The renewal of fires, combined with greater frequency of extreme fluctuations of precipitation and temperature, may have served to restore the forest to pre-settlement conditions by temporarily eliminating trend induced by understory competition and reestablishing macroclimate as a dominating factor. If such is the case, the polynomial curve option of standardizing chronologies from Fontenelle Forest has mixed blessings. While the polynomial curve may remove trends induced by non-climatic variables affecting all trees similarly, it also tends to remove low frequency climatic variations and lowers both variance explained by climate and total variance during periods when non-climatic trends are not significant. Using the polynomial in addition to one of the other curves in standardizing cores may provide a useful method to analyze and discriminate between trend induced by climate and trend induced by non-climatic variables.

The response function derived for the PN chronology using 20 eigenvectors extracted from data for the Nebraska East-Central Climatic Division is represented in Figure 4. Results compare favorably with response functions for three oak chronologies (*Quercus petraea*) from the British Isles (Hughes et al. 1978a, 1978b). A total of 70.4% of the variance is explained by climate and prior growth, or 53.4% by climate alone. Temperatures during the prior autumn are generally directly related to ring growth compared with an inverse relationship dominating during the prior December through current June. Precipitation remains positively associated with tree growth with the exception of early spring which could be complicated by snow melt characteristics. The monthly response function pattern displayed by bur oak indicates a distinct potential for reconstructing periods of significant water stress during incipient exploration and settlement of the eastern Great Plains (Lawson 1971, 1976).

SUMMARY AND PROSPECTS

The objectives of this study were realized in that bur oak in eastern Nebraska has proven suitable for dendroclimatic research. Four growth curve options were analyzed and, while those response functions based on a negative exponential curve, a sloping line, and a horizontal line through the mean were similar, that based on a polynomial curve yielded significantly different results. These differences suggest that response functions based on two or more growth curve options might be used to examine and distinguish between the effects of climatic and non-climatic variables in a complex and changing forest environment. The high correlation between the standardized chronologies and regional climatic data suggest the feasibility of regional climatic reconstruction based on bur oak cores. Further investigations concerning reconstruction of multiple climatic variables at a single site are in progress.

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A MEDIEVAL OAK TREE-RING CHRONOLOGY FROM SOUTHWEST ENGLAND

JENNIFER HILLAM

Department of Prehistory and Archaeology
University of Sheffield

ABSTRACT

Extensive rescue excavations in Exeter during 1972 produced large quantities of waterlogged oak timbers. These were used to construct a tree-ring chronology for the period A.D. 799-1216. The chronology crossmatches well with tree-ring sequences from other areas of the British Isles. It will thus form an important building block in the construction of a long English tree-ring curve which can be used to date archaeological timbers from most regions of Britain.

Des fouilles de sauvetage étendues réalisées en 1972 à EXETER, ont fourni de grandes quantités de poutres de chêne. Celles-ci ont été utilisées pour construire une chronologie s'étendant de 799 à 1216 A.D. Cette chronologie se synchronise bien avec les séquences obtenues dans d'autres régions des Iles Britanniques. Elle forme donc un ensemble important pour la construction d'une longue courbe dendrochronologique anglaise qui peut être utilisée pour dater les bois archéologiques de la plupart des régions de Grande-Bretagne.

Umfangreiche Rettungsgrabungen in Exeter im Jahre 1972 haben große Mengen an Eichenhölzern zu Tage gefördert. Sie dienten dem Aufbau einer Jahrringchronologie für die Zeit von 799 bis 1216 n.Chr. Die Chronologie zeigt eine hohe Ähnlichkeit mit Chronologien von anderen Regionen der britischen Inseln. Sie stellt somit einen wichtigen Baustein für den Aufbau einer langen englischen Jahrringkurve dar, die zur Datierung archäologischer Hözer aus den meisten Gegenden Großbritaniens eingesetzt werden kann.

INTRODUCTION

Dendrochronological research in the British Isles began in earnest in the late 1960s, when the use of tree-ring dating in this country was still in question because of Britain's very temperate climate. The doubts fortunately proved to be without foundation and the 1970s saw the production of many tree-ring chronologies of varying length from different regions of Britain. Some were constructed from modern samples with dendroclimatological research in mind (Leggett et al. 1978), others were used for the dating of archaeological timbers (Hillam 1979b) or art-historical objects (Fletcher 1977) and, in Ireland, long prehistoric sequences, produced from the examination of sub-fossil 'bog' oaks, were used primarily for the calibration of the radiocarbon timescale (Pilcher et al. 1977).

The production of these British chronologies have presented many problems. Progress was slow because, unlike many parts of the world, Britain has no trees which attain very great ages. Oak (*Quercus* sp.), the species used almost exclusively in British dendrochronology, rarely lives longer than 300 years and, in the past, it was normally felled at a much younger age. Thus, the construction of long tree-ring sequences is painstaking work involving the piecing together of short ring patterns, often with only 50-100 rings. Attempts at producing regional chronologies for the last 2000 years have been made more difficult by the scarcity of available timber whose rings cover certain periods, such as the 14th and 17th centuries (Baillie 1977a). Nor is it yet known how many regional reference curves will be needed to provide a dating framework for timbers from the whole of the British Isles, although it now seems possible that, despite regional variations in climate, fewer tree-ring sequences will be required than originally thought (Baillie 1978). This has been confirmed by the work outlined below.

Recent research tended to suggest that there was some difference between tree-ring curves from sites in the 'highland' zone and those in the 'lowland' zone, no doubt due to the distinct climatic and topographical features of the two areas. Sequences from northwest of the line in Figure 1 crossmatch well with each other, whilst southeast of

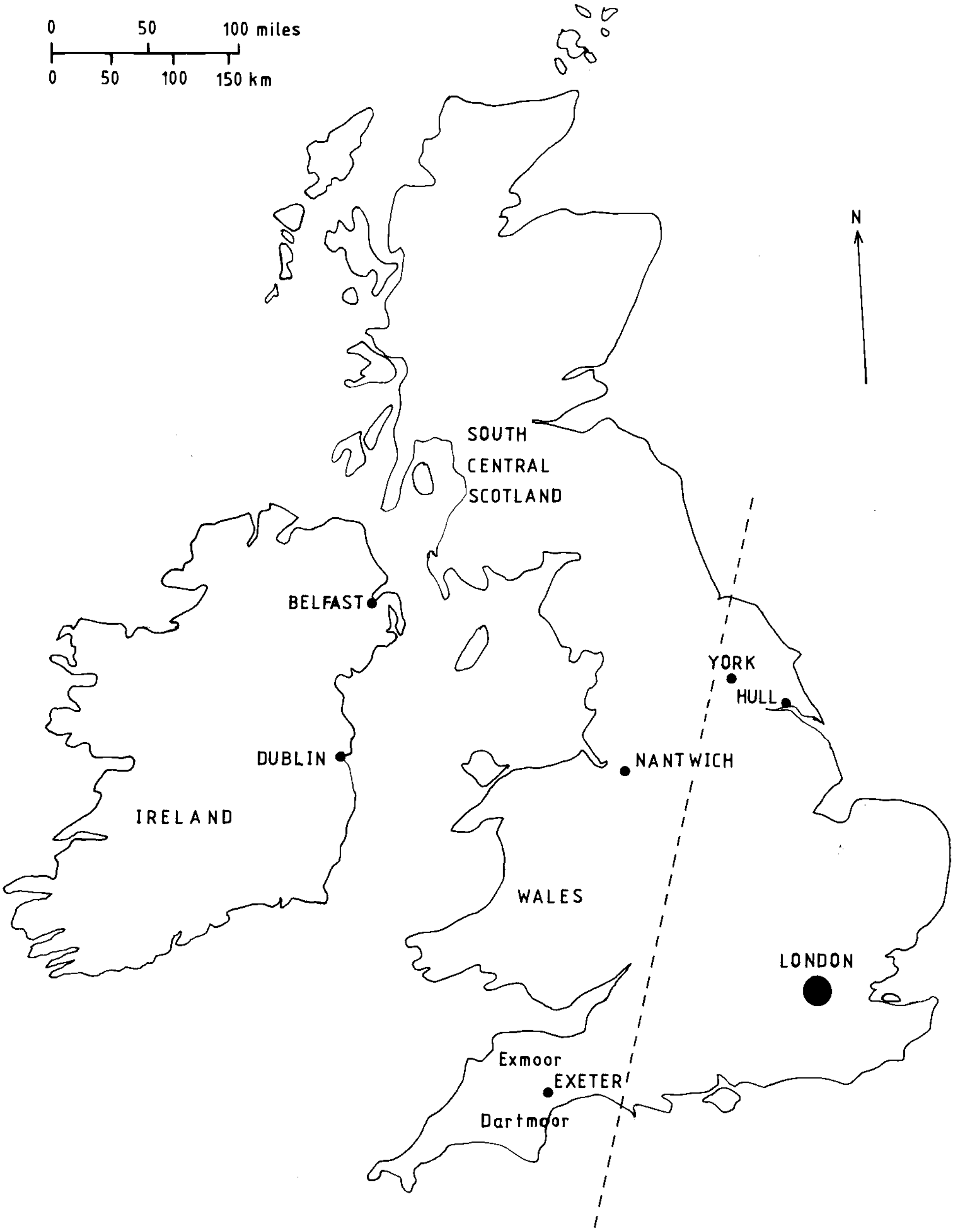

Figure 1. Map of the British Isles showing the location of Exeter and other sites mentioned in the text. The dotted line represents an arbitrary division between the 'highland' and 'lowland' areas, the latter being to the southeast of the line.

the line, considerable difficulty is often experienced in crossmatching timbers from a single site (Hillam and Ryder 1980). No evidence has been found, however, for the existence of distinct growth types for oak, dependent on differences in average ring widths (Fletcher 1977). Nor does it seem likely that chronologies from the 'highland' and 'lowland' areas will be so different in character as to make crossdating between them impossible, as suggested by Fletcher (1978). It has merely been noted that timbers from some 'lowland' regions show little or no similarity in ring pattern. Thus, out of the 95 samples so far examined from the Coppergate excavations at York, only 12 have been crossmatched to form a mean curve. This difficulty in dating 'lowland' samples may be partly due to the fact that less research has been carried out in this area; hence there are few suitable reference chronologies.

The Sheffield dendrochronology laboratory was established by the Department of the Environment in 1975; the tree-ring work is closely linked with rescue archaeology in England and concentrates on dating timbers from archaeological sites threatened by redevelopment. Thus, the construction of long tree-ring chronologies from a single area, such as that produced for the north of Ireland (Baillie 1977a), is out of the question. The principal aim, therefore, is to provide a dating service for archaeologists and, at the same time, produce reference curves for areas of England where no tree-ring work has previously been undertaken. By crossdating these sequences, it will eventually be possible to provide an absolute chronology extending from modern times back to the beginning of the Roman period.

Until 1977, southwest England was a region where there had been no dendrochronological work. However, extensive rescue excavations during 1972, on a site threatened by the proposed construction of a new shopping precinct in Exeter's city centre, offered an opportunity to explore the tree-ring potential of this part of Britain (Figure 1). Its climate overall is the mildest and most equable in the country but it can vary widely throughout the region: for example, parts of Dartmoor have up to 82 inches of rain each year compared with 31 inches in Exeter. Thus, it was not known whether a chronology from the Exeter area would be similar to curves from other upland regions or be more akin to those from southeast England or, indeed, whether it would be unique to that part of the British Isles.

THE TIMBER

Most of the wood samples came from the excavation in Trichay Street, a medieval street which ceased to be used in 1350 when the construction of a parish rectory blocked its entry at one end. The waterlogged timbers were found in pits scattered throughout the site. Although oak timbers of Roman, medieval and post-medieval date were examined at Sheffield during 1977, only the medieval samples proved useful in the construction of a tree-ring chronology; those of Roman and post-medieval age had few rings, being taken for the most part from fast-grown trees. The medieval timbers were mainly radially-split planks, containing between 100 and 300 rings, which had originally been used for the construction of buildings. This paper is primarily concerned with the importance of these timbers in the production of a reference curve for southwest England; further details of the tree-ring work with respect to the archaeology of the site can be found elsewhere (Hillam, in press).

The other site relevant to this chronology was that at and around the medieval Exe Bridge. The date of its construction is documented as late 12th-early 13th century

(Hoskins 1960), but part of the bridge can still be seen in Exeter today. Of the several timbers from the bridge's foundations, only one was suitable for dendrochronology. As it dated to the late 10th century, it must have been re-used, either from an earlier wooden bridge or from another building.

THE CHRONOLOGY

Slices of the waterlogged oak timbers were deep-frozen to give a firmer cross-section on which to work. They were planed so that the individual annual rings could be readily identified. The apparatus used for measuring the ring widths consists of a low-power binocular microscope over a travelling stage; the latter is connected by a linear transducer to a display panel which shows the ring width measurements in 0.1mm. The raw data were plotted on transparent semi-logarithmic recorder paper and the resulting tree-ring graphs compared together visually and by computer. Whilst it was the quality of the visual match that decided whether or not the cross-matching was acceptable, the Belfast CROS computer program (Baillie and Pilcher 1973) was used extensively to save time and to give some statistical meaning to the quality of the matches.

Similarities between the individual curves from Trichay Street were relatively easy to find in comparison to some English sites, such as the timbers from the Viking and late medieval levels at Coppergate, York, mentioned above. Originally two sub-masters were formed; these were linked together by tentative matches (Figure 2). Computer comparisons with dated reference chronologies showed up an exceptionally high correlation between Exeter and Dublin (Baillie 1977b), which confirmed this link and dated the Exeter curve to A.D. 811-1216. A working master was produced by averaging the ring widths of the matching ring patterns. The Student's *t* values, calculated by the Belfast computer program, between it and various sequences throughout the British Isles are set out in Table 1; values greater than 3.5 are statistically significant at the P<0.001 level (Baillie 1978). The agreement of $t = 13.12$ between Exeter and

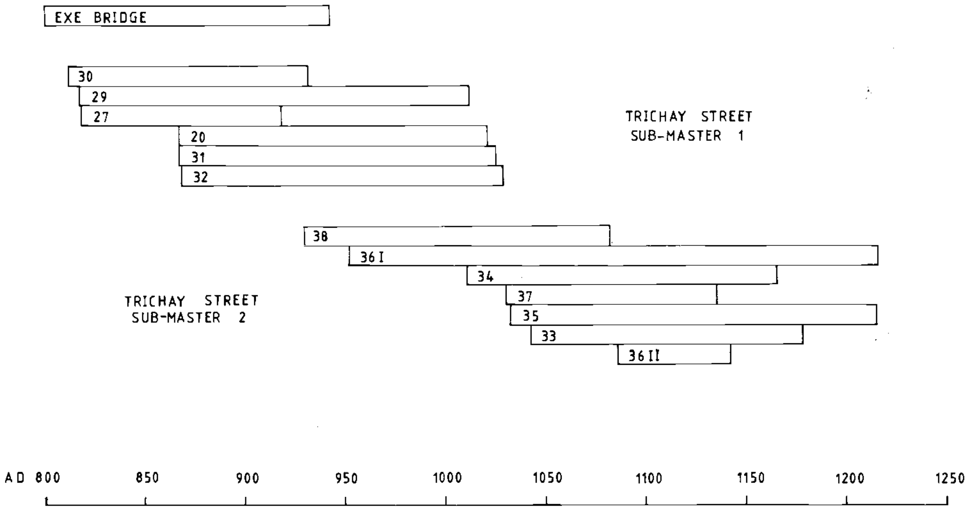

Figure 2. Block diagram showing the years spanned by each sample in the Exeter chronology.

Table 1. Comparison of the Exeter chronology with other sequences from the British Isles and Germany.

CHRONOLOGY	*t*-value
Dublin (Baillie 1977b)	13.12
Germany, Munich (Huber and Giertz-Siebenlist 1969)	2.01
Germany, Trier (Hollstein 1965)	2.08
Hull, Chapel Lane (Hillam 1979)	0.76
London, REF 6 (Fletcher 1977)	4.88
Nantwich (Leggett, pers. comm.)	2.94
Northern Ireland (Baillie 1977a)	6.49
South central Scotland (Baillie 1977c)	5.24
York, Coppergate (Hillam, unpublished data)	0.50
York, Lloyd's Bank (Morgan, pers. comm.)	3.50

Dublin is unusually high; it is reflected in the visual comparison, which shows very close similarity (Figure 3) for sites separated by a distance of ca. 350 km. The t-values for Exeter individual samples compared to the Dublin master range from 2.61 to 9.98 and are as high as between the Exeter individuals themselves. This at first suggested that the Exeter timber was of Irish origin but there is no archaeological evidence to support this theory, nor is it likely that timber was imported continuously over several hundred years as the results would necessitate. Instead, it seems more logical that the trees were growing, separated by the Irish Sea, under almost identical conditions and responding to the same climatic signals.

Apart from this spectacular agreement, the Exeter curve also correlates well with chronologies from Northern Ireland (Baillie 1977a), southern Scotland (Figure 3; Baillie 1977c) and the London area (REF 6 in Fletcher 1977). Comparison of Exeter with the Nantwich sequence (Leggett, pers. comm.) gives a t-value of only 2.94, but examination of the visual crossmatching indicated that the level of agreement between the two curves varied throughout the period of overlap. For the period A.D. 930-1060, there was a value of $t = 0.85$, but for the period A.D. 1061-1216, the t-value was as high as 4.55. Thus, trees growing in different regions responded to the same limiting factors in some centuries but not in others.

Although it shows poor agreement with some places, particularly those sites in the 'lowland' zone (eg. Chapel Lane, Hull, and Coppergate, York), the similarities between Exeter and other sites illustrate the potential of the Exeter curve as a tool for dating archaeological samples over large areas of the British Isles. The fact that there are significant t-values between Exeter and London and between Exeter and the sequence obtained from the Lloyd's Bank excavation in York (Morgan, pers. comm.) indicates that the difference between tree growth in 'highland' and 'lowland' areas might not be as great as first thought, although there will always be sites, such as Coppergate, York, that prove difficult.

The Exeter working master was further extended when the Exe Bridge timber was dated to A.D. 799-941 (Figure 2). After it was ascertained that no more samples could be included, this curve, plus the 13 dated Trichay sequences, was standardized using the INDXA computer package with a polynomial curve-fit option (Fritts et al. 1969).

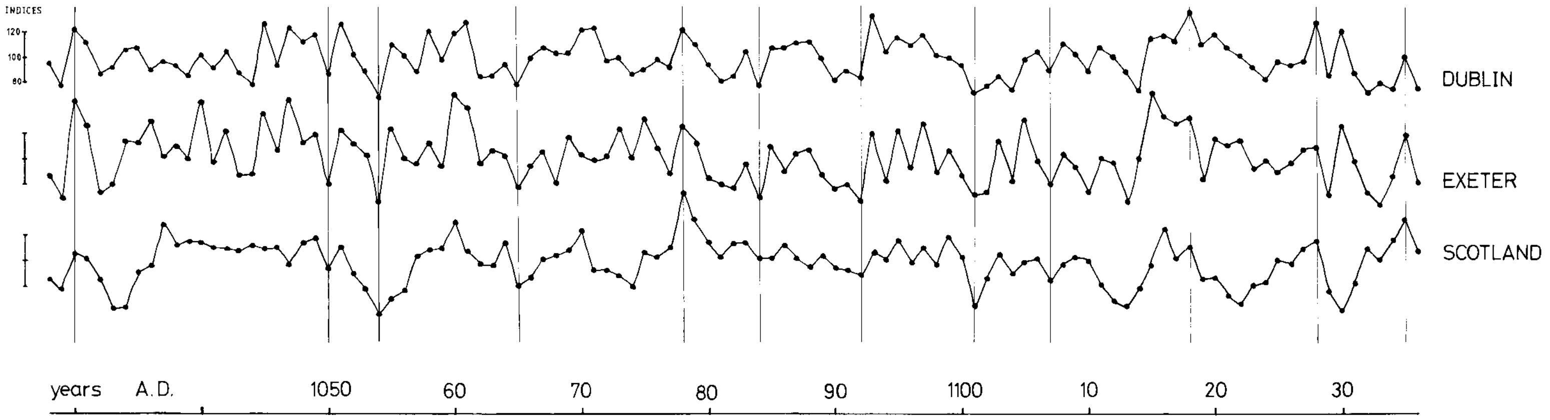

Figure 3. Comparison of the Exeter index chronology with the Dublin and Scotland index chronologies for the period A.D. 1028-1136.

A chronology of index values, covering the period A.D. 799-1216, was then produced (Table 2).

CONCLUSION

The 418-year Exeter chronology given here has already provided accurate archaeological dating for two sites in the city. It is now proving invaluable as a reference curve by which to date other Exeter timbers, such as those from Goldsmith Street (Morgan, pers. comm.). Furthermore, it is another building block, the most substantial yet in English dendrochronology, in the construction of an absolute tree-ring chronology for England going back to Roman times. As such, it has recently been used to date a group of tree-ring sequences from London; these span the period A.D. 682-968 and, in turn, will form the basis for crossdating timbers from earlier Saxon times.

Of wider significance is the successful correlation of Exeter with other regional reference curves, which confirms earlier suggestions that master chronologies, at least, can be synchronised over long distances (Baillie 1977c), particularly throughout Ireland and the 'highland' area of Britain (Hillam and Ryder 1980). Thus, the construction of independent 2000 year chronologies from each area of the British Isles seems to be unnecessary. Instead, shorter sequences from different parts of the country can be linked together to form a general British chronology. The problems encountered with some sites in the 'lowland' region, such as York, indicate that here tree growth may be more complex. However, in this respect, the links between Exeter and timbers from Lloyd's Bank, York, and from London are encouraging. This is especially so as, a little over a decade earlier, it was considered that the climate of the British Isles was such as to make the use of dendrochronology impossible.

ACKNOWLEDGEMENTS

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Table 2. Exeter oak chronology, A.D. 799 to 1216.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
799										145										1
800	135	102	155	133	88	112	78	72	67	105	1	1	1	1	1	1	1	1	1	1
810	87	108	113	115	96	104	99	87	128	92	1	2	2	2	2	2	3	4	4	4
820	82	119	134	117	121	81	114	84	84	73	4	4	4	4	4	4	4	4	4	4
830	55	63	76	89	85	86	72	137	79	123	4	4	4	4	4	4	4	4	4	4
840	104	86	93	87	86	108	70	91	81	77	4	4	4	4	4	4	4	4	4	4
850	80	76	141	127	117	119	110	99	117	141	4	4	4	4	4	4	4	4	4	4
860	130	89	117	117	97	112	133	116	94	140	4	4	4	4	4	4	6	7	7	7
870	117	90	94	74	75	86	124	108	78	108	7	7	7	7	7	7	7	7	7	7
880	139	142	111	150	132	107	122	102	97	101	7	7	7	7	7	7	7	7	7	7
890	102	113	110	113	96	120	106	74	62	87	7	7	7	7	7	7	7	7	7	7
900	124	71	91	101	90	89	110	105	84	83	7	7	7	7	7	7	7	7	7	7
910	84	88	103	93	75	55	56	111	90	88	7	6	6	6	6	6	6	6	5	5
920	73	73	78	95	93	115	84	114	87	110	5	5	5	5	5	5	5	5	5	6
930	107	85	81	74	105	72	107	114	108	90	6	6	6	6	6	6	6	6	6	6
940	96	116	89	96	128	111	134	104	123	86	6	6	5	5	5	5	5	5	5	5
950	118	86	95	111	117	110	75	100	95	77	5	5	6	6	6	6	6	6	6	6
960	101	95	79	102	75	67	81	78	100	95	6	6	6	6	6	6	6	6	6	6
970	124	114	107	62	63	101	102	128	91	125	6	6	6	6	6	6	6	6	6	6
980	117	79	117	112	68	91	96	97	90	105	6	6	6	6	6	6	6	6	6	6
990	85	118	95	107	115	100	98	122	126	141	6	6	6	6	6	6	6	6	6	6
1000	118	108	128	112	97	118	110	100	90	77	6	6	6	6	6	6	6	6	6	6
1010	88	81	55	60	73	85	97	100	102	87	6	6	5	5	5	5	5	5	5	5
1020	95	106	95	91	98	104	104	92	88	70	5	4	4	4	4	3	3	3	3	2
1030	146	128	74	80	114	113	130	103	110	101	3	3	4	4	4	4	4	4	4	4

Table 2, continued.

Year	Tree Ring Indices 0	1	2	3	4	5	6	7	8	9	Number of Samples 0	1	2	3	4	5	6	7	8	9
1040	145	98	122	88	89	136	108	148	114	120	4	4	5	5	5	5	5	5	5	5
1050	81	123	112	104	67	125	101	98	113	95	5	5	5	5	5	5	5	5	5	5
1060	151	141	97	107	104	78	95	106	82	117	6	6	6	6	6	6	6	6	6	6
1070	104	101	103	124	103	133	109	89	126	113	6	6	6	6	6	6	6	6	6	6
1080	86	81	78	96	71	110	91	105	108	89	6	6	6	5	5	5	5	6	6	6
1090	77	80	68	120	84	123	94	128	91	106	6	6	6	6	6	6	6	6	6	6
1100	88	72	74	114	84	131	100	81	104	94	6	6	6	6	6	6	6	6	6	6
1110	75	101	98	67	101	152	134	129	134	85	6	6	6	6	6	6	6	6	6	6
1120	116	112	115	94	99	91	97	108	110	73	6	6	6	6	6	6	6	6	6	6
1130	127	99	73	64	86	119	82	65	90	99	6	6	5	5	5	5	4	4	4	4
1140	114	104	101	109	79	89	104	93	77	107	4	4	4	3	3	3	3	3	3	3
1150	76	96	108	134	89	78	119	109	86	117	3	3	3	3	3	3	3	3	3	3
1160	96	80	84	92	87	97	106	92	82	83	3	3	3	3	3	3	2	2	2	2
1170	76	77	79	82	81	69	69	65	110	119	2	2	2	2	2	2	2	2	2	1
1180	90	75	75	90	90	120	90	120	60	105	1	1	1	1	1	1	1	1	1	1
1190	90	75	90	90	105	105	105	60	90	105	1	1	1	1	1	1	1	1	1	1
1200	90	90	105	150	75	90	120	90	90	105	1	1	1	1	1	1	1	1	1	1
1210	150	135	135	120	90	120	120				1	1	1	1	1	1	1			

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SIX MODERN OAK CHRONOLOGIES FROM IRELAND

JON R. PILCHER and MICHAEL G. L. BAILLIE

Palaeoecology Centre, Queen's University of Belfast,
Northern Ireland.

ABSTRACT

Six modern oak tree-ring chronologies from Ireland are presented. All are from planted or from disturbed-natural woodland of *Quercus petrea*. The final chronologies were tested for climate content by the response function method. The results range from 5% to 52% of the chronology variance explained by temperature and precipitation of a 14 month period during and prior to the growing periods. The relationship between these figures and the site and chronology details are examined. The relationship of the individual chronologies to each other is examined and the hypothesis put forward that Ireland can be considered as a single tree-ring area from a dating viewpoint.

Six chronologies éstablies sur des chênes modernes croissant en Irlande sont présentées. Toutes proviennent de forêts de Quercus petrea plantées, ou de forêts naturelles mais perturbées. Le contenu climatique des chronologies finales a été testé par la méthode des fonctions de réponse. Les résultats montrent que 5% à 52% de la variance de la chronologie est expliquée par les températures et les précipitations d'une période de 14 mois couvrant et précédant la saison de végétation. Les relations entre ces résultats et les détails concernant le site et la chronologie sont examinées de même que les relations entre chronologies individuelles. L'hypothèse est émise que du point de vue de la datation, l'Irlande peut être considérée comme une région unique.

Es werden sechs Chronologien aus rezenten Eichen (Quercus petraea) in Irland dargestellt. Sie stammen von Anpflanzungen sowie von gestörten, natürlichen Waldgebieten. Die Chronologien wurden mit Hilfe des Response-function-Verfahrens auf ihren Klimagehalt geprüft. Zwischen 5 und 52% der Varianz in den Chronologien können durch Temperatur und Niederschlag einer Periode von 14 Monaten vor und während der Vegetationszeit erklärt werden. Der Zusammenhang zwischen diesen Beträgen und einigen Standorts- und Chronologieparametern wird geprüft. Die Beziehung zwischen den einzelenen Chronologien führt zu der Annahme, daß Irland vom Datierungsstandpunkt aus als einheitliches Jahrringgebiet betrachtet werden kann.

INTRODUCTION

We present here six tree-ring chronologies from living stands of *Quercus petrea* from Ireland. The sites were selected as far as possible to be more than 80 km and less than 160 km apart. Site details are given in Table 1. Within this broad limitation oak woodland was sought and sampled by increment corer. The cores were measured and crossdated and the measurements converted to indices (Fritts 1976), using a polynomial curve fit. The indices of the individual cores were averaged to form the final site chronologies. None of the sites extends to before A.D. 1800 and the only previously published modern site chronology, Rostrevor (Pilcher 1976) extends to only A.D. 1750. While individual trees in large estates may be considerably older than this, there is no really old oak woodland in Ireland equivalent to the relict forests in Scotland (Baillie 1977) and England.

The chronologies were constructed for two purposes; firstly as part of a pilot study to examine the climate responses of oaks in the British Isles and secondly to examine, using modern trees, the size of the area over which good crossdating could be expected for archaeological dating chronologies.

Table 1. Sampling details for six modern Irish oak chronologies.

SITE	LATITUDE	LONGITUDE	ALTITUDE	NO OF CORES	SITE TYPE
Ardara	54°45'N	8°23'W	30 m	11	Small group of planted trees
Killarney	52°00'N	9°33'W	30 m	18	Open natural oak woodland
Lough Doon	52°50'N	8°40'W	30 m	12	Scattered trees near lake
Eniscorthy	52°50'N	6°32'W	30 m	13	Planted oaks on steep west facing slope
Glen of Downs	53°08'N	6°05'W	100 m	13	? natural oak woodland on steep east facing slope
Cappoquin	52°08'N	7°54'W	150 m	14	Oak woodland on steep east facing slope

CHRONOLOGY STATISTICS

Table 2 lists the statistics of the chronologies, and includes the previously published site of Rostrevor (Pilcher 1976). An average figure for the more useful descriptive statistics is given at the base of the table together with the averages for western and eastern United States given by DeWitt and Ames (1978). The mean sensitivity and standard deviation of the Irish chronologies are very similar to those of the eastern United States sites, but the serial correlation is higher. However, the percent common variance in the chronology is in general higher in the Irish than eastern U.S.A. sites. The mean value of about 37% is between the means of 29% and 60% for eastern and western United States respectively. DeWitt and Ames (1978) show that the low percent common variance effects the desirable level of sampling. The value of 'signal-to-noise ratio' has recently been used as a measure of chronology quality. This is derived from the percent common variance and the number of trees in the chronology. The figure of 15:1 commonly associated with the better western United States arid site chronologies is taken as a desirable target. DeWitt and Ames show that for the eastern United States some 35-40 trees would have to be sampled to reach this value. For most of the Irish sites 25 trees would be adquate. However none of the chronologies presented here reaches this target. The actual signal-to-noise ratios are given in Table 2.

CLIMATE CONTENT OF THE CHRONOLOGIES

In theory the common variance in the chronology should be a measure of the climate signal. It is used in this way by DeWitt and Ames. However the percent variance attributable to climate as calculated by the response function method is often very different from the common variance. The two most likely reasons for this are firstly that the climate data used for the response function does not relate closely to that experienced by the trees and secondly that there is a significant amount of common, non-climatic variance in the chronology. The latter will always be a potential problem in populated areas of the world where forests or woodlands may be affected by forestry practices such as selective thinning. The former problem simply means that the chronology contains useful climate information but that we can't model it directly as we have no local climate data. This does not mean that the chronology will be no use for climate reconstruction. In devising a grid of chronologies for climate reconstruction it would be valuable to be able to distinguish between these two scenarios. In the present case both Glen of the Downs and Cappoquin have what might be classed as reasonable chronologies (average standard deviations, mean sensitivity and serial correlation and over 35% common variance) and yet they have 5 and 7% variance attributable to climate in the response functions. The only common site factor between the two is that they are both steep east facing slopes, perhaps with a significantly different micro-climate from the climate recording stations used. Until a better method of assessing the climate potential of chronologies can be devised sites such as Glen of the Downs and Cappoquin will not be used in climate reconstruction grids.

CROSS CORRELATIONS AND IMPLICATIONS FOR ARCHAEOLOGICAL DATING

The areal extent of a usable dating chronology is not a thing that can be predicted

Table 2. Chronology statistics for six modern Irish oak chronologies.

Site	No. of trees	Start year	Start yr. for 10 cores	End year	Number of years	Mean width (mm)	Standard deviation	Mean sensitivity	Serial correlation	ANALYSIS OF VARIANCE RAW DATA % Var. Y	% Var. YT	INDICES % Var. Y	% Var. YT	Mean R bet. trees	Mean R with chron.	% var. with climate	Signal-to-noise
ROSTREVOR	18	1750	1757	1975	226	1.0	0.30	0.22	0.56	44.3	55.7	41.8	58.2	0.53		64	12.9
ARDARA	11	1803	1917	1978	129	1.58	0.28	0.21	0.62	34.4	65.6	39.1	60.9	0.49	0.70	22	7.07
KILLARNEY	18	1809	1852	1976	170	1.56	0.24	0.19	0.49	37.4	62.6	29.0	71.0	0.37	0.61	36	7.35
LOUGH DOON	12	1850	1892	1978	129	1.68	0.20	0.14	0.57	20.0	80.0	25.1	74.9	0.27	0.53	22	4.36
ENISCORTHY	13	1811	1861	1978	168	1.34	0.24	0.18	0.56	41.2	58.8	49.1	50.9	0.53	0.73	52	12.55
GLEN OF DOWNS	13	1809	1845	1978	170	0.96	0.32	0.21	0.68	42.3	57.7	39.0	61.0	0.46	0.68	5	8.33
CAPPOQUIN	14	1820	1852	1979	166	1.38	0.25	0.17	0.60	39.7	60.3	36.9	63.1	0.41	0.65	7	8.17
MEAN Ireland					165	1.37	0.255	0.18	0.59	37.0	63.0	37.1	62.9	0.44	0.65	24	8.7
MEAN Eastern U.S.A.							0.238	0.175	0.496			28.7					
MEAN Western U.S.A.							0.380	0.365	0.415			60.0					

Table 3. Students *t* values for cross correlations between seven modern Irish oak chronologies using a high-pass filter. Upper right of matrix gives distance apart in kilometers.

	ROSTREVOR	ARDARA	KILLARNEY	GLEN OF DOWNS	ENISCORTHY	CAPPOQUIN	LOUGH DOON
ROSTREVOR		158	320	105	180	240	215
ARDARA	2.48		315	235	280	290	224
KILLARNEY	5.46	4.46		260	205	115	108
GLEN OF DOWNS	3.18	2.41	3.07		80	155	165
ENISCORTHY	5.39	1.34	6.91	1.34		95	140
CAPPOQUIN	1.42	3.17	3.76	4.23	4.35		85
LOUGH DOON	5.41	7.31	7.10	2.73	4.81	3.04	
MEAN	3.89	3.53	5.13	2.83	4.02	3.09	5.07

or derived theoretically. One can start from a small area and gradually expand until the dating quality forces a halt, or as was found in Germany, some natural barrier such as a mountain range causes a natural break between dating areas. In Ireland the initial dendrochronological effort concentrated on a small area roughly within 80 km (50 miles) of Lough Neagh (Baillie 1973). More recently, crossdating has been established for the prehistoric period between sites throughout Ireland (Baillie 1980). The construction of the modern chronologies presented here gave the opportunity to examine crossdating between widely spaced site chronologies. Table 3 gives the cross correlations expressed of students *t* between all pairs of chronologies and their distances apart in kilometers. The correlations have been calculated using a high pass filter using the Baillie and Pilcher (1973) computer program. This gives a value for crossdating similar to the visual crossdating assessment based on the highest frequencies only. This is what would be used in an archaeological dating context. The most significant thing to emerge is that there appears to be no relationship between distance and correlation. Thus we could postulate that from a tree-ring dating point of view Ireland is a single unit for which a single chronology should be valid. On the other hand the results also suggest that there are considerable site differences that could make the dating of individual archaeological sites difficult. To pursue this idea further two other sets of correlations were performed (Table 4). Firstly each of the six sites against a mean of all six, i.e. an 'all-Ireland chronology', and secondly against the original North of Ireland composite chronology published by Baillie (1973). From this it can be that all individual sites would crossdate well with an area master (of ca. 100 trees) and also with the composite multi-site master (with only 30 trees). The implication for building dating chronologies in a new area is that the effort would be better spent on getting a scatter of trees from throughout the area than on working up a single site chronology.

Table 4. Students *t* values for cross correlations between site chronologies and the composite chronology formed from all sites as well as with the Belfast chronology.

	MODERN COMBINED MASTER	BELFAST CHRONOLOGY
ROSTREVOR	12.42	6.01
ARDARA	10.54	10.32
KILLARNEY	12.33	4.58
GLEN OF DOWNS	6.80	2.89
ENISCORTHY	8.15	4.76
CAPPOQUIN	7.76	2.99
LOUGH DOON	11.63	7.35
BELFAST	9.18	

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Table 5a. Ardara oak chronology.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1803				167	122	113	98	101	104	92				1	1	1	1	1	1	1
1810	112	56	104	89	97	97	109	62	44	63	1	1	1	1	1	1	1	1	1	1
1820	83	57	31	29	52	43	55	43	65	112	1	1	1	1	1	1	1	1	1	1
1830	72	72	51	71	80	74	60	52	107	120	1	1	1	1	1	1	1	1	1	1
1840	89	106	103	90	130	122	106	141	163	202	1	1	1	1	1	1	1	1	1	1
1850	187	107	137	131	159	150	90	99	83	115	1	1	1	1	1	1	1	1	1	1
1860	142	148	165	123	108	123	137	148	91	74	1	1	1	2	2	2	2	3	3	4
1870	110	120	81	97	100	97	91	55	98	78	4	4	4	4	4	4	4	4	5	5
1880	82	102	110	98	86	104	109	91	73	77	5	5	5	5	5	5	5	5	6	6
1890	118	103	109	89	68	86	106	138	87	121	6	7	7	7	7	7	9	9	9	9
1900	129	109	86	126	116	96	98	80	79	106	9	9	9	9	9	9	9	9	9	9
1910	119	106	118	129	90	94	105	90	79	101	9	9	9	9	9	9	9	10	10	10
1920	77	96	84	59	82	93	71	89	68	70	10	10	10	10	10	10	10	10	10	10
1930	85	90	94	98	82	116	117	110	105	138	11	11	11	11	11	11	11	11	11	11
1940	136	142	135	79	70	92	100	147	114	84	11	11	11	11	11	11	11	11	11	11
1950	131	124	118	133	92	113	64	63	83	128	11	11	11	11	11	11	11	11	11	11
1960	121	101	76	67	63	90	90	84	86	99	11	10	10	10	9	8	8	8	8	8
1970	92	96	70	88	100	83	118	142	93		8	8	8	8	8	8	8	8	3	

Table 5b. Killarney oak chronology.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1809										106										1
1810	122	172	178	163	141	123	119	107	89	107	1	1	2	3	3	3	3	3	4	4
1820	83	80	95	134	111	92	52	91	100	122	4	4	4	5	5	5	5	6	6	6
1830	121	106	101	114	110	107	84	117	124	87	6	6	6	7	8	8	8	8	8	8
1840	58	64	55	54	87	109	89	90	131	137	8	8	8	9	9	9	9	9	9	9
1850	101	77	112	119	102	121	77	80	60	64	9	9	10	10	10	10	12	12	12	12
1860	104	118	86	84	77	86	106	118	90	79	13	13	13	13	13	13	14	14	14	14
1870	101	170	155	134	103	117	104	82	105	85	14	14	14	14	15	15	15	15	15	15
1880	79	90	115	114	96	90	95	80	108	88	15	16	16	17	17	17	17	18	18	18
1890	133	122	122	65	67	99	80	135	92	83	18	18	18	18	18	18	18	18	18	18
1900	131	111	118	122	160	111	83	83	70	94	18	18	18	18	18	18	18	18	18	18
1910	99	109	109	88	103	121	117	128	97	74	18	18	18	18	18	18	18	18	18	18
1920	64	62	87	84	104	76	112	119	142	109	18	18	18	18	18	18	18	18	18	18
1930	82	90	83	74	60	101	83	89	93	108	18	18	18	18	18	18	18	18	18	18
1940	84	92	99	111	84	117	120	157	108	92	18	18	18	18	18	18	18	18	18	18
1950	102	131	91	111	105	80	79	87	110	94	18	18	18	18	18	18	18	18	18	18
1960	127	84	162	129	120	107	96	87	110	133	18	18	18	18	18	18	18	18	18	18
1970	90	84	68	93	100	81	99	77	84		18	17	17	17	17	17	17	16		

Table 5c. Lough Doon oak chronology.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1850	127	112	111	97	113	71	67	87	89	103	2	2	3	3	3	3	3	3	3	4
1860	114	145	147	129	105	110	101	80	52	58	5	5	6	6	6	7	7	7	7	7
1870	72	106	98	89	91	119	109	96	138	95	7	8	8	8	8	8	8	8	8	8
1880	99	102	109	102	97	90	103	90	121	100	8	8	8	8	9	9	9	9	9	9
1890	117	101	116	100	78	117	152	154	86	114	9	9	10	10	10	11	11	11	11	11
1900	123	111	88	91	104	88	78	88	92	117	11	11	11	11	11	11	11	12	12	12
1910	118	118	105	89	89	94	89	99	104	94	12	12	12	12	12	12	12	12	12	12
1920	74	84	89	81	91	89	90	111	111	87	12	12	12	12	12	12	12	12	12	12
1930	77	82	78	64	67	93	87	89	84	90	12	12	12	12	12	12	12	12	12	12
1940	95	82	102	76	84	91	103	125	95	112	12	12	12	12	12	12	12	12	12	12
1950	131	124	114	112	112	135	112	96	120	119	12	12	12	12	12	12	12	12	12	12
1960	154	117	167	120	133	128	99	79	84	91	12	12	12	12	12	12	12	12	12	12
1970	83	88	73	73	94	79	106	91	91		12	12	12	12	12	12	12	12	12	

Table 5d. Eniscorthy oak chronology.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1811		118	128	124	114	112	96	55	75	107		1	1	1	2	2	2	2	3	3
1820	93	100	107	151	113	91	63	100	133	148	3	3	4	5	5	5	5	5	5	5
1830	168	142	132	104	94	90	58	102	80	69	5	6	6	6	6	6	6	6	6	6
1840	51	84	76	63	37	77	73	76	67	68	6	7	7	7	7	7	8	8	8	8
1850	91	82	88	59	69	63	76	83	71	69	8	8	8	8	8	8	8	8	8	8
1860	82	77	83	99	122	128	100	121	112	112	8	10	10	10	10	11	11	12	12	12
1870	110	151	145	127	95	167	97	120	143	127	12	13	13	13	13	13	13	13	13	13
1880	122	115	149	140	101	90	112	84	114	75	13	13	13	13	13	13	13	13	13	13
1890	106	109	113	66	80	104	92	121	101	95	13	13	13	13	13	13	13	13	13	13
1900	112	94	99	111	117	91	72	82	81	87	13	13	13	13	13	13	13	13	13	13
1910	112	85	100	84	86	82	82	124	110	83	13	13	13	13	13	13	13	13	13	13
1920	93	66	79	64	101	95	86	107	135	106	13	13	13	13	13	13	13	13	13	13
1930	91	89	85	81	91	101	136	101	107	123	13	13	13	12	12	12	12	12	12	12
1940	89	97	101	103	95	113	112	147	110	77	12	12	12	12	12	12	12	12	12	12
1950	96	93	79	77	81	87	83	98	106	105	12	12	12	12	12	12	12	12	12	12
1960	148	118	144	130	126	127	119	85	103	93	12	12	12	12	12	12	12	12	12	12
1970	93	130	84	87	78	95	87	76	106		12	12	12	12	12	12	12	12	12	

Table 5e. Glen of the Downs oak chronology.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1809										149										1
1810	53	81	110	28	33	44	44	107	157	152	1	1	1	1	1	1	1	2	2	2
1820	122	103	131	163	161	160	108	109	63	85	2	2	2	2	2	3	4	5	5	5
1830	74	79	110	128	148	112	115	157	148	142	6	6	6	7	7	7	7	7	8	8
1840	135	123	108	64	58	95	70	66	49	79	8	8	8	8	9	10	10	10	10	10
1850	84	67	91	87	98	114	88	130	118	114	10	10	10	10	10	10	11	11	11	12
1860	143	142	168	106	66	99	107	66	49	63	12	12	12	12	12	12	12	12	12	12
1870	60	75	71	88	94	72	77	89	102	111	12	12	13	13	13	13	13	13	13	13
1880	129	170	132	104	110	121	102	72	45	81	13	13	13	13	13	13	13	13	13	13
1890	140	120	118	101	118	118	119	94	91	105	13	13	13	13	13	13	13	13	13	13
1900	121	96	85	95	134	119	86	109	138	144	13	13	13	13	13	13	13	13	13	13
1910	148	125	126	113	114	120	105	57	41	67	13	13	13	13	13	13	13	13	13	13
1920	83	94	80	56	70	72	68	96	112	98	13	13	13	13	13	13	13	13	13	13
1930	108	103	78	46	41	47	85	67	49	59	13	13	13	13	13	13	13	13	13	13
1940	78	100	135	105	121	150	95	129	119	110	13	13	13	13	13	13	13	13	13	13
1950	155	172	151	167	125	102	79	74	79	72	13	13	13	13	13	13	13	13	13	13
1960	77	62	145	147	132	128	114	114	107	113	13	13	13	13	13	13	13	13	13	13
1970	91	81	83	103	105	85	72	71	67		13	13	13	13	13	13	13	13	13	

Table 5f. Cappoquin oak chronology.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1813				137	105	98	162	101	69	64				1	1	1	1	2	2	2
1820	85	26	58	78	136	110	66	44	78	136	2	2	2	2	2	2	2	2	2	2
1830	171	117	123	135	105	79	86	151	105	90	2	2	3	3	4	5	5	6	6	6
1840	88	92	80	79	76	109	96	111	112	112	7	7	8	8	8	8	8	9	9	9
1850	128	142	143	117	109	128	90	105	92	93	9	9	10	10	10	10	10	10	11	11
1860	100	96	89	69	76	83	96	114	80	103	11	11	11	11	11	11	11	11	11	11
1870	107	92	96	105	108	122	99	104	106	96	11	11	11	12	12	12	12	12	12	12
1880	102	106	89	99	112	96	102	76	103	104	13	13	13	13	13	14	14	14	14	14
1890	111	103	110	94	100	100	97	129	90	118	14	14	14	14	14	14	14	14	14	14
1900	112	94	99	91	107	89	71	66	74	76	14	14	14	14	14	14	14	14	14	14
1910	109	106	108	90	79	67	72	88	65	59	14	14	14	14	14	14	14	14	14	14
1920	76	65	87	67	96	84	78	95	80	85	14	14	14	14	14	14	14	14	14	14
1930	94	90	110	87	97	140	182	135	138	138	14	14	14	14	14	14	14	14	14	14
1940	115	154	158	115	120	150	141	145	133	158	14	14	14	14	14	14	14	14	14	14
1950	146	136	104	113	79	73	82	92	104	98	14	14	14	14	14	14	14	14	14	14
1960	108	95	134	99	92	96	106	104	91	76	14	14	14	14	14	14	14	14	14	14
1970	69	72	67	63	74	95	77	101	73		14	14	14	14	14	14	14	13	11	

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ON REMOVING THE GROWTH TREND FROM DENDROCHRONOLOGICAL DATA

W. G. WARREN

Forintek Canada Corp.
Vancouver, B.C.

ABSTRACT

A new approach to removing the growth trend from dendrochronological data is described. It is assumed that the growth trend can be described by an expression of the form $a.x^b$ exp. (-cx), which has the attributes of an increment function, and that accelerated growth, due to release at various points in a tree's history, can be represented by additive components that have the same basic form. A method of estimation is presented, along with some results of preliminary testing. The method shows promise of being superior to currently available alternatives.

Une nouvelle approche destinée à éliminer la tendance de croissance présente dans les données dendrochronologiques est décrite. Il est supposé que la tendance de croissance peut être décrite par une expression de la forme $a.x^b$ exp. (-cx) qui a les caractéristiques d'une fonction d'accroissement, et qu'une accélération de la croissance, due à dégagements réalisés à certains moments de l'histoire d'un arbre, peut être représentée par des composantes supplémentaires qui ont la même forme. Une méthode d'estimation est présentée en même temps que quelques résultats de contrôles préliminaires. Cette méthode promet d'être supérieure à celles qui sont actuellement utilisées.

Es wird ein neues Verfahren zur Eliminierung des Alterstrendes aus dendrochronologischen Daten vorgestellt. Hierbei wird angenommen, daß der Wachstumsverlauf durch einen Ausdruck der Form $a.x^b$ exp. (-cx) und mit den Eigenschaften einer Zuwachsfunktion beschrieben werden kann. Ferner wird unterstellt, daß Wachstumsbeschleunigungen aufgrund von Erleichterungen während eines Baumlebens durch additive Komponenten von gleicher Grundform darstellbar sind. Ein Schätzverfahren und erste Ergebnisse eines Vorversuches werden angegeben. Das Verfahren verspricht, den gegenwärtig verfügbaren Alternativlösungen überlegen zu sein.

INTRODUCTION

There seems to be no better way to introduce this subject than to refer the reader to Fritts (1976) and, in particular, to the section on standardization (Fritts 1976: 261-68).

The main points made therein that have a bearing on the present paper relate to the various functions that have been used to estimate, and hence to remove, the growth trend in ring-width data, so as to be better able to focus on fluctuations caused by climatic factors. Fritts gives prominence to polynomial and exponential functions, the latter of the form a.exp. (-bx) + k. He observes that this exponential function has been found adequate for many North American conifers because it approximates the various parabolic, hyperbolic, and logarithmic forms that have been used, and because it resembles the declining rate in the conifer biological growth function. He points out, however, that there exist situations in which there are complications, stemming from stand disturbance or other changes in forest environment, that cannot be handled by the exponential function. In these circumstances he appears to favor the stepwise fitting of a polynomial.

Our experience with the data in which we are currently interested is that the exponential/linear fits are unsatisfactory. They are, of course, monotonic and thus cannot make any allowance for accelerated growth due to, for example, a reduction in competition. Evidence of such, perhaps as the result of the death or removal of a neighboring tree, is common in our data. Indeed, such phenomena should, perhaps, be regarded as the norm in tree-ring records that extend back for 100 years, 200 years or more. A consequence of fitting monotonic functions is the existence of long sequences (sometimes 50 — 80 years) where the observed values all lie above (or below) the fitted curve. Further, since, as observed by Fritts, the monotonic functions will not accommodate the increasing growth rate usually observed during the first 10 to 30 years of the life of a tree, one has to make an arbitrary decision as to what point to start the fit.

It would appear that polynomial fits have the potential to overcome some of these difficulties, but they bring with them their own problems. Firstly, as noted by Fritts, there is the danger that a high-order polynomial will follow responses to climate, rather than solely the pure growth trend, as affected by competition, etc. Also, to reduce the asserted undue influence on the polynomial fits of erratic data points near the beginning and end of a data sequence, the implementation of the polynomial fit undertaken by the Laboratory of Tree-Ring Research, The University of Arizona, Tucson, artificially extends the series at each end. Our experience suggests that this "corrective" action is beneficial in only a few instances, and in most cases has an adverse effect.

There is another problem in the mechanics of fitting orthogonal polynomials. Suppose that we have a pure cubic superimposed on a linear trend: then, in sequential fitting of orthogonal polynomials, the quadratic component will bring about no reduction in the variance. If, because of this, we terminate the procedure, we would fit solely the linear trend and omit the important cubic component. This is, admittedly, an overly simplified example, but it does illustrate the difficulty in establishing criteria for the inclusion and exclusion of components in a polynomial fit.

It is noted with interest (Tree-Ring Society Newsletter, March, 1979) that the orthogonal-polynomial curve option of the computer program has recently been replaced by a smoothing spline by the Tree-Ring Laboratory, Lamont-Doherty Geological Observatory, Palisades, New York. It is reported that "the smoothing spline is consistently superior to the polynomial fit for standardizing tree-ring series with suppression and release." At the time of writing, we do not have details on the nature of the spline functions used; however, it seems likely that there is no less a danger of unwantedly removing climatic variations. Another technique that has been used is exponential weighted smoothing (Barefoot et al. 1974), ascribed by these authors to Brown (1959). The method was originally devised for economic time series and, in the tree-ring application, is claimed to retain significant variations while removing underlying growth trends, defined as long-term and short-term aberrations due respectively to differing site factors and the cultural activities of man. It requires the judicious choice of a weighting factor and, again, is a data-rather than a model-based procedure.

The computer program for ring-width series standardization, developed by Fritts et al. (1960) contains essentially only exponential and polynomial fitting options, with the straight line as a special case. Indeed, under certain circumstances the exponential fit is rejected and replaced by a straight line. The program is designed to be flexible and thus requires that the investigator choose the specific kind of curve to be fitted, from those available, and that he specify whenever the model changes between one ring-width series and the next. This need for subjective interaction can be looked on from opposite viewpoints. It may appear as a serious inconvenience in the automated processing of a large quantity of tree-ring data. It would certainly be advantageous to have a single physically interpretable and adequately flexible functional form.

In what follows, a method recently developed at the Western Forest Products Laboratory, Forintek Canada Corp., will be outlined. It must be admitted at the outset that the possibility of tracking climatic variation has not been, and probably can never be, eliminated. It is believed, however, that the danger of so doing has been reduced. Also, although, as will be seen from its description, the method has been designed with a view to detecting and tracking growth response due to release, the tests carried out to date suggest that it may well be able to cope, satisfactorily, with the effects of suppression, as might result from an insect infestation. Alternatively, the same type of logic might be employed to extend the program to accommodate this latter phenomenon.

THE MODEL

Our starting point is the more general exponential form $a.x^b$ (-cx), which function, according to Prodan (1968) was noted by Peschel (1938) to have the attributes of an increment function. We generalize slightly to

$$y = a(x\text{-}t)^b \exp[-c(x\text{-}t)]$$

where y is the ring width at time *x* (= 1, 2, 3, ...). The time, *x*, is relative to the start of the record, but the tree may have been growing for several years prior to this; hence the introduction of the term *-t*, which is again measured relative to the start of the record. Thus if the tree were 20 years old at the start of the record, *t* would be set to -20. Then x-t = x- (-20) = x + 20 = age of tree.

The next step is to assume that, if the tree experiences release at time t_i, there is an additive response of the same form as the specified increment function. Thus, in general, the growth for the j^th^ year can be expressed as:

$$y_j = \sum_{i=0}^{n} \delta_{ij}\, a_i\, (x_j - t_i)^{b_i} \exp[-c_i (x_j - t_i)] \quad \begin{cases} \delta_{ij} = 0, x_j \leq t_i \\ \quad\;\; = 1, x_j > t_i \end{cases}$$

where $t_0 < t_1 < t_2$ . . . and i = 0 refers to the initial growth (i.e. at the start of the record) and there are *n* "releases". It is tacitly assumed that the record starts prior to the first release.

The problem now is to estimate the parameters and since, a priori, the number of "releases" is unknown, the number of parameters is also unknown. Before describing our approach to solving this problem, let me make some observations about the form of the growth curve. In general, the shape (a, b, c, >0) is given in Figure 1a. The maximum occurs at $x = t + b/c$. As $b \rightarrow 0$, $(x\text{-}t^b \rightarrow 1$, so that, for $x > t + b/c$, $y \rightarrow a \exp[-c(x\text{-}t)]$. Note that $y = 0$ at $x = t$ so that the form of the curve is then as in Figure 1b. If b is sufficiently small so that $b/c < 1$, then the curve is, effectively, the negative exponential.

On the other hand if $c \rightarrow 0$, then $\exp[-c(x\text{-}t)] \rightarrow 1$ and $y \rightarrow a(x\text{-}t)^b$, (for $x < t + b/c$). Thus, if b = 1, the curve would initially be approximately linear, Figure 1c.

Other situations can be considered; the point is that, particularly over a limited range, the function has great flexibility of form.

ESTIMATION

The basic step in the fitting process is the selection of a time base, N. This has to be chosen judiciously since (1) if N is too small, the resultant curve is liable to follow climatic variations; but (2), if N is too large, the fit will not respond to the "releases". The choice of N will be discussed further below.

We also choose to "linearize" the growth curve by taking logarithms, thus:

$$\ln (y) = z = \tilde{a} + b \ln (x\text{-}t), \ \tilde{a} = \ln (a)$$

Given *t,* the function is linear in the unknown parameters, $\tilde{a}$, b and c, and fitting can be carried out by standard least-squares procedures. The transformation also has the effect of stabilizing the residual variance, particularly in the initial stages where the variance appears to increase with the mean response level and, therefore on theoretical grounds, the transformed analysis would be more appropriate than unweighted nonlinear least squares. The parameter *t* can be estimated iteratively (see below), but in the case of t_0 we have found it preferable to use an external estimate which, with the data used for the development of the method, can generally be determined with sufficient accuracy.

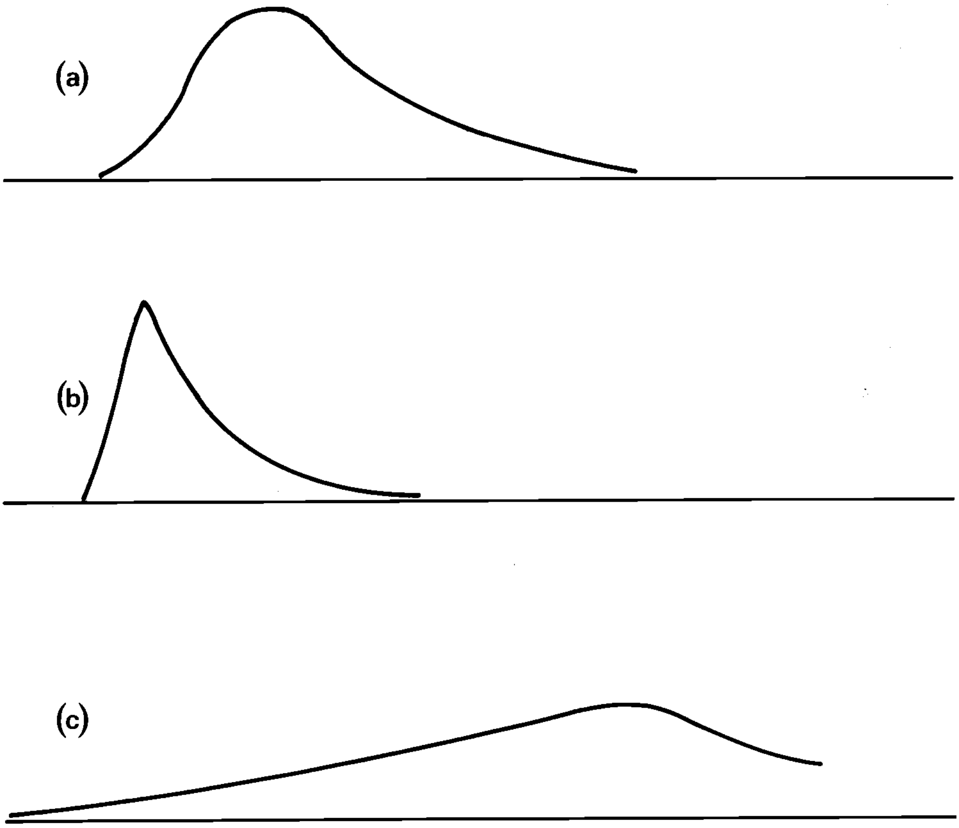


Figure 1. Shapes that may be assumed by the specified increment function.

Hence, given t_0, the parameters $\tilde{a}_0$, b_0, and c_0 are estimated by standard least squares for the first N years of the record. The resulting function is then extrapolated for the next N years, and the residuals obtained. A one-sided "*t*-test" is performed on these residuals; the test is one-sided because our action will be different according to whether the data points fall above or below the extrapolated fit. If the extrapolated line does not fall significantly below the data points, these N points are added to the previous set of the function refitted over the enlarged range. As with the time base, the level of the test has to be chosen judiciously. We have used a 10% level test, and believe it to be reasonable in this context. If the extrapolated line does fall significantly below the data points, it is assumed that a "release" has occurred and the growth curve is then fitted to the residuals.

At this point a difficulty can arise. Although the extrapolated fit may fall significantly below the data points, it is possible for one or more points to fall below the extrapolated fit; i.e. for the residuals to be negative. This prohibits the taking of logarithms. Accordingly, negative residuals are replaced by an arbitrary small positive quantity, but not too small to avoid ridiculously large negative values for the logarithms. This should be a relatively infrequent event and hence the fits not adversely affected by such action. Unfortunately Murphy's law applies, and experience has shown that cases can arise where the number of negative residuals is sufficiently large to upset the fitting process. The number of negative residuals can be reduced by making the *t*-test more stringent. The price, however, is failure to respond to trends which should, perhaps, be followed. Accordingly, prior to carrying out the *t*-test, the number of negative residuals is obtained and if this exceeds a specified fraction, F, of N, the number of points in the time base, the *t*-test is not performed and the option of fitting over the extended time base is exercised. The choice $F = N/3$ has been found satisfactory.

When the option of an additive component fitted to the residuals is employed, the parameter t_i is estimated iteratively. One proceeds through the sequence $t_i = 0, -1, -2, -3, \ldots$ (i.e. extending the time base in the reverse direction) until the residual mean square ceases to be reduced. The fit to the residuals is then added to the old function, and the result extrapolated to the next time period. The process is repeated until the data are exhausted.

Since the total record is not necessarily a multiple of N, the testing and fitting process is performed only if justified by the number of points remaining. If there are too few such (presently taken as less than 5), the fit to data is simply extended to cover them.

Note that, if at any stage the estimate of c_i is negative, it is replaced by an arbitrarily small quantity (currently 0.000001) and the system resolved for $\tilde{a}_i$ and b_i. Likewise, if the estimate of b_i is negative, it is replaced by an arbitrarily small value and the system resolved for $\tilde{a}_i$ and c_i. Note also that, if the initial estimate of b_i is negative, the estimate for c_i is necessarily positive.

Sometimes this process, which is an attempt to mimic what is going on in nature, results in a rather sharp transition (Figure 2a). This may occur, for example, if, during the estimation of a t_i, the minimum residual mean square corresponds to a small value for the estimate of b_i (although if the time base were extended even further back, one might find a second minimum resulting in a smoother transition).

The simplest means of mollifying, if not actually eliminating this feature, is to smooth the resulting fit. Indications are that third-order 7-point smoothing is reasonable. This has no effect on the already smooth points of the fit, but reduces the sharp transitions (Figure 2b).

From the practical point of view, with respect to the resulting indices (ratio of observed to fitted widths) or the intercorrelation of these indices (or the residuals) or their correlation with external factors, such as climatic variables, the effect of the smoothing procedure would be inconsequential. Its main purpose is, therefore, simply cosmetic.

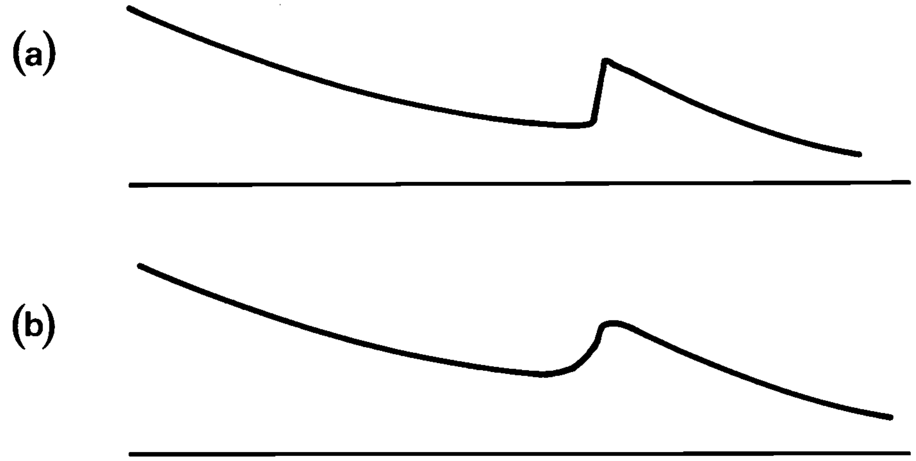


Figure 2. Smoothing sharp transitions in the estimated trend.

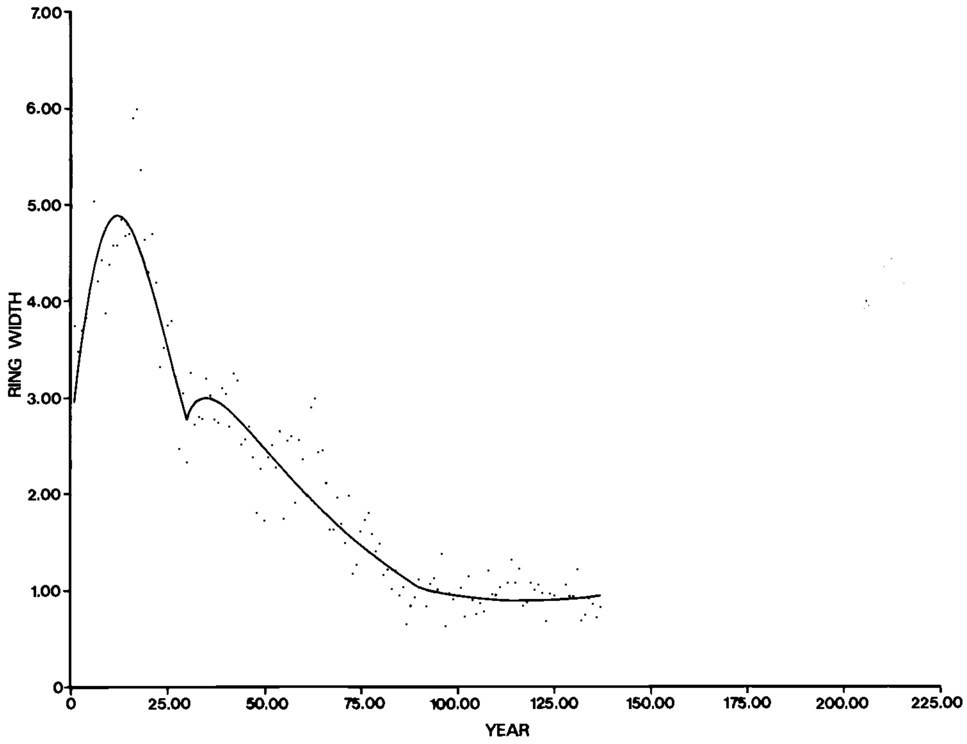
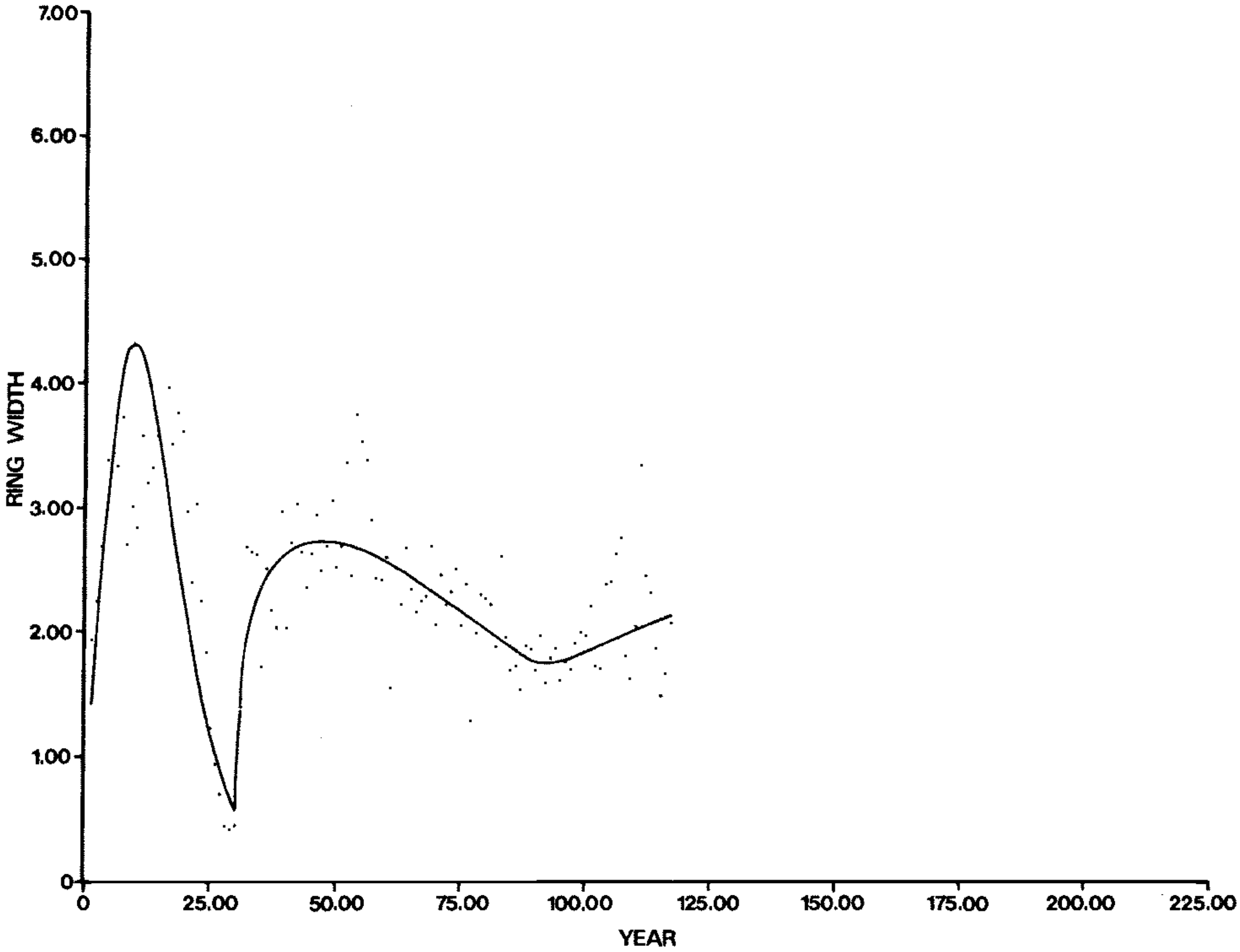
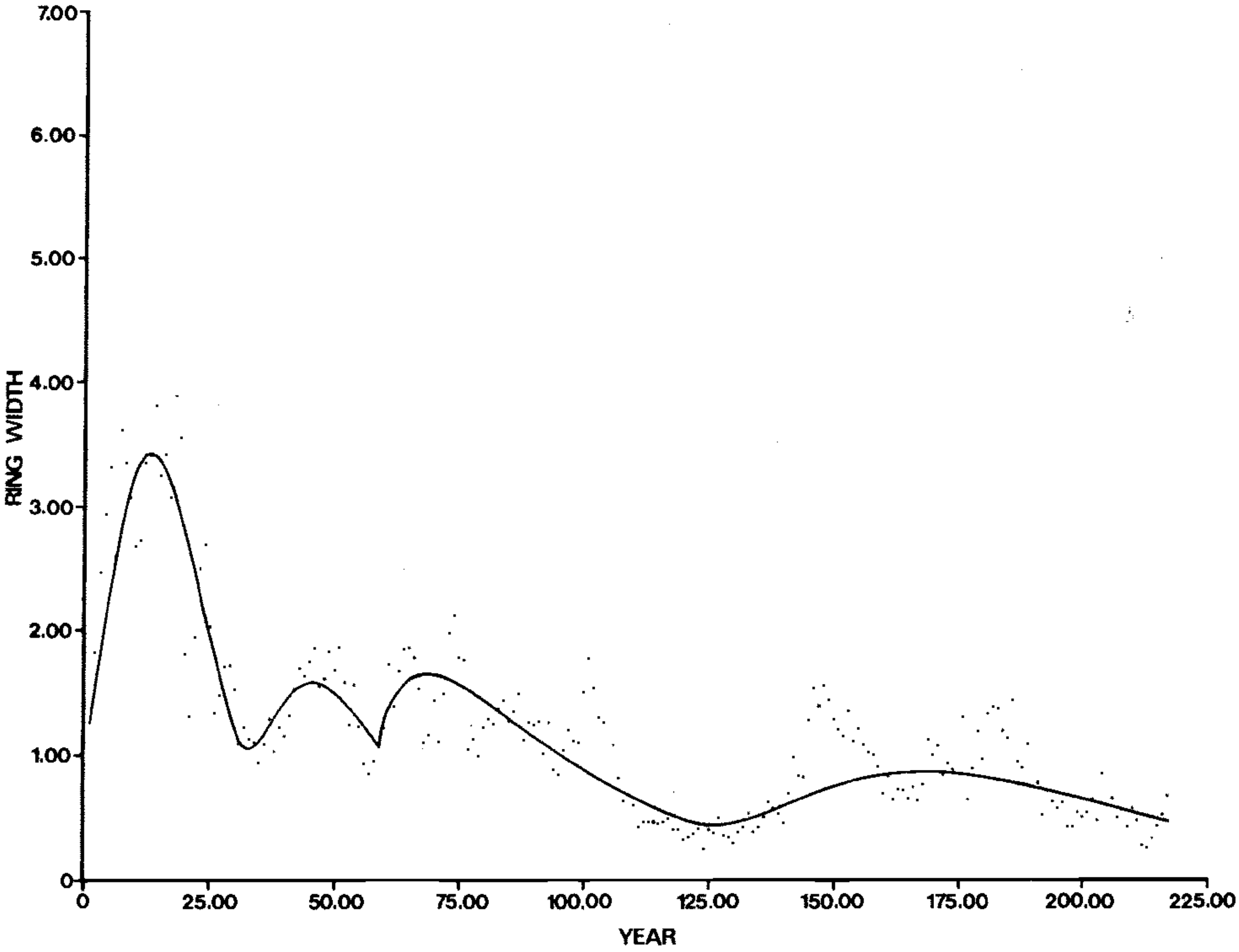


Figure 3 to 5. Examples of the fits to actual data obtained by the proposed method.



RING WIDTH
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0
0
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
225.00
YEAR



RING WIDTH
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0
0
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
225.00
YEAR

TESTS

Of the several "parameters" of the system, the time base, N, is believed to be the most critical. Data from 10 cores, which exhibit the range of characteristics encountered in a current study (single species, single watershed but three different sites), were fitted by the above method with time bases of 20, 25, 30, 35 and 40 years. For each tree, the five resulting plots (data points plus fitted curve) were scored by three interested people. The plots carried randomized code numbers, so that the scorer was unaware of the time base underlying each plot.

The longer time bases tended to be favored by two of the scorers. Although the 40-year base commonly received the best score from these individuals, there were also instances where they rated it as very poor. The other scorer tended to favor the shorter time bases but, again, sometimes gave these very poor scores. All three, although rarely scoring the 30-year base as best, consistently rated it as nearly best. Its overall score was, therefore, high with low variability. The 30-year base is thus regarded as the best compromise, at least for these data.

Plots obtained by using the 30-year base are given in Figures 3 to 5. For comparison the fits obtained by use of exponential and polynomial options of the Laboratory of Tree-Ring Research's program, for the last case, are given in Figure 6 and 7. The smoothing option had not been incorporated in our program at the time these were generated.

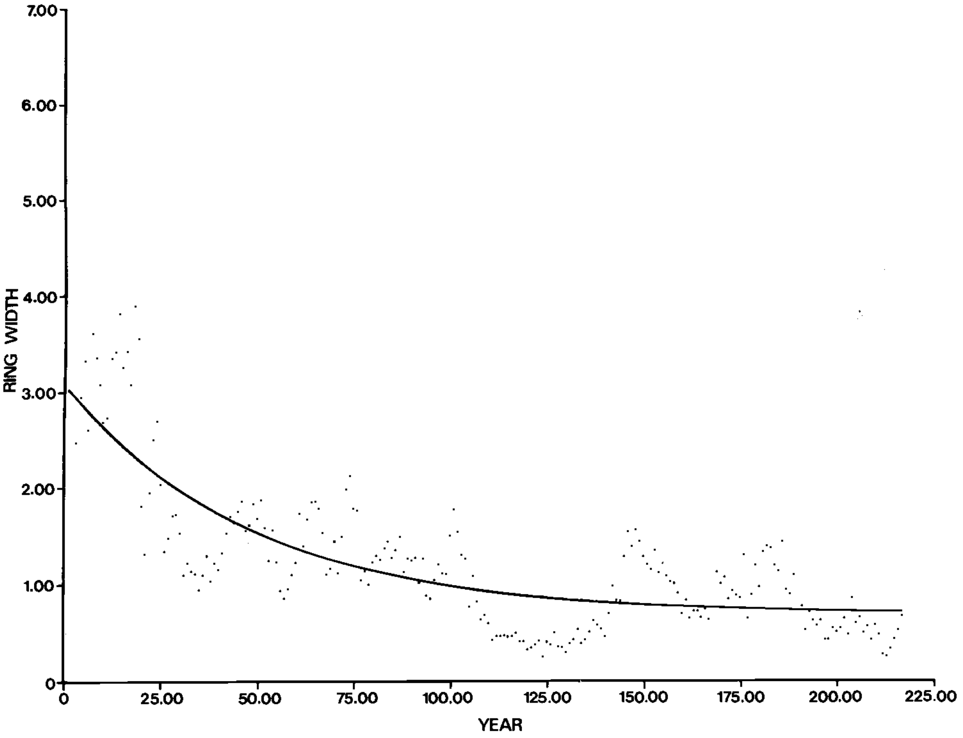


Figure 6. The negative exponential fit to the data of Figure 5.

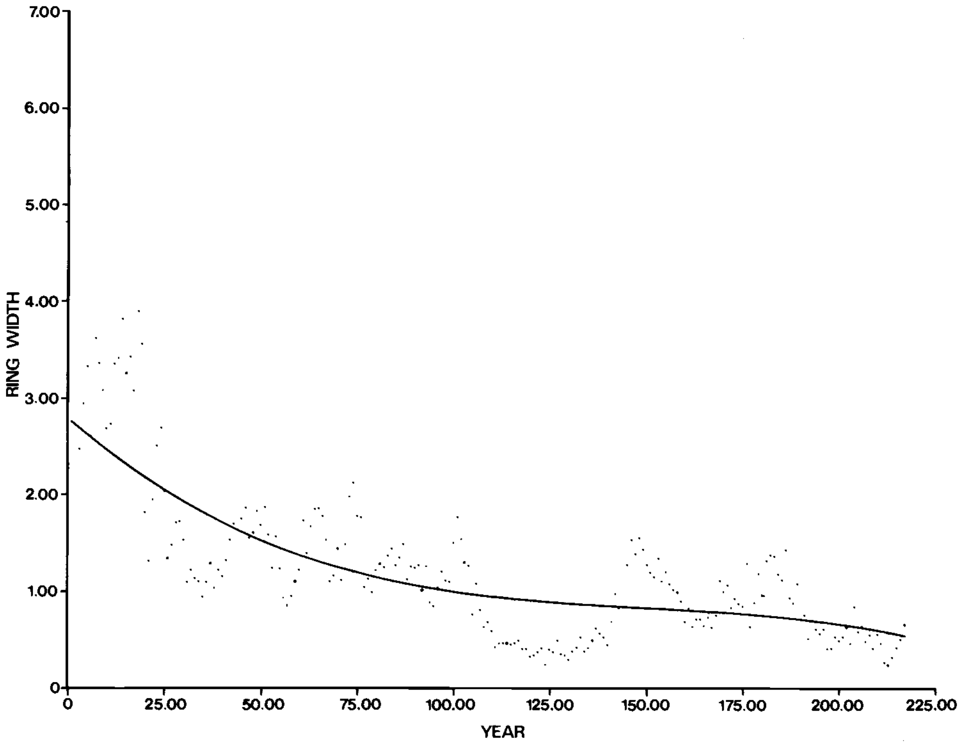


Figure 7. The polynomial fit to the data of Figure 5.

DISCUSSION

The next stage in testing, which is currently proceeding and should soon be reported, is to cross correlate the indices obtained by the proposed method and compare these correlations with those obtained by other methods. Heuristically, it can be argued that the stronger the correlation between indices (or residuals), the more likely that they are associated with common environmental changes, especially climatic fluctuations. The final stage will be the correlation with weather records and here, again, we shall be looking for a stronger level of association than has previously been reported.

There is no reason to suppose that the 30-year base would be uniformly best. A different value may well be better suited to different species and/or different regions. We presently envisage analyzing, along the lines outlined above, a representative sample from the data of a specific study and choosing, on the basis of this, the time base that appears most suited to the particular material, and then apply that value routinely to the remainder of the data.

It is not our intent to pretend that this method is perfect; it is likely that no perfect solution to this problem exists. It does, however, appear to accommodate, in a reasonable manner, the characteristics and difficulties in growth trend patterns that we have encountered. We feel that it is potentially superior to the currently available alternatives. It is unlikely to be our last word on the topic, but it forms what we believe is a sound basis onto which we can build further.

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EIGHT MODERN OAK CHRONOLOGIES FROM ENGLAND AND SCOTLAND

JON R. PILCHER and MICHAEL G. L. BAILLIE

Palaeoecology Centre
The Queen's University of Belfast, Northern Ireland.

ABSTRACT

Eight modern oak tree-ring chronologies are presented in index form. The sites are in Scotland and England. Chronology statistics including signal-to-noise ratios are presented, the latter ranging from 3.6 to 13.2. From calculations of response functions, the percent variance attributable to climate over a 14 month period before and including the growing season was found to range from 33 to 72%. Classical criteria of site selection were shown to bear little relation to the final variance due to climate in the chronology.

Huit chronologies de chenes modernes sont présentées sous la forme d'indices. Les sites sont en Ecosse et en Angleterre. Les statistiques des chronologies, incluant les rapports entre signal et bruit de fond, sont présentées (ces derniers varient de 3,6 à 13,2). Des calculs de fonctions de réponses, il apparait que le pourcentage de variance attribuable au climat des 14 mois précédant et couvrant la saison de croissance, varie de 33 à 72%. Les critères classiques concernant la sélection des sites ne montrent que peu de relation avec la variance finale due au climat présentée par la chronologie.

Es werden acht Jahrringchronologien rezenter Eichen aus Schottland und England in Indexform einschließlich ihrer statistischen Parameter vorgestellt. Die Signal-Rausch-Verhältnisse reichen von 3.6 bis 13.2. Die klimatisch verursachten Varianzanteile, die mit Hilfe des Response-function-Verfahrens für eine Periode von 14 Monaten vor und während der Vegetationszeit berechnet wurden, betragen 33 bis 72%. Die klassischen Kriterien für die Standortsauswahl zeigen eine nur geringe Beziehung zur klimatisch bedingten Varianz der Chronologien.

INTRODUCTION

The first replicated modern tree-ring site chronology from the British Isles was published in 1976 (Pilcher 1976) and the first response functions in 1978 (Hughes et al. 1978). At this time there were still only three single site, index, modern oak tree-ring chronologies from the British Isles. There was clearly a need to increase this number substantially if the dendroclimatic analysis anticipated in the Hughes paper was to be realized. This paper presents eight new chronologies from England and Scotland; elsewhere in this volume we present six new chronologies from Ireland. Our intention in publishing the chronologies is to make them available to those who may wish to attempt dendroclimatic analysis and to illustrate both the potential and the limitations of the material available for dendroclimatology in the British Isles.

THE SITES

There is very little natural oak forest or woodland in the British Isles and probably none that has not been extensively disturbed by man. In planning our sampling our intention was to find sites not closer than 50 miles (80 km) and not further than 100 miles (160 km) apart. Within these limitations we tried to find oak trees of reasonable age. Where possible we chose woodland rather than parkland. Several of the sites are

Table 1. Sampling details for eight chronologies from England and Scotland.

SITE	LATITUDE	LONGITUDE	ALTITUDE (m)	NO OF CORES	SITE TYPE
Glenluce	54°53'	4°50'W	20	14	Small wood near abbey + trees from riverside
Raehills	55°14'	3°28'W	155	20	Planted woodland on slope
Lockwood	55°16'	3°26'W	175	16	Relict woodland on slope
Scorton	53°56'	2°45'W	50	15	Planted woodland
Oxford (1)	51°48'	1°07'W	70	10	Small group of trees, boggy ground
Oxford (2)	51°49'	1°10'W	60	5	Open farmland on edge of old bog
Blickling	52°49'	1°13'E	40	13	Open farmland
Bath	51°22'	2°19'W	45	14	Hazel coppice with oak
Ludlow	52°21'	2°44'W	185	15	Open woodland/parkland

clearly far from ideal in that site conditions have probably changed markedly during the life of the trees. It is also true that subsequent analysis has shown that more cores would have been advantageous. In spite of these limitations all the sites have been included as they represent the best available at present. Site locations are given in Table 1 below.

SAMPLING

Sampling was by Swedish increment borer of 7 mm diameter. One of us has published previously in this journal a limitation of some 16 cm penetration of these borers in oak (Pilcher 1976). More recently we have found that by backing off the borer by a quarter turn for every full turn into the wood, the build-up of deposits is reduced and cores at least as long as 40 cm (our longest borer at present) can be safely obtained. Beeswax is used as a lubricant applied to the hot borer on withdrawing it from the tree. In our early work at Rostrevor (Pilcher 1976) and at Raehills where two cores per tree were used, the analysis of variance suggested that between core variation was small in oak. Greater benefit therefore derives from sampling more trees rather than more cores. Also as ring identification problems (missing or double) are very rare in oak, a second core is not needed to assist with crossdating as can be the case with conifers. As much of this work was a shoe-string exploratory operation, most of the chronologies fall below the desirable minimum of 20 trees per site (see below).

MEASUREMENT AND ANALYSIS

In common with our usual practice the cores were measured and were then crossdated using the plotted ring widths. Crossdating using the signature years on the wood does not work reliably on European oak. When crossdating was completed and dates assigned to each core, the measurements were converted to indices using the polynomial curve fit option of the INDXA computer package supplied by the Laboratory of Tree-Ring Research in Tucson. The indices of individual cores were averaged to form the site chronologies presented here. In the process of forming the chronologies, various statistics describing the chronologies were derived and these are presented in Table 2. The chronologies themselves are listed in Table 3. An analysis of variance was carried out both on the raw data and on the indices. The former highlights consistency or inconsistency in trends in the raw data. If indexing is doing its job the percent variance in common to the index series should be higher than that in common to the raw data series (see Table 2).

A further measure of the homogeneity of the series is provided by the cross-correlation results. These are given as the mean R between trees and also as the mean R of individuals against the master chronology. It has frequently been the case with this oak material that one or two cores (about 5% of the total) show very poor cross-correlation results. Visual inspection shows that the cores are correctly dated and in fact may show good quality crossdating. This anomaly seems to be due to the preservation of medium term trends (perhaps 20 – 40 years) in the indicies that are not common to all trees. While our inclination would be kept such trees in the chronology for dating purposes we have removed them from the chronologies presented here, as they probably do not contribute to a 'good' climate chronology.

An additional figure recently found useful in chronology assessment is the signal-to-noise ratio calculated from the percent variance in common and the number of

Table 2. Chronology statistics for eight oak chronologies from England and Scotland.

Site	No. of trees	No. of cores	Start year	Start for 10 trees	End year	Number of years	Mean width (mm)	Standard deviation	Mean sensitivity	Serial correlation	ANALYSIS OF VARIANCE				Mean R bet. trees	Mean R with chron.	Signal-to-noise ratio	Percent climate
											RAW DATA		INDICES					
											% Var. Y	% Var. YT	% Var. Y	% Var. YT				
GLENLUCE	15	1	1798	1886	1978	181	1.55	0.22	0.18	0.47	17.8	82.2	20.3	79.7	0.29	0.54	3.56	72
RAEHILLS	10	2	1824	1855	1975	152	2.19	0.26	0.18	0.61	37.9	62.1	23.0	77.0	0.30	-	6.11	61
LOCKWOOD	16	1	1571	1780	1975	405	0.93	0.24	0.17	0.60	18.0	82.0	19.5	80.5	-	-	3.63	38
SCORTON	15	1	1813	1869	1978	166	1.77	0.29	0.21	0.68	54.4	45.6	31.0	69.0	0.39	0.62	6.75	33
OXFORD (mean)	16	1	1781	1857	1978	198	1.79	0.23	0.21	0.36	49.0	51.0	45.3	54.7	0.50	0.68	13.24	52
BLICKLING	13	1	1717	1797	1978	263	1.43	0.29	0.18	0.66	19.98	80.1	37.5	62.5	0.43	0.66	7.79	40
BATH	14	1	1754	1885	1978	266	1.41	0.32	0.24	0.49	28.5	71.5	37.3	62.7	0.40	0.64	8.32	43
LUDLOW	15	1	1825	1836	1978	150	2.07	0.22	0.19	0.44	58.6	41.4	39.9	60.1	0.47	0.69	9.97	56
MEAN VALUES						223	1.64	0.26	0.195	0.54	35.5	64.5	31.7	68.3	0.40	0.64	7.4	49.4
MEAN Eastern U.S.A.								0.24	0.175	0.496			28.9	71.1				
	DeWitt and Ames 1978																	
Mean Western U.S.A.								0.38	0.365	0.415		c.	60.0	40.0				

trees (Cropper, in press). The figure of 15:1 commonly found in the semi-arid southwestern U.S.A. sites has been suggested as a standard to aim at in other more mesic areas. DeWitt and Ames (1978) show that 35 to 40 trees would need to be sampled in most eastern United States sites to reach this level, and the same would be true at least at some of the less good sites here. However, as pointed out by Cook (in press) there may be an advantage in using more sites with a low signal-to-noise ratio for a climate reconstruction grid rather than trying to improve individual sites. This would certainly be true in an area where human disturbance at individual sites is suspected. In this case more sites would be needed to iron out the effects of low frequency 'noise' that is preserved in the chronologies. Obviously the ideal would be the highest quality of chronologies from a dense grid of sites, but the realities of research force some compromise.

The final column of Table 2 gives the percent variance accounted for by climate (temperature and precipitation for a 14-month period before and including the growing period). These figures are calculated as described in Fritts (1976) by the response function method. The response function results will be discussed in detail elsewhere. The figures of percent variance due to climate show a similar range to that shown previously in Europe (e.g. Hughes et al. 1978, 34% – 64%; Schmidt 1977, 10% – 38%).

CONCLUSIONS

Two main points are clear from this work. Firstly the tree-ring series from British Isles oak contain a good climate signal. However the length of possible tree-ring records from living trees is short in most areas. Most easily available woodlands do not extend to before A.D. 1800 and to produce a well replicated series of chronologies back to A.D. 1700 will pose formidable problems.

The second point is that neither our subjective assessment of site quality (based on criteria such as slope, disturbance, tree shape, etc.) nor the chronology statistics seem to bear any relationship to the 'climate content' of the final chronology. Certainly the site criteria that apply in the semi-arid southwestern United States do not seem to apply to oak in Europe. An explanation of this may lie in the nature of the climate response. Oak is not at its distribution limits in the British Isles except in northern Scotland. It is not normally under any severe stress from a single climate factor such as drought. If we choose trees that show obvious signs of stress we may be selecting trees that are suffering a non-climatic stress. Evidence for this idea could be derived from the data in Table 2 where it can be seen that two sites with a high climate content are those with the greatest mean ring width. However when all available response functions for oak in the British Isles are examined (Gray, pers. comm.), it is clear that there is no systematic relationship between ring width and climate content. We can say therefore that wide ringed trees are not *necessarily* 'poor quality' from the point of view of the dendroclimatologist and can have a percent variance due to climate at least as high as obviously stressed trees.

ACKNOWLEDGEMENTS

Keith Briffa helped to core the Blickling site, Elizabeth Francis measured and processed the Blickling and Bath sites. Elizabeth Halliday measured and processed the Glenluce site. John Cropper of the Laboratory of Tree-Ring Research in Tucson provided the analysis of variance programs. Barbara Gray of the Climate Research Unit in Norwich calculated the response functions. To all these and to the site owners, the authors wish to express their thanks.

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Table 3a. Glenluce oak chronology

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1798									173	202									1	1
1800	150	96	83	60	87	96	121	115	120	152	1	2	2	2	2	2	2	2	2	2
1810	113	153	115	120	126	109	81	68	112	117	2	2	2	2	2	2	2	2	2	2
1820	92	70	96	98	95	92	72	62	56	83	2	2	2	2	2	2	2	2	2	2
1830	81	84	107	132	126	107	86	65	67	79	2	2	2	2	2	2	2	2	2	2
1840	63	68	69	75	81	84	87	83	80	74	2	2	2	2	2	2	2	2	2	2
1850	101	83	77	102	94	101	76	89	97	121	2	2	2	2	2	2	3	4	4	4
1860	108	100	104	71	87	125	116	118	74	81	4	4	4	4	5	5	6	7	7	7
1870	113	115	149	122	114	130	117	100	106	126	7	7	7	7	7	7	7	7	7	7
1880	78	104	120	124	86	85	109	82	95	75	8	8	8	9	9	9	10	10	10	10
1890	137	94	129	89	72	94	152	113	89	102	10	12	12	12	12	12	12	12	12	12
1900	133	105	98	139	105	75	98	85	88	81	12	12	12	13	13	13	13	13	13	13
1910	97	96	116	75	78	97	108	101	97	84	13	13	13	13	13	13	13	14	14	14
1920	90	93	104	74	101	77	87	87	80	111	14	14	14	14	14	14	14	14	14	14
1930	98	115	106	115	113	102	127	100	70	97	14	14	14	14	14	14	14	14	14	14
1940	100	131	97	85	96	89	103	146	105	76	14	14	14	14	14	14	14	14	14	14
1950	124	115	110	102	108	109	89	96	112	104	14	14	14	14	14	14	14	14	14	14
1960	97	78	91	90	109	96	90	95	107	128	14	14	14	14	14	14	14	14	14	14
1970	105	118	84	80	93	95	70	95	93		14	14	14	14	14	14	14	14	14	14

Table 3b. Raehills oak chronology.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1824					49	106	69	91	61	92					2	4	6	11	13	15
1830	84	119	103	125	154	168	143	120	101	94	16	17	17	17	17	17	19	19	19	19
1840	97	63	64	55	31	43	94	73	69	69	19	19	19	19	19	19	19	19	19	19
1850	78	85	94	103	88	111	103	126	145	165	19	19	19	19	19	20	20	20	20	20
1860	120	118	112	92	90	112	96	89	91	101	20	20	20	20	20	20	20	20	20	20
1870	128	115	120	113	99	115	103	101	89	88	20	20	20	20	20	20	20	20	20	20
1880	70	52	54	48	67	58	71	109	105	116	20	20	20	20	20	20	20	20	20	20
1890	161	139	163	137	83	94	142	146	101	139	20	20	20	20	20	20	20	20	20	20
1900	135	102	62	104	117	96	106	69	92	74	20	20	20	20	20	20	20	20	20	20
1910	91	127	89	84	113	97	102	108	111	118	20	20	20	20	20	20	20	20	20	20
1920	104	124	109	100	97	90	73	70	56	76	20	20	20	20	20	20	20	20	20	20
1930	72	69	77	125	108	68	109	90	81	121	20	20	20	20	20	20	20	20	20	20
1940	112	108	104	104	98	99	101	122	81	90	20	20	20	20	20	20	20	20	20	20
1950	110	96	124	117	100	126	95	93	111	155	20	20	20	20	20	20	20	20	20	20
1960	120	106	169	131	132	93	99	92	104	102	20	20	20	20	20	20	20	20	20	20
1970	91	81	70	82	84	131					20	20	20	20	20	20				

Table 3c. Lockwood oak chronology.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1571		49	32	55	48	68	123	144	82	127		1	1	1	1	1	1	1	1	1
1580	137	101	62	155	152	140	193	126	113	163	1	1	1	1	1	1	1	1	1	1
1590	137	128	151	198	155	123	93	102	96	97	1	1	1	1	1	1	1	1	1	1
1600	106	79	107	160	179	158	139	169	141	142	1	1	1	1	1	1	1	1	1	1
1610	95	96	65	51	49	89	57	57	79	85	1	1	1	1	1	1	1	1	1	1

(continued on next page)

Table 3c. Lockwood oak chronology. *(continued)*

1620	95	91	87	60	73	68	104	62	70	159	1	1	1	1	1	1	1	1	1	1
1630	105	87	117	102	103	60	58	86	120	65	1	1	1	1	1	1	1	1	1	1
1640	82	120	75	96	140	82	71	84	66	36	1	1	1	1	1	1	1	1	1	1
1650	43	37	72	92	89	96	71	103	96	89	1	1	2	2	2	2	2	2	2	2
1660	111	90	98	115	125	117	109	94	96	151	2	2	2	2	2	2	2	2	2	2
1670	161	140	167	127	106	102	106	121	104	98	2	2	2	2	2	2	2	2	2	2
1680	101	81	104	74	99	63	89	91	86	68	2	2	2	2	2	2	2	2	2	2
1690	56	58	57	71	97	85	98	96	90	65	2	2	2	2	4	4	4	4	4	4
1700	51	71	81	118	106	101	82	125	111	87	4	4	4	4	4	4	4	4	4	4
1710	62	83	85	92	110	84	68	105	86	131	4	4	4	4	4	4	5	6	6	6
1720	95	93	97	106	102	85	97	146	108	133	6	6	6	7	7	7	7	7	7	7
1730	113	141	95	102	85	77	76	96	95	95	7	7	7	7	7	7	7	7	7	7
1740	98	99	80	105	116	95	124	123	78	74	7	7	7	9	9	9	9	9	9	9
1750	78	88	92	103	115	100	103	108	117	127	9	9	9	9	9	9	9	9	9	9
1760	114	104	123	142	130	123	112	95	109	93	9	9	9	9	9	9	9	9	9	9
1770	81	92	133	120	106	78	89	81	80	126	9	9	9	9	9	9	9	9	9	9
1780	117	109	116	115	100	93	89	70	80	102	10	10	10	10	11	11	11	11	11	11
1790	101	103	96	75	81	66	63	78	84	105	11	11	11	11	11	11	11	11	11	11
1800	105	86	80	79	92	103	106	107	117	90	11	11	11	11	11	12	12	12	12	12
1810	96	112	106	122	112	107	93	82	121	102	12	12	12	12	12	12	12	12	12	12
1820	79	78	87	104	93	108	89	119	111	134	12	12	12	12	13	13	13	13	13	13
1830	123	127	113	105	141	141	115	99	95	92	13	13	14	14	14	14	14	14	14	14
1840	68	86	105	117	94	110	133	131	126	121	14	15	15	15	15	15	15	15	15	15
1850	130	104	118	103	106	116	100	98	115	110	15	15	15	15	15	15	15	15	15	15
1860	100	105	87	72	84	98	83	66	77	79	15	15	15	15	15	15	15	15	15	15
1870	102	84	100	88	87	88	93	91	90	94	15	15	15	15	15	15	15	15	15	15
1880	73	85	70	73	87	102	115	126	93	86	15	16	16	16	16	16	16	16	16	16
1890	129	102	126	97	91	69	77	94	82	105	16	16	16	16	16	15	15	15	15	15
1900	106	113	92	115	134	108	108	76	85	87	15	15	15	15	15	15	15	15	15	15
1910	96	117	116	121	139	134	128	132	104	91	15	15	15	15	15	15	15	15	15	15
1920	69	99	102	96	92	85	88	86	63	82	15	15	15	15	15	15	15	15	15	15
1930	94	90	76	101	119	111	110	116	98	93	15	15	15	15	15	15	15	15	15	15
1940	100	105	70	74	80	79	82	116	87	97	15	14	14	14	14	14	14	14	14	14
1950	121	92	109	105	87	102	80	74	93	97	14	14	14	14	14	14	14	14	14	13
1960	104	102	112	99	108	89	92	109	92	101	13	13	12	12	12	11	11	11	11	11
1970	96	113	120	113	87	123					11	10	10	7	4	4				

Table 3d. Scorton oak chronology.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1813				131	125	114	64	40	92	133				1	1	1	1	1	1	1
1820	64	53	69	58	35	34	57	76	73	131	1	1	1	1	1	1	1	1	1	1
1830	103	133	155	141	158	166	153	144	137	85	1	1	1	1	2	2	2	2	2	2
1840	37	12	16	15	19	35	44	92	132	132	2	2	2	2	2	2	2	2	2	2
1850	141	115	110	138	171	129	106	142	118	141	2	2	2	2	2	2	2	2	2	3
1860	105	83	113	86	122	113	105	90	73	89	3	3	3	3	6	6	7	8	8	11
1870	106	130	104	106	91	121	102	75	72	84	11	11	11	11	11	13	13	13	13	13
1880	106	104	112	102	125	95	130	89	118	103	13	13	13	13	14	14	15	15	15	15
1890	130	95	97	82	95	117	124	105	67	94	15	15	15	15	15	15	15	15	15	15
1900	107	101	87	92	95	90	82	73	85	74	15	15	15	15	15	15	15	15	15	15
1910	88	118	100	86	87	94	96	102	71	53	15	15	15	15	15	15	15	15	15	15
1920	51	115	125	95	114	107	103	137	127	112	15	15	15	15	15	15	15	15	15	15
1930	119	111	114	103	128	130	144	103	84	110	15	15	15	15	15	15	15	15	15	15
1940	95	94	70	79	116	91	73	84	72	90	15	15	15	15	15	15	15	15	15	15
1950	104	111	107	121	78	91	77	73	98	127	15	15	15	15	15	15	15	15	15	15
1960	148	99	135	120	119	98	114	127	96	101	15	15	15	15	15	15	15	15	15	15
1970	83	90	93	108	123	102	79	113	105		15	15	15	15	15	15	15	15	15	

Table 3e. Oxford oak chronology.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1781		74	127	98	151	65	74	108	99	130		1	1	1	1	1	1	1	1	1
1790	103	85	97	55	58	94	81	115	72	83	1	1	1	1	1	1	1	1	1	1
1800	61	53	78	65	90	95	113	104	58	32	1	1	1	1	1	1	1	1	1	1
1810	51	55	64	79	49	65	63	100	78	75	1	1	1	1	1	1	1	2	2	2
1820	77	82	116	114	150	76	70	105	111	138	2	2	2	3	3	3	3	3	3	4
1830	151	86	109	86	111	111	115	115	94	119	4	4	4	4	4	4	4	4	4	5
1840	102	119	91	83	51	74	83	117	94	107	5	5	5	5	5	5	5	6	6	6
1850	93	110	82	133	70	80	100	90	84	85	6	6	6	7	8	8	9	11	11	11
1860	117	102	112	106	102	126	134	130	94	124	12	12	12	14	14	14	15	15	15	15
1870	89	117	139	125	76	135	106	111	130	127	15	15	15	15	15	15	15	16	16	16
1880	93	77	88	92	87	73	92	75	81	85	16	16	16	16	16	16	16	16	16	16
1890	91	83	92	73	89	107	100	111	87	88	16	16	16	16	16	16	16	16	16	16
1900	126	110	80	114	128	94	96	110	112	100	16	16	16	16	16	16	16	16	16	16
1910	121	97	114	125	106	106	83	140	94	71	16	16	16	16	16	16	16	16	16	16
1920	66	55	103	86	100	120	144	131	106	109	16	16	16	16	16	16	16	16	16	16
1930	95	113	91	82	47	82	103	109	75	143	16	16	16	16	16	16	16	16	16	16
1940	101	94	73	69	50	114	114	122	97	92	16	16	16	16	16	16	16	16	16	16
1950	107	95	78	107	87	84	95	87	113	108	16	16	16	16	16	16	16	16	16	16
1960	117	97	117	102	107	109	118	143	116	96	16	16	16	16	16	16	16	16	16	16
1970	87	95	77	106	99	101	56	112	104		16	16	16	16	16	16	16	16	16	

Table 3f. Blickling oak chronology.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1717								81	121	96								1	1	1
1720	97	85	48	111	141	172	45	30	64	91	1	1	1	1	1	1	1	1	1	1
1730	29	31	17	17	9	39	34	35	147	149	1	1	1	1	1	1	1	1	1	1
1740	108	84	70	124	143	183	175	129	101	107	2	2	2	2	2	3	3	3	3	3
1750	82	127	127	100	113	78	93	116	125	130	3	4	5	5	5	6	6	6	6	7
1760	96	95	102	120	128	141	95	99	127	112	8	8	9	9	9	9	9	9	10	10
1770	104	94	103	85	70	103	116	118	109	78	10	10	10	10	10	10	11	11	11	11
1780	85	67	92	90	91	90	89	119	124	108	11	11	11	11	11	12	12	12	12	12
1790	102	95	92	82	71	73	66	109	115	88	12	12	12	12	12	12	12	13	13	13
1800	95	62	60	56	78	87	81	72	88	81	13	13	13	13	13	13	13	13	13	13
1810	113	114	108	108	99	87	91	92	108	113	13	13	13	14	14	14	14	14	14	14
1820	117	102	104	111	109	108	101	98	115	122	14	14	14	14	15	15	15	15	15	15
1830	134	132	92	114	130	103	108	114	86	95	15	15	15	15	15	15	15	15	15	15
1840	49	85	113	94	72	99	144	143	141	151	15	15	15	15	15	15	15	15	15	15
1850	129	142	106	109	88	88	92	114	110	98	15	15	15	15	15	15	15	15	15	15
1860	87	110	98	90	86	93	85	100	109	96	15	15	15	15	15	15	15	15	15	15
1870	117	124	98	92	59	67	73	83	98	106	15	16	16	16	16	16	16	16	16	16
1880	80	86	88	82	102	99	103	95	70	66	16	16	16	16	16	16	16	16	16	16
1890	92	94	138	112	105	93	83	79	80	85	16	16	16	16	16	16	16	16	16	16
1900	119	108	107	119	125	109	101	94	97	68	16	16	16	16	16	16	16	16	16	16
1910	81	103	107	143	119	117	122	171	163	137	16	16	16	16	16	16	16	16	16	16
1920	130	111	127	121	137	111	102	109	111	134	16	16	16	16	16	16	16	16	16	16
1930	83	81	60	67	71	86	99	123	79	78	16	16	16	16	16	16	16	16	16	16
1940	67	65	87	74	72	110	80	118	83	49	16	16	16	16	16	16	16	16	16	16
1950	81	70	95	118	110	103	87	74	115	96	16	16	16	16	16	16	16	16	16	16
1960	104	106	127	106	131	121	133	119	109	101	16	16	16	16	16	16	16	16	16	16
1970	104	115	90	97	90	104	94	87	118	76	16	16	16	16	16	16	16	16	16	16

Table 3h. Ludlow oak chronology.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1825						90	57	85	98	119						3	3	3	4	4
1830	132	149	118	137	137	119	100	119	72	90	5	7	8	9	9	9	10	10	10	10
1840	62	91	107	96	57	87	93	58	53	96	10	10	10	10	10	10	10	10	10	11
1850	117	147	133	128	99	115	100	142	115	133	12	14	14	14	14	15	15	15	15	15
1860	104	158	116	73	50	70	72	88	94	74	15	15	15	15	15	15	15	15	15	15
1870	81	88	98	108	77	122	79	89	110	100	15	15	15	15	15	15	15	15	15	15
1880	100	68	67	83	89	86	79	69	78	72	15	15	15	15	15	15	15	15	15	15
1890	90	125	158	132	85	128	93	113	90	96	15	15	15	15	15	15	15	15	15	15
1900	118	115	99	120	117	91	94	100	130	89	15	15	15	15	15	15	15	15	15	15
1910	123	98	111	116	110	96	94	99	118	98	15	15	15	15	15	15	15	15	15	15
1920	129	122	101	78	82	95	89	89	97	126	15	15	15	15	15	15	15	15	15	15
1930	111	86	104	105	123	107	98	98	102	118	15	15	15	15	15	15	15	15	15	15
1940	85	63	63	91	69	118	88	136	79	66	15	15	15	15	15	15	15	15	15	15
1950	81	83	97	96	90	103	75	69	112	105	15	15	15	15	15	15	15	15	15	15
1960	116	84	102	131	135	103	130	117	104	105	15	15	15	15	15	15	15	15	15	15
1970	110	121	95	106	73	85	79	107	124		15	15	15	15	15	15	15	15	15	

Table 3g. Bath oak chronology.

	Tree Ring Indices										Number of Samples									
Year	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1754					51	42	68	59	63	79					2	2	2	2	2	2
1760	88	85	57	134	150	139	202	116	130	96	2	2	2	2	2	2	2	2	2	2
1770	115	74	89	158	197	140	109	129	102	87	2	2	2	2	2	2	2	2	2	2
1780	117	130	173	195	264	68	50	33	42	86	2	2	2	2	2	2	2	2	2	2
1790	75	87	135	73	95	82	44	59	52	76	2	2	2	2	2	2	2	2	2	2
1800	64	75	68	63	75	110	115	140	121	114	2	2	2	2	2	2	2	2	2	2
1810	68	54	75	67	80	67	103	108	86	141	2	2	2	2	2	2	2	2	2	2
1820	130	123	90	129	127	104	82	126	119	114	2	2	2	2	2	2	2	2	3	3
1830	200	191	125	128	133	108	91	96	96	98	3	3	3	3	3	3	3	4	4	4
1840	42	96	63	69	38	103	80	115	113	82	4	4	4	4	4	4	4	4	5	5
1850	134	133	104	161	127	121	86	111	90	131	5	5	5	5	6	6	6	6	6	6
1860	122	126	88	79	74	108	96	118	86	107	6	6	6	6	6	6	6	6	6	6
1870	82	118	142	98	77	145	74	148	157	117	6	6	6	6	7	7	7	7	7	8
1880	101	77	72	82	82	67	112	79	100	86	8	9	9	9	9	10	11	11	11	11
1890	122	101	107	77	91	69	86	165	128	118	11	11	11	11	11	11	12	12	12	12
1900	140	100	106	111	110	101	111	108	96	101	12	12	12	12	12	12	13	13	13	13
1910	112	76	76	68	107	112	96	120	72	53	13	13	14	14	14	14	14	14	14	14
1920	61	50	65	61	93	78	121	133	111	111	14	14	14	14	14	14	14	14	14	14
1930	82	133	120	77	63	73	101	92	79	120	14	14	14	14	14	14	14	14	14	14
1940	92	76	102	112	98	107	100	113	81	85	14	14	14	14	14	14	14	14	14	14
1950	159	108	113	107	104	101	91	78	123	115	14	14	14	14	14	14	14	14	14	14
1960	116	98	114	121	123	122	125	100	107	83	14	14	14	14	14	14	14	14	14	14
1970	92	108	86	105	88	69	69	78	127	100	14	14	14	14	14	14	14	14	14	14

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A MICROCOMPUTER-BASED TREE-RING MEASURING SYSTEM

WILLIAM J. ROBINSON

Laboratory of Tree-Ring Research
The University of Arizona

and

ROBERT EVANS

Compu TA
La Mesa, California

ABSTRACT

A brief discussion is presented on a new measuring system based on an APPLE microcomputer. Aspects of both hardware and software are considered, with emphasis on the software that provides operator interaction. The system uses diskettes for data storage and completely eliminates both paper tape and key punch cards from the measuring process.

INTRODUCTION

In 1964, the Laboratory of Tree-Ring Research developed its first automatic device to record ring widths. This "measuring machine" replaced a Swedish manual ADDO-X which in turn had been a major advancement in data capture. This machine was designed and constructed by the Fred C. Henson Co. of California and was the product of development begun in 1939. The 1964 device consisted of two parts. First, a hand operated precision 1 mm pitch lead screw was employed to drive a mechanical stage and tree-ring sample under a fixed stereoscopic microscope equipped with a crosshair. The lineal displacement of each ring was encoded to a resolution of 0.01 mm by an electromechanical digitizing switch fitted to one end of the lead screw. Second, a custom "black box" scanned the digitizing switch, entered the data on an adding machine, caused the adding machine to print the increment on paper tape and to label each decade with its correct calendrical year. Later, punched paper tape output was added. This system was in operation for approximately five years.

In 1970, the need for additional measuring capability led the Laboratory to locally duplicate the Henson "black box" with updated electronics. An additional precision lead screw was acquired from Henson and both lead screws were fitted with optical incremental shaft encoders. The intention was to capture data on magnetic tape as well as on paper tape, producing a major improvement in the system. Unfortunately, this system proved to be unreliable electronically and mechanically and was in operation, off and on, for only a few years.

The continuing need for additional, reliable measuring devices was satisfied in 1972 by a new concept pioneered again by the Fred C. Henson Co. Due in part to projected costs of precision lead screws, this new system was based on a simpler measuring device operating directly on lineal displacement rather than encoded rotary motion. As a consequence, a newly-designed measuring stage was equipped with a dial indicator that was convertible to use with a standard lineal displacement transducer. The transducer was powered by a separate supply manufactured and maintained by a national firm. The output voltage from the transducer was directed to a "stock, off-the-shelf" measuring system which included visual digital display, a voltmeter to measure transducer output, and a conversion unit that supplied binary coded decimal

(BCD) output to a digital impact or thermal printer. This system had the advantages of good reliability and relatively low acquisition and operating costs. It had, also, two nagging disadvantages. One, the transducer required daily — or more frequent — calibration due to its sensitivity to both current change and physical movement. Second, the paper tape output consisted of columnar measurements without identification, calendar years, or other pertinent documentation. These were all entered by hand.

The development of the microcomputer-based measuring system discussed in this paper was precipitated by two events. First, a 1972-vintage measuring system suffered electronic failure after eight years of constant use and the cost of repair was estimated at a figure that appeared noneconomic. Second, an investigation of microcomputers suggested that many were cost competitive with the less sophisticated voltmeter system and could be interfaced to the encoding devices with a minimum of hardware. After investigation of cost, interfacing ease, software and support, an APPLE II Plus microcomputer was chosen as the basis of the system.

THE SYSTEM

Encoder

Since the Laboratory already possessed four measuring stages with precision lead screws (two custom Henson stages and two ADDO-X stages), optical incremental shaft encoders were fitted to all four stages by the University machine shop. The shaft encoders have a resolution of 0.002 mm. They are bidirectional and require + 5 volts, direct-current (vdc) input. They provide a square wave, TTL-compatible, output. The external connector is a standard 7-pin type mounted at the end of the encoder. In this case, only four pins were used; one for + 5 vdc, one for ground, one for incremental direction sensing, and one for reverse direction sensing. This part of the system may probably be used with nonprecision lead screws by replacing the transducer with a lineal glass encoder which has input/output characteristics identical to the shaft encoders under discussion. The Fred C. Henson Co. has developed this alternative and is offering their present laboratory model with the lineal glass encoder.

The advantages of the shaft encoder over a transducer lie in the lack of need to calibrate, in far superior immunity from dust or, in our case, charcoal bits, and in its lack of susceptability to inadvertent measurements due to physical motion. The cost of either type of encoding device is identical. In addition, the shaft encoder draws power directly from the APPLE and does not, therefore, require a separate power supply.

Interface

The connector on the shaft encoder is interfaced to the "game" port of the APPLE. This game port is a 16-pin DIP socket that provides, among other unused functions, + 5 vdc, ground, and three one-bit, TTL inputs. Two of the latter connect the two-channel output of the shaft encoder, while the third is used for a hand-held push button that initiates the measuring cycle and zeros the accumulator to receive another measurement. Wire-to-wire interfacing is accomplished using a standard 6-screw terminal strip mounted in a box. A 4-wire cable leads from the shaft encoder to the terminal strip, as does a 2-wire cable from the push button. One end of a 16-pin ribbon cable is inserted in the APPLE game port with the other end cut and stripped for attachment to the proper terminals. Thus the entire physical interfacing is extremely simple and requires no hardware modification of the APPLE.

The APPLE Microcomputer

The hardware used for the system includes an APPLE II Plus microcomputer with resident APPLESOFT language. This language is APPLE's version of MICROSOFT floating-point BASIC. The computer is configured with 48K of random-access memory (RAM), a 5" floppy disk drive, and a 9" black and white video monitor. Both the disk drive and the monitor sit on the APPLE so that the total space occupied by the system is only approximately 15" by 18". We place the system on a wheeled, 34" high projection table with the terminal strip box fastened to the table. This allows the operator to place the video screen at a convenient distance and angle for viewing, as well as to avoid placing both electronics and samples on the same surface.

The APPLE II Plus has an autostart feature that automatically loads and runs a program from disk when the APPLE is turned on. This allows for simple system startup. A possible improvement that would increase RAM memory and avoid the use of disks for the programs would be to place the measuring programs in read-only memory (ROM) on an I/O board. Once done, however, program changes would be precluded.

Software

The software developed for the measuring system was accomplished in three linked programs. The first, a standard "greeting" program, boots the disk operating system using the autostart feature. The greeting program automatically loads the two operating programs that will be discussed in greater detail.

The program titled PULSE COUNTER is written in assembly language and resides, after loading, between $0300 and $0396 in memory. This program monitors inputs from the shaft encoder, the operator control switch, and the computer keyboard. When a pulse train appears at the port, the program determines in which direction it should count and accumulates the count. When the operator signals the end of a measurement, the program stores the current count in a location used by both programs. It then passes control to the main program.

The assembly language program uses the instruction set of the 6502 microprocessor on which the APPLE is based, so PULSE COUNTER can not be transported to non-6502 based microcomputers. Assembly language, however, has the advantages of using very little space in RAM and of swift execution, which is important in the measuring process. The program is so compact, in fact, that it is placed in a memory area not usually available for programs, thus allowing more free RAM for data.

The main and visible program is called, appropriately enough, MEASURE. This is a menu-driven program written in BASIC and is approximately 6K in length. After loading this program, the APPLE has about 30K free RAM or sufficient memory to handle a core of nearly 10,000 years length.

The menu provides seven options: measure (1), review (2), put on disk (3), get from disk (4), edit (5), plot (6), and quit (7). Most of the error-trapping routines that are built into the program return to this menu. Selection from the menu is by single keystroke.

The measure option (1) first asks for the operator's name, the identification number of the sample to be measured (at present a 6 character alphanumeric code), the date, and the beginning year of the sample. The beginning year may be either a calendrical A.D. year or a positive arbitrary year such as would allow the end date to be less than 10,000. The program then queries the operator about the correctness of the input and allows a restart. If the operator agrees (by single keystroke) with this input, the program then sets up the measuring display for the monitor. On the right half of the screen, instructions are written to press the trigger to record a ring (or a zero) and to press the "9" key to end measuring and return to menu. The left half of the screen displays two matched columns with the years in one column and the actual measurements (in integer mm) in the other. As the screen fills, these columns scroll up so that a maximum of 20 measurements are displayed at any given time.

As the trigger is pushed, the program calls the assembly language program, gets the values of the counts from the shaft encoder, and converts them to integer millimeters. A single beep from the APPLE's speaker is also sounded. There are also subroutines to right justify the measurements in the column and to disallow a negative measurement.

When measurement is completed, usually at the end of a sample, the "9" key is pressed on the keyboard. This action terminates the measure option, adds a final year with the value of 999 as an end of file mark (Graybill 1979), and returns the operator to the menu. Thus, under this system, the maximum measurement possible is 9.98 mm. But this could easily be changed however if the end of file mark were changed.

The review option (2) returns the measurements and year labels to the screen in sets of 15 years from the beginning. A single keystroke displays the next set and a "9" key provides an escape and return to the menu. This option is used primarily to scan the data after completing a core, to check beginning and ending years, and to look at the placement of critical rings.

The two options (3 and 4) that deal with the disk are nearly self explanatory. Both ask for the core identification number of interest and then either write the file onto the disk or return it from the disk to memory. Files are treated as sequential text files with the usual commands of the disk operating system. A core may be returned from disk, edited, and reSAVEd on disk with all corrections intact.

The edit option (5) is similar to review in tha the measurements with their year labels are again displayed in 15-year groups beginning at the earliest year. However, a number of single keystroke commands are added and displayed at the bottom of the screen. These commands allow the operator to Insert a ring that has been missed, to Change the value of a ring by entering the value on the keyboard, to Remeasure a ring changing its value by means of actual measurement, to Delete an extra ring or a double that was measured as a ring, and to Quit and return to the menu. In most cases, after the command is entered on the keyboard, the screen asks the operator which year he wishes to alter, waits for the operator's input, and make the change. To delete, a further safeguard is afforded by displaying the value of the ring to be deleted and asking for verification. In both insert and delete the data set is adjusted automatically and the appropriate years are relabeled. A combination of commands has proved to handle the usual errors committed by measuring operators.

Finally, the plot option (6) provides a *simulation* of a skeleton plot to visually display placement of critical small rings in the measured series. Using low resolution graphics, the data set is divided into group of 40 years or somewhat less (dependent on the total length), the average ring value for each set is calculated and displayed in the traditional inverse relationship. Thus a zero ring has the greatest value which is a line length on the vertical scale approximately equal to the line length of 10 years on the horizontal scale. The displayed data set is limited to 40 due to the width of the display available in the APPLE's low resolution graphics mode.

Data Transmission

Another program has been developed to transmit ring-width data, via the telephone, to an interactive mainframe computer for subsequent data manipulation with programs RWLIST, INDEX, and SUMAC (Graybill 1979). The transmission program is structured to use a Micromodem II and is specifically configured to interface with a Digital Equipment Corp. System 10 mainframe computer. The software is menu-driven and provides options to transmit data or to print the data locally if the APPLE is interfaced to a line printer.

The primary concern in the design of the data transmission option was to keep operator interaction with the program at a minimum. This concern is justified by the amount of time involved in transmission of an entire tree-ring site (a minimum of 20 cores or "files"). An average southwestern US tree-ring site takes at least 60 minutes to transmit with the operator free to undertake other tasks while the program runs.

The system consists of a BASIC program in the APPLE and a FORTRAN receiving program on the DEC-10. After first running the program, the operator is asked to enter the file name (known as a job number) which identifies the DEC-10 disk file used. The operator then enters all the file names (core ID numbers) to be transmitted. The screen displays a list of these core numbers and provides an opportunity to add, delete, or correct any misentry. After acceptance of the core IDs by the operator, the BASIC program enters a loop that automatically dials the telephone and continues until a carrier signal is established. The operator then performs normal log-on procedure and is returned to the BASIC program. The data transmission program then issues a command to the DEC-10 to execute the FORTRAN receiving program and sends the file name (job number) to identify the disk file.

Each core (or other sample) is then individually read from the diskette, where it was stored by the MEASURE program and transmitted to the receiving program. For each core, a sum and a sum of squares is calculated by both the APPLE and the DEC-10. On completion of transmission, these sums are sent back from the DEC-10 to the APPLE where they are compared. If the results are not zero (with allowance for rounding errors), the entire file (one core) is retransmitted. Since this procedure produces duplicate data on the disk file, an error message containing the duplicated line numbers is produced on the line printer. The duplication is deleted before running RWLIST.

This procedure is repeated automatically until all files have been transmitted. The program then logs the user off the DEC-10 and prints a hardcopy list of the individual core ID numbers transmitted. Finally, the program returns to the menu for more transmission, hardcopy printing of data, or exit.

The print option provides a hardcopy listing of each core. In terms of operator interaction, this option is similar to data transmission and, in fact, shares subroutines. The operator enters a list of the core IDs to be printed and is given the opportunity to edit this list. The cores are loaded, one at a time, and printed. The format of this listing is similar to RWLIST in that each line contains the core ID number, decade, and ten (or less) values.

CONCLUSION

The measuring system has been operational for approximately four months and has received extensive testing through use. Operators accustomed to older systems have found conversion extremely easy. It is estimated that measuring time has been at least halved through the elimination of paper tape output. In addition, the programs provide for more sophisticated screening of data than previous systems. This insures greater accuracy of data when released by the operator for transmission and manipulation.

Data transmission has been tested along with the measuring system and has proven to be equally reliable and easy to use. Although transmission using a 300 baud telephone line is somewhat slow, the elimination of card punching and verifying has led to a dramatic overall increase in productivity. In addition, data storage on diskettes and magnetic tapes has replaced the need for card storage and handling.

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