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# HIGH-PRECISION $^{14}C$ MEASUREMENT OF IRISH OAKS TO SHOW THE NATURAL $^{14}C$ VARIATIONS FROM 200 BC to 4000 BC

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ABSTRACT. Bi-decade samples of dendrochronologically matched Irish Oak, measured with a precision of ca $\pm$ 20 years, covering the period 200 to 4000 BC are presented. The data are compared with the published data of Suess, de Jong, and Mook to provide a general calibration of the $^{14}C$ time scale for this period. Although the dendrochronologic sequences presented are not absolutely tied to present, the best fit (based on $^{14}C$ evidence) of the Belfast data to absolute chronologies, the error and evidence associated with such positioning is given. The intervals chosen for analysis were 20 years, reducing slightly the resolution of short-term variations when compared to 10-year intervals, which are sometimes measured. However, this calibration would suffice for most scientific purposes and certainly for the calendrical conversion of $^{14}C$ dates derived from archaeologic samples.

## INTRODUCTION

High-precision measurement of European oak can now provide a $^{14}C$ time-scale calibration from ca 300 to 4000 BC. De Jong, Mook, and Becker (1979) published some 700 years of calibration which was wiggle-matched to the bristlecone-pine chronology of Suess (1978) to give a zero date for the German Neolithic chronology of 4032 BC.

The Belfast laboratory has now made high-precision measurements ($\sigma = \pm$ 17 years standard deviation including all errors on corrections) (Pearson, 1979; 1980) of some bi-decade /decade samples of Irish oak covering a time period of some 5700 years; 3700 years in the BC period overlapping the calibration published by de Jong, Mook, and Becker, (1979). The AD $^{14}C$ measurements of Belfast and tree-ring standard on which the calibration is based appear in this volume (Pearson and Baillie, 1983). Full advantage was taken of technical improvements in counting systems with the large samples obtainable from British Isles oak chronology. The 300 dates, each measured for 300,000 counts, are calculated to have a realistic precision of $\pm$ 17 years and are statistically equivalent to 4800 average $^{14}C$ measurements to ± 68 years precision.

## METHOD

Analysis was made essentially as described in Pearson (1979; 1980) and Pearson and Baillie (1983). Because the system was for high-precision measurement, care was taken to investigate all likely sources of error; many factors were continuously monitored for the last seven years to assist in evaluating the accuracy of measurement. Some samples measured in 1975/76 carry a higher precision of ca ± 20 years to allow for the increased uncertainty of errors associated with weighing due to the use of plastic vial caps, the weight of which is variable with temperature and humidity (Pearson, 1979).

## VALIDITY AND ACCEPTABILITY OF CALIBRATION CURVES

A calibration should have two meaningful axes. For the BC period the choice has been limited to either low-precision $^{14}C$ measurement associated with an assumed absolute bristlecone pine calibration. In the past, neither of these alternatives have offered an ideal calibration curve, but recent developments in European dendrochronology and the high-precision $^{14}C$ measurement of a long Irish oak series now make the estimated error on the calendrical fixing of the dendro-age axis small, probably $<$ 20 years.

Baillie, Pilcher, and Pearson (1983) show a preliminary dendrochronologic match which fixes the position of the two floating Irish oak series (fig 1) in relation to each other. If this long floating sequence can soon be tied to the present, the high-precision measurement of European oak would be completely valid for $^{14}C$ time-scale calibration and, once independently duplicated, it would probably be universally acceptable.

## CALENDRICAL FIXING OF IRISH OAK DENDRO-AGE BC BY $^{14}C$ MEASUREMENTS

de Jong, Mook and Becker (1979) showed that a calendrical fix can be obtained for the German chronology by wiggle matching in a comparison between German oak and bristlecone-pine. The technique consists of constructing cubic spline functions through both sets of data using the Reinsch algorithm (Reinsch, 1967). The area under the curves are compared for a fixed number of years and the minimum difference in area is found by moving one curve incrementally over the other. Such a plot gave a minimum value and, hence, a fixing for the zero point

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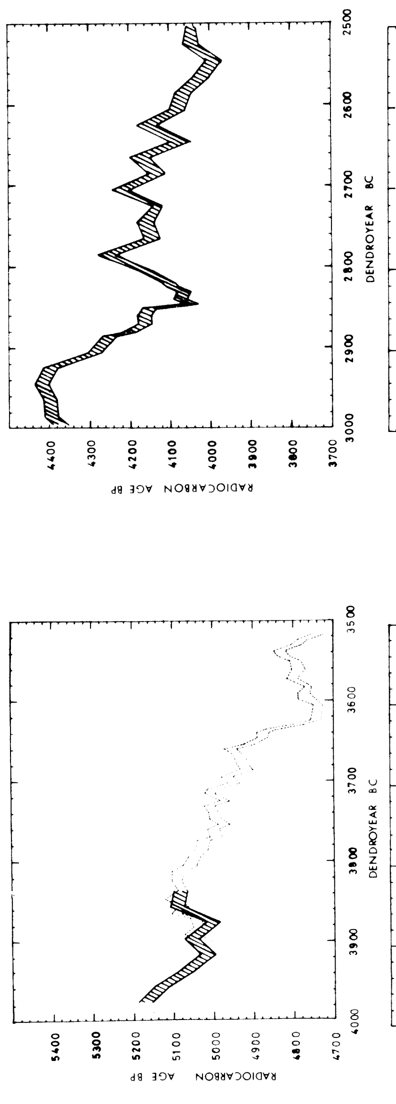


Fig 1A Bi-decade/decade interval measurements of Irish oak. Shaded area is ± 1σ error band. Dotted lines show data of de Jong, Mook, and Becker (1979), de Jong (1981).

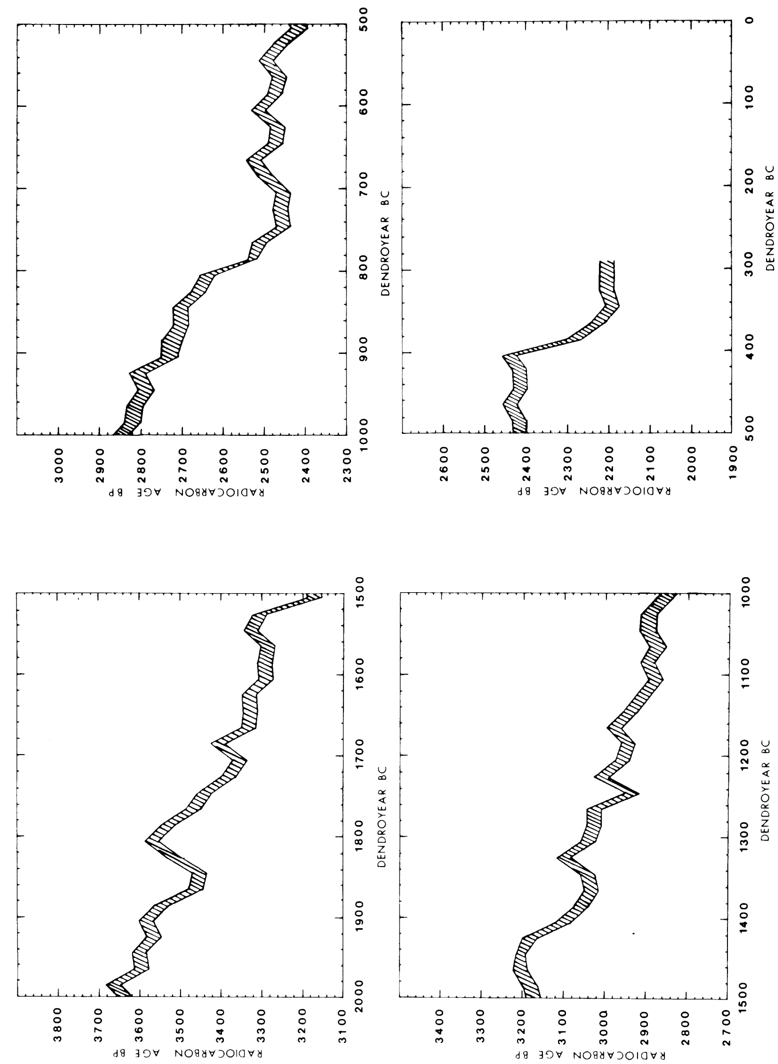


Fig 1B Bi-decade/decade interval measurements of Irish oak. Shaded area is $\pm$ 1$\sigma$ error band.

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of the South German Neolithic chronology of 4032 BC (de Jong, ms). A similar technique was used by Kruse et al (1980) to fix the same zero point using the independent $^{14}C$ measurement of German oak (Suess, 1978) compared to the same laboratory's measurement of bristlecone pine. The zero point for the South German Neolithic chronology from this method was identical to the most recent figure of 4032 BC (de Jong, ms).

Ca 1400 years of the Irish oak $^{14}C$ measurements were treated in a similar manner and gave a fixing for the 0 tree-ring year, 2075 ± 10 years BC (Pearson, 1980). If the Irish tree-ring year 0 is fixed at 2085 BC then the agreement with de Jong's published data over > 300 years is excellent (fig 1). Assuming the bristlecone-pine chronology is absolute then with agreement among three laboratories for fixing of the German and Irish oak floating chronologies, it is likely that the error in the calendrical fixing of the dendroage given by each chronology does not exceed ± 10 years.

A second floating Irish oak series, in which the zero point was provisionally fixed at 975 BC by wiggle matching, provided material for dating from ca 290 to 975 BC. The curve was visually wiggle matched to the bristlecone-pine measurements for the 1st millennium BC and to the German oak measurements, both of Suess. Unfortunately, the German dates end at ca 500 BC and overlap little, but are significant because of the variations in the $^{14}C$ concentration for that period. The end of this floating series at 975 BC has now been extended (Baillie, Pilcher, and Pearson 1983) and material that overlaps the long chronology of Irish oak dating from 900-400 BC is being measured at present. The provisional $^{14}C$ measurements agree sufficiently for the dendrochronologically fixed overlap to be considered correct within a possible variation of ± 10 years. If the above evidence is accepted for fixing the floating sequences, then the main weakness in European high-precision time-scale calibration for the BC period is removed.

## INTER-LABORATORY COMPARISON

Almost 2000 years of calibration has been compared between Belfast and Seattle laboratories (Pearson and Baillie 1983). The agreement, showing a bias of 3 ± 5 years is excellent. (Seattle data (Stuiver, 1982) can only be read to the nearest 5 years).

Results of several inter-laboratory studies conducted by the Belfast laboratory are discussed in Pearson and Baillie (1983). Also five identical wood samples of different bi-decades were measured by the Belfast and Groningen laboratories; the results show a mean bias of ca 20 years, Belfast results being slightly older. However, the bias is less between the Belfast and Groningen laboratories for the overlap period in the 4th millennium BC (fig 1) where the general agreement is compatible with the error limits quoted.

CALIBRATION CURVES

There is probably no individual calibration curve that would suffice for all $^{14}$C date "conversion" since so many variables exist, eg the error associated with the $^{14}$C date, ie, the precision quoted that should include all inaccuracies, the error in the calibration, the choice of sample material and knowledge of the growth period. The minimum precision quoted on a date is a statistical combination of the Poisson statistical counting errors derived from the total counts accumulated from sample standard and background measurement. The precision quoted should be increased to allow for all uncertainty, "an error multiplier" (Stuiver, 1982; Scott, Baxter, and Aitchison, 1981) established by the laboratory from inter-laboratory comparison and internal replication of analysis. "Accurate dates", or those "being without bias" even if accompanied by a low-precision error are needed. If a date is accurate with an appropriately corrected and propogated precision, maximum benefit can be obtained from a high-precision calibration curve with reliable dendro-age bands for interpretation.

The error on the calibration, itself, is dependent upon the precision obtained on the individual data points forming the curve. Before any data is combined it is essential that no significant bias exists among the proposed independent calibration measurements in order to justify a statistical average of the data.

Choice of sample material is not often made by the laboratory except for isolation of specific components of submitted samples. A homogeneous sample that provides a mean date for interpretation, or dates an event, at least as accurately as the $^{14}$C measurement allows, is preferred. Knowledge of the growth period of sample carbon is important for correct conversion. If the sample's growth period is less than the calibration interval, eg, single-year samples, such as seeds, nuts, straw, while dating a particular year of growth, it may carry an increased error if converted to a dendro-age using a decade or bi-decade calibration curve (Pearson and Baillie, 1983; Stuiver, 1982; de Jong, 1981 pers comm), because allowances have to be made for the smoothing function of the curve, particularly at points of inflection. Samples with growth period falling between 10 and 30 years are ideal for conversion to a calendar or dendro-age and may

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also justify high-precision measurement. Dating samples with growth period exceeding 100 years involves errors of averaging because of variation in the growth pattern. As it is extremely unlikely that an equal quantity of sample material is produced, this error is probably greater than the error in the calibration and may not warrant very high-precision measurement.

## USE OF CALIBRATION

The conversion of a $^{14}$C age to a dendro-age has been fully discussed (de Jong, ms ; Pearson and Baillie, 1983; Stuiver, 1982) and can be summarized as follows:

Evaluate the three errors discussed above

$\sigma_1$=The error on the date incorporating any allowance for inaccuracies outside of Poisson statistical counting error

$\sigma_2$=The error on the calibration, ie, half the average depth is $^{14}$C years of the time period between the upper and lower error limits (normally $\pm$ 17 years)

$\sigma_3$=Any allowance for samples of short growth period, it is recommended that 15 years is used for sample year's growth falling to zero as the growth period approaches 20 years.

The corrected error the date $\sigma_0$ can be calculated from

$$\sigma_0 = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2}$$

To convert the $^{14}$C age to dendro-age, draw a horizontal line across parallel to the X axis at the calculated date error limits and project the intercept with the calibration to the X axis; all dendro-ages falling between the upper and lower intervals of the calibration curve are valid calendar ages for the converted date. The dendro-age band varies considerably for $^{14}$C dates measured to the same precision, giving rise to multiple band widths in some cases and, in other cases, a reduction of the error in dendroyears to that quoted in $^{14}$C years.

## CONCLUSION

The $^{14}$C measurements presented here, together with those of Pearson and Baillie (1983) Stuiver (1982), and de Jong, Mook, and Becker (1979) provide a 6000-year high-precision curve for the conversion of $^{14}$C dates. The curve shows significant repetitive detail of ca 150 years' periodicity although the amplitude varies considerably. Good agreement exists among the Belfast, Seattle, and Groningen laboratories for the periods compared and the possibility of an absolute dendrochronologic axis for the last 8000 years looks very promising.

With continued effort, a full 8000-year high-precision calibration should be possible within the next three years.

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