Tree Ring-Series — A Valuable Source of Ecological and Environmental Information

A. McNALLY[1] and G. J. DOYLE

Botany Department,
University College Dublin.

INTRODUCTION

Uniform tree ring patterns are observed in particular sites or regions where tree growth is limited by a single factor or factors. The most obvious and readily measureable feature of such ring patterns is variable radial width. Such measures are used in the science of dendrochronology or tree ring analysis. The fundamental object of this approach is to place a time sequence on the ring-series, enabling us to place a calendar date on any particular ring.

If it is possible to correlate wide or narrow rings with some limiting factor, by experiment or by statistical analysis of measured environmental parameters, the tree ring-series becomes a valuable source of environmental and ecological information.

RING MEASUREMENT

The timber samples used can be cross sections or cores. Both are thoroughly dried before measurement. Dry cores are glued to grooved lathes for support during the final preparation which is essentially the same for cores and sections and involves abrasion with a variety of sand papers, until the annual rings are sufficiently obvious to view under a binocular microscope.

The ring widths are measured by passing the core or section on a graduated moving stage under a microscope fitted with cross hairs.

1 Present Address: Department of Biology, McGill University, 1205 Avenue Docteur Penfield, Montreal, PQ, Canada H3A 1B1.

The distance traversed by the stage (the ring width) is displayed on an electronic counting device in units of 0.01mm.

Normally, three radii per tree are measured. This allows a check against any inaccuracies which might arise if a single radius were measured, e.g. false or missing rings in part of the tree.

TREATMENT OF RESULTS

The ring width data may be plotted against a time scale. The ring width series in Fig. 1 is based on measurement of cores from living oak (*Quercus petraea*) from Killarney, in County Kerry. The long term trend in ring width with tree age has been removed by a

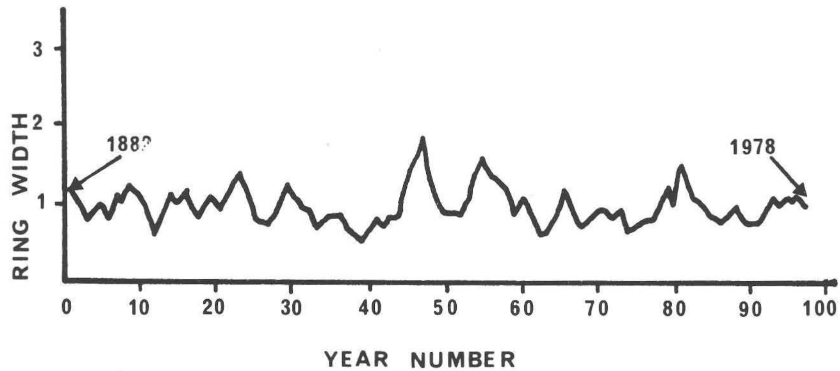

Fig. 1 A tree ring series from live oak (*Q. petraea*) at Killarney. The ring width scale is not given in absolute terms but is based on transformed data varying about a mean of one.

standardising procedure. Each ring width is expressed as a percentage of five ring widths: the current, two previous and two following. As a result each ring width is reduced to an index varying about a mean of 1. Since the formation year of the outer ring is known, it is possible to give a precise calendar date to any ring in the series. The particular tree in question is seen to have survived from 1882 until 1978 when the sample was taken.

The living tree-series may be used to date tree stumps in the area. If both have been subject to the same environmental influences for part of their lives, there will be an overlapping series with a similar pattern of wide and narrow rings. Fig. 2 shows a plot of the living oak ring-series mentioned above, and a series obtained from an adjacent oak stump. There is an obvious overlap in pattern during

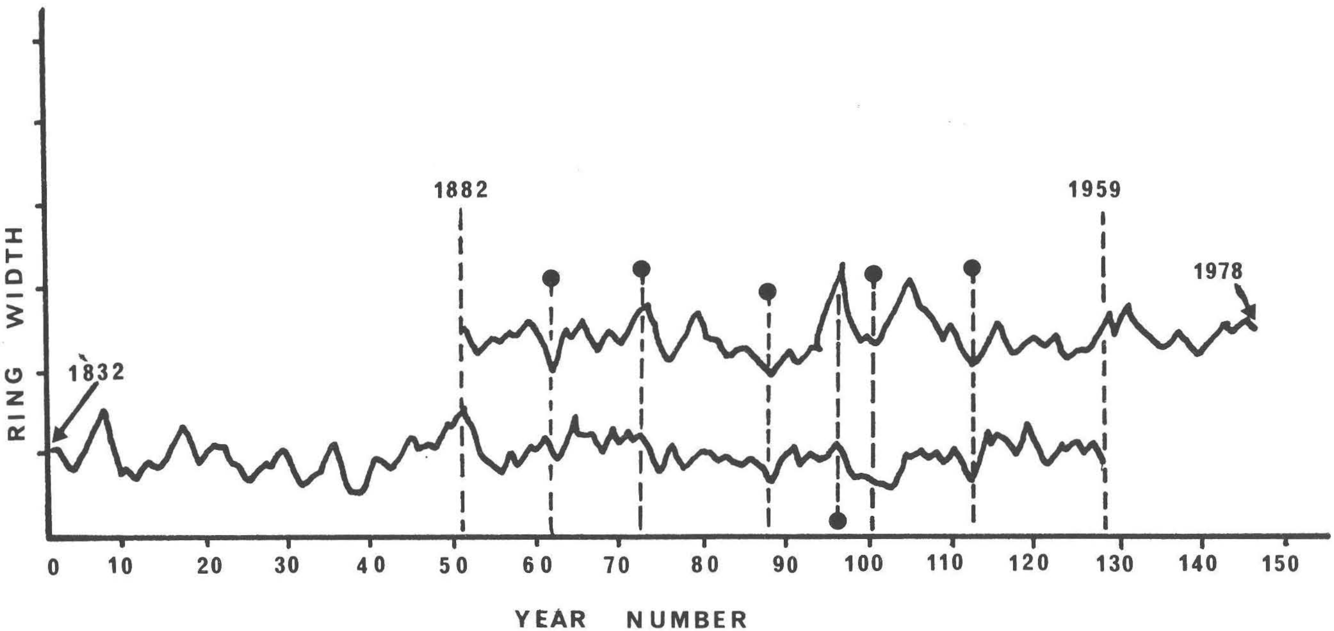

Fig. 2 Cross matching of ring series from a live (upper plot) and a dead oak stump (lower plot) from Killarney. The very obvious points of comparison are indicated by the dashed lines and solid spheres.

the period 1882 to 1959. As a result, it is now possible to put calendar dates on any ring of the undated stump. For example, it commenced growth in 1832 and was felled in 1959.

Overlap between tree ring series may be visually assessed, or may be statistically proven. The statistical comparison involves the calculation of a correlation coefficient for every possible overlap. A Student's t-test is used to indicate the most likely position of correspondance. When the live and dead ring-series above were compared in this way, a t-value of 6.4 was obtained with the 77 degrees of freedom involved. This indicates a very highly significant match.

The authors have computer programmes which will test for overlap in such series and will carry out the statistical procedures outlined below. These are written in FORTRAN 20 and designed to run on the DEC computer at University College Dublin. Copies will be made available on request.

Such techniques allow matching of a large number of ring-series from a particular area and subsequent computation of 'mean master series'. This involves averaging ring widths for each calendar year, based on the overlapping series. By combining information from living and dead timbers in this way long tree-ring-series can be obtained. Baillie (1973, 1977 a & b) has constructed long oak chronologies from Northern Ireland, spanning the period from 1001 A.D. to the present, and from Dublin for the Medieval periods, 885-1306 and 1357-1556 A.D. Pilcher et al. (1977) have set up a 2990 year floating chronology for bog oaks in Northern Ireland. If such series are absolutely dated, i.e. cross matched with present day series, they may be used in dating wooden archaeological materials made of oak. Medieval ships (Baillie 1978, McGrail 1978) and oak panel paintings (Bauch 1978, Fletcher 1978) have been dated in this way.

Oak is particularly suited to this type of analysis as it produces annual rings so consistently. Some species are less suitable as they produce false rings or have missing rings on occasional years. Coniferous species such as the Scots pine (*Pinus sylvestris*) are included in the latter category, but may be utilised if sufficiently rigorous cross checks are made. We have successfully matched pine chronologies from The Scalp and Glencullen in County Dublin, with others from Knocksink in Wicklow, and from a number of sites in Offaly and Kildare. The master chronologies from The Scalp and Glencullen are shown in Fig. 3 and show obvious crossmatching.

In some geographical areas, including the tropics, trees may not produce rings on an annual basis and are not suitable. Despite these

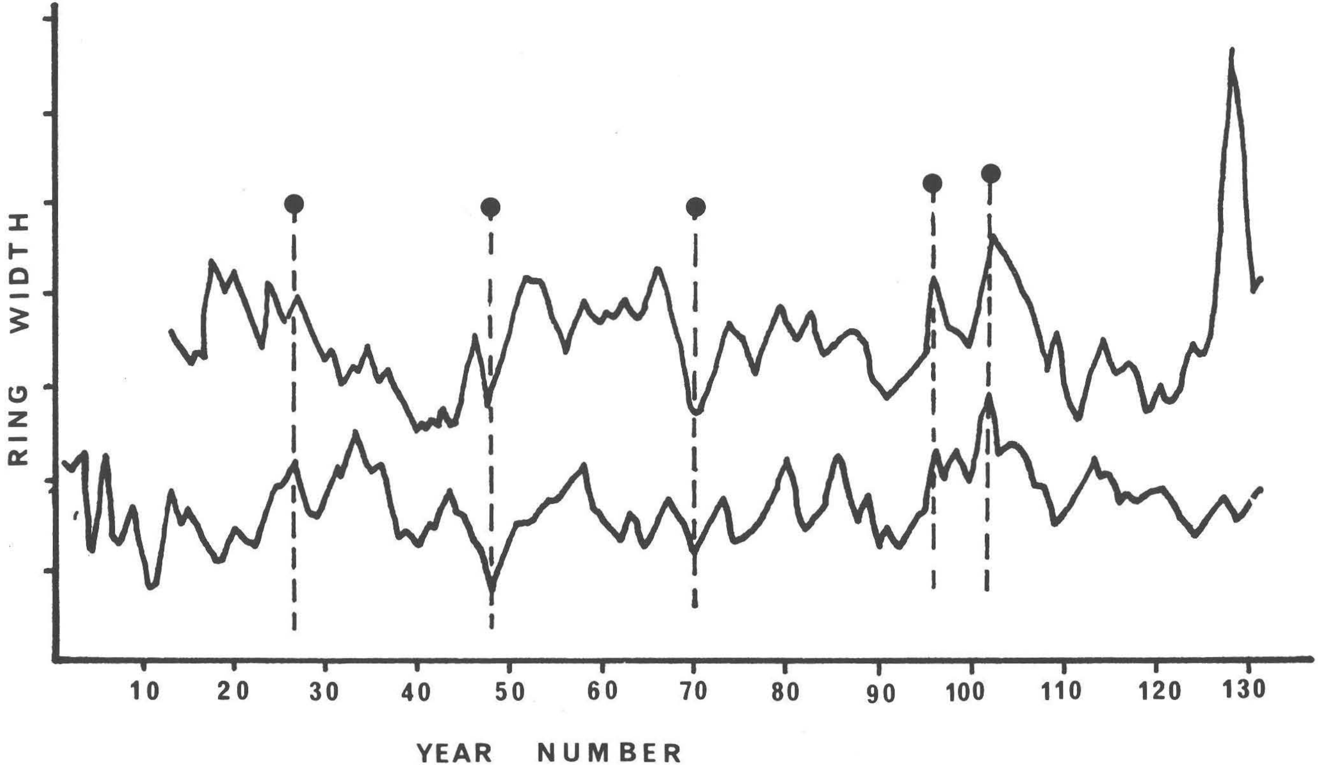

Fig. 3 Master chronologies for pine (*P. sylvestris*) at Glencullen (upper plot) and The Scalp (lower plot). Points of obvious comparison are indicated by dashed lines and solid spheres.

problems, quite a number of species from different geographical areas have been used in tree ring studies. A list of genera used is presented in Table 1.

Table 1 Genera utilised in tree ring studies.

Abies	*Cupressus*	*Picea*	*Sequoia*
Alnus	*Fagus*	*Pinus*	*Sequoiadendron*
Araucaria	*Fraxinus*	*Populus*	*Thuja*
Betula	*Juniperus*	*Pseudotsuga*	*Tsuga*
Cedrus	*Larix*	*Quercus*	*Ulmus*

Crossmatching between trees in any one site, or between sites, indicates the relationship between tree growth, or ring width extension, and some common influencing environmental parameter or parameters. When empirical environmental records are available for part of the period spanned by a tree ring-series, statistical techniques may be used to elucidate the relationship between ring width and particular factors.

The most basic of these techniques is simple regression analysis. Such analysis allows ring width to be regressed against a series of environmental paramenters such as temperature, precipitation etc. The analysis may be based on annual, seasonal or monthy measures depending on the type of environmental records available. The influence of these parameters in current or previous time periods may also be investigated by including parameters for previous years, seasons etc. in the analysis.

Fig 4 shows a plot of coefficients based on a regression of mean monthly temperatures recorded at the Phoenix Park, against the Scalp Pine chronology. The graph clearly indicates that pines at this site are positively affected by temperature for most months of the current year as well as the previous year. The relationship with temperature is particularly strong in the early part of the growing season — in February, March and April. These statistical conclusions make ecological sense, as the Scalp pines are located on a steep slope (45 degrees) and grow on a very poor thin soil in between large granite boulders. As a result, the majority of the tree roots are at, or near the surface and would be immediately affected by changing air temperatures.

Simple regression with other meteorological parameters does not show such a convincing relationship with ring width at the Scalp, so one must conclude that temperature is one of the most important limiting factors.

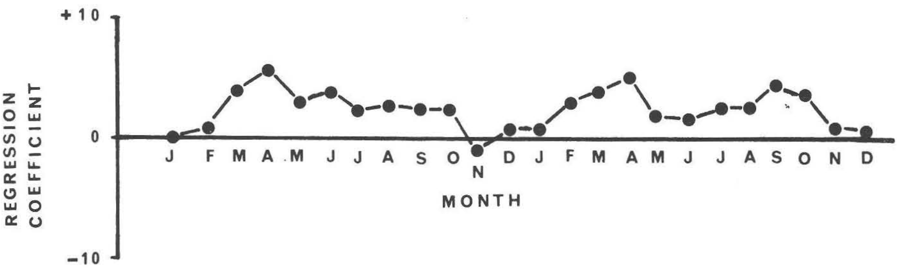

Fig 4 Regression coefficients of ring width from the Scalp pine master chronology against mean monthly temperatures recorded at the Phoenix Park. The monthly values for the previous and current year are included (data for the previous year to the left and for the current year to the right).

Once a relationship with temperature has been established one may wish to investigate the relationship between ring width and long term climatic trends in air temperature. To do this it is necessary to reduce the high frequency variation in the ring width series. This may be accomplished by a digital filtering technique (c.f. Fritts 1976) which involves multipying the original series with numerical weights that emphasise variation at selected wavelenghts (in years). We have applied this technique to the Scalp and Glencullen chronologies (Fig. 5), and have emphasised variations occurring at wave lenghts greater than eight years. These plots show remarkable correspondence, and indicate that there have been periods of above and below average ring growth over the past one hundred years. Superimposed on the graph are the mean surface temperatures based on 5-year averages from 1875-1970 (Chandler and Gregory 1976). The agreement with the Scalp master is immediately noticeable as the peaks and troughs coincide in almost every case. The correspondence with the Glencullen master is again striking but does not correspond to the temperature curve at all times. This difference might be explained on ecological grounds, as during particular warm periods above average precipitation was recorded. This would have affected trees at the two sites in different ways. As already indicated the Scalp trees are confined to very freely draining, shallow soil while at Glencullen the trees grow on relatively deep peat (0.5m) which becomes waterlogged in wet periods. As a result one would expect lower growth in a wet period at Glencullen, despite warmer temperatures.

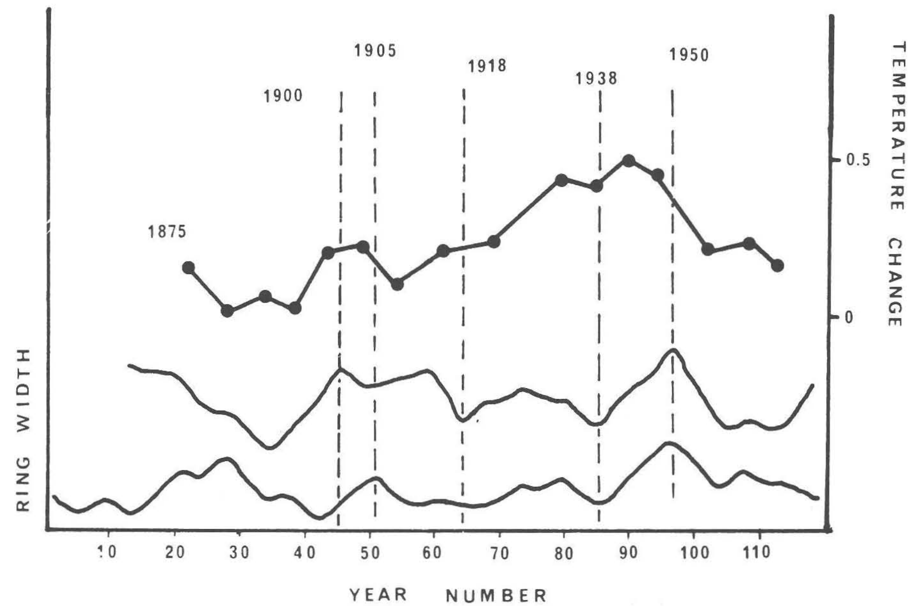

Fig 5 Pine chronologies from the Scalp (lower plot) and Glencullen (middle plot) treated with a digital filter to emphasise wavelengths greater than eight years. The upper plot shows changes in global mean surface temperatures (in degrees centigrade) since 1875 (based on Chandler and Gregory 1976).

Multiple regression analysis may also be used to elucidate the relationship between ring width and a combination of environmental factors. In this way one may account for a considerable proportion of ring width variation (80 percent) and may take into account such factors as autocorrelation, the influence of previous year's growth on the current ring.

Principal components analysis may be combined with multiple regression in a procedure called 'response function analysis' developed by Fritts et al. (1971) and described in detail in Fritts (1976). This technique has become widely used in specifying tree growth and climatic relationships. A set of parameters, measured over the period believed to encompass the greatest climatic influence on tree growth are chosen as predictor variables. Mean monthly temperatures and monthly precipitation for the fourteen month period from June of the previous year to July of the current year are usually used when dealing with conifers. This set of twenty eight variables with the ring-series are subjected to principal components analysis which extracts eigenvectors (principal components) which are each independent of each other. The procedure identifies the components responsible for the major portion of the variation in ring width, and allows selection of a smaller set of the most important variables. Multiple regression analysis is carried out on the selected components. This results in a set of coefficients related to the principal components, which are then transformed in terms of the climatic parameters. These transformed coefficients are plotted with their associated ninety five percent confidence limits and this represents a response function. Fig. 6 is a response function based on the Scalp pine chronology. The parameters investigated were the fourteen month's temperature and precipitation mentioned above. The significance of each monthly precipitation or temperature in affecting ring width

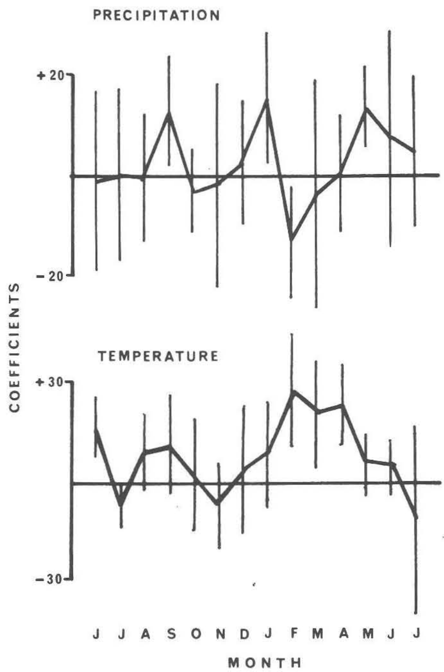

Fig 6 Response functions based on the Scalp Pine chronology. The climatic parameters used were monthly precipitation and temperature data for the fourteen month period from June of the previous year to July of the current year. The vertical bars are the 95% confidence limits.

may be either positive or negative and is significant only if the confidence bars do not intersect the zero axis. The response function indicates that monthly precipitation has little effect on ring width at this site. However, temperature has positive effects which are significant. These effects occur in June of the previous year, and February, March and April of the year the ring was laid down. In this way, the temperature effects on ring width may be broken down into monthly values, and ecological and physiological inferences may be more justifiably made. For instance, there is a marked negative effect of temperature in November, which would indicate that the tree was adversely affected by higher November temperatures. This may be explained in physiological terms as pines usually go through a hardening off process at this time, which is not properly accomplished in warmer weather.

The main advantages of this response function analysis are (1) a large number of climatic variables are included in the analysis, (2) interrelationships between these variables are eliminated, (3) the important variables are recognised, (4) the less important, or random variables which are unlikely to have an effect on tree growth are removed from the analysis and (5) the response function, in the form of plots with associated confidence limits are readily interpreted.

USES OF DENDROCHRONOLOGY

We have used these dendrochronological techniques in a study of subfossil forests preserved under Irish peat deposits. The majority of subfossil stumps and trunks are pine (*P. sylvestris*) but we also find oak (*Q. petraea*), yew (*Taxus baccata*) and birch (*Betula pubescens*).

The midland bogs developed by Bord na Mona are of particular interest as large numbers of stumps and trunks are excavated and piled up at the bog edges. These have provided us with most of our material. We have established a floating pine chronology of over six hundred years from bogs in Kildare and Offaly (this work will be fully described in a series of papers in preparation). Our chronology allows us to comment on (1) the rate of invasion of the peat surface, (2) the age-structure of the pine wood over the duration of the forest period, (3) the longevity of individual trees, (4) the length of time taken for the pine forest to die off and (5) the length of the whole forest period.

^{14}C dating has allowed us to place the forest period in time (circa 4000 B.P.) and has verified our cross-dating techniques. The date suggests that the pine period in the Irish raised bogs is equivalent to the Late Atlantic Pine Forest described from Europe (Munaut 1966, Munaut and Casparie 1971) and corresponds to the upper pine layer seen in western blanket bog (Malmer pers. comm.).

We have applied the climatological analyses to extant pines at various sites within a forty mile radius of Dublin City. The sites were chosen to present a spectrum of soil types, from the shallow Scalp soils to the relatively deep peat deposits at the edge of raised bogs near Edenderry. The sites had a variety of slopes, aspect etc. The results obtained in this way will allow us to reconstruct the environmental conditions prevailing before, during and after the pine period of four thousand years ago. In addition we have investigated vegetational changes associated with the forest period by pollen analysis.

These dendrochronological techniques have been applied in a wide range of other studies and have demonstrated correlations between ring patterns and regional environmental conditions as well as more local site factors. Ring-series from *Pinus longaeva, P. cembra* and *P. sylvestris* have been correlated with regional temperature and indirectly with glacial advances in the United States, the Alps and in Norway (La Marche and Fritts 1971, La Marche 1974, Matthews 1977). Many species have been shown to be influenced by precipitation and have been used to indicate pressure anomalies over the north Pacific and north America in historical times (Fritts 1976). At a more local level the techniques have been used to reconstruct streamflows (Stockton 1975) and water levels in deltaic wetlands (Stockton and Fritts 1973). In both of these cases the results obtained have proved particularly useful, as they showed much greater variability over an extended time period than was indicated in the recent records available. The reconstructed records were used as a basis for subsequent environmental planning. The techniques have also been used in pollution studies (Havas and Huttunen 1972, Taylor 1973) and have demonstrated the adverse effects of nitrogen dust and gaseous air pollutants on ring width.

As time progresses further applications of the techniques are being tested. They may be relevant to forestry studies as they can provide a clearer explanation of tree performance at particular sites, where the influence of regional climatic and local site factors such as soil type, nutrient status etc. on tree growth may be assessed in a realistic way.

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