

# Dendrochronology and Past Environmental Change

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**Summary.** The long oak tree-ring chronologies constructed in Ireland, England and Germany provide the background chronological framework for the archaeology of the past seven millennia in northern Europe. The chronologies also provide year-by-year records of the response of a biological system to climatic and environmental factors. Although each chronology and its consistent ring patterns can be investigated as a source of information on local change, the areal dimension provided by the geographical spread of chronologies means that comparisons can be made between responses through time.

Numerous parameters can be investigated spatially, from periods of growth initiation to periods of sample depletion, from ring-damage events to isotopic ratios within growth rings. Hopefully we can look forward to accumulating environmental information to add to the chronological backdrop. I shall consider several lines of research that have already produced indications of future possibilities.

## 1. Dendrochronology and environmental change

In northern European terms it is fair to say that dendrochronology has now supplied archaeology with precise time control. It is also fair to say that archaeology, which had barely come to terms with the interpretation of either raw radiocarbon or calibrated radiocarbon chronologies has been largely unprepared for the quantum leap in precision provided by dendrochronology. No methodology exists to deal with the integration of the new tree-ring dates with the pre-existing radiocarbon, typological and ancient historical

chronologies (Baillie 1991a). What is certain is that the number of precise dates for sites in early historic, proto-historic and prehistoric times are destined to increase; these well-dated sites will serve to mark out the course of the archaeological record and will require the rest of the archaeological record to fit itself around them. Archaeologists will have to come to terms with what could be called 'marker' dates (Baillie 1988; 1991b).

Rather similar things could be said about any environmental information which may derive from the tree-ring records. We have precise calendrical records which will supply some dated environmental information. Unfortunately this tree-ring/environmental 'kit' has come without a set of instructions and as a result techniques and approaches are having to be developed to allow attempts at reconstruction. There are basically four approaches:

i) To read off some specific tree-ring parameter as a direct indicator of some past phenomenon e.g., fire scars, moon rings, small early vessels etc.

ii) To measure some physical property of individual growth rings in the same way that measurement of carbon-14 concentrations allowed reconstruction of past variations in radiocarbon concentrations in the atmosphere.

iii) To perform regressions between tree-ring data and climate variables in the hope of forming predictive relationships.

iv) To use a proxy or indirect approach wherein parameters such as periods of tree abundance, episodes of growth initiation or synchronous tree death are used to infer environmental change.

In this article approaches i), ii) and iii) will be touched on only briefly, as their contribution to any archaeological understanding is mostly represented by hopes for the future. The main aim is to demonstrate how dendrochronology allows us to begin to document several episodes in the archaeological past where environmental change can be inferred and where, already, some pictures are beginning to emerge. One such episode, around 4000 BC, will be used to demonstrate how we may be able to integrate proxy environmental evidence from dendrochronology with pre-existing radiocarbon evidence in order to specify some events at the beginning of the Neolithic in the British Isles.

## 2. The background

Dendrochronology effectively began with attempts to reconstruct long-term cycles of tree-growth in semi-arid America. A.E. Douglass, an astronomer, was interested in relationships between earth climate and solar activity and reasoned that in the arid southwest, with almost constant sunshine, the

year-to-year variations in ring width would mostly be driven by variations in annual moisture availability. Any medium to long-term underlying trends might then be related to variations in solar output. As a result, in the early decades of this century, he produced long tree-ring chronologies and effectively reconstructed southwestern rainfall for the last 1500 years. Interestingly his basic thesis on solar variations also appeared to work and he noted that the apparently clear sunspot cycles, recorded in his chronologies, broke down in the 17th century—the Maunder minimum in solar activity (Zeuner 1958, 17). Of course the choice of location, with growth largely responding to one climatic variable, had made the task relatively straightforward.

One unfortunate side effect of Douglass's work was to fix in the minds of people that simplistic climate/tree growth relationships were to be expected. For example, in the 1960's, some workers were happily assuming that narrow rings in English oak trees were associated with drought. Indeed, on occasion, unsuccessful attempts were made to *date* ancient tree-ring records by coincidences between narrow rings and historically recorded droughts (Schove and Lowther 1957). Such attempts ignored the complex relationship between tree-growth and a range of climatic and other variables which pertain in temperate regimes (Pilcher and Hughes 1982). However one can see the attraction in attempting to identify phenomena in ring records which can be 'read off' as specific climate information and we will see an example below.

It needs to be understood that there are clear divisions between attempts to reconstruct 'climate'—which tends towards specific information—and attempts to reconstruct 'environment' where information can be much more general and much less quantified—at least in the first instance. Most recent research on climate reconstruction has moved away from the study of single trees or single chronologies to the analysis of widespread grids of chronologies. Virtually all such areal studies have as their primary aim the reconstruction of 'instrumental' style records—how wet, how dry, how cold, how hot? Working with large grids of chronologies is in part the result of the recognition of the limitations of single chronologies, however, it is also adopted as a preliminary step towards by-passing one of the most intractable problems in dendroclimatology; the problem of the use of trees from different sources in any long chronology.

With recent work in northern Europe we know now at annual resolution how some oaks and pines responded to short term alterations in climate/environment. One inevitable consequence, and we will see an example of this below, will be to move away from previous blanket assertions like 'this was a cold century' and to get closer to the reality of the very considerable variations in the seasons, years and decades which go to make up centuries. In addition, the spreading network of tree-ring chronologies should allow us to get away from the old, and previously inevitable, assumptions of the type

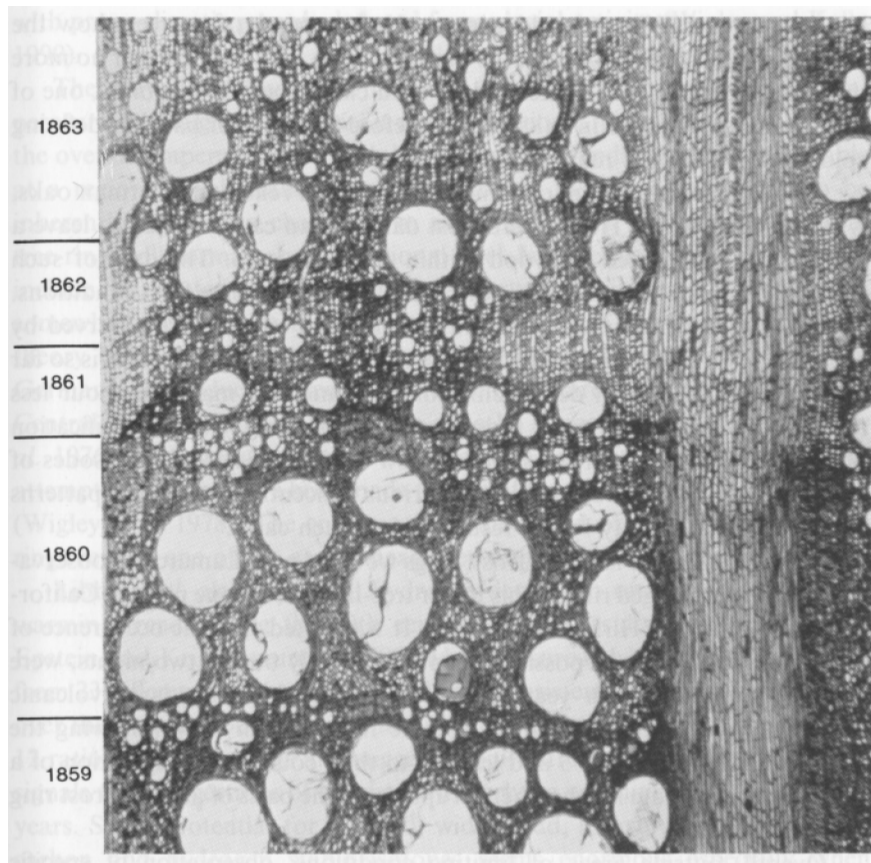
which held that 'if it was cold in Britain it was cold everywhere'. Hopefully we will begin to see the regional variability which may be the key to reconstructing changes in the past circulation patterns of the globe.

## **2.1 Direct indicator approach**

One of the most straightforward applications of dendrochronology to an environmental problem is the dating of fire-scars. In north America, where fire history has been studied extensively, records can be carried back for hundreds even thousands of years. Plots of fire frequency against time show periods when fires were rare or common. This proxy information can then be compared with environmental and archaeological information in order to separate out natural from human-induced change.

As was noted with Douglass's work, trees growing in limiting conditions can be extremely good indicators. In a more recent example, it has been observed that the narrowest 10% of growth rings in *Sequoia dendron* from Nevada show very good agreement with the Palmer Drought Index. This should allow reconstruction of frequencies over the last two millennia (Hughes 1989).

However, there can be difficulties associated with the interpretation of specific phenomena in tree-ring records. This is well exemplified in the case of an anomaly in European oak rings known as 'small early vessels' (SEV's). These anomalous rings make themselves obvious in that the hollow vessels formed at the beginning of an oak ring, usually in April to May, are abnormally small—diameters perhaps 0.06 mm or less compared to the normal 0.12 mm. These vessels fall below the resolving power of the human eye and the ring therefore appears as blurred or indistinct. The phenomenon tends to be rare, certainly in oaks in the British Isles, with only a few trees exhibiting such rings; indeed even those trees which exhibit SEV's may only exhibit one in a lifetime of several hundred years. So SEV's can be spotted fairly easily and it would be attractive if they could be related directly to some climatic variable. Existing literature from the Soviet Union (Bolychevtsev 1970) suggests that such rings are associated with severe frost causing damage to the growing tissue. However, an unpublished preliminary British study on long-lived oaks from Sherwood Forest, which attempted to relate SEV's to cold winters, could only be described as inconclusive. Interestingly, Fletcher (1975) did observe very clear and consistent SEV's seventeen years apart in the years AD 1437 and 1454 in many of the oak panels which he used in the construction of the 'English' type A art-historical chronologies. These observations were out of line with most other work in the British Isles, where no obvious SEV consistency has so far been observed. Indeed, this unusual feature served as a clue that the oaks concerned were probably not of English



**Figure 1.** Small Early Vessels in the growth ring for AD 1861 in an oak from Cadzow, Scotland. This could be a direct result of the severe cold conditions recorded for Christmas 1860.

origin. The situation was resolved and the SEV's better explained when it was proven that the oaks in question had come from the Eastern Baltic (Baillie *et al.* 1985; Eckstein *et al.* 1986). So perhaps we can still assume that there may be some relationships between SEV's and extreme cold conditions. We could therefore look to see if there are periods or areas in the British Isles in which they are more common. Figure 1 shows an extreme SEV in an oak from Cadzow in central Scotland in the growth ring for 1861. It can be seen that the spring vessels in this case are only 25% of normal size. The effect is so severe that ray tissue is also disrupted. This example highlights the problem with interpreting such phenomena. Jones (1959) cites a reference to oak being "the only indigenous deciduous tree to suffer notably from the severe weather of Christmas 1860". This seems to be evidence for a clear link

between some SEV's and cold winters. Unfortunately, few trees show the effect and it seems possible that the presence of an SEV may register no more than a single night of extreme cold or wind chill. The SEV anomaly, one of the few known to occur in oaks, may therefore form a poor basis for defining cold winters but does require proper analysis.

A related phenomenon, certainly observed in French and German oaks, is included sapwood. Here severe frost damage can cause an oak to leave a ring of unconsolidated sapwood within its main stem. The date of such obvious rings can immediately be attributed to very extreme frost conditions. Again, as might be expected with hindsight, such effects were observed by Fletcher in his Baltic timbers (Tapper *et al.* 1978). The phenomenon is so far not recorded by British dendrochronologists and this may reflect our less continental climate. However it does raise the possibility that identification of such effects in ancient trees might allow the identification of episodes of anomalous cold. The observation of curious concentric weathering patterns on some bog oaks may be the results of just such cases.

Having raised the issue of 'frost' rings we must note Lamarche's observations of frost damaged rings in his upper tree-line bristlecone pines in California (Lamarche and Hirschboeck 1984). It was noted that the occurrence of these frost effects, again possibly produced in only one or two nights, were strongly correlated with years of climatic upset following large volcanic eruptions—well exemplified by a notable frost ring in 1884 following the Krakatau eruption of 1883 and leading to their courageous suggestion of a 17th century BC date for the Thera eruption on the basis of a severe frost ring event in 1627 BC.

Overall, outside areas of limiting conditions, observation of specific effects in tree-rings which are attributable to specific causes will always tend to be rare and fortuitous.

## 2.2 Physical measurement approach

The concentration of radiocarbon in tree-rings was mentioned above as an example of a global variable which could be reconstructed by analysis of a single sample effectively anywhere on Earth. Pearson measured the  $^{14}\text{C}:^{12}\text{C}$  ratio in consecutive samples of Irish Oak from all periods of the last 7 millennia (Pearson *et al.* 1986) while Stuiver did the same, for the last 4500 years, using German wood (Stuiver and Becker 1986). So there is now a continuous record of past variation in radiocarbon concentration in the atmosphere, initially produced for correction of archaeological radiocarbon dates but now regarded as a proxy record of past solar variation. Although not overtly climatic, the radiocarbon to solar activity to Earth climate relationship has led to attempts to compare the past radiocarbon variations

with proxy climatic records deduced from glacial activity (Wigley and Kelly 1990).

The only climatic variable likely to have a global component is temperature. Although temperature is strongly regional it is clearly dependant on the overall temperature of the globe; underlying trends should be detectable at a regional level. Rainfall and pressure on the other hand tend to be inherently regional in character, so attempts to infer these variables from tree-rings will normally be at a regional level. Isotopes used for climatic study include  $^{13}\text{C}$ , deuterium ( $^2\text{H}$ ) and  $^{18}\text{O}$ . Unfortunately isotopic studies have a somewhat checkered history. The ratio of  $^{16}\text{O}$  to  $^{18}\text{O}$  in wood cellulose in theory holds the best hope for temperature reconstruction. One study on German oak produced a reconstructed temperature curve so similar to the Central England Temperature curve as to be almost unbelievable (Libby *et al.* 1976). Unfortunately other workers were less than convinced and no attempt appears to have been made to extend the record into the distant past (Wigley *et al.* 1978). The controversy remains and oxygen isotopes in tree-rings remain one of the great unexplored areas of climatic research.

Libby *et al.* also measured hydrogen/deuterium ratios and discerned a warming trend during the 19th century. Those results are borne out by Epstein and Krishnamurthy (1990) who measured the same ratios in trees from 23 different locations and found very consistent agreement on warming over the same period. Epstein and Krishnamurthy also reported carbon-13/12 ratios in growth rings and suggested quite strong and consistent climate signals with suggestions of consistent underlying warming over the last 1000 years. So the potential for detailed, widespread, measurements of oxygen, carbon and hydrogen stable isotopes seems enormous especially when coupled with the existence of precisely dated, seven millennia long, tree-ring chronologies from a number of areas.

One other physical parameter, which has been widely favoured in studies on conifers in Europe, is maximum late-wood density; which is taken to represent a relatively clear temperature record (Schweingruber *et al.* 1979; Hughes *et al.* 1984). The potential of the method is well exemplified in a recent reconstruction of summer temperatures in Fennoscandia (Briffa *et al.* 1990). In this work a linear regression equation relates summer temperature to both ring width and maximum latewood density in current and succeeding years. The resulting reconstruction is the longest so far reported at annual resolution. Their main conclusion is that for Fennoscandia at least the prevailing views on a centuries long medieval Warm Epoch followed by the centuries long Little Ice Age do not seem to hold. Most variability in their record is on a scale from years to decades. The potential in both isotope and density studies has to be considerable. Unfortunately their impact on archaeological understanding has so far been minimal.

### 2.3 The grid approach

Ideal situations for climate reconstruction are clearly those areas where growth is limited by one principle climate variable. Unfortunately in temperate areas such as Europe, such simple regressions are unlikely to be successful. The preferred approach in Europe, following the lead of Fritts in America (1976; Fritts *et al.* 1979), has been the establishment of large spatial grids of tree-ring chronologies and their regression onto climate variables such as temperature, rainfall and atmospheric pressure. The obvious complexity of regressing large grids of tree-ring data with large grids of climatic variables has led inevitably to some simplification of approach, admirably stated by Briffa *et al.* (1983) in their explanation of Fritts' procedures:

"They have used a transfer function approach where a set of dependant variables or *predictands* (such as atmospheric pressure at each of several locations, or the loadings on principal components of pressure patterns) is related, using canonical regression techniques, to a multivariate set of regressors or *predictors* (ring width series from a network of sites)".

This type of highly mathematical approach, applied to large grids of data, has so far been restricted to study of modern chronologies: in part this is because of the need for large numbers of chronologies, something not yet available for the distant past. It is also because most of the existing studies have involved attempts to verify reconstructions against existing instrumental records. Most of these exercises have been successful in showing that regression equations can produce reconstructions which account for significant proportions of the variance in the climatic data. Examples include reconstructions of English temperature and rainfall from a grid of 14 mostly British Isles chronologies (Briffa *et al.* 1983), atmospheric pressure from a similar grid (Briffa *et al.* 1986) and southern English riverflow from some seven chronologies in Britain and northern France (Jones *et al.* 1984). With more chronologies it becomes possible to undertake major experimental exercises. Briffa *et al.* (1987) used a grid of 75 modern chronologies to attempt "a series of exploratory reconstructions of European mean-sea-level pressure variations (over Europe) encompassing a number of...seasons...back to 1750". Their results were markedly good at reconstructing the known pressure patterns for the most extreme years but much less good for the remainder. It seems reasonable to assume that the current mathematical approaches will be refined and new approaches will be developed given the availability of the chronologies and the instrumental records. However, there seems little urgency to attempt long-term reconstructions until dendroclimatologists can maximise their success in explaining climatic variance from the tree-ring grids.

As noted above one of the major problems with attempting to extend such



areal reconstructions back in time, beyond recent chronologies, relates to the fact that most long chronologies are inevitably composed of ring patterns from unknown sources. The dendrochronologist, usually building long chronologies for dating purposes, links from modern trees with known site provenance to historic timbers which can only be attributed to a region. So built into any long chronology will be potential changes in tree response to climate.

The extreme case would be a chronology which extends back to trees which grew on the surfaces of bogs. It seems unlikely that such trees would have the same response to climate as modern parkland oaks. Such considerations, in conjunction with the relatively small number of long chronologies and the limited success in reconstructing climate variables has so far inhibited attempts at long reconstructions.

#### **2.4 The proxy approach**

We now want to look at the potential for identification and interpretation of phenomena in the tree-ring record which allow 'archaeological' style inferences to be made about environmental change. Although in the study of such phenomena the climate variables can seldom be specifically identified and quantified, they do frequently provide markers in the record of the ancient past which at least point to periods where detailed analysis might be worthwhile. After all, so poor is our knowledge of past environments that any information is potentially valuable at least as a starting point.

The types of information which we can glean immediately from the precisely dated tree-ring records relate to phenomena such as episodes of widespread depletion in the sub-fossil record and episodes of extreme growth reduction (presumably episodes of extreme growth enhancement would also be of interest). To give an example, if oak trees have been growing continuously on the surface of a bog for 1500 years and suddenly that bog no longer supports trees then something has changed.

We can hazard a guess that the change is environmental and that it was detrimental for tree-growth; a useful working hypothesis might be that conditions became wetter. A qualification would have to be put in to separate local effects from widespread effects. For example, oaks dying out on a single bog could be explained by some local change in drainage pattern; if oaks die out synchronously on bogs hundreds of kilometres apart then we are probably seeing the effects of environmental change (Leuschner and Delorme 1988).

Once we have specified any environmental event, we can look for other precisely-dated information with which to test our hypothesis. We can also pose the question of the likely effects of any significant increase in wetness on

early agricultural societies; if things are bad enough to wipe out oaks on bogs how were things on dry land? We can then look to the archaeological record for signs of associated change. Unfortunately, most of the time, the archaeological record lacks the time control necessary to make direct comparisons with suggested environmental effects derived from tree-rings.

Exactly such thinking has been occasioned by the discovery that some Irish oaks tended to put on their *narrowest* growth rings at the times of large volcanic dust-veil events, as marked in the Greenland ice-cores (Baillie and Munro 1988). We also know that when the Irish oaks suffered at 207 BC and AD 540 there are historical records of atmospheric effects and famines affecting human populations from Europe to China (Baillie 1991b). There are quite plausible suggestions of similar juxtapositions of environmental effects and human stress in both the 1620's BC and in the mid-12th century BC (Baillie 1989a; 1989b; 1990a). Interestingly if we hypothesise increased wetness in the 17th century BC we already know that bog oak systems which had been continuously regenerating on *both* East Anglian and Lancashire peatlands since 3200 BC, are interrupted some time after 1680 BC (Baillie and Brown 1988). However for the purposes of this paper we will concentrate on two events which allow us to draw in both environmental deductions from dendrochronology and dated archaeological evidence to demonstrate the power of this proxy approach.

#### 2.4.1 Case 1: the 208 BC event

During the construction of the Belfast 7000 year oak chronology some thousands of sub-fossil oaks were collected from northern Irish bogs. It proved possible to construct a continuous year-by-year chronology from 5289 BC to 949 BC and from 947 BC to 229 BC (Pilcher *et al.* 1984). At 229 BC ( $197 \pm 9$  BC estimated death date allowing for missing sapwood) bog oaks cease to be represented in the random collections; what happened? Subsequently it transpired that there was a large volcanic dust-veil event registered in Greenland at  $210 \pm 30$  BC (Hammer *et al.* 1980). Irish archaeological oaks show a 'narrowest' ring event at 207 BC (Baillie and Munro 1988); Lamarche observes a frost ring at 206 BC in American bristlecone pines (pers. comm. but see also Lamarche and Hirschboeck 1984). Pang and Chou (in Wiesburd 1985) point out records of atmospheric effects, summer cold and severe famines in China at the same time; Forsyth (1990) is able to accumulate similar records from early Roman sources relating to the middle of the same decade; Hollstein's German oaks show a severe reduction in ring width (Hollstein 1980); Becker and Schirmer (1977) indicate the initiation of a major phase of river gravel deposition. The Becker and Schirmer case is particularly interesting. They made a point of stressing a depositional phase

of river gravel oaks beginning in 226 BC—‘About 220 BC a renewed phase of flooding began to destroy the riverine forest...(shown by) 46 cross-dated trunks from eight exposures...(this was) obviously the most important horizon of (the) Holocene Main Valley...simultaneously evident in the Main and Danube area...’ (Becker and Schirmer 1977, 307). When this horizon was being referred to in the early 1980’s (Baillie 1982, 236) no specific environmental event was known about, so the specific 226 BC date for the initiation of a flooding phase was not regarded as significant. However now that we know of the 208–204 BC dust-veil event, with its implications for the demise of the Irish bog oaks around 200 BC, the date 226 BC from Germany takes on an added importance. Does it, as appears at face value, represent some sort of environmental downturn starting *before* the 208 BC event?—if so the 208 BC event may simply be superimposed on some pre-existing change.

The reason for raising this issue is because of the very high chronological resolution provided by dendrochronology and historical information; a few years become important in interpretation of events. It becomes important to know if Becker and Schirmer’s depositional phase really started pre-208 BC.

One key element in their 1977 paper related specifically to the dating—“...the Iron-Roman Age tree-ring patterns have been dated absolutely, following their successful correlation with the ring sequences of Roman oak bridges ...(Hollstein 1967...)” (Becker and Schirmer 1977, 307). So their ring patterns were actually dated against Hollstein’s chronology. However, we know that until the late 1970’s Hollstein had a 26 year error in his Roman-period chronology—he had mistakenly allowed the dating of his chronology, for the period before the 4th century AD, to be based on an historical reference to the bridge at Köln having been built in AD 310 (Hollstein 1980). Various workers both archaeological (Baatz 1977) and dendrochronological (Schmidt and Schwabedissen 1978) pointed out that there had to be an error in the placement of the chronology. By 1980 this error had been corrected by 26 years (a tree-ring date of AD 310 after correction became AD 336 (Hollstein 1980)). So it seems that Becker and Schirmer’s 226 BC initiation of a German flooding event, dated against Hollstein’s uncorrected chronology, should be moved forward by 26 years and actually refers to an initiation in 200 BC! If correct, and the deduction appears to be borne out by contemporary comments by Becker and Delorme (1978, 59), we can add to the list of environmental factors associated with the 208 BC event. The initiation of a 350 year depositional phase, in some German river valleys, immediately after the event suggests some significant environmental trigger mechanism. So is the observed demise of bog oaks in the north of Ireland and the deposition of river gravel oaks in Germany direct evidence for a climatic downturn which registered around (though not necessarily everywhere around) the

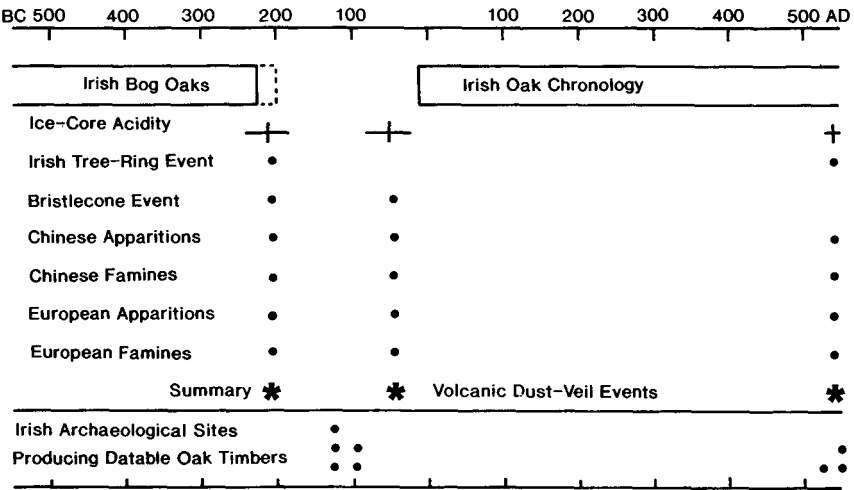


Figure 2. Accumulating evidence for three historically recorded, dust-veil related, environmental events in 208 BC, 44 BC and AD 536. The strange distribution of tree-ring dated archaeological sites in Ireland is included for comparison.

northern hemisphere? Is the combined evidence sufficient to confirm that after the 208 BC dust-veil conditions in northern Europe became a lot wetter?

Interestingly the 208 BC event is not the only one in the first few centuries BC. Although nothing shows up in Irish oaks, there is an exactly similar package of ice-core, bristlecone, Chinese and European information related to the important dust-veil event of 44–42 BC. The possible archaeological significance of these events becomes apparent when reference is made to Figure 2. When the Irish tree-ring chronologies are plotted for the period 500 BC to AD 500 the  $197 \pm 9$  BC to 13 BC gap is apparent. The indicated dust-veil events could be classed as independent information. However, it is the five tree-ring dated archaeological sites which are the most remarkable. In twenty years of sample accumulation only five Irish archaeological sites have produced timbers datable by dendrochronology in the thousand years from 500 BC to AD 500. All five lie between 208 BC and 44 BC; they are two major sections of bog trackway, two major sections of linear earthwork and the timbers from the ritual temple built at Navan Fort, the ancient capital of Ulster, in 95/94 BC. Something archaeological must have changed; perhaps new people or new social organisation or even something as mundane as changed conditions which favoured the survival of timbers.

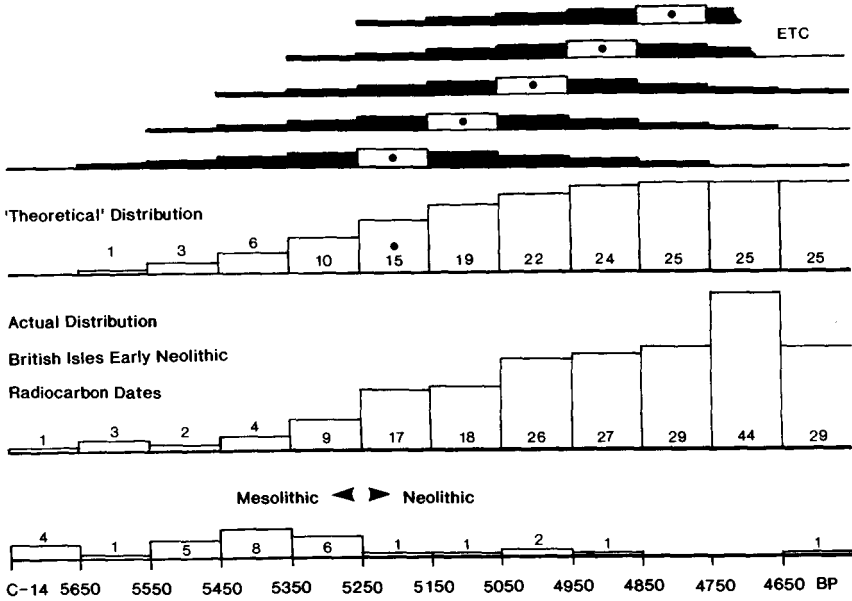
#### 2.4.2 Case 2: The early Neolithic event

If we trace back slightly further in the history of the development of the

Belfast oak chronology, there was a time, before its extension to 5289 BC, when the long chronology started at 3938 BC (Pilcher *et al.* 1977; Baillie 1982). Indeed, quite a lot of difficulty was encountered in splicing the extension onto the long chronology. Such chronology building problems are normally due to depletions in the number of available oaks (Baillie 1979). However, once the chronology had been successfully extended little further thought was given to the period of difficulty.

The date 3938 BC does however begin to take on some potential significance when, in the course of outlining an English prehistoric chronology, it is discovered that in Lancashire it is possible to build a bog oak chronology from 1680 BC to 3916 BC and another from 4023 BC to 4989 BC. Extensive random sampling fails to turn up any bog oaks crossing the period 4023 BC to 3916 BC. So in two areas, at around the same time, difficulties are associated with chronology construction using oaks which had grown on the surface of peat bogs! More interesting still, the very period at which there is a depletion in bog oaks is a period when English tree-ring workers are able to find oaks from an archaeological site, from river gravels and from submerged coastal sources (Morgan *et al.* 1987; Hillam *et al.* 1990). Indeed the last ring of the archaeological timbers—from the Sweet track in the Somerset levels—is now known to have grown in 3807 BC. Now in every case—a track across wet bogland—oaks deposited in river gravels and submerged coastal oaks—there is some suggestion of potential increased wetness or increased runoff. (The term ‘submerged coastal oaks’ is used quite deliberately in preference to ‘submerged forest’ for the simple reason that these submerged oak trees may not have grown where they are now lying but may have been deposited in these coastal estuarine sites by water action—this is currently an open question). When this is added to the bog oak depletions which again give rise to questions of increased wetness it becomes apparent that, again, something is going on; we can suggest an episode during which there was environmental change.

What may be more surprising is that in this case we may be able to bring in more archaeology than simply the Sweet Track. For the purposes of this paper all the British and Irish Neolithic and Mesolithic radiocarbon dates accumulated by the CBA up to 1980 were tabulated. These form a quite reasonable sample and they are plotted in Figure 3. Now the problem for anyone trying to work with Neolithic radiocarbon dates *and tree-ring dates* is that the two are incompatible. It is extremely difficult to convert radiocarbon dates into any sort of useful real-age ranges without extending their ranges to the point of absurdity. However, with the availability of the high-precision radiocarbon calibration curve (Pearson *et al.* 1986) it is possible to convert tree-ring dates to tight ranges of radiocarbon years. So we

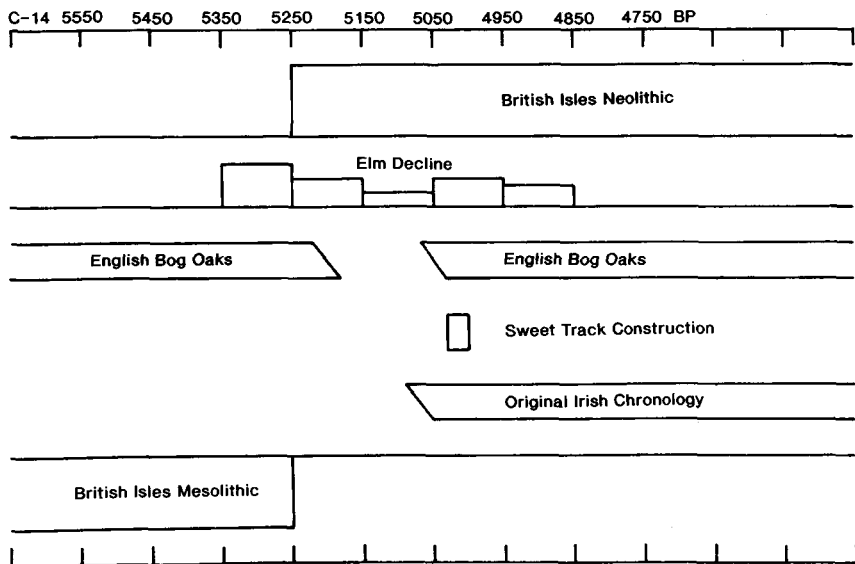


**Figure 3.** Suggested explanation for the observed distribution of Neolithic radiocarbon dates. Accumulated 'smeared' distributions for each century of the early-Neolithic (marked with dots) would account for the observed distribution. This approach suggests a sudden start to the Neolithic and demise of the Mesolithic.

can look at the environmental information in terms of radiocarbon years and compare this with the archaeological radiocarbon dates.

One obvious question in this context is "when does the Neolithic in the British Isles start?" Other workers have been seduced into belief in an 'earliest' Neolithic by the handful of very early radiocarbon dates for the Neolithic site at Ballynagilly in northern Ireland (Williams 1989) and by the occasional occurrence of cereal sized grass pollen in pre-elm decline deposits (Edwards and Hiron 1984). None of this evidence is very convincing and if Ballynagilly were taken out of the equation there would be essentially no archaeological evidence for an earliest Neolithic in the British Isles at all. The Ballynagilly dates are highly likely to have been affected by 'old wood' considerations, especially as the house was constructed using riven oak planks. Williams highlights this point but then makes the bizarre decision to *exclude* dates on the planks themselves while *including* dates on undifferentiated charcoal, and excludes the perfectly acceptable dates for the house fabric itself (*op. cit.* 512). As a non-believer in the early Ballynagilly dates, a different approach is advocated here.

Although the 'tail' of Neolithic radiocarbon dates extends back to 5800 BP (39th century bc), common sense and a realistic approach to the smearing



**Figure 4.** Simplified diagram, on a radiocarbon timescale, showing the end of the Mesolithic, the start of the Neolithic, the elm decline, a presumed environmental dislocation in bog oak survival and the construction of the Sweet Track. The close proximity of all these parameters raises the question of the role of environmental change in the Neolithic colonization of the British Isles.

of radiocarbon dates would suggest that the first serious Neolithic activity is around 5300 BP (33rd century bc). This can be justified by crudely modelling the likely spread of radiocarbon dates from the first century of Neolithic activity and accumulating similar spreads from each successive century. This approach can be justified on the strength of the eight century spread of 90% of the 62 routine radiocarbon dates associated with the English Neolithic tree-ring complex (Baillie 1990b). The effect of such modelling is shown in Figure 3 and the fit to the observed distribution suggests that this approach is on the correct lines. It is interesting to note that the main cluster of Mesolithic radiocarbon dates ends around 5400 BP (34th century bc).

In Figure 4 this simplified Mesolithic transition is indicated along with the spread of radiocarbon dates for the (almost certainly synchronous) elm decline (Edwards 1985), the accurate 'radiocarbon' dates for the English bog oak 'gap', the Sweet Track and the original end of the Belfast long chronology. It may be an illusion but it is possible that in this Figure we may be able to 'see' the Neolithic colonisation of the British Isles in an environmental context. Given the close proximity of something environmental happening at around the time of the colonisation, the question then becomes whether the Neolithic colonisation was prompted by some environmental pressure?

It should be noticed in this context that *two* German tree-ring laboratories

also experienced difficulties in their chronology construction around 4000 BC (Leuschner and Delorme 1984, 1988; Becker pers. comm.); so the environmental event, if there was an event, may have been widespread and extended in character. It would be a pity to leave this discussion without making one minor point. It is worth pointing out that the placement of the Sweet Track does, as would always have seemed sensible, fall *after* the suggested start of the Neolithic. This is important because the two dates are, to a large extent, arrived at independently.

What does this all mean? We have looked at two episodes where dendrochronology supplies not only time control but hints of environmental change. Irrespective of the fact that we cannot quantify those changes in degrees centigrade or in millimetres of rainfall, we can assert with some conviction that there is more than a suggestion of both environmental and social change at these times. We can also reasonably ask what else was going on at the same times which might be traced in the archaeological record. Dendrochronology is opening up a new kind of window into the past and suggesting significant events which until now have been virtually invisible. We have looked at two examples but there are others with every bit as much substance, for example at AD 536 (Baillie 1991b), 1159 BC (Baillie 1989b), 1628 BC (Baillie 1990a) and 3195 BC (Baillie 1989a). Obviously there must be others. At least some of these are periods of abrupt change and suggest that the concept of punctuated equilibrium requires further consideration in the archaeological record.

### 3. Conclusion

There appears to be unlimited potential for the reconstruction of various aspects of past environmental change from tree-ring records.

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