CLIMATE IN MEDIEVAL IRELAND

AD 500-1600

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PREFACE

The genesis of this dissertation grew out of a seminar paper for an undergraduate course on Climate Change taught by Pete Coxon in Trinity College, Dublin. Through the obscure workings of fate this was given as a lecture to the Association of Young Irish Archaeologists and published in a somewhat mangled form the same year under the title 'Climate Change and the Gaelic Annals' (Cantwell 1998 15-20).

At that time, given the quantity of entries in the Annals and the general interest in Climate History it was somewhat surprising to find that the literature, with the exception of a few works such as Wilde (1856), Britton (1937), and Lyons (1989), the field was completely unexplored. After a review of the possible sources the conclusion was drawn that these Annals and the Dendrochronological record were the only data sets that continuously covered the medieval period of AD 500-1600. At the time of writing (1998) the available Dendrochronological record was kindly given to me by Mike Baillie in indices form. At that time I had neither the expertise or training to make any headway with the exception of the realisation that they do not contain long term changes and that it was also difficult to make any correlation between indices and volcanic activity.

This work continues the research of this neglected subject

I wish to thank Mike Baillie for providing me with the data and for guiding me through the process as well as for his support and discussions throughout the year.

I would like also to thank Christian Pfister and Jurgen Luterbacher for useful discussions of the work in progress in July of this year.

My appreciation also goes to Fiona Fitzsimons who read some of the chapters and taught me lessons on editing, clarity and style.

To Cathy Dunne for our friendship.

To my children, Tadeusz and Jasmin, for permission to flee the nest and to them I dedicate this work.

"It may be a lie, but it will do 'til a bigger one comes along".

On Broadway, Damon Runyon (1928)

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INTRODUCTION

The aim of the dissertation is to reconstruct climate in Medieval Ireland using documentary and dendrochronological proxy data from Ireland and Northern Europe.

There is no comprehensive explanation for climatic change in either the long or short term. The overall external motor is solar forcing and other important influences are oceanic currents, atmospheric systems and the interplay between them. Other contributory factors are the earth's magnetic field and tectonic activity. None of these can be taken in isolation as all create feedback, either positive or negative, into the planetary climatic systems. It is important not to see the planet as a passive receptor of influences with predicable outcomes but a dynamic open system with inputs and feedback of varying magnitudes that can result in gradual or instantaneous change. The potential changes are unpredictable and developing research into Chaos theory may give further insight into some of the past and present climatic dynamics. Further complicating factors are stochastic terrestrial and extra-terrestrial events, which can influence climate by blocking out solar radiation for a number of years depending on the event's strength and global coverage.

The issue of regional climate change in the historic period is of importance because regional variations of climatic cycles have only begun to be researched in the last twenty years in Europe. Before 1980, historical climatologists tended to treat Europe as a homogenous region with uniform climatic periods. When European climate is compared to what can be deduced about Irish climate, in terms of the relative importance of oceanic and continental weather systems, it should be possible to a develop a regional synthesis relevant to Ireland. It was decided that rather than

attempt to fit Ireland, 52-55°N and 6-10°W, into the continental region, i.e. Northern Europe or Western Europe, it was reasonable to posit a region called the North West Atlantic Region, as a perspective for researching the primary influence of oceanic weather systems.

Since the 18th century instrumentation has become the standard methodology for the measurement of climatic parameters. Before then a wide number of proxy records have to be used, all of which have advantages and disadvantages. Within an Irish context the most complete in terms of coverage are documentary sources, *Quercus* tree-ring widths and palynological records from lacustrine and peat sources. The sources used in this dissertation are the Gaelic Annals and *Quercus* tree-ring widths, Other proxy record types, where they survive, do not have the requisite temporal definition for annual reconstruction.

Climate in Medieval Ireland is examined using two different methodologies. The first is the methodology of seasonal weather analysis pioneered by Pfister and the EURO-CLIMHIST programme for the scientific analysis of documentary sources and is supplemented by Lamb's similar research methodology on English climate. The second methodology is the analysis of *Quercus* tree-ring widths from Ireland and northern Europe. Both approaches are experimental though in the former methodology there is a ten-year publication record with which to make comparisons unlike the latter for which there is minimal literature and published methodologies.

Pfister (1995 332) states that the best climatic reconstructions are conducted by scholars who are:

- Native speakers of the language in which the sources are written
- Trained to distinguish between reliable contemporary and unreliable non-contemporary information
- Familiar with the economic and natural properties of the particular natural, social and institutional environment, in which the documents were created.

To which may be added:

- Familiar with the particular sciences involved in data interpretation and putting them into their environmental, historical and geographical contexts.

This author does not qualify as a native speaker of Gaelic (Primitive, Old, Middle or Early Modern) or Latin. The second point is not an issue as, according to the strict criteria laid down by the EURO-CLIMHIST programme there are no 'reliable contemporary' annals for Ireland and they are therefore not suitable for climatic reconstruction. The dissertation argues that they are reasonably consistent with each other and chronologically reliable. It would be unreasonable to ignore this wealth of data from a region for which there is no other information, especially when the focus of modern climatic research is an understanding of regional patterns. As for the third and fourth points, readers may make their own judgment.

The format of the dissertation is as follows: the first three chapters are introductory reviews of the Gaelic Annals, dendrochronology and climate in Ireland. The fourth chapter is a description and discussion of the research methodologies used. The next two chapters discuss the dendrochronological results and the following three offer a climatic reconstruction of the medieval period. Where possible links between dendrochronological and documentary results are noted. The last chapter concludes with conclusions, a discussion of the relevance of the findings to Irish social history and research recommendations.

Dating conventions

The calendar year, from 1st January to 31st December in the standard historic BC/AD classification, is the chronological format. When winter events began in December and continued into January, February and/or March, they have been counted once in the second year. All BP (before present i.e.1950) dates are standard calibrated radiocarbon years.

For the purposes of the dissertation the Medieval Period is taken to be from AD 500 to AD 1600. The traditional historic dates for the same period are c. AD 500-1534, which is followed by the Early Modern Period.

Dendrochronological data

All tree-ring widths in charts and tables are given as whole numbers where 100 represent 1mm. The agreement of 100 (1mm) with standard indices based on a value of 100 is a coincidence.

GAELIC ANNALS: AN INTRODUCTION

The potential of the Gaelic Annals as a source of data for the research of the history of climate change in North Western Europe during the medieval period has not been adequately appreciated. Firstly a discussion of what the annals are and how they came to be compiled would be useful. This is followed by an examination of their place in the overall context of Irish and European literature in the medieval period as well as a review of how these sources have been used for climatic reconstruction.

Origins

The annals are believed to have originated from written calculations for the date of Easter. These paschal tables were introduced into Ireland at least by the development of the monastic period in the late 7th and early 8th centuries but may have been here earlier with the introduction of Christianity in the 4th century. The methodology for computing accurate Paschal tables caused ongoing controversies in Europe at this time. Irish monks, in the early 7th century, based their calculations on an 84 year cycle derived from the Galician church of the 4-5th century. These computations were superseded by a work known as 'Cunniam's letter' (written c. AD 633) and a related text by the same author, *De ratione compuntandi* (O'Croinin 1995 201). It has been argued that from c. AD 700 monks got into the habit of writing some of the major events of the year onto the table's margins under the influence of European chroniclers from Antiquity, such as Eusabius and Jerome, (O'Croinin 1983 pp.74-86). These occasional entries developed into regular compilations, were expanded over the centuries and continued until the end of the AD 1500s; though with one major hiatus at the end of the 12th century.

It is likely that by the 12th century most major monasteries had an ongoing compilation as part of scriptrorial policy. However the course of Irish history has resulted in the destruction of all original annals. All that has survived is a number of copies and one translation, made in the late medieval and early modern periods. These collections are in Irish, Latin and Stuart English and have been published over the last 150 years, sometimes with translations of variable quality. The material is primarily necrologies, church and secular events and includes weather and other miscellanea (Mac Niocaill 1975 335-75).

The history of each particular compilation can be found within the introductions of published editions and in a number of secondary works. Suffice to say their origins are subject to continuos research and a partial picture of their respective histories and 'genealogies' is now emerging. It is now possible to say where they were compiled, in what periods, as well as argue how a particular political bias can indicate within which area of the island the annals, or part of, were compiled or copied. This has led to the realisation that these compilations do not necessarily have one point in origin but can come from several different monasteries and have been added together or copied at later periods. The terms 'original' and 'contemporary' have to be used cautiously as these concepts were not deemed important by medieval monks.

As all sets of Gaelic Annals are copies, consideration has to be given to possible editorial biases. It is now argued that most Irish literature went through a continuos process of copying. Internal examination of the literature shows how the process of redaction reflects the changing nature of political life and of the monasteries' role in

perpetual political power struggles. A comparison of the subtle changes in the copies over time allows historical reconstruction.

History

It is possible to discern three major cultural periods with there own trends and these can be roughly dated as AD 500-1100, AD 1100-1500 and AD 1500-1600. These are not coterminous with the evolution of the Gaelic Language defined and roughly dated as Primitive Irish before AD 600; Early Irish AD 600-900; Middle Irish AD 900-1200 and Early Modern Irish AD 1200-1500.

The first period, AD 500-1100 includes the establishment of Christianity into Ireland. Annalistic entries are usually short and not very informative, mythology and poetry is common. After about 700AD-800AD the quality of the information, from a 20th-21st century perspective, improves though care has to be taken with interpretation, given the considerable cultural differences of the last 1,000-1,500 years. From the middle 11th century the Church Reform movement started to influence the organisation and literary output of Christianity on the island. The reform process was accelerated by the arrival of Richard fitz Gilbert de Clare at the end of the 12th century as it inaugurated a major series of invasions and conquests, which led to the ultimate colonisation of most of the island by the end of the 17th century.

The combination of Church Reform and conquest caused a major hiatus in the keeping of Annals and the practice was temporarily abandoned in many of those monastic foundations that survived. After about AD 1250-1300 the practice was reintroduced in some monasteries from both cultural traditions though the Gaelic

predominates. Within the context of the period it was not the Annals that were considered wrong but it was the 'primitive' and 'superstitious' entries that caused offense to 12th century European intellectuals. Entries, from c. AD 1250, show a greater attention to detail and their accuracy and dating is more to modern research tastes though care still has to be taken in understanding the political and cultural context of any particular entry.

After about AD 1550 the impact of the Reformation and the Renaissance began to influence the Annals and they make a transition to narrative chronicles, particularly in the Annals of the Four Masters.

It is also worth noting that two of the major compilations, viz. Annals of the Four Masters and Annals of Clonmacnoise, date from the 17th century. The first is the result of a literary rescue operation set up when it was recognized that the very nature of Gaelic society was under threat from Tudor political expansion and Church Reformation. In the case of the Annals of Clonmacnoise the translation is in Stuart English and is not overly trusted as the original is missing. Again great care has to be taken with these two compilations in the former case with interpretation, as one has to appreciate that what we have are Renaissance perspectives of medieval history and mythology (Simms 1987 1-3). These are not necessarily sympathetic and this can be seen from the introductions of Michael O'Cleirigh and Conell Mac Geoghegan.

Interpretation

Overall the content of the annals have to be used with caution. Any interpretation must be in tune with the significant changes of the structure and expression of Gaelic

culture over the period, notwithstanding the impression given by medieval literature of an unchanging society. The modern interpreter must also be aware that the medieval concept of history was based on a providential perspective, i.e. that history reflects God's plan before the Second Coming of Christ. It is also worth noting that the last famine was over 150 years, or five generations, ago and this is the longest period between famines in recorded history. Historians forget the insecurity and uncertainty created by famine, plague and endemic violence, both real and potential, at their peril.

Weather events are unlikely to have suffered from editorial manipulation over this period, as there would be little advantage in doing so. There are, however, a number of other problems. Without recourse to the originals it is impossible to say whether the copying was complete or accurate. It is possible that when the entries were subsequently rewritten it was not necessarily in the same way, and this can lead to distortion, misinterpretation and, sometimes, total loss of meaning. Other problems include piecemeal destruction as described by Mac Geoghegan:

> "... Taylors to cutt the leaves of said Book & sliece them in long peeces to make theire measures off." (Annals of Clonmacnoise, translators introduction)

Chronology

Chronological issues are important and can be subdivided into the overall temporal framework and the dating of any particular entry. Though the period of literacy dates from the AD 700s the monastic communities inherited oral histories and these chronologies are believed to have been re-calculated to fit in with Biblical

chronology. The reason for this is related to the early Christian Church's search for their origins and how they fitted Irish history into Post-Flood migrations as described by the Old Testament. Historians now believe that Iron Age oral history and traditions were heavily reworked and fairly reliable dating starts about 500AD, material before then has to be used with extreme caution (reviewed by McCarthy 1998 98-116).

It must be noted that this assessment of chronology is based on the accepted historical models of the transmission of literacy and spread of Church literature, but there is no independent research from other academic disciplines. An interdisciplinary research programme would be useful here. McCarthy's recent article (McCarthy 1998 98-152) on the chronological apparatus of the Pre-Patrician Annals is a convenient starting though it focuses exclusively on the non-Irish material and has no discussion on how this may compare to the Irish material. It has to be said that it is easier to compare the non-Irish material with other European sources because the Irish material is rarely comparable with non-Irish literature. The influence of Christian chronology on the traditional oral chronology is not yet fully understood.

It is possible that significant natural events were important 'architectural' features in the chronological framework of oral traditions into which human events were then inserted. If this is the case natural events were less likely to suffer from 'loss of memory' unlike obituaries of early church founders, such as St. Patrick, who appears four times in the Annals of Ulster (O'Croinin 1995 26). This type of duplication is not found for natural events. Since the middle of the last century the issue of chronology has been explored in some detail and historians appear to be reasonably happy with the calibrations of the individual sets of Annals though they might dispute the dating

of any one particular event. A recent article that used astronomical data as a control found that the Annals of Ulster are accurate back to AD 773 with only a two year error before then back to the 5th century (McCarthy & Breen 1997 1-43).

There are sometimes differences of up to five years between the reporting of the same event in the different annals, particularly before AD 950, after about c. AD 1200 there is almost complete agreement. These differences are probably due to 'slippage' while copying, and this gives rise to the problem of chronological control of any particular entry. In general terms the Annals of Ulster are deemed to be the most accurate and the standard by which other sets of Annals are calibrated. An allied problem is the duplication of events in the Annals. It has been argued that this duplication has been has caused European climate historians to misinterpret the data by suggesting that certain periods were worse than they actually were (Pfister *et al* 1998 537). This is rarely seen in the Gaelic Annals.

Irish literature in a European context

These compilations can also be discussed within the context of European literature. Up to the 6th century the most important European historic sources are the Mediterranean Civil and Christian authors, based mostly in Rome and Constantinople. Literacy was principally a church profession after the collapse of the Roman Empire and was used mostly, if we exclude theological and related works, for writing history and developing the administrative apparatus for the Papal territories and the nascent Frank Empire. Over time there was an expansion in the number of manuscripts, about 7,000 manuscripts survive from the Carolingian period as compared with 500 from the Merovingian Court before AD 750. There was a decline of manuscript production

in AD 900-1000 believed to be due to the combined impacts of invading Hungarians, Vikings and Slavs. Manuscript production increased significantly thereafter due to the combined influences of the expanding Ottonian empire; foundation of Universities; and influence of the Latin and Greek scholars with texts who came to Italy after the fall of Byzantine empire (Pfister et al 1998 536-7). Literacy began to be used more within civil society particularly in relation to the control and administration of land and feudal relationships. A further major expansion occurred in the 15th century when the Church lost exclusive control of literacy because of Humanism and the first stirrings of scientific investigation.

In Ireland all early literature was imported from Antiquity, via France and Spain, and became the basis for future literary endeavors though this was influenced by established Iron Age oral traditions. The Early Medieval corpus contains the Annals and a large quantity of Law texts (*Seanchas* or *Peritia*); Latin and Gaelic educational texts; hagiographies; poetry; mythology and pseudo-history; as well as copies of the most important theological and associated works. The earliest manuscripts are from the late 5th century and production significantly increased after the foundation of monastic schools in the middle of the 6th century. Ireland also has the oldest vernacular literature in Europe dating from the 7th century at the latest (O'Croinin 1995 169-95). Most of this vast corpus is still in manuscript form or appears in published editions of varying quality over the last 150 years.

In comparison with the rest of Northern Europe, Gaelic literature represents a culture without a centralised kingship with associated court administration and is unique because Ireland was never directly affected by the expansion of the Roman Empire.

However, the original belief that Ireland single-handedly dragged Europe out of the 'Dark Ages' is now not accepted by Irish historians (O'Croinin 1995 196-232). In terms of quantity and coverage Irish literature is far superior to any other collections in Northern Europe until the 9th century.

Thereafter there appears to be a literary decline in Ireland and by the 11th century the number of Irish manuscripts were a small fraction of the European total. According to Pfister (1998 537) the combined total of Irish and British references to climate amounted to 2% of the total in AD 700-1300, though it is unclear whether any of the Gaelic material has been included due to it's non-contemporary nature. It would be useful to have these analysed by century as Ireland and Great Britain may show higher proportions for earlier centuries.

There are only a few, but essential, medieval works dealing with environmental topics in Ireland. These include an early 7th century description of Ireland by an anonymous author who used the pen name Augustine, entitled *De mirabibilus sacrae scripturae*; the *imran, Navigatio Sancti Brendani Abbatis* (about 120 known versions); and *Liber de mensura orbis terrae*, written c. AD 825 by Dicuil, a monk attached to the Carolingian Court. It is likely that a research programme into such Irish sources would provide complementary proxy climatic information for the early medieval period. A similar project is being currently carried out at the University of Ioannina, Greece, into Greek and Byzantine sources (Telelis & Chryros 1992 19-20).

From the 12th century there was a temporary decline in Gaelic literature until the mid-13th century but this is somewhat compensated by the introduction of Royal, estate,

legal, urban and local administrative records though these mostly only cover areas under Anglo-Norman control. From the mid-13th century there is a resurgence of Gaelic literature in competition with Anglo-Norman literature, though acculturation processes were a major influence. In the 16th century Renaissance, Humanism and the Counter Reformation inspired modernised monasteries, such as the Franciscan Order of Donegal, who were responsible for the Annals of the Four Masters and the copying of other Gaelic literature. The continuos literary tradition compares very well with the rest of Northern Europe, outside of the core Roman Empire, for example east of the Oder River literacy was not introduced until the 10-11th century.

Obviously it would be ideal to compare the Irish Annals with European literature. However this is a difficult task as they are dispersed widely and quantity of critical texts with adequate translations is limited. A major exception is the collection known as *Monumenta Germaniae Historica Scriptores* consisting of 33 volumes (Pfister *et al* 1998 536).

European Literature as a proxy source for climate research

There is a long tradition among a small number of historians and scientists who have used documentary data for the purposes of climatic reconstruction over the last 100 years, from northern Europe in particular. Their research publications have been critically reviewed over the last twenty years and have been found wanting. Modern researchers now criticize earlier researchers for having an uncritical approach to their source material by not fully discriminating between contemporary and non-contemporary sources. They also argue that earlier researchers often misunderstood the various styles of Calendars, mis-dated events, multiplied extreme events and

constructed incorrect climate chronologies (Pfister 1998 538 and Grove 1988 3). For instance Grove argues that this imprecision has caused scientists to have negative or agnostic attitudes to documentary sources (ibid. quoting Bell & Oglivie 1978 331-48). Modern authors therefore advise caution in interpretation and their present focus is on meticulous scientific exactitude where possible. However literary climatic research still remains controversial and some researchers question the validity of using such data (Landsberg 1985 28-30). This type of, possibly, extreme opinion has now been largely rejected as further progress in documentary analysis has been made in the last twenty years.

In some countries the scientific community tends to avoid the historic period, due to unpredictable anthropogenic influences, and the optimistic belief that historic sources will provide enough data to build environmental recontructions, as distinct from climatic history, (i.e. Edwards 1985 215). However many sources are ambiguous and not easily datable, which this gives problems of interpretation.

Lone researchers until about the 1960s have usually conducted historical climate research when some Universities began to specialise in the subject. In England under the influence of Manly and Lamb the University of East Anglia set up a Climatic Research Unit. Lamb developed historic climate research as an academic discipline in England and though his ideas are being criticised he is still the inspiration and benchmark of modern research. One of his major contributions was the development of synoptic maps of barometric pressure, which give geographical coverage of a time period as distinct from a time-transgressive series. This provides new insights into the regional variations of extreme climatic events.

The next major development was the founding of the EURO-CLIMHIST project in 1990 with three main aims (Pfister *et al* 1994 330):

- As a means to investigate the causes of climatic variation on two fundamental time-scales: decedal and century
- As a means to investigate the relationship between climatic variability and changes in the frequency and severity of anomalies
- As a tool to assess impacts of climatic changes on pre-industrial economies and societies both in the short and long-term.

Their major contribution has been the development of indices for the measurement of temperature and precipitation. The idea of indices is not new and have been experimented with since the 1920s by such researchers as Easton, Brooks and Vanderlinden and more recently by Lamb, Manley, Alexandre, Buisman & van Engleman and Pfister etc. (Glaser *et al* 1999 170 & Pfister *et al* 1998 536).

Pfister's indices have been integrated into the EURO-CLIMHIST project and have since been standardised and computerised and form the basis of their research some of which is in conjunction with PAGES (Past Global Change) under the auspices of the IGBP (International Geosphere-Biosphere Programme). This database has approximately 600,000 pieces of data from AD 750 of which 8,850 are for the period before AD 1300. Primary work was done on verification by contrasting Pfister's indices with instrumental data. European studies now include work on the Maunder Minimum, AD 1675-1715; the 16th century; the 14th century; and the early medieval

period. These studies cover seasonal weather patterns for the 16th-18th centuries and before then concentrate mostly on winter temperatures. At this stage there is a year by year understanding of the major atmospheric system patterns back to c. AD 1500, excluding Ireland (Pfister pers. com.).

The source material in Europe used for the indices are Annals; Chronicles; estate records; administrative records relating to the timing, amount and quality of agricultural produce; financial records of rents, prices, tithes and taxes; cultural events such as rogation ceremonies; ship's logs and weather diaries. Annals and Chronicles are extant for northern Europe back to 8th century and the vast majority of other record types survive from the late AD 1400s.

Medieval climate research in Ireland

Medieval climatic research is practically non existent in Ireland though some research has been published, particularly by Wilde in the late 1840s, Britton in the 1930s, and Lyons in the 1980s (see bibliography). In them climate is primarily a backdrop to the exploration of famine and disease on the island. The secondary literature on the history of medieval Irish climate is very poor, if not completely non-existent. Unfortunately there is no interdisciplinary research between historians and scientists in Ireland unlike Europe or the positive relationship that currently exists between archaeologists and palaeoecologists. This has had a knock on effect in the rest of Europe where the Gaelic sources are largely unknown, rarely appearing in Bibliographies and lists of Source Material (i.e. Lamb 1982). According to the EURO-CLIMHIST programme Irish climate history is largely unknown (Pfister pers. comm.).

It is worth noting that Ireland lacks most of the above mentioned late medieval and early modern documentary types because there was a poorly developed central and local government, and therefore few records were kept. During the period AD 1450-1680 the political situation was too unstable for the development of a Renaissance literature. There are some surviving Court, Administrative, Legal and Administrative records, AD 1200-1600, but these are patchy and from the climate historian's perspective not very informative. One example of the use of Estate records was by Lyons (1989) who attempted to quantify the effects of the Black Death but found that the records were so fragmentary that only tentative conclusions could be drawn. Many medieval manuscripts were unfortunately lost in 1922 when the Public Record Office of Ireland was destroyed during the Irish Civil War.

Historians have mostly ignored the data with some exceptions. By and large the tendency is to pick weather entries as part of the backdrop to their expositions and use Lamb (1977, 1982 & 1995) as a general source, notwithstanding the fact that he rarely refers to Ireland. Generally they don't appear to rate climate or climatic change of being of any particular importance. In this they are not alone as many European historians share the same ideology of political and cultural determinism. Recently scientists have used them as a source for catastrophic events, which have short or long-term effects on the environment and human population (i.e. Baillie 1995 & 1999). In both cases the entries, while of potential significance, are missing the overall climatic context.

In conclusion the Irish Annals have not been used as a source for the reconstruction of climate and climatic change for the medieval period. This however is only part of the problem because, compared to the rest of Europe, climatic research is undeveloped in Ireland by nearly all academic disciplines.

DENDROCHRONOLOGY: AN INTRODUCTION

This chapter will discuss the origins, nature and applications of dendrochronology and the advantages and disadvantages of the science as an analytic tool for climatic and environmental reconstruction.

Dendrochronology was developed in the early part of the 20th century and was quickly adopted as an analytic tool for chronological, solar cycle and climatic research, most notably among pioneers such as Douglass and Shvedov (Robinson *et al* 1989, 1-21). Since it's initial foundation the basic principles of dendrochronology have been established and the science of measurement and art of interpretation of tree rings has expanded. The practical applications of the science are widespread and range from the reconstruction of temperature and precipitation as a proxy for climate; absolute dating and social reconstruction within archaeological contexts; radiocarbon calibration; and the dating and scaling of stochastic environmental events.

The first major principle to be established was that different trees of the same species could be cross-dated. Research has shown that it is possible to develop absolute comparisons over a wide geographical area. This has allowed the construction of chronologies for a number of different species, of which the most notable are *Pinus* and *Quercus*. However there is not global coverage, for example hardwoods in Tropical Rain forests are difficult to analyse and environments, with extreme climates, there is a lack of vegetation suitable for this type of research.

The second principle is that response to climate signals, particularly, temperature and precipitation, is measurable and standard not only across any one species but is broadly comparable between species and that the mean chronology is the climate minus local signal (Baillie 1980 7-8). However measurements made for chronological purposes are not necessarily suitable for this type of analysis, as they are not necessarily climatically sensitive to the same degree (Pilcher 1980 148-50).

The research literature over the last twenty years has been largely exploratory with status reports on the development and applications of dendrochronological data from around the world. There have been advances in the statistical analysis of tree ring widths; ring densities; cell size; earlywood to latewood ratios; heavy metals and isotopes. The role of data standardisation is now an accepted part of the analytic research procedures, particularly in climatic research. This has resulted in a shift in emphasis as methodologies are now designed for the best analysis of specific questions relating to climatic signals and other environmental influences (Cooke & Briffa 1989 161). Statistical procedures are becoming increasingly sophisticated especially with the growth of computing power.

The International Tree-Ring Data Bank, University of Arizona, collect all known data sets and research publications. By 1996 they had 3,275 tree-ring chronologies and 2,804 tree-ring data sets from over 1,500 sites representing over 100 tree and bush species contributed by 139 researchers (Grissino-Mayer & Fritts 1997 235-8). Information on this collection can be accessed through Grissino-Mayer's web site (www.grissino@utk.edu) though the above statistics remain the same, as they have not been updated since 1996. It is now possible to access chronologies through the

World Wide Web in lieu of published sets, though some dendrochronologists have reservations about making their work freely available because of possible misinterpretation and commercial considerations.

Methodology

The formula for determining the influences for any individual tree is:

$$R_t = A_t + C_t + \delta D1_t + \delta D2_t + E_t$$

This states that a ring-width (R_t) series equals the combined influences of age related biological (A), climatic (C), endogenous (D1), exogenous (D2), and other random (E) factors over time. The growth trend of any particular tree is a function of its age, environmental milieu, combined climatic factors and stochastic processes. It is therefore necessary to sample a number of trees to find the mean growth trend as this allows the separation of the climatic signal from other 'noise' (Cook 1989 98-104). The sampling procedure of trees is determined by the research to be undertaken and is covered in most methodologies (Schwenbruber & Kairiukstis 1989).

A site is chosen and a sample number of trees are cored and the tree-ring widths measured. The measurements within one location are then aggregated; the mean is calculated and is called the site mean. The aggregate of a number of site means will give a regional mean and is often called the master chronology. This procedure has the benefit of eliminating biological and other local random endogenous and exogenous factors (Baillie 1982 pp. 68-92). Differences in local chronologies are thought to be due to site differences and not geographical distance (ibid. 101). The

implication of this latter hypothesis is that the definition of a region cannot be geographically determined.

Tree-ring influences

The contributing complex and interrelated factors that make up a tree-ring are discussed next. The main biological factor is ageing. In theory tree-rings are wide when the tree is young and narrow as it ages but this is rarely seen in Nature due to other influences.

The main interconnected climatic factors are temperature, precipitation and wind. Temperature is a function of the solar output absorbed by the atmosphere. In some locations there is a strong correlation between ring-widths and solar cycles, such as sunspot activity and cosmic ray fluctuations (Bitvinkas 1989 333 & Kocharov 1989 295-6). The relationship between solar cycles and the heat budget in trees from temperate areas is unknown.

Precipitation is a more complicated variable as trees respond to water availability, which is the sum of precipitation; soil moisture qualities; drainage patterns and water table levels. Soil undergoes complicated chemical changes over time and this can have a knock on effect on drainage, which can then influence water table levels. Water availability is also influenced by changes in underground topography particularly in karstic areas, changing sea levels and isostatic rebound. A calendar or hydrological year, therefore, does not necessarily have a high correlation with precipitation because the combined effects can last for a number of years. It is possible that response can lag up to five years as recent unpublished research

indicates that if Palmer's Drought Index is inverted and shifted forward for five years there is a very good visual match with 20th century tree-ring indices (Baillie pers. com.).

Wind provides its own unique events and in Ireland is usually related to the strength and direction of the prevailing wind. On exposed maritime locations salt laden winds add an extra burden to local vegetation.

Endogenous factors are the internal biological and chemical influences unrelated to ageing. The main exogenous factors include environmental characteristics and competition. Environmental factors include the whole mix of geological and geomorphologic contexts and processes in the short, medium and long-term. Competition between trees have a major influence, for example a tree on its own usually has wider tree-rings than a tree surrounded by others of a similar age or size.

Random factors are caused by many types of stochastic events and originate from atmospheric, biological, geological, geomorphological, astrophysical and anthropogenic processes. Their impacts can vary from a narrow ring for a year to the death of a tree.

None of these biological, climatic or environmental factors stand alone in the tree's ecosystem, a complex series of physical, chemical and biological inter-relationships create positive and negative feedback. These inputs affect the tree on a number of different time-scales, seasonally, annually, or diffused over a longer time period. The

widths of tree-rings are the result of these interactions and reflect the totality of a tree's reaction to its specific environmental history, in its broadest sense.

Analysis

For the purposes of climatic research tree-ring widths must be manipulated statistically to eliminate environmental and biological factors by the process of standardisation. This is a purely statistical procedure, achieved by fitting a curve to the data, which then computes all variations from standard 100 indicia, expressed as a straight line. Many types of curves are used, i.e. oaks are polynomial and conifers are exponential, and can either be loose or tight depending on the time-scale of information to be presented. Tight curves give short-term information while loose curves are better for longer time-scales. However in all such procedures long term changes in the overall trend are eliminated. It is also important to note that all indices are purely statistical and are not based on the biology of trees.

Ideally it would be possible to compute growth indices, i.e. to give the expected growth in any given year based on the tree's biology alone. The actual widths could then be 'corrected' and thus long-term trends could be preserved. However in practise this has proved impossible for *Quercus* though some attempts have been made to use exponential curves with conifers (Baillie 1982 86-91). A methodology that, therefore, excludes biological and other factors but keeps long-term trends has not yet been developed.

Dendrochronologists generally use these statistically derived indices for all their research programmes. Statistics and computer programmes have become increasingly

sophisticated and there is a lot of exploratory published work on the use of these techniques from this perspective. The basic procedure consists of the following steps: compute a statistical formula that best fits independent instrumental data and then verify the model by testing it against instrumental data from the same place but a different time period. If there is a good correlation, temperature or precipitation can then be estimated for the pre-instrumentation period and cross-checked with results from other research disciplines. There are pitfalls, for instance a recent article has claimed that current standardisation techniques are biased and recommends a specific corrective remedy (Cook & Peters 1997 361-70). The procedure of correlating derived indices with the original widths is not common or at least not commonly published. A bibliography that covers these research issues, up to 1996, is available on Grissino-Mayer's web page (*op. cit.*).

In recent decades research has moved from tree-ring width indices to the analysis of other properties such as tree-ring densities, cell size, earlywood to latewood ratios, and isotopes or combinations thereof. Researchers have mainly used similar types of statistical techniques for data analysis, but detailed discussion of these is outside the scope of this dissertation. Recently a number of researchers have set up of grids on a continental scale, particularly in Fennoscandia, which makes it possible to plot summer precipitation and temperature variations over large areas (Briffa *et al* 1992 111-119). At present grids are regionally oriented but in the future will probably be on a global basis. An example of this type of trend is the creation of synoptic maps (Baillie 1995 141) and further development of these climatic maps should prove to be important as it will be possible to compare these maps with those derived independently.

One recent example has been the use of combined ring-widths and ring-densities sampled using grid points in Fennoscandia (Briffa *et al* 1992 111-119). This research reconstructed summer temperatures in the area from 500AD. The researchers were of the opinion that there was a low correlation between Fennoscandia and other areas but offered the caveat that the statistical techniques were still at an experimental stage. They concluded that there was evidence to show warm periods in the 8th, 10-11th, and late 12th centuries, bracketed by cold periods. They also argued that there is little evidence of climatic deterioration in the 14th century and that the 15th was as warm as the so-called Medieval Warm Period, thus casting into doubt the ubiquity of the Little Ice Age. The authors argue that there was a '...probable spatial diversity of climate change, across Europe through the last millennium' (ibid. 119). It is worth noting that the seasonal temperatures and precipitation patterns do not necessarily correlate with annual patterns. In other words just because there has been a particular type of summer does not necessarily predicate a particular type of winter.

However not all tree-rings are of equal value. From the perspective of climate reconstruction it has been found that the most statistically significant results come from tree species in marginal areas because they are most likely to reflect climatic stress as distinct from local environmental factors (Fritts 1976 17 & 395-400). It has therefore been concluded, as a general rule, that trees from temperate areas, such as Western Europe, are not good climatic indicators. Their value lies elsewhere in other avenues of research.

It is worth noting that attempts have been made using *Quercus* from Great Britain and Ireland to reconstruct climate over the last 200 years (Pilcher & Gray 1982 297-304, Briffa *et al* 1983 233-42, & 1986 1-15). They were able to correlate tree-ring widths with temperature and precipitation measured instrumentally. They concluded that high rainfall in the growing season and high temperatures favoured growth, though high temperatures in the previous winter were detrimental to the following year's growth due to a loss of food reservoirs. However very wet years did not correlate as distinctly. The conclusion was that the basic statistical techniques provided a reliable year by year reconstruction but that these should not be over-interpreted, as significant results do not necessarily imply a causal relationship.

There are other problems with this approach because it is difficult to interpret measurements from different ecologies on macro and micro biogeographical scales (Baillie 1982 136-7). One example is the different responses of oaks from bogs, woodland, and riverine locations, which may reflect environmental factors and make interpretation problematical due to 'noise' in the overall data (ibid. 29).

It is worth adding that a tree-ring in fact represents a two-year period because spring vessels use food stores from the previous year (ibid. 46). Therefore the resulting widths, or derived indices, are not fully representative of one year's summer weather. The assumption appears to be that spring growth is always of the same width and that the previous year's weather has therefore no influence on it.

Another assumption appears to be that there are no longer response trends greater than one or two years, i.e. that the tree responds only to seasonal or annual time-scales and

is discussed above. Other interpretative problems include the variable production of mast, which appears to be biological rather than climatic though temperature must be a factor; the increase of carbon dioxide in the atmosphere, and industrially derived heavy metals, which have an unclear effect on growth patterns.

Applications

In the early days it was fortuitous that dendrochronologists concentrated their efforts on stress-sensitive trees otherwise the science might never have been developed. This appears to have bred optimism that the analysis of trees of all species from all biomes would provide historic climatic information. In recent times this has proved to be a lot more difficult than expected and the results do not appear to give other palaeoclimatologists confidence. This is perhaps the reason the EURO-CLIMHIST programme insists that dendrochonologically data is provided as temperatures, etc., and not as tree-ring values. It is instructive to compare the optimism of the early 1980s with the pessimism of the 1990s (Baillie 1982 250 & 1995 136).

Research is now concentrated in following specific areas:

- The research of conifers such as *Pinus*, *Picea*, *Abies*, *Cedrus*, *Thuja* from ecologically marginal areas proximate to North American glaciers and ice-fields, Kashmir, Tasmania and Tierra Del Fuego (i.e. *The Holocene*, 1991-99, all ten articles). These have been primarily used to reconstruct temperature and precipitation.
- The use of grids to re-construct seasonal temperatures in ecologically marginal areas such as the sub-Arctic (i.e. Briffa *et al* 1992 111-9)

- The identification of regional and planetary catastrophic events with deductions as to their overall climatic impacts and resultant effects on human society (i.e. Baillie 1995 & 1999).
- The analysis of issues relating to the calibration of the Radiocarbon curve, such as changing Carbon dioxide levels during the Holocene.

The first two relate to climatic research and are discussed above. The third area of research is the identification of stochastic events. The main trend of this direction is the development of catostrophism as a complementary perspective to uniformitarianism. There are two scales by which these are measured, the first local and the second global.

In terms of local events the evidence has been used to examine environmental changes caused by the expansion of glaciers, changes in soil moisture, rising lake and sea levels etc. It is worth noting that these are usually caused by changes in climate or the environment, though catastrophic events can also be significant. The type of information found depends on the region. Extreme mountain areas are different to temperate areas, for instance, glacial advances can be informative as the clustering of kill dates are usually chronologically secure and provide good evidence of glacial cycles. It is also possible to measure the life spans of sub-fossil trees, as this will provide the chronology of glacial retreats. The combination of life spans and kill dates can give a complete glacial history as in Alaska (Wiles *et al* 1999 163-174), though the technique has to be used with caution (Grove 1988 8).

Marginal areas occur in many other environmental settings, particularly where extreme natural events and processes of different scales are catastrophic. Trees in these areas provide different climatic and environmental perspectives to other biomes.

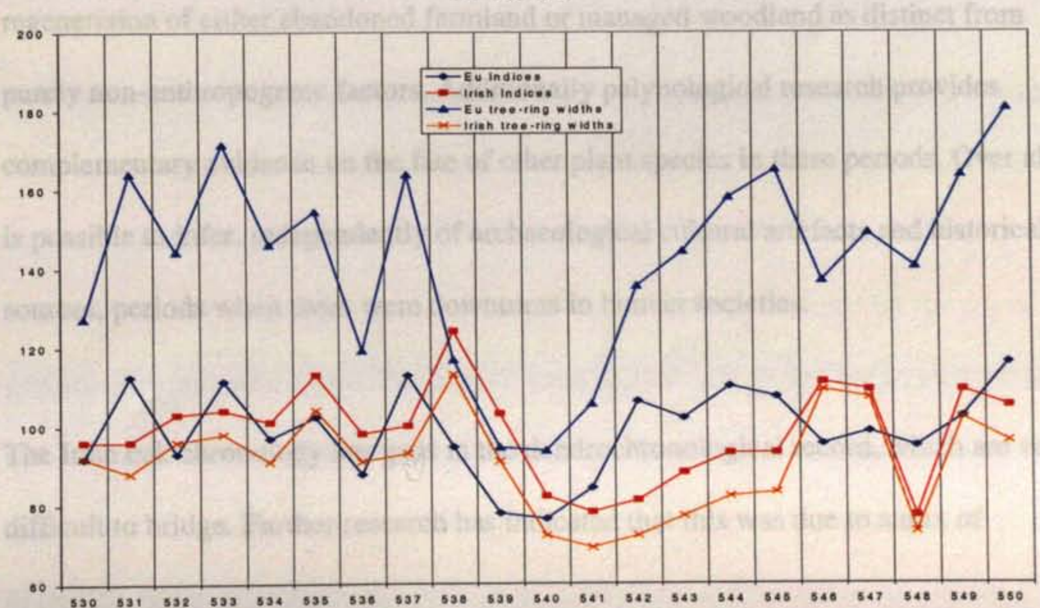
Interpretative problems occur when narrow widths continue long after the event has taken place. This may reflect a continuation of poor weather during later growing seasons or the time needed for trees to recover from the event. In the latter case is the tree's environment may be a factor, for instance a tree's response in a bog or forest make be different (Baillie 1999 79-80). Another problem is the chronological gaps that are environmentally caused due to changes in the local biome. It has been found that bogs, that preserve trees in large quantities, only do so when the moisture levels are conducive to the species in question. Worth noting are variations in the responses of various species such as oak and pine as these can behave either synchronously or asynchronously depending on moisture content (ibid. 27-8).

While such events are not uncommon on a local or regional level there is always the doubt that declines in tree-ring width values reflects the event or has some other specific local cause. Therefore, another focus is on the comparison of tree-ring widths and values on a global scale. One of the first publications was the classic article by Le Marche & Hirschboeck (1984 121-6) that discussed the probability that volcanic events depressed tree-ring widths in bristlecone pine and were related to frost events. This has since been expanded to the analysis of tree-ring widths and indices elsewhere and there is now agreement that such events can be identified from nearly all continents (Baillie 1999 48-61). The chronology and possible effects of these events

are still controversial, as there are major interpretative disagreements between dendrochronologists, ice-core scientists, volcanologists, archaeologists and historians.

It is worth noting the assumption that indices reflect environmental impacts better than tree-ring widths. Taking the AD 536-45 period Baillie (1995 97) uses both without comment whereas they may not be directly comparable. If the two Irish and European sets of data are compared (Fig. 1), it can be seen that Irish widths and indices match better than the European. It implies that biological factors were less significant in Ireland then the rest of Europe. If this is so it could be argued that there are regional differences when poor climate suppresses biological factors. Unfortunately we don't have the data to make annual regional assessments of the events of AD 536-45 so it is not possible to determine the relative strengths of climatic and biological influences, or even if the indices are an accurate reflection of the climatic input to the width.

Fig. 2.1 Comparison of Irish and European tree-ring widths and indices, AD 530-550



Other researchers are developing environmental histories, though these still tend to be event led, i.e. the explanations are of the 'boring' periods linking the moments of high drama. There are exceptions and one is Ireland due to the inter-disciplinary approach of palynology, dendrochronology and radiocarbon dating, particularly in Queen's University in Belfast and their active links with the archaeological community in Great Britain and Ireland.

One illustrative example is the link between Archaeologists and Dendrochronologists. Apart from the dating of specific sites, the analysis of archaeological sample dates has shown that these are not randomly spread over time but cluster within specific time frames. In Europe, as well, it has been found that there are periods where there are few dendrochronologically dated archaeological sites (Baillie 1995 42). These have been interpreted as periods of building hiatus and are believed to occur after severe environmental downturns that caused major human mortality. It is also possible to analyse the clustering of oak population cohorts, as this can indicate woodland regeneration of either abandoned farmland or managed woodland as distinct from purely non-anthropogenic factors. Additionally palynological research provides complementary evidence on the fate of other plant species in these periods. Over all it is possible to infer, independently of archaeological cultural artefacts and historical sources, periods when there were downturns in human societies.

The Irish oak chronology has gaps in the dendrochronological record, which are very difficult to bridge. Further research has indicated that this was due to a mix of

environmental and anthropogenic reasons and this low replication rate is found in the rest of Europe for many of the same time periods.

The oak in Ireland

At this point a short history of the oak in Ireland would be appropriate and is based on Birks (1989), Baillie (1982 & 1995), Baillie & Brown (1995) and Mitchell & Ryan (1998). At the end of the Younger Dryas, c. 10,000 BP, conditions improved and this resulted in the spread of many plant species Ireland. *Quercus* arrived in southern Ireland in 9000 BP and spread north reaching Cos. Mayo and Co. Down 500 years later. The general speed of travel was 350-500m@year^{-1} until 8000 BP when it slowed down to 50m@year^{-1}. Consequently it did not reach north west of Ireland until c. 7500 BP.

Quercus was successful and became the major canopy tree largely due to the absence of its main competitor, the beech. By 3,500 BC it had reached its fullest extent particularly in the midlands and areas under 300m altitude. Around this date there were a number of major events, the transition from Mesolithic to Neolithic farming, the Elm decline and extinction of bog oaks and these, combined, are believed to have had a major effect on natural woodland regeneration. There is a hiatus in the dendrochronological record around this time and it has been argued that there was general environmental down turn that affected the oak and caused major extinction and later regeneration of the species in peat bogs. The effect on parkland oaks is unknown because there are no surviving trees from this type of environment for most of the pre-historic period.

Similar gaps also appear in 4,000 BC, 947-9 BC, 220-13 BC, indicating severe environmental events that caused local extinction of oaks in bogs. Other gaps of the historic period appear in, the early 9th century and the middle of the 14th and 17th centuries. These gaps however are not climatic. The first is related to population pressure and related land clearances when oak became uncommon. The second is due to the lack of archaeological timbers because one of the effects of the Black Death was to halt the construction of new buildings. The third because of the building hiatus caused by the Cromwellian and Williamite wars. There is a further gap in the construction of new buildings in AD 648-720 due to the occurrence of plague.

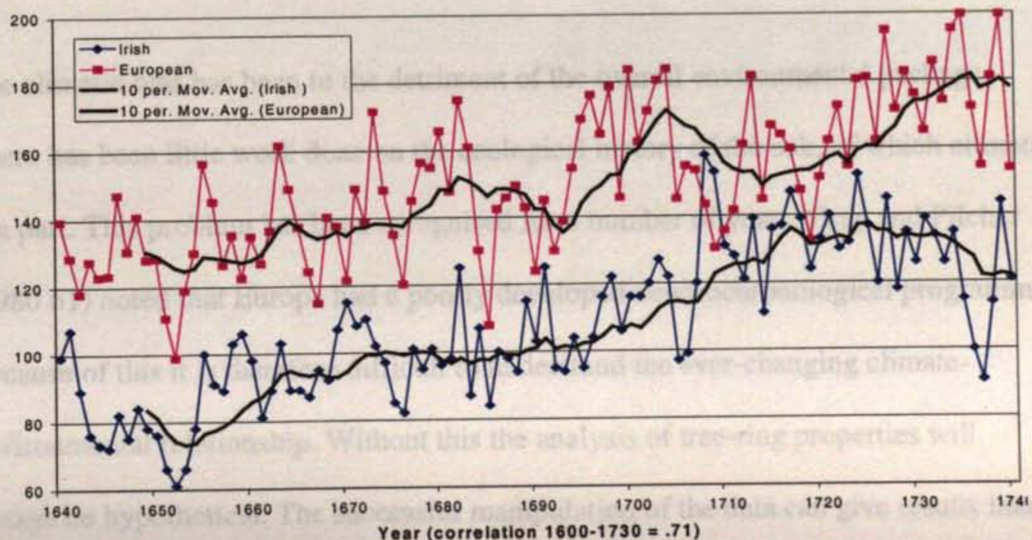
From the Neolithic period mankind used woodland as a source of agricultural land and building material and over time they shifted from natural to managed. Every new wave of agricultural innovation and colonisation resulted in the clearance of more land and by the medieval period the landscape was mostly agricultural with some large areas of managed natural forestry. These were jealously guarded as a major source of food, pannage, animal products, wood and timber. Most oak disappeared in the major woodland wipe-out of the 17th century leaving marginalised specimens, allegedly of poor genetic stock. Canopy trees were replaced by imported seedlings from the mid 18th century.

Oak samples usually come from bogs in the pre-historic period or archaeological sites up to about AD 1700, in the modern period they come from parkland without major competition. This raises the question whether oaks from bogs or ancient wild native forests have different characteristics, as it is possible that the oaks from

archaeological sites are from forests as bog-oaks may not have been suitable building material. Research by Baillie and Brown (op cit.) indicated that there is probably no difference between the two environments and that wider widths are better correlated with competition.

It is believed that tree-rings of modern oaks are, on average, double the width of oaks before 1700. This raised the question whether this was a function of climate change or the result of imported oaks from Europe growing particularly well in a more temperate climate. In recent times the opinion, at least anecdotally, has favoured the latter scenario. However a comparative analysis of the tree-ring widths in Northern Europe show the same trend and it could be argued that such a correlation cannot be biological as this would mean that Oak forest histories across Northern Europe are identical. It is also worth adding that this doubling is something of an illusion as they are based on the extremely low widths of the AD 1650s as the following diagram illustrates:

Fig. 2.2. Comparison of Irish and European tree-ring growth, AD 1600-1740



Conclusion

In conclusion tree-ring properties have proved to be a good proxy tool for the reconstruction of temperature and precipitation patterns, stochastic events and the identification of cohort populations life spans. The absolute chronologies available allow detailed reconstruction that can tie into other types of proxy data.

Since the 1950s the hypothesis that indices are a more accurate indicator of climate (as distinct from annual temperature and precipitation) than tree-ring widths has shifted from being an assumption to a paradigm. This is puzzling as it behoves the dendrochronological community to explain why tree-ring widths vary as they do both historically and geographically. Given the fact that indices are derived from widths, and not based on biological principles, a full understanding of the former is impossible without specific published explanations of the latter. In fact the majority of secondary sources have completely ignored the challenge of widths for maybe fifty years, but without an environmental explanation of tree-ring widths how do dendrochonologial palaeoclimatoligists ever expect to understand climate? Ignoring the problem is not a scientific solution.

The climatic bias has been to the detriment of the overall environmental package. There has been little work done on the ecological history of the oak, of which climate is a part. This problem has been recognised for a number of years, Gray and Pilcher (1980 61) noted that Europe had a poorly developed dendrochronological programme. Because of this it is therefore difficult to understand the ever-changing climate-environmental relationship. Without this the analysis of tree-ring properties will always be hypothetical. The successful manipulation of the data can give results that

mirror specific inputs such as temperature and/or precipitation with some degree of confidence. The developers of the North Atlantic Oscillation Index confirm this opinion but they do not use indices for their Index. They argue that while there is a fairly good correlation between the two sets of indices they are of the opinion that tree-ring indices do not predicate circulation patterns, due to biological or other random factors (Luterbacher pers. comm.).

Overall there have been major advances in the science since the days of Douglass and an understanding of the relationship between trees and their environment in the broadest sense has progressed considerably. The results can be seen in the areas of climatic research, solar activity, pollution, anthropogenic influences, and extreme global events to name but a few. However an explanation that explains the multifaceted response of trees to their total environment on all biological and ecological scales has not yet been developed.

CLIMATE IN IRELAND: AN INTRODUCTION

Before discussing historic climate is first necessary to describe the origins and types of weather systems that make up Irish climatic. This will be followed by a discussion on issues relating to previous research on historic climate and the Gaelic Annals.

Modern climate in Ireland

Climate is a function of solar radiation, atmospheric systems and ocean currents. In the northern Atlantic region these are particularly important because the island is at the interface between the Atlantic Ocean and the European sub-continent. In terms of understanding the island's climate it is easiest to think in terms of cyclonic and anti-cyclonic systems.

Weather systems affect Ireland to varying degrees depending on the season and, in the long term, on the climate in surrounding parts of the region. Ireland is an area where the boundaries of these systems meet. These boundaries are, of course, not constant and shift across Europe depending on the relative strengths of the competing weather systems at any one time. It does, however, appear that the island is in a significant geographical location and may be likened to 'frontier' country. The advantage of the metaphor is that at times when there are competing weather systems the boundaries often have unstable weather conditions.

In a recent work, Sweeney (1997 254-75), describes weather in Ireland, over the last one hundred years, as a 'struggle' between tropical and polar air masses. He argues that the island is a 'battleground' of these air masses who conquer and reconquer with

great speed and that it is these 'skirmishes' that determine the 'climatic fingerprints' of the European climate. These constant alterations create a climate that is highly variable i.e. the euphemistic 'four seasons in one day'. As a general point care has to be taken not overuse military metaphors when past or present Irish climate is described.

He also argues that the Irish temperature regime is determined by changes in the thermal characteristics of the North Atlantic Drift and precipitation determined by the origin of weather systems. In the former case land temperatures are highly correlated with sea temperatures and in the latter case two-thirds of Irish rainfall come from westerly cyclonic systems. He describes Ireland as 'England's shelter belt' and this is particularly true for southern England where most of the historic documentary sources originate. It could be argued that there is a positive relationship between the climatic shelter-belt region and documentary sources.

While these westerly systems have a major influence in mainland Europe they are heavily modified by the time they arrive there due to a number of reasons. These include loss of moisture; a warming of the air due to reflected radiation plus increased dust from the land mass; the homogenisation of the system through the loss of chaotic wind variability; the influences of other northern and eastern weather systems and the influence of Alpine topography.

A particular feature of anti-cyclones is the blocked system. This is caused by the closing of a circumpolar meander loop through complicated interactions with jet streams and results in the system becoming stationary or 'blocked' (Lamb 1995 36-7).

They are found in all seasons but are mostly a spring/early summer feature between 150°-15°W longitude, i.e. west of Ireland (Daniels *et al* 1997 24). Summer blocking anti-cyclones can often divert westerly wind systems in a northern loop and bring rain to continental Europe while Ireland is experiences hot and dry weather.

It would be useful to consider the main weather systems that make up Irish climate at the present time. There are five main types of systems, viz. The Oceanic maritime lows, the Polar maritime lows, the Continental Arctic highs, the Oceanic maritime highs, and the Continental African highs. These, with a description, can be ranked in importance as follows:

- Oceanic maritime low-pressure systems are the most important in Ireland. They are primarily of western or north-western origin and bring cool and wet conditions and are responsible for most of the precipitation on the island. It is worth noting that of the five types, they show the greatest variation in strength and intensity. This is presumably due to the fact that they border on the more turbulent Caribbean weather systems and it is likely that there is a relationship between turbulence there and in Ireland. Geographical variations also occur in the amount of precipitation as the west coast receives higher levels of rainfall than the east. In very wet years flooding can occur in river basins. Overall the predominance of these systems generate a relatively mild climate without large seasonal variations.

- Polar maritime lows are cold and wet and are primarily a winter phenomenon. They bring cold wet snow, sleet and hail; these do not have any lasting power due to continuing precipitation.

- Continental Arctic Highs are the primary winter system for much of continental Europe. It is mainly a winter phenomenon though the chances of it impacting in Ireland in this time are low, as it appears that they do not have the strength to move this far west or compete with westerly low pressure systems. They are associated with blizzards and frosts that freeze water bodies and at particular periods are intense from the human perspective. Spring melt can occasionally cause flooding.

A variant are Polar maritime highs, these are similar to continental Arctic highs. The Polar High is not described as a separate climate systems type as only the direction of origin is different. Their separate point of origin is possibly due to abnormalities in the northern circumpolar vortex and the positioning of anticyclones (Lamb 1995 30-35). For instance if they are centered over Iceland they bring heavy snows but over Scandinavia they bring severe frosts (Daniels *et al* 1997 27). In the period 1961-1990 they have become less frequent with about 5-6 snow days per annum in Ireland with the exception of the extreme north west which receives about 8-12 snow days per annum (Barrow & Hulme 1997 46).

- Oceanic maritime highs come from the southwest and are characterised by warm and damp conditions. They are a common summer weather system and often alternate with Oceanic Lows. A combination of both types often brings intense short storms and powerful lightning due to the mixing of air of unequal temperatures.

- Continental African Highs bring hot dry weather in the summer and in extreme cases can cause droughts (as well as dustings of Saharan sand). They are uncommon at this time.

Occasionally hurricanes of Caribbean origin break through and sweep through the islands with wind speeds of up to $11ms^{-1}$ causing considerable destruction. Recent examples have included Hurricane Debbie in 1961, Hurricane Charlie in 1986, and Hurricane Isadore plus Hurricane Gustav in 1990. In some circumstances they are diverted to Ireland away from their normal western Atlantic track. Otherwise it is believed that remnant pockets of warm air from dying hurricanes are absorbed by cyclonic systems. These pockets intensify the low pressure and the strengthened system then follows the normal westerly track to Ireland. These have always been a part of Irish weather patterns though there is usually not enough detail to say whether historic storm events are hurricanes or very powerful gales.

These systems make up our climate and it is the variations of long-term patterns on which climatic reconstruction in Europe has been based and it is to these that the discussion will now turn.

Climate Reconstruction in Europe

Notwithstanding the difficulties of reconstruction, up till recently, there was a general consensus regarding climate change in Europe over the last 2,000 years. This consensus was that after the Iron Age lull, 500BC-AD 300, there was a slow warming, with some intense variability, to about AD 900-1000. This was followed by a benign period to about AD 1250, called the Medieval Warm Period, followed by a

deterioration into wetter and colder weather. From AD 1570s there was an increase in cold conditions, called the little Ice Age, that lasted to about 1850.

Recent research, particularly over the last ten years, has queried this consensus. Regional studies in Europe and other parts of the world have shown that it is impossible to classify global weather into periods with specific weather patterns. It is now argued that shifting atmospheric patterns affect different parts of the world in dissimilar ways and that these changes are not synchronous in time. However the labels 'Medieval Warm Period' and 'Little Ice Age' have remained because no alternative definitions are acceptable.

Climatic research over the last 100 years has used an interdisciplinary approach to documentary, biological and glacial proxy records. Significantly this research has primarily been conducted on mainland Europe where the climate is mainly continental with high-pressure systems predominating. Researchers focus on the 'Medieval Warm Period' and the later 'Little Ice Age', which is not surprising given the topography of the mainland and the wide variety of different records that became available from the 16th century. In the modern period, particularly from AD 1850, instrumental records are used to define climatic parameters. Instrumental records now provide the verification of models used in historic climatic reconstruction.

The general assumption is that Ireland is part of the European climatic region. This assumption is questionable because oceanic maritime weather is predominant with a strong bias towards low-pressure systems. A further point is that published research has never clearly stated whether Ireland is in Western Europe or Northern Europe.

There may be a geographical bias in the literature, as the tendency is for French and German researchers to assume that Ireland is in either Western Europe or Northern Europe respectively.

Unfortunately there has been very little research done on Ireland and this may be due to two factors. The first is that the most important author from this region, Lamb, appears to have a continental bias as most of his sources come from mainland Europe and he uses Irish sources rarely, with the exception of Bourke who discussed the mid 19th century Irish famine (Lamb 1995 pp. 393-411). It is worth noting that Lamb cannot be overly criticised, as there has been no published research carried out in Ireland for this period and most Irish authors use Lamb uncritically. It is also not clear whether he, or other writers, consider this island to be worthy of independent study for the purpose of providing complementary data on historic climate change given the fact that most analysis is done for much larger regions.

However he is a source worth listening to because his climatic and historic erudition has set the standard for the study of climate history, his theories are those whom everyone seeks to prove or disprove. He has concentrated on the 'big picture' as a necessary pre-condition for more detailed regional research.

This continental bias can create some curious interpretations. Consider his map of north west Europe (Lamb 1995 164) plotting coastal changes caused by sea flooding for the period AD 400-1100 where Ireland is completely missing. Obviously he is not arguing that Ireland was completely covered in water at this time but it indicates that

he has no information as to the impact of flooding from the island and so left it out altogether.

At the present time continentally based researchers still maintain this perspective and include Ireland in Northern or Western Europe even though none of the Irish sources have been used. There is an assumption, perhaps, that southern English data is sufficient to include Great Britain and Ireland into this regional definition. In cultural terms this could be seen (frivolously) as a kind of unconscious '*Mitteleurop* climatic imperialism' based on the historic development of the European core from the 11th century.

In historic terms the science of climate reconstruction was developed in Germany and Switzerland in the mid 19th century and has been dominated by important Alpine research into glacial history, this area can be called the core research area. By 1940 climate research had spread to northern Germany, the Netherlands, England and Northern Italy. These climate historians have been primarily guided by temperature as can be seen from climatic period definitions such as the 'Medieval Warm Period' and the 'Little Ice Age'. Recently research has spread to the periphery of Scandinavia, Poland, Czechoslovakia, Greece, Spain and Northern Africa. These countries maintain a natural bias towards the central European paradigm.

In Ireland and adjacent regions precipitation is an important climatic parameter and just as influential as temperature. This dissertation will propose and test that the North West Atlantic Region (hereafter NWAR) is a more appropriate perspective in discussing climate in Ireland as compared to the rest of Europe. There are no fixed

boundaries to this region and at various times will include England, Scotland, Wales and Brittany depending of the climatic regime current at the time. When the regimes change over time it is possible to argue that Scotland is part of south west Fennoscandia and south east England and Brittany part of western or northern Europe.

The North West Atlantic Region and the above mentioned weather systems will provide the focus for a following chapter, which will attempt to reconstruct climate in Medieval Ireland. First it would be constructive to discuss some of the issues that arise from research for a previous publication (Cantwell 1998 20-7)

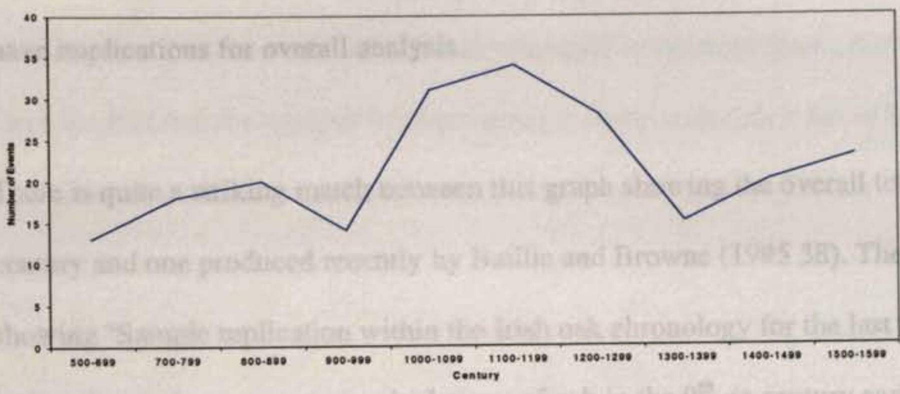
Climate issues in the historic period

It is worth analysing the entries themselves as a basis for further discussion of their potential usefulness. A analysis of the number of weather entries per century based on the major seven Annals shows the following:

Table 3.1 Number of Weather Entries by Century in the Annals

Years	500-699	700-799	800-899	900-999	1000-1099
Numbers	13	18	20	14	31
Years	1100-1199	1200-1299	1300-1399	1400-1499	1500-1599
Numbers	34	28	15	20	23

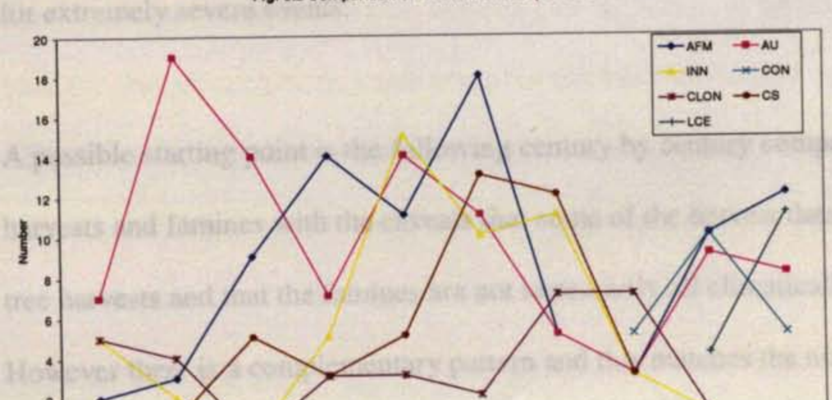
Fig. 3.1 Number of Weather Events per Century



The total number of independent entries is c. 216 at c. 21 entries per century or one about every five years. There are two declines in the 10th and 14th centuries with a peak period 1000AD-1300AD.

However if an analysis of the entries of the various annals is done then the following graph is produced.

Fig. 3.2 Comparison of Weather entries per set of Annals



The variations can be explained by gaps in the Annals; uneven coverage; incomplete copying; and the unpredictable vagaries of the compilers and copiers. It can be seen

that for any particular century some Annals are better than others are and this may have implications for overall analysis.

There is quite a striking match between this graph showing the overall total by century and one produced recently by Baillie and Browne (1995 38). Their figure 1, showing 'Sample replication within the Irish oak chronology for the last two millennia...' shows two major depletions of oak in the 9th (a century earlier than the above) and 13th-14th centuries with a strong peak in the 11th-12th centuries.

The above match between numbers of weather entries and replicate oaks is intriguing. Is may be possible to argue that as climate got worse there was less likelihood for it to be recorded. O'Croinin (1995 229-232) argues that there was a decline in literature from the 10th century and this may indicate that the two declines are symptomatic of a cultural decline. It may be simply a case that if weather didn't change, no matter how bad it was, it ceased to be news it was not recorded. This problem is discussed later for extremely severe events.

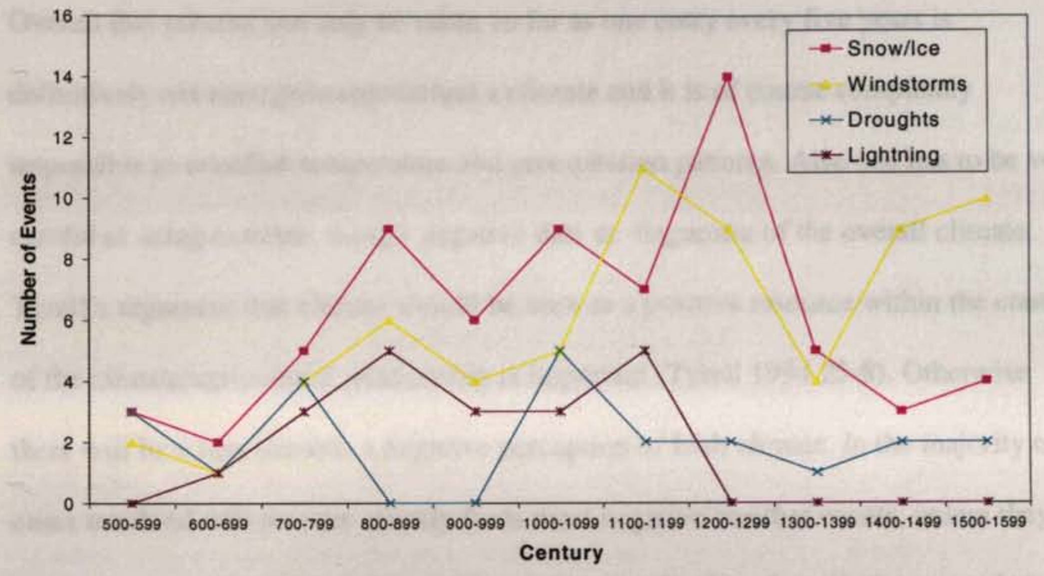
A possible starting point is the following century by century comparison of good harvests and famines with the caveats that some of the harvest data relates to managed tree harvests and that the famines are not necessarily all climatically induced. However there is a complementary pattern and this matches the numbers of weather entries and replicate oaks with the exception that the first famine maxima is a century than the sample replication earlier in the 8th and two earlier than the decline in reporting weather events.

In general negative events far outweigh the positive by 80% to 20%, with some references to good harvests of field and managed forest crops (mast, hazel, apple etc.). Here the fact that the weather has been good is implied though it has to be noted that tree yield cycles do not necessarily correspond to clement times. Other interpretations of implied data are difficult to prove one way or another. For example references to 'putrid black fish' coming out of mountains is suggestive of bog bursts, this may therefore imply increased rainfall over the previous number of years. A reference to a 'Fire from Heaven' burning up the mountains of Connaught may imply very dry conditions that provided the conditions for a major bog conflagration.

It is important to note that there are no references to patterns of change and this is typical of Annals. There are occasional references to the worst/best since a particular year but these are rarely over one generation, i.e. c. 30 years, apart and primarily relate to domesticated and managed wild harvests.

The importance of the data is that one can plot sequences of weather event types and look for change; such an example would be the climatic decline from around the AD 1270s that can be seen from the increased references to high winds and heavy storms. This is certainly a lot more useful than knowing that there was a particular storm in a particular year. Trends can be plotted and then compared to European climate and other types of Irish proxy climate data; though published research of the latter does not exist in any large quantities for the period.

Fig 3.3 Weather Events by Century



However before the values are taken at face value, questions need to be raised as the extent of the coverage. Obviously if there is change in climate over a generation the extreme events are likely to be mentioned as in the beginning they will be new. However if the compilers are used to a particular weather regime these events will not be unusual and therefore won't be mentioned unless they are particularly extreme, such as some of the cold events that lasted for up to three months during first millennium AD. Neither do we know how regularly any particular weather event happened. These are questions may be clarified with reference to other European documentary sources. There may be other interpretations involved as well. For instance there are rarely references to lightning storms and their associated destructive powers after the 13th century. This may mean that the transition from wood to stone for important buildings, particularly churches, was complete. It may also reflect a decline in weather systems originating in the Mediterranean and further west which often produce destructive lightning.

Overall this process can only be taken so far as one entry every five years is definitively not enough to reconstruct a climate and it is of course completely impossible to establish temperature and precipitation patterns. Also one has to be very careful in using extreme, mostly negative data as diagnostic of the overall climate. Tyrell's argument that climate should be seen as a positive resource within the context of the climate/agricultural relationship is important (Tyrell 1994 25-8). Otherwise there will be a bias towards a negative perception of Irish climate. In the majority of cases mankind will recover quickly from most negative weather events, unless they last three years or longer, the limit of grain storage. So therefore a balance needs to be struck between interpreting weather incidents as occasional stochastic events or as indicators of climate change. There is a danger in over-interpreting this primarily negative data.

Notwithstanding the problems a general description of climate in Medieval Ireland is attainable.

METHODOLOGIES AND ISSUES

The research of dendrochronological and annalistic data can be broken down into two specific methodologies and is therefore discussed separately:

DENDROCHRONOLOGY

Correlation

The tree-ring widths of Ireland, as compiled by the Department of Palaeoecology, Queen's University, Belfast, was entered into Windows Excel (1998) with the mean tree-ring widths of seven different locations from Northern Europe, viz. Sheffield, London, Netherlands, Denmark, Hamburg, Göttingen, and Poland, which had been averaged to create a Northern European mean.

The Irish tree-ring widths were made into linear charts on a number of different scales i.e. 100 years, before and after AD 1000, etc. and an attempt was made to offer a comparative interpretative analysis of correlation coefficients of Ireland and Europe.

Correlation between the Irish and European averages were plotted on the basis of ten, twenty, thirty, fifty and one hundred running curves. While the application of the statistical functions was straightforward, problems occurred with the interpretations. This is largely due to the fact that there are no established methodologies for the interpretation of tree-ring width correlation curves due to the difficulties of separating climatic and biological inputs; discussed earlier.

While a complete analysis of correlation was beyond the scope of this dissertation a number of cameos were chosen for further analysis based on their asynchronous nature or their lack of correlation.

Variation

A second methodology was devised to study variations since it was thought that certain periods would show higher variability with others. The procedure was to:

- Compute a ten year running average
- Subtract the tree ring widths from the running average for yearly variations
- Square and square root these to remove minus values
- Compute a ten year running average to obtain decadal figures
- A linear and polynomial (6^{th} order) trend line was then added to the chart.

The decadal figures can be called a Variance Index. Periods with higher variations may indicate instability whereas low variations may indicate stable conditions. These are not all necessarily climatic, as other environmental influences can be significant.

The same procedure was carried out with the European average. It would be expected that the mean of seven chronologies would significantly dampen variability however there are periods where variability was high for all parts of Europe.

Finally a ten year running correlation curve was fitted to the Irish and European average.

The above procedure measured total variation. An alternative procedure was not to remove negative values at step three and compute an average by where positive and negative canceled each other out. This left extreme values that were plotted. Steps four and five were repeated and a correlation curve fitted with a polynomial (6^{th} order) trend line.

Other Methodologies

Other cameos were chosen based on their interest in the development of stochastic events and the dates chosen are years or periods arising from the Annals or from Baillie (1995 and 1999). The general methodology was to compare the average tree ring widths, five years before the event, with the width during the event itself and are explained in the text.

Finally an interpretive narrative analysis was attempted for the Irish tree-ring widths over the last 2,000 years

DOCUMENTARY SOURCES

This section deals with the sources and methodology used in compiling data from the Annals followed by a description and discussion of the EURO-CLIMHIST project's indices with reference to Ireland.

There is no complete set of weather entries for Ireland. The best and earliest is Wilde (1856). He was a surgeon by training who was employed as a statistician during the 1841 and 1851 Census enumeration. In the latter his responsibility was to collate and

analyse data on mortality between the two periods; but he additionally collected all references to famines and infectious diseases from Irish literature, either published or in manuscript, available to him. Before AD 1200 this included the whole corpus of Irish Annals excluding the Annals of Lough Ce and Chronichum Scotorum. After AD 1200 most of the Anglo-Norman chronicles were used and from AD1500 some published Tudor English and Renaissance Gaelic contemporary literature was included (Crawford 1989 1-2).

Britton (1937) compiled a similar set of data for Great Britain and Ireland, which is useful as climatic comparisons can be drawn between Ireland and Great Britain. However a detailed critique of this work was not attempted.

In recent times a compilation, from AD 900-1500, was published by Lyons, a medieval historian, (1989 31-74) for a work on the history of Irish Famines. This contains a useful discussion on the nature and extent of Irish sources. The listing is not complete as not only are entries missing but she also often quotes only one set of annals when a particular event occurs in more than one. The strength of her compilation is in her translations of Latin texts, particularly from the Anglo-Norman sources, but it is not clear whether this is a complete listing.

Crawford published a transcript of Wilde's entries from AD 1500-1850 and included entries omitted by Lyons to AD 1500. It includes a list of the sources used by Wildle plus a short appreciation of his scholarship (Crawford 1989 1-30).

Lyon's used two other sources. These were Titow's compilation of Estate records from the Bishopric of Winchester and published dendrochronological indices from Dublin and Belfast. Both were used as control data and for comparative purposes. The former is problematic as it assumes that climate in the south east of England is comparable to Ireland. The author recognised this and states that while it may be valid for the south and east of Ireland (excluding marginal land) it is not necessarily apt for the north and west. The latter use of the indices purely as an indicator of rainfall is not a position acceptable to dendrochronologists. She was considerably more cautious in making this assumption in her unpublished thesis on the Medieval Manorial economies of the Archbishopric of Dublin.

More recently Cantwell compiled an index of entries from the most important and accessible Gaelic Annals on a page by page basis for all weather references. These were Annals of Clonmacnoise, AD 500-1408 (gap AD1182-99); Annals of Connaught, AD 1328-1544; Annals of the Four Masters, AD 500-1599; Annals of Inisfallen, AD 500-1328 (gap AD 1131-59); Annals of Lough Cé, AD 500-1140 (gap AD 1317-1413); Annals of Ulster, AD 500-1541 (gap AD 1132-55); and Chronicum Scotorum, AD 500-1140.

For the purposes of this dissertation additions and corrections were made using Lyons and Crawford (*op. cit.*) A copy of the author's compilation index and copies of Crawford and Lyons appears in an appendix. Ideally, for the convenience of future researchers, there should be a database containing full transcripts of all entries in Gaelic and Latin with their respective and sometimes variant translations, however within the time frame of this dissertation this proved impossible.

EURO-CLIMHIST Indices

Christian Pfister first developed the methodology used for the creation of indices in 1984 for analysis he conducted in Switzerland. This has since become the basis of the research conducted by the EURO-CLIMHIST project from the early 1990s and has been used successfully as reported by numerous publications over the last ten years, as has been discussed earlier. The Department of History, Bern University, currently holds this database. It is planned to put it on the World Wide Web by the turn of the millennium but at time of writing this has not yet happened.

Overall the main advantages of this using documentary data are (quoted from Pfister *et al* 1982 332):

- An absolute dating control
- A high (seasonal, monthly or daily) time resolution
- A disentanglement of the effects of temperature and precipitation
- A coverage of all seasons of the year (this is particularly crucial for the cold season, for which documentary data are often the only or most accurate proxies)
- A high sensitivity to anomalies and natural hazards: the more extreme an event, the more often and more meticulously it is described

The main disadvantages (ibid. 333) are:

- They are discontinuous and may be biased by the selective perception of the observer
- Compilations are mostly made up of a mishmash of reliable and unreliable data and the entries are not fully documented.

The methodology of reconstruction using this type of proxy data has been discussed by Pfister *et al* (1994 329-76) and the indices themselves described in the introductions to all articles. The basic aim is that every month is given a value depending on whether it is average (0), colder or wetter than normal (-1), or warmer or dryer than normal (+1). These are then added together to get a seasonal figure that range from +3 to –3. These are then plotted in a seasonal temperature or precipitation time-series. Finally, should there be sufficient data, a curve such as thirty-year running mean or Gaussian low pass filter with an eleven year cut off period, is computed (Glaser 1999 172-5 & Pfister 1998 538-9 & 547-8).

The seasons are subdivided into winter (December to February), spring (March to May), summer (June to August) and autumn (September to November). The published literature shows that this seasonal breakdown works best after about AD 1500 when there is sufficient data that can be analysed with chronological exactitude. Before AD 1500 results on only winter temperatures have been published and this probably for two reasons. The first is that it there are difficulties in classifying the data with sufficient seasonal, let alone monthly, precision. The second is that documentary data is the only proxy record available for winter and they provide an essential complementary understanding to reconstructed summer temperatures.

It should be noted that the concept of 'average' does cause difficulties because this can be taken as the average of the period in question or to a modern period such as AD 1901-61. Certainly the contemporary observer will observe the weather in terms of the average he is used to, but for a proper reconstruction of temperature and precipitation it has to be relative to a documented instrumental period. This tends to

assume that climate dynamics are the same throughout history and that by reconstructing temperature and precipitation climate can also be reconstructed. In effect this assumes that it is possible to read climate backwards. In reality this hypothesis remains to be proved and should not become a paradigm.

Two specific problems can be used as an illustration. The first is that one season does not predicate another and the documentary literature indicates that the balance of different types of season have changed over time for reasons that are little understood. The second is that climate in the pre and post-industrial periods are not necessarily comparable due to the major anthropogenic influences, particularly the increase of CO_2 in the atmosphere. Climatologists now recognise that the last 100 years have been particularly benign and unrepresentative of climate of the last 2,000. Therefore researchers who use contemporary rather than modern 'averages' may not be altogether wrong and that the two perspectives should be used for their complementary points of view.

Overall it is possible that due to the historian's rejection of the relationship between climate and history and the scientists rejection of documentary data there is a major effort to make the project as scientific as possible. However it is hoped that history does not get completely lost in the process.

An example of the winter indices is as follows (Pfister *et al* 1998 540):

Table 4.1 EURO-CLIMHIST Winter Indices

Index	Type of Winter	Descriptive Data (monthly)	Proxy Indicators
-3	severe	3 'cold' months	extreme duration of snow cover; water bodies ice-covered for several weeks
-2	cold	2 'cold' months	ground snow-covered for several weeks; water bodies ice-covered for 1-3 weeks
-1	cool	1 'cold' month and 1 'warm' month	none
0	average	offset of 'cold' and 'warm' months	none
1	mild	1 'warm' or 2 'warm' and 1 'cold' month	none
2	warm	2 'warm' months	little or no snow cover and activity of vegetation
3	very warm	3 'warm' months	little or no snow cover and activity of vegetation

The general conclusion is that the methodology works as high correlation values are found between the indices and instrumental records on an annual and geographical basis. Pfister *et al* (1984 343-4) notes that, notwithstanding the common assumption that 'descriptive weather comments are imprecise and inaccurate', there was an 'encouraging degree of uniformity and accuracy'. It was also noted the distribution of

the verifiable data was more important because they provided synoptic charts that were "meteoro-logical" i.e. 'consistent with physical laws of the atmosphere'.

There are two problems relating to their use in Ireland. The first is that under the strict guidelines laid down by the EURO-CLIMHIST programme the Gaelic Annals cannot be used as they are all non-contemporary and secondly there is not enough entries to develop climatic patterns for this oceanic region (Pfister pers. comm.). The first is a valid criticism but is ideally used where there are other contemporary records available, which is not the case in Ireland. As already discussed the issue of chronological control has been extensively researched in Ireland and the chronological framework for the various compilations is accepted by Irish historians. It does seem unreasonable to reject the whole corpus of data on this basis when it is unique in terms of its temporal and geographical coverage. England is not necessarily an adequate alternative, as most of the records tend to come from the south east, which is more continental in climate.

It is certainly the case that there are not enough entries to provide overall climatic patterns but the process was carried out so that the methodology and its implications could be understood. It was deem likely that a comparison of Ireland and northern Europe would be a useful indicator for regional analysis. This is not a specific problem to Irish sources as the extent of documentary coverage in Europe is highly variable.

In the future it may be better to move away from an overly strict definition of seasons and measure the length of winters, which often include spring, by snow cover and low

temperatures; and summers by proxy agricultural data. It is not possible to categorise the data with sufficient seasonal exactitude before AD 1000.

There are three sets of published sets of indices that cover European data before AD 1600.

- The first is an examination of winter temperatures in 'Western Europe' (Pfister *et al* 1998 535-552). The indices are not given and have been reconstructed from the charts. These are difficult to interpret with exactitude and have been confirmed from the text where dates have been discussed.
- The second is an examination of winter temperatures in 'Europe' in the 14th century (Pfister *et al* 1996 91-108). The indices are published in an appendix.
- The third is an examination of 16th century seasonal temperature and precipitation in various countries in 'Central Europe' (Glaser *et al* 1999 169-200). The indices are not published but it is possible to reconstruct them from the charts. The areas covered by the charts are Germany, Switzerland and the Czech Republic. Only Germany has year by year coverage and comparison was confined to that country.

There are still major lacunae covering the 15th century and the earlier medieval period excluding winter temperatures.

OTHER INDICES

A second set of climatic indices for southern England, developed by Lamb, have been published for AD 1200-1439 (Oglivie & Farmer 1997 124-8). These have been up-dated and corrected by the Climatic Research Unit, University of East Anglia, to

improve the chronological precision missing in previous analysis. These indices are based on a monthly score of precipitation and temperature where ± 2 indicates conditions slightly more severe than normal while ± 3 indicates a particularly severe month. Negative values indicate drier or cooler conditions while positive values indicate warmer or wetter conditions, depending on whether they are scoring temperature or precipitation. These are than added together on a seasonal basis, pace Pfister, and give maximum values of ± 9 per season. These can then be developed into decadal annual temperature or precipitation indices (ibid. 121 & 129).

They are not directly comparable with the EURO CLIMHIST indices. The main difference appears to be that while EURO CLIMHIST is concerned with length Lamb is concerned with severity. The purpose of the comparison is to get a further indication of the boundaries between the regions.

A third set of indices are those compiled by C. Easton for western Europe in his 1928 work *Les hivers dan l'Europe occidentale*. These have been partially republished by Lamb (1982 45) who concentrated on the coldest winters by century. Easton's ratings range between 10 (coldest) to over 80 (warmest). The coldest periods are rated as 10 or 21.

While noting that this index may not pass the strict criteria laid down by the EURO CLIMHIST programme, and therefore may not reflect actual winters they are included as a chronological contrast. It is not until AD 764 that there is the first chronological correlation between Easton and Ireland, thereafter two thirds are correlated with Europe.

As a general point there are difficulties in indexing such short references as 'Great snows' or 'Great droughts'. It is only when they are more descriptive in terms of the length of time such 'Great snow on the 29th April' or 'Abnormal Ice and snow from Epiphany to Shrove' can such indexing be more seasonally exact. Earlier observers were of course not scientists but it can be possible to deduce the intensity of an event or season through the effects such as famine, crop damage or cattle mortality. Therefore a certain amount of judgment is necessary to index ambiguous entries. Any individual interpretation may be incorrect or may not be recognised as appropriate by international researchers and to cover this eventuality all indices are given in a separate appendix for critical examination.

The analysis of winter temperatures and summer temperatures plus precipitation was the most successful. It was mainly impossible to index any entries for spring and autumn, as most of the entries can not be placed in these seasons with adequate precision. Another type of analysis that was impossible to perform was winter precipitation because there were no entries in the Gaelic Annals. Taking each major type of analysis the following tentative methodological conclusions were established.

Winter Temperature

This is a proxy record of extreme winters based on snowstorms, freezing of water bodies and the length of time of each. One of the associated problems is that it is not always clear whether they are always take place only in the winter as many fall into the first month of spring. This was always significant as it usually delayed spring plowing. Where possible this has been noted but failing these entries have always been put into the winter season. It is difficult to properly index entries where no dates

or duration are given. However this can be deduced sometimes if the effects of famine and animal mortality are used as proxy indicators. In earlier periods this is often impossible, but most severe winters are given a –3 due because they would not have been mentioned unless there had been a serious human impact given the fact that extreme winters are unusual on the island.

Unlike the rest of Europe there were no references to unusual warmth of winter even though the concept was recognised in Irish literature (Kelly 1998 3). By and large all events are anomalies from the contemporary perspective of the compilers.

Summer temperature and precipitation

This is somewhat variable due to the lack of adequate data. The contemporary average is sufficient rainfall and sunshine for pasture and crop growth and anomalies are either too little or too much of each. While there appears to have been little complaint about high temperatures, associated droughts could have serious consequences. In Ireland they to go together and represent African continental high-pressure systems. In these situations +1 to +3 was given for temperature and precipitation. Where there was too much rain and/or too little sunshine the range was –1 to –3. Like winter crop failure and animal mortality was used as a proxy indicator.

The lack of many references to extreme seasonal variations indicate that Irish climate was largely benign. In fact what worried the Irish farmer was storm damage caused by anti-cyclonic and cyclonic systems or tropical hurricanes. These were usually short episodes but varied in intensity and geographical coverage. Their implications for precipitation patterns is unclear and they have not been included as part of the

precipitation analysis. However two separate set of charts were drawn, the first combining summer precipitation indices and storms (the latter given a value of -0.5) and another giving the incidence of storm types either storm, lightning and hail. In most cases storms are associated with mortality and damage to animals, crops and/or property.

The results show that the Gaelic annalists compiled observations that were of direct relevance to agricultural production. Therefore winter events were noted for the impact they had on early plowing and the availability of winter grass. Summer events were given if there was either a drought or precipitation destroyed crops. Storms were only significant if they caused damage. A detailed examination of the results will be found in the chapter relating to Climate History and various tables and charts can be found in an appendix.

DENDROCHRONOLOGICAL RESULTS

The statistical results are divided into of the correlation coefficient analysis, variation analysis and other results based experimental correlation between widths and two specific classes of entries from the Annals, earthquakes and mast harvests. The interpretation of the tree-ring width behavior will form the basis of the next chapter.

Correlation Curves

Correlation curves were plotted using ten, twenty, thirty, fifty and one hundred year running correlation values and are presented below (Figs. 5.1-5.5).

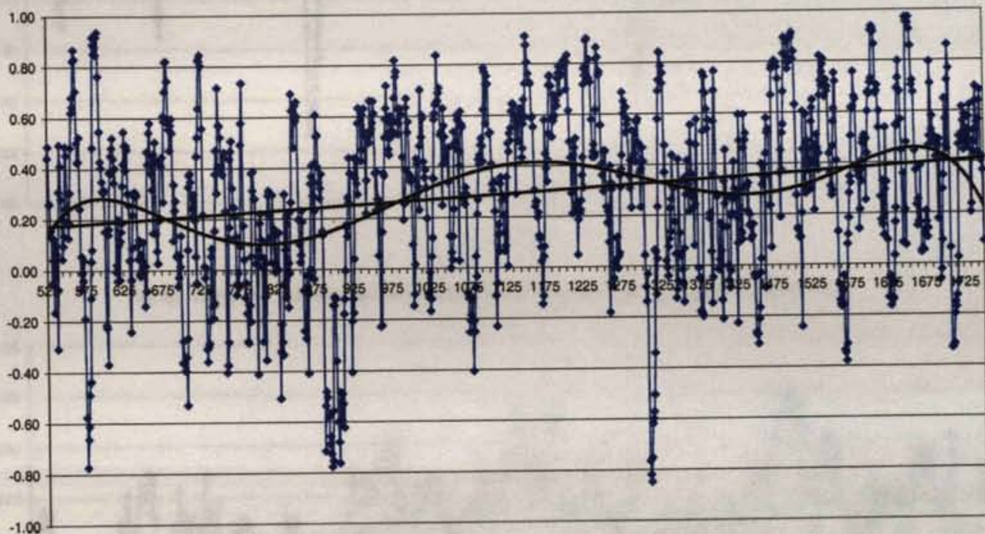
There is a general upward linear trend over the last 2000 years but the charts show a cyclic pattern when fitted with a polynomial curve. These curves show the same pattern over the various periods of correlation of increasing and decreasing synchronous response but with an apparent overall trend of increasing synchronosity.

While the general trend is of a positive correlation coefficient of around 0.2-0.4 there are periods when response is random, indicating chaos in the climatic system, or negative which may indicate Ireland is in a different dendroclimatic zone. Random responses may also be an artefact of the trend from positive to negative or vice versa. An exploration of this zonal concept and its possible implications are discussed later.

It is worth noting the cycles in the ten year running correlation curve (Fig. 5.1) shift from positive to negative and back suddenly. This may indicate that there are periods of highly variable cyclical response. It is difficult to ascertain any overall pattern but some features are noticeable. The first are the major shifts in AD 566-571, AD 886-911 and AD 1298-

1320. In between AD 566 and AD 886 there are about nine other short term reversals compared to seven in AD 911-1298, i.e. one every 35 years as compared to one every 55 years. In the former period reversals appear to be stronger as they achieve lower negative correlation coefficients.

Fig. 5.1 Ten year running correlation of Irish and European tree-ring widths, AD 525-1752



After AD 1320 there are six reversals until AD 1458 (one every 23 years) but these could also be interpreted as random responses. Since then these reversal are uncommon with only four until AD 1752 (one every 75 years).

Periods when there are fewer reversals coincide with higher average positive correlation values. These periods of high correlation are worth noting, as given the problems of interpreting widths; they may indicate intervals when climatic influences are strongest. Given the nature of the data over such a large geographical area these high values indicate that there was a high synchronous response to climate among oaks at these times.

Fig. 5.2 Twenty year running correlation of Irish and European tree-ring-widths, AD 535-1752

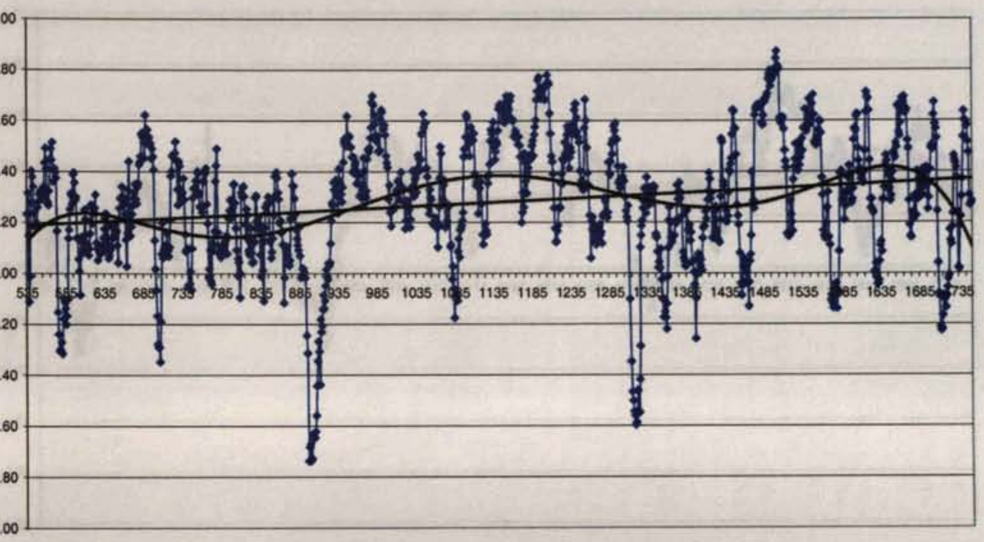


Fig. 5.3 Thirty year running correlation of Irish and European tree-ring widths, AD 545-1752

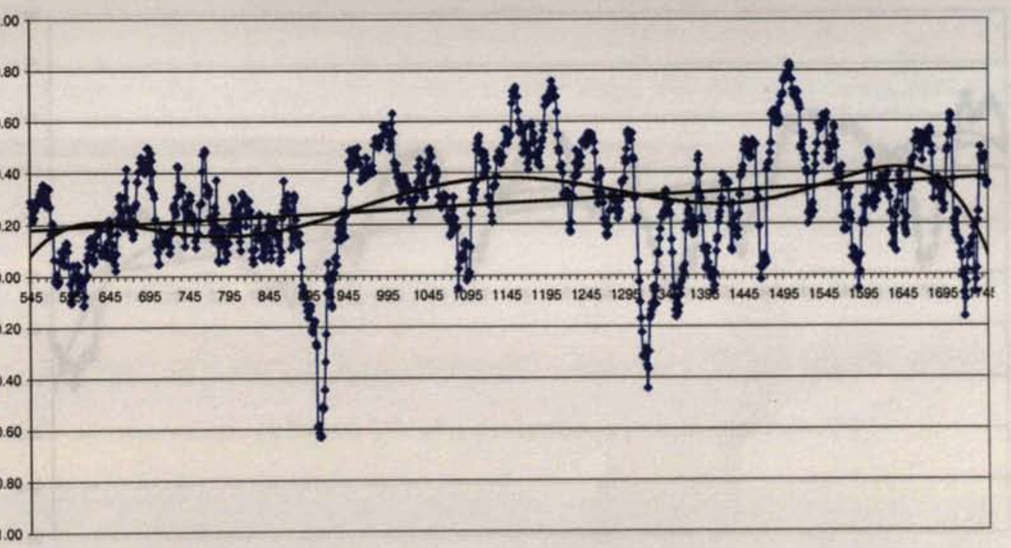


Fig. 5.4 Fifty year running correlation of Irish and European tree-ring widths, AD 565-1753

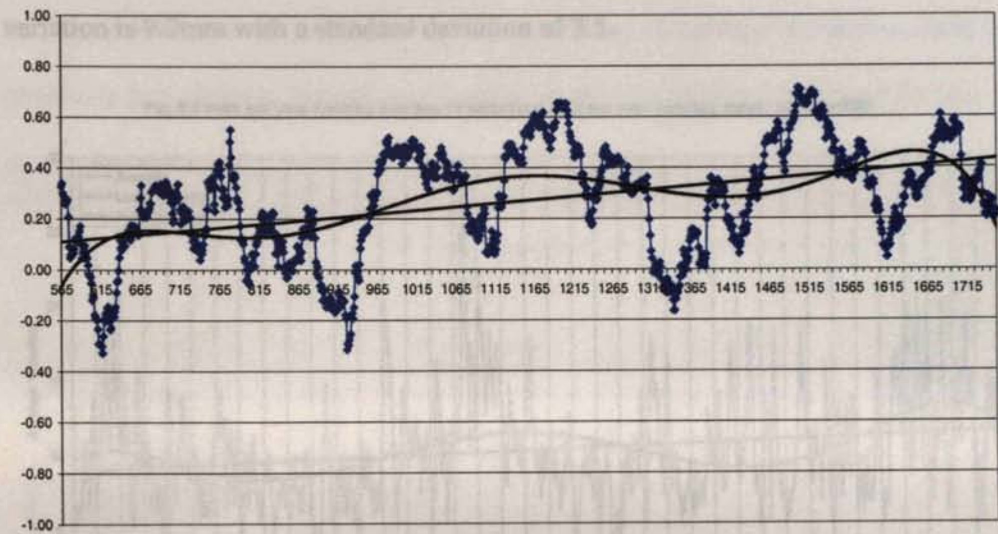
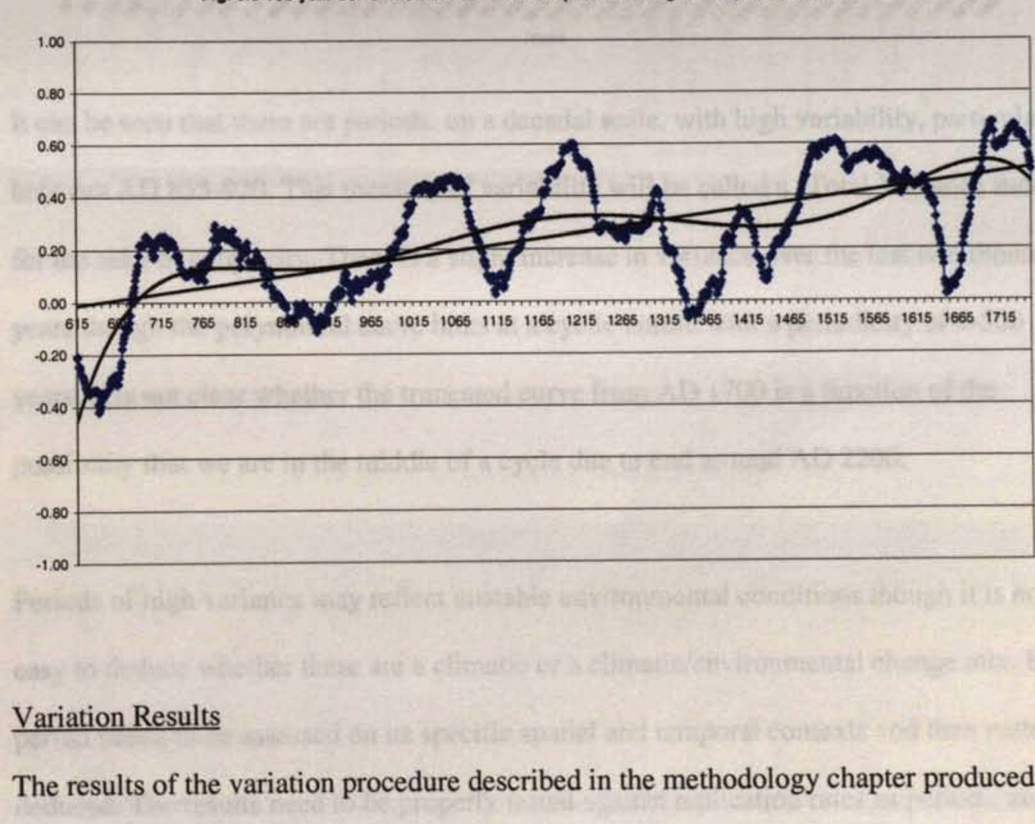


Fig. 5.5 100 year correlation of Irish and European tree-ring widths, AD 615-1752

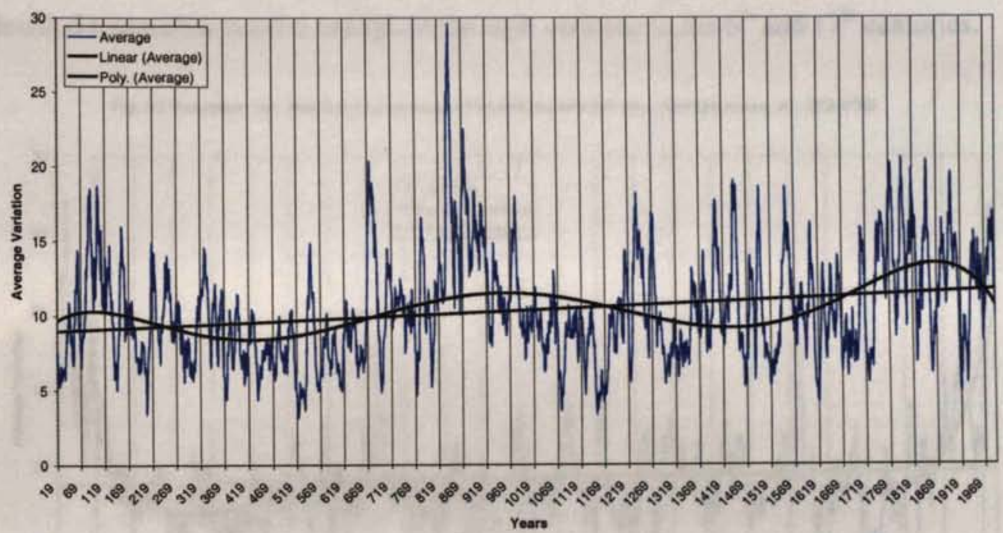


<u>Variation Results</u>

The results of the variation procedure described in the methodology chapter produced the following chart (Fig. 5.6) for Ireland. To put this in context the average Irish tree-ring width is 110.8mm (AD 1-1992) with a standard deviation of 21.7, whereas the average variation is 10.4mm with a standard deviation of 3.6. In comparison the European average

tree-ring width is 131.3mm (AD 516-1752) with a standard deviation of 18.9, an average variation is 9.2mm with a standard deviation of 3.5.

Fig. 5.6 Irish ten year running average of variations off a ten year running mean, AD 510-1993

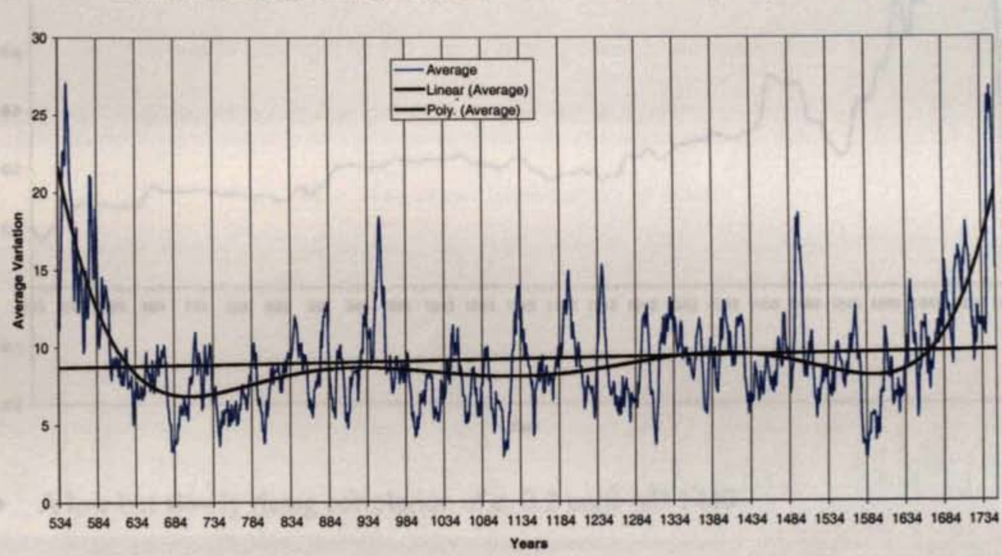


It can be seen that there are periods, on a decadal scale, with high variability, particularly between AD 835-920. This measure of variability will be called a 'Total Variance Index' for the sake of simplicity. There is a slight increase in variance over the last two thousand years though the polynomial curve hints at a cyclic nature with a periodicity of 4-500 years. It is not clear whether the truncated curve from AD 1700 is a function of the possibility that we are in the middle of a cycle due to end around AD 2200.

Periods of high variance may reflect unstable environmental conditions though it is not so easy to deduce whether these are a climatic or a climatic/environmental change mix. Each period needs to be assessed on its specific spatial and temporal contexts and then patterns deduced. The results need to be properly tested against replication rates as periods, such as the mid 9th century, with low numbers of trees could have higher variations. It is not clear whether the trends at periods of low replication are exaggerated or completely unrepresentative due to local factors

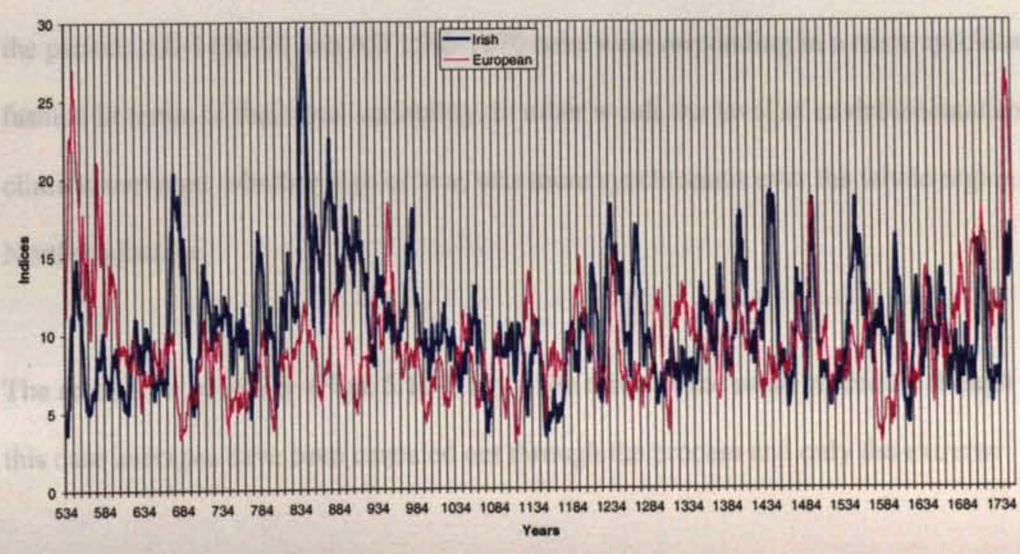
A comparison with the European average (Fig. 5.7) is interesting because while the averaging process will dampen variability to a European average of variance there are obviously periods when the response covers all the chronologies. However further detailed research is needed to explain the high variance in the 6th and 17th centuries.

Fig. 5.7 European ten year running average of variations of a ten year running mean, AD 525-1743

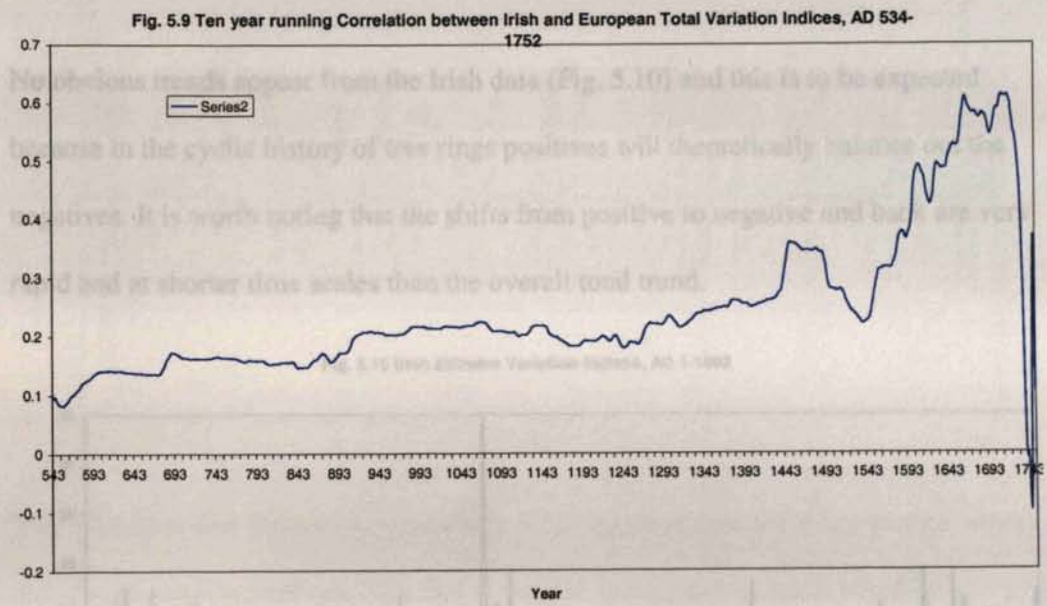


A comparison between the Irish and European Variance Indices (Fig. 5.8) is seen on the next chart and this provides an apparently good visual match. One point of interest is the occasional periods when the European average variance is higher than Irish variance.

Fig. 5.8 Comparison of Irish and European Total Variatrion Indices, AD 525-1752



The following chart (Fig. 5.9) is a ten year running correlation between the two sets of indices and provide an unexpected result. The main points being:



- A low but slowly rising correlation of c. 0.2 until AD 1440
- A sharp increase between AD 1450-90
- A decrease to AD 1540
- A sharp rise then to 1670 followed by a major shift to no correlation until AD 1720

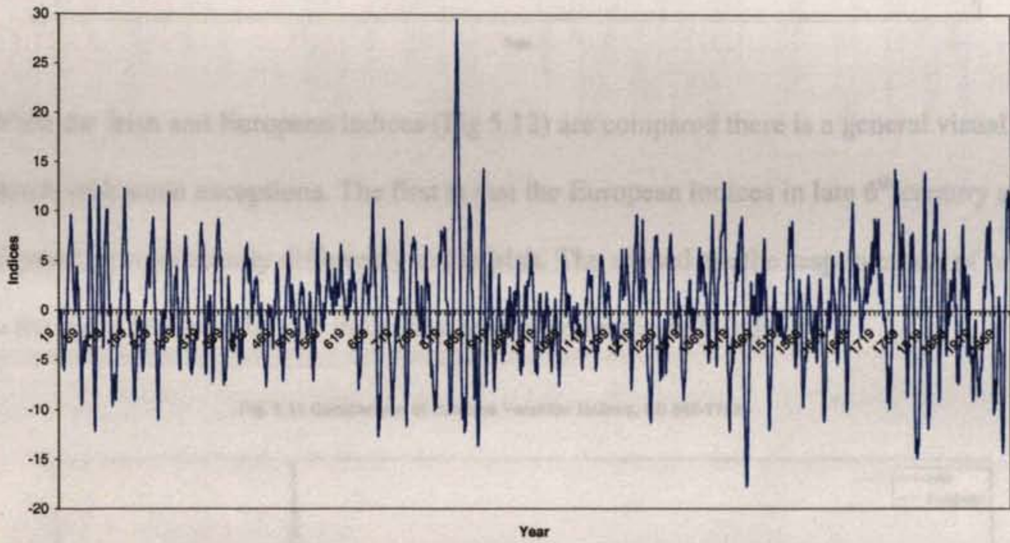
None of this appears to have any climatic corollary and all that can be supposed is that in the periods AD 1450-90 and AD 1540-1670 oaks were responding in a more synchronous fashion in terms of their total variability. In other words the level of environmental and/or climatic variance, whether high or low, was more synchronous over the whole region of Northern Europe.

The second set of charts (Figs. 5.10-5.13) is the result of the same procedure though in this case averages have been canceled out through the process and only the extreme

positive and negative variations are left. Otherwise the same procedures were carried out. This is called the 'Extreme Variance Index'.

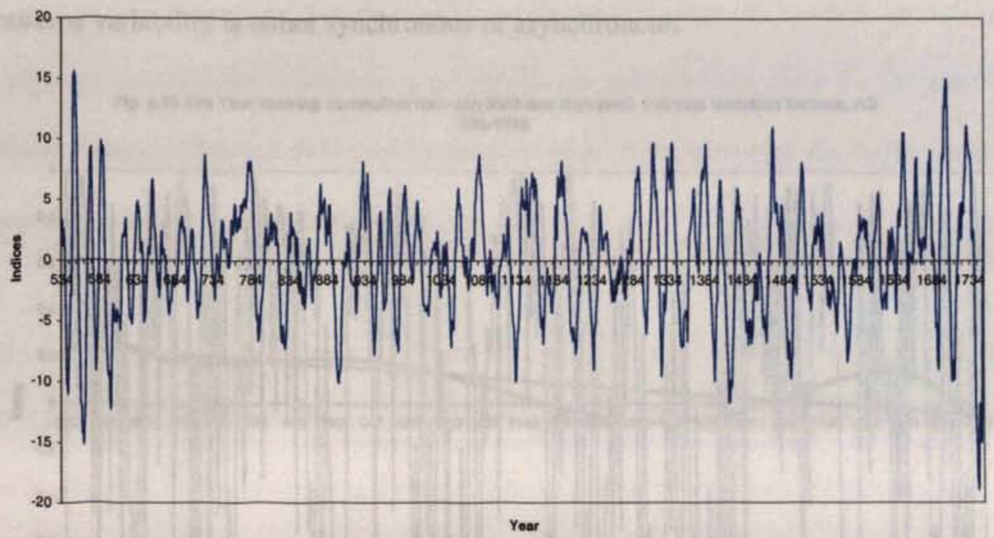
No obvious trends appear from the Irish data (Fig. 5.10) and this is to be expected because in the cyclic history of tree rings positives will theoretically balance out the negatives. It is worth noting that the shifts from positive to negative and back are very rapid and at shorter time scales than the overall total trend.

Fig. 5.10 Irish Extreme Variation Indices, AD 1-1992



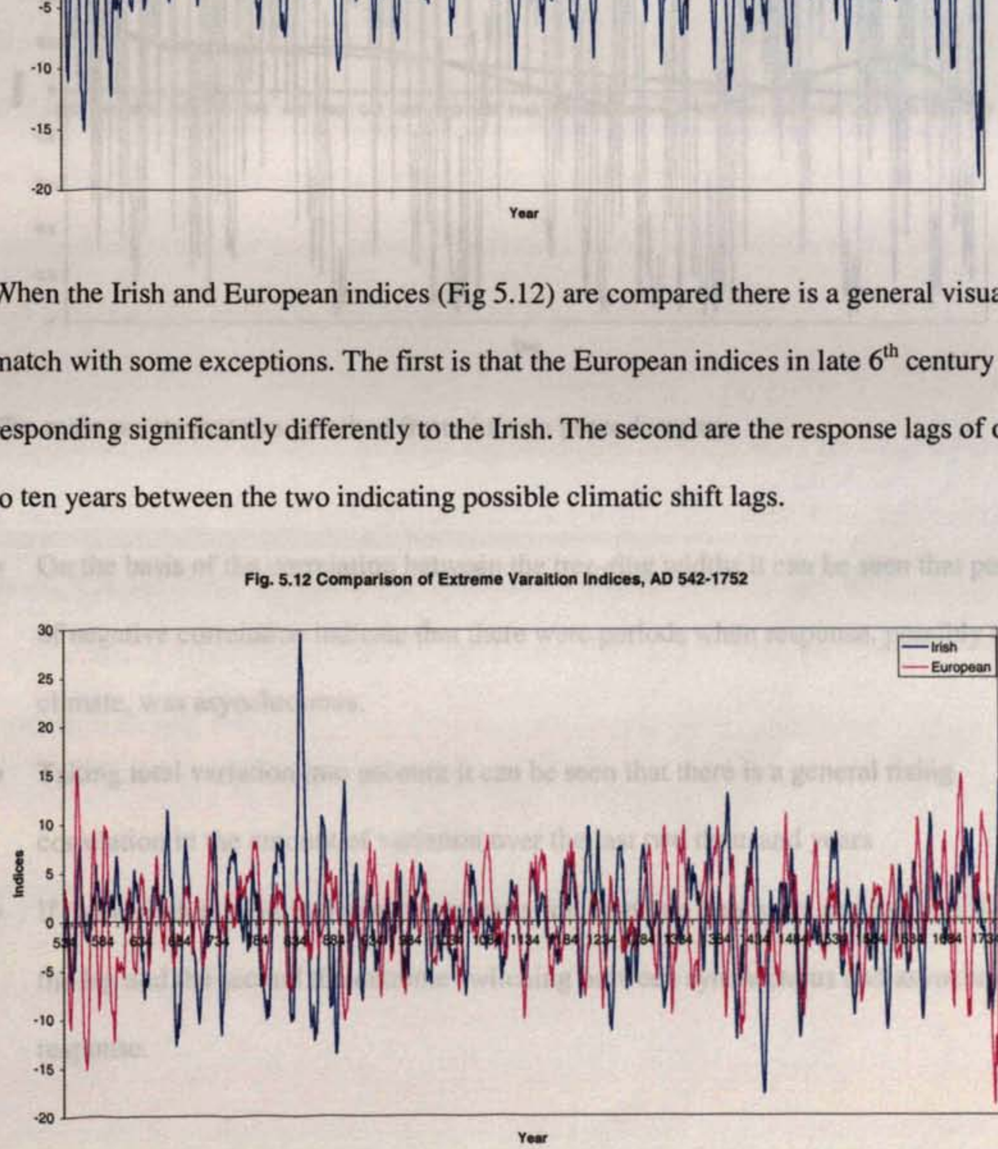
In Europe variation (Fig 5.11) will theoretically be canceled out through the meaning of the seven chronologies and one possible added effect is that the cycles are longer. The one oddity is the higher levels of extreme variation at the end of the 6th and early 18th centuries, a characteristic also found when total variation is plotted and mirrors the average European tree-ring widths, at least for the 6th century.

Fig. 5.11 European Extreme Variation Indices ,AD 534-1752



When the Irish and European indices (Fig 5.12) are compared there is a general visual match with some exceptions. The first is that the European indices in late 6th century are responding significantly differently to the Irish. The second are the response lags of one to ten years between the two indicating possible climatic shift lags.

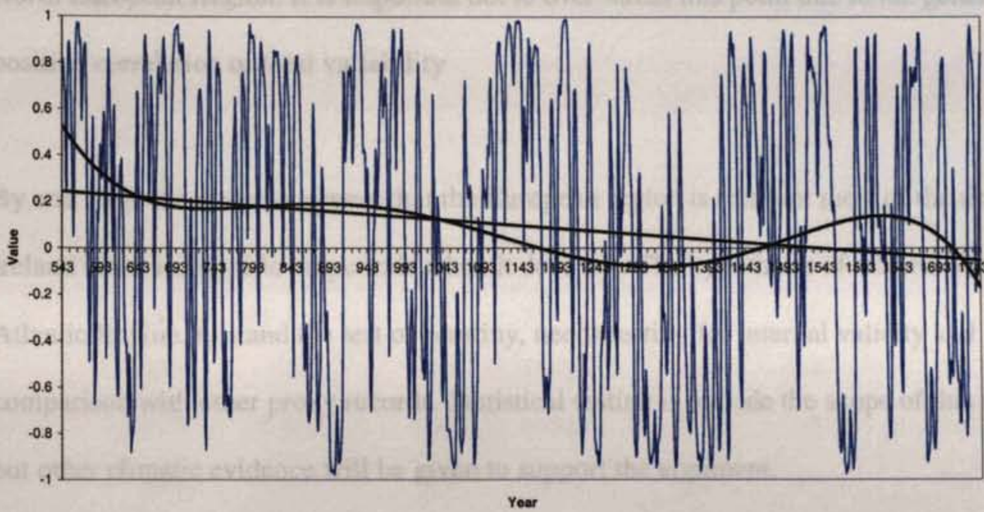
Fig. 5.12 Comparison of Extreme Varaition Indices, AD 542-1752



When a correlation curve (Fig 5.13) is fitted between the two sets a graph is plotted that is significantly different from the former derived from total variability. What are seen are

rapid shifts between high positive and negative correlation, in other words, periods when extreme variability is either synchronous or asynchronous.

Fig. 5.13 Ten Year running correlation between Irish and European Extreme Variation Indices, AD 535-1752



The main points that can be taken from the two procedures are:

- On the basis of the correlation between the tree-ring widths it can be seen that periods of negative correlation indicate that there were periods when response, possibly to climate, was asynchronous.
- Taking total variation into account it can be seen that there is a general rising correlation in the amount of variation over the last two thousand years
- If the variation is limited to extreme variation than two trends are noticed, the first is the lag and the second the extreme switching between synchronous and asynchronous response.

The extreme variations appear to show that there are periods of time when environmental and climatic conditions create greater variation in widths. They are not synchronous and have a spatial and temporal trend. By analogy it may be likened to a westerly storm sweeping across the continent but at a much slower speed and represents periods when

the boundaries of the dendroclimatic regions are moving east or west. The lags and negative correlation would then show the exact periods when the North West Atlantic Region was over Ireland whereas synchronous responses would show the ubiquity of the North European Region. It is important not to over-stress this point due to the general positive correlation of total variability

By and large the it would appear that the European region is relevant most of the time to Ireland there are significant periods when it does not. The hypothesis of a North West Atlantic Region, to stand the test of scrutiny, needs testing for internal validity and comparison with other proxy records. Statistical testing is outside the scope of this work but other climatic evidence will be given to support the argument.

It appears that there are short, medium and long-term cycles at work here and the shifts noted reflect these change. It is impossible to say what is the actual relationship between biological and climatic input. It is possible that climatic influences are strongest particularly at times when correlation between widths and extreme variations are either very high or very low.

ANNALS AND TREE-RING WIDTHS

Earthquakes

The following table is the widths of the earthquake years divided by the average width of the previous five years and multiplied by 100 to compute the percentage difference.

Table 5.1 Earthquakes and Tree-ring widths

	Years	Widths	Years	Widths	Years	Widths	Years	Widths
	675	140.0	702	97.0	716	113.0	725	112.0
	676	125.0	703	112.0	717	102.0	726	106.0
	677	113.0	704	114.0	718	86.0	727	128.0
	678	100.0	705	113.0	719	82.0	728	122.0
	679	110.0	706	103.0	720	95.0	729	126.0
Average		117.6		107.8		95.6		118.8
	680	80.0	707	105.0	721	104.0	730	106.0
Year/Average %		68.0		97.4		108.8		89.2

	Years	Widths	Years	Widths	Years	Widths
	735	108.0	764	114.0	654	128.0
	736	98.0	765	111.0	655	120.0
	737	84.0	766	125.0	656	106.0
	738	76.0	767	104.0	657	127.0
	739	93.0	768	115.0	658	127.0
Average		91.8		113.8		121.6
	740	110.0	769	114.0	659	116.0
Year/Average %		119.8		100.2		95.4

There is no correlation between the seven events. This is probably due to a number of factors. Earthquakes don't necessarily happen during the growing season. If an earthquake is the result of isostatic rebound then the effects are likely to be localised and there is no guarantee that the above trees were from the relevant locality.

Oak Mast

The following chart shows the widths of mast years divided by the average width of the previous five years and multiplied by 100 to compute the percentage difference. When the Annals gave or implied consecutive good harvests then only the last year was analysed.

Table 5.2 Oak Mast Harvests and Tree-ring widths

Years		Widths	Years	Widths	Years	Widths	Years	Widths
	667	148.0	755	118.0	764	114.0	801	95.0
	668	158.0	756	122.0	765	111.0	802	97.0
	669	153.0	757	121.0	766	125.0	803	94.0
	670	113.0	758	102.0	767	104.0	804	110.0
	671	112.0	759	103.0	768	115.0	805	105.0
Average		136.8		113.2		113.8		100.2
	672	125.0	760	113.0	769	114.0	806	117.0
Year/Average %		91.4		99.8		100.2		116.8
	830	74.0	930	136.0	962	113.0	976	105.0
	831	89.0	931	121.0	963	148.0	977	133.0
	832	94.0	932	153.0	964	125.0	978	99.0
	833	131.0	933	108.0	965	97.0	979	126.0
	834	113.0	934	113.0	966	137.0	980	137.0
Average		100.2		126.2		124.0		120.0
	835	135.0	935	100.0	967	114.0	981	94.0
Year/Average %		134.7		79.2		91.9		78.3
	980	137.0	1005	113.0	1027	109.0	1052	93.0
	981	94.0	1006	103.0	1028	113.0	1053	85.0
	982	109.0	1007	113.0	1029	99.0	1054	64.0
	983	116.0	1008	128.0	1030	128.0	1055	96.0
	984	97.0	1009	113.0	1031	122.0	1056	97.0
Average		110.6		114.0		114.2		87.0

985	107.0	1010	118.0	1032	98.0	1057	89.0
Year/Average %	96.7		103.5		85.8		102.3
1061	124.0	1070	114.0	1077	99.0	1087	108.0
1062	95.0	1071	102.0	1078	121.0	1088	108.0
1063	95.0	1072	93.0	1079	105.0	1089	101.0
1064	98.0	1073	104.0	1080	95.0	1090	86.0
1065	80.0	1074	99.0	1081	87.0	1091	86.0
Average	98.4		102.4		101.4		97.8
1066	109.0	1075	101.0	1082	91.0	1092	87.0
Year/Average %	110.8		98.6		89.7		89.0
1088	108.0	1093	118.0	1103	88.0	1106	94.0
1089	101.0	1094	93.0	1104	73.0	1107	88.0
1090	86.0	1095	99.0	1105	98.0	1108	105.0
1091	86.0	1096	89.0	1106	94.0	1109	97.0
1092	87.0	1097	106.0	1107	88.0	1110	86.0
Average	93.6		101.0		88.2		94.0
1093	118.0	1098	98.0	1108	105.0	1111	93.0
Year/Average %	126.1		97.0		119.0		98.9
1126	88.0	1143	91.0	1195	131.0	1305	111.0
1127	95.0	1144	87.0	1196	114.0	1306	123.0
1128	103.0	1145	99.0	1197	91.0	1307	102.0
1129	70.0	1146	95.0	1198	88.0	1308	98.0
1130	93.0	1147	89.0	1199	100.0	1309	106.0
Average	89.8		92.2		104.8		108.0
1131	84.0	1148	95.0	1200	98.0	1310	107.0
Year/Average %	93.5		103.0		93.5		99.1

The average percentage is 100% with a standard deviation of 13.6%. Ten (42%) of the entries are between 90-99% of the previous five year average. Overall there appears to be little relationship between good crops of oak mast and tree-ring widths.

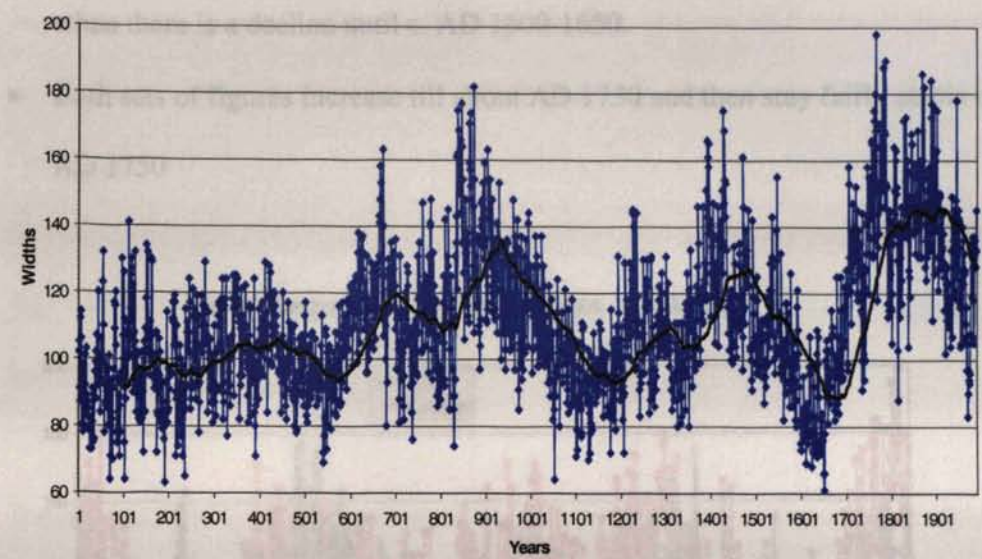
IRISH *QUERCUS* TREE-RING WIDTH CYCLES

There are no established methodologies for the analysis of tree-ring widths as previously discussed. What follows is therefore experimental and explores the data, because it offers a different perspective of the *Quercus* response to regional climatic and biological trends. Where possible these have been disentangled through a mixture of mathematical formulae allied with visual examination. Within the framework of this dissertation only an introduction is possible with the addition of cameo samples of some of the more interesting examples and trends.

The chart (Fig. 6.1) below shows the patterns of tree-ring widths of the last 2,000 years in Ireland and has a one hundred year moving average added (charts analysing widths on a centennial scale are in an appendix). It is of course possible to use a number of different averages and this is done when greater detail is needed. However it does show the general trend and it is interesting to note those extreme widths whether positive or negative tend, with a few exceptions, happen when the average is either rising or falling respectively. Therefore low values always have to be taken within the context of where they are in the overall trend. In comparison indices, which are relative variations from a mathematical curve, are perhaps more appropriate for identifying years with extreme values.

The character of cyclic change in the previous 5,000 years is different but the period of depressed widths extends back to the 2nd century BC (Baillie pers. com.)

Fig. 6.1 Irish tree-ring widths, AD 1-1992



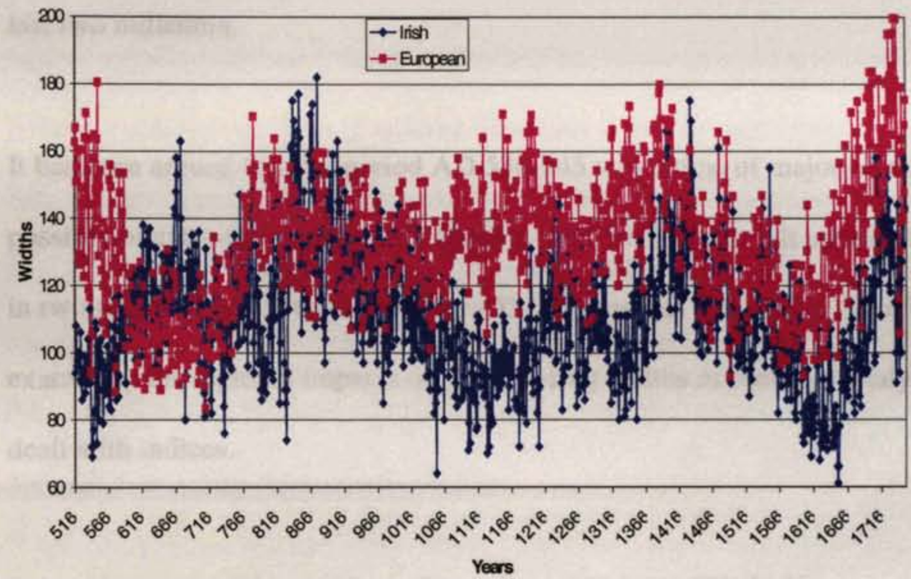
A purely climatic interpretation would argue that rises indicate increasingly 'good' summers and falls increasingly 'bad summers'. This is patently not the case as the most other sources indicate that the period AD 950-1250 was a warm period and that this was followed by climatic deterioration at least up to the beginning of the 19th century.

Before analysing the Irish series in detail it is worth comparing the above with the European average series (Fig. 6.2). This shows a completely different character and the main points can be listed as follows:

- Irish tree-ring widths are mostly narrower than the European average except for the periods, c. AD 630-730 and 910-20.
- European widths do not show the same cycles though this is not unexpected given the nature of the averaging process.
- The European average shows a decline in the 6th and early 7th century, which is not mirrored by the Irish data

- From c. AD 800 the European average stays fairly constant until about AD 1400 when there is a decline until c. AD 1600-1650.
- Both sets of figures increase till about AD 1730 and then stay fairly stable until AD 1750

Fig. 6.2 European and Irish tree-ring widths, AD 516-1752



AD 1-550

In Ireland some climatic trends can be hypothesized. If the period up to c. AD 570 is examined it can be seen that over this time tree rings growth was depressed compared to later times. This may be equated to the Iron Age lull usually dated from about 300 BC to AD 300. It can be seen that there was a slight improvement from about AD 253 to about AD 500 with some good summers in AD 97-126 and AD 152-164. This of course assumes that biological factors are of little importance. Weir (quoted in Baillie 1995 145) has argued that there was major woodland regeneration from the around the second and first centuries BC and it is possible that after the previous cycle the slight decline after AD 500 is age related.

However what is striking here is the large number of years with very depressed widths in AD 70-94, AD 175-200 and AD 217-237. All are narrower than AD 536-45 with four years, AD 71, 104, 193, and 237 exhibiting lower widths than in AD 541, the lowest in that specific downturn. It is also worth noting that the particular pattern of AD 538-545 can also be found at AD 247-253 but these appear to be unique in the last two millennia.

It has been argued that the period AD 536-545 was a time of major catastrophes possibly of extra-terrestrial origin (Baillie 1995 91-107, etc.). It appears to have come in two stages in AD 536 followed by AD 538 onwards It is worth, therefore, examining the regional impacts on the tree-ring widths as previous analysis has only dealt with indices.

Table 6.1 Regional breakdown of tree-ring widths AD 535-546

Years	Ireland	Sheffield	London	Netherl	Denmark	Gott	Hamburg	Poland
535	104	95	286	71	256	141	165	66
536	91	79	193	66	150	120	158	68
537	93	105	346	75	196	156	188	80
538	113	96	137	67	179	153	136	49
539	91	53	186	69	57	140	107	49
540	72	56	145	70	83	126	137	38
541	69	57	127	95	113	138	146	62
542	72	82	134	164	153	169	154	91
543	77	103	207	167	160	158	156	58
544	82	101	249	144	211	143	185	72
545	83	100	243	140	266	155	197	53

546	109	119	181	116	167	130	189	55
Ave. 535-546	88	87	203	104	166	144	160	62
Correlation		0.5	0.3	-0.4	0.3	0.1	-0.1	-0.2

In AD 536 all chronologies, except Poland, declined in varying percentages though these are deceptive as London and Denmark dropped from higher values. The first set of underlined figure above show the year when the second decline happened per region. It can be surmised that the effects of the impact moved from east to west as Ireland's oaks responded a year later. However it lasted a good deal longer, until AD 546, as the rest of the European oaks responded to better conditions between AD 541-543. Poland is not included as AD 521-564 is marked by extremely poor summer conditions, particularly between AD 553-561 when the widths vary between 0.34-0.44mm. It is also, perhaps, worth noting that the widths in Netherlands and Denmark were also declining from about AD 531.

The various areas therefore responded differently depending on the relationship between the catastrophe's impacts and the regional climatic processes at the time. This is confirmed by the weak to non-existent correlation of Ireland and the other regions, which shows an east to west trend.

The discussion will now turn to an examination of the Irish tree-ring widths and is divided into periods of either rising or falling values for the first cycle followed by a consideration of the second cycle, particularly the extremely low values of the mid 17^{th} century. It will conclude with a brief discussion of the period after the mid 18^{th} century.

AD 550-700

The first period of increase is from about AD 550-700 and is fairly steady except for AD 664-675, which has a higher than average widths of 1.36mm with seven of the nine years ranging from 1.40-1.63mm. It is worth noting however that this period had a number of major plague events, and this must have had major implications for the population. Such population decreases are usually followed by woodland regeneration, therefore the overall increase may be biological with the possible exception of AD 664-675.

In contrast the European tree-rings are wider, by about 0.4mm, than the Irish though by the time the series starts in AD 516 there is a slow decline from unresearched origins. From AD 591 there is a sharp drop and they are narrower than the Irish widths until about AD 700, which is in contrast from the normal pattern of them being wider. The transition at AD 590-1 is quite marked with a drop of the average from 1.38mm to 1.11mm when the decades before and after are compared.

A detailed analysis of the separate tree ring widths indicates that the areas in which the impact of this climatic transition were greatest are shown in the table below:

Table 6.2 Regional tree-ring width averages AD 581-600

Years	Ireland	Sheffield	London	Netherl	Denmark	Gott	Hamburg	Poland
Ave. 581-590	106	124	178	110	157	150	151	97
Ave. 591-600	109	98	132	89	122	129	149	57
Difference	-3	-26	-46	-22	-35	-21	-2	-40

The areas with the largest differences are Poland, Denmark and London. The reason that London shows a high value of 0.46mm it because it had extremely high values in the early AD 580s of 1.63-2.22mm indicating that it was possibly making a transition to a different climatic summer regime. Overall it appears that there was a climatic shift of possible Fennoscandian origins towards the south though Hamburg is an anomaly, especially compared with Göttingen, approximately 250 km to the south.

This drift also appears in the correlation of Ireland and the European averages, on a decadal level. These show very high values 0.85 (AD 577-586) to 0.94 (AD 584-593) with a sharp drift downwards to 0.32 (AD 591-600). There is no significant change of correlation, however, at longer periods of over twenty years. It may be significant that between AD 575-580 there is a negative correlation indicating that before AD 591 Irish oaks were responding independently to the rest of Europe

The following table shows the regional breakdown of average widths for the AD 664-675 period.

Table 6.3 Regional tree-ring width averages AD 664-675

	Ireland	Sheffield	London	Netherl	Denmark	Gott	Hamburg	Poland
Ave.	136	92	114	102	77	120	156	93

This indicates that Ireland was possibly within a summer system area independent of the rest of Europe. Hamburg, again is an anomaly.

AD 701-832

This period shows a decline in Ireland with some low width values scattered through AD 718-810, AD 820 and AD 827-832. It is difficult to say whether they reflect a predominance of climatic or biological influences over all, though the low values are possibly climatic. At the same time the European low width values, which had declined to AD 710, now start to increase and their average becomes higher than Ireland after c. AD 770. Correlation values during the years AD 692-708 on a decadal scale show a cluster of negative values, which may indicate that this transition was marked by asynchronous responses by Irish oaks.

The European average shows a general increase from about AD 750-850 and this may be due to regeneration since this period is difficult to bridge with archaeological samples all over Europe. However this can only be taken so far as European regeneration is not seen in earlier centuries. There may be cultural causes due to the collapse of the Roman Empire. It is worth noting that the European average is heavily influenced by very low Polish widths over this period AD 521-715, they average at 0.78mm (ranging from 0.38-1.26mm with one very high value of 1.70mm in AD 569) compared to the total European average of 1.16mm. This may have implications for any interpretations of Northern European oaks at this time.

The AD 820 event is unique to Ireland and Northern England with values of 0.85mm and 1.14mm respectively compared to the rest of the regions, which vary between 1.33mm and 1.41mm with the exception of Göttingen at 2.65mm. The following table indicates a similar pattern during AD 827-832 with a general trend of higher widths

moving in a southerly direction, though Hamburg is unexpectedly lower than Denmark.

Table 6.4 Regional tree-ring width averages AD 827-32

Years	Ireland	Sheffield	London	Netherl	Denmark	Gott	Hamburg	Poland
Ave. 827-32	88	114	146	121	129	221	94	104

AD 833-1200

This next period shows a marked increase in Irish widths to c. AD 912 with some very high values in AD 840, 849, 866,869, and 876, all over 1.70mm. This is followed by a decline to c. AD 1200.

Baillie argues (1995 125-7) that there is a missing generation of oaks around this time due to 'intense building activity between AD 720-840' and this resulted in a major shortage, followed by regeneration in the 9th century. One rapid shift happens in the ten-year period of AD 823-832 and AD 833-41 respectively with an average increase of 1.06mm to 1.37mm. The anthropogenic factor may explain the upward trend though the increase is shorter, lasting till c. AD 930s. It appears that oaks used in archaeological structures show a complete population cohort break at this time. It is worth noting that at this period the great majority of Irish oaks in archaeological contexts are either before or after this date with three trees bridging the gap between AD 832-3. The tree-ring width evidence therefore supports Baillie's hypothesis and allows a more precise identification of the date of transition

In comparison, the rest of Europe remains uniform for most of this period though this may be a function of the averaging of the seven series. A detailed analysis of these is

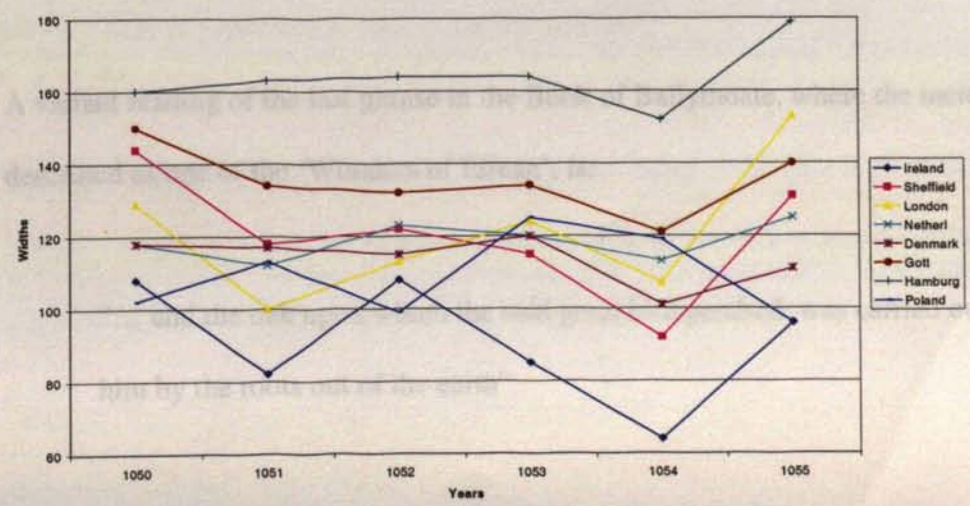
beyond the scope of the dissertation but several cameos will be explored. The first is the 1054 event, which gives a value of 0.64mm, the narrowest width in the cycle, and is comparable with the extremely low values at AD 71,104, 193 and 237.

If this is compared with the rest of Europe than the following table (Table 6.5) and chart (Fig. 6.3) show the regional patterns.

Table 6.5 Regional comparison of tree-ring widths AD 1050-1955

Years	Ireland	Sheffield	London	Netherl	Denmark	Hamburg	Gott	Poland
1050	108	144	129	118	118	150	160	102
1051	82	118	100	112	117	134	163	113
1052	108	122	113	123	115	132	164	99
1053	85	115	124	120	120	134	164	125
1054	64	92	107	113	101	121	152	119
1055	96	131	153	125	111	140	179	96
Ave. 1050-3	96	125	117	118	118	138	163	110
% diff. 1054/Ave	66.67	73.60	91.45	95.76	85.59	87.68	93.25	108.18

Fig. 6.3 The AD 1054 event in Europe



The effects of event appears to have moved from west to east, its intensity lessening with distance though all areas are affected. It appears to have been a short-term event and the great majority of European chronologies show a recovery of trees the following year with the exception of Poland due to unknown factors.

This event is of interest because the Annals of the Four Masters and Chronichum Scotorum, under AD 1054, give a very confused, but detailed, account as follows:

> "A steeple of fire was seen in the air over Ros-Deala on the Sunday of the Festival of George; innumerable black birds passing into it and out of it, and one large bird in the middle of them; and the little birds went under his wing when they went into the steeple. They came out and raised up a greyhound, that was in the middle of the town, aloft in the air, and let it drop down again so that it died instantly and they took up three cloaks and two shirts, and let them drop in the same manner. The wood in which these birds perched fell under them; and the oak tree upon which they perched shook with its roots in the Earth."

A variant reading of the last phrase in the Book of Ballymoate, where the incident is described as one of the 'Wonders of Eirean', is:

> "... and the oak upon which the said great bird perched was carried out by him by the roots out of the earth"

O'Donovan, the editor, identified Ros-Deala, as near Durrow, Co. Westmeath. He also notes that the Festival of George was on Saturday in AD 1054, and Sunday the following year. His opinion was that the text probably meant the Sunday following the event as he states that the chronology of the Annals of the Four Masters is accurate for this period. This opinion could be questioned as the previous great winter is recorded in the same Annals under AD 1048, but AD 1047 in the other annals. Overall it is likely that the event did take place in AD 1054 but a year either side is also possible. The Festival of George is intriguing, as this saint is also associated with dragons, sometimes seen as a metaphor for extra-terrestrial phenomena.

In a recent article McCarthy (1997 1-43) stated that this is a very garbled account of the first sighting of the Crab Nebula, which is not otherwise recorded in European contemporary sources. An alternative scenario is that it was an extremely climatic event, i.e. a tornado, since obviously it is impossible for a nebula to impact on tree-rings in this way. The main argument against the latter alternative is that none of the Annals describe any destruction with the exception of a lake moving from Sewran to the Boyne, both in Co. Meath. Certainly some major short-term event can be hypothesised, though on the basis of extant Irish sources, it is impossible to identify what exactly was the reason for the narrow widths.

The second period covers the period AD 886-911 which show very high values of negative correlation and this indicates that summers in Ireland were responding in a completely opposite way to the rest of Europe (Fig. 6.4-6.6).

Fig. 6.4 Asynchronous Widths, AD 886-897 & AD 903-911

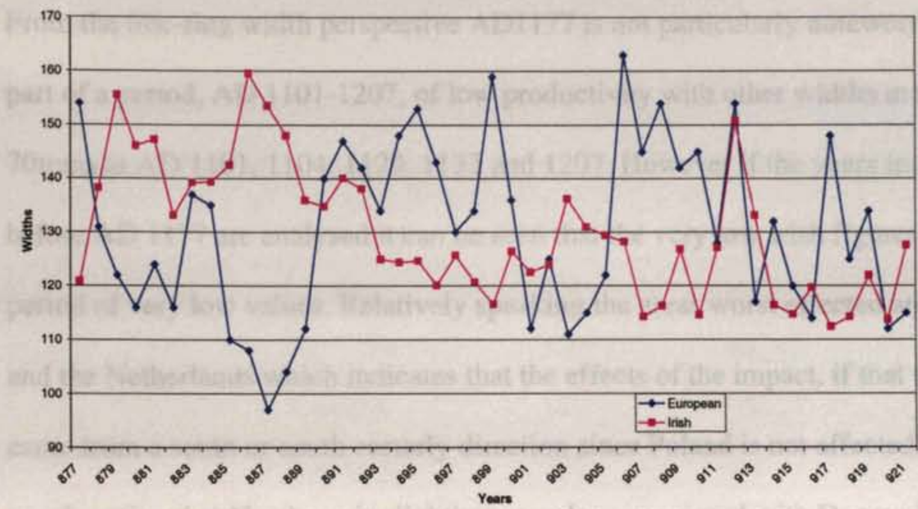
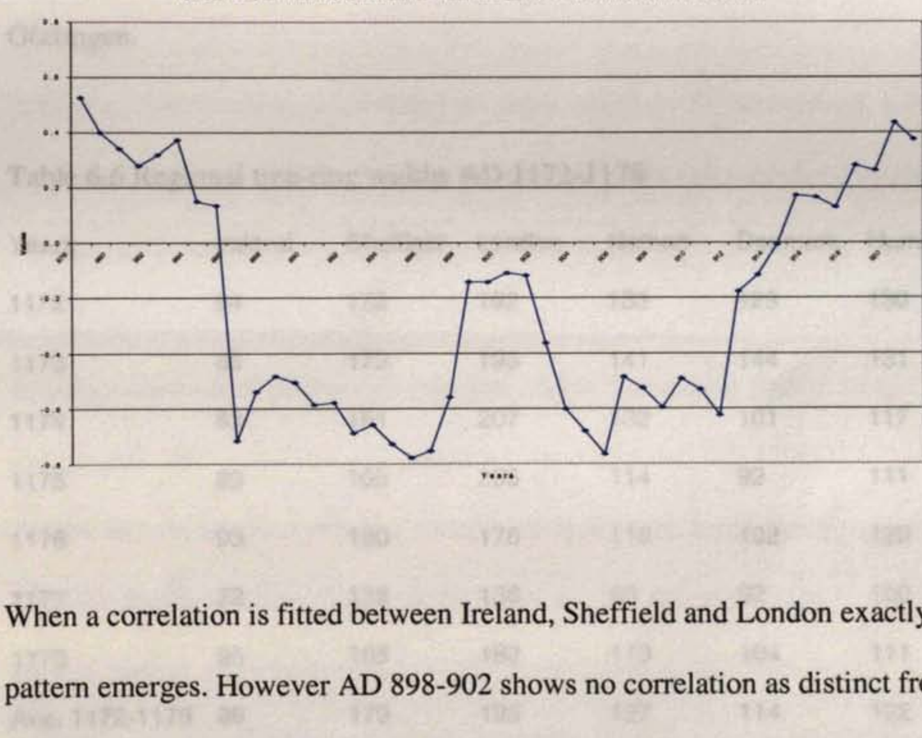
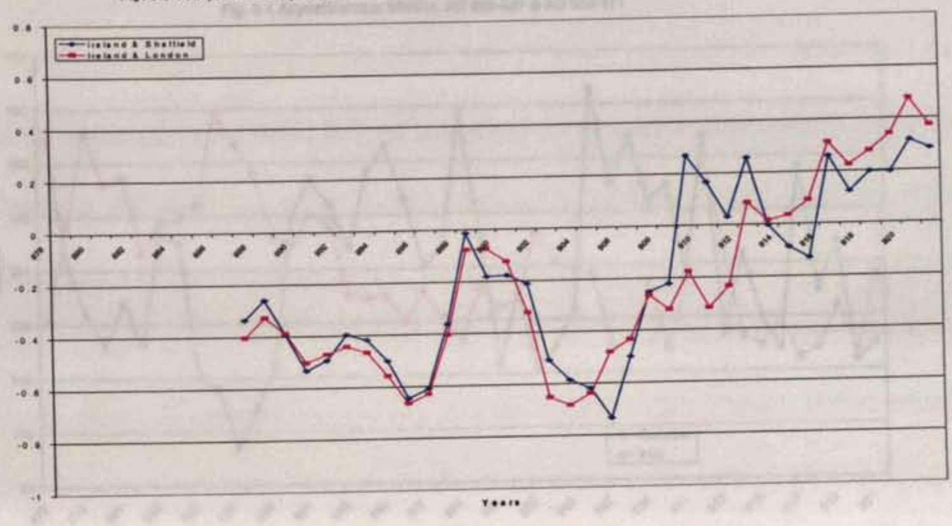


Fig. 6.5 Ten year running correlation of Irish and European tree-ring widths, AD 878-921



When a correlation is fitted between Ireland, Sheffield and London exactly the same pattern emerges. However AD 898-902 shows no correlation as distinct from a negative correlation which implies that at this period the trend to asynchronous behaviour must have a gradual east-west divergence.

Fig. 6.8 Ten year running correlations between Ireland with Sheffield and London, AD 878-929



A third cameo is the AD 1163-89 period identified by Baillie (1996 107 &1998 57-58) who states there was a major negative value as measured by tree-ring indices. This includes a minimum value at AD 1177 and possibly related extraterrestrial events in AD 1173 and 1178. The first is a possible bombardment of moon seen from Canterbury and the second a fireball moving westwards seen from Ulster. If these are interpreted literally, they support a theory put forward by Bailey, Clube and Napier that this was a period of risk from cometry debris. However it has to be added that such descriptions in the Gaelic Annals are mostly visual and yet such an object would almost certainly travel faster than the speed of sound and therefore generate sonic booms. Without a description of 'thunder', i.e. AD 735, identification can only remain tentative. However it has been recently argued that a tunguska-type object impacted in the Pacific Basin c. AD 1178 (Spedicato 1997 1-17). Whether or not the Irish 'fireball' is evidence for this hypothesis or not is unclear, it is however intriguing to note that three annals refer to a snowstorm called variously a 'snow of venom', 'noxious snow', and a 'snow of destruction' the following winter in AD 1179. This may indicate tephra contamination.

From the tree-ring width perspective AD1177 is not particularly noteworthy and is part of a period, AD 1101-1207, of low productivity with other widths in the low 70mms at AD 1101, 1104, 1129, 1132 and 1207. However if the years immediately before AD 1177 are analysed it can be seen that the very low Irish figures belong to a period of very low values. Relatively speaking the areas worst effected are London and the Netherlands which indicates that the effects of the impact, if that what it was, came from a south or south easterly direction since Poland is not affected. Again it is worth noting that Hamburg is slightly anomalous compared with Denmark and Göttingen.

Table 6.6 Regional tree-ring widths AD 1172-1178

Years	Ireland	Sheffield	London	Netherl	Denmark	Hamburg	Gott	Poland
1172	84	172	192	133	129	130	128	143
1173	86	172	195	141	144	131	142	141
1174	83	161	207	132	101	117	126	134
1175	83	165	205	114	92	111	116	125
1176	93	180	178	116	102	120	125	142
1177	72	138	136	90	92	100	110	133
1178	95	165	192	113	104	111	119	138
Ave. 1172-1176	86	170	195	127	114	122	127	137
% 1177/Ave.	83.72	81.18	69.74	70.87	80.70	81.97	86.61	97.08

AD 1200-1650

This period follows the same cyclic pattern as AD 550-1200 with an increase from AD 1200-1310, a decrease to AD 1345, an increase to AD 1437, followed by a

decrease to AD 1655. This cycle is about 75 years shorter than the previous as the following table shows.

Table 6.7 Comparison of Irish phases AD 550-1200 and AD 1200-1655

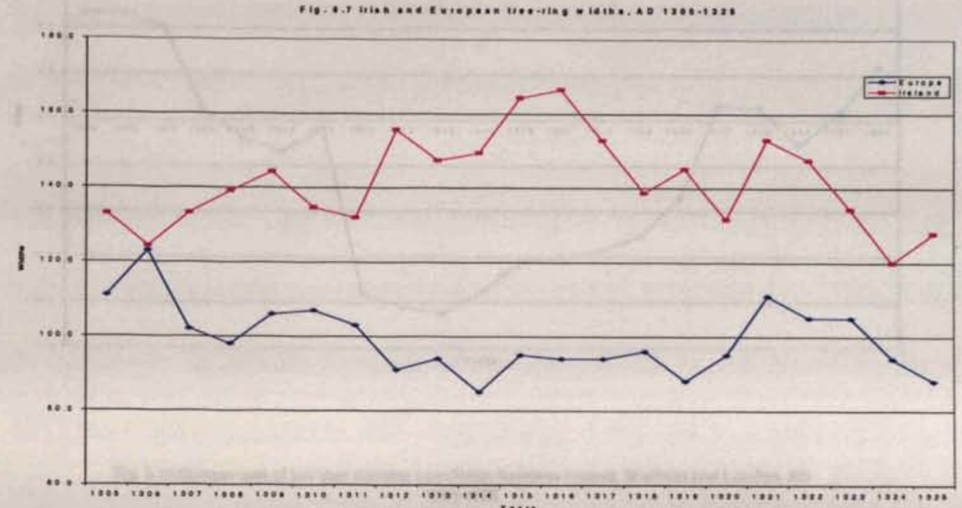
Movement	AD 550-1200	AD 1200-1655
Increase	150	210
Decrease	130	35
Increase	100	100
Decrease	260	220
Total Years	640	565

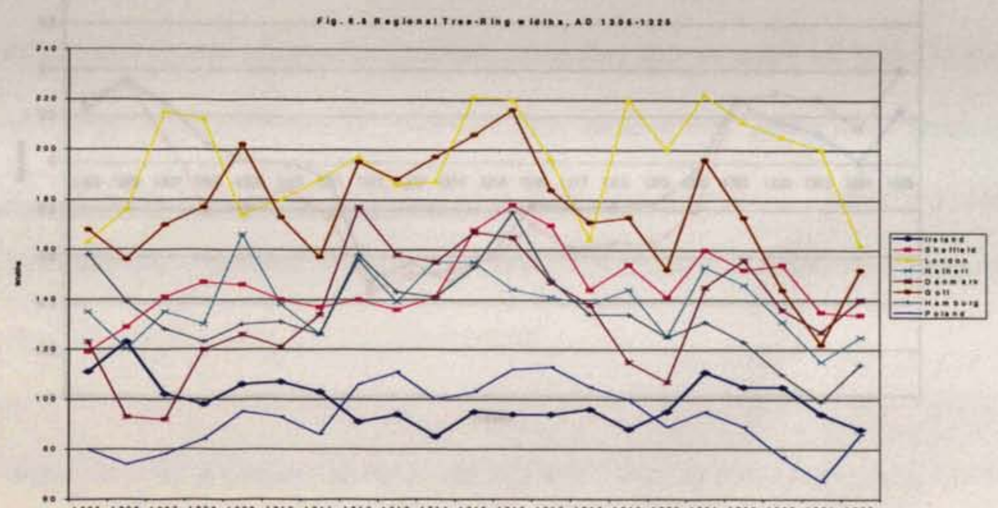
In both cycles the first increase and decrease of the cycle, on average, is lower than the second increase. This raises the question as to the mechanisms involved, i.e. whether they are primarily biological or climatic.

In comparison the European average has higher values and does not vary very much until c. AD 1405. There is a significant period between AD 1298-1312 and AD 1311-1320 when the ten year running correlation is asynchronous implying completely opposite conditions and this is followed by no correlation at all to c. AD 1316-1325. This is curious since this period is well known around Northern Europe as a period of similar weather and intense famines stretching from Ireland to Poland (Lamb 1995 195) due to cooling and increased precipitation. The disappearance of severe winters from AD 1297 and the transition to cooler and wetter conditions symptomatic of the following 250 years may be significant and is discussed in a later chapter.

The following charts (Fig. 6.7 and 6.8) shows Irish and European and regional

variations:





The next two charts (Fig. 6.9 and 6.10) shows the correlation of Ireland with the European average and London and Sheffield specifically

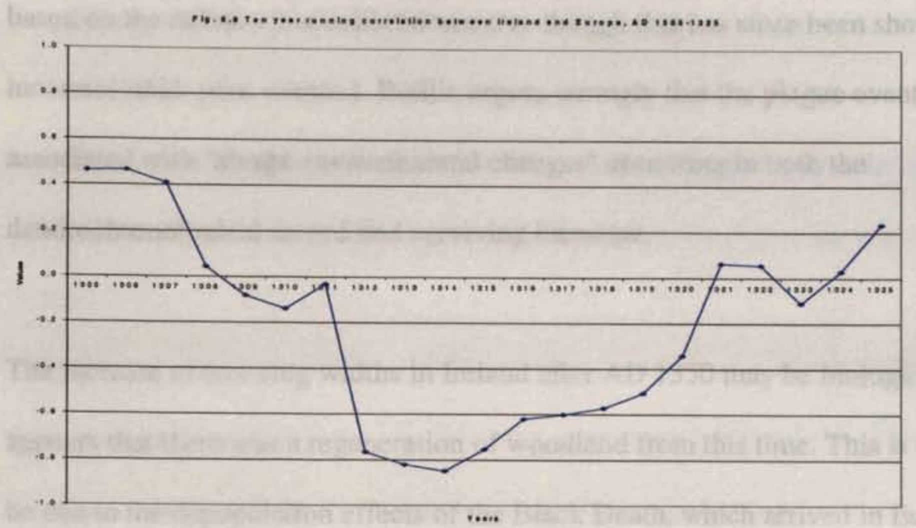
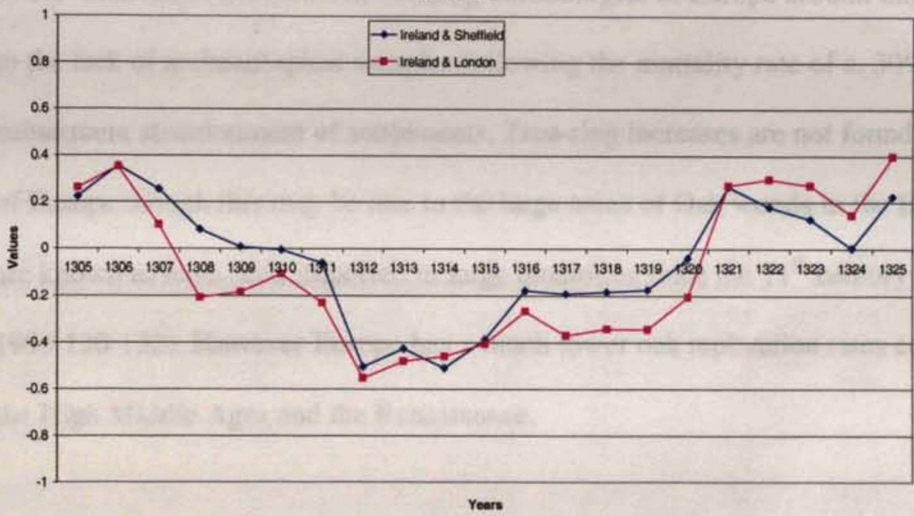


Fig. 6.10 Comparison of ten year running correlation betwenn Ireland, Sheffield and London, AD 1305-1325



These indicate similar patterns though the asynchronous pattern between Ireland and England is less pronounced, which implies that there is an east-west trend to this pattern.

In comparison with the widths, the derived indices (Baillie 1998 62-72) have lower values from AD 1325-1350 with a secondary decrease around AD 1360. The hypothesis was put forward that this may have been due to a major out-gassing event

based on the radiocarbon calibration curve though this has since been shown to be incorrect (ibid. pers. comm.). Baillie argues strongly that the plague event was associated with 'abrupt environmental changes' appearing in both the dendrochronological record and surviving literature.

The increase of tree-ring widths in Ireland after AD 1350 may be biological, as it appears that there was a regeneration of woodland from this time. This is thought to be due to the depopulation effects of the Black Death, which arrived in Europe in AD 1347 but is first recorded in AD 1333 (Baillie 1995 124-5 & 1998 62-65 & 69-72). There were major problems in building chronologies in Europe around this time due to the lack of archaeological samples following the mortality rate of c. 30% and subsequent abandonment of settlements. Tree-ring increases are not found in the rest of Europe though this may be due to the large areas of Oak woods in the Baltic, which are known to have been imported in large quantities since the 11th century (Baillie 1995 130-132). However Europe has a much lower oak replication rates compared to the High Middle Ages and the Renaissance.

A second type of pattern similar to the AD 832-3 shift in Ireland occurs in AD 1209-1210 where the average AD 1200-1209 is 93.6 whereas AD 1210-1219 is 112.5. A shift in the opposite direction happens at AD 1311-12 where the average AD 1302-1311 is 109.8 compared to the average AD 1312-1321 is 94.3. The reasons for these shifts do not appear to be anthropogenic though the cause is unknown, perhaps the latter is related to the climatic shift of that time.

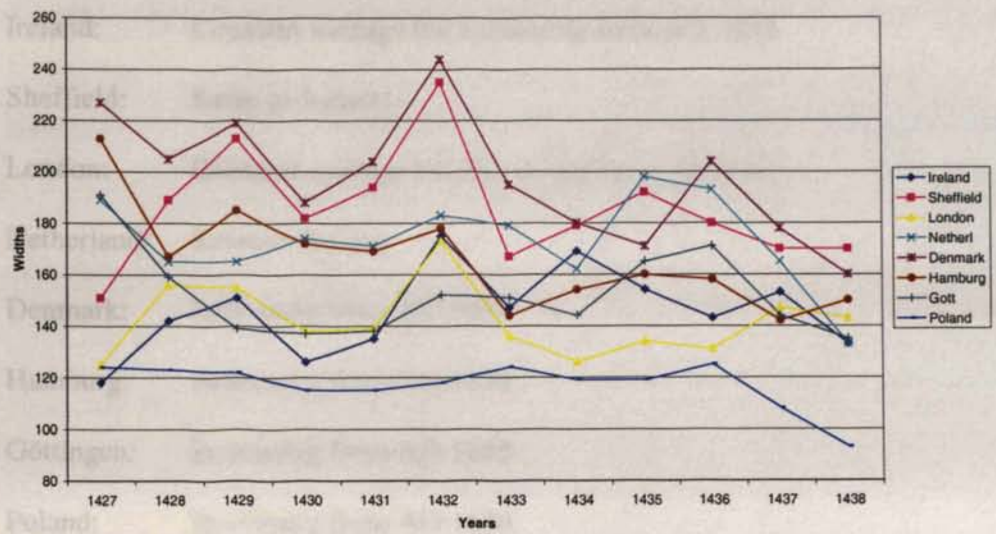
During the peak of AD 1390-1437 there are some relatively high values at AD 1396-9 and AD 1432-4, these appear to be unique to Ireland though an analysis of the latter period gives a different regional picture. The table below shows that the increase in AD 1432 is found over all of Europe as is a decline in the following year except in Poland.

Table 6.8 Regional comparison of tree-ring widths AD 1427-38

Years	Ireland	Sheffield	London	Netherl	Denmark	Hamburg	Gott	Poland	Mean
1427	118	151	125	189	227	213	191	124	167.2
1428	142	189	156	165	205	167	159	123	163.2
1429	151	213	155	165	219	185	139	122	168.8
1430	126	182	138	174	188	172	137	115	154
1431	135	194	139	171	204	169	138	115	158.1
1432	175	235	173	183	244	178	152	118	182.2
1433	147	167	136	179	195	144	151	124	155.4
1434	169	179	126	162	180	154	144	119	154.1
1435	154	192	134	198	171	160	165	119	161.6
1436	143	180	131	193	204	158	171	125	163.1
1437	153	170	147	165	178	142	144	108	150.9
1438	133	170	143	133	160	150	135	93	139.6
Average	145.50	185.17	141.92	173.08	197.92	166.00	152.17	117.08	159.85
Correlation		0.62	0.44	0.06	0.10	-0.36	-0.23	0.12	0.35

It also shows that Ireland has a high correlation with Sheffield and London but moving eastwards there is a shift to no correlation with Netherlands and Denmark to a slightly negative correlation with Germany.

Fig. 6.11 Regional tree-ring widths, AD 1427-38



From this peak there is a decline over all of Europe with slight increases around AD 1466-87 and AD 1532-55. The decline continues in Ireland until AD 1654 when the width is 0.61mm, the lowest in the last two thousand years. In comparison the rest of Europe's decline stops between AD 1610-50. In Ireland the average width is 0.82mm for the period AD 1600-1654 with a standard deviation of 11.1. The following table of average widths puts Ireland within the European regional context though in this case the Danish figures are anomalous compared to Germany and the Netherlands.

Table 6.9 Regional tree-ring averages AD 1600-1654

	Ireland	Sheffield	London	Netherl	Denmark	Hamburg	Gott	Poland	Mean
Average	82.3	145.1	164.3	104.9	166.0	125.3	123.5	113.6	128.1

When the widths are analysed by region over the period the data based on a ten year running average from AD 1600 (a chart is not given due to complexity of the data) shows the following trends:

Ireland:	Constant average but increasing from AD 1655
Sheffield:	Same as Ireland
London:	Constant average but increasing from AD1630
Netherlands	Same as Ireland
Denmark:	Increasing from AD 1610
Hamburg:	Increasing from AD 1638
Göttingen:	Increasing from AD 1655
Poland:	Increasing from AD 1640

However notwithstanding the differing nadirs the correlation values indicate that there is a north-south divide of Ireland, Sheffield, Netherlands and Hamburg to the north and the rest to the south, though Denmark is an anomaly. Worth noting too is that London has the lowest correlation and percentage decrease over the previous five years.

Table 6.10 Regional tree-ring widths AD 1647-1655

Years	Ireland	Sheffield	London	Netherl	Denmark	Hamburg	Gott	Poland
1647	75	164	130	104	205	126	135	115
1648	84	200	208	112	204	125	124	142
1649	78	145	156	109	202	131	136	127
1650	76	135	161	111	175	122	144	166
1651	66	114	174	96	159	120	116	146
1652	61	130	150	77	144	105	100	107
1653	66	107	180	87	213	120	141	155
1654	78	160	182	104	229	125	153	139

1655	100	191	197	122	249	142	156	184
Ave. 1647-1651	76	152	166	106	189	125	131	139
%1652/Ave	80.26	85.53	90.36	72.64	76.19	84.00	76.34	76.98
Correlation		0.83	0.51	0.91	0.77	0.90	0.67	0.60

AD 1650-1752

From this period there is a marked increase of widths on a European wide scale until about AD 1730 when they begin to level off. This period is associated with high correlation values between Ireland and Europe but change to low positive values after AD 1730, they continue until the European data finishes in AD 1752. In Ireland the widths increase to the AD 1750s when it reached its highest value, in the last 2,000 years, of 1.88mm in AD 1784 and there are many years over 1.60mm. These widths tend continue with the exception of some low values between AD 1794-1803 and AD 1816, the latter associated with the AD 1815 Tambora Volcanic eruption, and called 'the year without a summer'.

The period of the early 1740s is well known because of major famines and demographic crises in Northern Europe and also happens to be one of the key dates as thrown up by the indices (Baillie 1995 105-6). The widths show that it was not as serious as previous episodes but there are significant drops in width values all the same. A chart (Fig.6-12) of the period shows the following regional patterns:

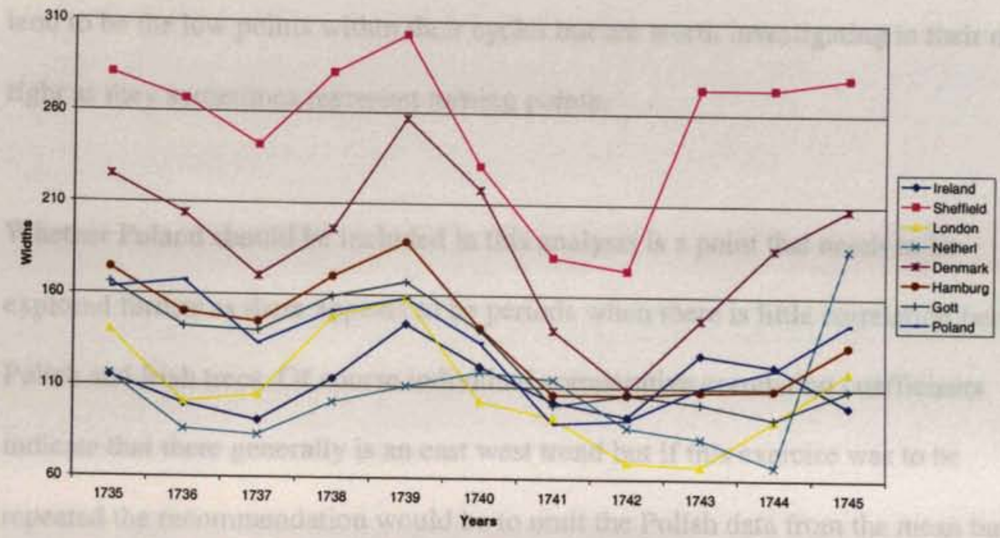
The following table shows that, excluding the Netherlands, there was a greater percentage drop in mainland Europe and England than in Ireland. This may be due to the lower average AD 1735-39. In terms of the overall responses AD 1735-42 there is a high correlation with most regions except Poland, which may be to be too far

eastwards. Overall there is no identifiable geographical trend. Worth noting is the high ring widths for Sheffield which, unexpectedly, are much wider than London, normally it is visa versa. Most of the regions show a recovery in AD 1743 except London, Netherlands, Göttingen, and Hamburg. This indicates that central European oaks were the slowest to recover.

Table 6.11 Regional tree-ring widths AD 1735-45

Years	Ireland	Sheffield	London	Netherl	Denmark	Hamburg	Gott	Poland
1735	115	281	140	116	225	174	166	163
1736	100	267	101	86	204	150	142	167
1737	91	242	105	83	170	145	140	133
1738	114	282	148	101	196	170	159	151
1739	144	303	158	110	257	189	167	158
1740	121	231	102	118	218	142	141	134
1741	102	181	93	114	141	106	100	90
1742	94	174	69	88	109	106	106	92
1743	128	274	67	82	147	108	101	110
1744	122	274	92	67	186	109	93	120
1745	100	280	119	186	208	133	109	145
Ave. 1735-9	112.8	275.0	130.4	99.2	210.4	165.6	154.8	154.4
Ave. 1740-3	105.7	195.3	88.0	106.7	156.0	118.0	115.7	105.3
%Ave. 40-3/35-9	93.7	71.0	67.5	107.5	74.1	71.3	74.7	68.2
Correlation		0.63	0.76	0.66	0.81	0.71	0.64	0.47

Fig. 6.12 Regional tree-ring widths, AD 1735-1745



Conclusions

In conclusion it is possible to argue that the period AD 1-570 and 1650-1730 is primarily climatically determined and the intervening period, AD 570-1650 primarily biologically determined. However within these cycles there are relative anomalies, which indicate that interpretation of tree response is not a simple process. Certainly we are no nearer to a methodological solution for the identification of long-term climatic trends on the basis of tree-ring widths. At best the current practise of indices computation is probably the best method, within dendrochronology, for deducing annual temperature and precipitation patterns. These annual growing season data sets can be put together to create patterns over time as graphs or over space as synoptic charts. However they are do not give a complete perspective and the tree-ring widths provide a complementary viewpoint.

For instance if the issue of the worst years is taken than according to the indices these are AD 540, 1177,1325, and 1740 (Baillie 1998 57) whereas the lowest Irish widths

are in AD 71, 104, 193, 237, 1054 and 1652. However in the case of the widths these tend to be the low points within their cycles but are worth investigating in their own right as they sometimes represent turning points.

Whether Poland should be included in this analysis is a point that needs to be explored further as there appears to be periods when there is little correlation between Polish and Irish trees. Of course individual comparative correlation coefficients indicate that there generally is an east west trend but if this exercise was to be repeated the recommendation would be to omit the Polish data from the mean but to include the French data if it is of northern, rather than Mediterranean, origin. It would be interesting to tie in Atlantic Iberian chronologies if such were available. Furthermore a region by region inter-comparative survey would be useful.

There is also the problem of anomalies, which were regularly noted above. For instance it is not clear why Hamburg is often out of step with Göttingen, Denmark and the Netherlands. Whether this has implications for regions or is an artefact of Hamburg's research methodologies is unknown but may be worth investigating.

One of the questions raised by the above process is the definition of a region. This has been recently discussed by Baillie (1982 73-82) who concluded that 'the question was reduntant' and that in fact that the evidence shows a north-west Europe signal as distinct from a one from the British Isles that was 'mutualy exclusive' (as defined by Fletcher) to mainland Europe at least for the period AD 1780-1959. Since then he has used master chronologies from Ireland to Poland (but generally excluding France used in the 1982 article) implying at least that there is a northern European signal.

However as previously noted there appears to an increasing level of synchronisity between AD 516-1752 but it is unknown whether this continued to modern times as if it did this would have implications for the conclusions.

There are now four complementary perspectives

- Indices indicate strong regional positive correlation
- Widths indicate long periods of positive correlation interspersed with short periods of negative correlation.
- Total variation indicates a rising positive correlation
- Extreme variation show rapid shifts between positive correlation and negative correlation

They may appear to be contradictory but they can be paired, the first with the third and the second with the fourth.

We can only speculate as to why Ireland should diverge in such a fashion. Biology does not appear to be an issue here as these periods have reasonable replication. Overall the indications that the boundaries of the regions, however they may be defined, vary over space and time and sometimes show sharp inter-regional differences rather than diffuse incremental changes.

A theory that encompasses these perspectives will be a major step forward in Dendrochronology.

CLIMATE IN IRELAND – AD 500-1300

Gaelic literature suggests that the ranking of weather systems, discussed in a previous chapter, is not static and there were periods when others were more important. It is possible to plot periods when particular weather regimes were predominant and it is sometimes possible to plot transitions. The history of this change is the primary focus of this study and the above descriptive system will be used as a perspective. These periods will be compared with the climate of the 20th century with the understanding that it is not necessarily typical but is at the benign end of climate variation.

The focus will be to interpret the data and compare it to European climate and offer some conclusions as to how Ireland compares and contrasts with the mainland and the relevance of the continental model in discussing Ireland. Particular note will be paid to the Oceanic/Continental relationship and to geographical variations between the northern sub-continent and Ireland. For the purposes of the discussion three main periods, AD 500-1000, AD 1000-1300, and AD 1300-1600 will be considered, though these dates are arbitrary and based on European models. The last period of AD 1300-1600 is discussed in the following chapter.

First a short review of Irish climate in the pre-historic period will set the scene.

THE HOLOCENE AND PRE-HISTORIC CLIMATE

The end of the last glacial epoch, known as the Midlandian in Ireland, is dated to 13,000 BP. This was followed by a reasonably warm period that was interrupted by a cold snap, the Younger Dryas, that lasted 750-1000 years and ended approximately

10,000 BP (11,500 BC). This period is known for its periglacial activity; glaciation was unknown with the exception of a few mountain corries. It is believed that climate in the last ten thousand years was similar to the present day though there were moderate variations of temperature and precipitation. The old European climate designation of the Boreal warm dry climate lasting until c. 500 BC with the exception of the Atlantic cool wet period of c. 5000-3000 BC is not now believed to be the best historic model though many of the opinions are still accepted with reservations.

The Bronze Age, c. 2000-500 BC, is thought to have been several degrees warmer than modern times and was followed by a climatic collapse and soil deterioration, which marks the transition to the Iron Age around 500 BC. The result was a contraction of grasslands and a decline of arable farming followed by a period of woodland regeneration that probably lasted from c. 500 BC to AD 200-300 and is generally called the Iron Age lull (Mitchell & Ryan 1998 237 & Baillie 1995 45). Raftery colourfully describes the plight of the farmer as being soaked, cold and hungry, living under leaden skies and unceasing rain, wondering if they were on the 'Brink of Armageddon' (1994 36-7). This lull is a global phenomena found in most documentary and proxy sources, though there are regional differences (Lamb 1995 152-4).

Worth noting is the fact that oak ring widths are very low through the Iron Age Lull with a period when no Irish bog oaks are known to have survived. Tree ring widths are depressed though there is slight average increase from c. AD 275. This is followed by a slight average decline from c. AD 450 but significant average increases are not found until AD 570. It is possible to offer the hypothesis that the cause of increasing

widths to the end of the third century AD was climatic and the decline that followed was biological as the oak population was possibly near the end of its growth cycle. The average increase that followed in AD 570 possibly represents the start of a new cohort though climate may be a factor as there is a relative decline across Europe from the beginning of the 6th century. The Irish dendrochronological evidence may support the ending of the Iron Age lull in Ireland but not necessarily in the rest of Europe.

In cultural terms it is argued that the period to the end of the 6th century was a time of political upheaval with the formation of new dynasties and the submergence of old population groups (O'Croinin 1995 41). This may indicate more clement times as political 'winners' had more to gain from control of agricultural and craft production.

It is very difficult to concisely date the end of this period, as the proxy records are inconsistent. The possible interpretations of three sets of evidence are as follows.

- Gaelic Literature does not record any climate change. Historians usually take the beginning of the historic period as c. AD 300-500. This opinion is based on the date when the literary evidence becomes trustworthy.
- There is a steady increase of oaks (from very few) from archaeological sites for the period c. AD 1-550.
- The tree-ring widths may indicate a change in summers from around the third century AD though this data is probably heavily compromised by biological influences.

- Palynological research indicates that there is no coherent signal of change due to anthropogenic influences.

CLIMATIC IMPROVEMENT, AD 500-1000

This period is poorly documented in Europe and as such only a broad picture can be conjectured. Lamb, particularly, notes a major lack of documentary evidence around 50° latitude for most of the period before AD 600 but from that then it is that summers were wet during AD 500-700 (with a run of very wet years in the AD 580s) and AD 800-900. Cold winters appear to be common for most of the period, though the earliest to be documented is in the AD 760s (Lamb 1995 163-6). Lamb, in the mid 1970s, thought that between AD 300-500 and in AD 900-1000 there were an anomalously high number of anti-cyclones at 50° latitudes (Severin 1979 179). With the exception of extreme anomalies EURO-CLIMHIST (Pfister 1998) does not discuss winters before AD 1000 and analysis only begins in AD 750 when Europeans start to trust their documentary sources.

To this may be added Grove who stated that there were glacial advances in Europe in the 2-6th centuries (Grove 1988 304) though there is insufficient evidence to make any direct comparisons with the 'Little Ice Age'.

In Ireland the situation is similar in terms of documentation though there is more than the rest of Northern Europe. To put this period in climatic context it is worth noting what the Irish Wisdom texts of the 9th century have to say about ideal and unseasonable weather. The former is taken from *Tecosca Cormaic* and the latter from *Immacallam in dá thúarad* (Kelly 1998 3).

Season	Ideal	Unseasonable
Winter	Fine and frosty	Leafy
Spring	Dry and windy	Without flowers
Summer	Dry and showery	Gloomy
Autumn	Heavy dewed and fruitful	Without fruits

What is striking about the latter text is the absence of snow and freezing in the winter, which indicates that, except for exceptional circumstances, this was not a major problem. Winters that were too warm were claimed to be more of a hazard but they are never referred to in the Irish Annals. Perhaps this concept was a borrowing from European literature. Another possible question is whether these texts reflect good/bad weather from a pastoral or arable viewpoint.

Monastic agricultural ideology, according to early hagiographies of Saints, was oriented towards a vegetarian grain economy (Stout 1997 129-30). However this may be questioned as there was a strong demand for cattle hides for the making of vellum and it is well documented that Irish monasteries were not immune to the secular habit of cattle raiding against other monasteries (Lucas 1967 172-229). While a vegetarian economy may have been found in smaller and early monastic foundations it does not appear to be general in larger monasteries with large land holdings. Lyons (1989 38) argues that pastoral was more important than arable farming based on the lack of references to the success or failure of grain harvests until the 11th century. However the heavy focus of monastic legal texts to arable farming indicates its importance and it has to be noted that entries describing 'scarcity and hunger' are given without

further detail. Also worth noting is that the first Famine of 6th century in AD 536 is described as a 'failure of bread'.

Overall the type of famine recorded appears to relate to the season it which it happened. In other words cattle mortality was due to abnormally cold winters while grain failures were due to growing seasons that were either too dry or too wet.

<u>Winter</u>

If the winter season is examined first then, taken at face value, there is a steady increase in the number of intense cold winters recorded over the centuries with eight each in the 9th and 10th centuries, double the 8th though this may be an artefact of the compilations. For instance there are eight references to weather in AD 536-599 as compared to five in AD 600-699. A comparison of Irish and European winter temperature indices is instructive.

Table 7.1 Winter Indices of Ireland, Europe and Easton AD 500-1000

Year	545	554	566	587	588	590	593	635	670	688	695	748	760	762	764	789
IRL				-2	-2	-2		-2	-2	-3		-3		-2	-3	-2
EU															-3	
WE	21	10	21				21				10		21		10	
Year	799	811	815	818	819	822	845	853	854	856	860	871	874	881	895	913
IRL	-2		-3	-2	-1			-1	-2	-3		-1			-2	
EU		-1				-3	-3				-3		-3			
WE						10	21			21	10		21	21		10

Year	917	928	934	941	944	955	959	975	993
IRL	-3		-1	-2	-2	-3	-1	-1?	-1?
EU				-3				-1	-2
WE		21		21				21	

It can be seen that there is a clear pattern, which indicates, that with a few exceptions, continental winters did not extend this far west and the only reasonable conclusion is that the vast majority of anomalous Irish winters came directly from the Polar North. From AD 750 they appear about every twelve years, close to the sunspot cycle (Lamb 1995 68). In many of the cases they are associated with the freezing of lakes and in one instance, AD 684 (AFM), is there a possible reference to sea ice. The Annals report that there was a great frost that froze lakes and rivers and that it was possible to walk from Ireland to Scotland. It is highly likely that is exaggerated but it does indicate the possibility of ice floes clogging the North Channel, c. 22km wide at the narrowest point. If this is true it may represent an abnormal Arctic calving event thought has to be said that the means by which they might have arrived is highly conjectural given the prevailing ocean currents. Perhaps a likelier alternative is that persistent north westerly winds created pancake ice, a not uncommon feature during blocking high-pressure situations (ibid. 37 & Daniels *et al* 1997 24-7).

An early Irish medieval author, Dicuil, writing in Charlemagne's court around AD 825, stated that c. AD 800 Gaelic monks were making regular visits to Iceland in February (Severin 1979 180). This appears to indicate that the North Atlantic was generally free of ice except at a days sailing north of the Iceland (Grove 1988 15). The implication is twofold firstly these intense winters were anomalies and that at

these time at least the winter climate regime in the NWAR was different to the Northern European Region.

The impact of these severe winters appeared to have been sometimes catastrophic with major famines reported in AD 635, 684, 700, 764, 799, and 964. At other times scarcity was reported though without reported human mortality, winters with recorded animal mortality are AD 748, 815, 917 (including salmon), 955 and 993. Others only record scarcity. The majority of these episodes refer to cattle mortality, as they were vulnerable to severe winter weather. Cattle at this time were completely dependent on winter grass because haymaking was not practised in Ireland until the late 12th century (Kelly 1998 46-7).

One of the winters that stands out is AD 764, and is described as the 'most outstanding cold episode in the last 2000 years' (Pfister 1998 541). It is described by sources in Germany, France and Constantinople where Theophanes the Confessor reported icebergs on the Bosphorus (Telelis and Chrysos 1992 17-32). Easton's indices broadly support those devised by EURO-CLIMHIST with the exception of AD 856 referenced by Easton and the Gaelic Annals but not by EURO-CLIMHIST.

Overall winters probably matched the monastic ideal though blocking polar high-pressure systems appeared at regular intervals.

<u>Spring</u>

Spring weather is rarely recorded with the exception of the occasional snowfall in AD 780, 855 and 917 the last a continuation of winter. Presumably therefore this season

was benign overall with no impacts on the normal practise of ploughing and sowing in March (Kelly 1998 230-1).

Summer

There were two types of bad summers from an agricultural viewpoint, these were when it rained too much or there were droughts. The former is only listed three times in AD 720, 777 ('a summer like winter') and 801, compared to five of the latter in AD 587-91, 663, 714, 764 and 934. The effects of these are not given; however there are three references to grain shortages in AD 536, 765 and 899, though no reason is given, presumably they were failures of the growing season of March to September. However it has to be noted that seasonally unclassifiable events took place around AD 875-80 and c. AD 975 with laconic statements such as 'very bad weather'. In AD 879 the description of a scarcity of cattle fodder in spring and abundance in autumn could mean either a cold or wet winter followed by a cold or wet spring and then a normal summer and autumn. The hagiographies of Gaelic Saints indicate that heavy rain was a constant hazard and was responsible for many crop-saving miracles (O'Croinin 1995 93).

The drought of AD 748 is of interest as it followed a very severe winter. It appears to have been a European wide phenomenon as it described as follows: 'The world was parched with an unusual drought'. This indicates that there was a continuation of high-pressure systems for about nine months. This is the first Irish reference to this type of winter-summer pairing.

Lamb (*op. cit.*) argued that there were wet periods in Europe c. AD 500-700, particularly the AD 580s, and around AD 800-900. The implication is that increased precipitation came from the west but there is no Irish evidence of this one way or another. The Annals don't specifically refer to any periods of increased precipitation.

It may be significant that this period has a major period of asynchronous behaviour between Irish and English oaks. There is negative correlation in AD 878-97, no correlation in AD 898-901, negative correlation AD 902-8 followed by a trend to positive correlation from AD 916. It therefore appears that Irish oaks are responding to a different type of summer regime and that the Irish Sea is the boundary between them. This may be a 'blocking' zone and is discussed in more detail for the AD 1298-1320 period when there is more information. It is worth adding that while this is the second longest phase of asynchronous behaviour there are rapid shifts between positive and negative correlation between c. AD 700-925. The climatic implications are that, based on the response of oaks, summers of the NWAR went through climatic phases that were different, and perhaps opposite, from England and mainland Europe at this time.

Autumn

There are no references that can be identified with this season.

Storms

Twenty nine storms are reported in this period, the first in AD 564. Of these fifteen are called 'Great winds' or 'Great storms', the other fourteen state that there was lightning. The former appear to be either gale-force storms associated with low-

pressure systems or hurricanes, and when destruction is mentioned it is limited to damage to buildings and flooding but not to agriculture. They are scattered randomly through time at about one every 35 years to AD 875 and one every twenty years thereafter to AD 1000.

Of the fourteen lightning storms, eleven are in the period AD 767-876. This may indicate a prevalence of Maritime high-pressure systems at this time. In a few cases destruction of woods and buildings are mentioned, with Armagh Cathedral mentioned twice in AD 773 and 995. They could also be spectacular; in AD 772 an assembly of people conducted a hand clapping ritual 'at which occurred lightning and thunder like the Day of Judgement', they also fasted against the fear of 'Fire from Heaven'. In fact some of these lightning storms may be called 'Fires from Heaven'. These weather rituals were often associated with evil times because lightning was often seen as a harbinger of plague.

Conclusions

Overall this period appears to have been climatically benign. O'Croinin (1995 108-9) states:

> "... high productivity implied by the substantial rents and food renders, give an impression of relative prosperity."

He also notes the possibility of over-population in the period before AD 684 as agricultural land was in short supply. Leaving aside the combined effects of bad weather, plagues and animal diseases discussed later, the impression is of a settled

society who recovered quickly from the occasional bad year and, though at times, the shortages were extreme they never lasted longer than a year. In comparison to the rest of Europe Irish winters were milder and summers dryer if Lamb's opinions (1992 163-6) are correct.

It can be concluded that the climate in NWAR, for the period AD c. 500-1000, can be called the 'Early Medieval Dry Period'.

'MEDIEVAL WARM PERIOD', AD 1000-1300

The classic description of the 'Medieval Warm Period' (MWP) in Europe comes from Lamb (1977 435)

> "In most of Europe the warmest period seems to have been between 1150 and about 1300, though with notable warmth also in the late 900s".

Though he is more circumspect in a later work (1995 171-186) his general conclusions have not changed radically. His hypothesis has come under critical review in recent times and has been recently reviewed by Hughes and Diaz (1994 109-142), using a mix of evidence from tree-rings, ice cores, geomorphology and documentary sources. They conclude that this warm period was neither global nor synchronous (ibid. 109 & 116). In comparing Europe and Fennoscandia they note that at this time these areas had higher temperature variations then elsewhere but are unable to decide whether this reflects reality or is an artifact of the various research methodologies (ibid. 116 &120). In reviewing Europe they note a range of opinions and these may be put as follows (ibid. 131):

Lamb (1977)

- European wide warm period AD 900-1300, peaking in AD 1150-1300

Alexandre (1987)

- Europe, north of the Alps, AD 1150-1330 cold winters predominating. Rainfall AD 1240-1400 higher than AD 1170-1240
- Europe, western, warm springs AD 1220-1310 followed by a sharp decline in the period AD 1300-1350. High rainfall in the periods AD 1150-1200 and after AD 1310, dry during AD 1200-1310.

Guiot (1988 & 1992)

- 12th century cold, AD 1200-1300 temperatures as modern, and AD 1300-1400 modern or slightly less.

Hughes and Diaz (1994)

- Highest temperatures AD 1472-1561 and AD 1202-1321

Oglivie and Farmer (1997 130) argued that there was stable dry weather in western Europe with a general increase of precipitation during AD 1240-1426 but that southern England's temperatures declined between AD 1240-1340. They describe the period as climatologically complex and that the term MWP is not easily defensible. They also question the temperature seesaw between Greenland and Northern Europe.

Pfister (1998 546-9) argued that, while he agreed with the chronological boundaries proposed by Lamb, the MWP was restricted to winters (which were not homogenous) in western central Europe and there was not enough evidence to support the definition for all seasons in Europe. He also noted Oglivie and Farmer's dismissal of the concept of the MWP but thought that it should be kept, as there was no other acceptable alternative definition.

It can be seen that there is yet no consensus though this may be a function of definition and perspective. For instance taking Alexandre as an example it is not clear exactly, whether Ireland is north of the Alps or in Western Europe. In general the above authors delineate the following regions, Mediterranean, Alpine, Western, Eastern and Fennoscandia. As noted the NWAR does not fit easily into any of the above regional continental perspectives, which encompass a wide range of latitudes and longitudes.

Overall however there seems to be a growing continental consensus that in Europe there is no strong evidence for a ubiquitous Medieval Warm Period c. AD 1000-1250 but high variability and regional variations on a decadal and multidecadal scale. The one criticism of Hughes and Diaz, and possibly others, is that they did not discuss famines as a possible proxy indicator of climate. For instance the period AD 1315-20 was a period of intense cold and wet summer weather and is seen as the cause of the First European Famine (Lamb 1995 195-202). This has obvious implications for some of the above interpretations, which state that warm temperatures continue until the AD 1320s.

Winter

A comparison of Irish and European winter indices indicate that before AD 1111 the majority of Irish winters continue to originate directly from the Polar Arctic as only one of these nine winters is reported in Europe. There then appears to be a transition as the majority of winters after that date appear to be of easterly origin, though of the 47 abnormal winters in Europe until AD 1300 only eight (17%) are reported in Ireland. A further six abnormal winters in Ireland is not reported in Europe.

Southern England from AD 1200 appears to be mostly effected by easterly Arctic rather than Northern Polar high-pressure systems. There is a problem in how to interpret severe winters in England that are not referenced in either Ireland or Europe particularly in the period AD 1286-94. It may be that there is a lacuna in the sources, possibly in Ireland as that would be the best fit. It is probably impossible for a severe winter of a north-easterly direction to only effect England. Included here are periods in England which were warmer than normal of which AD 1216 and 1285 are of interest as they indicate possible boundaries between two opposite types of temperature regimes.

Table 7.2 Winter Indices of Ireland, England and Europe AD 1000-1300

Year	1007	1008	1012	1021	1026	1028	1037	1045	1047	1061	1070	1075	1077	1082	1084	1092
IRL	-1	-2			-1	-1			-2							-3
EU			-1	-1			-1	-2	-2	-2	-2	-2	-3	-1	-1	
Year	1093	1095	1096	1101	1105	1108	1111	1115	1116	1124	1125	1126	1132	1133	1143	1150
IRL	-3	-3	-1		-3		-2	-3	-3							
EU				-2		-1	-1	-2	-2	-3	-2	-2	-1	-1	-3	-3

Year	1157	1160	1163	1165	1166	1168	1174	1177	1179	1183	1193	1205	1207	1210	1211	1213
IRL	-3								-1		-3					
EU	-1	-1	-1	-2	-1	-2	-2	-1	-2	-1		-3	-1	-2	-1	-2
ENG												-6		-4		

Year	1215	1216	1217	1219	1221	1225	1227	1230	1234	1242	1251	1248	1249	1253	1254	1256
IRL						-3			-1		-1					
EU	-1	-3	-2	-2		-2	-1	-2	-3					-1	-1	-1
ENG		2			-2			-2	-4	-2		6	8		-4	

Year	1258	1261	1263	1267	1269	1270	1271	1273	1274	1275	1276	1279	1280	1282	1284	1285
IRL						-1	-3						-2	-3	-3	-3
EU	-2		-1	-1		-2		-1	-1	-1	-2					-1
ENG	2	-4			-6	-6	-6					9		-3		6

Year	1286	1287	1289	1292	1293	1294	1296	1297
IRL							-1	-1
EU					-1		-1	
ENG	-6	-6	-6	-7		-4		

The majority of the northern Polar winters in Ireland record heavy snows and/or frost but appear to have been less destructive overall compared to those that arrived from the eastern Arctic and was European-wide. The winter of AD 1047 was particularly bad with a 'Year of great snow' from the Festival of Mary to the Feast day of St. Patrick. It was recognised as an important event as the Annals of the Four Masters have the following couplet:

> "Seven years and forty fair, and a thousand of fine prosperity
> From the birth of Christ, of fame unlimited, to the year of the great snow"

While it is impossible to say whether the couplet is tinged with Golden Age nostalgia or based on empirical evidence is difficult to say, the event is recognised as significant. It caused a forced migration of the northern population of Ulaid (Ulster) to Leinster, even though they were traditional enemies. Given the fact that this snow caused mortality of cattle, birds, wild animals and sea life the implication is that this winter was northern in origin and then moved eastwards declining in intensity. The reference to sea-life mortality is the only one recorded in the period under review indicating a possible reversal of the North Atlantic Current, a taste, perhaps, of the climate during the Younger Dryas. This winter inaugurated the series of famines caused by downturns longer than one season and one year, the AD 1047 famine lasted till at least AD 1051. In contrast the rest of Europe only suffered excessive snows without major effect (Pfister 1998 542).

The winter of AD 1157 may have followed a similar track from the Polar North, as the mainland was milder. Whether the same could be said about AD 1225 is difficult to judge as war and fever were reported as well, particularly in Connaught, where there was a major power struggle between the Anglo Normans and the recently deposed High King of Ireland. The winters of AD 1092-5 also had serious effects with human and animal mortality referenced in most of the annals, but these appear to have had a minimal impact on the rest of Europe.

Likewise AD 1115 and 1116 were very serious in Ireland. In the first instance extreme bad weather was recorded from the end of December 1114 to February the following year. This resulted in a great scarcity of food with the deaths of men, animals and birds. This caused a Spring Famine and it was reported that 'man ate

man' and that children were sold for food. In the following year frost, snow and boisterous weather were reported in most annals causing the death of men, cattle and birds with a famine, mostly in Leinster, and forced migration throughout Ireland and overseas. It was certainly as serious as AD 1047-51 but somewhat mitigated by an excellent harvest in AD 1156. In Europe it is still an open question whether this was one episode or two but is not seen as particularly extreme (ibid. 543).

In contrast the winter of AD 1077 was a major event in terms of its length and extreme severity in Europe and is recorded in more than 35 independent sources. The explanation is that a period of Polar maritime air was followed by a phase of dry Arctic air and intensified north of the Alps due to a combination of dryness and a snow covered landscape. This led to positive feedback, which intensified the development of the anti-cyclone. These are now known as a cyclonic bora (ibid. 542). In Ireland a great scarcity in AD 1076 and 1077 is recorded but no cause is given. It is worth adding that this is not a duplication as the in the latter year it states that the scarcity continues.

The winters of AD 1150 and AD 1234 were two other major European events that had a minimal effect in Ireland, in the latter case only a great frost was recorded and the former is not mentioned at all in Ireland. This may have implications for the hypothesis that the latter winter is analogous to the Great Winter of AD 1675, which occurred during the Late Maunder Minimum. Sun spot cycles and solar radiation are seen as a possible causes (ibid. 544). However it is still unclear whether sun spot cycles reduce or redistribute solar radiation (Pfister *et al* 1994 289).

There is a gap in severe winters lasting more than one season from AD 1118 until about AD 1270 when there is a definite deterioration in climate. There was a famine from unspecified causes in AD 1268 and was followed by two bad winters in AD 1270 and 1271. More extreme winters followed in AD 1280-1284 and AD 1294-7

Spring

The only two references that can be specifically related to this season are the continuation of snow to Easter in AD 1008 and the very bad year of AD 1117. This latter year followed the extremely bad winters of the previous two years. Heavy rains from Candlemas to August destroyed crops and 'caused a hunger so widespread' that settlements were deserted and destruction in Ireland and Europe was 'staggering'.

Summer

Summer weather is difficult to reconstruct but on the basis of lack of many abnormal events it therefore must have been normal to the contemporary observer. Droughts were rare and are mentioned in AD 1095, 1129, 1252, and 1262. The first is noted in Chronicum Scotorum as the third year of heat but it is only in the last year that human mortality is mentioned.

The AD 1252 drought was stated to have scorched trees and that harvesting was over by mid-July, two months earlier than normal, and though this should not be taken literally, it indicates crops had ripened early. Lamb's indices have a warm period for the months, March, April, May, July and August at +2 per month in AD 1252 but AD 1262 has no reference at all.

In England the years AD 1236, 1241, 1242 and 1288 stand out as being very wet. In Ireland the only one referenced is in AD 1236 when great rains caused a famine.

Autumn

As before AD 1000 there are no references that can be taken to be specific to the season.

Storms

The period to AD 1100 do not appear to be very stormy though the frequency increases in AD 1100-50 and there is an appearance of cycles in AD 1187-90, 1218-24 and around AD 1250. Only ten lightning storms are mentioned and these appear to be uncommon.

Conclusions

The main features of the period are the following.

- AD 1000-1299, 7-9 events of heavy snows and intense frosts per century, for the period AD 1200-1299, seven are after AD 1270. From AD 1047 periods of bad weather could last longer than one season or year. Major famine periods are AD 1047-51, 1115-17, and 1280-1297, with minor episodes in AD 1011-12, 1157-58, 1224-5 and 1270-1
- Droughts, 3-4 events per century AD 1000-1199 and two AD 1200-1299
- Windstorms, around ten events each for the period AD 1100-1299, though most relate to destruction and death in specific localities. This is double the number of

previous centuries. . In the intervening periods between the great winter famines of the AD 1270-97 there are many references to very stormy weather.

- The peak of good harvests of field and managed tree crops is in the period AD 1000-1199 with over ten reports in each century. This compares to the number of reported famines, about two per century before AD 1200 but eight in AD 1200-1299, though four of these are after AD 1270.

The question that arises is did Ireland have a Medieval Warm Period? The evidence is ambiguous and what follows a disparate set of indictors and caveats. In terms of winter weather, if the particularly bad period of AD 1093-1117 is excluded, than there is little change from the previous centuries up to AD 1270. Taking summer weather it may be that, on the basis of the numbers of good harvests, the 11th century was the warmest and thereafter declined.

Table 7.3 Number of good harvests 10th-13th centuries

Century	10th	11th	12th	13th
Harvests	4	12	7	4

However it is important not to take these at face value. It may be that there was an increase in references to good grain harvests due to ideological reasons referred to above but which were stronger during the Reform period of the 11th century onwards. It has been argued that there is a very close link between cerealisation and the expansion of Christianity from this time around Europe and particularly east of the Oder River (Bartlett 1994 152-6), though the main impact of the reform movement is after AD 1170. The decline in references later may simply reflect an acceptance of good harvests rather than be an accurate reflection of their number.

There are a couple of references to viticulture in Co. Wexford in the early 13th century (Terry Barry pers. comm.). This corner of the island is the most likely to have had the required summer temperatures but it does not indicate an increase in temperatures as it is likely that viticulture was imported by Continental Orders c. AD 1200. Lamb (1995 195) notes that many new vineyards were started at this time in England. He argues that this indicates average summer temperatures 0.7-1.0°C warmer than the current averages and 1.0-1.4°C warmer than central Europe (Lamb 1995 179-80). Viticulture has been attempted, without any great success, in this area in the 1920s.

The only contemporary commentator, Geraldus Cambrensis, writing in the early 1180s had this to say:

> "For this country more than others suffers from storms of wind and rain... What is born and comes forth in the spring and is nourished in the summer and advanced can scarcely be reaped in the harvest because of unceasing rain."

While his political and cultural biases are viewed with a certain amount of suspicion this comment may not be inaccurate as he was brought up on the other side of the Irish sea and would have been familiar with the climate of the region. It is therefore possible that summers were wetter than first appears. The Annals indicate that very severe storms came about every ten years and if this is compared with the above quotation then it appears that there were large variations between oceanic and continental weather systems. There may also have been instability at the boundaries of climatic system as they shifted seasonally, annually and over longer time periods.

There is strong evidence in Great Britain and Norway of expansion of tillage to greater altitudes in this period (Lamb 1995 177-9). Unfortunately the same has not been found in Ireland and this is probably due to a number of factors; Irish altitudes were more exposed and less fertile, the popularity of transhumance, and the expansion of ridge and furrow potato crops before AD 1845. As a general point it is extremely difficult to assess climatic change through agriculture at this time because of the major cultural changes brought about by the absorption of the island into the English Kingship. Overall we are not able to compare like with like.

Having taken the various caveats into account it is possible that the summers did improve in the 11th century though in the following two centuries there was higher variations in temperature and precipitation over all seasons. The cycle of bad years of AD 1047-51 and 1095-1117 are the first of their type and may indicate a shift in winter variability. There were also increases in storminess from the 11th century and a shift of abnormal winters of Arctic origin. Overall this cannot be classified as a MWP for the NWAR but if the AD 1270-97 is included it may be more accurate to call it the 'Medieval Transition' because there is an increase in climate variability. It may reflect a time of transition between the benign climate before AD 1040 and the major shift to a lull after AD 1310. There is not yet enough evidence to say that that this is a definable climatic period in Ireland.

CLIMATIC DECLINE, AD 1270-1600

The climatic decline can be dated to between AD 1270-1310 when there was a complete change in climatic characteristics. From AD 1310 and perhaps from as early as AD 1298, the growing season became cooler and wetter and winters milder. This section will be divided into AD 1270-1499 and AD 1500-1600 not because there was any significant change at this point but is the dividing line between the published indices of EURO-CLIMHIST. The latter two decades of the 16th century are then discussed as the point where changes in the temperature regime indicate the onset of the colder winters diagnostic of the 'Little Ice Age'.

The 13th century in Europe is seen as a period of climatic deterioration. Lamb (1995 191-4) argues that increased storminess can be dated from the middle of the century in coastal north-west Europe and that from AD 1300 precipitation increased markedly particularly in the summer with an all year round decline in temperature of about 1°C (ibid. 84-5 & 195-9). There is perhaps some contradictory evidence in Ireland, as it appears that AD 1000-1300 was a time of dune stability (McClenahan 1997) though this may be due to temporal resolution. There was also a short period of glacial advance in the Alps around 1300 (Grove 1988 354).

Detailed analysis of winters by Pfister (1996 100-2) of central and western Europe, but excluding Ireland, northern England, Scotland, Denmark and Fennoscandia, concluded that there was no clear trend in 14th century winter temperatures and identified four different time sub-periods. However he believed it was reasonable to argue that the shift from the 'Medieval warm epoch' the 'long' Little Ice Age took

place at the beginning of the 14th century. However the onset of major glaciation in Iceland, Scandinavia and the Alpine region is dated to c. AD 1570-1600 (Grove 1989 18, 107, 113 & 167). A comparison of the number of references to winter in Central Europe shows that they almost doubled from 27 in the 13th century (average indices 1.56) to 47 in the 14th (average indices 1.70).

There is little agreement as to the nature and extent of the Little Ice Age. The arguments presented in European climatic literature argue contradictorily that it exists or it doesn't, i.e. it is a katathermal. Those researchers who favour the former argue than it begins anytime between AD 1250 and 1600. Those that argue for an early date appear to assume that that climatic decline of the AD 1270s predicates the further decline of the late 16th century.

There is problem with an early date from the NWAR perspective, The evidence for Ireland suggests that there are not that many climatic similarities before and after AD 1600. The second is that the term 'Little Ice Age' is a central European definition that is determined by glaciation and temperature, whereas in the NWAR the main determinant for the period c. AD 1270-1590 is precipitation. There is no evidence of long-term cold temperatures and almost none of snow/ice with the exception of periglacial sollifluction in *Gleann na Sneachta* (Glen of the snow), Co. Kerry (P. Coxon, unpublished research) and occasional references in the Annals.

Jones and Bradley (1992 658-660), concluded that there is 'considerable uncertainty' about the timing and characteristics of the 'Little Ice Age' and note that the main problem is that there is no standard definition and without this it is impossible to

explain the nature and timing of the period. Surveying the global evidence, presented in the compilation they edited, they concluded that there has not been a monotonously cold period over the last 500 years, but geographical variability in the intensity and timing of temperature on an annual and seasonal basis. They, however, do not offer any definition and only recommend that the term 'Little Ice Age' be used cautiously.

Winter

As mentioned in the previous chapter there was a major decline in the weather in Ireland from AD 1270. This can be seen in the sudden increase of entries that relate to snow, frost and wind storms. However as the following table indicates, such winter systems largely disappeared until the late AD 1580s with the exception of AD 1335-9 and AD 1434-5 and a few outliers. This is in marked contrast to the rest of Europe where winter systems steadily got colder and there was a resurgence of glaciers in Europe. The following chart shows Irish and European indices to AD 1300-1399, there are no published indices for Europe between AD 1400-1500.

Table 8.1 Winter indices of Ireland, England and Europe

Year	1303	1305	1306	1308	1309	1310	1311	1314	1315	1317	1318	1319	1322	1323	1325	1326
IRL											-1					
EU	-2	-1	-3	-2	-1	-1	-2	-2		-2		-3	-2	-3	-1	-3
ENG		-4	-7			-3		-6	-4	-6			-3			-6

Year	1328	1330	1333	1335	1336	1338	1339	1340	1342	1349	1351	1352	1353	1354	1355	1359
IRL						-2	-2									
EU	-2		-2	-2	-1		-2		-1		-1	-1	-1		-3	-2
ENG	-6	-6		-9			-8	-6	-2	-6	-6			-8		

Year	1361	1363	1364	1367	1369	1370	1371	1378	1379	1380	1382	1384	1387
IRL													
EU	-1		-3	-1	-2	-1		-1	-2	-1	-1	-1	-1
ENG		-6	-9				-4						

In England Lamb's indices are published to AD 1439 and they list severe winters in AD 1408, 1414, and 1429 but not AD 1434 or 1435. The first three have no Irish references and the latter two are curious as given the European-wide severity of this winter it is puzzling to find no references in England, this may be due to lacunae in the English sources.

The main Irish exceptions to severe winters are AD 1335, 1338 and 1339 and AD 1434, 1435, 1462 and 1465. In AD 1335 a great spring snow when most of the birds died is described, whereas England winter severity lasted from December, the previous year, to March indicating that the Irish suffered a particularly bad easterly blizzard. In Ireland, the deep snows and intense frost (many sheep of an unknown disease) of AD 1338, may be of northerly origin due to the lack of references from England or Europe. The following year the winter was severe everywhere in Europe but it is not clear whether this is a continuation of northerly polar weather or an easterly arctic anti-cyclone. In Ireland the combination of snow and frost killed off cattle due to the destruction of winter grass.

The winters of AD 1434-5 were as serious but not anywhere near as bad as Europe where it is called the second European Famine and seen as a period of settlement desertion (Lamb 1977 590). In Ireland AD 1434 was called the 'summer of quick acquaintance', as people were unwilling to recognise relations or friends, but, unlike

Europe, there is no evidence of settlement desertion. In AD 1462 a great frost is recorded from the beginning of the year to the middle of February. AD 1465 was more serious with a great snow and frost that froze the ground and prevented spring growth until the middle of May. The resulting delay in ploughing caused a famine.

With the exception of these episodes there is the almost complete disappearance of severe abnormal winters for nearly 200 years until the AD 1580

Spring, Summer and Autumn

As has been noted the climate went through a major downturn from AD 1310 that affected the main growing season starting with a 'hard spring' of that year. The following years, until about AD 1320, were disastrous in Ireland with major cattle and grain shortages. Cattle murrains caused by damp weather were common and were conducive to human mortality. This period is known as the first European Famine but unlike the rest of Europe there is not the same type of settlement desertion. In Ireland there was a transition from arable to pastoral farming by Gaelic farmers who took over lands abandoned by Anglo-Norman settlers (Barry 1988 350-4). However a contributing factor is the unstable political situation caused by the Gaelic Resurgence and the Bruce invasion of AD 1315-8. The latter was responsible for considerable destruction of crops and farmland in Ulster and northern Leinster until the Battle of Faughert in AD 1318. It is likely that the grain shortages of this period were as much a function of warfare as of heavy rainfall. Grain shortages were a fact of life up the AD 1330s, for example, in AD 1331, stranded whales in Dublin Bay are recorded as easing a famine amongst the citizenry.

In AD 1326 and 1333 there are the first references to a good summers and autumns with successful early harvests and the climate appears to have been fairly benign, though wet, until the AD 1390s. The Gaelic and Anglo-Norman sources present a sorry picture of climatically induced famines for the next 100 years. These in brief are:

- AD 1397. Summer and autumn windy wet and cold
- AD 1410. Scarcity of corn and a great famine
- AD 1443-50. This period had extremely bad springs, summers and autumns with a combination of cool temperatures, continuous rains and torrential storms that caused cattle mortality, grain shortages and famines. AD 1450 is called a 'warlick' year, this word may be the old dialect word 'warlock' which stands for cruciferous weeds indicating a survival diet for the starving.
- AD 1462. 'The worst spring and summer in a long time'.
- AD 1478. 'A hard niggardly year'.
- AD 1488-97. Another bad period of continuous rains and stormy weather in AD 1488, 1491, 1496 and 1497. AD 1491 was called the 'Dismal year' and in AD 1497 there is a possible reference to cannibalism, the first reported since AD 1315-8.

Droughts are rare and only one is reported in AD 1419. It appears to have been very serious as it was described as a 'living fire in the earth', while crops suffered, wild trees and bushes produced a major crop. Clement summers are equally infrequent and are reported only in AD 1333 and 1471

In comparison, Lamb's index for Southern England to 1439, show the following periods with dry summers: AD 1297-1313, 1325-1388, and 1407-24, particularly in June and July. Periods that were wetter than normal were AD 1314-16 and 1399-1404. Springs tended to be the harbinger of summer in that they were similar. However Augusts and autumns tended to be wet in most years. It therefore appears that Southern England and Ireland experienced two very different summer regimes.

Storms

Stormy weather continued from the previous period but to be cyclic with episodes around AD 1310, 1360 and a long period from AD 1470-1528. These are primarily storms though hailstorms are listed in AD 1470 and 1471 and lightning-storms in AD 1306, 1308, 1330, and 1487. As in earlier periods they are mostly related to destruction so it is unclear whether the above are representative or not.

AD 1500-1600

This century is dealt with separately as comparative published indices covering all seasons can be used. However the downside is that there is a decline in the Gaelic sources so the quantity and quality of information is reduced and has to be complemented by available English authors writing about Ireland.

In Europe warm summers appear to have begun earlier and lasted for a longer period, AD 1461-1561 (Hughes & Diaz 1994 122) with a peak in England in the AD 1520s (Lamb 1995 84). However there was, according to Pfister (quoted in Lamb 1995 213) a decline in winter temperatures in the Alpine area from the AD 1540s though the period AD 1530-60 was otherwise similar to the 20th century climatic optimum

(Pfister 1992 135). This does not appear to have had an impact in Ireland until the AD 1590s and even then was not as severe as Scotland, which had seven famines during this decade (Lamb 1995 221).

Winter

A comparison of German (Glaser *et al* 1999 184) and Irish winter temperature indices indicates that Irish winters remained mild until about 1588 when snows returned with cold temperatures lasting until spring. Southern English winters are of the same origin as central Europe, and those that are not referenced in either England or Europe are probably European or Scandinavian in origin, as severe winters are not a feature in Ireland for this period. The last decade is poorly recorded but other historical sources indicate a deterioration of winter temperatures particularly in mountainous areas. It is likely that this season is under reported. No famines are recorded but there does appear to have been a decline in agricultural output in marginal areas. The first 17th century reference to famine comes in 1600 due to a combination of a 'great frost and tempestuous weather' (Crawford 1989 9). Overall winter climate was predominantly western, with the exception of AD 1541, which continued into spring.

Table 8.2 Winter indices of Ireland and Germany

Year	1502	1503	1504	1508	1509	1511	1512	1513	1514	1517	1522	1525	1526	1529	1534	1535
IRL																
GY	-2	-3	-2	-2	-2	-3	-2	-2	-3	-3	-2	-2	-1	-2	-3	-1

Year	1536	1537	1541	1543	1544	1546	1548	1550	1554	1557	1561	1563	1564	1565	1569	1571
IRL			-3													
GY	-2	-1	-2	-2	-2	-2	-2	-2	-1	-1	-3	-1	-1	-3	-3	-3

Year	1572	1573	1574	1576	1578	1586	1587	1588	1589	1590	1591	1592	1593	1595	1599
IRL								-1			-1	-1			
GY	-1	-3	-1	-1	-1	-2	-3		-1	-3	-3		-1	-3	-2

Spring, Summer and Autumn

These three seasons are, as usual, hard to differentiate due to the difficulties of dating and the fact that heavy rainfall was often found in two to three of the seasons. However for the most period it appears to be similar to the previous 180 years with anomalies of very wet and cool periods, such as AD 1502-25, which appears to be a less extreme continuation of the 1490s. Compared with German indices it can be seen that these Irish wet summers and autumns, with the exception of the summer of 1503, did not reach central Europe.

Table 8.3 Summer and Autumn indices of Ireland and Germany AD 1500-25

Year	1502	1503	1506	1519	1523	1525
IRL P summer	-2	-2	-2	-3	-3	
IRL P autumn		-2		-1		-2
GY P summer	2	-3	3	1	0	1
GY P autumn	-1	2	2	1	1	0

There were only two droughts in this century, AD 1568 and 1575. In Germany the following values for precipitation and temperature are found:

Table 8.4 Summer indices of Ireland and Germany AD 1568 and 1575

Year	1568	1575		1568	1575
IRL P	3	3	IRL T	3	3
GY P	-1	-2	GY T	-1	3

In both years it appears that the African high-pressure systems over Ireland did not spread eastwards to central Europe. The fact that the precipitation indices were lower than average in Germany, i.e. there was more rain than normal, indicates that the high pressure acted as a blocking system and forced oceanic westerly systems on a north-south arc over the sea where they absorbed higher levels of moisture. The first Irish reference however adds that dryness was 'natural to the season' and this may indicate that dry summers were usual for perhaps the previous 10-20 years. Otherwise there is not sufficient information on Irish climate in the 16th century to conduct a proper comparative analysis

Storms

There were three periods of storminess reported in AD 1502-06, 1517-28 and 1581-2

Conclusions

Overall the period c. AD 1300-1600 the disparate evidence suggests that after about 1270 there was a decline in the weather with an increase of colder and wetter weather over much of Europe though this wasn't synchronous. Ireland experienced similar conditions though it was not as cold but was probably wetter and stormier. There were severe periods in AD 1310-20, 1462-91 and 1497-1506. Occasionally there were some milder phases but these appear to have been of very short duration with the possible exception of c. AD 1560-75.

The evidence for Ireland indicates that there was a major transition of climatic characteristics between AD 1297-1310. The first major trend was the disappearance of blocking winter anti-cyclones and the second was the decline in temperatures and increase of precipitation in the other three seasons accompanied by an increase of tempestuous stormy weather.

There is a possible correlation between the asynchronous tree-ring widths of AD 1308-24 in Ireland, England and the rest of Europe and the documentary sources. The decline does coincide with the change to cooler and wetter weather in Ireland but it remains to be seen whether this is diagnostic given the fact that a similar climatic decline happened in the rest of Europe. Further detailed comparative analysis needs to be done between the EURO-CLIMHIST indices for the summer season and Lamb's indices with Irish and European tree-ring widths.

A possible explanation is that from AD 1270 there was the build up of climatic change, as measured by increasing atmospheric turbulence, that lasted until AD 1294-7, which triggered a sudden climatic shift. The change is obvious in Ireland as the climate changed to cooler wetter conditions with the disappearance of regular high pressure blocking systems. The weather in AD 1294-97 was extremely bad and is referenced in all the Annals as lasting three years. Clyn, in AD 1294, adds that

> "On the festival of the Blessed Virgin Mary there was lightening and meteors destroying the blades of corn, whence proceeded very great scarcity, by which many perished of famine " (Crawford 1989 5)

This is the only set of Annals that note such a specific cause and by itself appears unverifiable. However in China, AD 1295, there are reports of fireballs the size of houses, and the following year there was an extraterrestrial impact in Russia and major forest fires among Sequoias in California in AD 1297 (Baillie 1999 23). It is possible that the planet passed through a meteorite dust cloud in the AD 1290s. It may be that a bombardment acted as a trigger, catalyst or was a significant cause in the climatic shift, since its arrival would have intensified the natural cycle of climatic change. If it can be taken that Atmospheric turbulence is a measure of the 'competition' between the forces for change and inertia in the climatic systems, then inertia was possibly more powerful before AD 1294. Perhaps they are related on a deeper level that has not yet been considered.

The tree-rings tell a slightly different story. From the asynchronous behavior previously noted it is possible that there was a climatic boundary down the Irish Sea that divided Ireland from England and the rest of Europe between AD 1298-1324. At this time Irish oak responses were completely the converse to the rest of Europe except for the period AD 1312-20 where there is no relationship at all (though this may be an artefact of the trend of change). The closest analogy is of a blocking high to the west of Ireland with an eastern boundary through the Irish Sea. This mirrors the location of atmospheric blocking systems but have they last longer.

It may be that the climatic shift moved from west to east and that for the Irish trees responded first in AD 1307, followed by England (Sheffield is slightly ahead of London here) in AD 1320 and the rest of Europe in AD 1325. Or it could be the

opposite direction. If this were the case than it would appear that there was a response lag across Europe, perhaps similar to the lags seen in the extreme variance curves of tree-ring widths (pp. 76-7). The period AD 1312-20, where there is no correlation, may indicate chaos in the response of oaks to the climatic shift. The logic would therefore be that change was not instantaneous as it takes a few years to completely change the global atmospheric system. There are also possible geographical variations in climatic inertia that needs to be considered.

It is worth noting the coincidence of dates between the end of the AD 1294-7 famine and the beginning of asynchronous behaviour in AD 1298; and the AD 1312-20 period, the height of the European Famine. It is however not possible to explain the reason behind the different responses between Ireland and the rest of Europe since climate, as we perceive it, suggests that change was roughly synchronous. Oaks responses provide a different perspective to this climatic shift. However because we have no real idea why oaks behave as they do we have no way of explaining why there are two different responses.

It is also worth noting that there were major environmental changes in the early 14th century, though more in China and East Asia than in Europe. This is believed to have triggered the latest plague, the Black Death, which lasted until the late 15th century though with some later outliers. On the basis of this outbreak and the previous wave 500 BC-AD 550 it is possible to hypothosise that initial plaque outbreaks are climatically related. They tend to flourish during climatic periods, which in Ireland is represented by cool, wet and stormy conditions, i.e. the Iron Age and Medieval lulls.

It is difficult to make definitive comparisons for the rest of the period but in general it appears, at times, to have been significantly different from England and Europe where Ireland suffered and over abundance of precipitation Europe suffered from declining temperatures. Irish Summers were much cooler though the two 16th century droughts are odd since they were not noted in Europe.

In conclusion the period AD 1310-1590 is analogous to the Iron Age lull of 500 BC to AD 300 and for this reason the NWAR could be defined as experiencing a 'Medieval Lull'. After c. AD 1590 the deterioration in winter temperatures suggests that the katathermal called the 'Little Ice Age' began in Ireland. However it has not been successfully established whether this is a culmination of the previous three hundred years of climatic processes or the result of a completely different set of environmental and climatic conditions.

Conclusions, Discussion and Recommendations

The aim of the dissertation was to reconstruct climate in medieval Ireland using documentary and dendrochronological data. This has been successful subject to the limitations of the data and methodologies. The findings offer new perspectives on climate in Ireland, in relation to Europe in particular. What follows are the main conclusions, a discussion that relates climate to Irish history, and the main recommendations for future research into a hitherto unexplored subject.

Conclusions

Climate

The weather over the last 2,000 years has gone through cycles of warm/cold and wet/dry. These are not invariable and it appears that various types of solar, climatic and environmental cycles are active at any one time. Grove (1988 307), for instance, argues that glacial advances are at 1,000-1,500 year intervals and this appears to be one of the medium term cycles but they are intermixed with a variety of short and long term cycles such as sun spot activity (Lamb 1995 p. 69). Within the North Atlantic setting there are two added effects. The first is that increased moisture in the atmosphere causes greater turbulence through the injection of energy, and the second are the extreme values in the atmosphere as measured by the North Atlantic Oscillation, which creates greater climatic stress between the two 'poles' of Iceland and the Azores. Also worth noting is the impact of terrestrial and extra-terrestrial catastrophic events.

In Europe, the first part of the first millennium AD appears to have been poor up to around the end of the 4th century and is associated with the Iron Age Lull of most of the sub continent. There was a gradual improvement with a peak c. AD 1100-1200 but was followed by a decline to wetter weather and cooler temperatures. Colder conditions set in the latter part of the 16th century.

Ireland tends to follow this pattern but there are some significant differences. Given the nature of the data and the various caveats, that have been discussed previously, the following tentative conclusions can be drawn.

- The Iron Age Lull is typified by cool and wet summers and winters and ended around AD 300, though it is difficult to be precise.
- The Early Medieval Dry period is identified by mild winters with occasional severe episodes of Polar origin specific to the NWAR. Warm springs, summers and autumns were showery but not overly wet. Extremely bad summers, either too wet or dry, appear to be uncommon but there is insufficient evidence for any categorical statements.
- The beginning of the Medieval Transition is hard to date due to seasonal differences and any chosen will be arbitrary. To a certain extent change was by degree with an increase in variability but not a change in climate type. However three points can be noted:
  1. From the mid 11th century the incidence of storminess increases
  2. From the mid AD 1090s severe winters increase and were more likely to last for longer than one year such as AD 1092-1116 and AD 1270-1297

3. Summers and associated seasons are more difficult to assess due to the vagueness of the data and the number of unclassifiable seasonal events particularly around AD 875-80 and c. AD 975. Generally summers appear to be fairly similar to the earlier period

Overall it appears that from around AD 1050-1100 the climate became more variable with abnormal seasons lasting longer and westerly cyclonic systems becoming more turbulent but there does not appear to be major changes in temperature or precipitation.

- The Medieval Lull. The beginning can be dated to AD 1270, when a severe run of winters began; AD 1298 when cold winters almost disappeared; or from around AD 1310 when cool and wet weather became predominant. There was a definite decline in spring, summer and autumn temperatures and increasing precipitation associated with an intensification of stormy weather from AD 1310 at the latest. The latter date is, perhaps, preferable but it depends on whether the choice is temperature or precipitation. Taking the evidence into account it appears that the AD 1294-7 event was typical of the weather over the previous 250 years with an increase of intensity after c. AD 1270. After AD 1310, at least, the climate has a completely different character as measured by temperature and precipitation. It therefore appears that the change is between AD 1298-1310. The difference is clearly seen in Ireland though this does not appear to be the case in Europe due to different regional climate dynamics and perspectives.
- The 'Little Ice Age' in Ireland begins around AD 1588 but there was poor weather in the other seasons.

One argument of this dissertation was that there is sufficient evidence to support the validity of the North West Atlantic Region hypothesis. It has been argued that climate dynamics in Ireland can be significantly different to Great Britain and mainland Europe through the use of climatic and dendrochronoligical data. The north-south boundary can sometimes be seen in the Irish Sea, but there is a need for more regional proxy data from England, Scotland, Wales, Brittany, and the northern Iberian Peninsula for a fuller picture of how climatic patterns shift in space and time. It is also essential to test whether this region, if it exists, is ephemeral or permanent.

Dendrochronology

As may have been expected an analysis of the tree-ring widths of *Quercus* could not be directly related to long term climate and climatic changes due to biological and environmental factors. There are some hints that some of the changes seen in the dendrochronological record can be correlated with periods of climatic change such as in the beginning of the 14th century. However considerable work yet needs to be done on tree-ring history to elucidate the patterns of change found in the series. The tree-ring widths also provide evidence that supports the human-environmental relationship and oak population life cycles.

An elucidation of the oak's total response to its ecosystem on micro and macro scales has proved to be difficult, as the disentanglement of biological, climatic and environmental influences is problematical. The reality is that there is no comprehensive theory that explains the response patterns of tree-ring widths. Notwithstanding the methodological problems an attempt was made to provide an

outline of their history over the last 2,000 years though all suppositions must be regarded as tentative.

Regional issues came to the fore with the discovery of regional asynchronous behaviour. While the idea has been explored before now this work indicates that the boundaries can be geographically located at specific time periods. The nature of the differences has yet to be discovered but if a theory can be provided that explains the apparently contradictory evidence, than it may be possible to find enough information to compare dendroclimatic and climatic zones or regions, whatever their life-span.

Many other questions remain unanswered such as the cause of the decline of widths in AD 700-830 and AD 1410-1445 in Ireland as well as the pan European (including Ireland) rise from c. AD 1650 to mention but a few.

However the exercise was worthwhile as it gives a different perspective on the behaviour of oaks. It provided a greater understanding of the biological and environmental issues pertaining to the ecology of *Quercus*. Also without the research on widths the value of indices would not have been appreciated. However it must be noted that a major research limit was statistical competence. While simple statistics were understood easily enough, in the higher reaches understanding was primitive i.e. 'High Correlation is Good' and 'Low Correlation is Bad (or just plain different)'. Most interpretation at this stage was based on the visual examination of charts that were often dimly understood.

Discussion

It is worth exploring the relationship between climate and history using the different perspectives of the research results. It is not the intention to go into any great detail, but to explore the possible consequences by navigating a safe passage between the shoals of political and climatic determinism. What, in other words, are the implications of these perspectives and what does it tell us about the Irish social history? A full analysis of this interplay is outside the scope of this dissertation, as it would entail rewriting Irish history. However it behoves the historian to make some attempt at revision, no matter how limited it is. Whether this is relevant to the modern debate on climate change, as often claimed, is perhaps open to question.

It has been noted that Irish agricultural society benefited from a benign climate to about AD 1270 with the exception of a 25 year period at the turn of the 12th century. The island supported a mixed agricultural economy of cattle and grain, famines were few and though they could be very severe recovery was apparently quick. From the end of the 13th century medieval expansion appears to have halted and an agricultural retrenchment took place reflecting the colder wetter conditions of the 14th-16th centuries and the severe winters after AD 1590. This of course is not the whole story and the impact of infectious diseases; endemic warfare, agricultural innovations and cultural change were also significant factors in shaping history over this time.

The first major event that we know of is the famine of AD 536 with the laconic statement of a 'shortage of bread'. This can not be taken very far as it there is no way of knowing its intensity or duration, except to say that the impact of the catastrophic event, possibly of extra-terrestrial origin and discussed fully by Baillie (1995 91-107

& 1999), must have happened after March. This event is recorded in tree-rings world-wide, though in Ireland the impact is not so clear and this may be due to the fact that tree-ring widths were depressed at this time. The Irish widths recovered over the following two years but declined again during AD 539-45. The impact on the human population is unclear since we do not have any direct correlation between the annals and tree-rings widths.

The Justinian Plague followed in AD 545, with recurrences in AD 549 and 556 with smallpox in AD 554 and 577 and Leprosy (Hansen's disease) in AD 576. Other diseases are harder to identify and many were named by 19th century medical historians, particularly, William Wilde. Modern epidemiologists note that over time virus and bacteria either become extinct or mutate into something else, either becoming benign or more toxic and/or virulent and are a function of the never-ending competition between immune systems and diseases. The combination of ambiguous diagnostic information and these mutations often make the identification of historic diseases problematical.

While the mid 6th century catastrophe was important, in terms of negative impacts on a global scale, it is important not to take it out of context. For instance it is likely that the Mediterranean was tectonically active at the plate margins, for example there was the volcanic eruption of Vesuvius in AD 513 and a major earthquakes in and around the basin in the 6th century. (Zinsser 1935 107). A second point is that while the Justinian Plague was the worst that had been known; it followed the Athenian Plague of 430 BC; and others in 54 BC; AD 80; AD 165-89 (Plague of Antoninus or Galen);

AD 250-6 (Cyprian plague); AD 310-13; AD 445-6; AD 467 and AD 477 (ibid. 99-106).

However the origins of epidemics are complex. There appears to be a general relationship between climate and spread amongst some diseases such as the plague. In any environmental catastrophe, there is a migration of rodents, their parasites and a miscellany of viral and bacterial diseases. These diseases usually have a major impact on populations with no natural immunities. However human disturbances, such as landscape clearances, can also have the same effect.

The issue is complicated by urbanisation, the effects of which have been recognised since the time of Hippocrates if not earlier. Urban centres are major disease vectors because of their location, their trade functions and their cultural mores. This is not only a question of poor sanitation; but also any large agglomerations of people, whether permanent or temporary, create the conditions by where transfers of DNA become very straightforward and this allows rapid mutations of diseases into possibly more virulent and toxic forms. A further issue is the relationship between the breakdown of sexual mores and the mutation of sexually transmitted diseases, which tends to be ignored (with the exception of gonorrhoea) until the 16th century when syphilis became a major epidemic.

A possible explanation for the plague is that at the global climate downturn in 500 BC there was major environmental changes to the natural world. This resulted in the spread of vegetation cohorts to new locations and extinction at the old, followed by the knock-on effect on the fauna, including the major disease vector, the rodent. The

spread of rodents would then cause the breakout of infectious diseases and this would have a major impact on traditional agricultural societies and then travel on the existing trade networks. The above chronology suggests waves of plague coming from Asia and Africa, being channelled through Turkey and into Europe, becoming stronger and reaching further west every time culminating in the strongest and last of the succession, the Justinian Plaque.

The aetiology of these various waves of plague show different characteristics suggesting that they are all different variants, each more powerful than the previous. It is likely that as the human population builds up immunity the virus almost completely dies out except for the mutations that survive through random natural selection. These mutations are therefore stronger and more virulent and the ancestors of the next outbreak. Human immune systems unfortunately breed stronger plague variants, though it happens at a slower time scale than the modern period of antibiotics. This supplements the relationship between climatic lulls and plague outbreaks but climatic effects on other major diseases are largely unknown.

It is also worth noting that Smallpox, believed to have originated in India c. 2000 BC, has been implicated in the Plague of Athens and the Justinian Plague, as well as some of the others. Recently the theory of 'Gumbo diseases' has been put forward which argues that disease combinations often have deadly interrelationships (Garrett 1998 207). Smallpox appears on it's own at other times and is found in nearly all periods of history but became less toxic over time. In Ireland mortality rates for smallpox appear to have been lower than the plague.

This relationship of plague and climate may help to define climatic lulls, though plague outliers appear to last well into changed climatic times. In the modern period most of our new diseases originate from the destruction of Tropical Rain Forests, but a climatic downturn to 'Lull' type conditions could intensify the current wave of infectious diseases as new outbreaks of plague arrive from Asia. It is perhaps debatable whether environmental disturbance is the sole forcing mechanism because there may be an independent relationship between some other climatic signal and viral mutation of the plague (and other infectious diseases) and its subsequent spread.

When the Justinian Plague arrived in Europe it caused a major loss of life amongst the Mediterranean population with a possible mortality rate of one-third. However this outbreak was mostly among people with some built up immunity in contrast to Ireland where there is no evidence of previous outbreaks of plague. The question than arises as to the mortality rate in Ireland in the AD 540s. The annalists say that two-thirds of the world died, perhaps they were closer to the truth than we care give them credit for. The following outbreaks between AD 664-684 appear only to happen in Ireland indicating it took a few generations, perhaps three to five, for the community to build up immunity.

It can also be noted that the spread of animal diseases follows the same patterns. It is therefore difficult to say whether any particular outbreak is climatically related or a result of the importation of a new disease on an animal population that had no previous immunity. This is particularly a problem of island biogeography, though Ireland is large enough not to face complete extinction of its animal (or human) populations, though the evidence suggests that it came close on a number of

occasions. A very large mortality can cause major food shortages and famines and it takes time to re-establish herd sizes.

The first great murrain, as the Annals invariably call animal diseases regardless of type, arrived in AD 700 and lasted about eight years and is followed by a less severe outbreak in AD 774-779. From then only occasional outbreaks are listed with two concentrations of bad disease periods, AD 954-993, AD 1286-1324.

Animal diseases are often directly related to climatic factors such as precipitation (Bourke 1989 256-273). This development can be seen in the early decades of the 14th century, in the occasional references to the pairing of 'murrains' and weather in Irish sources and in the modern period as well. Bourke (ibid.) discusses this relationship with particular reference to modern crop diseases, not discussed here.

To return to Irish history, plague reappeared in AD 664-8 and 683-4. These are called the 2nd and 3rd 'Great Mortality' and appear to have had a major effect on Irish society. O'Croinin argues that there may have been a land shortage due to excess population before this time but afterwards there is evidence of settlement desertion. The documentary evidence comes from Bishop Tírechán, who complained that church settlements were taken over by Clonmacnoise, these had belonged to Armagh and had been deserted because of the plague. Bishop Adomnán, Columba's biographer, implies that the Iona community annexed property as well (O'Croinin 1995 109 & 160-1).

This view is complemented by dendrochronology as it has been found that, as of 1988, there were no Archaeological timbers surviving between AD 648-720 (Baillie 1995 127-8). He argues that, with further samples, this may shrink to AD 660-90 but that there is a definite hiatus in building in Ireland at this time.

In time Ireland recovered and by the middle of the 8^{th} century there is a major expansion of society in progress. It is interesting that later sources don't mention further over-population but this may be due to developments in agricultural and grain milling technology. If the continuing impact of cattle raiding, succession squabbles, power struggles between regional kings, the Vikings, the regular arrival of miscellaneous human and animal diseases are ignored, it is possible to say that the people of Ireland were doing well, given the climatic circumstances.

In the middle of the 11^{th} century Ireland suffered the first of it's many great famines. While famines were not unknown they were usually seasonal and related to cattle mortality caused by either abnormal winters or diseases. What made the Famine of AD 1047/8-51 so serious was that it was lasted for longer than one year and for both summer and winter seasons. It was deemed serious enough for Donchad Ui Brian, King of Munster and sometime High King of Ireland, to enact laws for the return of good weather in AD 1050.

The series of great climatic famines, to AD 1600, are, AD 1115-7, 1280-6, 1294-7, 1312-18, 1444-47, and 1496-7. These were interspersed by occasional events lasting for one season as well as shortages caused by infectious diseases. There are two other changes worth mentioning. The first is that there is an increase in number of famines

from the c. AD 1200, i.e. in the 12th century there were three excluding the AD 1115-7 period but seven between AD 1200-70. The second is the appearance of the first reference to a war induced famine is in AD 1153, thereafter they are not uncommon and often implicated as part of the cause of famine, such as the Bruce Invasion, AD 1314-18. This problem appears to be at its worst in the 16th century, though this may be a function of the brutally honest and innovative literature of the New English Adventurers.

As noted above the change in climate in the early 14th century caused major problems with infectious diseases. This relationship is not necessarily as clear as it should be because there is not a direct correlation of climate with the major environmental changes that appeared later. From AD 1286 there is a major upsurge of animal diseases and there was some human 'pestilence' during the Major Famine of AD 1294-7 as well, as Smallpox and influenza in AD 1327-8. The Black Death arrived in AD 1349 and this is another period where the Annals go very quiet. It has been this researcher's experience that the worse the event the less is written, probably because these horrendous periods brought about communal amnesia. In fact the full scale of these major disasters may never be known because of this understandable type of under-reporting. All the major famine and plague periods share this characteristic though it has to be said that this is difficult to prove in the early medieval period because most entries are too short.

We therefore know very little about the course of the plague in Ireland, though twenty five subsequent outbreaks are reported up till AD 1575. This averages to about one

every ten years and appears to come in periods of variable intensity. Other diseases mentioned are Smallpox, Influenza, Sweating Sickness, Typhoid and 'Flux'.

The climate in this period bears a strong resemblance to the Iron Age Lull and calls to mind Raftery's description of the farmer's plight, which sounds very similar to the conditions of the later cycle. The Great Famine of the early 14th century is of a completely different character to earlier ones and it is worth noting that the end of the previous period, the Medieval Transition, and the beginning of the new, the Medieval Lull, are marked by major famines. There were two further bad periods of the same character in the mid AD 1440s and 1490s. The early AD 1500s was intermittently bad during the growing season though many 16th century famines are also associated with warfare.

There are signs of a recovery in Ireland from the middle of the 15th century as measured by an expansion of trade. The 16th century was a period of rising political conflict and warfare and this resulted in the destabilisation of society. One of the effects being the increase of pastoral farming at the expense of tillage as movable wealth was more secure and/or easier to recapture than crops (Nicholls 1972 97). Climatically one would have expected the opposite because there was a definite moderation of climate in the AD 1560-70s, if not earlier. Europe experienced a slight improvement of climate in the mid 16th century and this may have contributed to the European expansion of these times.

Then there was the minor matter of the Normal Invasion and the resulting incomplete conquest AD1179-?? . The latter date is not yet agreed, though it had various cycles

and those that concern us here, with their rough dates, are; the Norman conquest AD 1179-1250, the Warlord Age, AD 1270-1500, the Tudor to Williamite expansion, AD 1500-1690. Some of these climatic-political issues are briefly discussed next but first a reflection on a topic of a spiritual nature.

The Irish Anchorite tradition AD 500-700

It is well known that Ireland is unique in Europe because the Church was organised on monastic lines, which had developed from an initial informal structure based on bishoprics. It has to be said that the process of transformation is still controversial with many competing opinions. However part of the monastic life was the anchorite tradition, which arrived in Ireland from Syria via France. The role of St. Martin of Tours was important though there is some slight evidence of direct links between Ireland and the Eastern Mediterranean.

It is worth asking if the impacts of occasional climatic downturns and bubonic plagues in the 6th and 7th centuries were part of the inspirational ideology for the strong anchorite tradition and the whole phenomena of the *peregrini* (wandering monk). Certainly the spread of Irish monks in isolated islands such as the Faeroes, Iceland, possibly Greenland and Newfoundland, and elsewhere, is well documented as is the tradition by where monks would set sail and land wherever winds and currents took them. It may be that these disasters, which showed the futility of striving in the material world, were part of the motivation for the extreme self-imposed ascetic traditions and penitentials that were practiced in Ireland and Irish monasteries in Europe.

The First European Expansion AD 1000-1250

There is an interesting temporal relationship between the classical view of the Medieval Warm Period and the major expansion of north west Europe, especially among the Franks. This resulted in major waves of migration, conquest and colonisation that took adventurers from Ireland to Jerusalem, Spain to Poland. It is however difficult to say whether Ireland was a beneficiary of this reputedly warm period.

Gaelic Resurgence 1270-1300

The height of the Norman Conquest and colonisation was between c. AD 1170-1250 and was followed by a period of entrenchment in the best lands leaving surviving Gaelic leaders in marginal areas of the island. This was followed by a period of conquest, known as the Gaelic Resurgence. It is now believed that this was not a political movement but a response, on a regional level, of a number of up and coming warlords to a centralised government that was in decline. Part of the reason for the decline was because the Kings of England in the 14th century were primarily concerned with power struggles against French Kings and the conquest of Scotland. Ireland was treated as a source of provisions but not of investment. This resulted in weakening Dublin administration and the loss of lands controlled by the monarchy.

At the same time the climate deteriorated from around AD 1270 and as a result marginal lands became uneconomic. This forced tenants to migrate to the poorly defended Anglo-Norman lowland estates and take them over. This can be seen in a number of areas such as the Wicklow mountains, south of Dublin, where manorial

economies controlled by secular lords and the Archbishop of Dublin were permanently lost to newly emergent Gaelic dynasties and their hungry followers.

The European Famine, 1312-5

This period saw a major decline in weather across northern Europe, and resulted in widespread famine, demographic collapse and land abandonment. The position in Ireland was somewhat different, certainly the island suffered the worst effects of the famine but unlike the rest of Europe there does not appear to have been any abandonment of settlements. What appears to have happened is that settlements were abandoned by Anglo-Norman tenants who found that it was impossible to continue cereal production (soil degradation may have also been a factor) but that these farms were immediately taken over by the Gaelic Irish who were predominantly pastoral farmers. This continued the process of land take over which had started c. AD 1270 except the reasons were somewhat dissimilar. Other farms were not abandoned until later as can be seen from the survival of the defensive moated farmstead into the 14th century.

The question however remains whether the change from arable to pastoral agriculture was climatic or cultural. It has always been the case that cattle were important in Gaelic culture for reasons of status as well as nutrition. It is somewhat difficult to come to any decision since the role of cereals and cattle were a part of the cultural divide and conflicting evidence is found in the negative propaganda produced by both sides. It may be that the Gaelic Irish preferred pastoral activity though climatic and soil factors were undoubtedly important.

The Nine Years War, 1594-1603

It has been increasingly recognised over the last few years that this period was not a purely Ulster phenomena but that the Wicklow mountain territories, under the control of Feach Mac Hugh O'Byrne and his Leinster allies, played in important part in AD 1580-90. However by AD 1597 the Wicklow Mountains had been reduced to submission and the majority of the leaders killed and followers dispersed by the Dublin based English armies.

It is worth noting that the mid 1590s saw the arrival of increasingly cold winters and this had a major negative impact on the agriculture of the mountains and resulted in the decline of accessible food resources. The impression from the sources is that the leaders came under considerable pressure to maintain food stocks and declined from being warlords to outlaws.

The Ulster Plantation, 1603-10

After the defeat of the Gaelic Ulster leaders in AD 1603 and subsequent migration to Spain and Italy their lands were confiscated and were made available for plantation by loyal English and Scotch subjects. There was a very poor take up by the English but the Scots migrated in large numbers.

It is worth noting that the 1590s were a time of extreme winter conditions in Scotland and famine occurred in seven years of the decade. It is likely that Scotland was part of the Fennoscandia climatic area at this time. It is therefore probable that the Irish opportunity was a major lifeline for many and that this was the major motivation for

their migration. It is comparable to Scottish migration to other parts of Europe such as Sweden, Poland and Austria.

The storms of 1588 and 1796.

The destruction of the Spanish Armada by storms is well documented and is one of history's great 'what might have been' had the Armada made a successful landfall. The impact in Ireland is more difficult to estimate as little is known about the actual methods that Spain would have used to rule Ireland. However the major land confiscation of the 17th century probably would not have happened.

The 1796 storms were responsible for preventing the French fleet from landing in Bantry bay. Success here may have meant that Napoleon would have poured more resources into Ireland rather than try and limit England's wealth through his invasion of Egypt and take-over of the Red Sea. The following 1798 rebellion was fought without any French assistance, except for some token assistance when it was too late, and failed.

The Famine, 1845-7

The primary cause of the Irish Famine was the failure of the potato crop for three years through the fungal blight, *Phytophthora infestans*. The effects of this failure, where about one million people died, are well documented particularly on the western seaboard where the mortality levels were very high. The climatic reasons for its spread have been well documented by Austin Bourke. It is worth adding that the climate through the winter of 1846 was particularly bad with heavy snows and many

storms. The result of this was that normal fishing routines were disrupted and this loss of access added to the mortality.

The Land League, 1879

The primary cause for establishment of this society is largely seen within the context of landlord-tenant relationships and the developing political movement whose main ideology was Home Rule. This ultimately led to a variety of Land Acts that in the early 20th century resulted in the transfer of the ownership of majority of land from landlords to tenants.

It is worth adding that the increasing rains and declining temperatures, after a benign period from 1850, was also a factor. The resulting crop failures resulted in the inability of tenants to pay rents and rent-reduction became a major plank of their protest with fixture of tenure and the free sale of leaseholds. On a wider level these crop failures were found all over Europe, and resulted in the United States of America becoming a net exporter of grain to Europe and this forever changed the economic balance between the two continents.

In conclusion it can be seen that climate has had a major role to as the provider of heat and moisture essential for agriculture but also a cause of agricultural failure. This climatic/environmental relationship needs to be researched further so that a proper understanding of the interplay of culture and climate is understood.

Recommendations

Documentary Sources

Collection

- That a full transcript of all climatic references from the Irish Annals be made
- That this be supplemented with a review of Early Irish literature for general climatic information so that our understanding of this perspective can be deepened
- That these are supplemented, for the 12-16th century, by other source types, which are primarily administrative.

Interpretation

- That a set of Irish indices be agreed.
- That they are compared with Pfister's indices for Europe and Lamb's for England. Before AD 1000 they should be simplified to the seasons of 'Winter' and the 'Growing Season' since the data does not allow for greater precision. A general picture of the main course of climate over time needs to be achieved before we can attain any understanding of the four seasons.

Research

- That the 'North West Atlantic Region' hypothesis be tested
- That AD 1297-1310 is researched to test for significant climate change elsewhere and then debate whether this is better understood using a uniformitarian or stochastic paradigm.
- That this transition be compared to other known climatic transitions
- That the period AD 1310-1580 be compared to the Iron Age Lull

- That the 'Medieval Warm Period' in Europe, loosely defined as AD 500-1250, be compared with the earlier Bronze Age climatic optimum.
- That the prevailing tracks of high-pressure systems, originating around the North Pole, be researched, since Irish abnormal winters in the early Medieval Period, may aid in our understanding of the circumpolar vortex
- That Irish climate is put in its proper environmental context on Irish, European and Global scales.

Dendrochronology

The main recommendation is that dendrochronologists develop environmental histories based on tree-ring widths for the better understanding of the interactions of trees with their environments, including climate and climatic change. It follows that this will provide a testable hypothesis that will explain biological responses of *Quercus* and *Pinus* from different perspectives.

The research in previous chapters has only scratched the surface of the potential of the data and further specific areas of research that come to mind are:

- A further investigation into negative anomalies between Ireland and the rest of Europe
- Further research into the 'Variance Index' hypothesis. Can periods of high or extreme variability be cross-referenced to other proxy sources?
- The whole issue of the cyclic change in Ireland over the last 2000 years needs to be addressed especially in comparison to the previous 5000 years since our understanding of the history of tree-ring widths is still very basic.

Interdisciplinary Research

There are other possible avenues of research using a wider variety of proxy sources such as palynology, tephrachronology, historic carbon dioxide levels, Coleopteran distributions, Protozoan distributions, environmental archaeology, astronomical investigations of extra-terrestrial orbits and impacts, etc. A research programme, that utilised some or all of these disciplines, could provide a complementary understanding of the human, climatic and environmental relationships on longer time scales, particularly in earlier historic periods when documentary evidence is lacking or difficult to interpret.

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MISERY INDEX

In an earlier work (Cantwell 1998 30) the concept of a 'Misery Index' was explored and while this index is not scientific it may be an avenue worth pursuing on a European level if the criteria for constructing such an index could be established. It was concluded that the periods where it was at its highest were the mid 6th century, AD 662-83, 759-86, 1114-8, 1224-7, 1315-23, 1461-70, 1487-98, and 1595-1603. On the basis of the present work certain revisions were deemed necessary and the dates now deemed as more representative are the mid 6th century, AD 662-83, 759-86, 1044-51, 1113-7, 1224-9, 1280-6, 1294-7, 1310-15, 1444-7, 1488-98, and 1595-1603.

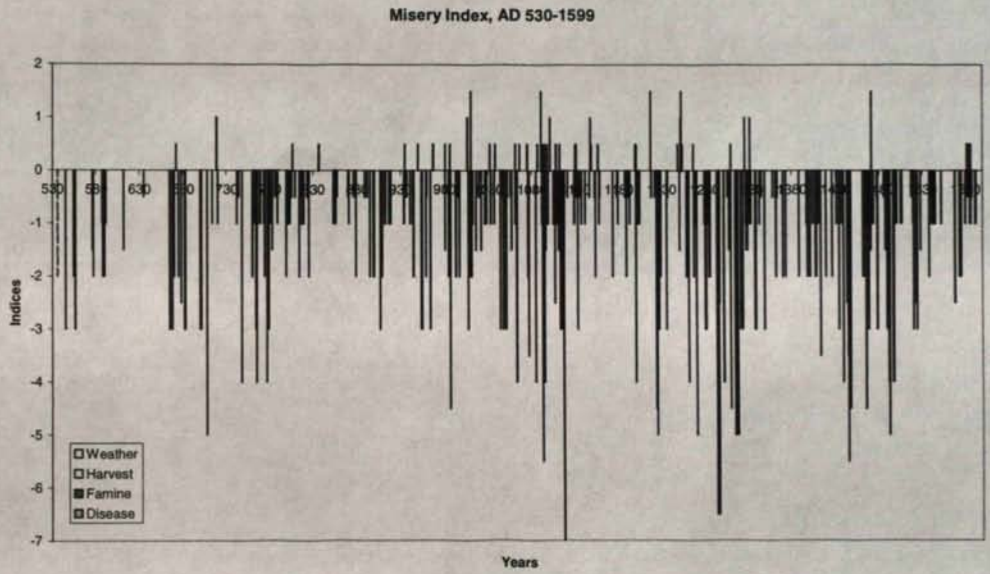
Following this on it was decided to experiment with an index that attempted to portray the total impact of famine and disease. Pure climatic indices are not suitable for portraying the intensity and the, often cumulative, effect of weather. This index has been constructed in such a way to attempt a depiction of these effects to suit the perspective though other methodologies and/or values may be more suitable. Therefore the methodology and values are given without discussion since the process was subjective. Overall it was attempted to measure the likely impact through the interpretation of the annalist's depiction. These figures have to be treated with caution due to many factors influencing the writing and the copying of such entries.

The following values were chosen:

- All negative climatic events, regardless of season, were given a value of –1. This includes droughts as they were often as destructive as very wet summers. There is no evidence that the people classified droughts as 'a good thing'.
- All storm events were given the value of -0.5
- All climatic famine events were given a value of –1 to –3 depending on their severity
- All disease famine events were given a value of –1 to –3 depending on their severity
- All positive references to good harvests were given a value of 1
- All references to good harvests of wild trees etc. were given a value of 0.5

It was regretfully decided not to give values to the negative events of warfare notwithstanding the fact that some periods were considerably worse than others. The main reasons are the subjectivity of the sources, the different regional impacts plus the impossibility of coming to any means of objectively deciding how to differentiate between cattle-raiding, internal and external power struggles, invasions and conquest. There is also the problem of compilation, i.e. a proper index would need to have a complete list of all events in chronologically discrete time-frames. This task is the work of a Herculean. The likely main result would be that periods of political instability are correlated with higher levels of social disorder. However it is regrettable that the third junior partner of the Horsemen of the Apocalypse could not be included.

The chart is presented in black and white due to the complexity of data and the Excel programme's inability to give colour definition to cumulative bar charts or any other chart type.



As may have been expected there are cycles of varying length, these are a function of climatic, environmental and cultural inputs, the importance of each changing over time. It can be seen that there were short periods of intense suffering in the 6th, 7th, 8, and 9th centuries mostly caused by plague and winter famines. From AD 900 there is an increase of tempo of misery inducing events until the early 12th, a relatively benign period for the next 150 years followed by an intense period between AD 1250-1450. There is a possibility of decline in the 16th but this is offset by the increase of warfare.