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Multi-Proxy Evidence from Bogs for Environmental Change in Ireland over the last 1,200 years


Thesis submitted to the University of Dublin, Trinity College, for the Degree of Doctor of Philosophy

October 2000
I hereby declare that this thesis is my own work, except where otherwise acknowledged in the text, and that it has not been previously submitted to this or any other University. I give my permission to the library of the University of Dublin, Trinity College to lend or copy this thesis upon request.

Edwina E. Cole
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Summary

In order to understand recent and future climate change, it is necessary to document how climates have varied in the past. Literature and research concerning climate change of the last 1,200 years, namely the Medieval Warm Period, Little Ice Age and 20th Century Warming, are discussed. Ireland has a wealth of palaeoecological records based on its vegetation since the last ice age which provide some very good records of past climates and their associated impacts. Unfortunately many lack the temporal resolution necessary to investigate small climatic changes on centennial to millennial scales and to provide information on these and the environmental changes that may have occurred as a result of these climatic changes.

This thesis presents the results of a high resolution multiproxy record of climate and its environmental impact over the last 1,200 years from three sites in Ireland. These sites follow a gradient of increasing wetness across the country from east to west. Vegetation changes and anthropogenic impacts are also provided from these sites for this time period.

The various methods used in this investigation include pollen analysis, fungal spore and testate amoebae analysis, charcoal analysis, loss on ignition and dating in the form of radiocarbon dating and tephrochronology. These methods are explained and discussed in Chapter III and the results presented in Chapters IV to VIII.

Both the radiocarbon dating and tephrochronology resulted in the satisfactory construction of a time-depth chronology for each site for the last 1,200 years. The regional pollen record, along with the charcoal and loss on ignition data in places, reflect the typical history of the time such as the mass clearance of trees from the landscape as the pressure for land increased over time including the commercial exploitation of trees in the 17th Century, the increases in agriculture especially pastoral over time, the significant decline in Coryloid pollen reflecting the increased pressure on the land prior to the Great Famine, the effects of the Great Famine itself, the introduction of new exotic species from the mid-18th Century onwards and the Economic War between 1932 and 1938. Both the local pollen and fungal spore analysis reflect the history of what was happening in the immediate locality of each site, on the bog surface. The local vegetation changes occurring at each site over the last 1,200 years appear to be site specific being very local and not national phenomena. The fungal spore data also provided a record of the palaeohydrological
history of each site which demonstrated, similar to the local pollen record that changes in
the hydrology appear to be site specific also.

On a climatic front, the regional pollen record provides little information with regards to
the Medieval Warm Period, the Little Ice Age and 20th Century Warming mainly due to
anthropogenic impacts on the landscape, the effects of which are very difficult to
disentangle from those caused by climate. Evidence from the local pollen and fungal
spores suggest that between AD 1150 and AD 1300 Ireland in general experienced mainly
wet conditions whereas between 1550 and 1700 dry conditions are suggested by the data.
Increasing dry conditions are illustrated in some way in records from each of the three sites
during the time of 20th Century Warming. These dry conditions (as suggested by either
local pollen or fungal spore data) during this time period may be due to anthropogenic
impacts also such as drainage and peat cutting but climate is also thought to play a role in
causing this dryness. The sensitivity to climate appears to follow the increasing wetness
gradient across Ireland. The climatic signals appear to more pronounced in the most
western site. This may be due to a combination of its remoteness, its proximity to the
Atlantic ocean and the fact that this area is the least anthropogenically disturbed site of the
three sites investigated.

The multiproxy approach taken has certainly resulted in a detailed, well dated
calaeoecological record of the last 1,200 years in three sites across Ireland. Details of
climate however are more difficult to interpret and from this study different types of data
appear to contradict others with respect to similar time periods in the cores. This may be
due to the large influences of humans in the landscape over the last 1,200 years. Another
source of error may be the fungal spore record where the identification of more wet and dry
taxa would aid in establishing a more precise and accurate local wet and dry record from
each site. Testate amoebae were only counted from the pollen slides and therefore were
not a true representative of the faunal component of the peat. A different method of testate
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<td>BP</td>
<td>Before Present (i.e. 1950)</td>
</tr>
<tr>
<td>Calib.</td>
<td>Calibrated</td>
</tr>
<tr>
<td>DCA</td>
<td>Detrended Correspondence Analysis</td>
</tr>
<tr>
<td>EDMA</td>
<td>Energy Dispersive Microanalysis</td>
</tr>
<tr>
<td>EPMA</td>
<td>Wavelength Dispersive Microanalysis</td>
</tr>
<tr>
<td>FAZ</td>
<td>Fungal Assemblage Zone</td>
</tr>
<tr>
<td>IGBP</td>
<td>International Geosphere-Biosphere Programme</td>
</tr>
<tr>
<td>LHB</td>
<td>Liffey Head Bog</td>
</tr>
<tr>
<td>LIA</td>
<td>Little Ice Age</td>
</tr>
<tr>
<td>LOI</td>
<td>Loss on Ignition</td>
</tr>
<tr>
<td>MWP</td>
<td>Medieval Warm Period</td>
</tr>
<tr>
<td>NAO</td>
<td>North Atlantic Oscillation</td>
</tr>
<tr>
<td>NNR</td>
<td>National Nature Reserve</td>
</tr>
<tr>
<td>PAGES</td>
<td>Past Global Changes</td>
</tr>
<tr>
<td>PAZ</td>
<td>Pollen Assemblage Zone</td>
</tr>
<tr>
<td>PANASH</td>
<td>Palaeoclimates of the Northern and Southern Hemispheres</td>
</tr>
<tr>
<td>PEP</td>
<td>Pole-Equator-Pole</td>
</tr>
<tr>
<td>pSAC</td>
<td>Proposed Special Area of Conservation</td>
</tr>
<tr>
<td>SCP</td>
<td>Spherical Carbonaceous Particle</td>
</tr>
<tr>
<td>SPA</td>
<td>Special Protection Area</td>
</tr>
<tr>
<td>TWC</td>
<td>20th Century Warming</td>
</tr>
</tbody>
</table>
Introduction

1.1 Why Study Recent Climate Change?

Climatic change is a significant feature of the Earth’s natural history. It is very clear from the palaeoclimate record that sudden changes have occurred in the global climate system at certain times in the past. The understanding of mechanisms of climate variability on time scales of several months to many years is a prerequisite for any prediction of climate (World Meteorological Organisation, 1997). In order to understand recent and future climate change, it is necessary to document how climates have varied in the past (Nicholls et al., 1996). The direction and magnitude of future climate change are currently impossible to predict with any degree of certainty and consequently predicting the potential impact of this change on the environment is saddled with the same uncertainty. Hence scientists must understand the complex causes of climatic change before they can attempt to predict future conditions. Only as a more comprehensive and reliable record of past climatic oscillations is built up can the possibility of identifying causes and mechanisms of climate variation be increased (Bradley, 1999).

Documentary evidence provides an important insight into past climates particularly those that span the time period from AD 1100 to the beginning of instrumental meteorological recordings. The age of instrumental meteorology began in the mid 17th Century following the development of the liquid-in-glass thermometer and the barometer (Ingram and Underhill, 1979). Europe, and certain areas in eastern USA contain many of the earliest instrumental records dating from approximately 1650-1750 (Ingram and Underhill, 1979). However most parts of the world have instrumental records that do not extend further back than the late 18th Century.

Beyond information found in historical writings and data from instrumental records, climatologists depend on evidence recorded by the natural environment during climatic change i.e. that deduced from palaeoclimatic records. Such natural phenomena are climate dependent and therefore incorporate into their configuration a measure of this dependency. They provide a proxy record of climate (Bradley, 1999). However no single palaeoclimatic proxy record exists that is representative of global palaeoclimates. Therefore regional and multidisciplinary data have to be collected and collated in order to obtain a global view of past climate change (Bradley et al., 1995).
1.2 Climatic Events of the Recent Past

The Earth's climate varies naturally on time scales from hundreds of millions of years to only a few years (Folland et al., 1990). Glacial-interglacial cycles have occurred on a time scale of 100,000 years over the last two million years characterised by large changes in global ice volume and sea level. Average global surface temperatures varied by 5-7°C during this period. Palaeoecological and -climatic evidence clearly illustrate that the Earth emerged from the last ice age 10,000 to 15,000BP (Folland et al., 1990). It was only during the 1840s, when indisputable evidence of former ice ages was found, that the realisation that climate has changed radically with time came about (Barry and Chorley, 1992). Within the last few thousand years, the climate in many parts of the world has altered sufficiently enough to affect the viability of agriculture and settlement. Since 10,000BP global averaged surface temperatures have fluctuated over a range of 2°C on time scales of centuries or more (Folland et al., 1990). Even the climatic record of the last 1,000 years seems to include a distinct range of climatic regimes. Such anomalies include the 'Medieval Warm Period' and 'Little Ice Age'. There is much speculation as to the causes of these climatic changes. Many proposed explanations involve feedback mechanisms concerned with the atmosphere and ocean (Grove, 1988). Research by Hughes and Diaz (1994) suggests that the available climatic data of the last millennium exhibit significant decadal to century scale variability throughout. Evidence also suggests that there is a discernible human influence on global climate (Carson, 1999). According to Stuiver et al. (1997) the Medieval Warm Period and Little Ice Age temperature trends of the past millennium are compatible with solar climate forcing.

1.2.1 The Medieval Warm Period

For a few centuries in the Middle Ages the climate in most parts of the world experienced a climatic change of increased temperature which approached that of the warmest postglacial times (Lamb, 1977). This warm time period is known as the Medieval Warm Period. The onset and duration of the Medieval Warm Period exhibited global variability as the climax of this warm spell was not quite contemporaneous everywhere. Many regions show no evidence of its occurrence (Tyson and Lindesay, 1992; Hughes and Diaz, 1994). Briffa et al. (1995) describes how northern Fennoscandia experienced predominantly warm summers during the 11th and 12th Centuries while the northern Urals were mainly cool. These findings provide support for the fact that the Medieval Warm Period was not a
globally synchronous, multicentury period as originally thought. Stine (1994) however provides evidence to suggest that the Medieval Warm Period was at least hemispheric (with respect to the northern hemisphere) from investigations he carried out in the Sierra Nevada, California. He found, from relict tree stumps, that this area experienced severe drought conditions for more than 200 years before AD 1112 and for 140 years before AD 1350. A period of wetness separated the two drought periods and persisted for less than 100 years. In general the Medieval Warm Period is thought to have occurred from AD 1100-1375 but other commencement dates have also been documented — AD 1150-1300 (Lamb, 1977), AD 1000-1300 (Hammer et al., 1980), 11th-13th Century (Roberts, 1991), AD 1100-1250 (Graybill and Shiyatov, 1992), AD 900-1300 (Tyson and Lindesay, 1992) and 11th-12th Century (Nicholls et al., 1996). It is thought that the climax of warmth of the Medieval Warm Period peaked as early as AD 900 in China (Lamb, 1982) and in South Africa (Tyson and Lindesay, 1992) but the period on a whole continued later in Western and Northern Europe than elsewhere (Lamb, 1982). Lamb (1979) claims that this peak of warm conditions also occurred a few centuries earlier in Greenland and much of the Arctic compared to many parts of Europe. In most areas this warm regime does not appear to have exceeded 200 to 300 years.

Fossil evidence from oxygen isotope measurements and tree ring data suggests that the Medieval Warm Period was in general warmer and drier than the preceding centuries (Lamb, 1977; Roberts, 1991). Research by Petersen (1994) however suggests that this climatic period in the USA was characterised by warm and wet conditions. The mean temperature in general rose by 1 to 1.5°C which caused the tree line and the upper limits of various crops on the hills of central Europe to be higher than they are today. Vikings established farmsteads in Greenland's fjords and vineyards thrived in central England (Cowie, 1998). Dry climatic conditions during the 10th Century are thought to have played a role in dune formation on the Veluwe in the Netherlands (Berendsen and Zagwijn, 1984). This climatic period was also remarkably storm free which facilitated intensive exploration and colonisation in the northern lands (John, 1977). The growth limit of grain crops moved northwards during this period which enabled oats and barley to be grown in Iceland (Cowie, 1998; Lamb, 1977). It was also a period of high civilisation, (most notably around the 11th Century) and throughout this period Euro-Asian trade, conquest and colonisation increased in intensity (Cowie, 1998). This warm period did however have a catastrophic effect on the world in that it aided the spread of vermin species which led to one of
mankind’s most horrific periods in history – the ‘Bubonic Plague’ or ‘Black Death’. This plague wiped out almost one third of the global population (Cowie, 1998).

Changes in settlement patterns occurred over much of South Africa around AD 1000 where the higher parts of the subcontinent in places such as Natal and Zululand, were settled by farming communities (Tyson and Lindesay, 1992). It is thought that the warmer conditions of the Medieval Warm Period may have influenced this movement of people. McGhee (1979) reports on the culture of the Thule folk who were natives of Alaska and the ancestors of the present Eskimos of Arctic Canada and Greenland. This population of people appeared suddenly approximately 1,000 years ago and throughout the centuries developed a complex maritime hunting technology for open water hunting of large sea mammals such as the bowhead and right whale (*Balaena mysticetus*). Many Thule culture winter villages containing the bones of several large whales have been found in several Arctic islands in areas far beyond the present ranges of such mammals and in areas such as the northern coast of Greenland which today would not be navigable because of severe ice conditions. This culture of people moved southwards along the coast of west Greenland and by AD 1600 had abandoned their High Arctic habitat. It is thought that this movement of an entire culture was brought about by a deterioration in climatic conditions at the time.

A possible cause for the Medieval Warm Period has been postulated by Lamb (1977) – the explanation lies in a circulation pattern in which the northern hemisphere subtropical anticyclones were displaced somewhat to the North during this warm epoch in Europe, Greenland and North America. Stine (1994) suggests this northward shift may have been caused by a contraction of the circumpolar vortex or because of a persistent ridge of high pressure that steered cyclonic disturbances to relatively high latitudes. It is thought that the middle latitudes westerly winds were weaker and less widespread in latitudes 40° and 60°N than now and places in central and northern Europe enjoyed variable and somewhat more frequent anticyclonic winds. Lamb (1977) has suggested that the Mediterranean region experienced an increase in cyclonic activity of various types and benefited from rainfall above recent levels during the Medieval Warm Period because of ‘bitrack’ depressions. He relates this to indications of increased river flow in Sicily and peat growth in the Azores. Recent research by Bradley (2000) suggests that the widespread nature of hydrological anomalies during the Medieval Warm Period suggests that changes in the frequency or persistence of circulation regimes may account for the unusual nature of the period, and naturally this may have led to anomalous warmth in some (but not all) regions.
1.2.2 The Little Ice Age

There is considerable uncertainty about when the Little Ice Age began (and ended) and what its climatic characteristics were despite the fact that the Little Ice Age is the best documented period of climatic change that occurred in Europe during the entire Holocene (Bintliff, 1982). Observational and palaeoclimatic evidence suggest that there is geographical variability in these climatic anomalies, where the coldest periods in one region are not synchronous with those in other regions (Jones and Bradley, 1992). Many dates have been suggested for the Little Ice Age—AD 1550-1700 (Lamb, 1977), AD 1500-1920 (John, 1977), AD 1550-1800 (Grove, 1988), 16th-19th Century AD (Ballantyne, 1991), AD 1590-1850 (Roberts, 1991), 14th-18th Century AD (Chambers, 1993) and AD 1450-1850 (Gajewski, 1993). Research carried out in Canada suggests an onset date for the Little Ice Age of as early as AD 1142 (Luckman, 1995). Matthews et al. (1996) found no evidence to suggest the existence of the Little Ice Age in western Norway while Selsing et al. (1991) report on a climatic deterioration in the period AD 1300-1800 in south west Norway. The majority of research carried out on the Little Ice Age is in agreement with the consensus that this climatic period was not a synchronous cold interval. However overall it appears to be the most globally extensive cool period since the Younger Dryas (Tyson and Lindesay, 1992).

The extent of ice on the Arctic sea and that on land appears to have been greater during the Little Ice Age than at anytime since the last major glaciation (Lamb, 1979). Much of the evidence of the Little Ice Age is based on reconstructions of glacier fluctuations (Gajewski, 1993). The beginning of the main glacial advances which brought ice fronts near to their Little Ice Age maxima in Europe is best dated in the Alps where glaciers are known from historical records to have reached advanced positions by AD 1600 (Grove, 1988). Glaciers advanced in the Alps sporadically until AD 1850. Lamb (1977) suggests that glacial advances between AD 1540-1700 were mainly due to lengthening of the snow season and shortening of the summer ablation period while those between AD 1780-1850 owed more to increased precipitation.

During the entire period of the Little Ice Age the mean summer temperature was approximately 1°C below current standards (Kullman, 1987). During the coldest phases of the Little Ice Age (i.e. AD 1690s) summer temperatures were 2°C below the 20th Century mean (Grove, 1988; Kullman, 1987; Matthews, 1993). Such temperature changes were
sufficient enough to cause measurable meteorological, geomorphological and vegetational changes (Grove, 1988). As well as colder winters and very variable summer temperatures, Europe also experienced pronounced storminess (Berendsen and Zagwijn, 1984: Lamb, 1982). Documented evidence suggests that western Norway experienced various forms of mass movement such as landslides and avalanches during the Little Ice Age (Grove, 1972). Large floods occurred between AD 1250 and AD 1450 as the climate slipped from the height of the Medieval Warm Period into the Little Ice Age. Flooding episodes in Norway resulted in masses of sand, gravel and stones being deposited on the fields (Grove, 1972). Poor summers followed by harvest failures and widespread famine have been documented (John, 1977), along with an increase in incidence of disease and death among the human and animal population (Lamb, 1977). From 1564 to the 1730s malaria was an important cause of illness and disease in several parts of England (Reiter, 2000). Transmission began to decline only in the 19th Century when the present warming was well under way. Although there were huge cuts in the human population, a corresponding decline in some countries’ infrastructure did not occur but actually allowed them to re-organise their economy favourably (Cowie, 1998). The colder climate of the Little Ice Age, with its harsher winters, lowered the population of vermin and so aided in bringing the Black Death to an end. The average growing season in England probably decreased by 5-6 weeks and the upper limit of cultivation dropped by between 150m and 200m. It has been assumed that the former contributed in part to the causes of the Highland troubles in Scotland and the lasting abandonment of farmland and settlements in many parts of Europe as well as unrest and constitutional changes that occurred there also (Lamb, 1982). The tree line was also lowered in many areas of central Europe (Lamb, 1977; Roberts, 1991).

Briffa et al., (1988) reconstructed summer temperature variations over Europe for the period 1750-1850 using a network of maximum latewood density chronologies of coniferous trees (Picea, Pinus and Abies) and found that Europe experienced cooler summers from 1812 to 1816 and during the 1830s. The cold summer of 1816 was found to be most extreme in the United Kingdom, less so in central Europe and hardly detectable in Scandinavia. Temperature anomalies were found in this study with temperatures higher in southern Europe in 1830 (with 1.3°C anomaly over the Alps) and lower in Scandinavia (0.5°C below normal). In 1831 the reverse situation occurred where Scandinavia experienced 1°C above normal temperatures and southern Britain, France and most of the rest of western Europe experienced cool conditions.
Despite the trend toward cooler and wetter regimes, there were intermittent episodes of warmth and drought (Baron, 1992). Most European records indicate relatively warm conditions in the 16th and 18th Centuries (Jones and Bradley, 1992; Nicholls et al., 1996). Records from areas of Africa north of the equator, Algeria and the Sahel zone exhibit evidence of several drought years especially between 1590 and 1650 and 1690 and 1780 (Lamb, 1979). Lamb (1977) states that Spanish historical records indicate frequent contiguity of severe drought and flooding seasons during the period of the Little Ice Age. Such alternations of extreme seasonal conditions can be found in several European records (particularly in the 14th, 16th and 18th Centuries) and is thought to have been the most damaging aspect of the climatic anomalies to the economies of the times in question with severe effects on farming routines, harvests and the health of people and livestock (Lamb, 1979). It has been argued that in Britain the Little Ice Age played a part in the movement from a rural to urban-based population therefore assisting in the provision of an available workforce for the forthcoming Industrial Revolution (Cowie, 1998).

Well documented evidence of the Little Ice Age exists from areas outside of Europe also. Lamb (1979) reports on the abandonment of the cultivation of oranges in the Kiangsi province of China due to the occurrence of frequent frost between 1654 and 1676. Prior to this, the growth of oranges had been practised for centuries in this region. Evidence suggests that the glaciers in eastern equatorial Africa on Mount Kenya and Mount Kilimanjaro were in a more advanced position than at their present day limits (Lamb, 1979). Dendrochronological evidence from old-growth Huon pines suggest that the Little Ice Age occurred in Tasmania during the 17th Century. However its presence is weakly expressed in comparison to many records from the northern hemisphere which may suggest that southern oceans have significantly restrained its effect on Tasmania (Cook et al., 1992). Tyson and Lindesay (1992) claim that the Little Ice Age experienced in South Africa was mostly a period of cold and dry conditions. This theory is supported by pollen assemblages reconstructed from Nuwevelberg which indicate an existence of dry climatic conditions from the fourteenth to mid-nineteenth centuries (Sugden and Meadows, 1989) and also from research carried out in east Africa (Verschuren et al., 2000). Increasing Poaceae and decreasing Asteraceae pollen after this period suggest a return to more moist conditions. The advance of sea ice in the Arctic was the main reason for the death of the European population occupying Greenland during this period (McGhee, 1979). This increase in sea ice around Greenland and its southward movement forced the abandonment of traditional sailing routes between Iceland and the Norse colonies in Greenland (Porter,
1979). Evidence from the southern Rocky Mountains in the USA suggests that the Little Ice Age was a time period of cold and dry conditions which terminated in the mid AD 1800 (Petersen, 1994).

Many suggestions and theories have been proposed to explain the occurrence and duration of the Little Ice Age. According to Hammer et al. (1980) it appears certain that the effect of volcanic aerosols in the stratosphere may have contributed to the Little Ice Age by screening off some of the incoming solar radiation. Hammer et al. (1980) found that there was a significant increase in volcanic activity all through the development of the Little Ice Age and on into the 19th Century compared to the warmest millennia of postglacial times where very little volcanic origin deposits were found. Barry and Chorley (1992) hypothesise how the southward spread of sea ice could impede the conveyor belt circulation, stopping heat release to the atmosphere and causing the Little Ice Age.

1.2.3 20th Century Warming

The warm climate of the late 20th Century is anomalous in the context of at least the past millennium and counters a millennial-scale cooling trend which is consistent with long-term astronomical forcing (Mann et al., 1999). Pfister et al. (1998) suggest that the 1961-90 level of winter temperatures in western central Europe is within the threshold of natural variability of the last thousand years, albeit at its upper boundary. Research by Briffa et al. (1995) on a tree-ring-based reconstruction of mean summer temperatures over the northern Urals since AD 914 concludes that after a slight cooling in temperatures to the end of the 19th Century there was an abrupt rise and sustained warmth during the 20th Century. They found that the 20th Century was clearly the warmest period in the Urals during the past 1,000 years. Alpine glacier advance and retreat chronologies investigated by Wigley and Kelly (1990) suggest that at least in alpine areas, global 20th Century temperatures may be higher than any time period since AD 1000. Nicholls et al., (1996) provide a summary of research into the 20th Century warming experienced in many places across the globe in both the northern and southern hemispheres. Certainly warming appears to be more significant in some locations than in others. Overall, however, it appears that the 20th Century has been at least as warm as any century since at least AD 1400. In at least some areas, the recent period appears to be warmer than has been the case for a thousand years or more (Nicholls et al., 1996).
Research by Kiely (1999) suggests that an increase in precipitation was found to occur in Ireland after 1975 which is most noticeable on the west of the country. Furthermore, analysis of extreme rainfall events show that a much greater proportion of extremes have occurred in the period since 1975. This coincides with a change in the North Atlantic Oscillation (NAO) index also. The NAO is an oscillation in the pressure field between Iceland (65°N) and a zone about 40°N across the Atlantic (Barry and Chorley, 1992) and is the most important mode of variability in the northern hemisphere atmospheric circulation (Greatbatch, 2000). Fluctuations in the NAO give rise to alternating mild/severe winters in north-west Europe.

Decadal trends are apparent in the historical record of the NAO and may be due to either stochastic or deterministic processes (Stephenson et al., 2000). Gerten and Adrian (2000) found evidence for uncommonly warm winter and spring seasons between 1988 and 1998 from phytoplankton studies and that they were significantly related to the NAO. Stephenson et al. (2000) suggest that the NAO exhibits ‘long-range’ dependence having winter values residually correlated over many years. The NAO index was generally low from 1925-1970 while prior to 1925 a regime of colder climatic conditions was associated with a higher NAO index (Barry and Chorley, 1992). The increased NAO since 1975 is associated with increased westerly airflow circulation in the northeast Atlantic and is correlated with the wetter climate experienced in Ireland compared to that prior to 1925.

It has also been suggested that the NAO is modulating the Earth’s ozone shield such that the calculated anthropogenic total ozone decrease is enhanced over Europe (for the last 30 years) whereas over the North Atlantic region it is reduced (Appenzeller et al., 2000).

1.3 The PAGES Project

Past Global Changes (PAGES) is the International Geosphere-Biosphere Programme (IGBP) core project concerned with providing a quantitative understanding of the Earth's past environment and defining the shell of natural environmental variability within which anthropogenic impact on the Earth's biosphere, geosphere and atmosphere can be assessed. Within the PAGES project lies the Palaeoclimates of the Northern and Southern Hemispheres (PANASH) project. PANASH investigations are linked in a series of Pole-Equator-Pole (PEP) transects focused on the sequence and phasing of major climatic fluctuations on two different streams based on time-scale (Bradley et al., 1995). Stream 1
is concerned with the last 2,000 years while Stream 2 spans the last 250,000 years. The project reported in this thesis shares many questions posed in Stream 1 of the PANASH project. Such questions include issues such as the importance of human impact on climate, the dates of commencement and duration of the Little Ice Age and Medieval Warm Period and their consequences on the environment and how the 20th Century climate compares with that of the last 2,000 years. The PANASH project is concerned with these issues on a global scale with investigations in both the northern and southern hemispheres. This thesis is only concerned with these issues on a regional scale—their effect with respect to Ireland and its environment.

1.3.1 Where does Ireland fit into this Investigation?

Ireland is located on the extreme west of the third PEP transect, the Afro-European transect, established by the PANASH project. Gasse (1995) states that within PEP III a west-east transect across Europe exists to provide data on the climatic gradient from the North Atlantic ocean. Therefore a climatic gradient from east to west exists across Europe from a continental to an oceanic climate. Ireland is in a very suitable location to study recent climate change because of its position on the edge of the North Atlantic. It is most subject to sea surface temperature changes of the North Atlantic, which largely controls and drives the climate of north-west Europe. Any changes that may occur with respect to sea surface temperatures will have important consequences on PEP III where Ireland will experience the initial impact. It is assumed that such oceanic margin sites exhibit the most sensitive record with respect to proxy climate signals (Blackford and Chambers, 1995). Within Ireland itself there exists a climatic gradient of increasing precipitation from east to west across the country.

Most palaeoecological investigations in Ireland have been based on reconstructing the Irish vegetation since the end of the last ice age. These provide some very good records of past climates and their associated impacts on the environment. Some studies have focused on the entire Holocene (e.g. O'Connell, 1980; Pilcher and Larmour, 1982; Smith and Goddard, 1991; Fossitt, 1994), others on the late-glacial period (e.g. Craig, 1978; Watts, 1977; Andrieu et al., 1993; O'Connell et al., 1999) and many others on various vegetation changes within the Holocene e.g. the Pine decline approximately 4,000BP (Bradshaw and Browne, 1987; Hall et al., 1994a) and the Elm decline approximately 5,000BP (Molloy and O'Connell, 1987). Much of this research is carried out at time scales too large to
detect small climatic changes on centennial to millennial scales; they lack the temporal
resolution necessary to investigate the Little Ice Age and Medieval Warm Period and the
environmental changes that may have occurred as a result of these climatic events. This
concentration on Holocene reconstructions had resulted in little attention being given to
vegetation, land-use and climatic history of more recent times. However in recent years an
increasing number of investigations in Europe, and particularly in the British Isles, have
been concerned with vegetation and climatic change focusing for the most part on those
that have occurred over the last 2,000 years (Barber et al., 1994; Blackford and Chambers,
1995; Chambers et al., 1999; Barber et al., 2000).

Although palynological investigations of landscape change in Ireland have been carried out
for over 60 years, studies focusing on the last two thousand years have been few; those that
have been performed have concentrated mainly on the north of Ireland (Hall, 1989; Hall,
1990b; Hall, 1994; Hall et al., 1994a; McVicker and Hall, 1997; Hall 1998) with some
from the midlands (van der Molen, 1988; van Geel and Middeldorp, 1988) and the south of
the country also (Jelicic and O’Connell, 1992). Much research focusing on recent
vegetation history has been largely concerned with anthropogenic influences/impacts on
the landscape. Investigations by Hall et al., (1993) showed extensive landscape changes
between AD 750 and AD 1150 in the north of Ireland. Woodland clearance occurred
before AD 860 while regeneration began in the 10th Century. It was found that agricultural
activity declined in this area after AD 860 and while its causes remain a mystery, it has
been suggested that climate may have played a role (severe weather and crop failures
documented in historical records in years AD 854-858) whereby it affected the people
during this time but not the landscape vegetation i.e. oak trees (Hall et al., 1994a).

1.4 Climate in Ireland

Some would suggest that there is no such thing as climate in Ireland; we only experience
an irregular succession of varying weather patterns with the emphasis on frontal systems
that bring wind and rain (Mitchell and Ryan, 1997).

The geographical position of Ireland provides the country with two major factors that
influence the type of climate that occurs on the island; those of the westerly atmospheric
circulation of the middle latitudes and the proximity of Ireland to the North Atlantic ocean
(Rohan, 1986). Frontal systems and depressions with their associated meteorological
patterns are a feature of this westerly circulation over the ocean and provide Ireland with a very variable climate (Aalen, 1978; Rohan, 1986). The proximity of the North Atlantic ocean gives the climate a marked maritime character with frequent rain, high relative humidity and low annual temperature ranges. Summers can be cool and cloudy while winters in Ireland are damp but exceptionally mild for its latitude (Aalen, 1978). Temperature extremes and severe frost are rare while rainfall is higher in the west and declines towards the east coast (Aalen, 1997). The eastern coastlands are the driest parts of the country which had aided in their evolution as a geopolitical focus since the time of the Boyne valley tombs onwards (Aalen, 1997). The west receives between 920mm and 1400mm of rainfall per year while the eastern half of the country receives between 690mm and 920mm on average annually (Aalen, 1978).

The earliest references to meteorological events in Ireland can be found in the Irish annals (see Table 1.1). Native annalists naturally record only weather conditions which are extreme by Irish standards but all present a similar picture of a climate which may have been very difficult for the growing of cereals and pulses (Kelly, 1997). From 1800 onwards, meteorological observations were made on a regular basis at an increasing number of locations in Ireland (Rohan, 1986). Some of these early instrumental observation records must be viewed with caution however due to the lack of standardisation in exposure, design and calibration. Homogeneity was fairly well achieved in the recording of instrumental observations by approximately 1880 (Rohan, 1986).
Table 1.1 Reports on weather conditions and their consequences in Ireland from the Irish Annals (After Kelly, 1997)

<table>
<thead>
<tr>
<th>Source (Annals of)</th>
<th>Date (AD)</th>
<th>Weather reported</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ulster</td>
<td>748</td>
<td>Snow of unusual depth</td>
<td>Mass death of cattle</td>
</tr>
<tr>
<td>Ulster</td>
<td>764</td>
<td>Excess snowfall</td>
<td>Dysentery flourished</td>
</tr>
<tr>
<td>Ulster</td>
<td>773</td>
<td>Unusual drought and sun heat</td>
<td>Failure of bread</td>
</tr>
<tr>
<td>Ulster</td>
<td>879</td>
<td>-</td>
<td>Starvation of livestock</td>
</tr>
<tr>
<td>Innisfallen</td>
<td>1012</td>
<td>Heavy rain</td>
<td>Corn crop destroyed</td>
</tr>
<tr>
<td>Innisfallen</td>
<td>1077</td>
<td>Gales</td>
<td>Corn crop damaged</td>
</tr>
<tr>
<td>Innisfallen</td>
<td>1129</td>
<td>Hot summers</td>
<td>Mortality in cattle due to lack of water</td>
</tr>
<tr>
<td>Innisfallen</td>
<td>1172</td>
<td>Bad weather</td>
<td>Death of most livestock</td>
</tr>
<tr>
<td>Connacht</td>
<td>1252</td>
<td>Hot, dry summers</td>
<td>Wheat and all other cereals harvested 3 weeks before beginning of August</td>
</tr>
<tr>
<td>Innisfallen</td>
<td>1282</td>
<td>Snow and frost, violent winds</td>
<td>-</td>
</tr>
<tr>
<td>Connacht</td>
<td>1328</td>
<td>Thunder and lightning</td>
<td>Corn damaged</td>
</tr>
<tr>
<td>Ulster</td>
<td>1433</td>
<td>-</td>
<td>Hungry summer</td>
</tr>
<tr>
<td></td>
<td>1471</td>
<td>Hail showers</td>
<td>Bean and other crops destroyed</td>
</tr>
</tbody>
</table>

5.1 Ireland since AD 500

The island of Ireland appears to have been inhabited by humans since 7000 BC (Mitchell and Ryan, 1997). It is thought to have been one of the last countries in Europe to be colonised by human populations, but despite this it is particularly rich in prehistoric remains (Harbison, 1988). The earliest detailed record of human occupation in Ireland was found at Mount Sandel, south of Coleraine in the north-east of the country 9,000 years ago (Harbison, 1988; Mitchell and Ryan, 1997) where excavations revealed an extensive Early Mesolithic settlement (Woodman, 1994). They settled in places such as river banks, lake margins and coastal areas. Such sites provided an ample supply of food for people such as these who were entirely dependent on hunting, fishing and gathering of wild fruit and berries (Brindley, 1994; O’Connell, 1994a). Birds and fish were particularly important food resources in the Mesolithic diet while wild pigs appear to be the largest animals that they hunted and ate (Mitchell and Ryan, 1997). They used stone tools made from many different types of stone although flint is thought to have been the predominant type of stone utilised (Woodman, 1994). These early Mesolithic people entered an island which
was heavily forested and although it is thought that these first settlers did not alter the woodland and soil development of Ireland (O’Connell, 1994b), by their adaptation to the island environment they forged the first distinctive Irish identity. From the later Iron Age forests in Ireland have survived in a landscape dominated as never before by agriculture and pastoralism (Mitchell and Ryan, 1997). In the Iron Age and especially the succeeding Early Christian Period, there is evidence that Ireland was not only culturally vigorous but also more intensively settled than ever before. Unlike the preceding Bronze and Neolithic Ages, habitation sites are very numerous (Aalen, 1978). During the Iron Age, Ireland was divided into hundreds of petty kingdoms or tuaths whose inhabitants appear to have engaged in regular warfare and predation on their neighbours. The earliest surviving Irish written manuscripts date from the 12th Century AD but their contents are thought to be older (O’Kelly, 1989). It is believed that the Ulidian cycle of stories to which the ‘Tain’ belongs, does not reflect Irish society in the 4th Century AD but that of a much earlier time (approximately 1st Century AD). The author of a 9th Century series of geographical triads clearly regarded large woods as unusual in the Ireland of his day (Kelly, 1997). From the Bronze Age until the Middle Ages society remained tribal and rural. Pastoral activities were important and the pattern of settlement was essentially scattered where the predominant settlement form was the independent single farmstead surrounded by a circular earthwork (Aalen, 1978). Fixed fields are evident only in the immediate vicinity of such farmsteads, and thus there is no reason to suppose that extensive areas of landscape were enclosed during this time (Aalen, 1978).

The Irish colonies in western Britain, by way of intermarriage and the seizure or purchase of slaves, were probably the source of the first Christians to come to Ireland in the 5th Century (Mitchell and Ryan, 1997). Christianity spread throughout Ireland in the 5th and 6th Centuries (Stout and Stout, 1997). Monastic sites were often located on islands of relatively good land on the bogs of the Midlands and the place name cluain, so often associated with many of them (Clonfert, Clonard, Clonmacnoise) seems to carry the implication of forest clearance (Mitchell and Ryan, 1997). By the 8th and 9th Centuries monasteries were effectively proto-urban centres (Stout and Stout, 1997). Due to its escape of the Roman imperial occupation, Ireland did not possess an urban system to serve as ecclesiastical centres. Therefore Christianity became an essentially rural organisation relating to rather than modifying the traditionally diffuse pattern of farm settlements (Aalen, 1978). Monasteries became important economically and rapidly became owners of extensive amounts of land. Their economy was dominated by tillage but by the middle of
the 12th Century, with the foundation of many new religious orders from abroad, land management practices changed. The Cistercians (the first continental order to come to Ireland) played a major role in agricultural development which included the creation of internal and external markets for cattle, horses and wool. They also divided the monastic lands into farms and reclaimed a considerable area of wetlands and woodlands (Stout and Stout, 1997). The opening up of the otherwise inhospitable large expanses of the midlands by the monasteries led to direct conflicts between kingdoms of the north and south which lasted for almost four centuries (Mitchell and Ryan, 1997).

Between AD 914 and AD 1014 Ireland suffered at the hands of the Norsemen (Vikings). Monasteries were the chief targets of these Scandinavian pirates who exploited their wealth, ruined their churches and settlements and stole their precious materials (Curtis, 1950; Ryan, 1994a). Credit must be attributed to them however as they were responsible for the first towns in Ireland, the increases in expertise in shipbuilding and an expansion of foreign trade (Ryan, 1994a; Wallace, 1994). Prior to this there had been no urban infrastructure in Ireland (Aalen, 1978). The expansion of agriculture and the heavy demands placed on oak woods led in time to a shortage of timber during this time. Dendrochronological evidence suggests that oak suitable for building was rare in the 8th to 12th Centuries and therefore management of such woods would have been essential (Mitchell and Ryan, 1997). Evidence from dendrochronology suggests that in the later 1st millennium, mature oak had become rare and management of woodlands to produce structural timbers of good size may have become important (Mitchell and Ryan, 1997). Woodland was not uniform throughout the island; Pine was more common in the west and while in the east woodlands consisting of trees such as oak, ash and pine were confined to the river valleys and upland areas. Agriculture in the 11th and 12th Centuries was able to finance extensive church building with Romanesque structural and decorative features (Mitchell and Ryan, 1997). A gradual slight warming in climate and the absence of recorded plagues in the period from the 7th to the 13th Century suggested that the population was rising in line with a steady increase in agricultural production (Mitchell and Ryan, 1997). The first explicit mention in Irish of turf as a fuel is in the early 12th Century (Kelly, 1997).

The introduction of Anglo-Norman farming in Ireland predated the Norman invasion with the consecration of the Cistercian abbey at Mellifont in 1157 (Kelly, 1997). After the military invasion of 1169, Anglo-Norman colonists took over much of the best land in the
country (Ryan, 1994b), particularly in the east (Kelly, 1997). It has been suggested by meteorologists that the Anglo-Normans arrived in Ireland during a phase of very favourable climate but there is nothing about the distribution of their sites to suggest that at that time better drained soils stretched farther to the north west than they do today (Mitchell and Ryan, 1997). Initially they left the great tracts of mountains and wooded areas to the native Irish chiefs but as time went on they took over more and more land and by 1272 the Normans had possession of most of the land in Ireland (Curtis, 1950) but their authority at any time never extended over the whole of the country (Aalen, 1978). The Normans introduced manorial organisation and village settlements to the eastern and southern parts of the country (Aalen, 1978). Castle building came into its own in the period AD 1190 to AD 1310 (Sweetman, 1994). An important innovation of the Normans was the practice of saving hay to supply fodder for livestock during the winter and also an increase in cereal production. The success of Anglo-Norman cereal farming in Ireland is demonstrated by the large amounts of grain which were exported to England and elsewhere, especially during the 13th Century. The Major of London imported 1,000 crannocks of wheat from Ireland in 1224-1225 (Kelly, 1997). Mean annual temperatures were rising during this time to a peak in the 13th Century in England. The establishment of the Anglo-Norman settlers led to considerable reclamation of new land, especially through deforestation (Aalen, 1978). Forest clearance not only provided new land for agriculture but was also undertaken to facilitate safe communication between settled areas (Aalen, 1978). The Welsh correspondent Giraldus Cambrensis who came to Ireland in 1185 reported how Ireland had many woods and marshes and how its land was rich in fertile soil that supported pastures rather than grain crops but how the country suffered from storms of wind and rain (Mitchell and Ryan, 1997). This trade in cereals declined however during the 14th Century due to the unstable political situation in Ireland and the economic difficulties she was experiencing (Stalley, 1994), the devastating effects of the Black Death of 1348 (this bubonic plague reduced the population by almost 30% (Barry, 1994)) and a marked deterioration in climate (Ryan 1994b; Kelly, 1997; Mitchell and Ryan, 1997). The native Irish people escaped the Black Death better than the Anglo-Irish population due to their pastoral economy and rural and diffuse settlement pattern rather than being clustered in towns and manors as the latter were (Curtis, 1950; Aalen, 1978).

This period saw a change in agricultural practices with a shift towards a more pastoral economy (Barry, 1994). This swing away from arable farming seems to be reflected in the vegetational changes recorded by pollen analysis, a typical example being from Littleton
Bog in Co. Tipperary. Here the initial wave of Anglo-Norman expansion in the 12th and 13th Centuries is marked in the pollen record by a decline of woodland and a matching expansion of cereal cultivation. After 1300 cereals declined, grasses and plantain expanded and in placed hazel is thought to have invaded the grasslands (Mitchell, 1965). It has been reported that the Bruce invasion in the early part of the 14th Century left ‘neither wood nor lea nor corn nor crop nor stead nor barn nor church’; instead all were burned to leave a bleak landscape (Mitchell and Ryan, 1997).

From the end of the 14th Century until approximately 1477 the native Irish race recovered almost two thirds of the land back from the English despite the fact that the Anglo-Irish remained in entire possession of the Irish government until 1485 (Curtis, 1950). From this time until 1534 the Earls of Kildare became the real rulers of Ireland. Kildare was removed from power in 1494 by Edward Poyning but this did not last long and by 1496 Home Rule was restored under Kildare (Curtis, 1950). After this period a lot of destruction occurred in the form of wrecking of abbeys and relic burning. In 1537 King Henry was declared the Supreme Head over the Church in Ireland and from this time until 1800 Ireland fluctuated between British and Irish rule (Curtis, 1950). Rebellions by Irish chieftains in the mid 16th Century and later resulted in a revival of the policy of ‘planting’ English settlers, which had already been tried by the Anglo-Norman conquerors (Ryan, 1994c) These settlers brought ploughs and improved breeds of livestock with them which almost definitely raised the standard of farming in the settled regions (Mitchell and Ryan, 1997). The uplands of the Wicklow Mountains was used as a centre from which Irish forces would frequently emerge to harass the farms and towns of the surrounding lowlands (Mitchell and Ryan, 1997).

The Munster Rising of 1579 ended in 1583 and left Munster in a devastated position (Curtis, 1950). At this time pastoral farming predominated the Munster landscape and, after land, wood was the most important resource. The woods of Munster were exploited by the plantation settlers to build houses, ships and in the manufacture of barrel staves. It was particularly used in the iron works industry where large quantities of charcoal were required (Mitchell and Ryan, 1997). Iron was in great demand by the ordnance industry for the manufacture of cannon and cannonballs and since most of the woodland in England had been cleared by the 17th Century, the great woods of Munster were next to go (Power, 1994). The counties of Laois and Offaly, counties which today are almost completely
reclaimed and enclosed, were still well wooded at the time of their plantation in the late 16th Century (Aalen, 1978).

Cromwell came to Ireland in 1649 and by 1655 he had confiscated nine counties from Ireland and left her with twenty six in total (Curtis, 1950). The period 1689 to 1691 saw wars in Ireland which started off with the Siege of Derry and also the Battle of the Boyne in 1690. By the end of the 17th Century the pattern of landholding in Ireland had been radically altered (Ryan, 1994c). After the 1720s a favourable shift in the relative price of cattle gave a boost to livestock farming and encouraged the conversion of some of the traditional tillage lands to pasture (Aalen, 1978). After approximately 1760 the population of Ireland increased and began to use the poorer hill and bog areas for land (Whelan, 1997). In 1782 Ireland entered a period of great prosperity but the more important and wealthy Ireland became the more England wanted to manage her and by 1800 she was under British Rule again (Curtis, 1950). However between 1760 and the 1820’s there was a marked increase in tillage again and the export of both grain and livestock expanded considerably (Whelan, 1997). In the 1830’s there was a reversal to pastoral farming which lasted throughout the 19th Century (Aalen, 1978). Deforestation was the official policy in Ireland during the 17th Century with increasing iron smelting and glass manufacturing industries being introduced (Dunlevy, 1994). This systematic clearing of woodlands was also due to the use of timber for military-strategic reasons (Aalen, 1978). It is estimated that approximately an eighth of Ireland was still covered in woodland in 1600 (McCracken, 1971).

One of the most striking features of the 16th Century was the foundation of new towns in the midlands as part of the English government’s policy of conquering Ireland (Bradley, 1994).

The 17th Century was a period of transition in Ireland; it was medieval in the early part of the century but by the end the modern world was already established in Ireland (MacLysaght, 1979). In the early 1700’s the more remote parts of Ireland were considered barbarous (MacLysaght, 1979). By the end of the 17th Century many houses that were built had elaborate gardens which included the planting of exotic trees not native to Ireland (Fitzpatrick, 1933; MacLysaght, 1979; Mitchell and Ryan, 1997). This can be seen from many pollen diagrams where the introduction of taxa such as *Fagus, Picea, Acer* and *Juglans* occur around this time period (Edwards, 1985). Landowners and their agents also
began to give some attention to the art of forestry which before had not concerned them. The Government too realised its importance and as early as 1654 a regular forestry service was established in Co. Wexford and Co. Wicklow (MacLysaght, 1979). The principle of compulsory planting of trees was introduced in certain cases by the end of the 17th Century (MacLysaght, 1979; Mitchell and Ryan, 1997; Whelan, 1997). In 1735 the Royal Dublin Society began to offer premiums for the planting of trees. This system proved to be effective as by 1800 more than 52,000ha of plantations had been added to what native woods survived (Mitchell and Ryan, 1997). Timber at this time was mainly used for fuel for iron-works, fences, shelter, housing, shipping, hoops, casks and ornament (MacLysaght, 1979). The 18th Century and the first two decades of the 19th Century was a time of general economic growth in which a variety of manufacturing enterprises existed (Aalen, 1978) and a system of roads and canals were set up. The most ambitious project undertaken was that of the construction of the Military Road built through the heart of the Wicklow Mountains after the 1798 rebellion to facilitate easy movement of troops in an area which before had been relatively inaccessible (Aalen, 1978).

Little of the ground of the vast woods that were devastated by the end of the Cromwellian campaigns occupied was reclaimed for agriculture. Agricultural production in Ireland has always consisted mainly of livestock (MacLysaght, 1979; Mitchell and Ryan, 1997). Comparatively little hay was made as the mild Irish winters allowed the wintering of stock on the land eating withered grass left ungrazed and uncut during the summer (MacLysaght, 1979). Tillage was not extensive. Sometimes attempts were made to add a temporary fertility to the land that was intended for corn crops (such as oats) by burning the surface sod but the after effects of this practice of ‘bettimore’ were very deleterious and it was widely condemned by all progressive farmers (MacLysaght, 1979).

The Irish economy remained relatively buoyant until the end of the Napoleonic wars in 1815 but the remainder of the 19th Century was characterised by economic decline (Aalen, 1978). Potatoes were the staple food in Ireland by 1657 (MacLysaght, 1979) and people lived on them all year round. By the 1830s the population of Ireland was close to 9 million people (Whelan, 1997). The use of the potato permitted an expansion of population into boggy and hilly land which had been previously uncultivated. It yielded nourishing food from land which was of little value for alternative uses and therefore extended the ecological range of Irish rural society and especially of the poorer elements within it (Aalen, 1978). The rural and remote areas in the west of Ireland were most dependent on
the lumber potato while those in the east were least dependent (Whelan, 1997). The year 1845 saw the Great Famine in Ireland when the land was intensely cultivated for potatoes and wheat and other crops for export. The repeal of the Corn Laws which permitted the free entry of cheap corn into Ireland from abroad was a blow to Irish tillage and saw most of the tillage land go into pasture (Curtis, 1950). The great blight occurred in 1846 and between 1845 and 1851 approximately 800,000 people died due to starvation and its aftermath of disease (Aalen, 1978) and twice as many emigrated. Emigration was not really an issue in the western parts of Ireland after the Famine; there was no post-Famine decline in total population until towards the end of the 19th Century and population growth continued in many western areas, including the most congested and depressed seaboard regions until the 1880's (Aalen, 1978). However once emigration was initiated in the west at the end of the 19th Century, the trend of decline was very severe and sustained. The population pressure in the 18th and 19th Centuries led to the intensified use of peat as a resource and to the reclamation of ‘cut away’ bog for agricultural purposes (Aalen, 1978). Lead and zinc mines in the Wicklow Glens, especially Glendalough, Glandasan and Glenmalure were worked sporadically during the 19th Century but all activity has now ceased (Aalen, 1978).

After the famine, programmes for tree planting were abruptly terminated as landlords were no longer able to afford new plantations of trees on the scale that had existed before the famine (Mitchell and Ryan, 1997). In the mid 1870's bad weather brought crop failures on a massive scale (Mitchell and Ryan, 1997). Between 1850 and 1900 timber was used as a source of cash where many landlords sold their stands of timber to travelling sawmillers who came over from England and moved across the country from estate to estate. The woods that survived this destruction vanished during World War I when over 80,000ha of woodland were felled and left less than 0.5% of Ireland covered by forest (Mitchell and Ryan, 1997).

A network of railways was built in Ireland from the 1830s onwards (Aalen, 1978).

The major part of the Irish road system was completed by the mid 19th Century but the first roads to ever penetrate the remote peninsulas of the western seaboard i.e. in Kerry, were built as late as the 19th Century (Aalen, 1978). The area of farmed land was expanded considerably and its productive capacity much enhanced in the later 18th and early 19th Centuries as new ideas of agricultural improvement were implemented (Aalen, 1978). The
absence of a dynamic economy in the 19th Century has spared most of the country from the impact of the industrial revolution and its associated clutter (Aalen, 1978).

The first decade of the 20th Century in rural Ireland was not unlike that of 250 years ago where old farm machinery was used such as the swing plough, scythe and sickle (MacLysaght, 1979). The light density of population in Ireland is mainly due to the absence of large-scale industrialisation and the pastoral emphasis of Irish farming, with an extensive rather than intensive use of land (Aalen, 1978). In 1903 the first steps were made to restore substantial areas of woodland in Ireland at a national level (Mitchell and Ryan, 1997).

The use of peat as a fuel on an industrial scale had already attracted attention by the middle of the 19th Century and 100 years later the use of peat as a fuel was exploited fully. World War II created a demand on agricultural products and again various trees, woodlands and plantations were felled (Mitchell and Ryan, 1997).

Probably the most recent adversity that has occurred in Ireland is that of the Economic War with Great Britain from 1932 to 1938. The mid 1930's were characterised by a major decline in agriculture but this was then followed in the 1940's by a distinct recovery especially in arable farming practices (Huang and O'Connell, 1991).

A marked increase in the degree of human interference with the environment caused a large scale depletion of the natural vegetation cover in order to provide open areas for cultivation and livestock grazing. In such circumstances it becomes more difficult to distinguish or disentangle climatic causes from human interventions (Aalen, 1978). About 70% of the farmed area in Ireland is at present devoted to permanent pasture. Hay occupies a further sixth of the farmed land and the remainder is devoted to a variety of crops, mainly cereals, potatoes and sugar beet (Aalen, 1978).

1.6 Aims of the Project

The primary aim of this project is to provide a high resolution multi-proxy record of climate and its environmental impact over the last 1,200 years in Ireland. Meeting this aim will also provide data on human impact over this period. Literature concerning recent climate change will be reviewed to investigate if the changes resulting from climate
documented correspond with any changes found in the profiles from the sites examined. Three sites will be investigated in the east (Wicklow), midlands (Offaly) and south west (Kerry) of Ireland to provide an east-west transect across the country along the greatest climatic gradient of increasing precipitation. It is hoped that this investigation will help bridge the gap between the modern meteorological record and the long term record of traditional palaeoclimatology.

The east of Ireland was chosen as the first area of investigation. A number of palaeoecological investigations exist from this area of Ireland. As already stated, many do not have the temporal resolution capable of discerning climate change of 100 to 200 years duration – Bradshaw and McGee (1988) carried out research in Arts Lough, Co. Wicklow where the resolution at the top of the pollen diagram was poor (in the context of climate detection) with approximately 230 years between the top samples analysed. Research by Van Geel and Middeldorp (1988) in Co. Kildare covered the last 850 years. The resolution was very good for this site but the results obtained based on $\delta^{18}O$ ratios appeared to be negatively correlated with the Little Ice Age and Medieval Warm Period (Van Geel and Middeldorp, 1988). The midlands were chosen as the second area of investigation traversing the country across its climatic gradient of increasing precipitation. Again, similar to the east of Ireland, palaeoecological studies from this area are concerned with the entire Holocene and do not provide the resolution necessary for elucidation of climatic events of the last 1,200 years (O’Connell, 1980; Heery, 1998; Connolly, 1999). To complete the transect across Ireland of increasing wetness the final site was chosen from the south west in Kerry. This site lies just 10km from the south west coast of Ireland and so is ideally positioned at the edge of the Atlantic Ocean on the extreme west of the PEP III transect. This means that this site should be most subject to sea surface temperature changes of the North Atlantic out of all three sites investigated. Studies from this area of Ireland are mainly concentrated in Killarney and again deal with the entire Holocene or do not pay particular attention to climatic events of the recent past.

A multidisciplinary approach will be taken to investigate the climate and its environmental impact over the last 1,200 years in Ireland. Various proxy methods will be used in order to reconstruct the climatic and vegetational history of Ireland during this time period. These include pollen analysis, fungal spore and testate amoebae analysis, charcoal analysis, tephra analysis and loss on ignition. These investigations will be carried out on the top metre of sediment extracted from each of the three peatland sites.
1.6.1 Why use Peat Bogs and Particular Methods?

Peats and soils can be regarded as mirrors of past conditions and changes in the immediate environment and surrounding land (Bengtsson and Enell, 1986). Peat bogs have been used as a source of proxy climatic information since the last century and, despite the hazards in interpretation, their use as sinks of palaeoclimatic information is widespread. Bogs contain a valuable archive of past climates. Lake sediments were thought to be unsuitable for this type of investigation as their most recently deposited sediments contain lots of inwashed material and undergo significant remixing which would not provide a reliable and true record of recent climatic and environmental changes.

Pollen analytical data from peat provide information relevant to the reconstruction of past vegetation. As contemporary vegetation is related in a broad manner to present day climate, pollen analysis can provide indirect information relevant to the reconstruction of past climates over specific time spans (Birks, 1979). Pollen is unusually well preserved in the anaerobic conditions of peat bogs. As the bogs themselves grow upwards naturally through continued surface accumulation of only partially decayed bog moss and other organic material, the older bogs incorporate a record of vegetational changes in the surrounding areas.

Both fungal spores and testate amoebae (Protozoa: Rhizopoda) inhabit the surface layers of peatlands (Woodland et al., 1998) and have distinctive features which facilitates their identification (Tolonen, 1986b). They are habitat specific with a strong relationship of many species to precise ecological conditions especially substrate wetness. Therefore the analysis of many of these sub-fossils can be used to derive an index of palaeohydrological changes in peatlands (Charman, 1992; Warner and Charman, 1994; Hendon and Charman, 1997).

The analysis of charcoal from a sediment provides a record of fire history from its catchment area. When charcoal analysis is employed with fine-resolution pollen analysis, it can aid in providing a greater understanding in the estimation of the interactions between vegetation, climate and human disturbances over the last few thousand years (Patterson et al., 1984; Williams et al., 1993).
Tephra analysis deals with air-fall volcanic particles which have been ejected during a volcanic eruption. Tephra form widespread chronostratigraphic marker horizons which have proved very important in terms of dating because of their distinctive characteristics and rapid deposition over large areas (Dugmore et al., 1995) and hence can be used as a valuable dating tool (Hunt and Hill, 1993).

Loss on ignition analysis results in an estimate of the percentage of organic matter present in a sediment (Grimshaw, 1989). Such analysis has proved valuable in detecting disturbances that may have occurred in the catchment area and also may provide information on the accumulation process of a particular sediment (Aaby, 1986).
II Description of Sites

2.1 Liffey Head Bog, Co. Wicklow

Liffey Head Bog (Irish Grid Reference O 142 134; 06° 17’W 53° 09’N) is situated in the Wicklow Mountains, 25km south west of Dublin city and 15km from the east coast of Ireland (see Figure 2.1). It has an altitude range of a mere 30m, lying between 490m and 520m above sea level. It covers an area of approximately 1,700ha (IPCC, 1992). The source of the river Liffey lies within the bog (Figure 2.2). Three other rivers also rise in this area – the rivers Cloghoge (Annamoe), Gleencree and Dargle (Ryan, 1992).

Liffey Head Bog lies on the Caledonian Leinster batholith. This batholith consists of calc-alkaline granites and is Cambrian to Silurian in age.

Precipitation is high at Liffey Head Bog with a mean annual rainfall for this area of the Wicklow mountains amounting to between 1,200mm and 1,600mm (Meteorological Service, 1980b). The mean daily temperature of the warmest month (July) is 15.0°C and the coldest month (January) 5.5°C (Meteorological Service, 1980a).

Liffey Head Bog is an example of a montane-type blanket bog (Hammond, 1981) and is characterised by a series of pool complexes on relatively flat bogland. Such a bog is termed ombrogenous, where the only source of nutrients to the bog is due to aerial input. Blanket bog development in general is controlled by precipitation and is not confined by topography. It is not an intact bog however. The periphery of the bog exhibits signs of disturbance from peat cutting.

This upland blanket bog has been rated as an area of scientific interest (ASI) of international significance for its botanical, ecological and zoological importance (Ryan, 1992). It has been declared a National Nature Reserve (NNR) (IPCC, 1992) and has been designated as an Area of Scientific Interest (ASI), a proposed Special Area of Conservation (pSAC) and a Special Protection Area (SPA) (Foss and O’Connell, 1996). It is also a National Heritage Area within the Wicklow Mountains National Park. The bog is owned by the National Parks and Wildlife Service and by multiple private owners.
Figure 2.1 The island of Ireland showing the location of the three sites under investigation.
As stated earlier, bog pools are a common feature of Liffey Head Bog and are dotted throughout the relatively flat and even surface of the bog (Conboy, 1991) (Plate 2.1). Their depth varies from 1 or 2 cm to 2 m. There are no trees either on the site or in the immediate locality – the vegetation mainly consists of typical blanket bog taxa such as Cyperaceae, *Sphagnum* and Ericaceous species including *Calluna vulgaris*. Typical fauna on the bog include sheep, sika deer and grouse.

Conboy (1991) investigated the cause/s of blanket bog initiation at this site. Using pollen analysis he concluded that blanket bog initiation here appears to have been primarily caused by a deterioration in the regional climate – bog formation occurring as part of a natural, climatically determined process. Mitchell and Conboy (1993) suggest this initiation occurred approximately 8,000 years BP.

The interception of small particles such as pollutants, tephra and microscopic charcoal in cloud water onto Liffey Head Bog can occur without the need for precipitation due to its high altitude.

Bowler and Bradshaw (1985) and McGee and Bradshaw (1990) report on extensive erosion occurring in blanket peat throughout Co. Wicklow at altitudes above 500 m. At Liffey Head Bog, however, no obvious signs of erosion were found. This excludes the occurrence of bog bursts and erosion at the head waters of the streams present (Ryan, 1992). In 1984 major turf extractions occurred at Liffey Head Bog. However, it is assumed that little, if any, turf cutting occurred on the site prior to the advent of the Military road in approximately 1800 (Ryan, 1992).

### 2.2 All Saint’s Bog, Co. Offaly

All Saint’s Bog (Irish Grid Reference N 012 113; 07° 59’ W 53° 09’ N), also known as Little Newtown Bog, is situated approximately 8 km north west of Birr in Co. Offaly (see Figure 2.1). It lies north east of the Little Brosna Callows from which it is separated by an esker ridge (Figure 2.3). The Rapemills river forms the northern boundary of the bog (Cross et al., 1991). The bog lies at an altitude of 40 to 45 m above sea level.

The midlands of Ireland has developed upon gently folded Lower Carboniferous strata (mainly limestone) which in places are broken by minor hills of sediments and volcanics of
Plate 2.1 A surface view of Liffey Head Bog. Note the presence of typical bog flora such as *Eriophorum vaginatum* and the large pool of open water in the foreground; these open pool systems are a characteristic feature of Liffey Head Bog.
Figure 2.3 Map showing position of study site, All Saint’s Bog. The ‘★’ indicates the position from where the monoliths were extracted. (1:50,000 Ordnance Survey Map, Discovery Series, 53)
Ordovician and Silurian age, together with old red sandstone (Cross & Dwyer, 1991). These are mostly covered by glacial drift of Midlandian age.

The climate of the Midlands is quite mild with an average rainfall of approximately 820mm yr\(^{-1}\). The mean daily temperature of the warmest month (July) is 15.5°C and the coldest month (January) 4.4°C (Meteorological Service, 1980a).

All Saint’s Bog is an example of a relatively intact midlands raised bog, of approximately 345ha in area. An estimated 29% of this is cut away - mostly on the north east edge by Erin Peat products and private owners. Almost half the area of the intact part of the bog (112ha) is owned by the National Parks and Wildlife Service. It was purchased from Bord na Mona in 1991 for conservation which was, in part, funded by the European Union (Foss and O’Connell, 1996). It has been designated as a National Nature Reserve (O’Brien, 1997), a Natural Heritage Area (NHA) and also a proposed Special Area of Conservation (pSAC) (Foss and O’Connell, 1996). The bog is an important habitat for Greenland white-fronted geese which congregate on the adjacent callows in winter.

A most interesting feature of All Saint’s Bog is the pine and birch woodland (of approximately 20ha in area) which grows in the centre of the intact area in an irregular band (Cross, 1987) (Plate 2.2). It exhibits a unique insect fauna indicative of ancient woodlands (Foss and O’Connell, 1996). Underneath this area of the bog and woodland lies a mineral ridge which forms part of an unusual topographic bog floor (Cross et al., 1991). The bog exhibits two principal vegetation types:

1. ombrotrophic bog vegetation which contains typical plants of raised bog communities
2. flushed areas

Nutrient flushes are common on the bog due to upwelling of groundwater on the bog surface. The complexities of bog hydrology are insufficiently understood to explain this phenomenon.

2.3 Ballygisheen Bog, Co Kerry

Ballygisheen Bog (Irish Grid Reference V 695 814; 09° 54’W 51° 58’N) is situated within the Macgillycuddy’s Reeks mountain range approximately 10km south east of Glenbeigh
Plate 2.2 A south west view of the pine/birch wood on All Saint’s Bog. Note the typical hummock and hollow topography of the open bog surface in the foreground.
and 16km south west of Killorglin in Co. Kerry (see Figure 2.1). The bog lies at an altitude of approximately 150m above sea level.

This area lies on Old Red Sandstone (Rayner, 1981; Aalen, 1997) approximately 10km from the south west coast of Ireland.

Ballygisheen Bog receives one of the highest amounts of rainfall per year in Ireland with a mean annual rainfall for this area in excess of 2000mm (Meteorological Service, 1980b). The mean daily temperature of the warmest month (July) is 15.5°C and the coldest month (January) 6°C (Meteorological Service, 1980a).

Ballygisheen Bog is one of the most extensive areas of relatively intact lowland blanket bog remaining in Co. Kerry. It covers an area of almost 565ha (Foss and O'Connell, 1996) some of which is owned by Coillte. This blanket bog lies within a broad valley and is sheltered on all sides (except the north east) by a 'horseshoe' shaped ridge of mountains which includes Knocknacusha (594m) and Knocknagapple (454m) (see Figure 2.4). The eastern side of the bog is bordered by a 20 year old sitka spruce plantation which is owned by Coillte (Maurice Lynch, pers. comm.) (see Plate 2.3). This plantation covers approximately 13% of the area of the bog. Tributaries of the River Caragh flow through the bogland area.

Ballygisheen Bog has been rated as an Area of Scientific Interest (ASI), a Natural Heritage Area (NHA) and has been proposed as a Special Area of Conservation (pSAC) (Foss and O'Connell, 1996). It has been damaged by afforestation (Foss and O'Connell, 1996) and by grazing of sheep and, to a lesser extent, cattle. Both machine and hand-cutting of turf has taken place on the bog during the past.

Despite the damage that has occured to Ballygisheen Bog, it remains one of the largest and least disturbed areas of lowland blanket bog in the county. The vegetation consists mainly of conventional bog taxa such as Calluna, Erica tetralix and Sphagnum. However the bog itself is characterised by several tussocky Schoenus-dominated interconnecting pool systems featuring Racomitrium and Sphagnum capped hummocks and pools containing Drosera intermedia and Menyanthes sp.. The floristic diversity of the site is increased by the occurrence of stream channels within it. The vegetation of Ballygisheen Bog has been affected by periodic fires in the past.
Figure 2.4 Map showing position of study site, Ballygisheen Bog. The ‘★’ indicates the position from where the monoliths were extracted. (1:50,000 Ordnance Survey Map, Discovery Series, 78)
Plate 2.3 A view of the Sitka Spruce Coillte plantation that borders the eastern edge of Ballygisheen Bog. Note the Macgillycuddy Reeks in the background and the typical bog flora and open water pool in the foreground.
III Analysis Methods

3.1 Introduction

The nature of this investigation necessitates a multiproxy approach; the description and justification of each method used are detailed in this chapter.

3.2 Monolith Collection

On both October 18 1995 and January 17 1996 a monolith was extracted from the open surface of a slightly raised area of Liffey Head Bog. It was decided to take the monolith from close to the centre of the bog, away from the edge as, according to Barber et al. (1994), this minimises complications arising from marginal drainage changes resulting from either natural (bogbursts) or human (peat cutting) activity. (This method was used for all three sites under investigation). A 97cm monolith was extracted using a Wardenaar corer on October 18 1995 and a 100cm monolith on January 17 1996 (Wardenaar, 1987). The monoliths were wrapped in cling film and aluminum foil (to prevent desiccation) and indelibly labelled which included an indication of the site, boring location, date of collection, depth and which end was uppermost in the stratigraphic sequence. Care was taken during this procedure to minimise contamination and to ensure that the monoliths retained their form. The monoliths were stored in a coldroom at 4°C to inhibit oxidation and microbial degradation.

On June 26 1996 two monoliths were extracted from All Saint’s Bog, Co. Offaly equidistant from the bog edge and the birch wood on the callows/west side using a Wardenaar corer (Wardenaar, 1987). The two monoliths were taken 14cm apart and were 103cm and 95cm respectively. The same procedure as described in the previous paragraph regarding the wrapping and storage of monoliths was followed.

On August 11 1997 three monolith cores were extracted from a raised area of Ballygisheen Bog, Co. Kerry using a Wardenaar corer (Wardenaar, 1987). The three monoliths were taken from within a one metre square quadrat and were 81cm, 107cm and 106cm in depth respectively. The same procedure as described in the first paragraph regarding the wrapping and storage of monoliths was followed.
The bog flora surrounding each of the coring site was recorded and is detailed in Appendix I.

3.3 Sediment Description

The composition and structure of each monolith (from the three sites under investigation) was described using the Troels-Smith system of sediment description and classification (Troels-Smith, 1955). This was carried out with the aid of a Cambridge Instruments (Model Z30 E) binocular stereomicroscope in order to examine the peat structure more closely. This objective system for sediment classification recognises that most sediments have a mixture of properties and gives an immediate impression of the nature of the deposit. It may also yield useful information regarding the environment and conditions in which the sediment was originally formed which can be important when interpreting microfossil data (Birks and Birks, 1980).

The above system recognises three key factors of the sediment which are thought to be important –

1. Physical properties (colour, dryness, stratification and elasticity),
2. Humicity (degree of decomposition of the organic component) and
3. Composition (the constituents of the sediment i.e. whether it is lake mud, Sphagnum peat, silt etc.)

The physical and compositional properties are described using symbols and a five point scale (0-4) for degree or abundance, the latter of which is defined as follows-

0 = absence of
1 = up to 25% of
2 = from 25% to 50%
3 = from 50% to 75%
4 = maximum or sole presence of
+ = trace, less than 12.5%

Five categories of physical features are described which include nigror (the degree of darkness), stratificatio (the degree of stratification), elasticitas (the degree of elasticity), siccitas (the degree of dryness) and limes (the nature of the boundaries between adjoining sediment types). Humicity, which is the degree of decomposition of the organic material into humic acid, is estimated by squeezing the sediment and recording the colour of the resultant solution.
The compositional features of the sediments are characterised into six basic groups – *turfa* (mainly underground parts of plants and plant parts connected to the root system), *Detritus* (above ground parts of plants not directly attached to the roots), *Limus* (aquatic mud), *Argilla* (mineral particles <0.06mm in size), *Grana* (mineral particles >0.06mm in size) and *Substantia humosa* (humous substance). These basic groups can be sub-divided as necessary and their proportions estimated using the five point scale (0-4), where traces of elements are denoted by using a plus sign (+).

The Troels-Smith system also makes allowances for ‘accessory elements’, such as charcoal, which may occur rarely in the sediment and so are estimated separately to the total of the main components.

Detailed descriptions of the above main categories listed, their sub-divisions (where applicable) and accessory elements can be found in Troels-Smith (1955) and Birks and Birks (1980).

### 3.4 Loss on Ignition

Loss on ignition analysis estimates the percentage of organic matter in a sediment. All peat sediments contain a proportion on minerogenic matter but over 90% of it consists of organic matter. Loss on ignition is not a true measure of organic matter however as, at the temperatures that ashing occurs, some bound water is lost from the clay particles and is included in the overall loss (Grimshaw, 1989). This error is more serious for soils where the organic content is low.

Establishment of the percentage of organic material by loss on ignition can be used for a variety of inferences. Such analysis can be important in detecting disturbances that may have occurred within the catchment area which may in turn be indicative of anthropogenic activity around the site of investigation (Aaby, 1986). It can be used to determine the soil-peat boundary in a profile and provide information on the accumulation process of the sediment. Fluctuations observed in the values of the loss on ignition profile may be indicative of disturbances to the profile (Dwyer, 1995).

Loss on ignition profiles were constructed for each of the three sites investigated to determine the percentage of organic material in the sediment. Determination of the
percentage organic content of the sediments involved an adaptation of the standard method as detailed in Grimshaw (1989) and is as follows –

1. A monolith from each site was sub-sampled at 1cm intervals and a volume of wet sediment from each sub-sample was added to a weighed, indelibly labelled dry porcelain crucible. The weight of the crucible and the wet sediment was recorded and the wet sample weight was calculated.

2. The samples were dried in an air-circulation oven at 80°C until a constant dry weight was achieved for each sample.

3. The samples were transferred into a desiccator (to prevent moisture absorption of the samples from the air) and left to cool to room temperature. They were then weighed and the sample dry weights were calculated.

4. The samples were placed in a muffle furnace and the temperature was raised gradually from 150°C to 550°C under the following regime –
   
   1 hour @ 150°C
   30 min @ 180°C
   30 min @ 200°C
   30 min @ 220°C
   30 min @ 240°C
   1 hour @ 300°C
   5 hours @ 550°C.

5. The samples were transferred to a desiccator and left to cool to room temperature. They were then weighed and the ignited sample weights were calculated.

6. The percentage loss on ignition was calculated for each sample using the following equation –

\[
\%\text{LOI} = \frac{\text{oven dry wgt (g)} - \text{ignited wgt (g)}}{\text{oven dry wgt (g)}} \times 100
\]

A gradual increasing temperature regime was used so as to prevent ash losses by violent burning of the samples which can occur if the sediments have a high organic component. It has been reported that at temperatures above 500°C losses of volatile minerals may occur but at lower temperatures there is a risk of incomplete combustion occurring (Grimshaw, 1989). Therefore a temperature of 550°C was chosen as being a satisfactory temperature to carry out loss on ignition under to receive satisfactory results.
3.5 Tephrochronology

Tephra is a collective term used to describe all air borne pyroclastic materials which have been ejected during a volcanic eruption. Tephrochronological investigations deal with these air-fall volcanic particles which range in size from several microns upwards. The whole basis behind the study of tephra are the presumptions that a tephra horizon is deposited instantaneously (in geological terms) and has a unique geochemical signature (Hunt and Hill, 1993). Its presence therefore characterises an isochrone or plane of equal age in any deposit in which it is found (Hall et al., 1994c; Bradley, 1999). Dugmore et al. (1992) reports how tephra shards can retain their overall chemical integrity on at least a four millennial time-scale independent of its depositional environment. Because of these attributes it can be used as a dating tool as the tephra from each eruption has a specific chemical composition and once a specific tephra has been traced down to a specific eruption, comparisons can be made between other tephra chemical compositions to find out which eruption and date it came from. Although the assumption that each tephra horizon has a unique geochemical configuration holds, compositional changes can occur during the course of an eruption. However most tephra layers exhibit very small, if any, differences between discrete horizons where the layers themselves are typically uniquely characterised by their major and minor element composition (Hunt and Hill, 1993). Dates obtained from tephra findings are often of higher precision than radiocarbon dates, especially for the last 500 years where the error associated with radiocarbon dates is often quite large. Tephrochronology therefore forms part of the suite of Quaternary dating techniques even in areas far removed from the site of volcanic activity. In combination with its use in dating, the technique provides further opportunities to evaluate the impact, if any, of large volcanic events on the vegetation on the Holocene (Bennett et al., 1992; Blackford et al., 1992; Grattan and Charman, 1994; Hall et al., 1994a). Tephra layers have the potential to be valuable for accurate correlation between replicate cores from a single site.

The first findings of Icelandic tephra in the British Isles were from peats in Caithness in northern Scotland (Dugmore, 1989). During the last 11 centuries in Iceland at least 24 eruptions have produced silicic tephra. The volumes produced by these eruptions vary by nearly five orders of magnitude and although some have been carried overseas to northwest Europe, most are unlikely to travel as far due to their small volume and the wind direction at the time of the eruption (Larsen et al., 1999). A considerable patchiness of distributions may result producing significant geographical variability of Icelandic tephra depositions in
the British Isles (Dugmore *et al.* 1995) indicating that it is not advisable to rely on any one site for a definite tephrochronology of a given geographical region. Over 20 Holocene tephras from Icelandic eruptions are known to have been deposited in northwest Europe but not all have been attributed to specific eruptions (Dugmore *et al.*, 1996). A considerable amount of tephra research has been carried out in Ireland (Dwyer, 1995; Dwyer and Mitchell 1997) and in particular in Northern Ireland (Pilcher and Hall, 1992; Hall *et al.*, 1993; Hall *et al.*, 1994a; Hall *et al.*, 1994b; Hall *et al.*, 1994c; Pilcher *et al.*, 1995; Pilcher *et al.*, 1996; Hall, 1998).

Edwards *et al.*, (1994) found that a distinct change in the pollen assemblage from sediment in Hellisbjarg, Papey in Iceland occurred coincident with the tephra horizon of Hekla in 1766. Here Cyperaceae values decreased and *Salix* and Gramineae pollen increased in abundance directly after the tephra deposition. It has been suggested that the correlation between ash-fall and vegetation change could be an alteration to the nutrient status of the soil where the tephra ash may have promoted increased drainage, thereby favouring Gramineae over Cyperaceae (Edwards *et al.*, 1994). However a change in land use could also have caused such a change in the pollen record. Edwards *et al.*, (1994) not only investigated tephra layers deposited in Iceland but also looked at Icelandic tephra deposited in two sites in Scotland. At Altnabreac at Caithness they found that the pine decline that occurred approximately 4,000BP (as seen in many British and Irish pollen diagrams) occurred at the same stratigraphic position as that of the deposition of Helka 4 and suggests that both may be in some way connected e.g. the eruption of Helka 4 may have caused a climatic change of sufficient magnitude to alter the hydrological conditions of Altnabreac. The second site investigated was Keith’s Peat Bank at Orkney and from their findings they concluded that if the tephra found at this site had any impact, that it was indistinguishable from the variability already present in the pollen data.

Contrary to evidence found in Northern Scotland (Blackford *et al.*, 1992; Edwards *et al.*, 1994), investigations carried out by Hall *et al.* (1994a) on two raised bogs in the north of Ireland concluded that there was no temporal link between the decline in pine pollen and tephra deposited from Hekla 4. The vegetation in this area of the north of Ireland was unaffected by this eruption. Hall *et al.* (1994a) suggest however that climatic deterioration or effects of volcanic activity in the aftermath of the eruption of Helka 4 may only have been restricted to the north of Scotland supporting the hypotheses put forward by Edwards *et al.* (1994). Results from Dwyer (1995) and Dwyer and Mitchell (1997) are consistent
with investigations in Northern Ireland which suggest that there was no appreciable landscape changes at the time of Helka 4 deposition (Hall et al., 1994a).

Dendroclimatological investigations suggest that a deterioration in climate can follow large scale volcanic activity. La Marche and Hirschboeck (1984) and Baillie and Munro (1988) propose the possible existence between major volcanic dust veils and frost damaged or extremely narrow bands of tree-rings in subfossil and modern wood from both hardwoods and softwoods collected over wide areas of the USA and the British Isles. Several extremely narrow bands of tree-rings found in oak trees from Northern Ireland have been suggested to correspond to dates of major volcanic eruptions. One set of these narrow tree-rings found is thought to have occurred as a result of the eruption of the Aegean island of Santorini in c.1628 BC (Baillie and Munro, 1988).

3.5.1 Tephra Detection

None of the tephra layers found in terrestrial deposits throughout the British Isles have been visible to the naked eye (Pilcher and Hall, 1996). Hence analysis on the presence of tephra was carried out on ignited samples from the three sites under investigation. The method used to detect tephra layers was that described by Pilcher and Hall (1992) which involves combustion of peat samples. Each monolith sediment was first sampled in vertical 5cm block intervals and the organic matter was burnt off. Each sample then underwent several washes in acid and water and a sieving stage as detailed below. They were mounted and examined microscopically. If tephra was detected within a 5cm block, closer sampling was carried out in order to pinpoint the layer to within 1cm. If present the abundance and general morphology of the tephra particles were recorded.

1. Contiguous 3x3cm cross section x5cm vertical blocks of peat were taken the length of one monolith from each site investigated. They were dried in indelibly labelled crucibles overnight in an oven at 80°C and subsequently ignited in a furnace for 5hrs at 550°C to remove any organic material present (same burning method as described in Section 3.4). The temperature was not raised above 550°C as higher temperatures may cause the edges of the tephra shards to melt, rendering identification difficult.

2. The burnt ash was allowed to cool and was removed from the crucibles into indelibly labelled 10ml centrifuge tubes using 25% HCl solution. Approximately 10ml of 25% HCl was added to each tube, were placed standing in a water-bath (approximately
70°C) for 5 minutes and were stirred at regular intervals with glass rods. The tubes were centrifuged at 5,000 r.p.m. for 10 minutes, decanted and the supernatant was discarded. This step involving HCl is carried out in order to dissolve the soluble ash fraction of the peat samples.

3. The samples were washed using cold 25% HCl solution. The tubes were centrifuged at 5,000 r.p.m. for ten minutes, decanted and the supernatant was discarded.

4. The samples were washed twice with distilled water. Again they were centrifuged at 5,000 r.p.m. for 10 minutes, decanted and the supernatant was discarded.

5. The samples were sieved through a 22.4μm sieve in order to improve sample clarity using copious amounts of distilled water. If the samples appeared cloudy, they were subsequently sieved through a 10μm sieve to remove the fine fraction of the inorganic matrix.

6. The residues left on the sieves were returned to the 10ml centrifuge tubes and washed with distilled water. The tubes were centrifuged at 5,000 r.p.m. for 10 minutes, decanted and the supernatant was discarded.

7. The remaining ash was transferred into indelibly labelled glass vials using clean pasteur pipettes. 2-3 drops of absolute alcohol were added to each vial to prevent fungal growth.

8. The ash was allowed to settle overnight. After the settling period some ash was transferred from the vials onto labelled microscope slides using pasteur pipettes. The drying process was accelerated by placing the slides on a warming plate.

9. When the water had evaporated from the slides, a drop of DPX mountant was placed on the ash, covered with a coverslip and allowed to set. DPX mountant is used in this procedure as it is permanent, colourless and has a high refractive index (Rawlins, 1992) which aids in the detection of tephra.

10. The samples were examined microscopically for the presence of tephra.

An Olympus BX 40 binocular microscope at x400 magnification was used to examine the prepared slides. Plane polarised light was also used to aid in distinguishing between tephra shards and other mineral matter. The general morphological description of shards was recorded. If tephra was found in a 3x3x5cm block the process was repeated with 3x3cm cross section x1cm vertical samples taken from the same depth in the monolith in order to pinpoint the exact depth of the tephra layer.
3.5.2 Tephra Extraction

Once tephra layers have been located microscopically, they have to be extracted and prepared for energy dispersive microanalysis with the electron microprobe. Unfortunately the above method outlined for tephra detection cannot be used for the extraction of tephra as the high temperatures at which the ashing process occurs (Section 3.5) has the ability to disrupt/alter the geochemical composition of the tephra shards, principally by the addition of excess potassium (Pilcher and Hall, 1992). Therefore a separate method is employed to extract the tephra. The method used in this investigation follows the variation of the wet oxidation technique described by Dugmore (1989) as detailed in Dwyer (1995). This process entails a combination of concentrated sulphuric acid and nitric acid which is used to oxidise the organic content of the peat to produce a clear sample of volcanic glass. This extraction technique does not alter the mass or particle-size distribution of tephra shards (Dugmore et al., 1995) or their geochemical signal (Dugmore, 1991). Once the tephra is extracted it is mounted in a resin and then highly polished.

1. The blocks of peat of 1cm thickness from where tephra layers were found were placed in 1L round bottomed flasks.
2. The flasks were placed on a warm hot plate (Mark 5) and conc. sulphuric acid was added slowly until the peat was suspended in the acid.
3. Conc. nitric acid was added very slowly to the mixture until a reaction was observed where orange fumes of nitrous oxide were evolved, and then a glass funnel was placed into the neck of the flask. The mixture was allowed to react on the hot plate until the nitrous oxide had ceased evolving and white fumes were emitted. The flask was then removed from the heat source and allowed to cool.
4. Once cool, more conc. nitric acid was added (again, very carefully) and the flask was placed back on the hot plate. The flasks were swirled regularly to ensure that no undigested material adhered to the walls of the flask (the adherence of undigested material was minimised by the type of flask used – the round bottomed flask together with the glass funnel provided a chamber which allowed maximum circulation of fumes which in turn caused condensation to run down the sides of the flask washing any undigested material adhered to the walls back into the reaction mixture).
5. This whole procedure was repeated several times until the mixture had changed from its dark brown colour to a transparent yellow/clear liquid. At this point the organic
fraction had been digested from the mixture. The length of time that this whole process took varied considerably between samples but on average took 1.5 to 3 hours.

6. Once a transparent yellow/clear liquid was obtained, the flasks were removed from the heat source and left to cool down completely. The mixture was then carefully diluted in 2-3 litres of distilled water. The solution was sieved through a 22.4μm mesh and washed well with distilled water as any sulphuric acid left adhering to the tephra particles can cause problems and obscure later analysis with EDMA (Valerie Hall, per. comm.).

7. The tephra residue on the sieve was transferred into a 10ml centrifuge tube and centrifuged at 3,500 r.p.m for 10 minutes. The supernatant was decanted and discarded and the sample was washed twice with distilled water and centrifuged as before.

8. The tephra residues were transferred from the centrifuge tubes to indelibly labelled glass vials until needed for analysis. 1-2 drops of absolute alcohol were added to each vial to prevent fungal growth.

During most of the tephra extractions, a precipitate was encountered which was visible once the organic fraction was close to full digestion. The precipitate was thought to be a wax (Valerie Hall, per. comm.) and was eventually dissolved by carrying out the whole digestion procedure again. Some samples underwent the wet preparation three times while one sample (K6465) was digested five times in order to dissolve the wax precipitate.

3.5.3 Sample Preparation for EDMA Analysis

The standard technique of preparing a thin section for microprobe analysis is detailed below. The resultant product in this technique is a layer of tephra shards which is embedded underneath the surface of the resin. The resin is then polished down so that many clean cut and highly polished surfaces of tephra shards are exposed for analysis (Dwyer, 1995).

Microscopic slides of exact thickness were used to mount the tephra for Energy Dispersive Micro Analysis (EDMA). Ordinary microscopic slides were ground to an exact thickness of 1200μm using a Logitech LP40 lapping machine in the Geology Department, Trinity College. Ground slides were used for this procedure for two reasons – (a) a strong bond between the resin and the slide is essential. The ground side of the slide provides a better bond for both the tephra and epoxy resin it is mounted in to the slide. The adherence of the
tephra and resin to the slide is therefore maximised and, hence, the likelihood of the tephra and resin mixture being polished off the slide is reduced and (b) slides of precision thickness are paramount for the polishing procedure (Neil Kearney, per. comm.).

A variation on the standard technique of preparing a thin section of tephra was employed here and is as follows:

1. Slides of exact thickness were labelled with a diamond pen and were placed on a warming plate (ground face upwards) and allowed to heat gently. A few drops of the aqueous tephra suspension were pipetted onto the middle of the slide and the water was allowed to evaporate.

2. This pipetting and evaporating procedure was repeated until a concentrated area of tephra existed in the middle of the slide.

3. 1-2 drops of Logitech epoxy resin were placed on the slide and were spread over the area of tephra over a heat source of approximately 70°C (hot plate). The resin was allowed to harden over a period of 30 minutes.

4. The mounted slides were ground down using a Logitech LP40 lapping machine until the resin thickness was reduced to 40μm

5. The samples were viewed microscopically to check for the presence of tephra.

6. The mounted slides were then polished using a Buehler Petropol polishing machine down to a thickness of 20μm. This procedure is carried out to remove the excess resin and to expose a surface of cut tephra particles for EDMA analysis.

7. The slides were washed, gently cleaned in an ultrasonic bath for 30 seconds to remove any residual particles from the polishing procedure and cut to the dimensions appropriate to the electron microscope (3cm x 2.5cm).

*Steps 3-7 were carried out in the Geology Department, Trinity College.*

The samples were mounted on metal stubs using Leit C conductive carbon cement and were then carbon coated under vacuum. A carbon coating is essential to prevent a buildup of a significant electrostatic charge that may be generated as a result of incident electrons on nonconductive samples such as silicate glasses (Hunt and Hill, 1993). Carbon is also highly conductive and does not heavily absorb X-rays (Friel and Barbi, 1992).
3.5.4 Microanalysis of Tephra

Although tephra layers can be loosely correlated on the basis of colour, morphology and stratigraphy, the geochemical analysis of individual shards is essential in order to identify what parent volcanic eruption the shards originated from. The geochemical composition of the tephra can be determined by carrying out X-ray microanalysis on the shards. There are two methods that can be employed to analyse X-rays emitted from a sample – Energy Dispersive Microanalysis (EDMA) and Wavelength Dispersive Microanalysis (EPMA). The former analyses X-rays by an energy dispersive spectrometer which operates by discriminating X-ray energies while the latter analyses X-rays by crystal spectrometers which use a diffracting crystal to select the wavelength of interest. Both these methods and the basis behind them are explained in detail in Friel and Barbi (1992).

Most tephra analysis is carried out using wavelength dispersive analysis. However, energy dispersive microanalysis has also been used (Bennett et al., 1992; Dwyer, 1995; Dwyer and Mitchell, 1997). There are advantages and disadvantages associated with each of the two methods and in the long term, availability of equipment will dictate the particular analysis technique employed (Dwyer, 1995).

Six of the thirteen tephra layers recorded at the three sites investigated were analysed using Energy Dispersive Microanalysis (EDMA). The other seven layers found did not contain sufficient material to analyse using EDMA. Analyses were carried out using a Hitachi Variable Pressure Scanning Electron Microscope S-3500N at the Electron Microscope Unit, Trinity College. Samples were analysed for 100 seconds at 20.0kV voltage, at a probe current of 1.0nA and a working distance of 20.0mm. The accuracy of analyses was assessed using a widely analysed obsidian from Lipari (Hunt and Hill, 1993).

3.6 Radiocarbon Dating of Samples

The stratigraphic locations for radiocarbon dating were chosen from the base of each of the three cores used for pollen analysis. Samples from Liffey Head Bog and Ballygisheen Bog were taken for bulk radiocarbon analysis. 15g dry weight was used as a guideline for the minimum amount of carbon necessary for this procedure. Due to the high Sphagnum content of the sediment from All Saint’s Bog (low dry weight), it was decided to submit a
basal sample of sediment for accelerator-mass-spectrometry (AMS) instead of bulk radiocarbon analysis as too much sediment was required to obtain 15g dry weight.

The three samples were dried overnight at 80°C in an air-circulation oven, weighed and wrapped in tinfoil. They were then packaged carefully and dispatched to Beta Analytic Inc. radiocarbon laboratory in Miami, Florida for radiocarbon dating. Preparation for dating involved pretreatment with hot acid and alkali solutions.

For bulk radiocarbon analysis the sample carbon was synthesised to benzene (92% C) and measured for $^{14}$C content in a scintillation spectrometer. The radiocarbon age was then calculated. AMS analysis involved the reduction of the sample carbon to graphite (100% C) which was measured for $^{14}$C in an accelerator-mass-spectrometer. The calibrations of radiocarbon age determinations were used to convert BP results to equivalent calendar ages using the program CALIB version 3.0 (Stuiver and Reimer, 1993).

3.7 Pollen Analysis

Pollen analysis is a method that is used to reconstruct former vegetation by means of the pollen grains it produced (Faegri and Iversen, 1989). It is also the principal technique used in the reconstruction of past environments (Birks and Birks, 1980). Pollen grains (produced by seed plants, angiosperms and gymnosperms) and spores (produced by pteridophytes, bryophytes, algae and fungi) are the most widespread and abundant type of fossils preserved in Quaternary terrestrial deposits (Moore et al., 1991). They range in size from 10-150μm. The chemical composition of the outer wall of the pollen grain (the exine) renders it resilient to chemical attack and so it can be preserved in anoxic conditions for long periods of time. Pollen grains are different morphologically and can be identified by light microscopic examination by their distinct shape, size, exine sculpturing and number of apertures (Bradley, 1999). Most grains can be identified to genus level but in many cases identification to species level may be possible (Faegri and Iversen, 1989). Plants produce copious amounts of pollen and, with only a very small percentage fulfilling its reproductive function, most is released into the atmosphere, mixed well by wind movements and is finally deposited on the ground providing a uniform pollen rain at any given site. The stratified nature of sediments analysed in pollen analysis enables the reconstruction of past vegetation through time.
Discussions on the general concepts, principles and methods involved in pollen analysis have been detailed by many authors and can be found in Birks and Birks (1980), Bradley (1999), Faegri and Iversen (1989) and Moore et al., (1991).

The objective of pollen extraction techniques is to concentrate the pollen from a subsample and to remove the bulk of undesirable organic and inorganic sediment as possible, ultimately leading to the production of pollen rich samples which permit identification and counting.

3.7.1 Sub-sampling and Sample Preparation

The extraction of samples from the monoliths (pollen analysis was carried out on one monolith from each of the three sites) was preceded by a careful cleaning of the peat surface. This involved the scraping away of any superficial material using a sharp clean knife to avoid the possibility of extraneous contamination that would have occurred during the monolith extraction procedure. The scraping should always be sideways or perpendicular to the axis of the monolith of sediment to avoid contamination of any given level of sediment with material from a position above or below it. Each monolith was cut into 0.5cm thick slices; each slice was placed in a small plastic bag and indelibly labelled according to the depth of the sample and location of site. The plastic bags were stored in the cold room at 4°C until sub-sampling was commenced.

Sub-samples (of 1cm³ volume) were taken in stratigraphic sequence down each of the three monoliths every 2cm using a volumetric copper syringe (capacity 0.5cm³). The sub-samples were placed in indelibly labelled (site location and depth) glass vials and stored in the cold room (4°C) until they were required for pollen extraction. Distilled water was added to each glass vial (just enough to cover the sample) to avoid desiccation.

All implements and working surfaces were washed with distilled water between sub-sampling to minimise contamination.

Standard physical and chemical extraction processes described by Faegri and Iversen (1989) were used to remove the sediment matrix to produce pollen rich samples. Due to the highly resistant nature of pollen and spores, these treatments do not adversely affect them. The processes employed are detailed below:
1. The samples of peat (of 1 cm³ volume) were removed from the glass vials into indelibly labelled plastic centrifuge tubes using 10% KOH solution. The top sub-sample from each monolith consisted mainly of vegetation. Pollen was extracted from these samples by placing the vegetation in a conical flask containing 150 ml distilled water and shaking it for approximately 20 min. The contents were then filtered using a coarse sieve and the remaining solution was washed into a large centrifuge tube, stirred and centrifuged at 2,500 r.p.m. for 5 min. The supernatant was decanted and discarded. The sediment was then transferred into a plastic labelled centrifuge tube using 10% KOH solution as the transferring medium.

2. A known quantity of a marker, in this case 0.5 ml *Lycopodium clavatum* spore suspension (of known concentration), was added to all tubes. This enables the calculation of the absolute pollen concentration in a sample (Stockmarr, 1971). Four different batches of spore suspension were used during the pollen preparation procedure (Batch 10 56,000 grains.ml⁻¹; Batch 11 39,500 grains.ml⁻¹; Batch 12 41,600 grains.ml⁻¹; Batch 13 53,100 grains.ml⁻¹). The *Lycopodium* batch solution was mixed thoroughly for at least 1 hour before use using a magnetic stirrer. In the case of the sub-samples consisting of vegetation it was not possible to extract volumetric samples; consequently the *Lycopodium* suspension was not added.

3. Approximately 10 ml of 10% KOH solution was added to the sediment in the centrifuge tubes. The tubes were placed in a hot water bath (approximately 90°C) for 7 min and were stirred at regular intervals with glass rods. The samples were centrifuged at 2,500 r.p.m. for 5 min and the supernatant decanted and discarded. The KOH treatment has the dual function of deflocculation and release and removal of soluble humic acids.

4. The sediment was resuspended and washed through a fine mesh sieve (125μm in aperture size) into 50 ml centrifuge tubes using distilled water. The sievings were carefully washed to ensure all the pollen was collected in the filtrates and were then stored with distilled water in plastic lidded containers and later examined for charcoal fragments. The residues were stirred, centrifuged at 3,000 r.p.m. for 5-7 min and the supernatant decanted and discarded.

5. The sediments were decanted from the large centrifuge tubes back into the small plastic centrifuge tubes using distilled water. Approximately 10 ml of distilled water was added to each tube, the sediment stirred and centrifuged at 2,500 r.p.m. for 5 min. The supernatant was decanted and discarded. If the supernatant appears dark, then there is
too much humic acid present. If this occurs the sediment should be washed again with distilled water or until a transparent supernatant had been obtained.

6. The sediment was resuspended in approximately 10 ml 10% HCl solution, stirred and centrifuged at 2,500 r.p.m. for 5 min. The supernatant was decanted and discarded.

7. The sediment was resuspended in approximately 10 ml glacial acetic acid. This dehydrates the sediment and prepares the samples for the next stage in the procedure which involves treatment with a strong acid. From now on contact with water should be avoided and subsequent stages should be carried out in the fume cupboard. The samples were stirred and centrifuged at 2,500 r.p.m. for 5 min. The supernatant was decanted and discarded into the sink in the fume cupboard.

8. 10 ml of acetolysis mixture (acetic anhydride and conc. H2SO4 in the ratio of 9:1) was added to each tube. They were placed in a hot water bath (90°C) for 5 min and stirred regularly. The tubes were centrifuged at 2,500 r.p.m. for 5 min. The supernatant was decanted into the waste bottle provided. This step has a powerful dehydrating effect, breaking down cellulose and other polysaccharides by the removal of water molecules. Acetolysis also serves to darken the pollen grains which assists in their identification in the absence of a staining agent.

9. The sediment was resuspended in approximately 10 ml glacial acetic acid. The samples were stirred, centrifuged at 2,500 r.p.m. for 5min and the supernatant decanted and discarded in the sink in the fume cupboard. Glacial acetic acid was added to neutralise any mixture remaining in the sample tubes. This treatment also removes the soluble cellulose-acetate products of acetolysis.

10. The sediment was resuspended in approximately 10 ml absolute alcohol. The samples were stirred, centrifuged at 2,500 r.p.m. for 5 min and the supernatant decanted and discarded.

11. The sediment was resuspended in approximately 10 ml tertiary-butyl-alcohol (TBA). The samples were stirred, centrifuged at 2,500 r.p.m. for 5 min and the supernatant decanted and discarded. TBA was used to help remove any excess glacial acetic acid.

12. The residues were transferred from the plastic tubes to labelled glass vials using pasteur pipettes and TBA as the transferring medium. Approximately 4-5 drops of silicone oil (viscosity 2,000 centistokes) were added to each sample which were then stirred using wooden cocktail sticks.

13. The vials (uncovered) were placed in an oven at a temperature of 60°C and left overnight in order to evaporate the TBA and leave a residue of concentrated pollen
suspended in silicone oil. The vial lids were then replaced and the samples stored until required for slide preparation and counting.

The samples were stirred to ensure that the residue in each vial was well mixed. Slides were mounted for microscopic examination by placing a drop of the pollen extracted onto a slide, spreading it into a thin film and covering it with a glass coverslip (Size No.1 22x22mm). Care was taken during this procedure to ensure that no suspension was exposed outside the area of the coverslip. If the suspension appeared too concentrated a drop of silicone oil was added to dilute it. The coverslip was fixed into position by applying a drop of clear nail polish at the corners. The major advantage of using silicone oil as the mounting medium is that pollen grains and spores are free to rotate and can be turned by applying slight pressure to the surface of the coverslip. In this way pollen grains and spores can be viewed in both equatorial and polar view to aid in their identification.

3.7.2 Mounting on Slides and Pollen Identification

All pollen and spores were counted at a magnification of x400 using a Leitz Ortholux binocular microscope. Closer inspection at x1000 using anisol was occasionally required to clarify identifications. A minimum of 350 regional pollen grains (excluding *Lycopodium* spores) were counted and recorded in each sample traversing the slide from left to right at regular intervals. Brooks and Thomas (1967) have shown that smaller pollen grains tend to travel towards the edge of the coverslip more readily than larger ones; therefore traverses were made over the entire slide. The identification of pollen grains was aided by the use of the key and illustrations of Moore *et al.* (1991), the illustrations of Reille (1992) and specific slides from the pollen reference collection in the Botany Department, Trinity College. Illustrations in van Geel (1978) and Hendon and Charman (1997) formed the basis of identification of fungal spores and some testate amoebae. The pollen of *Corylus* and *Myrica* were not differentiated but placed within the ‘Coryloid’ group. The pollen of Ericaceous plants (excluding *Calluna*) and *Empetrum* sp. were not differentiated but placed within the ‘Ericaceae-type’ group. Cereal-types were based on a maximum size of greater than or equal to 40μm with a pore diameter of greater than or equal to 3μm and a pore annulus diameter of greater than or equal to 8μm (Andersen, 1979).
3.7.3 Analyses of Data

Pollen Percentages and Calculations
The pollen counts for each site investigated were calculated and presented in the form of pollen percentage and concentration diagrams and plotted against stratigraphic depth and/or age using TILIA version 2.0.B.4 and TILIA GRAPH (Grimm, 1991). Percentage calculations were based on the ‘Pollen Sum’ which was defined as the sum of counts of identified trees, shrubs, Pteridophytes and non-peatland herb taxa. Pollen and spores of local origin were eliminated from the pollen sum to reduce their influence on the representation of regionally important taxa (Moore et al., 1991). Unidentified grains (indeterminates) comprising of unknown, deteriorated, crumpled, broken and buried grains were also excluded from the pollen sum. The total pollen sum comprised of $\Sigma$pollen + $\Sigma$local pollen + $\Sigma$indeterminates and was used in the calculation of local pollen percentages.

Pollen concentrations were calculated on the basis of the number of *Lycopodium* spores counted in each sample. The presentation of such pollen concentrations aids in the interpretation of the fossil record. Since the concentration of *Lycopodium* suspension was known (Stockmarr, 1971), the absolute concentration of pollen in each sample was calculated and expressed as grains cm$^{-3}$.

Zonation
The complexity of pollen analytical data necessitates the subdivision of pollen stratigraphic sequences into zones for ease of description, discussion, interpretation and comparison (Gordon and Birks, 1972; Birks and Gordon, 1985; Birks, 1986) and also elucidation of regional and local variations of vegetation sequences (Birks, 1986).

Zonation (the division of pollen sequences into zones) can be determined using several methods (Birks and Birks, 1980). Computer implemented numerical methods were chosen as the preferred option in this analysis in defining the position and number of pollen zones in each sequence. The composition of the pollen data alone is used in order to ascertain the pollen zone lines. No other criteria are taken into consideration (Birks, 1986) and therefore such zones are considered local pollen assemblage zones.
In this research the method of constrained sum of squares cluster analysis (CONISS) (Grimm, 1991) was used to determine the position of zone lines within the pollen data. This analysis is a hierarchical system (Bennett, 1996) that clusters stratigraphically adjacent pollen samples into successively larger units on the basis of similarity (Birks, 1986). The zone lines are then drawn between the clusters which are created; the first zone line is drawn between the last two clusters formed (the two most dissimilar clusters) and so on. Before carrying out the CONISS analysis, the pollen percentage dataset was reduced to include only pollen taxa with an abundance of 5% or more in any level. Pollen and spore types with values of less than 5% were not considered for the purposes of zonation as they are of little numerical importance in biostratigraphic terms (Gordon and Birks, 1972). They can be of great importance when interpreting results however. The representation of the new dataset was then recalculated to the proportion of the sum of included types, as recommended by Birks (1986) and Bennett (1996). This new dataset was then transformed using a square root transformation, as advised by Grimm (1987), and subjected to CONISS analysis using the TILIA program version 2.0.b.4 (Grimm, 1991).

Unfortunately the CONISS program does not determine the number of statistically significant local pollen assemblage zones in a pollen sequence. Two methods exist for determining this (Bennett, 1996); that of randomised datasets and the Broken-Stick model. The Broken-Stick model was used in these analyses. The basis behind this procedure is to separate zones that are formed by non-random variation in a pollen dataset from zones that are likely to be due to random variation. During the zonation procedure used, the total variance of the pollen sequence is split into smaller variances that are associated with each zone. These variances are then compared with the variances generated by the zonation of the same pollen dataset but with the samples in random order. The broken stick model then predicts the changes in the proportion of variance as zones are generated in the randomised dataset (Bennett, 1996). The number of zones was then plotted against both the variance accounted for by the randomised dataset and the variance accounted for by the original pollen dataset. The point at which the two curves cross is considered as the maximum number of statistically significant zones applicable to the original pollen sequence. After this point the proportion of variance accounted for by a zone does not exceed the proportion expected by the broken-stick model for the equivalent zone. This method was carried out using EXCEL version 7.
The advantages of employing zonation to pollen data and the different methods used are discussed in detail in Birks and Birks (1980), Birks and Gordon (1985) and Birks (1986).

Estimation of Pollen Sample Ages
The most common method used in the estimation of pollen sample ages is linear interpolation, where sample ages are calculated from straight lines that are drawn between known dates from a sequence. The disadvantage associated with this interpolation method is that it may lead to unrealistic abrupt changes in the time-depth relationship of a sequence at the depth of the known dates. Two other methods can be used to construct time-depth relationships, namely cubic spline and polynomial line fitting equations (Bennett, 1994).

In this investigation linear, cubic spline and polynomial line fitting models were tested on sequences from Liffey Head Bog, All Saint’s Bog and Ballygisheen Bog in order to obtain the best age-depth relationship for each site. The known tephra and radiocarbon dates from each site were used. Age-depth modelling was carried out using TILIA version 2.0.B.4 (Grimm, 1991).

Detrended Correspondence Analysis (DCA)
DCA is a multivariate ordination method designed to simplify complex data sets by reducing their dimensions. It is a non-parametric technique. The axes derived in DCA are arrived at by a process of reciprocal averaging where the first axis expresses more of the total variation in the data than any of the subsequent axes and all axes are orthogonal to each other. The distances between points on an ordination graph are an approximation to their degrees of similarity. Most interpretation is carried out on two-dimensional graphs (two axes) by superimposing other data. In palaeoecological data, samples and species are plotted together so that the relationship between the two can be seen (Kovach, 1995). Inspection of these graphs can then enable trends in the data to be recognised and hypotheses to be generated concerning changes in vegetation communities over time. If there are clear gradients across the graph then gradients can be assigned to the axes or alternatively patterns of high or low distribution may be observed in different parts of the graph and interpreted accordingly (Kent and Coker, 1992).

DCA manages to solve the problems of the arch effect and the compression of data points at the end of axes that are associated with Correspondence Analysis (CA) (Kovach, 1995) but can also introduce distortion or instability of its own (Legendre and Legendre, 1998).
However despite this, DCA remains as a widely used and effective indirect ordination technique and is probably as good as any other ordination in most situations and better than most in many (Kent and Coker, 1992). A more detailed description of DCA can be found in Kent and Coker (1992).

DCA was carried out on the regional pollen taxa (>5%), the main local pollen taxa and the fungal spore taxa (>5%) using the PCORD program. The position of the taxa from the DCA were also plotted on the ordination graphs of samples for comparison and interpretation.

3.8 Charcoal Analysis

The combustion of carbonaceous material (wood, coal etc.) produces a large number of charcoal particles which, if deposited in suitable conditions, can be preserved in accumulating sediments throughout geological periods (Tolonen, 1986a). It preserves well but may be subject to breakage. It is possible to distinguish between carbonaceous particles that have been formed from the combustion of fossil fuels and those derived from the incomplete combustion of plant tissues (Patterson et al., 1987). The former are known as ‘spherical carbonaceous particles’ (SCPs) while those from the latter as ‘charcoal fragments/particles’.

Fire has been recognised as a prominent factor in shaping the landscape for centuries (Kozlowski et al., 1991). Charcoal preserved in sediments provides a record of fire history. When employed in association with fine-resolution pollen analysis, charcoal analysis and the resultant fire history regimes can provide a greater understanding in the estimation of the interactions between vegetation, climate and human disturbances over the last few thousand years (Patterson et al., 1987; Williams et al., 1993). A study of both fossil pollen and charcoal deposition in a deciduous forest around Devil’s bathtub in New York suggest that changes in the fire regime in this forest have accompanied the principal vegetation and climatic changes experienced there during the last 10,400 years (Clark and Royall, 1996). Other studies have revealed that peat deposits have an excellent and continuous record of airborne charcoal fragment input and are superior to records from lake muds as post-depositional mixing and transport is generally absent (Tolonen, 1986a).
Charcoal particles vary in size from sub-microscopic to macroscopic (up to several centimetres in diameter), with small particles presumably being transported further (Patterson et al., 1987). Evidence from Scottish profiles suggest that microscopic charcoal is not always transported over very great distances (Macklin et al., 2000). The production of charcoal is an irregular event unlike pollen production which tends to be relatively constant over time. However it is assumed that relatively high frequencies and/or intensities of fire are expressed by high charcoal fragment peaks in the sediment (Tolonen, 1986a).

The problems associated with interpreting pollen records applies to that of charcoal records also. In spite of these problems the analysis of stratigraphic charcoal to reconstruct fire history has led to valuable insights into the dynamics of vegetation and of anthropogenic interactions with the environment (Clark, 1982). Comprehensive accounts of the factors affecting the occurrence of charcoal in sediments can be found in Tolonen (1986a), Patterson et al. (1987), Clark (1988b) and O'Sullivan (1991).

3.8.1 Macroscopic Charcoal Analysis

Macroscopic charcoal is indicative of local fire as its transport is restricted due to its size and weight. Hence, comparisons of macroscopic charcoal with pollen diagrams can aid in defining the effects of local fire on vegetation dynamics.

The residual material retained from sieving during the pollen extraction procedures were used to estimate the presence and abundance of macroscopic charcoal in each of the sub-samples. The material were resuspended in distilled water and poured into labelled petri dishes. They were left to dry under normal laboratory conditions. Charcoal abundance was estimated using the 'random quadrat' technique described by O'Sullivan (1991). Once dry, the petri dishes were placed over a petri dish template of 20 randomly placed squares (1cm x 1cm) and the number of charred particles within each quadrat was counted under a Cambridge Instruments (Model Z30 E) binocular stereomicroscope. These 20 squares represented approximately 28% of the total petri dish area. (The Sphagnum abundance was so great in the samples from All Saint's Bog that the ability to see the template through the Sphagnum was extremely difficult. To alleviate this problem the template was drawn on clear acetate and was placed over the petri dish. The charcoal fragments were then counted by focusing down through the template and onto the material on the petri dish). The count
per quadrat was totalled and the results were expressed as the number of charcoal fragments per unit volume (number of fragments, cm$^3$).

The method of macroscopic charcoal analysis employed here introduces significant problems in interpreting the data obtained. This method ignores the size variation in charcoal particles, giving the same significance to large particles as to small ones, and so may lead to an erroneous impression of the real charcoal content (O'Sullivan, 1991). This method does not allow specific interpretation as to whether the peaks in the record signify a single significant fire event, or a series of fires occurring within a relatively short period of time.

3.8.2 Microscopic Charcoal Analysis

There is no single method that has been universally accepted for dealing with the analysis of microscopic charcoal. Clark (1988a) suggests using petrographic thin sections in order to determine fire history. However the 'point count' method developed by Clark (1982) appears to be the most widely accepted technique. It is a simple and rapid method and can be carried out using the same slides that were used for pollen analysis. A disadvantage of this method however is the fact that it only gives the total particle area but does not provide information on either the size distribution of the charcoal particles or the number of particles present.

Using an Olympus BX 40 compound microscope with a magnification of x400 and an eyepiece graticule with an array of 22 points, transects were carried out at regular intervals across each slide until at least 200 fields of view of the sample slide were reached. For each field of view when a charcoal particle was touching one of the scale points, a hit was recorded. If there was uncertainty as to whether a point was touching the edge of a charcoal fragment every second such point was counted. A mechanical tally counter was used to record the number of charcoal hits, the number of fields of view and the number of marker grains counted. *Lycopodium* marker grains were recorded to enable the calculation of charcoal concentration for the sample volume. The area of the coverslip was calculated along with the area of the field of view of the microscope (at magnification x400). Using the formula given in Clark (1982), the area of the slide taken up by charcoal particles recorded was converted to absolute concentration.
Charcoal Concentration =
\[
\frac{\text{(no. charcoal hits/(fields of view*22)\times area of coverslip)\times no. of Lycopodium per cm}^3)}{\text{[((no. of Lycopodium counted/fields of view)\times no. of fields of view in coverslip)\times 1]}}
\]

This gives the estimates area of charcoal (cm²) per unit volume of sediment (cm³).

3.9 Fungal Spore and Testate Amoebae Analysis

Fungal remains, especially hyphae and fruiting bodies (which resemble spores) are very common in Quaternary deposits and are often encountered during routine pollen analysis (Lowe and Walker, 1997). Testate amoebae are microscopic animals which inhabit the surface layers of peatlands and other moist soils, as well as living in the benthic environment of freshwater lakes (Woodland et al., 1998). Both fungal spores and testate amoebae (Protozoa: Rhizopoda) are generally well preserved in sediments and have distinctive structures which facilitates their identification, in most cases to species level (Tolonen, 1986b). They are habitat specific with a strong relationship of many species to precise ecological conditions and the ecology of most species appears to be constant within a wide range of geographical locations. The main ecological factor explaining the variations in distribution is substrate wetness (Woodland et al., 1998) followed by availability of humus (Tolonen, 1986b). Therefore the analysis of many of these subfossils can be used to derive an index of palaeohydrological changes in peatlands (Charman, 1992; Hendon and Charman, 1997), particularly peat accumulating systems that contain Sphagnum (Warner and Charman, 1994). In addition to providing palaeoecological information on the hydrological conditions of the sediment, some species are associated with particular plant species and hence may indicate the presence of a plant species which may not have been evident in the pollen record (Lowe and Walker, 1997).

Almost all fungal spores and testate amoebae identified in a sediment occur in situ (van Geel, 1986). Consequently information derived from these pertains to local conditions and provides data on the environment which existed at the time of sediment deposition (Dwyer, 1995).

Fungal spores and some rhizopod types were counted on the same slides that were used for pollen analysis (for the three sites) using keys and illustrations in Corbet (1973), van Geel (1978) and Hendon and Charman (1997). Counts of at least 150 spores and tests (with the exception of 6 levels from Liffey Head Bog and 2 levels from All Saint’s Bog) were made for each level counted. Charman (1999) claims that 150 tests are an adequate size count to represent the main faunal components in a sediment. Higher counts would however increase the number of taxa detected but such rare taxa would add little to the environmental interpretation on the data. The data were processed in the same way as the pollen data using the TILIA plotting package (Grimm, 1991) and were presented as fungal spore percentage and concentration diagrams.

It has been found that testate amoebae counts from samples prepared for pollen analysis must be viewed with extreme caution and are unrepresentative of the faunal content in both absolute and relative terms (Hendon and Charman, 1997). Due to time constraints it was decided to count fungal spores and testate amoebae remains from the pollen samples. The acetolysis procedure of the pollen extraction (as described in Section 3.7.1) can destroy some of the more delicate tests but does not appear to adversely affect the fungal component of the samples. An extraction of rhizopods using a simple technique of dissaggregation in water followed by sieving has been suggested (Dan Charman pers. comm.) but was not employed in this investigation.
IV Chronology

4.1 Introduction

The recent nature of the sediments under investigation provided difficulties with respect to dating. The most conventional form of dating, radiocarbon dating, is of little use within the last two millennia as, on calibration, the age span of each radiocarbon date is too wide to allow comparison of palaeoecological evidence of vegetation changes, especially where these are short lived (Hall et al., 1993). Therefore radiocarbon dating could only be used on the basal samples of each core. The high errors associated with such radiocarbon dating of recent sediments would not have provided the accuracy and precision necessary to construct age-depth curves of temporal accuracy of decadal time scale which was fundamental for this study. Tephrochronology was therefore employed to obtain dates for the three sites. The results of the two methods of dating used are detailed below.

4.2 Radiocarbon Dating

The results of the radiocarbon determinations for the three samples are given in Table 4.1.

Table 4.1 Results of radiocarbon determinations from the three sites investigated

<table>
<thead>
<tr>
<th>Site</th>
<th>Sample Depth (cm)</th>
<th>Material</th>
<th>Lab. No.</th>
<th>C-14 age (yrs BP ± δ)</th>
<th>Age Range (cal AD)</th>
<th>Intercept of Age Range* (cal AD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHB</td>
<td>88-92 peat</td>
<td>Beta-124770</td>
<td>1160 ± 60</td>
<td>800 to 975</td>
<td>885</td>
<td></td>
</tr>
<tr>
<td>ASB</td>
<td>90-92 peat</td>
<td>Beta-124764</td>
<td>1030 ± 50</td>
<td>985 to 1030</td>
<td>1010</td>
<td></td>
</tr>
<tr>
<td>BGB</td>
<td>96.5-100.5 peat</td>
<td>Beta-124765</td>
<td>1150 ± 60</td>
<td>855 to 980</td>
<td>890</td>
<td></td>
</tr>
</tbody>
</table>

* calibrated to calendar years using the program CALIB version 3.0 (Stuiver and Reimer, 1993)
4.3 Tephrochronology

Using the tephra detection and extraction procedures as outlined in Chapter III, seven tephra layers were found in Liffey Head Bog, two tephra layers were found in All Saint’s Bog and four tephra layers were found in Ballygisheen Bog.

Tables 4.2, 4.3 and 4.4 present a summary of all the tephra layers recorded from each site indicating shard colour and morphology, stratigraphic position, mode of analysis and proposed identities where possible. Figure 4.1 illustrates the stratigraphic positions of each of the tephra layers with respect to the three cores investigated.

The results of the Lipari standard analysis are detailed in Appendix II. The results of individual shard analysis of the analysed layers are presented as percentage oxide concentrations for the major elements. Only total percentage values exceeding 95% obtained from analysis are considered as suggested by Hunt and Hill (1993). The three oxides most useful in the identification of Icelandic tephras (calcium, iron and potassium oxides) are plotted as ternary plots using TriPlot 3.0 (Beta B) and are compared to data from known Icelandic eruptions in an attempt to identify the analysed layers. All ternary plots are plotted with 10% lines illustrated.

4.3.1 Results of EDMA analysis

**Liffey Head Bog Layer 4-5cm**

This tephra layer consisted of brown shards. Most shards were long and plated but the occasional vesicular shard was found. EDMA analysis of the individual shards from this layer are presented in Table 4.5 and a ternary plot of these results is presented in Figure 4.2. These results were plotted against published geochemical profiles of Hekla AD 1947 (Larsen et al., 1999) and are presented in Figure 4.3. On comparison of these results, the geochemical profile of this tephra suggests Hekla AD 1947 as the eruption source.

**Liffey Head Bog Layer 6-7cm**

This layer consisted of mainly long and plated brown tephra shards with occasional colourless shards. The low abundance of suitable shards from this layer resulted in an insufficient volume of material for analysis.
Table 4.2 Stratigraphy and descriptions of the seven tephra layers found in Liffey Head Bog

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Morphology</th>
<th>Method of Analysis</th>
<th>Identity of Source</th>
<th>Date of Eruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 - 5</td>
<td>Brown shards, mainly long and plated</td>
<td>EDMA</td>
<td>Hekla</td>
<td>AD 1947</td>
</tr>
<tr>
<td>6 - 7</td>
<td>Brown shards, mainly long and plated; Occasional colourless shards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 - 22</td>
<td>Colourless shards, mostly plated</td>
<td>EDMA</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>33 - 34</td>
<td>Both brown shards and colourless vesicular shards</td>
<td>EDMA</td>
<td>Hekla</td>
<td>AD 1510</td>
</tr>
<tr>
<td>45 - 46</td>
<td>Colourless shards, both plated and vesicular</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>47 - 48</td>
<td>Colourless shards, both plated and vesicular</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>53 - 55</td>
<td>Abundant colourless shards, highly vesicular appearance</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4.3 Stratigraphy and descriptions of the two tephra layers found in All Saint’s Bog

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Morphology</th>
<th>Method of Analysis</th>
<th>Identity of Source</th>
<th>Date of Eruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 - 12</td>
<td>Frequent brown shards, mainly plated</td>
<td>EDMA</td>
<td>Hekla</td>
<td>AD 1947</td>
</tr>
<tr>
<td>76 - 77</td>
<td>Abundant colourless shards, both vesicular and plated</td>
<td>EDMA</td>
<td>Hekla 1</td>
<td>AD 1104</td>
</tr>
</tbody>
</table>
Table 4.4 Stratigraphy and descriptions of the four tephra layers found in Ballygisheen Bog

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Morphology</th>
<th>Method of Analysis</th>
<th>Identity of Source</th>
<th>Date of Eruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 - 15</td>
<td>Brown shards, plated;</td>
<td>EDMA</td>
<td>Hekla</td>
<td>AD 1947</td>
</tr>
<tr>
<td></td>
<td>Occasional colourless shards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>64 - 65</td>
<td>Brown shards;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Occasional colourless shards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>71 - 72</td>
<td>Colourless shards, mostly</td>
<td>EDMA</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>vesicular</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>84 - 85</td>
<td>Colourless shards, both</td>
<td>EDMA</td>
<td>Hekla 1</td>
<td>AD 1104</td>
</tr>
<tr>
<td></td>
<td>vesicular and plated</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 4.1 Stratigraphic position of each tephra layer found in the cores extracted from Liffey Head Bog, All Saint's Bog and Ballygisheen Bog.
Table 4.5 Individual shard analysis (EDMA) of tephra layer 4 - 5cm from Liffey Head Bog

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Total 100.01 100.00 100.01 100.02 100.00 100.01 100.02 100.01 100.01 100.01 100.01 100.01 99.99 100.01 100.00 100.00 %
Liffey Head Bog Layer 21-22cm
This layer contained occasional colourless shards which were mostly plated in appearance. EDMA analysis of the individual shards from this layer are presented in Table 4.6 and a ternary plot of same are presented in Figure 4.4. These results were plotted against various known geochemical profiles of Icelandic eruptions, however no match was found.

Liffey Head Bog Layer 33-34cm
This layer contained an abundant amount of both brown and colourless shards. Both vesicular and plated brown shards occurred while the colourless shards found were mainly vesicular in appearance. EDMA analysis of the individual shards from this layer are presented in Table 4.7 and a ternary plot of these results are presented in Figure 4.5. From the plot in Figure 4.5 there appears to be two distinct populations of tephra within this layer. These results were also plotted against known geochemical profiles of Hekla AD 1510 (Pilcher et al., 1996) and are presented in Figure 4.6. The comparison of these analyses suggest Hekla AD 1510 as the eruption source of this layer.

Liffey Head Bog Layer 45-46cm
This layer consisted of frequent plated and vesicular colourless shards. However, after extraction, the volume of suitable shards for EDMA analysis was very low in this layer and hence no analyses were carried out.

Liffey Head Bog Layer 47-48cm
This layer contained colourless shards of both plated and vesicular appearance. The low abundance of suitable shards from this layer resulted in an insufficient volume of material for analysis.

Liffey Head Bog Layer 53-55cm
On examination after the tephra detection procedure this layer contained an abundant amount of colourless shards which were highly vesicular in appearance. However on examination after the extraction procedure, the volume of suitable shards for EDMA analysis in this layer was insufficient for analysis.

All Saint’s Bog Layer 11-12cm
This layer consisted of frequent brown shards which were mainly plated in appearance. EDMA analysis of the individual shards from this layer are presented in Table 4.8 and a
Table 4.6 Individual shard analysis (EDMA) of tephra layer 21 - 22cm from Liffey Head Bog

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Figure 4.4 Ternary plot of analyses of colourless tephra shards from Liffey Head Bog, Layer 21-22cm (star).

Figure 4.5 Ternary plot of analyses of brown tephra shards from Liffey Head Bog, Layer 33-34cm (star). Note the two distinct populations of tephra.
Table 4.7 Individual shard analysis (EDMA) of tephra layer 33 - 34cm from Liffey Head Bog

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Total 100.00 99.99 99.99 100.01 100.01 100.00 100.00 100.00 100.00 100.00 100.00 100.00 99.99 100.01 100.01 100.01

%
Figure 4.6 Ternary plot of analyses of brown tephra shards from Liffey Head Bog, Layer 33-34cm (star). Published analyses of Hekla AD 1510 from Garry Bog (X) and Sluggan Bog (triangle) (Pilcher et al., 1996) are included for comparison.

Figure 4.7 Ternary plot of analyses of brown tephra shards from All Saint’s Bog, Layer 11-12cm (star).
Table 4.8 Individual shard analysis (EDMA) of tephra layer 11 - 12cm from All Saint’s Bog

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ternary plot of these results is presented in Figure 4.7. These results were plotted against published geochemical profiles of Hekla AD 1947 (Larsen et al., 1999) and are presented in Figure 4.8. These analyses were also plotted against the Liffey Head Bog Layer 4-5cm which also contained brown tephra shards and are presented in Figure 4.9. Figures 4.8 and 4.9 suggest that both Liffey Head Bog Layer 4-5cm and All Saint’s Bog Layer 11-12 cm have a very similar geochemical composition and that both are attributed to Hekla AD 1947.

**All Saint’s Bog Layer 76-77cm**

This layer contained an abundance of both vesicular and plated colourless tephra shards. EDMA analysis of the individual shards from this layer are presented in Table 4.9 and a ternary plot of these results is presented in Figure 4.10. These results were plotted against published geochemical profiles of Hekla 1 AD 1104 (Pilcher et al., 1995; Pilcher et al., 1996) and are presented in Figure 4.11. These results suggest that Hekla 1 AD 1104 is the eruption source of this layer.

**Ballygisheen Bog Layer 14-15cm**

This layer contained both brown and colourless shards. The brown shards were more abundant than the colourless shards and were mainly plated in appearance. The occasional colourless shards were both plated and vesicular. EDMA analysis of the individual shards from this layer are presented in Table 4.10 and a ternary plot of these results is presented in Figure 4.12. These results were plotted against published profiles of Hekla AD 1947 (Larsen et al., 1999) and are presented in Figure 4.13. These results were also plotted against Liffey Head Bog Layer 4-5cm and All Saint’s Bog Layer 11-12cm which contained brown tephra shards also and are presented in Figure 4.14. Figures 4.13 and 4.14 suggest that Liffey Head Bog Layer 4-5cm, All Saint’s Bog Layer 11-12 cm and Ballygisheen Bog Layer 14-15cm have a very similar geochemical composition and that all are attributed to Hekla AD 1947.

**Ballygisheen Bog Layer 64-65cm**

This layer consisted of both brown plated shards and occasional colourless shards. The low abundance of suitable shards from this layer resulted in an insufficient volume of material for analysis.
Figure 4.8  Ternary plot of analyses of brown tephra shards from All Saint’s Bog, Layer 11-12cm (star). Published analyses of Hekla AD 1947 (triangle) (Larsen et al., 1999) are included for comparison.

Figure 4.9  Ternary plot of analyses of brown tephra shards from All Saint’s Bog, Layer 11-12cm (diamond) and Liffey Head Bog 4-5cm (star). Published analyses of Hekla AD 1947 (triangle) (Larsen et al., 1999) are included for comparison.
Table 4.9 Individual shard analysis (EDMA) of tephra layer 76 - 77cm from All Saint’s Bog

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<td>CaO</td>
<td>2.35</td>
<td>2.42</td>
<td>2.22</td>
<td>2.28</td>
<td>2.45</td>
<td>2.39</td>
<td>2.29</td>
<td>2.44</td>
<td>2.25</td>
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<td>2.36</td>
<td>2.37</td>
<td>2.35</td>
<td>0.08</td>
</tr>
<tr>
<td>FeO</td>
<td>3.20</td>
<td>3.20</td>
<td>3.36</td>
<td>3.18</td>
<td>3.30</td>
<td>3.19</td>
<td>3.36</td>
<td>3.33</td>
<td>3.23</td>
<td>3.25</td>
<td>2.87</td>
<td>3.35</td>
<td>3.24</td>
<td>0.13</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.15</td>
<td>0.13</td>
<td>0.18</td>
<td>0.10</td>
<td>0.21</td>
<td>0.13</td>
<td>0.15</td>
<td>0.23</td>
<td>0.16</td>
<td>0.15</td>
<td>0.12</td>
<td>0.19</td>
<td>0.16</td>
<td>0.04</td>
</tr>
<tr>
<td>Total %</td>
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<td>99.98</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>99.99</td>
<td>100.01</td>
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<td>100.00</td>
<td>99.97</td>
<td>100.00</td>
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<td></td>
</tr>
</tbody>
</table>
Figure 4.10 Ternary plot of analyses of colourless tephra shards from All Saint’s Bog, Layer 76-77cm (star).

Figure 4.11 Ternary plot of analyses of colourless tephra shards from All Saint’s Bog, Layer 76-77cm (star). Published analyses of Hekla AD 1104 from Owenbeg (cross) (Pilcher et al., 1995) and Sluggan Bog (triangle) (Pilcher et al., 1996) are included for comparison.
Table 4.10 Individual shard analysis (EDMA) of tephra layer 14 - 15cm from Ballygisheen Bog

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Mean</th>
<th>Stdev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na$_2$O</td>
<td>6.41</td>
<td>19.68</td>
<td>7.91</td>
<td>6.03</td>
<td>10.01</td>
<td>6.50</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>70.19</td>
<td>62.03</td>
<td>60.76</td>
<td>61.84</td>
<td>63.71</td>
<td>4.36</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>14.02</td>
<td>16.84</td>
<td>15.49</td>
<td>15.75</td>
<td>15.53</td>
<td>1.16</td>
</tr>
<tr>
<td>MgO</td>
<td>0.33</td>
<td>0.85</td>
<td>1.32</td>
<td>1.35</td>
<td>0.96</td>
<td>0.48</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>3.19</td>
<td>0.00</td>
<td>1.87</td>
<td>1.92</td>
<td>1.75</td>
<td>1.31</td>
</tr>
<tr>
<td>CaO</td>
<td>2.36</td>
<td>0.46</td>
<td>4.81</td>
<td>5.06</td>
<td>3.17</td>
<td>2.18</td>
</tr>
<tr>
<td>FeO</td>
<td>3.31</td>
<td>0.10</td>
<td>7.31</td>
<td>7.47</td>
<td>4.55</td>
<td>3.53</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>0.18</td>
<td>0.02</td>
<td>0.52</td>
<td>0.58</td>
<td>0.33</td>
<td>0.27</td>
</tr>
<tr>
<td>Total %</td>
<td>99.99</td>
<td>99.98</td>
<td>99.99</td>
<td>100.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 4.12 Ternary plot of analyses of colourless and brown tephra shards from Ballygisheen Bog, Layer 14-15cm (star).

Figure 4.13 Ternary plot of analyses of colourless and brown tephra shards from Ballygisheen Bog, Layer 14-15cm (star). Published analyses of Hekla AD 1947 (triangle) (Larsen et al., 1999) are included for comparison.
Figure 4.14 Ternary plot of analyses of colourless and brown tephra shards from Ballygisheen Bog, Layer 14-15cm (triangle), Liffey Head Bog, Layer 4-5cm (star) and All Saint's Bog, Layer 11-12cm (cross). Published analyses of Hekla AD 1947 (X) (Larsen et al., 1999) are included for comparison.

Figure 4.15 Ternary plot of analyses of colourless tephra shards from Ballygisheen Bog, Layer 71-72cm (star).
Ballygisheen Bog Layer 71-72cm

This layer contained colourless shards which were mostly vesicular in appearance. EDMA analysis of the individual shards from this layer are presented in Table 4.11 and a ternary plot of same are presented in Figure 4.15. These results were plotted against various known geochemical profiles of Icelandic eruptions, however no match was found.

Ballygisheen Bog Layer 84-85cm

This layer contained frequent colourless vesicular and plated shards. EDMA analysis of the individual shards from this layer are presented in Table 4.12 and a ternary plot of the results are presented in Figure 4.16. These results were compared to and plotted against known geochemical profiles of Hekla 1 AD 1104 (Pilcher et al., 1995; Pilcher et al., 1996) and are presented in Figure 4.17. These results were also plotted against All Saint’s Bog Layer 76-77cm which were attributed to Hekla 1 AD 1104 and are presented in Figure 4.18. The results presented in Figure 4.17 suggest that these shards in Layer 84-85 cm are attributed to Hekla 1 AD 1104 also.

4.3.2 Discussion of the Tephra Records Found

Unfortunately not all the tephra layers detected and extracted were analysed. Many, once extracted, did not contain an adequate amount of material to analyse using EDMA. Of those analysed only two layers remain of unknown origin. The results were plotted against published data from various known Icelandic eruptions but no correlations were found.

Results from Liffey Head Bog Layer 21-22cm contained only three analyses (see Figure 4.4) which are dissimilar to one another and do not appear to reflect a typical tephra composition. Similarly Ballygisheen Bog Layer 71-72cm contained four analyses (see Figure 4.15) which once plotted, appear very scattered and do not appear to resemble a tephra composition. The layers identified to known volcanic eruptions are presented in Table 4.13 and Figure 4.19.
### Table 4.11 Individual shard analysis (EDMA) of tephra layer 71 - 72cm from Ballygisheen Bog

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Mean</th>
<th>Stdev</th>
</tr>
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<tbody>
<tr>
<td>Na₂O</td>
<td>10.19</td>
<td>11.81</td>
<td>19.32</td>
<td>8.28</td>
<td>12.40</td>
<td>4.83</td>
</tr>
<tr>
<td>SiO₂</td>
<td>58.81</td>
<td>57.70</td>
<td>63.10</td>
<td>58.43</td>
<td>59.51</td>
<td>2.44</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>19.11</td>
<td>18.97</td>
<td>16.45</td>
<td>14.34</td>
<td>17.22</td>
<td>2.27</td>
</tr>
<tr>
<td>MgO</td>
<td>0.77</td>
<td>0.85</td>
<td>0.81</td>
<td>1.24</td>
<td>0.92</td>
<td>0.22</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.70</td>
<td>0.82</td>
<td>0.00</td>
<td>1.94</td>
<td>0.87</td>
<td>0.80</td>
</tr>
<tr>
<td>CaO</td>
<td>8.18</td>
<td>7.38</td>
<td>0.17</td>
<td>5.29</td>
<td>5.26</td>
<td>3.60</td>
</tr>
<tr>
<td>FeO</td>
<td>1.97</td>
<td>2.30</td>
<td>0.12</td>
<td>9.65</td>
<td>3.51</td>
<td>4.20</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.25</td>
<td>0.17</td>
<td>0.01</td>
<td>0.84</td>
<td>0.32</td>
<td>0.36</td>
</tr>
<tr>
<td><strong>Total %</strong></td>
<td>99.98</td>
<td>100.00</td>
<td>99.98</td>
<td>100.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4.12 Individual shard analysis (EDMA) of tephra layer 84 - 85cm from Ballygisheen Bog

<table>
<thead>
<tr>
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<th>1</th>
<th>2</th>
<th>Mean</th>
<th>Stdev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na$_2$O</td>
<td>2.21</td>
<td>4.60</td>
<td>3.41</td>
<td>1.69</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>76.28</td>
<td>69.74</td>
<td>73.01</td>
<td>4.62</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>13.68</td>
<td>11.90</td>
<td>12.79</td>
<td>1.26</td>
</tr>
<tr>
<td>MgO</td>
<td>0.36</td>
<td>0.61</td>
<td>0.49</td>
<td>0.18</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>2.59</td>
<td>2.52</td>
<td>2.56</td>
<td>0.05</td>
</tr>
<tr>
<td>CaO</td>
<td>2.38</td>
<td>2.00</td>
<td>2.19</td>
<td>0.27</td>
</tr>
<tr>
<td>FeO</td>
<td>4.08</td>
<td>3.73</td>
<td>3.91</td>
<td>0.25</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>0.17</td>
<td>0.32</td>
<td>0.25</td>
<td>0.11</td>
</tr>
<tr>
<td><strong>Total %</strong></td>
<td>101.75</td>
<td>95.42</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 4.16 Ternary plot of analyses of colourless tephra shards from Ballygisheen Bog, Layer 84-85cm (star).

Figure 4.17 Ternary plot of analyses of colourless tephra shards from Ballygisheen Bog, Layer 84-85cm (star). Published analyses of Hekla AD 1104 from Owenbeg (X) (Pilcher et al., 1995) and Sluggan Bog (triangle) (Pilcher et al., 1996) are included for comparison.
Potassium oxide (%) Calcium oxide (%) Iron oxide (%)

Figure 4.18 Ternary plot of analyses of colourless tephra shards from Ballygisheen Bog, Layer 84-85cm (cross) and All Saint’s Bog, Layer 76-77cm (star). Published analyses of Hekla AD 1104 from Owenbeg (X) (Pilcher et al., 1995) and Sluggan Bog (triangle) (Pilcher et al., 1996) are included for comparison.
Figure 4.19 Stratigraphic position of each tephra layer, and their associated dates where identified, found in the cores extracted from Liffey head Bog, All Saint's Bog and Ballygisheen Bog.
Table 4.13 Tephra layers identified to known volcanic eruptions.

<table>
<thead>
<tr>
<th>Site</th>
<th>Depth (cm)</th>
<th>Identity of Source</th>
<th>Date (AD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liffey Head Bog</td>
<td>4-5</td>
<td>Hekla</td>
<td>1947</td>
</tr>
<tr>
<td>All Saint’s Bog</td>
<td>11-12</td>
<td>Hekla</td>
<td>1947</td>
</tr>
<tr>
<td>Ballygisheen Bog</td>
<td>14-15</td>
<td>Hekla</td>
<td>1947</td>
</tr>
<tr>
<td>Liffey Head Bog</td>
<td>33-34</td>
<td>Hekla</td>
<td>1510</td>
</tr>
<tr>
<td>All Saint’s Bog</td>
<td>76-77</td>
<td>Hekla 1</td>
<td>1104</td>
</tr>
<tr>
<td>Ballygisheen Bog</td>
<td>83-84</td>
<td>Hekla 1</td>
<td>1104</td>
</tr>
</tbody>
</table>

The problem of ‘sodium drift’ is encountered in the microanalysis of tephra whereby sodium is volatilised or mobilised outward from the electron beam during analysis (Hunt and Hill, 1993). This can have the result in effecting the readings of other elements, resulting in their overrepresentation. This phenomenon appears to be more pronounced in EDMA analysis than in EPMA analysis. This is due to the way in which the analyses are carried out - all elements are analysed together using EDMA whereas there is the option of analysing sodium first in EPMA thereby reducing the risk of under-representation of sodium. Suggestions for reducing the problem of sodium drift when using EDMA could include analysing each tephra shard for a slightly shorter time period or using a rastered beam where a specific area of the shard would be analysed rather than one distinct point (Dwyer, 1995).

4.4 Age-Depth Models

The radiocarbon dates and tephra dates, as detailed in Sections 4.2 and 4.3, were used to construct age-depth models. The three types of age-depth models (linear interpolation, cubic spline interpolation and polynomial line-fitting, see Section 3.7.3) were tested on the three sites in order to estimate sample ages. An estimate of the top sample of -45BP,
-46BP and -47BP for Liffey Head Bog, All Saint's Bog and Ballygisheen Bog respectively were also included in the calculations.

Bennett (1994) stressed the importance of including confidence intervals of all values as an essential part of the presentation of palaeoecological data. However in this investigation the majority of dates used in the calculation of the age-depth models presented were those derived from tephra horizons which do not have a standard deviation associated with them. Only one radiocarbon date was involved with the calculation of age-depth models for each site; therefore the sample age estimates are presented without error i.e. confidence intervals are not plotted with the models.

**Liffey Head Bog**

The linear interpolation, cubic spline interpolation and polynomial line-fitting age-depth models for Liffey Head Bog are presented in Figure 4.20. The dates that were used to construct these models are presented in Table 4.14.

Table 4.14 The four dates used in the construction of age-depth models for Liffey Head Bog

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Date (Calib. years BP)</th>
<th>Date (calendar years AD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-45</td>
<td>1995</td>
</tr>
<tr>
<td>4.5</td>
<td>3</td>
<td>1947</td>
</tr>
<tr>
<td>33.5</td>
<td>440</td>
<td>1510</td>
</tr>
<tr>
<td>90</td>
<td>1160 ± 60</td>
<td>885</td>
</tr>
</tbody>
</table>

All models, with the exception of the 2-term polynomial, pass through the four dates. With radiocarbon dates the model curve does not necessarily have to pass through all the points because such points are only statistical estimates of the 'true' (unknown) radiocarbon age of the sample (Bennett, 1994). Because the dates used are more 'real' than those of radiocarbon estimates, it would not be unreasonable to require the model to actually pass
Figure 4.20 Age-depth modelling for Liffey Head Bog using linear interpolation, cubic spline interpolation, 2-term polynomial line-fitting and 3-term polynomial line-fitting of the four known dates (black triangles) from the core.
through the four date points. The 3-term polynomial gives very similar estimated dates to
the cubic spline model back as far as 440BP after which it deviates considerably and gives
older age estimates, by as much as 77 years at approximately 70cm. The linear
interpolation model matches very well with the 2-term polynomial throughout giving
similar ages with the exception of the beginning of the profile where they differ by
approximately 20 years from 5.5cm to 21.5cm. The linear interpolation was chosen as the
most suitable age-depth model for Liffey Head Bog (Figure 4.21). Although the age
estimates resemble those of the 2-term polynomial, the most recent ages as estimated by
the linear interpolation reflect the presumed natural accumulation rate of the top of a bog.

**All Saint’s Bog**

The linear interpolation, cubic spline interpolation and polynomial line-fitting age-depth
models for All Saint’s Bog are presented in Figure 4.22. The dates that were used to
construct these models are presented in Table 4.15.

Table 4.15 The four dates used in the construction of age-depth models for All Saint’s Bog

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Date (Calib. years BP)</th>
<th>Date (calendar years AD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-46</td>
<td>1996</td>
</tr>
<tr>
<td>11.5</td>
<td>3</td>
<td>1947</td>
</tr>
<tr>
<td>76.5</td>
<td>846</td>
<td>1104</td>
</tr>
<tr>
<td>91</td>
<td>1030 ± 50</td>
<td>1010</td>
</tr>
</tbody>
</table>

Similar to the age-depth models constructed for Liffey Head Bog, all models with the
exception of the 2-term polynomial pass through the four dates. Both the cubic spline
interpolation and the 3-term polynomial line-fitting models estimate very similar ages
throughout the profile. The largest number of years they deviate by is 5 years at 27.5cm.
The linear model suggests a fairly constant accumulation rate throughout with the
exception of between 0cm and 11.5cm where the rate is very different to the rest of the
profile. Both the cubic spline interpolation and the 3-term polynomial estimate similar
Figure 4.21(a) Age-depth model (in years BP) for Liffey Head Bog based on linear interpolation of the four known dates (black triangles) from the core.

Figure 4.21(b) Age-depth model (in calendar years AD) for Liffey Head Bog based on linear interpolation of the four known dates (black triangles) from the core.
Figure 4.22 Age-depth modelling for All Saint's Bog using linear interpolation, cubic spline interpolation, 2-term polynomial line-fitting and 3-term polynomial line-fitting of the four known dates (black triangles) from the core.
ages to the linear interpolation model between 0cm (-46BP) and 11.5 cm (3BP) and between 76.5cm (846BP) and 91cm (1030 ± 50BP) but differ dramatically between 11.5cm and 76.5cm, by a maximum of 71.3 years at 33.5cm. The natural accumulation rate of the top section of the bog is different to the lower sections, and although the change in rate as suggested by the linear interpolation model seems to be too dramatic it does coincide with a change in the sediment environment at approximately 8cm (see Table 5.3). This would suggest a sharp change in sedimentation rate which is more clearly expressed by the linear interpolation model rather that the more gradual rate which is conveyed by both the cubic spline and 3-term polynomial models. Therefore the linear interpolation model was chosen as the most suitable age-depth model for All Saint’s Bog (Figure 4.23).

**Ballygisheen Bog**

The linear interpolation, cubic spline interpolation and polynomial line-fitting age-depth models for Ballygisheen Bog are presented in Figure 4.24. The dates that were used to construct these models are presented in Table 4.16.

Table 4.16 The four dates used in the construction of age-depth models for Ballygisheen Bog

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Date (Calib. years BP)</th>
<th>Date (calendar years AD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-47</td>
<td>1997</td>
</tr>
<tr>
<td>14.5</td>
<td>3</td>
<td>1947</td>
</tr>
<tr>
<td>84.5</td>
<td>846</td>
<td>1104</td>
</tr>
<tr>
<td>98.5</td>
<td>1150 ± 60</td>
<td>890</td>
</tr>
</tbody>
</table>

All four models tested on Ballygisheen Bog pass through the four dates. The cubic spline interpolation, 2-term polynomial line-fitting and 3-term polynomial line-fitting all estimate very similar ages to each other. The linear interpolation model also matches well with these estimated ages between 0cm (-47BP) and 14.5cm (3BP) and between 84.5cm (846BP) and 98.5cm (1150 ± 60BP). Between 14.5cm and 84.5cm however the linear interpolation model is preferred.
Figure 4.23(a) Age-depth model (in years BP) for All Saint's Bog based on linear interpolation of the four known dates (black triangles) from the core.

Figure 4.23(b) Age-depth model (in calendar years AD) for All Saint's Bog based on linear interpolation of the four known dates (black triangles) from the core.
Figure 4.24 Age-depth modelling for Ballygisheen Bog using linear interpolation, cubic spline interpolation, 2-term polynomial line-fitting and 3-term polynomial line-fitting of the four known dates (black triangles) from the core.
interpolation model deviates in its estimated sample ages considerably from the other models - the maximum difference being 140.8 years at 49.5cm. The nature of the linear interpolation model suggests a change in the accumulation rate at each of the four date points which is unlikely to be the scenario and is not reflected in the sediment record. Therefore the 2-term polynomial line-fitting was chosen as the most suitable age-depth model for Ballygisheen Bog (Figure 4.25). The polynomial line-fitting model was chosen over the cubic spline interpolation model as polynomials in general produce narrower confidence intervals than interpolation models (Bennett, 1994).

4.5 Peat Accumulation Rates

The peat accumulation rates for each of the sites investigated were calculated from the known dates (Sections 4.2 and 4.3) and most suitable age-depth models for each site (Section 4.4) and are presented in Figure 4.26. It can be seen from this graph that the mean rate of peat accumulation for each site is quite similar – Liffey Head Bog has the lowest peat accumulation rate of 0.748mm.yr⁻¹ while those of All Saint’s Bog and Ballygisheen Bog are 0.846mm.yr⁻¹ and 0.811mm.yr⁻¹ respectively.

Peat accumulation rates differ significantly between sites as time is split into set periods of years. The initial time period, 500-1000 years exhibits peat accumulation rates that are quite similar between sites. Liffey Head Bog appears to have the highest peat accumulation rate while Ballygisheen Bog has the lowest. The lowest peat accumulation rate observed in the graph occurs in this time period where the rate at Ballygisheen Bog is only 0.56mm.yr⁻¹. The rates at Liffey Head Bog and All Saint’s Bog are almost identical at 0.8mm.yr⁻¹ and 0.78mm.yr⁻¹ respectively in this time period.

The difference in peat accumulation rates between sites is slightly more dramatic for the period 50-500 years. Ballygisheen Bog has the highest peat accumulation rate of 1.022mm.yr⁻¹ while that of Liffey Head Bog remains the lowest at 0.667mm.yr⁻¹. The rate of All Saint’s Bog is intermediate between Ballygisheen Bog and Liffey Head Bog at 0.778mm.yr⁻¹, only 0.002mm.yr⁻¹ lower that its value in the previous time period.

The final time period, 0-50 years, exhibits a very large difference in peat accumulation rates between sites. Ballygisheen Bog appears to have the highest rate of peat
Figure 4.25 (a) Age-depth model of Ballygisheen Bog (in years BP) based on 2-term polynomial line-fitting of the four known dates (black triangles) of the core.

Figure 4.25 (b) Age-depth model of Ballygisheen Bog (in calendar years AD) based on 2-term polynomial line-fitting of the four known dates (black triangles) of the core.
Figure 4.26 Peat accumulation rates for each of the three sites investigated plotted from known dates and the most suitable age-depth models from each site.
accumulation in the last 50 years reaching 3.1mm.yr⁻¹. Liffey Head Bog has the lowest rate of 0.9mm.yr⁻¹ while All Saint’s Bog accumulated 2.3mm.yr⁻¹ of peat in the last 50 years.

The trends in the overall rates of peat accumulation differs significantly between sites. That of Liffey Head Bog seems to decrease from the base of the profile to the last 50 years and then increase to a similar value in the last 50 years to between 500-1,000 years. The trend in All Saint’s Bog is similar to that of Liffey Head Bog in that the peat accumulation rate is higher in the period 500-100 years than between 50-500 years. Similar to Liffey Head Bog the accumulation rate at 0-50 years is higher than previous time periods but at All Saint’s Bog the rate is significantly larger at 2.3mm.yr⁻¹. The pattern of peat accumulation rate in Ballygisheen Bog is one of increasing significantly between time periods (2-fold from 500-1,000 years to 50-500 years and 3-fold from 50-500 years to 0-50 years) to reach its highest rate in the time period 0-50 years. It would appear that during the last 50 years the peat accumulation rate increases from site to site, going from east to west along the greatest climatic gradient of increasing wetness across Ireland. This is what would be expected as Ballygisheen Bog receives the highest amount of rainfall of the three sites and is least disturbed by man – two criteria that would optimise peat growth. The opposite pattern occurs during the time period 500-1,000 years where the peat accumulation rate decreases from Liffey Head Bog (the most eastern site) to Ballygisheen Bog (the most western site) across the country.
5.1 Introduction

This chapter reports the results of sediment stratigraphy, loss on ignition and charcoal analyses; the methods and justifications of which are detailed in Chapter III. These three types of analysis provide information on the physical composition and structure of the sediment, the percentage of organic material present in the sediment and the fire history of the sites under investigation respectively. Each type of analysis can provide valuable information which may help elucidate the type of scenario being interpreted from the pollen analytical data (Birks and Birks, 1980).

5.2 Sediment Stratigraphy

The sediment stratigraphy of each of the cores from the three sites used in this investigation are described in Tables 5.1-5.5 and are also illustrated in Figures 5.1-5.3. All depths quoted are measured from the sediment surface.

Table 5.1  Sediment description of Liffey Head Bog Core A (pollen) using the Troels-Smith (1955) system of sediment classification

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Troels-Smith notation</th>
<th>Sediment description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 11</td>
<td>nig 3; strf 0; elas 3; sicc 2; lim 2; hum 1; calc 0; Th +; Tb 1; T1 +; Dl 1; Dh 2; Ld +</td>
<td>Dark brown fibrous peat with fragments of plant remains, especially <em>Molinia</em></td>
</tr>
<tr>
<td>12 - 16</td>
<td>nig 2; strf 0; elas 2; sicc 2; lim 2; hum 2; calc 0; Th 1; Tb +; Dl +; Dh 2; Dg 1; Ld +; As +</td>
<td>Brown fibrous peat; partially humified with plant remains</td>
</tr>
<tr>
<td>17 - 97</td>
<td>nig 3; strf 0; elas 2; sicc 2; lim 0; hum 2; calc 0; Th 2; Dh 2; Ld +; As +; Anth +</td>
<td>Dark brown quite humified fibrous peat; quite wet in places</td>
</tr>
</tbody>
</table>
Table 5.2 Sediment description of Liffey Head Bog Core B (tephra) using the Troels-Smith (1955) system of sediment classification

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Troels-Smith notation</th>
<th>Sediment description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 13</td>
<td>nig 2; strf 0; elas 2; sicc 3; lim 1; hum 2-3; calc 0 Tb +; Ti +; Th 1; Dl +; Dh 2; Dg 2; Ld +; Ag +; Anth +</td>
<td>Brown fibrous peat with plant remains, esp. roots</td>
</tr>
<tr>
<td>14 - 100</td>
<td>nig 3; strf 0; elas 3; sicc 3; lim 1; hum 3; calc 0 Tb +; Ti +; Th 1; Dl +; Dh 1; Dg 2; Ld +; Ag +; Sh +</td>
<td>Dark brown fibrous peat; quite decomposed with some plant remains</td>
</tr>
</tbody>
</table>

Table 5.3 Sediment description of All Saint’s Bog Core B (pollen & tephra) using the Troels-Smith (1955) system of sediment classification

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Troels-Smith notation</th>
<th>Sediment description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 7</td>
<td>nig 2; strf 0; elas 3; sicc 2-3; lim 3; hum 0-1; calc 0 Tb 2; Ti 1; Th 1; Dl +; Dh +; Dg +; Anth +</td>
<td>Brown/green/red sediment full of non-decomposed <em>Sphagnum</em> and rootlets</td>
</tr>
<tr>
<td>8 - 52</td>
<td>nig 3; strf 0; elas 3; sicc 2-3; lim 0; hum 3; calc 0 Tb 1; Ti +; Th 1; Dl 1; Dh 1; Dg +; Ld +; Anth +</td>
<td>Chocolate brown sediment; very compact and closed; contains some plant remains, especially <em>Sphagnum</em></td>
</tr>
<tr>
<td>53 - 95</td>
<td>nig 3; strf 0; elas 2-3; sicc 2; lim 0; hum 2; calc 0 Tb 2; Ti +; Th 1; Dl +; Dh 1; Dg +; Ld +</td>
<td>Dark brown sediment; not very compact; <em>Sphagnum</em> remains evident</td>
</tr>
</tbody>
</table>
Table 5.4 Sediment description of Ballygisheen Bog Core B (pollen) using the Troels-Smith (1955) system of sediment classification

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Troels-Smith notation</th>
<th>Sediment description</th>
</tr>
</thead>
</table>
| 0 - 27     | nig 3; strf 0; elas 3; sicc 3; lim 1; hum 2; calc 0  
Tb +; Tl 1; Th 2; Dl +; Dh 1; Dg +; Ld + | Dark brown peat with plant remains consisting mainly of fine rootlets |
| 28 - 107   | nig 2-3; strf 0; elas 3; sicc 2-3; lim 1; hum 2-3; calc 0  
Tb +; Tl 1; Th 1; Dl +; Dh 2; Dg +; Ld +; Anth + | Brown peat; quite humified with some plant remains |

Table 5.5 Sediment description of Ballygisheen Bog Core C (tephra) using the Troels-Smith (1955) system of sediment classification

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Troels-Smith notation</th>
<th>Sediment description</th>
</tr>
</thead>
</table>
| 0 - 8      | nig 1; strf 1; elas 3; sicc 3-4; lim 0; hum 0; calc 0  
Tb 3; Th 1; Dl +; Dg + | Sediment full of non-decomposed moss remains; segments of sedges and liverworts present |
| 9 - 24     | nig 3; strf 0; elas 3; sicc 3; lim 1; hum 2; calc 0  
Tb +; Tl +; Th 3; Dl +; Dh 1; Dg +; Ld + | Dark brown peat with plant remains only partly decomposed |
| 25 - 106   | nig 2-3; strf 0; elas 2; sicc 3; lim 2; hum 2-3; calc 0  
Tb +; Tl +; Th 2; Dl +; Dh 2; Dg +; Ld +; Anth + | Brown humified peat with plant remains |
Figure 5.1a
Sediment lithology of Liffey Head Core A
(Dates are interpolated)

Figure 5.1b
Sediment lithology of Liffey Head Bog Core B
(Dates are interpolated)
Figure 5.2
Sediment lithology of All Saint's Bog Core B
(Dates are interpolated)

- Sphagnum remains
- Brown peat, quite humified
- Dark brown peat with some Sphagnum
Figure 5.3a
Sediment lithology of Ballygisheen Bog Core B
(Dates are interpolated)

Figure 5.3b
Sediment lithology of Ballygisheen Bog Core C
(Dates are interpolated)
5.3 Loss on Ignition

5.3.1 Description of Loss on Ignition Profiles

Liffey Head Bog
The loss on ignition curve for Liffey Head Bog (Core A) is illustrated in Figure 5.4. Values appear high throughout with all above 93%. Values remain above 98% for the lower two-thirds of the profile and then steadily decline from 20.5cm at 97.6% to less than 94% at 12.5cm. Percentages rise again from this point to the top of the profile but never reach 98%. The highest value of loss on ignition occurs at 74.5cm (99.1%).

All Saint’s Bog
The loss on ignition curve for this site (Core B) is illustrated in Figure 5.5. Similar to the loss on ignition curve of Liffey Head Bog (Figure 5.4), the values remain above 98% for the lower two-thirds of the profile with the exception of 80.5cm where values drop to 95%. Percentages decline from 24.5cm (97.8%) to the lowest loss on ignition value in the profile at 16.5cm (93.3%). After this point percentages gradually increase again towards the top of the profile but again, similar to the top section of the Liffey Head Bog profile, never reach 98%.

Ballygisheen Bog
The loss on ignition curve for Ballygisheen Bog (Core B) is illustrated in Figure 5.6. Values remain above 97% throughout. There appears to be an overall steady decreasing trend of percentages from the base to the top of the profile. The highest value occurs at 88.5cm (98.8%) and after this point percentages decrease towards 70.5cm (97.4%). From 70.5cm values increase to 44.5cm (98.3%) and then decline to 97.5% at 2.5cm. The lowest value of loss on ignition in the profile occurs at 10.5cm (97.2%).

5.3.2 Interpretation and Comparisons of the Loss on Ignition Profiles of each Site

The decline of percentage values observed in the Liffey Head Bog loss on ignition profile (Figure 5.4) between 20.5cm (97.6%) and 12.5cm (93.6%) does not appear to be big in terms of percentage values but is a significant change in values relative to the previous stability of percentages seen in the lower two-thirds of the profile. The decline in values occurs over several levels and so is a real trend rather than a decrease in values at one level.
Figure 5.4 Loss on Ignition profile for Liffey Head Bog (Core A) with respect to depth.

Figure 5.5 Loss on Ignition profile for All Saint's Bog (Core B) with respect to depth.

Figure 5.6 Loss on Ignition profile for Ballygisheen Bog (Core B) with respect to depth.
only which could be due to any number of factors including experimental error. This area of the profile with lower loss on ignition values corresponds to a distinct section of sediment as described by the Troels-Smith (1955) system of sediment classification in Table 5.1. Sediment from 12cm to 16cm is characterised by the presence of clay particles (As=mineral particles <0.002mm) which would cause a decrease in loss on ignition values in this area of the profile and may suggest a period of erosion. According to the age-depth model of Liffey Head Bog (Section 4.4) this section of the profile corresponds to the time period AD 1766 to AD 1842. Various papers have been published relating to erosion in the Wicklow mountains (Bowler and Bradshaw, 1985; Bradshaw and McGee, 1988; McGee and Bradshaw, 1990) and have concluded that erosion probably began in this area of Wicklow around 3,000 years BP (McGee and Bradshaw, 1988). It is thought to have been a natural process where neither climate nor anthropogenic influences are thought to have been the causal agent. Certainly human and domestic animal disturbance and air pollution over the last few hundred years may have intensified recent rates of erosion. The presence of clay particles in this part of the core may also be due to the building of the Military road in c.1800. Despite evidence of current and former erosion in the Wicklow mountains, there is evidence of recent peat accumulation (Bowler and Bradshaw, 1985). This can be seen from this study where active peat accumulation has occurred at Liffey Head Bog (see Figure 4.26). The beginning of the decline of loss on ignition values observed at 20.5cm corresponds to the occurrence of a tephra layer at 21-22cm in the Liffey Head Bog profile. The presence of tephra may reduce the percentage of loss on ignition at the level of its occurrence, if abundant, but would not be the causal agent for a steady decline in values over several cm and so this decline in percentage loss on ignition values cannot be attributed to the occurrence of tephra in this section of the core.

Unlike the scenario at Liffey Head Bog, the decline in values from 24.5cm to 16.5cm in the All Saint’s Bog core does not correspond with a change in the sediment composition of the profile (Figure 5.2). The start of this decline is very gradual. This area of the profile (24.5cm to 16.5cm) corresponds to the time period AD 1778 to AD 1882 as calculated from the age-depth model constructed for All Saint’s Bog (Section 4.4). The upper decline in loss on ignition values at 8.5cm and 6.5cm, which equates to the time period 1960 to 1969, does correspond with a change in the sediment composition of the core (see Table 5.3 and Figure 5.2). Such a decrease in values could be attributed to the aerial transport and subsequent deposition of material from the adjacent esker. The esker has been excavated for sand and gravel. No evidence of clay, sand or silt were found in the
sediment at these levels however. The upper section of the curve would suggest that land use may be relatively high in this area.

The values of loss on ignition from Ballygisheen Bog remain stable and constant throughout the profile. There appears to be no major decreases in values indicating a change in sediment composition that corresponds to a change recorded in the Troels-Smith (1955) system of sediment classification of the profile. Hence there are no visible signs of erosion occurring in the surrounding landscape in the profile. Such a stable and high loss on ignition curve would also suggest that the level and intensity of land use in the vicinity of Ballygisheen is low. This bog lies in one of the least afforested and undisturbed valleys in Co. Kerry.

The loss on ignition profiles of Liffey Head Bog and All Saint’s Bog appear rather similar to one another due to the decline in values at approximately 20.5cm and 24.5cm respectively. Unlike both of these sites, the surrounding landscape of Ballygisheen Bog does not have surrounding hills that would be a source of erosion or eskers as a source of mineral particle deposition which are suspected to have caused the decline in values at each site respectively.

5.4 Charcoal

5.4.1 Microscopic Charcoal Analysis

The amount of microscopic charcoal is expressed as surface area of charcoal per centimetre cubed (cm².cm⁻³) of sediment.

Liffey Head Bog

The microscopic charcoal content of Liffey Head Bog with respect to depth is illustrated in Figure 5.7. The values of microscopic charcoal content fluctuate throughout the profile. The largest value occurs at 23.5cm while the lowest occurs at 9.5cm. Microscopic charcoal was not found at every level counted. There appears to be three main areas within the profile where microscopic charcoal values are high – between 1.5cm and 5.5cm, 21.5cm and 27.5cm and 41.4cm and 45.5cm. The profile commences at high values at 1.5cm and rise to a high at 3.5cm after which they decrease and oscillate until they increase dramatically to the highest
Figure 5.7  Microscopic charcoal concentration profile for Liffey Head Bog with respect to depth.

Figure 5.8  Microscopic charcoal concentration profile for All Saint's Bog with respect to depth.

Figure 5.9  Microscopic charcoal concentration profile for Ballygisheen Bog with respect to depth.
value at 23.5cm (1.7cm\(^2\cdot cm^{-3}\)). Values sharply decline after 23.5cm and then increase at 39.5cm, sharply to high values at 41.5cm and 45.5cm. Values dramatically decrease after 45.5cm and remain low, albeit oscillating, until the base of the profile. Values per level are lower in the lower half of the profile compared to those in the upper half although there is a higher incidence of charcoal per level in the basal half of the monolith.

### All Saint's Bog

The microscopic charcoal content of All Saint’s Bog with respect to depth is illustrated in Figure 5.8.

Less than 40% of the total amount of levels counted for this site contained microscopic charcoal. Most of the charcoal recorded occurs in the top half of the profile. The highest value occurs at 7.5cm (1.7cm\(^2\cdot cm^{-3}\)). The charcoal curve rises dramatically from 3.5cm to the highest point at 7.5cm after which it sharply decreases to 13.5cm. From 13.5cm values appear sporadically down the profile. There is a higher occurrence of values near the base of the profile (from 77.5cm to 91.5cm).

### Ballygisheen Bog

The microscopic charcoal content of Ballygisheen Bog with respect to depth is illustrated in Figure 5.9.

The values for microscopic charcoal fluctuate dramatically throughout the profile. Not all levels counted contain charcoal – many of these occur in the upper half of the profile. The values exhibit an overall increasing trend towards the base of the profile with the highest values occurring within the basal 20cm. The highest value occurs at 81.5cm (1.8cm\(^2\cdot cm^{-3}\)) while the lowest occurs at 37.5cm (0.06cm\(^2\cdot cm^{-3}\)). Values of microscopic charcoal increase from the top of the profile to 11.5cm after which they disappear until 27.5cm. From 27.5cm values steadily increase to a high at 51.5cm and fluctuate significantly to the highest value at 81.5cm. Values exhibit an overall slight decrease from 81.5cm towards the base of the profile. No charcoal was found in the basal level of the profile.

### 5.4.2 Interpretation and Comparisons of the Microscopic Charcoal Profiles of each Site

The microscopic charcoal profile for Liffey Head Bog (Figure 5.7) appears to have five major 'pulses' of charcoal which are represented by almost normal distributions. The peaks of these five pulses are 0.8cm\(^2\cdot cm^{-3}\) (3.5cm; AD 1958), 1.7cm\(^2\cdot cm^{-3}\) (23.5cm; AD 1661), 1.2cm\(^2\cdot cm^{-3}\) (45.5cm; AD 1357), 0.5cm\(^2\cdot cm^{-3}\) (57.5cm; AD 1204) and
0.5cm³.cm⁻³ (83.5cm; AD 873). The mean charcoal value for the entire profile is 0.3cm³.cm⁻³. Each of the five peaks of charcoal lie above the mean charcoal level which may suggest that each represents a burning phase or a fire occurrence. The lower tail of each of these ‘normal distributions’ of microscopic charcoal may represent charcoal downwash in the sediment. Prior to the 1930s Liffey Head Bog was managed for grouse using an approximate 12-year burning cycle. Since then it has been irregularly burnt, accidentally or by local farmers, to encourage forage for grazing sheep (Ryan, 1992). The uppermost peak in microscopic charcoal may represent an occurrence of this irregular burning as mentioned previous.

The microscopic charcoal profile of All Saint’s Bog (Figure 5.8) differs to that of Liffey Head Bog in that only one major peak in charcoal occurs in the profile; that of 1.7cm³.cm⁻³ at 7.5cm. This peak in the profile corresponds to approximately AD 1964. The peak is surrounded on both sides by somewhat lower values of charcoal concentration from 13.5cm to 3.5cm. According to the time-depth model constructed for All Saint’s Bog in Section 4.4 this part of the profile corresponds to the time period AD 1921 to AD 1981. Cross et al., (1991) mention how the northern part of All Saint’s Bog is burned on a frequent basis. This peak in values in the top 10cm of the profile may reflect this frequent burning phenomenon. More charcoal was counted in the top 10cm of the All Saint’s Bog profile than in the rest of the core. The mean concentration of charcoal counted is 0.1cm³.cm⁻³. Only four of the levels in which charcoal was found counted do not exceed this mean value, namely 17.5cm, 27.5cm, 41.5cm and 85.5cm. Many of the levels counted in this profile did not contain microscopic charcoal; only 39% of levels contained microscopic charcoal compared to 89% of levels at Liffey Head Bog suggesting that fire occurrence and frequency is less at All Saint’s Bog than at Liffey Head Bog.

The microscopic charcoal profile of Ballygisheen Bog (Figure 5.9) is very different to that of All Saint’s Bog in that the majority of microscopic charcoal found in the profile occurs in the lower 50cm of the core. Similar to that of Liffey Head Bog, almost 75% of all levels counted contained microscopic charcoal. The mean concentration of charcoal counted in this profile amounts to 0.4cm³.cm⁻³; almost 58% of the levels that contain microscopic charcoal exceed the mean concentration calculated. There appears to be five peaks of charcoal present in the lower half of the profile at 97.5cm, 89.5cm, 83.5cm, 81.5cm and 51.5cm. These depths correspond to AD 826, AD 998, AD 1119, AD 1157 and AD 1632 respectively. Such peaks in values may imply that large fires occurred on or in the vicinity
of Ballygisheen Bog at these times. No charcoal was found between 25.5cm and 13.5cm which corresponds to the time period AD 1887 to AD 1956 which would suggest that this bog and its immediate surrounding landscape may have been free of fires and burning activities during this time.

5.4.3 Macroscopic Charcoal Analysis

The amount of charcoal is expressed as number of charcoal fragments per centimetre cubed (fragment number.cm^{-3}).

**Liffey Head Bog**

Figure 5.10 shows a record of the occurrence of macroscopic charcoal for Liffey Head Bog from the sievings retained on a 125μm sieve during the pollen extraction procedure. Charcoal is present at every level counted; the lowest occurring at 19.5cm where 7 number of fragments.cm^{-3} were counted. The highest value observed is at 1.5cm where close to 600 number of fragments.cm^{-3} were counted. There are three large peaks evident in the profile – at 1.5cm (557 number of fragments.cm^{-3}), 43.5cm (367 number of fragments.cm^{-3}) and 83.5cm (385 number of fragments.cm^{-3}). Values dramatically decline from the top of the profile to a low at 19.5cm after which they increase to 43.5cm. After 43.5cm the values decrease but remain higher than those between 0cm and 43.5cm. They remain relatively stable until 69.5cm after which they decline again and fluctuate to the base of the profile. Values appear higher in the lower half of the profile but overall there is a general oscillation of values throughout.

**All Saint’s Bog**

Figure 5.11 shows a record of the occurrence of macroscopic charcoal for All Saint’s Bog from the sievings retained on a 125μm sieve during the pollen extraction procedure. The highest value of macroscopic charcoal counted can be observed at 79.5cm where close to 500 number of fragments.cm^{-3} were counted. Values fluctuate in the upper half of the profile but show a gradual decreasing trend from 7.5cm to 33.5cm. After 33.5cm values dramatically increase to a high at 39.5cm, and then sharply decrease again to form a stable level between 49.5cm and 71.5cm. It is in this area that some of the lowest values of macroscopic charcoal counted occur. Values dramatically rise again to the highest values at 79.5cm and sharply decrease to the base of the profile. The lowest value occurs at
Figure 5.10 Macroscopic charcoal concentration profile for Liffey Head Bog with respect to depth.

Figure 5.11 Macroscopic charcoal concentration profile for All Saint's Bog with respect to depth.

Figure 5.12 Macroscopic charcoal concentration profile for Ballygisheen Bog with respect to depth.
87.5 cm where only 3 fragments were counted per cubic centimetre. Values are generally higher in the upper half of the profile.

**Ballygisheen Bog**

Figure 5.12 shows a record of the occurrence of macroscopic charcoal for Ballygisheen Bog from the sievings retained on a 125 μm sieve during the pollen extraction procedure. Charcoal is present at every level counted. Its values fluctuate throughout the profile but at values considerably lower to those observed in Liffey Head Bog and All Saint’s Bog. Note the scale of both Liffey Head Bog (Figure 5.10) and All Saint’s Bog (Figure 5.11) is from 0 number of fragments cm\(^{-3}\) to 600 number of fragments cm\(^{-3}\) while that of Ballygisheen Bog (Figure 5.12) is half of that, from 0 number of fragments cm\(^{-3}\) to 300 number of fragments cm\(^{-3}\). The highest value occurs at 57.5 cm where 148 number of fragments cm\(^{-3}\) were counted; the lowest at 31.5 cm where a mere 11 number of fragments cm\(^{-3}\) were counted. Overall the charcoal curve generally increases towards the middle of the profile with large peaks occurring throughout (41.5 cm, 57.5 cm and 63.5 cm) then decreases again towards the base of the profile. There appears to be three major areas with high charcoal levels – between 9.5 cm and 11.5 cm, 41.5 cm and 63.5 cm and 85.5 cm and 99.5 cm.

**5.4.4 Interpretation and Comparisons of the Macroscopic Charcoal Profiles of each Site**

Macroscopic charcoal was found at each level counted from the Liffey Head Bog profile (Figure 5.10). The highest amount of charcoal was found in the top sample at 1.5 cm where 557 fragments of macroscopic charcoal were counted per cm\(^3\). In general values appear higher in the lower half of the profile. Over 39% of the samples counted contain macroscopic charcoal levels higher than the mean number of fragments counted per cm\(^3\) (143 number of fragments cm\(^{-3}\)). There does not appear to be a general trend in the macroscopic charcoal profile. However the three peaks of charcoal described in Section 5.4.3 (83.5 cm, 43.5 cm and 1.5 cm) would suggest significant fire occurrences on or near the site at AD 873, AD 1383 and AD 1979 respectively. The most recent date may correspond with an irregular burning episode that may have been accidental or caused by local farmers (Ryan, 1992) or to the complete devastation of Powerscourt House by fire in 1974.

Similar to the Liffey Head Bog profile macroscopic charcoal was found in every level counted from the All Saint’s Bog profile. Two major peaks in macroscopic charcoal are
evident from the profile (Figure 5.11) at 79.5cm and 39.5cm. Values either side of these depths form a ‘normal distribution’ curve around the highest value. Values in the top half of the profile are significantly higher than those in the bottom half with the exception of the peak at 79.5cm. 30% of the samples counted contain macroscopic charcoal levels higher than the mean number of fragments counted per cm$^3$ (82 number of fragments.cm$^{-3}$). The mean value calculated from the Liffey Head Bog profile is almost twice that from All Saint’s Bog. The profile suggests that there were two major burning episodes recorded from the site centering around AD 1066 and AD 1584. Fire frequencies between these dates appears to be low while from AD 1584 to 1996, burning seems to have been a common occurrence.

The Ballygisheen Bog macroscopic charcoal profile (Figure 5.12) is similar to those of Liffey Head Bog and All Saint’s Bog in that macroscopic charcoal is present at every level in the profile. Unlike the other two sites, values are much lower. The mean number of fragments counted per cm$^3$ is 52 which is almost half of that calculated from All Saint’s Bog. 33% of levels exceed the mean value calculated. The three areas where higher values occur in the profile (as described in Section 5.4.3) between 99.5cm and 85.5cm, 63.5cm and 41.5cm and 11.5cm and 9.5cm correspond to AD 781 to AD 1080, AD 1465 to AD 1747 and 1965 to 1972 respectively which would suggest a higher frequency of fire occurrences during these times compared to the rest of the profile. The vegetation of Ballygisheen Bog has been affected by periodic fire and, where recent, regenerating *Molinia* predominate.

There is no absolute way of telling whether the charcoal found was caused by anthropogenically induced or natural occurring events. Both the profiles constructed and the mean values calculated for each site illustrate a definite decreasing trend in macroscopic charcoal recorded traversing from east to west across Ireland.

5.5 Comparison of the Sediment Stratigraphy, Loss on Ignition and Charcoal Results of each Site

Comparisons of the results of each of the three methods detailed in this chapter for each site are tabulated in Tables 5.6, 5.7 and 5.8 and illustrated in Figures 5.13, 5.14 and 5.15. Table 5.6 and Figure 5.13 deal with each of the results from the Liffey Head Bog profile. From this table and figure it can be seen that the change in sediment stratigraphy between
Figure 5.13
Loss on ignition and charcoal results from Liffey Head Bog plotted with respect to age.

Figure 5.14
Loss on ignition and charcoal results from All Saint's Bog plotted with respect to age.
Figure 5.15
Loss on ignition and charcoal results from Ballygisheen Bog plotted with respect to age.
AD 1766 and AD 1842 corresponds with low loss on ignition values in the profile. No charcoal was found in most of the samples examined during this time period (c.AD 1695 to c.AD 1830) but is found at either side of this time span. The only date where both microscopic and macroscopic charcoal peak simultaneously is at AD 873. This would reinforce the possibility of a fire episode occurring on or near the bog at this time.

The results of all three methods from All Saint’s Bog are presented in Table 5.7 and Figure 5.14. Similar to the Liffey Head Bog profile, a change in sediment stratigraphy corresponds to lower loss on ignition values in the core. This occurs at c.1964. A peak of microscopic charcoal levels is also present at this date. The earlier change in sediment stratigraphy at AD 1415 does not appear to correspond with a lowering in loss on ignition values or a higher frequency of charcoal in the profile. Another similar feature to the Liffey Head Bog profile is the lack of high charcoal values during the period of lower loss on ignition values between AD 1778 and AD 1882. This phenomenon is not repeated with the more recent decrease in loss on ignition values as this period corresponds with one of high microscopic charcoal values. The lower half of the All Saint’s Bog profile only has one incidence of high charcoal levels; those of macroscopic charcoal at AD 1066.

Table 5.8 and Figure 5.15 illustrate the results from the Ballygisheen Bog profile. The loss on ignition values for this site do not increase or decrease significantly throughout. Only one change in stratigraphy occurs in the profile, at AD 1872, and does not appear to correspond to any changes in the loss on ignition or charcoal values at this time. Three of the microscopic charcoal peaks observed correspond with high levels of macroscopic charcoal which would suggest a higher probability of fire occurring during these times compared to the high levels of only macroscopic charcoal occurring at AD 1119 and AD 1157.
Table 5.6 Table of dates at which changes occur in the sediment stratigraphy, loss on ignition and charcoal profiles of Liffey Head Bog

<table>
<thead>
<tr>
<th>Time</th>
<th>Sediment Stratigraphy</th>
<th>Loss on Ignition</th>
<th>Charcoal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>-45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>-29</td>
<td></td>
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</tr>
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<tr>
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</tr>
<tr>
<td>1827</td>
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<td>low loss on ignition</td>
</tr>
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<tr>
<td>1676</td>
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<td>↓ loss on ignition</td>
<td></td>
</tr>
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<td>771</td>
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↑ increase in values  ↓ decrease in values  ↑↑ peak in high values
Table 5.7 Table of dates at which changes occur in the sediment stratigraphy, loss on ignition and charcoal profiles of All Saint’s Bog

<table>
<thead>
<tr>
<th>Time</th>
<th>Sediment Stratigraphy</th>
<th>Loss on Ignition</th>
<th>Charcoal</th>
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<td>↑ loss on ignition</td>
<td>high microscopic</td>
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</tr>
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<td>high microscopic</td>
</tr>
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<td>high microscopic</td>
</tr>
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↑ increase in values  ↓ decrease in values  ↑↑ peak in high values
Table 5.8 Table of dates at which changes occur in the sediment stratigraphy, loss on ignition and charcoal profiles of Ballygisheen Bog

<table>
<thead>
<tr>
<th>Time (AD)</th>
<th>Calib. C^{14} yrs BP</th>
<th>Sediment Stratigraphy</th>
<th>Loss on Ignition</th>
<th>Charcoal</th>
</tr>
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<td>1872</td>
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<td>change in sediment</td>
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</tr>
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<td>high macroscopic</td>
</tr>
<tr>
<td>1632</td>
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<td></td>
<td>high macroscopic</td>
</tr>
<tr>
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<td>485</td>
<td></td>
<td></td>
<td>high macroscopic</td>
</tr>
<tr>
<td>1157</td>
<td>793</td>
<td></td>
<td>↑↑ microscopic</td>
<td></td>
</tr>
<tr>
<td>1119</td>
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<td></td>
<td>↑↑ microscopic</td>
<td></td>
</tr>
<tr>
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<td>high macroscopic</td>
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<td>↑↑ microscopic</td>
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<tr>
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</tr>
</tbody>
</table>

↑ increase in values  ↓ decrease in values  ↑↑ peak in high values
VI Regional Pollen

6.1 Introduction

The aim of this chapter is to provide a formal description of the regional pollen component of each of the three sites in order to construct a picture of what was happening in the landscape surrounding each site over time. Comparisons will be made between each site to see if changes in the vegetation component of the surrounding landscape of each is similar to and/or synchronous or very different to one another. Similarities between the physical characteristics of each site (sediment stratigraphy, loss on ignition and charcoal) and the regional pollen data will be included in the comparison and interpretation. Comparisons will also be made between the data from the three sites investigated and other sites covering a similar time period in Ireland.

A total of 47 sub-samples from Liffey Head Bog, 47 sub-samples from All Saint’s Bog and 52 sub-samples from Ballygisheen Bog were analysed for fossil pollen. A depth sampling interval of 2cm was used in each site. The most suitable age-depth model for each site (see Chapter IV) was used to provide a chronology for percentage regional pollen diagrams for same (Figures 6.1, 6.2 and 6.3).

6.2 Numerical Zonation of Regional Pollen Diagrams

The results of the constrained incremental sum of squares (CONISS) analysis for each site is presented in the form of dendrograms in Figures 6.4, 6.5 and 6.6. The first two divisions of the Liffey Head Bog CONISS analysis (as illustrated in Figure 6.4) at 14.5cm and 42.5cm were found to be statistically significant according to the broken stick model (Bennett, 1996); the graph of which is illustrated in Figure 6.7. Similarly the first division of the All Saint’s Bog CONISS analysis (as depicted in Figure 6.5) at 22.5cm and the first two divisions of the Ballygisheen Bog CONISS analysis (as depicted in Figure 6.6) at 10.5cm and 38.5cm were found to be statistically significant. The broken stick models for these two sites are shown in Figures 6.8 and 6.9 respectively. These divisions were used to divide the data into local pollen assemblage zones and were given the prefixes LH (after Liffey Head Bog), AS (after All Saint’s Bog) and BG (after Ballygisheen Bog) respectively. The main features of each of the local pollen assemblage zones (according to site) are detailed below.
Figure 6.1
Liffey Head Bog
Regional pollen percentage diagram
Figure 6.2
All Saint's Bog
Regional pollen percentage diagram
Figure 6.4
Liffey Head Bog
CONISS analysis (regional)

Figure 6.5
All Saint’s Bog
CONISS analysis (regional)

Figure 6.6
Ballygisheen Bog
CONISS analysis (regional)
Figure 6.7 Variance accounted for by the CONISS zonation of Liffey Head Bog regional pollen as a proportion of the total variance (full line) compared with values from the broken stick model (dashed line). The point where the two lines cross gives an indication of the number of statistically reliable zones. In this pollen dataset three zones are proposed.

Figure 6.8 Variance accounted for by the CONISS zonation of All Saint's Bog regional pollen as a proportion of the total variance (full line) compared with values from the broken stick model (dashed line). The point where the two lines cross gives an indication of the number of statistically reliable zones. In this pollen dataset two zones are proposed.
Figure 6.9 Variance accounted for by the CONISS zonation of Ballygisheen Bog regional pollen as a proportion of the total variance (full line) compared with values from the broken stick model (dashed line). The point where the two lines cross gives an indication of the number of statistically reliable zones. In this pollen dataset three zones are proposed.
6.3 Results of Regional Pollen Analysis

6.3.1 Liffey Head Bog

LH 1: *Alnus* - Coryloid - Gramineae; 91.5cm-42.5cm; 1,179BP-555BP; AD 771-AD 1395

The percentage of arboreal pollen begins at the base of the zone at values over 80% but decreases towards the top of the zone to approximately 50% (Figure 6.1). *Alnus, Betula* and Coryloid pollen account for most of this spectrum with the occurrence of *Fraxinus* (<10%), *Quercus* (<15%), *Salix* (>5%) and *Ulmus* (>5%) also. Most of the individual arboreal pollen curves remain stable with some showing gradual decreases towards the top of the zone i.e. *Alnus, Fraxinus, Quercus* and Coryloid. The Coryloid curve decreases from approximately just over 35% at the base of the zone to values close to 20% at the top. *Pinus* is present intermittently/sporadically throughout the zone.

The non-arboreal component of this zone mainly consists of Gramineae, *Plantago* and *Pteridium*. There are also many other types of herb pollen present but at values of less than 5%. Many of these are present sporadically with some only occurring once or twice in the zone. The Gramineae curve exhibits a general increase towards the top of the zone, rising from values of just over 10% at the base to almost 25% at the top. The *Plantago* values remain fairly stable throughout the zone while those of *Pteridium* show a general trend of increasing values towards the top from less than 5% at the base of the zone to an excess of 15% at the top. A peak of *Pteridium* values can be observed in the lower half of the zone at 81.5cm where they reach almost 16%. Cereal-type pollen, although present, is not continuous throughout this zone. It appears at the base of the zone at values of less than 1% but is continuous from 67.5cm and increases steadily to the top of the zone. Values for Cereal-type however never exceed 3%. Filicales are present throughout while *Polypodium* occurs intermittently.

LH 2: *Betula* - Coryloid - Gramineae; 42.5cm-14.5cm; 555BP-154BP; AD 1395-AD 1796

Throughout this zone the arboreal pollen curve exhibits a decreasing pattern from values of just under 50% at the base to less than 25% at the top. The major contributors to this curve are again *Alnus, Betula* and Coryloid pollen, and to a lesser extent, *Fraxinus, Quercus* and *Ulmus*. All the above mentioned taxa are present at lower values to those in LH-1. *Alnus,*
Betula, Quercus, and especially Coryloid pollen decrease towards the top of the zone (the latter from values of close to 15% at the base to less than 8% at the top). Both Fraxinus and Ulmus appear to remain pretty stable throughout. Pinus is present throughout most of the zone but at very low percentages (>1%). However from 21.5cm it is present continuously and rises from less than 1% at this level to almost 3% at the top of the zone.

The non-arboreal part of this zone consists mainly of Gramineae, Plantago and Pteridium, and to a lesser extent, Cereal-type, Filipendula and Ranunculaceae. There are many other types of herb pollen present intermittently in this zone also but again at percentage values of less 5% and some only occurring once or twice in the zone (i.e. Prunus, Centaurea-type). The Gramineae curve shows a general increase towards the top of the zone with values higher than those in LH-1. It rises at the base of the zone to a high of almost 38% but decreases and then generally increases to the top. The Plantago curve exhibits an overall increase of values to the top of the zone, from less than 1% (base) to just over 15% (top). Pteridium values remain fairly stable throughout but slightly decrease at the base of the zone, gradually increase again and then after 19.5cm decrease to the top of the zone. Cereal-type pollen is present remaining below 4% throughout. It does however decrease towards the middle of the zone dropping to values of less than 1%. Values at either extreme of the zone are approximately 3%. Both Filipendula and Ranunculaceae are present consistently in this zone albeit at percentages of less than 5%. Both curves are stable throughout. Huperzia appears at 21.5cm and rises towards the top of the zone.

LH 3: Pinus - Gramineae - Plantago; 14.5cm-0cm; 154BP -45BP; AD 1796-AD 1995

Arboreal pollen exhibits an overall increase in presence throughout this zone but never reaches values close to those in LH-1. The main arboreal components of this zone are Alnus, Betula, Pinus, Quercus, Coryloid and, to a lesser extent, Fagus, Fraxinus and Ulmus. Alnus percentages remain constant throughout lying between 1% and 4%. The Betula curve increases from the base of the zone (1%) to the top (11%). Pinus is present throughout this zone and exhibits a definite and steady increase towards the top where it reaches values close to 30%. The Quercus curve gradually increases towards the top of the zone but is present at lower percentages compared to LH-1 and LH-2. Its highest value in this zone is 6% at 0cm. The lowest values of the whole profile for Coryloid pollen lies in this zone where there is a gradual trend of decreasing values to the top of the zone. These values never reach higher than 7%. Fagus, Fraxinus and Ulmus all occur in this zone,
albeit at low percentages (all under 7%), and remain constant with the exception of *Fraxinus* which shows a general decrease towards the top of the profile. Non native arboreal pollen are also found in the zone i.e. several grains of *Tilia*, *Picea* and *Carpinus* were identified.

The non arboreal portion of this zone comprises mainly of Gramineae, *Plantago*, Ranunculaceae and *Pteridium*. Again there are many other types of herb pollen present intermittently in this zone also but at percentage values of less 5% and some only occurring once or twice in the zone (i.e. *Prunus*, *Rhinanthus*). The Gramineae curve accounts for most of the non arboreal pollen as it reaches values close to 60% in this zone. *Plantago* values exhibit an overall decrease towards the top of the zone, falling from a value of 18% at the base to just under 2% at 0cm. Ranunculaceae values remain fairly constant throughout but never reach higher than 2%. The *Pteridium* curve exhibits an overall decrease from the base to the top of the zone, with values of 5% at the base to 2% at 0cm. The Cereal-type curve consists of very low values, but once exaggerated exhibit a ‘dipped’ curve that decreases towards the middle of the zone and increases again towards the top. Values drop to less than 1% in the middle of the zone. *Huperzia* decreases from the base of the zone to a final petering out at 3.5cm. It does not reappear in the rest of the zone.

6.3.2 All Saint’s Bog

AS 1: *Alnus* - Coryloid - *Pteridium*; 91.5cm-22.5cm; 1,036BP-146BP; AD 914-AD 1804

Arboreal pollen is the dominant portion of this zone with values of 90% at the base of the profile (Figure 6.2). The arboreal pollen curve exhibits an overall decrease towards the top of the zone where it has values of approximately 40%. This decrease is gradual but steady up to approximately 31.5cm (75%) where after this level it decreases at a steeper rate. The main component of the arboreal curve is Coryloid pollen followed by *Alnus*, *Betula*, *Quercus* and, to a lesser extent, *Fraxinus* and *Ulmus*. The Coryloid curve remains fairly constant at high percentages (between 43% and 70%) up until 31.5% after which it decreases rapidly to values close to 9% at the top of the zone. *Alnus* percentages exhibit a gradual decreasing pattern towards the top of the zone from close to 20% at the base to just over 5% at the top. The *Betula* curve remains constant throughout (values between 1% and 7%) with the exception of a minor increase at 25.5cm, to 10%, followed by a decrease to the top of the zone. *Quercus* values also show a gradual decreasing pattern towards the top.
of the zone. They never reach higher than 12%. Both *Fraxinus* and *Ulmus* are present throughout at percentages of approximately 7% and 5% respectively. They too show a very gradual decrease towards the top of the zone. *Pinus* pollen is present intermittently/sporadically throughout this zone at values of less than 1%. *Salix* is also present but again at very low percentages.

The non arboreal part of this zone comprises mainly of Gramineae, *Plantago*, and *Pteridium*. Many other herbs are present in this zone but at very low percentages, some only occurring once or twice in the zone (i.e. Caryophyllaceae, Leguminosae and *Galium*). Percentages of Gramineae appear to be constant throughout with percentages lying between 1% and 13%. They do show a very gradual increase in values however, towards the top of the zone which is especially evident after 31.5cm. Values rise to 22% at the top of the zone. Values for *Plantago* are low at the base of this zone, never rising above 5% but after 45.5cm they tend to increase towards the top of the zone where they reach almost 20%. The *Pteridium* curve exhibits a general increase also towards the top of the zone. Within this general increasing pattern there are two areas of higher values, one at 51.5cm (11%) and another at 35.5cm (15%). Cereal-type pollen is present (at very low percentages of less than 1%) in this zone but not consistently throughout. The *Filipendula* curve also shows a trend of increasing values towards the top of the zone but this is more evident with exaggeration. Its percentages are very low and is not present at every level but from 35.5cm onwards its abundance increases to the top of the zone. Filicales and *Polypodium* percentages are present at most levels at very low percentages.

AS 2: *Pinus* - Gramineae - *Plantago*; 22.5cm-0cm; 146BP - 46BP; AD 1804-AD 1996

The arboreal pollen curve shows a decrease in values from the base of the zone to approximately 17.5cm after which it increases steadily to the top of the profile. It reaches a value of just over 55% at 0cm. The main components of the arboreal pollen are *Pinus* and Coryloid and, to a lesser extent, *Alnus*, *Betula*, *Fraxinus*, *Ulmus* and *Fagus*. The *Pinus* curve shows a steady increase in values towards the top of the profile from 0% at 19.5cm to 19% at 3.5cm. The values then decrease towards the top to 10% at 0cm. Coryloid percentages are dramatically lower than those in AS-1. They show a general trend of decreasing slightly from the base of the zone to approximately 17.5cm then remain stable until 3.5cm after which they increase to the top of the profile to just over 20%. *Alnus*, *Betula*, *Fraxinus*, and *Ulmus* all exhibit the same pattern of having low values compared to
those in AS-1 and gradually increase towards the top of the zone. *Fagus* appears for the first time in the profile in this zone at 15.5cm and increases slightly towards 0cm. Its percentage values remain low throughout (less than 1%-3%). Other non native arboreal pollen are found in this zone i.e. several grains of *Carpinus* and *Picea* and one each of *Tilia* and *Juglans* were identified.

The non arboreal portion of this zone is represented in the main by Gramineae pollen. *Plantago, Pteridium, Cereal-type and Rumex* sp. also play a role. Gramineae values increase steadily to the top of the zone increasing from 27% at the base to 54% at 3.5cm. The percentages then decease to 30% at 0cm. *Plantago* has larger values in this zone than in AS-1. Percentages start off at the base of the zone at approximately 22% but decrease after 9.5cm to a low of 3% at the top of the profile. This decrease in values is very steep. The *Pteridium* curve exhibits a very similar trend to that of *Plantago*. Its values are high (26% at 19.5cm) at the base of the zone (again, higher than those in AS-1) and then generally decrease towards the top of the zone. The decrease in percentages is however more gradual than that observed in *Plantago*. Cereal-type and *Rumex* sp. are continuous throughout the zone and show similar trend of increasing slightly from the base of the zone to the middle and then decreasing slightly to the top. Both have low percentage values of approximately 3% at their highest abundance. There are many other types of herb pollen present intermittently in this zone, but at percentage values of less than 5% and some only occurring once or twice in the zone (i.e. *Cirsium, Urtica* and *Rhinanthus*). Spores of *Polypodium, Huperzia* and Filicales were also found in this zone.

6.3.3 Ballygisheen Bog

BG 1: *Betula - Coryloid - Gramineae; 100.5cm-38.5cm; 1,192BP-173BP; AD 758-AD1777

The percentage of arboreal pollen begins at the base of this zone at approximately 45%, rises somewhat and then decreases overall to the top of the zone where it accounts for less than 20% of the pollen counted (Figure 6.3). It never rises above 65% throughout. Coryloid accounts for most of the arboreal pollen present followed by *Betula, Alnus* and *Quercus*. The Coryloid curve exhibits a general and steady decrease towards the top of the zone. It starts off at just under 10% but increases to a high of 29% at 83.5cm and then decreases to 7% at the top of the zone. The *Betula, Alnus* and *Quercus* curves all have a similar trend of decreasing values towards the top of the zone. Their percentage values
never rise above 20% with the exception of Betula where it has a value close to 25% at 91.5cm. Other arboreal taxa are present such as Fraxinus, Salix, Ulmus and Pinus but intermittently and at low percentages throughout. Non native arboreal species are also found in this zone i.e. grains of Fagus, Tilia, Carpinus and Juglans were identified.

The non arboreal portion of this zone comprises mainly of Gramineae. Plantago, Pteridium and Ranunculaceae also play a role albeit minor. There are also many other types of herb pollen present but at values of less than 2% and many only occur once or twice in the zone. The Gramineae curve fluctuates throughout but has an overall increasing tendency towards the top of the zone. It reaches a high of 59% at 43.5cm. Plantago values also gradually increase towards the top of the zone. Its values are much lower than those of Gramineae and lie below 10% at its highest occurrence. The Pteridium curve mirrors that of Plantago but, unlike the latter, increases steeply from 43.5cm to 18% at the top of the zone. Its percentages are slightly higher than those of Plantago throughout. Ranunculaceae values remain fairly stable throughout never reaching higher than 3%. Cereal-type occur in this zone but only in a few levels and only then with one or two occurrences. Polypodium and Filicales are present sporadically at low percentages while Huperzia and Osmunda occur once in this zone.

BG 2: Gramineae - Plantago - Pteridium; 38.5cm-10.5cm; 173BP- -18BP; AD 1777-AD 1969

The arboreal portion of this zone has the lowest percentage values for the entire profile. It exhibits a gradual increasing trend towards the top of the zone but values never reach beyond 20%. In this zone the arboreal component consists of mainly Pinus, Betula and Coryloid. There are also continuous curves of Alnus and Fraxinus present with the sporadic occurrence of Fagus, Salix and Ulmus and the occasional grain of Carpinus, Ilex and Sambucus. The Pinus curve increases gradually to the top of the zone, and rises from less than 1% at the base to over 7% at 10.5cm. The Betula and Coryloid percentages remain pretty stable throughout but are lower than those in BG-1. Alnus and Fraxinus also remain stable throughout the zone both below 3%.

Similar to BG-1, the dominant component of the non arboreal pollen portion is Gramineae. Values for Plantago and Pteridium are higher than those in BG-1. Again many other types of herb pollen are present but at very low percentages and some only occurring once or twice in the zone i.e. Caryophyllaceae, Leguminosae, Urtica, Artemisia and Rhinanthus.
The Gramineae curve exhibits a somewhat stable curve with high values throughout with an increase in values occurring at the base of the zone. Values fluctuate between 51% and 62% after the increase at the base. *Plantago* percentages tend to be significantly larger than those in BG-1 and decrease from approximately 15.5cm (18%) to the top of the zone (12%). The *Pteridium* curve does not mirror that of *Plantago* as it decreases quite swiftly from values as high as 33% at the base to approximately 5% at the top of the zone. Cereal-type pollen is present in this zone but at very low percentages (>1%). *Rumex* undiff. is present continuously and at percentages higher than those in BG-1. So too is Ranunculaceae but at lower percentages than in the previous zone. Filicales spores are present throughout at low percentages (<1%) while *Polypodium* spores occur sporadically with only one or two spores present in the zone.

BG 3: *Pinus* - Gramineae - *Plantago*; 10.5cm-0cm; -18BP- -47BP; AD 1969-AD 1997

The percentage of arboreal taxa increases dramatically in this zone reaching values higher than those at the base of the profile. The dominant arboreal taxon in this zone is *Pinus* followed by *Betula* and Coryloid. Many other arboreal taxa occur in this zone but at very low percentages. Such taxa include *Fraxinus*, *Salix* and *Ulmus* and non native arboreal pollen such as *Fagus*, *Picea*, *Carpinus* and *Juglans*. The *Pinus* curve increases dramatically to the top of the profile from values of approximately 12% at the base to close to 43% at the top. *Betula* percentages also increase to the top of the zone but never reach the high values it had in BG-1. The Coryloid curve remains stable throughout never rising above 6%. *Alnus* and *Quercus* values also remain stable throughout at similar values to those in BG-2.

The non arboreal part of this zone is again dominated by Gramineae. Similar to BG-1 and BG-2, *Plantago* and *Pteridium* also play a role. Again many other types of herb pollen are present but at very low percentages with some only occurring once or twice in the zone i.e. Caryophyllaceae, Chenopodiaceae, Leguminosae, *Galium*, *Artemisia* and *Filipendula*. The Gramineae curve exhibits a general decrease in values towards the top of the profile. It falls from values close to 60% to less than 32% at the top of the zone. The *Plantago* and *Pteridium* percentages have similar patterns to one another in that they both decrease steadily towards the top of the profile. *Plantago* values drop from just under 15% to under 3% while *Pteridium* values fall from 4% to just under 1%. Cereal-type pollen is absent from this zone. Filicales are present at very low percentages.
6.4 Interpretation and Comparisons of the Regional Pollen Component of each Site

In order to compare the three regional pollen diagrams that were produced from this study it was decided to plot each with respect to age (Figures 6.10, 6.11 and 6.12). In these percentage diagrams age is the primary axis while depth is the secondary one. Such diagrams provide an image of the sedimentation rate of the site as the nature of the diagrams stretches out or bunches together the sample depths according to when each sample was deposited. Plotting the diagrams in this way also provides a common scale for all three sites which simplifies comparisons between them. Figure 6.13 was also drawn to illustrate the zone boundaries of each site relative to one another. Pollen concentration diagrams were constructed from the original counts from each site (Figures 6.14, 6.15, 6.16). Pollen concentration values facilitate the intersample comparison within a profile without the possible distortion which may result in the percentage curves from the local dominance of a single taxon or few taxa (O'Connell, 1986).

6.4.1 Liffey Head Bog

The lower zone (LH 1) of the regional pollen diagram of Liffey Head Bog (Figure 6.10) suggests a landscape composed of mixed woodland with some open areas. The composite trees curve decreases throughout this zone. The dominant trees during this time period (AD 771-AD 1395; 1,179BP-555BP) appear to be *Alnus, Betula, Coryloid*, and *Quercus*. The term Coryloid refers to both *Corylus* and *Myrica*. *Myrica* grows on peaty areas, but does not usually grow in nutrient poor areas such as Liffey Head Bog. It can therefore be assumed that Coryloid in this case refers to mainly *Corylus* pollen. Gramineae percentages increase throughout this time period and along with the continuous presence of *Plantago lanceolata, Pteridium* and, to a lesser extent Ranunculaceae and *Rumex* sp., suggest open grassland/pasture areas in the landscape surrounding Liffey Head Bog. *Plantago lanceolata* is considered to be the classic anthropogenic indicator of pasture land (Behre, 1981); due to its high light requirements it will not grow in grazed woodlands. Agricultural activity, in the form of arable practices, is evident at this time from the presence of Cereal-type pollen grains, albeit at low percentages. *Centaurea*-type and *Rumex acetosella* (both reliable arable indicators (Behre, 1981)) appear sporadically during this time.
Figure 6.10
Liffey Head Bog
Regional pollen percentage diagram plotted with respect to age.
Figure 6.11
All Saint's Bog
Regional pollen percentage diagram plotted with respect to age
Figure 6.12
Ballygisheen Bog
Regional pollen percentage diagram plotted with respect to age.
Figure 6.13 Diagram of regional pollen zone boundaries of each site drawn with respect to age.
Figure 6.14
Liffey Head Bog
Concentration Diagram of Main Regional Taxa
(plotted with respect to age)
Figure 6.15
All Saint's Bog
Concentration Diagram of Main Regional Taxa
(plotted with respect to age)
Figure 6.16
Ballygisheen Bog
Concentration Diagram of Main Regional Taxa
(plotted with respect to age)
Similar trends are evident in LH 2 (AD 1395-AD 1796; 555BP-154BP) as woodland cover decreases to lower values while Gramineae percentages increase. *Alnus, Betula, Coryloid, Fraxinus* and *Quercus* decrease as the indicators of open pasture areas increase in abundance. Cereal-type pollen percentages increase also suggesting an increase in arable farming practices during this time. From c.1760 onwards cereal cultivation expanded in Ireland in response to growing British markets (Whelan, 1997).

The loss on ignition curve follows a similar trend to that of the composite sums trees and shrubs curve in this time period. The latter part of the curve may reflect an increase in erosion as trees were cleared from the region due to pressures on land use as the population of Ireland expanded prodigiously. This would have led to the erosion of the slopes surrounding Liffey Head Bog. This major expansion began c.1760 as the population began to use poor hill and bog areas for land (Whelan, 1997). This corresponds nicely with the steep decrease in loss on ignition levels from AD 1736 (214BP) to AD 1796 (154BP). The highest amount of macroscopic charcoal is recorded in the profile from AD 1661 (289BP) to AD 1691 (259BP) which may indicate an increase in land clearance for agricultural use. Dodson (1990) concluded that fire played a significant role in land management practices from correlations he found between high charcoal and Cereal-type pollen levels.

Woodland cover appears to begin an increase to its former levels in LH 3 (AD 1796-1995; 154BP- -45BP). During this time period all tree species increase with the exception of Coryloid. This is also evident from the concentration diagram (Figure 6.14). Non-native tree species such as *Tilia, Fagus* and *Picea* begin to appear in the profile. *Fagus* pollen increases in abundance from c.1811. *Fagus* was first extensively planted in Co. Wicklow at the end of the 18th Century (Forbes, 1933) and so was presumably contributing to the regional pollen deposition by the mid 19th Century (Bowler and Bradshaw, 1985). Tree taxa constitute almost 60% of the regional pollen at the top of the profile yet no trees are present in the immediate locality today. These pollen types must arrive at the bog from regions far from the coring site which reflects the regional pollen source area of Liffey Head Bog.

*Pinus* values are extremely low and, in some places, absent from the profile. *Pinus* values do however appear and start to increase from c.1842 (109BP) to the present day. In 1837, when Queen Victoria was coronated (Poole and Finch, 1953), a coronation Pine plantation was planted approximately 4km south west of Liffey Head Bog to mark her coming to the
Allowing approximately 10-15 years for Pinus to mature and flower (Pinus sylvestris trees can set seed as young as 6 years (Carlisle and Brown, 1968)), and assuming that the Pinus increase observed in the pollen diagram is due to the Pine plantation, this coincides quite well with the time-depth curve constructed for Liffey Head Bog. This date also ties in nicely with time data calculated by Mitchell et al. (1991) from Kippure which is adjacent to Liffey Head Bog.

Although Gramineae values are high during LH 3, Coryloid, Plantago lanceolata, Rumex sp., Ranunculaceae and Cereal-type appear to decrease. This may be due to a more intensive form of agriculture being practiced where increasing additions of fertiliser to the land to improve pasture for grazing would cause an increase in grasses but would also cause a decrease in Coryloid and anthropogenic and weedy indicator species. Coryloid pollen begins to decline at c.1751 (199BP) which may reflect the increase in pressure on the land prior to the Great Famine of AD 1845 when the population of Ireland was at its highest at close to 9 million people (Whelan, 1997). The loss on ignition curve for LH 3 reaches high percentages after AD 1860 (94BP). This may reflect the retreat of people from the poorer hill and bog areas that had been so assiduously colonised in the pre famine period (Whelan, 1997) as erosion declined due to decreases in land usage.

6.4.2 All Saint’s Bog

The landscape surrounding All Saint’s Bog in the time period AD 914 to AD 1804 (1,036BP-146BP) (as suggested by AS 1 in Figures 6.11 and 6.15) appears to be one dominated by mixed woodland with small amounts of open areas present. According to Aalen (1978) both Laois and Offaly were thickly wooded areas until approximately the early 15th Century. The landscape is dominated by Coryloid, Alnus, Betula and Quercus. In this case Coryloid refers to both Corylus and Myrica as Myrica is found forming part of the undergrowth of the pine and birch woodland that grows on part of the intact area of All Saint’s Bog. Low percentages of Gramineae and Plantago lanceolata are present throughout this time period which would suggest the presence of some open pasture land in the vicinity of the site. Cereal-type, Ranunculaceae and Rumex sp. are also found during this time indicating the presence of anthropogenic influences in the landscape. Farm land was primarily used for pasture during this time while tillage was practiced on a smaller scale (Parkes, 1987; Turbridy, 1987a).
Tree pollen appears to decrease in abundance from AD 1247 (703BP) and declines to approximately 60% at AD 1791 (159BP). The decline in tree abundance seen between AD 1610 (340BP) and AD 1636 (314BP) may reflect the felling of the Great Woods of Clonmacnoise which took place in 1622 (Tubridy, 1987b). From approximately AD 1714 (236BP) onwards this decline is particularly evident especially from the Coryloid curve. This dramatic decline in Coryloid is also evident from Clara Bog in Co. Offaly but it occurs at a much earlier date of approximately 510BP (Connolly, 1999). Van der Molen (1988) carried out a palaeoecological study on Woodfield Bog, near Clara, Co. Offaly and found that Corylus decreased dramatically from AD 1733. He attributes this decline to the cutting of hazel scrub for the creation of plantations and demesnes in the area. The decrease in Coryloid values illustrated in Figure 6.11 may well reflect this clearing of scrub. At the same time Gramineae, Plantago lanceolata, Pteridium and Cereal-type increase. There does not appear to be a decrease in Cereal-type pollen around the time of the Great Famine of 1845 as is evident in other diagrams (Van der Molen, 1988). Anthropogenic indicators such as Rumex sp. and Chenopodiaceae also increase in abundance. The increase in Gramineae and Pteridium suggests an opening up of the landscape compared to previous times while those of Plantago lanceolata and Cereal-type suggest both pastoral and arable agriculture increasing in the surrounding landscape. An increase in Compositae tubuliflorae at the onset of the Pinus increase may reflect the ploughing of fields for intended plantations (Van der Molen, 1988).

Tree pollen begins to increase again after approximately AD 1869 (81BP) to the present day but this appears to be mainly due to increases in Pinus, Quercus and the appearance of non native species such as Tilia, Picea, and Carpinus from the late 19th/early 20th Century. This does not agree with research carried out by Van der Molen (1988) in Co. Offaly where tree pollen was seen to decrease from approximately 1960 to the 1988. The increase in trees is not very large however as Gramineae values are still increasing during this time. A close source of both Pinus and Betula for this time period is the pine and birch woodland that extends over 20ha in the centre of All Saint’s Bog. A study carried out by Heery (1993) on this pine and birch woodland concludes that the birch trees are a relict population resulting from a more extensive pre-dating stand. This theory is supported by the discovery of the dipteran Dcitenidia bimaculata (O’Connor and Speight, 1987) in a rotting birch stump in the wood. This species forms part of the ancient fauna of Europe and so Betula pollen found throughout this profile may well come from this source. Heery (1993) also concluded that the relatively recent invasion of Pinus resulted from the
reintroduction of this tree into Ireland and that it is most likely that the trees invaded the bog by self seeding from pines planted in the vicinity.

Peaks of macroscopic charcoal seen in the All Saint’s Bog profile (Figure 5.11) may reflect the tradition of ‘boiting’ of agricultural land. This involved the paring and burning of soil and vegetation and was practiced up until the early 19th Century (Tubridy, 1987a). The large peaks observed in both the microscopic charcoal (Figure 5.8) and macroscopic charcoal (Figure 5.11) records at c.1965 is thought to reflect the establishment of the Shannonbridge Power Station by the ESB at this time (Tubridy, 1987c).

The loss on ignition curve for All Saint’s Bog (Figure 5.5) seems to reflect the composite sums tree curve over the entire profile. The lowest loss on ignition value coincides with that of the lowest tree percentage at AD 1882 (68BP). This may reflect the clearance of esker woodland for land use or for sand and gravel extraction purposes. Such extraction work would cause land disturbance which would encourage the establishment of weedy species such as Chenopodiaceae and Rumex sp. Both of these plant groups reach their highest values at this time.

Plantago lanceolata values decrease from 1947 (3BP) onwards while those of Gramineae begin to decline from 1973 (-23BP). Cereal-type also decreases from this time which, along with the increase in Coryloid values, suggests a decline in agricultural activity in this time period. Tillage farming has decreased over time (which would cause a decline in Cereal-type pollen) and since the 1930s over 90% of farm land in the surrounding landscape has been used for pasture (Tubridy, 1987a).

6.4.3 Ballygisheen Bog

From AD 758 (1,192BP) to AD 1777 (173BP) the landscape surrounding Ballygisheen Bog (Figure 6.12) appears to be one of mixed woodland with quite a substantial amount of open grassland present. Tree pollen never exceeds 70% throughout this time period and is composed of Betula, Coryloid, Alnus and Quercus. Similar to the scenario at Liffey Head Bog, Coryloid refers to mainly Corylus pollen. A significant portion of open landscape is evident from the high percentages of Gramineae present throughout. This, along with the continuous stable presence of Plantago lanceolata and the sporadic occurrence of Cereal-type pollen, would suggest that pastoral agriculture was the predominant form of
agriculture practiced during this time. The presence of other pastoral indicators such as *Rumex* sp. and Ranunculaceae reinforce the presence of this kind of agriculture.

Tree pollen begins to decline from approximately AD 1465 (485BP) to its lowest value at AD 1824 (126BP). This can be seen in all the tree taxa curves at this time, from both percentages and pollen concentrations (Figures 6.12 and 6.16). Gramineae and *Plantago lanceolata* increase during this time which would suggest the clearance of land for agricultural use. This time period corresponds to high amounts of charcoal present in both the microscopic (Figure 5.9) and macroscopic charcoal (Figure 5.12) records for the site and may indicate the use of fire for such a clearance of wooded areas for agricultural land. The declines in *Quercus* and *Betula* c.1747 (200BP) correspond with those found in Uragh Wood at the same time (Little *et al.*, 1996) which both coincide with a period of widespread woodland exploitation for charcoal to fuel iron smelters in the Kerry region (McCracken, 1971). This theory fits in with the high charcoal levels as mentioned previous. The highest charcoal levels found in the microscopic record (Figure 5.9) do not correspond with any significant change in the pollen record for the site. The peak in *Pteridium* values from AD 1767 (183BP) to AD 1824 (126BP) supports the theory of the opening up of the landscape as this fern does sporulate well under shaded conditions. This time period was also that when the population grew at an enormous rate prior to the Great Famine (Whelan, 1997). During this time poorer land was cleared to cater for the needs of the growing population and so fits in well with the clearing of the landscape as illustrated during this time period in Figure 6.12.

From 1887AD (63BP) to the present day an increase in tree species occurs. This can be seen from the native trees present but also from the arrival of non native trees such as *Fagus, Picea, Carpinus* and *Juglans*. From around AD 1700 onwards evidence of such introduced species can be seen in various pollen diagrams across the country (Edwards, 1985). Evidence has been provided by Lynch (1981) to suggest that both *Fagus* and *Juglans* were introduced into the Kerry area as early as Norman times (13th Century). The introduction and increase in *Picea* percentages from 1985 (-35BP) to the present day is thought to have been caused by the sitka spruce plantation that was established on the eastern edge of the bog by Coillte in 1979 (Maurice Lynch, pers. comm.). *Pteridium* values steadily decrease from AD 1887 (63BP) onwards reflecting the closing in of the landscape as trees cause shade conditions to increase. Both microscopic and macroscopic
charcoal levels are at their lowest values during this time period (AD 1887 to present day) suggesting that fire occurrences were at a minimum.

Neither *Centaurea* nor Cereal-type pollen are found in the profile between 1969 (-18BP) and 1997 (-47BP) suggesting that arable farming plays only a minor, if any, role in agricultural practices in recent times. It would appear that pastoral farming had also declined in recent years from the decrease in Gramineae and *Plantago lanceolata* values observed.

The loss on ignition curve for Ballygisheen Bog (Figure 5.6) remains static throughout suggesting no erosion or deposition of inorganic materials onto the site occurred during this time.

### 6.4.4 Comparison of Sites

Figure 6.13 illustrates the position of each of the zone lines that were constructed from the regional pollen assemblages of each site. It would appear that only one zone line corresponds at each of the three sites investigated, namely that at AD 1796 (154BP) in Liffey Head Bog, AD 1804 (146BP) in All Saint’s Bog and AD 1777 (173BP) in Ballygisheen Bog. No other zone lines match between the three sites. This matching zone line at c.1790 occurs in the three profiles at a time when there is evidence of a significant change in the regional pollen component of the sediment. It also corresponds with the decline in Coryloid values and the increase in *Pinus* percentages seen in the regional pollen data from each site. It is the last significant division of the CONISS analysis of each data set with the exception of that from Ballygisheen Bog where a further significant division occurs at 1969. This is very recent and appears to be caused mainly by a sudden decline in Gramineae and *Plantago lanceolata* values and a significant increase in *Pinus* percentages which are most likely to be due to anthropogenic influences, such as a change in agricultural practices, on the landscape.

Detrended Correspondence Analysis (DCA) was carried out on the pollen taxa greater than 5% from each site investigated as described in Section 3.7.3; the results of which are illustrated in Figures 6.17A-D. In Figure 6.17A it can be seen that there appears to be two groups forming in the data – Group 1 seems to spread along Axis 1 and Group 2 spreads along Axis 2. This spread of groups can be related to their taxa composition in that Group
Figure 6.17
A. DCA plot of Axis 1 and Axis 2 of regional pollen from all sites for taxa >5%
B. DCA plot of Axis 1 and Axis 2 of regional pollen from all sites for taxa >5%
with different symbols for pre and post Coryloid decline levels
Figure 6.17
C. DCA plot of Axis 1 and Axis 2 of regional pollen from all sites for taxa >5% with levels from each site differentiated
D. DCA plot of Axis 1 and Axis 2 of regional pollen from all sites for taxa >5% with levels from each regional pollen assemblage zone differentiated
1 has a stronger Coryloid component while Group 2 has a stronger Gramineae, Pinus, Pteridium and Plantago lanceolata component. Figure 6.17B explores Groups 1 and 2 by differentiating pollen levels that are either pre or post the Coryloid decline. The Coryloid decline occurs simultaneously at each site at approximately AD 1750 and so such an exploration is possible. From this figure it can be seen that Groups 1 and 2 fall almost exactly in to the pre and post Coryloid decline groups respectively. Such a finding confirms the strong influence of the taxa composition in the groupings in that levels from the pre Coryloid decline group together similar to Group 1 with a high Coryloid component while those from the post Coryloid decline group similar to Group 2 with a stronger Gramineae, Pinus, Pteridium and Plantago lanceolata component. Figure 6.17C illustrates which levels are from each site. From this graph it can be seen that in the Group 1 cluster All Saint’s Bog lies closest to the high Coryloid component and that this site is most different to Ballygisheen Bog. Liffey Head Bog occupies the middle ground between these two sites. It is evident from the pollen diagrams constructed (Figures 6.10-6.12) that All Saint’s Bog has higher Coryloid percentages compared to Liffey Head Bog and Ballygisheen Bog which is to be expected as All Saint’s Bog is situated in the Midlands at a low altitude compared to the other two sites and hence would have more Corylus scrub present in the landscape. In contrast to this the Group 2 cluster does not show site gradation – all levels appear mixed up in the cluster with no obvious trend visible. An interesting feature of the Group 2 cluster is that the spread of levels relates to different proportions of Pinus versus Plantago lanceolata and Pteridium which is also related to time in the upper zones of the profiles (Figure 6.17D).

The underlying message therefore from this DCA analysis is that sites are quite distinct from one another before the decline in Coryloid values at approximately AD 1750 but after the decline, tend to converge.

A number of similar trends are visible between the three sites investigated. Probably the most obvious similarity is the distinct decline in Coryloid values at approximately AD 1750 at each site. This decline was also found in Carbury Bog in Co. Kildare but occurred earlier at AD 1700 (van Geel and Middeldorp, 1988) and earlier again at Clara Bog in Co. Offaly in the mid 15th Century (Connolly, 1999). Of the three sites investigated in this study, the Coryloid decline appears to have occurred latest at All Saint’s Bog in the midlands. Palaeoecological studies from Northern Ireland (Hall, 1990a; Hall, 1990b; Hall, 1994; McVicker and Hall, 1997) also reveal this classic opening up of the landscape in the
18th Century as indicated by decreasing Corylus values and increasing Gramineae and agricultural indicator species. The commercial exploitation of forests prior to this in the 17th Century is also evident from the three sites with decreases in all tree types (mainly Quercus, Betula, Alnus and Fraxinus) occurring during this time. This phenomenon can also be seen from other studies in Ireland (Mitchell, 1965; O’Connell, 1986; van Geel and Middeldorp, 1988). Deforestation was the official policy in Ireland during the 17th Century with increasing iron smelting and glass manufacturing industries being introduced (Dunlevy, 1994). This systematic clearance of wood was also due to the use of timber for military-strategic reasons (Aalen, 1978).

The recent increase in Pinus percentages is also evident from each site which occurs from the mid to late 19th century. Pinus increases earliest in the landscape surrounding Liffey Head Bog in AD 1842 and latest surrounding Ballygisheen Bog in AD 1887. Similarly non native tree species arrive earlier in the Liffey Head Bog profile and latest in the Ballygisheen Bog profile. This may be as a result of the proximity of the eastern coast to Britain where most of the non native tree species found were imported from. Fitzpatrick (1933) reports on the commencement of building of country residences early in the 18th Century and how exotic tree species were planted in Ireland from this time. The majority of reports of such plantings however were collected from mainly eastern locations. In 1698 the Irish Parliament passed the first of a series of acts designed both to conserve remaining stocks and to encourage the planting of trees (van Geel and Middeldorp, 1988).

The Gramineae record from each site are similar to one another in that Gramineae increases as Coryloid declines in values. Gramineae also decreases at the top of the profile of each site. Plantago lanceolata also behaves in the same way at each site. In contrast Cereal-type pollen appears to more prevalent in the landscape surrounding Liffey Head Bog than at the other two sites. Its presence seems to decrease traversing Ireland from east to west. This may reflect the pressure to produce grain crops in order to sustain the increase in population that occurred at this time (early 1800s) and also to meet the demand for grain as an export food to Britain (Whelan, 1997). The decline in the general level of prosperity of Ireland from 1670s to 1850s seen in Mayo (O’Connell, 1986) is not seen at the three sites investigated. In Mayo farming practices were observed to decline while scrub vegetation increased during this period. Such changes in vegetation are not evident from this study. Findings of Cereal-type pollen at the base of the Liffey Head Bog and All Saint’s Bog profiles may be accounted for by the presence of monastic settlements in the
landscape between AD 500 and AD 1000. It has been suggested that their abstinence from meat may have thrown more emphasis on the production of cereals and other vegetables (Mitchell, 1965). The monastic settlement of Clonmacnoise is situated approximately 20km north of All Saint’s Bog.

Of the three sites investigated the landscape surrounding Ballygisheen Bog was the most severely affected by the Great Famine of AD 1845 (Whelan, 1997). Sixty percent of the population in Kerry were in receipt of rations in the summer of 1847 compared to 30% in Offaly and 15% in Wicklow. This reflects the dependency on the lumper potato during this time which was greatest in Kerry and least in Wicklow. Pollen of Solanum tuberosum did not occur in any samples counted. Potatoes produce very little pollen and is not readily fossilised (Hall, 1989). O’Connell (1986) found low Pteridium values associated with the time of the famine suggesting an intensive utilisation of land at this time. Similar low percentages of Pteridium were not found at any of the three sites at this time. Van Geel and Middeldorp (1988) relate high Plantago levels with the high population density in the pre-famine period. Similar high percentages of Plantago lanceolata were found at the three sites in this study also before 1845.

One of the other major catastrophes that occurred during the time span of the records investigated was that of the Black Death in 1349 (c.600BP). A decline in agriculture would be expected due to the collapse of tillage and abandoning of farms. Such trends are evident from All Saint’s Bog and Ballygisheen Bog with declines in Gramineae, Cereal-type and Plantago lanceolata and increases in the Coryloid curve at this time. Gramineae does decline at Liffey Head Bog during this time and the Coryloid values remain high but the Cereal-type curve does not decrease in size. Evidence of this plague is also evident from Mayo (O’Connell, 1986).

Probably the most recent adversity that has occurred in Ireland is that of the Economic War with Great Britain from 1932 to 1938. The mid 1930s was characterised by a major slump in agriculture but then was followed in the 1940s by a distinct recovery especially in arable farming (Huang and O’Connell, 1991). Such a pattern can be seen to a degree in the three sites investigated in that Cereal-type declines at all three sites around the 1930s but only recovers again from 1958 onwards at Liffey Head Bog. No such recovery is evident from All Saint’s Bog or Ballygisheen Bog.
VII Local Pollen

7.1 Introduction

The aim of this chapter is to construct a picture of what was happening on the bog surface of each site over time. A formal description of the local pollen component of each site will be provided. Comparisons will be made between each site to see if changes in the local vegetation of each are similar and/or synchronous or very different to one another. Whether these changes show some insight into any climate changes that may have occurred in the last 1,000 years will be examined. Similarities between the physical characteristics of each site and the local pollen will be included in the comparison and interpretation. Comparisons will also be made between the data from the three sites investigated and other sites covering a similar time period in Ireland.

The local pollen results originate from the same samples that were analysed for regional pollen (see Section 6.1). The most suitable age-depth model for each site (see Chapter IV) was also used to provide a chronology for local pollen percentage diagrams (Figures 7.1, 7.2 and 7.3). Local pollen percentage diagrams were constructed from the overall pollen data but were eliminated from the ‘pollen sum’ (see Section 3.7.3) to reduce their influence on the representation of regionally important taxa (Moore et al., 1991). Therefore what is represented by the local pollen percentage diagram is what is happening on the bog surface and is not influenced by the regional taxa from the surrounding landscape. The local pollen dataset for each site was zoned independently of its corresponding regional pollen, the details of which are in Section 7.2.

7.2 Numerical Zonation of Local Pollen Diagrams

The results of the constrained incremental sum of squares (CONISS) analysis concerning local pollen for each site are presented in the form of dendrograms in Figures 7.4, 7.5 and 7.6. The first three divisions of the Liffey Head Bog CONISS analysis (as illustrated in Figure 7.4) at 8.5cm, 44.5cm and 50.5cm were found to be statistically significant according to the broken stick model (Bennett, 1996); the graph of which is illustrated in Figure 7.7. Similarly the first division of the All Saint’s Bog CONISS analysis (as depicted in Figure 7.5) at 58.5cm and the first four divisions of the Ballygisheen Bog CONISS analysis (as depicted in Figure 7.6) at 2.5cm, 40.5cm 62.5cm and 96.5cm were
Figure 7.1
Liffey Head Bog
Local pollen percentage diagram
Figure 7.2
All Saint's Bog
Local pollen percentage diagram
Figure 7.3
Ballygisheen Bog
Local pollen percentage diagram

Exaggeration x10
Figure 7.4
Liffey Head Bog
CONISS analysis (local)

Figure 7.5
All Saint's Bog
CONISS analysis (local)

Figure 7.6
Ballygisheen Bog
CONISS (local)
Figure 7.7 Variance accounted for by the CONISS zonation of Liffey Head Bog local pollen as a proportion of the total variance (full line) compared with values from the broken stick model (dashed line). The point where the two lines cross gives an indication of the number of statistically reliable zones. In this pollen dataset four zones are proposed.

Figure 7.8 Variance accounted for by the CONISS zonation of All Saint's Bog local pollen as a proportion of the total variance (full line) compared with values from the broken stick model (dashed line). The point where the two lines cross gives an indication of the number of statistically reliable zones. In this pollen dataset two zones are proposed.
Figure 7.9 Variance accounted for by the CONISS zonation of Ballygisheen Bog local pollen as a proportion of the total variance (full line) compared with values from the broken stick model (dashed line). The point where the two lines cross gives an indication of the number of statistically reliable zones. In this pollen dataset five zones are proposed.
found to be statistically significant. The broken stick models for these two sites are shown in Figures 7.8 and 7.9 respectively. These divisions were used to divide the data into local pollen assemblage zones (PAZ) and were given the prefixes LHL (after Liffey Head Bog, local pollen), ASL (after All Saint’s Bog, local pollen) and BGL (after Ballygisheen Bog, local pollen). The main features of each of the local pollen assemblage zones (according to site) are detailed below.

7.3 Results of Local Pollen Analysis

7.3.1 Liffey Head Bog

LHL 1: *Calluna* - Cyperaceae - *Sphagnum*; 91.5cm-50.5cm; 1,179BP-657BP; AD 771-AD 1294

The main components of this zone are *Sphagnum*, Cyperaceae and *Calluna*, and to a lesser extent, *Narthecium* (Figure 7.1). *Sphagnum* percentages tend to fluctuate throughout and increase towards the top of the zone reaching almost 35%. Values for *Calluna* are fairly stable and remain below 20% throughout the zone. The Cyperaceae curve seems to exhibit a very gradual decrease in values from the base of the zone at values of approximately 25% towards the top where values reach 6%. This curve tends to fluctuate throughout this decreasing trend. *Narthecium* values remain fairly stable and low, not rising above 5%. Ericaceae-type are present throughout but at percentages of less than 3%. *Potentilla*, *Drosera rotundifolia* and *Lythrum salicaria* only appear three times, twice and once respectively with a single grain occurrence each time within this zone.

LHL 2: *Calluna* - Cyperaceae - *Sphagnum*; 50.5cm-44.5cm; 657BP-580BP; AD 1294-AD 1370

*Sphagnum* appears to be the dominant component of this zone with values as high as 61% at 47.5cm. The *Sphagnum* curve increases from the base of the zone to its highest value at 47.5cm after which it begins to decrease again reaching values of approximate size to those at the base of the zone (close to 30%). The *Calluna* curve remains stable throughout with values not rising above 15%. Cyperaceae values exhibit a gradual increasing trend from the base of the zone to the top from just over 5% to over 10% respectively. Ericaceae-type values remain very low and stable throughout while those of *Narthecium* demonstrate a slight increasing trend towards the top of the zone. Two grains of *Potentilla* occur within
this zone. *Drosera rotundifolia* and *Lythrum salicaria* are also present; one grain of each was counted in this zone.

LHL 3: *Calluna* - Cyperaceae - *Narthecium* - *Sphagnum*; 44.5cm-8.5cm; 580BP-63BP; AD 1370-AD 1887

The major component of this zone appears to be Cyperaceae where values increase from the base of the zone to 43% at 37.5cm and remain at this high level to the top of the zone. The values remain fairly constant throughout with the exception of between 35.5cm and 29.5cm where Cyperaceae percentages fall to approximately 25%. *Calluna* values remain stable throughout varying between 7% at 41.5cm to 14% at 33.5cm. The Ericaceae-type curve exhibits a gradual increasing trend towards the top of the zone. Despite this its values remain below 2%. *Narthecium* reaches its highest percentage value in this zone at 41.5cm where it peaks at 12%. From this point on towards the top of the zone *Narthecium* percentages steadily decrease to values of just over 1%. Single grain occurrences of *Potentilla* appear at various levels in this zone. The only incident of *Pinguicula* in this profile occurs in this zone at 19.5cm where one grain was found.

LHL 4: *Calluna* - Ericaceae-type - Cyperaceae; 8.5cm-0cm; 63BP- -45BP; AD 1887-AD 1995

*Calluna* appears to be the dominant taxon in this zone. Its values increase steadily from the base of the zone to the top of the profile where they account for almost 45% of the local pollen at 0cm. Cyperaceae values exhibit an opposite trend to *Calluna* where they decrease steadily towards the top of the zone. Cyperaceae percentages decrease from 36% at the base to 12% at the top of the profile. The Ericaceae-type curve continues its increasing trend that began in LHL 3 and its values reach their highest percentage value close to 10% at 1.5cm. Values of Ericaceae-type decrease from 1.5cm to the top of the profile. *Sphagnum* percentages remain stable and low throughout of between 2% and 4%. *Narthecium* values are very low throughout this zone while *Potentilla* occurs only once within same.
7.3.2 All Saint's Bog

ASL 1: Calluna - Cyperaceae - Sphagnum; 91.5cm-58.5cm; 1,036BP-613BP; AD 914-AD 1337

_Sphagnum_ is by far the dominant component of this zone (Figure 7.2). Its values fluctuate dramatically throughout ranging from 76% at 59.5cm to a low of 19% at 61.5cm. The _Calluna_ curve remains fairly constant throughout this zone with values lying between 3% to just over 10% in places (12% at 81.5cm). However there appears to be a very gradual decreasing curve from the base of the zone to the top. Cyperaceae percentages remain stable, not rising above 8% throughout. The Ericaceae-type curve is constant throughout this zone with very low percentages. _Potentilla_ occurs once within this zone while _Narthecium_ is present intermittently at very low percentages.

ASL 2: Calluna - Cyperaceae - Sphagnum; 58.5cm-0cm; 613BP-46BP; AD 1337-AD 1996

The main local taxa components of this zone are _Sphagnum, Calluna_ and _Cyperaceae_ and, to a lesser extent, Ericaceae-type. The _Sphagnum_ curve in this zone fluctuates dramatically with several peaks in high values occurring throughout. Overall _Sphagnum_ values do not appear to be as high as in the previous zone, ASL 1. They tend to increase towards the top of the profile with a peak of 35% occurring at 1.5cm. _Calluna_ values appear to oscillate throughout this zone but exhibit the opposite trend to _Sphagnum_ in that they tend to decrease towards the top of the zone. _Calluna_ falls from values of just over 20% at 11.5cm to 7% at 0cm. Values of Ericaceae-type remain very low throughout, similar to those in ASL 1 but exhibit a very gradual increasing trend towards the top of the profile. Ericaceae-type percentages never rise above 4% in this zone. _Narthecium_ is present in this zone, albeit not at all levels. It peaks at approximately 11.5cm where it reaches 6%. After this peak its values decrease towards the top of the profile. Several grains of _Drosera rotundifolia, Menyanthes_ and _Potentilla_ were found in this zone.

7.3.3 Ballygisheen Bog

BGL 1: Calluna - Cyperaceae - Narthecium; 100.5cm-96.5cm; 1,192BP-1,102BP; AD758-AD 848

The main local taxa components of this zone are _Calluna, Sphagnum_ and _Narthecium_. _Calluna_ percentages appear stable throughout lying between 16% and 19% (Figure 7.3).
Those of Cyperaceae also appear stable with a slight decreasing trend towards the top of the zone. Values for Narthecium decrease towards the top of the zone to values less than 10% while the Sphagnum curve increases from the base of the zone to the top. Ericaceae-type and Potentilla are present throughout this zone at very low percentages.

BGL 2: Calluna - Cyperaceae - Sphagnum; 96.5cm-62.5cm; 1,102BP-470BP; AD 848-AD 1480

Both Calluna and Cyperaceae dominate this zone. Calluna values seem to increase towards the top of the zone while those of Cyperaceae tend to decrease from 25% at the base of the zone to a mere 13% at the top. The Ericaceae-type curve comprises of low percentage values that oscillate throughout but never rise above 4%. Sphagnum percentages appear to initially decrease in value but then increase again to 15% at 73.5cm. Narthecium values tend to oscillate throughout this zone but also exhibit a very gradual decreasing trend towards the top of the zone. Potentilla, Drosera rotundifolia and Manyanthes are present sporadically at low percentages; the latter having a peak of values at approximately 65.5cm (4%).

BGL 3: Calluna - Cyperaceae - Sphagnum; 62.5cm-40.5cm; 470BP-193BP; AD 1480-AD 1757

This zone is dominated primarily by Calluna. Calluna percentages reach their highest value in this zone at 55.5cm with 53%. After this peak they steadily decrease towards the top of the zone, but remain above 30%. Cyperaceae values remain stable throughout, at lower values than in BGL 2. Sphagnum percentages also remain fairly constant throughout but seem to exhibit a slight gradual increasing trend towards the top of the zone. The highest values of Ericaceae-type in the profile occur in the upper half of this zone at 43.5cm and 41.5cm where they reach 8% at both levels. Narthecium values oscillate throughout while those of Menyanthes decrease to very low percentages towards the top of the zone. Potentilla appears sporadically throughout while the only grain of Nymphaea found in this profile occurs in this zone at 47.5cm.

BGL 4: Calluna - Cyperaceae - Sphagnum; 40.5cm-2.5cm; 193BP- -42BP; AD 1757-AD 1992

Calluna carries on to be the dominant taxon in this zone but Cyperaceae and Sphagnum are important contributors also. The Calluna curve oscillates throughout while exhibiting a general decreasing trend towards the top of the zone. Values lie between 22% and 42%.
Sphagnum values show a similar oscillating yet decreasing trend also. The highest value of Sphagnum occurs at 39.5cm where it reaches 30%. It decreases to below 5% at the top of the zone. The Cyperaceae curve peaks in the lower half of this zone where percentages reach just over 22%. Their values then decrease gradually and steady off to less than 10% at the top of the zone. Ericaceae-type values remain low and stable throughout while those of Narthecium are present at low percentages and exhibit a general decreasing trend towards the top of the zone. Potentilla, Drosera rotundifolia and Menyanthes all occur sporadically throughout.

BGL 5: Calluna - Cyperaceae - Sphagnum; 2.5cm-0cm; -42BP- -47BP; AD 1992-AD 1997

Cyperaceae appears to be the dominant component of this zone and exhibits an increasing trend towards the top of the profile where it reaches 14%. Similarly Ericaceae-type values increase towards the top of the zone albeit at considerably lower percentages to Cyperaceae. Calluna exhibits the opposite trend; its values decrease to approximately 10% at 0cm. Sphagnum values also decrease towards the top of the profile but do so very gradually. Narthecium is present throughout at very low percentages. Its values can be seen to decrease towards the top of the zone with the aid of exaggeration. Potentilla and Drosera rotundifolia are also present in this zone but only occur in the surface sample.

7.4 Interpretation and Comparisons of the Local Pollen Component of each Site

In order to compare the three local pollen diagrams that were produced from this study it was decided to plot each with respect to age (Figures 7.10, 7.11 and 7.12). In these percentage diagrams age is the primary axis while depth is the secondary one. Such diagrams provide an image of the sedimentation rate of the site as the nature of the diagrams stretches out or bunches together the sample depths according to when each sample was deposited. Plotting the diagrams in this way also provides a common scale for all three sites which simplifies comparisons between them. Figure 7.13 was drawn to illustrate the local pollen zone boundaries of each site relative to one another. Local pollen concentration diagrams were constructed from the original counts from each site (Figures 7.14, 7.15 and 7.16).
Figure 7.10
Liffey Head Bog
Local pollen percentage diagram
(plotted with respect to age)
Figure 7.11
All Saint's Bog
Local pollen percentage diagram
(plotted with respect to age)
Figure 7.12
Ballygisheen Bog
Local pollen percentage diagram
(plotted with respect to age)
<table>
<thead>
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<th>Liffey Head Bog</th>
<th>All Saint's Bog</th>
<th>Ballygisheen Bog</th>
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Figure 7.13 Diagram of local pollen zone boundaries of each site drawn with respect to age.
Figure 7.14
Liffey Head Bog
Concentration Diagram of Main Local Pollen Taxa
(plotted with respect to age)
Figure 7.15
All Saint’s Bog
Concentration Diagram of Main Local Taxa
(plotted with respect to age)
Figure 7.16
Ballygisheen Bog
Concentration Diagram of Main Local Taxa
(plotted with respect to age)
7.4.1 Liffey Head Bog

The lower zone (LHL 1) of this profile (Figure 7.10) from AD 771 to AD 1294 (1,179BP-656BP) would suggest a typical bog surface composed mainly of *Calluna*, Cyperaceae and *Sphagnum*. *Narthecium* values are seen to fluctuate and are seen to be highest in this zone between AD 975 (975BP) and AD 1077 (873BP) and to a lesser degree between AD 1128 (822BP) and AD 1230 (720BP). Such an increase in percentages, along with high *Sphagnum* values may suggest wetter conditions on the bog surface during these time periods.

*Sphagnum* reaches its highest values in the profile between AD 1294 (657BP) and AD 1370 (580BP). This peak is also evident from the concentration diagram (Figure 7.14). This peak in *Sphagnum* is difficult to interpret as *Sphagnum* does not necessarily increase sporulation under specific climatic conditions. It does not appear to correspond to any changes in the physical characteristics investigated. This brief increase in *Sphagnum* values is followed by a significant increase in both Cyperaceae and *Narthecium* at AD 1395 (550BP). This coincides very well with an increase in the occurrence of both microscopic and macroscopic charcoal (Figures 5.7 and 5.10). Values for both *Narthecium* and Cyperaceae (both wet indicators) gradually decline to AD 1485 (465BP). *Narthecium* values remain stable until AD 1631 (319BP) and then decrease again. During this time (AD 1485-AD 1631; 465BP-319BP) Cyperaceae percentages fluctuate but in general remain high while those of Ericaceae-type and *Calluna* are stable. This may indicate a persistence of wet conditions which may not have been as intense as between AD 1395 (550BP) and AD 1485 (465BP).

During the last 100 years (1887-1995; 63BP--45BP) Liffey Head Bog appears to be drying out. *Calluna* and Ericaceae-type increase in abundance towards the present day while Cyperaceae and *Narthecium* decline. Such a trend is also evident from other research carried out in the Wicklow Mountains (Bowler and Bradshaw, 1985). Ryan (1992) suggests that the current domination of *Calluna* on Liffey Head Bog is most likely as a result of drainage for turf cutting. It is thought that little, if any, turf cutting occurred on the site prior to the advent of the Military Road c.1800 (Ryan, 1992). The *Calluna* curve for this time period seems to reflect that of the corresponding loss on ignition curve (Figure 5.4) and macroscopic charcoal curve (Figure 5.10) in that all graphs exhibit an increasing trend towards the top of the profile. The Ericaceae-type curve also increases during this
time. Research by Mallik and Gimingham (1985) has shown that all Ericaceous species sprout vigorously after burning. Liffey Head Bog has been burned for grouse management since the last century up until the 1930s (Ryan, 1992). Since then sheep grazing with associated burning and turf cutting on the fringes have been the major impacts on the bog surface. Therefore a combination of drainage and frequent fires may well be responsible for the vegetation community present on Liffey Head Bog for the last 100 years. This change in vegetation composition also coincides with a change in sediment lithology (Figure 5.1) from a brown, partially humified peat to a fibrous peat with fragments of plant remains.

7.4.3 All Saint’s Bog

A relatively stable bog surface vegetation comprising mainly of *Sphagnum* and *Calluna* is suggested by ASL 1 (Figure 7.11) during the time period AD 914 (1,036BP) to AD 1337 (613BP). *Sphagnum* appears to fluctuate during this period to quite high values. As explained in Section 7.4.2 *Sphagnum* peaks are difficult to interpret. The general abundance of *Sphagnum* during this time period would suggest a prevalence of wet conditions. This theory is not reflected in the *Narthecium* curve as its presence during this time period is extremely sporadic.

A peak in *Calluna* percentages between AD 1350 (600BP) and AD 1454 (496BP) corresponding with a trough in *Sphagnum* values may suggest a short period of dry conditions. *Sphagnum* then appears to decline in its abundance from AD 1480 (470BP) to AD 1947 (3BP). *Calluna* and Ericaceae-type percentages exhibit the opposite trend to *Sphagnum* during this time period increasing in value as time progresses. This trend may suggest a prevalence of dry conditions on the bog surface.

A significant peak in *Narthecium* values occurs between AD 1895 (55BP) and AD 1956 (-6BP) (see Figure 7.15 also) which would suggest a wet period during this time. *Menyanthes* was also found at the same time as the highest *Narthecium* percentage (1947AD; 3BP) which would reinforce the presence of wet conditions. A decline in *Calluna* or Ericaceae-type was not observed during this period.

The sedimentation rate appears to be highest in the top 50 years of the peat. This coincides with a change in sediment lithology during this time at approximately 1964 to a peat
dominated by *Sphagnum* remains. Here *Sphagnum* appears to increase significantly in the pollen record compared to previous values. Cyperaceae values also increase while those of *Calluna* and Ericaceae-type decline, suggesting that All Saint’s Bog, unlike Liffey Head Bog, has been getting increasingly wetter in the last 50 years despite the fact that approximately 20% of the bog has been cut away (Cross *et al.*, 1991). This may be due to the complex hydrology that appears to exist on All Saint’s Bog (Heery, 1993). Evidence for this stems from the presence of the pine and birch woodland which appears to be associated with a nutrient rich area. This may suggest that water movement through the bog system may have masked the impact of drainage associated with peat cutting.

7.4.4 Ballygisheen Bog

The lowest zone (BGL 1) from the Ballygisheen Bog profile illustrated in Figure 7.12 (AD 758-AD 848; 1,192BP-1,102BP) suggests a wet bog surface dominated by Cyperaceae and *Narthecium* with some *Calluna* present. This situation changes however and from AD 848 (1,102BP) to AD 1039 (911BP) the bog appears to be getting drier with increasing *Calluna* and Ericaceae-type values and declining percentages of Cyperaceae and *Narthecium*. Both *Calluna* and Ericaceae-type decrease in the time period AD 1039 (911BP) to AD 1195 (755BP) when *Narthecium* values are high. Cyperaceae or *Sphagnum* percentages do not increase during this time period. However the peak in *Narthecium* values may suggest this is a wetter period to previous (AD 848-AD 1039).

*Calluna* percentages appear to increase from AD 1195 (755BP) to AD 1480 (470BP) and then remain at high levels until AD 1757 (193BP). This trend is somewhat reflected in the Ericaceae-type curve. A slight decline in values at AD 1434 (516BP) along with peaks in *Narthecium* and *Menyanthes* would suggest a brief wet interval in the record at this time.

The time period that is represented by BGL 4 (AD 1757-AD 1992; 193BP- -42BP) seems to suggest a decline in *Calluna* and Ericaceae-type values but also decreases in *Narthecium* and *Sphagnum* percentages. An increase in values of Cyperaceae between AD 1824 (126BP) and AD 1887 (63BP) corresponds with a slight peak in *Narthecium* values indicating a wet period on the bog surface at this time.

An interesting feature observed in the Ballygisheen Bog record is that the *Calluna* and macroscopic charcoal curves (Figure 5.12) appear to match each other in that values of
each appear to increase and decrease at the same time throughout the profile. This is somewhat similar to the scenario at Liffey Head Bog. This may be attributable to the same fact that Ericaceous species are known to sprout vigorously after a burning episode (Mallik and Gimingham, 1985).

The last 100 years at Ballygisheen Bog appear to have been quite stable. The *Calluna* curve decreases somewhat towards the top of the profile as does the *Sphagnum* curve after an initial increase. However the Ericaceae-type, Cyperaceae and *Narthecium* percentages remain constant throughout which would suggest that neither and increase or decrease in wet conditions had occurred on the bog in the recent past. Both local hand cutting and machine cutting of turf has taken place on the bog in the past. Drainage has only taken place in the most easterly portion of the bog. Despite these activities, Ballygisheen Bog remains one of the most extensive areas of relatively intact lowland blanket bogs in Co. Kerry. The peat accumulation rate stands at over 3mm yr$^{-1}$ for the last 50 years. This does not appear to coincide with changes in the sediment lithology or dramatic changes in the pollen record but is what would be expected as this area of Ireland receives a high amount of rainfall every year which is highly favourable to peat formation and growth. The total concentration of pollen grains in the sediment over the last 100 years appears to be fairly stable also (Figure 7.16).

7.4.4 Comparisons of the Sites

On a coarse level the description and interpretation of each site illustrates the principal differences between each site type. Living bogs show more or less complex patterns in vegetation that are closely associated with the microtopographical differentiation of the bog surface (Schouten, 1990). In this study it appears that the raised bog (All Saint’s Bog) is dominated by *Sphagnum* with less *Calluna* and Cyperaceae while the blanket bogs (Liffey Head Bog, Ballygisheen Bog) have less *Sphagnum* present with more *Calluna* and Cyperaceae. This is typical of such mire types (Hammond, 1981). According to Hammond (1981) some of the differences between Atlantic blanket bog and mountain blanket bog lie in their surface vegetation i.e. Atlantic blanket bog has more *Molinia, Drosera* and *Potentilla* present than mountain blanket bog. Such a difference is evident from this investigation in that the amount of both *Drosera* and *Potentilla* pollen found at Ballygisheen Bog (Atlantic blanket bog) is significantly greater than at Liffey Head Bog (mountain blanket bog) albeit at low percentages.
Figure 7.13 illustrates the position of each of the zone lines that were constructed from the local pollen assemblages of each site. No similarities are evident between any of the zone boundaries from each of the three sites investigated. The closest correspondence between sites would be the zone lines at AD 1370 (580BP) at Liffey Head Bog and at AD 1337 (613BP) at All Saint’s Bog with 33 years between them. Such a distinct lack of corresponding zone boundaries would suggest that the vegetation changes occurring on each site over the last 1,000 years are site specific being very local and not a national phenomenon. When the local zone boundaries are compared to the regional pollen zone boundaries in Figure 6.13 it can be seen that again no striking similarities are found either between sites or within sites. The closest correlations evident are those in the Liffey Head Bog and Ballygisheen Bog profiles at AD 1370 (local) and AD 1395 (regional) and at AD 1757 (local) and AD 1777 (regional) respectively. With respect to Liffey Head Bog these zone boundaries correspond with a slight decrease in Coryloid and other tree taxa values and an increase in Gramineae and *Plantago lanceolata* and a major decline in *Sphagnum* values and increases in Cyperaceae and *Narthecium* percentages suggesting a change to wet conditions on the bog surface at this time. With respect to Ballygisheen Bog these zone lines correspond to the national decline in Coryloid and other tree taxa values and the subsequent increase in Gramineae, *Plantago lanceolata* and *Pteridium* percentages and an increase in *Sphagnum* and decline in Ericaceae-type and *Calluna* values, again suggesting a change to local wet conditions on the bog surface.

Detrended Correspondence Analysis (DCA) was carried out on the main local pollen taxa (*Calluna*, Ericaceae-type, Cyperaceae, *Sphagnum* and *Narthecium*) from each site investigated as described in Section 3.7.3; the results of which are illustrated in Figure 7.17(A-C). Figure 7.17A illustrates how the taxa involved take on a triangular distribution. *Sphagnum* plots over on the right hand side of Axis 1 while *Narthecium* and Cyperaceae plot at the top of Axis 2 and *Calluna* and Ericaceae-type plot at the bottom of Axis 2. This would suggest that Axis 1 is a *Sphagnum* gradient while Axis 2 is a wet/dry gradient. When the sites are taken into consideration it would appear that All Saint’s Bog skews over towards the high *Sphagnum* part of the plot (which is evident from its high *Sphagnum* component in the pollen diagram plus what would be expected of a raised bog compared to blanket bogs). Liffey Head Bog appears to plot at the wetter end of Axis 2 than Ballygisheen Bog. This is not what would be expected as Ballygisheen Bog experiences higher rainfall and is more intact compared to Liffey Head Bog. Figure 7.17B introduces the individual zones from each of the sites into the analysis. The most common trend
Figure 7.17
A. DCA plot of Axis 1 and Axis 2 of main local pollen taxa from all sites with levels from each site differentiated
B. DCA plot of Axis 1 and Axis 2 of main local pollen from all sites with levels from each local pollen assemblage zone differentiated
Figure 7.17
C. DCA plot of Axis 1 and Axis 2 of main local pollen taxa from all sites with different symbols for pre and post Coryloid decline levels.
visible here is that the lower zones of each site occupy the middle area of the plot (with the exception of BGL 1) whereas the upper zones spread out from here. In contrast to the scenario seen with the regional pollen (Section 6.4.4), the three sites appear to start off indistinguishable but then deviate from each other over recent time. This may be due to the influence of human impact on the vegetation of the sites such as the occurrence of drainage and peat cutting in recent decades. Figure 7.17C has the regional pollen pre and post Coryloid decline divide imposed on the data. The pattern observed in Figure 7.17C is not as clear as that in Figure 6.17B but there is certainly some kind of trend evident that illustrates how the post Coryloid decline (AD 1750) levels appear to occupy the drier and less *Sphagnum* dominated areas of the plot suggesting that the bog surfaces are drier now compared to earlier in the profiles. Again this is what would be expected taking anthropogenic influences into consideration.

Figure 7.18 was constructed from the DCA Axis 2 scores and illustrates how these scores change in time. This was done in order to explore the wet (high values) and dry (low values) implications of DCA Axis 2. All three sites exhibit many troughs and peaks as they fluctuate throughout time. Some coincide at each site while others exhibit opposite patterns. Between AD 900 and AD 1000 all three sites appear to have a peak in wet conditions. A peak in wet conditions is also evident at Liffey Head Bog and Ballygisheen Bog after AD 1000 but not at All Saint’s Bog. Similarly a decline in Axis 2 values is seen at Liffey Head Bog and Ballygisheen Bog between AD 1000 and AD 1100 but again not at All Saint’s Bog. After this point all three sites exhibit dissimilar trends and then between AD 1250 and AD 1350 Liffey Head Bog and All Saint’s Bog tend towards dry conditions while Ballygisheen Bog does not. Ballygisheen Bog has a peak in dry conditions at approximately AD 1230. All three sites show significant tendencies towards wet conditions between AD 1375 and AD 1525 and again (although not as significant) between AD 1550 and AD 1625. After approximately AD 1750 the site curves tend to deviate and do not follow a similar pattern. This was also reflected in the ordination plot Figure 7.17C. From this plot is would appear that implications of wet conditions prevailed on all three sites between AD 900 and AD 1000, AD 1375 and AD 1525 and AD 1550 and AD 1625. At other times in the profile two sites show a similar trend while the third exhibits the opposite pattern i.e. at c.1630 both Liffey Head Bog and All Saint’s Bog have peaks in implications of wet conditions while that of Ballygisheen Bog is one of clearly dry conditions. After 1750 no definite correlation can be found between the three sites. When the dry phases as suggested by Figure 7.18 are compared to the macroscopic charcoal
Figure 7.18 Plot of DCA Axis 2 scores of local pollen (dashed line Liffey Head Bog; heavy full line All Saint's Bog; narrow full line Ballygisheen Bog) against time (years AD).
curves from each site (Figures 5.13-5.15), only in records from Liffey Head Bog does there appear to be a correlation between them. In the last 100 years at Liffey Head Bog the macroscopic charcoal record increases along with Calluna percentages. This is most likely due to management practices and anthropogenic influences on the bog as explained in Section 7.4.2.

Research carried out by Van der Molen (1988) on Woodfield Bog in Co. Offaly concluded that between AD 1689 and AD 1733 wet conditions prevailed, between AD 1735 and 1930 dry conditions were dominant, between 1933 and 1955 high humidity along with large amounts of rainfall occurred while from 1958 to 1983 relatively dry local conditions dominated. When this is compared to All Saint's Bog (the closest site investigated) it would appear that from AD 1689 to 1955 the records are somewhat similar but are in contrast to one another from 1958 to 1983 where wet conditions are implied from the All Saint’s Bog pollen record during this time. The wet period between 1933 and 1955 at Woodfield Bog fits in very nicely with a peak in Narthecium values and a decline in both Calluna and Ericaceae-type at All Saint’s Bog during this time period. Similarly the dry period at Woodfield Bog between AD 1735 and 1930 coincide with increasing Calluna and Ericaceae-type percentages and decreasing Sphagnum values during this period at All Saint’s Bog.

Van Geel and Middeldorp (1988) concluded that $^{2}H/^1H$ ratios carried out on a bog in the east of Ireland contrasted with historical climatic data. They found that between the periods AD 1130 to AD 1280, AD 1280 to AD 1420, AD 1420 to AD 1640 and AD 1640 to 1981 dry local conditions, wet conditions, dry conditions and very dry local conditions prevailed, respectively. When these time periods are considered in the Liffey Head Bog data it would appear that they correspond quite well with the exception of dry conditions between AD 1130 to AD 1280 and AD 1420 to AD 1640. Certainly between AD 1280 and AD 1420 wet conditions are experienced at Liffey Head Bog with increases in Cyperaceae and significant peaks in Narthecium and Sphagnum. The period AD 1640 to 1981 appears to be relatively dry with high Calluna and Ericaceae-type values and decreasing Cyperaceae and Narthecium percentages. Similar trends are not evident from the All Saint’s Bog data. Dry conditions are evident at Ballygisheen Bog from AD 1420 to 1981 with high Calluna and declining Narthecium values but no other similarities were found from this site.
8.1 Introduction

The aim of this chapter is to construct a palaeohydrological picture of wet and dry conditions on the bog surface of each site over time. As explained in Section 3.9, due to the relationship of many fungal spore and testate amoebae to precise ecological conditions, especially substrate wetness, the analysis of these can be used to derive an index of the palaeohydrological changes in peatlands (Charman, 1992; Hendon and Charman, 1997). The nomenclature used follows that of van Geel (1978) of 'Types'. The majority of 'Types' recorded are those of fungal spores with the exception of Types 31A, 32B and 46 which are rhizopods, namely *Amphitrema flavum*, *Assulina seminulum* and *Hyalosphenia subflava* respectively, Type 52 which are animal hairs, Type 72A which are cladoceran postabdomina of *Alona rustica* and Type 88A which are the mandibles of various invertebrates (van Geel, 1978; Hendon and Charman, 1997). Table 8.1 refers to the 'Types' found in the sediments investigated and any indicator value associated with them. In this investigation Copepoda (Type 28), *Amphitrema flavum* (Type 31A), Zygnemataceae (Type 58) and *Alona rustica* (Type 72A) are considered wet indicator taxa and *Gelasinospora* sp. (Type 1), Type 3A, *Pleospora* sp. (Type 3B), Type 5, Type 10, *Meliola* sp. (Type 14) and Type 24 are considered dry indicator taxa following van Geel (1978).

A formal description of the fungal spore and testate amoebae component of each site will be provided. Comparisons will be made between each site to see if changes in the fungal spore component of each are similar and/or very different to one another. Whether these changes will show some insight into any changes in climate that may have occurred in the last 1,200 years will be examined. Similarities between the physical characteristics, local pollen and the fungal spores and testate amoebae will be included in the comparison and interpretation. Comparisons will also be made between the data from the three sites investigated and other sites covering a similar time period in Ireland.

The fungal spore results originate from the same samples that were analysed for regional pollen (see Section 6.1) as fungal spores were counted simultaneously with pollen grains. The most suitable age-depth model for each site (see Chapter IV) was used to provide a chronology for fungal spore percentage diagrams (Figures 8.1, 8.2 and 8.3). The fungal
Figure 8.1
Liffey Head Bog
Fungal Spore Percentage Diagram
Figure 8.3
Ballygisheen Bog
Fungal Spore Percentage Diagram
spore dataset of each site was zoned independently of the corresponding regional and local pollen, the details of which are in Section 8.2.

Table 8.1 Table indicating name of types found, their host or substrate specificity and any indicator value they may have

<table>
<thead>
<tr>
<th>Type No.</th>
<th>Name, Taxon</th>
<th>Observed host or substrate specificity</th>
<th>Indicator value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gelasinospora</td>
<td></td>
<td>local dryness</td>
</tr>
<tr>
<td>3A</td>
<td></td>
<td></td>
<td>local dryness</td>
</tr>
<tr>
<td>3B</td>
<td>Pleospora</td>
<td></td>
<td>local dryness</td>
</tr>
<tr>
<td>4</td>
<td>Anthostomella</td>
<td></td>
<td>Eriophorum vaginatum leaves</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>very dry local conditions</td>
</tr>
<tr>
<td>8</td>
<td>Microthyrium,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Actinopeltis,</td>
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<td></td>
</tr>
<tr>
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<td>Stomiopletis</td>
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</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td>roots of Calluna vulgaris</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td>cyperaceous remains</td>
</tr>
<tr>
<td>13</td>
<td>Chytridales</td>
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<td>various bog taxa including Calluna</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>vulgaris, Erica tetralix, Calluna</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sphagnum imbricatum, Andromeda</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>vulgaris</td>
</tr>
<tr>
<td>14</td>
<td>Meliola</td>
<td></td>
<td>Calluna vulgaris</td>
</tr>
<tr>
<td>16A, 16B, 16C</td>
<td></td>
<td></td>
<td>graminaceous host plants?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>mesotrophic conditions?</td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td>ombrotrophic peat</td>
</tr>
<tr>
<td>18</td>
<td>Eriophorum vaginatum</td>
<td></td>
<td>‘younger’ Sphagnum peat</td>
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<tr>
<td>19</td>
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<td></td>
<td></td>
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<tr>
<td>20</td>
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<td></td>
<td></td>
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<td>22</td>
<td>Herpotrichella</td>
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<td></td>
<td>ombrotrophic Sphagnum peat</td>
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<td>Sphagnum cuspidatum</td>
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<td>Copepoda</td>
<td></td>
<td>open water</td>
</tr>
</tbody>
</table>

123
adapted from van Geel (1978)

8.2 Numerical Zonation of Fungal Spore Diagrams

The results of the constrained incremental sum of squares (CONISS) analysis concerning fungal spores for each site are presented in the form of dendrograms in Figures 8.4, 8.5 and 8.6. The first two divisions of the Liffey Head Bog CONISS analysis (as illustrated in Figure 8.4) at 10.5cm and 18.5cm were found to be statistically significant according to the broken stick model (Bennett, 1996); the graph of which is illustrated in Figure 8.7. Similarly the first three divisions of the All Saint’s Bog CONISS analysis (as depicted in Figure 8.5) at 8.5cm, 28.5cm and 72.5cm and the first three divisions of the Ballygisheen Bog CONISS analysis (as depicted in Figure 8.6) at 22.5cm, 62.5cm and 82.5cm were found to be statistically significant. The broken stick models for these two sites are shown in Figures 8.8 and 8.9 respectively. These divisions were used to divide the data into
Figure 8.4
Liffey Head Bog
CONISS analysis (fungal)

Figure 8.5
All Saint’s Bog
CONISS analysis (fungal)

Figure 8.6
Ballygisheen Bog
CONISS analysis (fungal)
Figure 8.7 Variance accounted for by the CONISS zonation of Liffey Head Bog fungal spores as a proportion of the total variance (full line) compared with values from the broken stick model (dashed line). The point where the two lines cross gives an indication of the number of statistically reliable zones. In this fungal spore dataset three zones are proposed.

Figure 8.8 Variance accounted for by the CONISS zonation of All Saint's Bog fungal spores as a proportion of the total variance (full line) compared with values from the broken stick model (dashed line). The point where the two lines cross gives an indication of the number of statistically reliable zones. In this fungal spore dataset four zones are proposed.
Figure 8.9 Variance accounted for by the CONISS zonation of Ballygisheen Bog fungal spores as a proportion of the total variance (full line) compared with values from the broken stick model (dashed line). The point where the two lines cross gives an indication of the number of statistically reliable zones. In this fungal spore dataset four zones are proposed.
fungal spore assemblage zones (FAZ) and were given the prefixes LHF (after Liffey Head Bog, fungal spores), ASF (after All Saint’s Bog, fungal spores) and BGF (after Ballygisheen Bog, fungal spores). The main features of each of the fungal spore assemblage zones (according to site) are detailed below.

8.3 Results of Fungal Spore Analysis

8.3.1 Liffey Head Bog

LHF 1: Copepoda (Type 28) - Type 10 - Meliola sp. (Type 14); 91.5cm-18.5cm; 1,179BP-214BP; AD 771-AD 1736

The main components of this zone are Copepoda (Type 28), Type 10 and Meliola sp. (Type 14) followed by Invertebrata (Type 52) (Figure 8.1). Both the wet and dry indicator taxa curves oscillate throughout this zone but the dry indicator taxa appear to be present at higher abundance levels to those of the dry indicator species. Copepoda (Type 28) remains at relatively constant levels throughout with the exception of a slight peak in values at 61.5cm to 25%. Values of Amphitrema flavum (Type 31A) and Zyg nemataceae (Type 58) remain low throughout, the latter being present at only certain levels. Alona rustica (Type 72A) values are highest at the base of the profile and then exhibit a gradual decreasing yet oscillating trend towards the top of the zone where they drop to 1% at 19.5cm. Gelasinospora sp. (Type 1), Type 3A, Pleospora sp. (Type 3B) and Type 5 (all dry indicator taxa) occur sporadically throughout the zone. Type 10 follows an oscillating trend from high values (46% at 87.5cm) at the base of the zone to a low of 1% at 49.5cm after which the curve increases again to 37% at 39.5cm and steadily decreases to 14% towards the top of the zone at 21.5cm. Values of Meliola sp. (Type 14) fluctuate slightly while exhibiting a gradual decreasing trend towards the top of the zone. Values never rise above 22% throughout. Many of the non indicator taxa are present at very low percentage levels in this zone, many only occur sporadically such as Types 16C, 17a, Tilletia sphagni (Type 27), Hyalosphenia subflava (Type 46), Type 69 and Xylariaceae (Type 93). Types 16A (2 celled) and 16A (4 celled) have very similar abundance trends throughout this zone. They both start off with low values at the base which increase to a high of 24% and 17% at 67.5cm respectively. Values then decrease and increase again between approximately 51.5cm and 43.5cm after which they decrease and disappear from the zone at 35.5cm. Values of both types reappear at 31.5cm and 29.5cm respectively and increase towards the
top of the zone. Values of Invertebrata (Type 52) and Type 99 remain stable throughout the zone, the latter decrease from 29.5cm to the top of the zone.

LHF 2: Copepoda (Type 28) - *Alona rustica* (Type 72A) - Invertebrata (Type 52); 18.5cm-10.5cm; 214BP-93BP; AD 1736-AD 1857

This zone is characterised by a very large peak in the wet indicator taxa curve which is mainly due to Copepoda (Type 28). Copepoda (Type 28) values are very high in this zone compared to the rest of the profile. These values reach their highest percentage at 15.5cm with a high of 47%. After this point they gradually decrease. Values of *Alona rustica* (Type 72A) increase from the base of the zone at 1% (17.5cm) to the top at 12% (11.5cm). Dry indicator taxa such as *Gelasinospora* sp. (Type 1), Type 3A, *Pleospora* sp. (Type 3B) and Type 5 are almost absent from this zone; the latter two types do not appear at any level throughout. The decreasing curve of Type 10 at the top of LHF 1 is continued in this zone where values drop to 1% at 11.5cm. The curve of *Meliola* sp. (Type 14) remains constant throughout this zone while values of Types 16A (2 celled) and 16A (4 celled) decrease towards the top of this zone to very low values of 1% and 0% at 13.5cm respectively. Types 18 and 19a also exhibit a similar decreasing trend towards the top of the zone. *Assulina seminulum* (Type 32B) values remain low and constant throughout the zone, never rising above 4%. Those of Acari, Oribatei (Type 36c) and Invertebrata (Type 52) exhibit an increasing trend towards the top of the zone, the latter occurring at higher abundance levels to Acari, Oribatei (Type 36c). Many types that were present in LHF 1, albeit at very low percentages, are absent from LHF 2, namely Types 24, 16C, 17a, 20, 23, *Tilletia sphagni* (Type 27), Xylariaceae (Type 44), *Hyalosphenia subflava* (Type 46), Type 53, *Lasiosphaeria* sp. (Type 63), Types 69, 82 and 99.

LHF 3: Type 10 - *Assulina seminulum* (Type 32B) - Invertebrata (Type 52); 10.5cm-0cm; 93BP-45BP; AD 1857-AD 1995

This zone exhibits an opposite trend to the previous zone, LHF 2, in that it is characterised by a peak in dry indicator taxa. This curve reaches values close to 60% in this zone, the main contributor of which seems to be Type 10. Wet indicator taxa such as Copepoda (Type 28) and *Alona rustica* (Type 72A) are present at much lower levels than in LHF 2. Copepoda (Type 28) percentages remain stable throughout, not reaching values higher than 14% while those of *Alona rustica* (Type 72A) exhibit a decreasing trend from the base of
the zone to the top of the profile to 1% at 5.5cm. Spores of *Alona rustica* (Type 72A) are absent from 3.5cm and 1.5cm but are present in the surface sample. *Amphitrema flavum* (Type 31A) and Zygnemataceae (Type 58) are present in this zone albeit sporadically and at very low percentages. *Gelasinospora* sp. (Type 1) only appears in the surface sample of this zone while spores of *Pleospora* sp. (Type 3B) and Type 5 occur twice in this zone. The Type 10 curve is characterised by a significant peak in values. They reach their highest percentage at 9.5cm where they reach 57%. After this point values steadily decrease to the top of the profile where they fall to 6% at 0cm. *Meliola* sp. (Type 14) values are higher in this zone than in LHF 2. They increase from the base of the zone to a high of 16% at 5.5cm. They then decrease towards the top of the zone. A few non indicator taxa exhibit similar trends of increasing values towards the top of the profile, albeit at different abundances. Such types include Type 8 (undifferentiated), *Helicoon plurisepatum* (Type 30) and *Assulina seminulum* (Type 32B). The increase in values of *Helicoon plurisepatum* (Type 30) is very dramatic, rising from 3% at 9.5cm to 44% at 0cm. Similarly *Assulina seminulum* (Type 32B) increases from 1% at 9.5cm to 30% at 1.5cm. Acari, Oribatei (Type 36c) and Invertebrata (Type 88A) remain fairly stable throughout this zone while those of Invertebrata (Type 52) oscillate and then steadily decrease from 35% at 5.5cm towards 0cm where they fall to 2%.

8.3.2 All Saint’s Bog

ASF 1: Type 10 - *Meliola* sp. (Type 14) - Type 23; 91.5cm-72.5cm; 1,036BP-794BP; AD 914-AD 1156

The dominant component of this zone is Type 10 which is also the main contributor to the dry indicator taxa curve which exhibits values close to 80% in this zone (Figure 8.2). Values for wet indicator taxa appear to be low; those of Copepoda (Type 28) remain stable throughout not rising above 5%. Values for *Amphitrema flavum* (Type 31A) start off at 13% at 91.5cm and then decrease to 3% at 81.5cm. After this point they steadily increase towards the top of the zone and reach percentages of similar value to those at the base of the zone. *Alona rustica* (Type 72A) is present in this zone but at very low percentages and not at every level counted. Type 3A, *Pleospora* sp. (Type 3B) and Type 5 are also present but at very low percentages. Those of Type 3A are seen to increase towards the top of the zone with the aid of exaggeration while those of Type 5 appear to exhibit a decreasing trend towards the top of the zone. Values for Type 10 reach their highest value in the
profile in this zone reaching 71% at 81.5cm. Values steadily decrease after this point towards the top of the zone falling to 43% at 73.5cm. Percentages of Meliola sp. (Type 14) remain stable throughout while the only occurrence of Type 24 in the profile occurs in the basal sample. Values of Chytridales (Type 13), Assulina seminulum (Type 32B), Acari, Oribatei (Type 36c) and Invertebrata (Type 52) remain constant throughout. Many non indicator taxa only occur at one level each in this zone, namely Types 17a, 20 and Helicoon pluriseptatum (Type 30). Values of Type 23 begin high at the base of the zone reaching 28% at 89.5cm but steadily decrease towards the top of the zone to a mere 1% at 75.5cm. Tilletia sphagni Type 27, Invertebrata (Type 88A) and Type 99 are present sporadically throughout at very low percentages.

ASF 2: Copepoda (Type 28) - Amphitrema flavum (Type 31A) - Type 10; 72.5cm-28.5cm; 794BP-223BP; AD 1156-AD 1727

The main feature of this zone is the oscillating trend exhibited by both wet and dry indicator taxa curves. Amphitrema flavum (Type 31A) appears to account for most of the wet indicator taxa curve while Type 10 appears to play a very similar role in the dry indicator taxa curve. Copepoda (Type 28) remains relatively stable throughout this zone with the exception of a slight peak in values to 21% at 41.5cm. Amphitrema flavum (Type 31A) values fluctuate throughout this while exhibiting a general decreasing trend towards the top of the zone. Values at the base of the zone continue the increasing trend that began at the top of ASF 1 to a high of 48% at 67.5cm. Values drop to 17% at 65.5cm but then rise to 44% at 63.5cm. After this peak in high values they decrease to a low of 1% at 43.5cm. They increase again after this level to 33% at 33.5cm and decrease again towards the top of the zone. Alona rustica (Type 72A) is present throughout this zone at relatively low percentage levels; values never rise above 10% throughout and don’t exceed 4% until near the top of the zone where they reach 10% at 31.5cm. Gelasinospora sp. (Type 1) appears twice in this zone at 55.5cm and 51.5cm respectively. Both Type 3A and Pleospora sp. (Type 3B) are present in this zone but only occur sporadically throughout. Values of Type 10 fluctuate throughout but appear to increase towards the top of the zone. Values are low at the base of the zone (7% at 67.5cm) but increase to 53% at 45.5cm. After this point values oscillate towards the top of the zone. Meliola sp. (Type 14) appears to exhibit quite a similar trend to that in ASF 1 in that values remain stable throughout. However a slight decrease in values occurs at the top of the zone to 6% at 29.5cm. Types 8, 17a, 18, 19, 20, Tilletia sphagni (Type 27), Helicoon pluriseptatum (Type 30),
Invertebrata (Type 88A) and Type 99 all occur sporadically and at low levels throughout this zone. Types 16A (2 celled), 16A (4 celled), 16B and 16C occur for the first time in the profile in this zone. Invertebrata (Type 52) is present at all levels in this zone and at higher abundance values to ASF 1. This species exhibits an increase in values between 59.5cm and 43.5cm compared to its values in the rest of the zone.

ASF 3: Copepoda (Type 28) - Type 10 - Type 16A; 28.5cm-8.5cm; 223BP-10BP; AD 1727-AD 1960

The main components of this zone appear to be Copepoda (Type 28) and Type 10. Both the wet and dry indicator taxa curves oscillate throughout this zone; the wet indicator taxa curve seems to exhibit a decreasing trend towards the top of the zone. The Copepoda (Type 28) curve begins with high values at the base of the zone (40% at 25.5cm) but generally decrease towards the top of the zone. Those of *Amphitrema flavum* (Type 31A) are present at the base and top of the zone only; they are absent from most of the levels in the zone. Zygnemataceae (Type 58) appears three times in this zone at 19.5cm, 17.5cm and 9.5cm respectively. Values of *Alona rustica* (Type 72A) appear fairly stable throughout this zone, not rising above 9%. *Gelasinospora* sp. (Type 1), Type 3A and *Pleospora* sp. (Type 3B) occur sporadically throughout. Values of Type 10 fluctuate throughout but exhibit a general trend of decreasing values from the base of the zone (33% at 27.5cm) to the middle (7% at 17.5cm) and then increase again to the top of the zone (38% at 9.5cm). *Meliola* sp. (Type 14) values remain relatively stable throughout but decrease slightly at 15.5cm to 0%. Values of *Meliola* sp. (Type 14) never rise above 5% in this zone. Values of Types 16A (2 celled) and 16A (4 celled) are more abundant in this zone than in the rest of the profile. Here both curves peak at 17.5cm to 34% and 25% respectively. After this peak the values steadily decrease towards the top of the zone. Types 16B, 16C, 17a, 20, *Herpotrichella* sp. (Type 22), *Tilletia sphagni* (Type 27), *Helicoon pluriseptatum* (Type 30), Xylariaceae (Type 44), *Hyalosphenia subflava* (Type 46), Araneida (Type 71b), Invertebrata (Type 88A) and Type 99 are all present sporadically at very low percentages throughout the zone. Values of Chytridales (Type 13) and Acari, Oribatei (Type 36c) are low but stable throughout. Those of Type 18 exhibit an increasing trend towards the top of the zone rising from 2% at 27.5cm to 16% at 9.5cm. Invertebrata (Type 52) percentages rise from the base of the zone to a peak of 23% at 19.5cm after which they decrease towards the top of the zone.
This zone is mainly dominated by Type 10. The wet indicator taxa curve is characterised by two peaks in values at 5.5cm and 1.5cm while that of the dry indicator taxa curve initially decreases from its high values at the base of the zone of just over 60% to 13% at 1.5cm. Values increase to 55% at 0cm. All four wet indicator taxa found in the profile are present in this zone; Copepoda (Type 28) values appear stable throughout not rising above 9%, while those of *Amphitrema flavum* (Type 31A) steadily increase towards the top of the profile rising from 1% at 7.5cm to 18% at 1.5cm. Values of *Zyg nemataceae* (Type 58) exhibit the opposite trend in that they decrease towards the top of the zone reaching a low of less than 1% at 0cm. *Alona rustica* (Type 72A) values remain stable for most of the zone but decrease at the top to 1% at 0cm. Both Gelasinospora sp. (Type 1) and Type 3A are present at only one level each in this zone while values for *Pleospora* sp. (Type 3B) exhibit a dramatic increase towards the top of the profile. Values rise from 1% at 7.5cm to 34% at 0cm. Type 10 is quite abundant at the base of the zone but exhibits a steady decreasing trend towards the top of the profile. Values fall from 55% at 7.5cm to 18% at 0cm. Values of *Meliola* sp. (Type 14) peak at 5.5cm (16%) and then decrease towards the top of the zone. Values of Chytridales (Type 13), Types 16A (2 celled), 16A (4 celled), 19 and *Hyalosphenia subflava* (Type 46) are all stable and low throughout this zone. Taxa such as Types 16B, 17a, Araneida (Type 71b) and Invertebrata (Type 88A) all occur at one level each throughout. Several types exhibit an increasing trend in percentage values in this zone, namely *Tilletia sphagni* (Type 27), *Helicoon pluriseptatum* (Type 30), *Assulina seminulum* (Type 32B) and, to a lesser extent, Invertebrata (Type 52), while those of Types 20, 23 and Acari, Oribatei (Type 36c) decrease towards the top of the profile. *Tilletia sphagni* (Type 27), *Helicoon pluriseptatum* (Type 30) and *Assulina seminulum* (Type 32B) reach their highest abundance levels in the profile in this zone at 1.5cm where they amount to 15%, 10% and 22% respectively.
8.3.3 Ballygisheen Bog

BGF 1: Copepoda (Type 28) - *Alona rustica* (Type 72A) - Type 10; 100.5cm-82.5cm; 1,192BP-812BP; AD 758-AD 1138

This zone is characterised by a general increasing wet indicator species curve and a fluctuating dry indicator species curve (Figure 8.3). Values of Copepoda (Type 28) exhibit a steady increasing trend from the base of the profile to the top of the zone. Values increase from 4% at 100.5cm to 23% at 83.5cm. Those of *Amphitrema flavum* (Type 31A) are low throughout, not rising above 6%, and decrease towards the top of the profile. Values of *Alona rustica* (Type 72A) oscillate in this zone. They are high at the base of the zone (19% at 99.5cm) and then decrease to 3% at 91.5cm. After this point they increase again to the top of the zone reaching 21% at 83.5cm. The dominant component of the dry indicator species curve in this zone is Type 10. Values of Type 10 fluctuate throughout starting off with abundance levels close to 40% at the base and then oscillate to a high of 31% at 91.5cm and then steadily decrease towards the top of the zone. *Meliola* sp. (Type 14) values peak at 93.5cm but remain below 15% throughout the zone. *Gelasinospora* sp. (Type 1) is present in three levels in this zone. Values of Type 16A (2 celled) and *Helicoon pluriseptatum* (Type 30) remain stable and low throughout this zone while those of Acari, Oribatei (Type 36c) and Invertebrata (Type 52) also remain stable but at higher percentages to Type 16A (2 celled) and *Helicoon pluriseptatum* (Type 30). Type 16A (4 celled) values decrease from the base of the zone towards the top while those of Type 23 fluctuate throughout. Many types appear at one or two levels in this zone, namely Types 11, 17a, 18, *Tilletia sphagni* (Type 27), Types 69 and 99.

BGF 2: Copepoda (Type 28) - *Alona rustica* (Type 72A) - Type 23; 82.5cm-62.5cm; 812BP-470BP; AD 1138-AD 1480

The main feature in this zone is the high values exhibited in the wet indicator species curve which corresponds with the low values seen in the dry indicator species curve. Values of Copepoda (Type 28) gently oscillate throughout this zone, remaining between 11% and 28% throughout. *Amphitrema flavum* (Type 31A) peaks at 79.5cm and then dramatically decreases to values of similar abundance levels to those in BGF 1. *Alona rustica* (Type 72A) is by far the largest contributor to the wet indicator species curve and exhibits a steady increasing trend from the base of the zone (10% at 81.5cm) to 67.5cm where it
reaches 44%. After this point *Alona rustica* (Type 72A) values gradually decrease towards the top of the zone. Only three of the six dry indicator species present in the Ballygisheen profile are found in this zone. Of these only two are present at every level counted, namely Type 10 and *Meliola* sp. (Type 14). *Gelasinospora* sp. (Type 1) is present at only three levels. Type 10 values are low throughout this zone, never rising above 11%. Those of *Meliola* sp. (Type 14) are very low and stable throughout, all remaining below 2%. Values for Type 16A (2 celled), *Helicoon pluriseptatum* (Type 30), Type 69, Invertebrata (Type 88A) and Type 99 are all low throughout BGF 2. Type 16A (4 celled) rapidly decrease from the base to just over 2% for most of the zone and then at the top begin to increase again to 8% at 63.5cm. Those of Type 17a are low throughout but with the aid of exaggeration seem to exhibit an increasing trend towards the top of the zone. Values for Type 23 achieve their highest abundance at the base of this zone (42% at 81.5cm) but the steadily decrease towards the top of the zone where values fall to less than 1% at 63.5cm. *Assulina seminulum* (Type 32B), Acari, Oribatei (Type 36c) and Invertebrata (Type 52) remain stable and at values similar to those in BGF 1. Types 18, 19, 69, Araneida (Type 71b), Invertebrata (Type 88A) and Type 99 occur sporadically throughout the zone.

BGF 3: Copepoda (Type 28) - Type 10 - Invertebrata (Type 52); 62.5cm-22.5cm; 470BP-43BP; AD 1480-AD 1907

This zone appears very different to the previous one. In contrast to BGF 2 this zone is dominated by high values of dry indicator species. Values of wet indicator species decrease towards the top of the profile while those of dry indicator species increase. Values for Copepoda (Type 28) appear fairly stable throughout this zone with only a slight decreasing trend evident towards the top of the zone. *Amphitrema flavum* (Type 31A) is present in BGF 3 but only at very low percentages and not at every level counted. Values of *Alona rustica* (Type 72A) are quite dissimilar to those in BGF 2 in that they exhibit a steep decrease from values in the previous zone and remain below 8% from 57.5cm to the top of the zone. Values for Type 10 exhibit the opposite trend. They increase from their low values in BGF 2 to 60% at 55.5cm and from here they remain at a similar abundance oscillating only slightly until the top of the zone. *Gelasinospora* sp. (Type 1), Type 3A and *Pleospora* sp. (Type 3B) are present sporadically and at very low percentages throughout this zone. Values of *Meliola* sp. (Type 14) are relatively stable at the beginning of the zone but exhibit a gradual decreasing trend from 43.5cm towards the top of the zone falling to values of less than 1% and 1% at 31.5cm and 27.5cm respectively. Values for
Types 8 (undifferentiated), 23, *Helicoon pluriseptatum* (Type 30), Invertebrata (Type 88A) and Type 99 remain stable and at low percentages throughout while those of Types 16A (2 celled) and 16A (4 celled) exhibit an oscillating trend where both begin the zone with peaks in values at 57.5cm (11%) and 61.5cm (30%) respectively, then steadily decrease to lower values and then increase again to values not quite so high as previous at 27.5cm (4%) and 29.5cm (16%) respectively. After these points values for both decrease towards the top of the zone. *Tilletia sphagni* (Type 27) values peak at 39.5cm and then steadily decrease to 0% at 25.5cm. Values for Invertebrata (Type 52) oscillate throughout this zone but also exhibit an increasing trend towards the top of the zone. Invertebrata (Type 52) values are higher in this zone than in BGF 1 and BGF 2 ranging between 6% and 24%.

BGF 4: Type 10 - *Meliola* sp. (Type 14) - Type 53; 22.5cm-0cm; 43BP-47BP; AD 1907-AD1997

This zone carries on from the trend set in BGF 3 in that the dry indicator species curve increases towards the top of the profile while that of the wet indicator species decreases. Both Copepoda (Type 28) and *Alona rustica* (Type 72A) decrease towards the top of the zone reaching 4% and 1% at 1.5cm respectively. Both types increase in value at 0cm to 15% and 2% respectively. *Amphitrema flavum* (Type 31A) and Zygnemataceae (Type 58) are present sporadically and at very low percentages throughout this zone. Similarly *Gelasinospora* sp. (Type 1), Type 3A and *Pleospora* sp. (Type 3B) are present sporadically and at low percentages whereas Type 10 values increase again in abundance reaching their highest values in the profile in this zone. They increase from 46% at 19.5cm to 70% at 3.5cm after which they decrease to 0cm. Again, similar to the previous zones, Type 10 accounts for most of the dry indicator species curve. *Meliola* sp. (Type 14) increases in value from the base of the zone to 11.5cm (12%) and then its values gradually decrease towards 0cm (6%). Values for Types 16A (2 celled), 16A (4 celled), 17a, 18, 19, 23, *Tilletia sphagni* (Type 27), Type 69 and Invertebrata (Type 88A) are present sporadically and at very low percentages throughout this zone. Those of Type 8 (undifferentiated) and *Helicoon pluriseptatum* (Type 30) are seen to increase towards the top of the profile with the aid of exaggeration. Similarly *Assulina seminulum* (Type 32B) increases towards the top of the zone reaching 20% at 0cm. Invertebrata (Type 52) exhibits an opposite trend in that it gradually decreases from 24% at 21.5cm to 3% at 0cm. Values of Type 99 reach their highest abundance levels in this zone at 17.5cm (8%) after which they slowly decrease towards the top of the profile.
8.4 Interpretation and Comparisons of the Fungal Spore Component of each Site

Similar to Sections 6.4 and 7.4 it was decided to plot each of the fungal spore percentage diagrams with respect to age (Figures 8.10, 8.11 and 8.12) to simplify comparisons both between themselves, the pollen and the physical characteristics of the sediment from each site. Figure 8.13 was also drawn to illustrate the zone boundaries of each site relative to one another. Fungal spore concentration diagrams were constructed from the original counts from each site (Figures 8.14, 8.15 and 8.16).

8.4.1 Liffey Head Bog

The lower zone of Liffey Head Bog (Figure 8.10), from AD 771 to AD 1736 (1,179BP to 214BP), illustrates a fluctuating environment of wet and dry conditions on the bog surface. Dry conditions appear to be overall more dominant but all taxa tend to oscillate throughout. A very different scenario occurs between AD 1736 and AD 1857 (214BP to 93BP) where it is clear from the record that wet conditions prevailed during this time period. Copepoda (Type 28) dominates this period which can also be seen from the fungal spore concentration diagram (Figure 8.14). This is not particularly evident from the local pollen record for Liffey Head Bog as during this time period taxa appear stable with no major fluctuations. Cyperaceae values appear to be high during this period but not any more than before or after this time period. The opposite trend is evident from AD 1857 (93BP) to the present day as dry conditions initially dominate and then decline steadily from 1902 to the present day. This is in sharp contrast to the local pollen record for Liffey Head Bog (Figure 7.10) for this time period where the abundances of Calluna, Ericaceae-type, Cyperaceae and Narthecium suggest a drying out of the bog surface.

Many types identified, while indicating local wet or dry conditions on the bog surface, also indicate the presence of specific plant taxa or substrate presence (Table 8.1). *Gelasinospora* sp. (Type 1) has been associated with charcoal in the past and is thought to be carbonicolous (van Geel, 1978). When the *Gelasinospora* sp. (Type 1) record from Liffey Head Bog is compared with those of both micro and macroscopic charcoal (Figures 5.7 and 5.10) from the same site it can be seen the *Gelasinospora* sp. (Type 1) does not occur at all levels where charcoal is present. It appears to be correlated more with the microscopic charcoal profile being present at three of the four highest charcoal peaks at
Figure 8.11
All Saint's Bog
Fungal Spore Percentage Diagram
(plotted with respect to age)
Figure 8.12
Ballygisheen Bog
Fungal Spore Percentage Diagram
(plotted with respect to depth)
Figure 8.13 Diagram of fungal spore zone boundaries of each site drawn with respect to age.
Figure 8.14
Liffey Head Bog
Concentration Diagram of Main Fungal Spore Taxa
(plotted with respect to age)
Figure 8.15
All Saint's Bog
Concentration Diagram of Main Fungal Spore Taxa
(plotted with respect to age)
Figure 8.16
Ballygisheen Bog
Concentration Diagram of Main Fungal Spore Taxa
(plotted with respect to age)
Type 8 (undifferentiated), Chytridales (Type 13), Herpotrichella sp. (Type 22) and in particular Type 10 and Meliola sp. (Type 14) are all associated with Calluna vulgaris in some way. Some have been observed living on C. vulgaris or require it as its specific substrate. Comparing the abundance and presence of these types to Calluna vulgaris percentages it can be seen that Type 8 (undifferentiated) exhibits a similar trend to Calluna in that it remains fairly stable for most of the profile but increases from approximately AD 1900 (50BP) up to the present day. Type 10 and Meliola sp. (Type 14) do not match the Calluna curve; both types fluctuate throughout most of the profile unlike Calluna percentages which remain stable. Type 10 exhibits the opposite trend to Calluna and declines in abundance in the last 100 years suggesting that the presence of these Types would not necessarily indicate the presence of Calluna or its particular trend throughout the profile.

Several types are also associated with Sphagnum species but only one was found in the profiles examined, namely Tilletia sphagni (Type 27). The abundance of Tilletia sphagni (Type 27) in the Liffey Head Bog profile is very low and sporadic and its presence at certain levels does not reflect increases or decreases observed in the corresponding Sphagnum curve. This is not a strange scenario however as the spore record of Sphagnum is actually a record of sporulation and not presence/absence and, coupled with the fact that peaks in Sphagnum are difficult to interpret and are not indicative of certain local conditions, there would appear to be no reason why both curves should match.

The presence of Type 16A microfossils would suggest that Molinia caerulea was present on the bog surface at various times throughout the profile (O’Connell and Doyle, 1990) especially between AD 1230 and AD 1781 (720BP and 169BP).

8.4.2 All Saint’s Bog

Dry conditions appear to prevail at All Saint’s Bog from AD 914 to AD 1156 (1,036BP to 794BP) as illustrated by the high percentage of dry indicator taxa in Figure 8.11 during this time period. This appears to be followed by a somewhat wetter phase up until AD 1350 (600BP) characterised by high percentage values of Amphitrema flavum (Type 31A). This
is not reflected in the local pollen record. From AD 1350 to AD 1960 (600BP to -10BP) no obvious wet or dry conditions are evident as the indicator taxa curves fluctuate throughout this period exhibiting no general patterns. A similar scenario can be seen from the local pollen during this time period as species remain fairly stable with no significant peaks or trends visible. Dry conditions seem to dominate from 1960 (-10BP) to the present day which contradicts what is observed in the local pollen data for this period with declines observed in Calluna, Ericaceae-type and a peak in Sphagnum. This is not particularly evident from the fungal spore concentration diagram (Figure 8.15) where both dry and wet indicator taxa appear low in concentration.

The Gelasinospora sp. (Type 1) and charcoal scenario at All Saint’s Bog is similar to that at Liffey Head Bog in that the presence of Gelasinospora sp. (Type 1) appears to be correlated more with the microscopic charcoal profile (Figure 5.8) than the macroscopic charcoal record (Figure 5.11). The highest occurrences of Gelasinospora sp. (Type 1) recorded match those of microscopic charcoal at 1956 (-6BP), and 1964 (-14BP) where the abundances of charcoal are greatest. This is not the case with respect to Gelasinospora sp. (Type 1) and the macroscopic charcoal record.

Not many similarities are evident between types associated with Calluna vulgaris and the Calluna curve for All Saint’s Bog (Figure 7.11). The high values of Type 10 exhibited in ASF 1 between AD 914 and AD 1156 (1,036BP and 794BP) indicating local dry conditions is not reflected in the Calluna percentages during this period. Similarly the low values of Type 10 and Meliola sp. (Type 14) at c.1964 (-14BP) do not correspond with low Calluna values at this time. The only real similarity present between the two profiles is the decline in values from 1960 (-10BP) to the present day visible in both the Calluna curve and Type 10 and Meliola sp. (Type 1). However, despite these decreases, it would appear that this period was predominantly dry as illustrated from the indicator taxa curves. This suggests again that these types would not be reliable to use to trace trends in Calluna abundances at particular sites over time.

Similar to the scenario at Liffey Head Bog, the abundance of Tilletia sphagni (Type 27) in the All Saint’s Bog profile is very low and sporadic and, with the exception of the last 50 years, its presence at certain levels does not reflect changes in the corresponding Sphagnum record. Both the Tilletia sphagni (Type 27) curve and the Sphagnum curve from the All Saint’s Bog profile exhibit the same trend in the last 50 years where an initial increase.
followed by a steady decrease is observed. *Tilletia sphagni* (Type 27) is most highly associated with *Sphagnum cuspidatum* than with any other *Sphagnum* species (van Geel, 1978). This species is only found growing in bog pools on the bog surface which would suggest that this period may have been wet. Van Geel (1978) does not list *Tilletia sphagni* (Type 27) as a wet indicator taxon but its presence as a wet indicator would hold with that suggested by the decline in percentage values of both *Calluna* and Ericaceae-type insinuating wet conditions during this time.

The high abundance of Type 16A between AD 1727 and AD 1960 (223BP and -10BP) would suggest the local presence of *Molinia caerulea* on the bog surface (O'Connell and Doyle, 1990) during this time while the presence of Type 18 during this same time period would suggest the local presence of *Eriophorum vaginatum* (van der Molen, 1988; O'Connell and Doyle, 1990). This species prefers dry conditions which would add to the not so strong dry signal exhibited by the fungal spore data for this time period.

6.4.3 Ballygisheen Bog

The wet and dry indicator taxa curves suggest that Ballygisheen Bog has experienced mainly dry conditions for the last 1,200 years (Figure 8.12). A clear wet period appears to have prevailed between AD 1138 and AD 1480 (812BP and 470BP) characterised by high percentages of Copepoda (Type 28) and *Alona rustica* (Type 72A). Such conditions are also illustrated by the fungal spore concentration diagram for Ballygisheen Bog (Figure 8.16). No dramatic change in species abundance is evident in the local pollen record (Figure 7.12) that may suggest a change in local bog conditions. From AD 1480 to 1997 (470BP to -47BP) dry conditions appear to dominate the local conditions on the bog surface especially from c.1947 (3BP) to the present day. Type 10 dominates the record. This trend of dry conditions between AD 1480 and 1997 (470BP and -47BP) is reflected in the local pollen record for Ballygisheen Bog where *Calluna* and Ericaceae-type values increase to relatively high levels from AD 1465 (485BP) and remain quite high until the present day. However the significant increase in local dry conditions seen in Figure 8.12 from 1947 onwards is not evident in the local pollen record.

*Gelasinospora* (Type 1) presence corresponds with three out of the four highest peaks of microscopic charcoal found in Ballygisheen Bog (Figure 5.9), namely at AD 998 (952BP), AD 1119 (831BP) and AD 1632 (318BP) and its presence between AD 1632 (318BP) and
AD 1726 (224BP) corresponds with quite a concentration of microscopic charcoal during the same time period. Unlike the scenarios at Liffey Head Bog and All Saint’s Bog, the *Gelasinospora* (Type 1) record corresponds quite well with that of macroscopic charcoal (Figure 5.12) for Ballygisheen Bog. The highest concentration of *Gelasinospora* (Type 1) found in the profile between AD 1552 (398BP) and AD 1787 (163BP) coincides nicely with a high concentration of charcoal during this time. This provides support for the occurrences of fire episodes during these time periods.

When the *Calluna* curve of Ballygisheen Bog (Figure 7.12) is compared with those of Types 8 (undifferentiated), 10 and *Meliola* sp. (Type 14) it can be seen that some similarities do occur. The higher values of Type 10 and *Meliola* sp. (Type 14), and to a lesser extent, Type 8 (undifferentiated) between AD 758 and AD 1138 (1,192BP and 812BP) in BGF 1 compared to BGF 2 are also reflected in higher values of *Calluna* for this time period but the difference between *Calluna* in this time period and that above it is not as dramatic as that of Type 10 and *Meliola* sp. (Type 14). The dramatic increase in values of Types 8 (undifferentiated), 10 and *Meliola* sp. (Type 14) at AD 1495 (455BP) can also be seen in the *Calluna* record. However during the last 100 years contrasting results are evident with declines in *Calluna* percentages yet increases in Types 8 (undifferentiated), 10 and *Meliola* sp. (Type 14) values. Again this illustrates how these types associated with *Calluna* cannot exclusively be used to determine the behaviour of *Calluna* on the bog surface.

A striking similarity is evident between the *Sphagnum* curve and the *Tilletia sphagni* (Type 27) curve of Ballygisheen Bog between AD 1747 and AD 1841 (203BP and 109BP) where a peak in values of *Tilletia sphagni* (Type 27) coincides with a similar shaped peak in *Sphagnum* values for the exact same time period. Such a similarity between taxa may suggest a local wet phase on the bog surface during this time.

The Type 16A curve appears to follow that of the dry indicator taxa curve and is least abundant during the wet period of AD 1138 to AD 1480 (812BP to 470BP). Its presence is thought to indicate the local presence of *Molinia caerulea* (O’Connell and Doyle, 1990).
6.4.4 Comparisons between Sites

Figure 8.13 illustrates the zone lines that were constructed from the fungal spore assemblages of each site. Only two sets of zone lines appear to match up between the three sites during a similar time period, namely the lowest zones lines in the All Saint’s Bog and Ballygisheen Bog profiles at AD 1156 (794BP) and AD 1138 (812BP) respectively and those at AD 1736 (214BP) at Liffey Head Bog and at AD 1727 (223BP) at All Saint’s Bog. The lower matching zone lines both occur in their respective profiles at a time when there is evidence of a change from local dry conditions to local wet conditions. Unfortunately the upper matching zone lines do not exhibit such a trend – the Liffey Head Bog zone line at AD 1736 (214BP) does occur where there is an apparent change to local wet conditions but that at All Saint’s Bog at AD 1727 (223BP) appears to be influenced by non indicator taxa also and is not indicative of a change in local hydrological conditions. This may be due to anthropogenic influences on the surrounding landscape or just to the abundance of certain non indicator taxa (Type16A and Invertebrata (Type 52)) masking any change that may have been occurring in the hydrological environment (Copepoda (Type 28) and Alona rustica (Type 72A) appear to increase while Type 10 and Meliola sp. (Type 14) decline suggesting a change to wet conditions). When the fungal spore zone lines are compared to those of the regional pollen zone lines (Figure 6.13) it is evident that no real similarities are present. This is what would be expected as what is happening on the immediate bog surface will be quite different to what is happening in the surrounding landscape. However when compared to the local pollen zone lines (Figure 7.13) some vague similarities are seen. There are only 30 years between the local zone line at AD 1887 (63BP) and the fungal spore zone line at AD 1857 (93BP) in Liffey Head Bog. This corresponds to increases in Calluna and Ericaceae-type values and dry indicator taxa suggesting a change to local dry conditions at this time. A similar scenario is evident in the Ballygisheen profile where the local pollen zone line at AD 1480 (470BP) and the fungal spore zone line at AD 1450 (500BP) are only 30 years apart also and again correspond to increases in Calluna and increases in dry indicator taxa suggesting a change from local wet conditions (especially evident from the fungal spore record (Figure 8.12)) to local dry conditions at Ballygisheen Bog at this time.

Looking at just the wet and dry indicator species curves for each site it is clear that what is happening at each site is very different to the others (Figure 8.17 A-C). However the dominant types present in each of the fungal spore assemblages seem to be very similar
Figure 8.17  (A) Diagram of percentage wet and dry indicator taxa curves from Liffey Head Bog plotted against time (AD) (B) Diagram of percentage wet and dry indicator taxa curves from All Saint's Bog plotted against time (AD) (C) Diagram of percentage wet and dry indicator taxa curves from Ballygisheen Bog plotted against time (AD).
Wet indicator taxa (dark line); Dry indicator taxa (light line)
between sites. Copepoda (Type 28), Type 10, Meliola sp. (Type 14) and Invertebrata (Type 52) all appear to be significant components in each of the three sites. There are other components which appear to be important contributors to some of the sites but not others i.e. Alona rustica (Type 72A) is very abundant in the Ballygisheen Bog profile but does not feature as prominently in the Liffey Head Bog or All Saint's Bog profiles. Similarly Amphitrema flavum (Type 31A) appears to be the dominant component of the wet indicator species curve in All Saint's Bog yet appears to play quite a minor role in percentage values of the wet indicator species curves in the profiles of Liffey Head Bog and Ballygisheen Bog.

Detrended Correspondence Analysis (DCA) was carried out on the fungal spore taxa greater than 5% from each site investigated as described in Section 3.7.3; the results of which are illustrated in Figure 8.18A-D. Figure 8.18A illustrates the data from all three sites plotted with the main fungal taxa analysed. No obvious trend is visible from the DCA. The wet, dry and non indicator taxa plot out mixed up together with no visible pattern. Figures 8.18B and C are DCA plots of the data after it had been manipulated by downweighting of rare taxa and a square root transformation respectively. Downweighting of rare taxa in DCA involves downweighting the abundances of taxa rarer than Fmax/5 (where Fmax is the frequency of the commonest taxa) in proportion to their frequency. Again no obvious gradients or trend are visible from the plots. Figure 8.18D illustrates the data untransformed with downweighting and with the sites identified but similar to the previous figures, there appears to be no patterns evident in the data.

Both the percentage plots of fungal spores (Figures 8.10, 8.11, 8.12 and 8.17) and the DCA plots (Figure 8.18A-D) illustrate how all three sites are very different to one another with respect to climatic gradients and trends. Any climatic signals suggested by the data are not very strong and are certainly not seen at the same time at all sites. The two most prominent changes in inferred wet and dry conditions are seen at c. AD 1157 (793BP) at Ballygisheen Bog (c. AD 1169 (781BP) at All Saint's Bog) and at AD 1751 (199BP) at Liffey Head Bog. The change from local dry conditions to wet conditions at approximately AD 1160 at Ballygisheen Bog and All Saint's Bog does not last for the same time span at both sites; it lasts significantly longer at Ballygisheen Bog. The change from dry conditions to wet conditions at Liffey Head Bog at AD 1751 (199BP) is not found at either of the other two sites. An interesting feature observed at all three sites is the fact that Assulina seminulum (Type 32B) appears to have higher values towards the very top of each of the three
Figure 8.18
A. DCA plot of Axis 1 and Axis 2 of fungal spores from all sites for taxa >5%
B. DCA plot of Axis 1 and Axis 2 of fungal spores from all sites for taxa >5% after downweighting of the data
Figure 8.18
C. DCA plot of Axis 1 and Axis 2 of fungal spores from all sites for taxa >5% after a square root transformation of the data
D. DCA plot of Axis 1 and Axis 2 of fungal spores from all sites for taxa >5% with levels from each site differentiated
profiles. Values have increased within the last 40 years at both All Saint’s Bog and Ballygisheen Bog and the last 80 years at Liffey Head Bog. Tolonen (1986b) suggests that Assulina seminulum (Type 32B) is indicative of drier habitats on bogs. Although this does not agree with the local pollen record from all three sites for these time periods, it may reflect very local conditions of increasing dryness due any number of factors the effects of which may not be strong enough to be picked up by the local pollen.

Few studies exist that include the analysis of testate amoebae and fungal remains, especially those concerned with the last 1,000 years. Research by van der Molen (1988) in Co. Offaly exhibits few similarities to the results obtained from All Saint’s Bog (the closest site of those investigated). However these similarities are not clear cut and definite. The wet period experienced between AD 1689 and AD 1730 at Woodfield Bog characterised by enormous quantities of Tillettia sphagni (Type 27) is not so evident at All Saint’s Bog. No Tillettia sphagni (Type 27) spores were found during this time period. Local dry conditions are evident from the Woodfield Bog study between AD 1735 and 1930 from high amounts of Type 10 and Meliola sp. (Type 1 and low percentages of Amphitrema flavum (Type 31A). Meteorological data collected from Birr Castle for this period is dominated by low temperature levels and small amounts of rainfall (van der Molen, 1988). It is difficult to ascertain whether this period was locally dry at All Saint’s Bog. Very little Amphitrema flavum (Type 31A) is present in this period yet Copepoda (Type 28) is quite dominant. Type 10 values are quite high also but Meliola sp. (Type 14) percentages are low. Wet conditions are dominant from the Woodfield Bog data between 1933 and 1955. This period at All Saint’s Bog contains high amounts of both Copepoda (Type 28) (wet indicator) and Type 10 (dry indicator). From 1958 dry conditions prevail at Woodfield Bog. This also appears to be the case at All Saint’s Bog where high values of Type 10 and Meliola sp. (Type 14) are found. This is not reflected in the local pollen record for this period at All Saint’s Bog unlike that at Woodfield Bog where high Calluna and increasing Ericaceae-type values dominate.

When the results from the three sites investigated are compared to those of van Geel and Middeldorp (1988) from Carbury Bog in Co. Kildare some similarities along with stark contrasts are found. From AD 1130 to AD 1280 relatively dry conditions were experienced on Carbury Bog with high values of Type 3A and Amphitrema flavum (Type 31A) recorded. The same time period at Liffey Head Bog reveals no real trend in wet or dry indicator taxa while at All Saint’s Bog and Ballygisheen Bog local wet conditions are
insinuated from the high amounts of *Amphitrema flavum* (Type 31A) and *Alona rustica* (Type 72A) and low amounts of Type 10 and *Meliola* sp. (Type 14) recorded. From AD 1280 to AD 1420 local wet conditions appear to prevail at Carbury Bog. A similar situation occurs at Ballygisheen Bog but the opposite is illustrated at Liffey Head Bog while All Saint’s Bog exhibits fluctuating wet and dry indicator curves with no clear trend visible. Local dry conditions are experienced at Carbury Bog between AD 1420 and 1981 but in particular between AD 1640 and 1981. A similar pattern is visible from the Ballygisheen fungal spore data during this time period with high values of Type 10 and *Meliola* sp. (Type 14) and low amounts of *Alona rustica* (Type 72A). Dry conditions are suggested at both Liffey Head Bog and All Saint’s Bog between AD 1420 and AD 1640 but after this time taxa fluctuate with no significant pattern existing. These findings are in contrast to those of local pollen from the three sites as discussed in Section 7.4.4 – the only scenario common being local dry conditions at Ballygisheen Bog between AD 1420 and AD 1640 as suggested by both fungal spore and local pollen which matches with those found at Carbury Bog in Co. Kildare.

There may be various reasons why hydrological gradients are not strong or synchronous between the three sites investigated. The bog is reflecting local conditions which may well differ between sites as these may not be a national phenomenon. This can be seen from the local pollen record and from data from other sites (van der Molen, 1988; van Geel and Middeldorp, 1988). However the fungal spore record and pollen record do not necessarily match time wise within sites suggesting that something else may be influencing the record. The number of taxa that are wet or dry indicators are few compared to the non indicator taxa which may mean that any signal that the wet or dry taxa may be picking up may be masked by the abundance of non indicator taxa. The presence of so few indicator taxa also means that the indicator taxa curves will be sensitive to the impact of any significant increase or decrease in one of its components i.e. *Pleospora* sp. (Type 3B) increases dramatically in the surface sample of All Saint’s Bog and so causes the dry indicator taxa curve to increase also even though the main dry indicator taxa, Type 10 and *Meliola* sp. (Type 14) decrease. Some non indicator taxa behave like wet and dry indicators and so may hinder the ability to detect strong climatic signals from the indicator taxa. Such a taxon is Type 16A which in the Ballygisheen Bog profile behaves similar to a dry indicator taxon. The fact that only a few specific indicator taxa are present may also be due to the preparation procedure used. Although the acetolysis procedure of the pollen extraction does not adversely affect the fungal component of the samples, it can destroy some of the
more delicate tests of the rhizopods. All preparation procedures suitable for pollen extraction were found to reduce the number of tests recorded by up to 80% and the number of taxa recorded by 60% (Hendon and Charman, 1997). Therefore such counts must be viewed with extreme caution as they may be unrepresentative of the faunal component of the sample in both absolute and relative terms (Hendon and Charman, 1997). All these factors may help account for the reason the fungal spore results differ so much between sites and within sites when compared to the local pollen component of each.

Research on the rhizopod fauna of bogs in both America and Europe exists (Charman and Warner, 1992; Warner and Charman, 1994; Woodland et al., 1998) where canonical correspondence analysis was carried out on the faunal composition of the peatlands and various associated environmental parameters. Conclusions from such studies include how both pH and depth to water table are the main environmental variables to which testate amoebae respond (Charman and Warner, 1992; Warner and Charman, 1994) and how it is difficult to compare different data sets if samples are taken at different times of the year (Charman and Warner, 1992; Woodland et al., 1998). In this study only three species of testate amoebae were found and no environmental parameters were recorded such as pH or percentage moisture of the sediment. All three sites were sampled at different times of the year which, combined with only finding three species, leaves comparisons of the rhizopod fauna between sites extremely difficult.

Although it is possible to derive quantitative estimates of changing soil moisture conditions from testate amoebae, care should be taken in interpreting results, particularly from non-Sphagnum-rich peats, until more is learned about the distribution and ecology of modern faunas (Warner and Charman, 1994).
9.1 Introduction

The results of the methods used in this investigation have been presented and discussed in Chapters III to VII. As the chapters have progressed their results have been incorporated into the proceeding chapters and links, similarities and differences between each have been established. The issue of climate has been somewhat ignored so far however, therefore this chapter aims to deal with the three major climatic events of the recent past, namely the Medieval Warm Period, the Little Ice Age and 20th Century Warming (see Chapter I) and to investigate whether signs or characteristics of these climatic periods are evident in the various proxy records established from the three sites or not. Of course human impact cannot be ignored in the interpretation of climatic signals as it has been an integral part of life in Ireland over the last 1,200 years and therefore will be mentioned throughout this chapter.

In order to look at these particular climatic periods with respect to the results obtained in this study it was decided to construct percentage diagrams of 1. the main regional pollen taxa from each site combined, 2. the main local pollen taxa from each site combined and 3. the wet and dry fungal indicator curves from each site combined with the Medieval Warm Period, Little Ice Age and 20th Century Warming illustrated on each. As explained in Chapter I there are various dates postulated for the beginning and end of each of the climatic periods. For the purposes of this study it was decided to use the dates and durations of both the Medieval Warm Period and Little Ice Age climatic periods as suggested by Lamb (1977) for Britain as it is the closest geographical country to Ireland and therefore it was assumed that these dates would be the closest to those in Ireland if both periods occurred here. The percentage diagrams with the climatic periods illustrated are presented in Figures 9.1 to 9.3.

9.2 The Medieval Warm Period

According to Lamb (1977) the Medieval Warm Period is thought to have occurred in Britain between AD 1150 and AD 1300. All three sites appear to exhibit very similar trends with respect to total tree cover during this time period in that all decrease somewhat as time progresses, but in general remain pretty stable throughout (Figure 9.1). Tree taxa
Figure 9.1
Percentage Diagram of Main Regional Taxa from LHB, ASB and BGB
(Climatic periods illustrated)
Figure 9.2
Percentage Diagram of Main Local Taxa from LHB, ASB and BGB
(Climatic periods illustrated)
Figure 9.3
Percentage Diagram of Wet and Dry Fungal Indicator Taxa from LHB, ASB and BGB (Climatic periods illustrated)
such as *Alnus, Betula* and *Quercus* remain fairly constant while *Fraxinus* appears to peak in the middle of this time period at All Saint's Bog. This very gradual decline in tree cover may be due to the beginning of the Anglo-Norman invasion where they reclaimed new land for agriculture (Aalen, 1978). The Gramineae curves also appear stable with a slightly increasing trend as time progresses. This is what would be expected from the corresponding slow decline in tree cover as the land was being cleared (albeit slowly) for presumed agricultural use. Cereal-type pollen is present at this time but at very low percentages. In Britain the climate at this time is reported to have been warmer and drier than previous which would favour the increased growth of cereals. This, coupled with the fact that monastic settlements (whose economy was dominated by tillage farming (Stout and Stout, 1997)) were at their peak at the beginning of this period, would suggest that cereal-type pollen abundance should have been higher than that recorded. The invasion of the Normans in the 12th Century would also have caused an increase in cereal production. The success of Anglo-Norman cereal farming in Ireland is demonstrated by the large amounts of grain which were exported to England and elsewhere, especially during the 13th Century (Kelly, 1997) but this does not appear to be reflected in the pollen record from any site. Cereal pollen can be severely underrepresented in pollen records (Huang and O'Connell, 1991).

Figure 9.2 illustrates the main local pollen taxa from each site combined. Vegetation stability is suggested from this figure at all three sites with the exception of the *Sphagnum* curves. That at All Saint's Bog tends to oscillate during this period while those at Liffey Head Bog and Ballygisheen Bog tend to increase as time progresses; Liffey Head Bog more steadily than Ballygisheen Bog. As already explained, high percentages of *Sphagnum* are difficult to interpret and do not necessarily indicate wet conditions. *Narthecium* tends to behave similarly both at Liffey Head Bog and Ballygisheen Bog in that it tends to decline as time progresses while its sudden presence at All Saint's Bog during this time period may suggest that local conditions were wetter at this site than in previous times. Cyperaceae and *Narthecium* values are lower at Ballygisheen Bog during this period than they are either before or after which may suggest drier conditions at this site between AD 1150 and AD 1300. Similarly Cyperaceae values are lower at Liffey Head Bog during this period compared to before AD 1150 or after AD 1300 also suggesting drier conditions but this is not reflected in the *Narthecium* curve; the opposite trend of wetter conditions is suggested by this curve with values higher both before and after this time period.
The wet and dry fungal indicator signals for this period appear to be strongest at Ballygisheen Bog (Figure 9.3). Here clear-cut strong signals of local wet conditions prevail especially at Ballygisheen Bog and All Saint’s Bog suggested by the high wet indicator and low dry indicator values. Certainly conditions appear significantly drier at Ballygisheen Bog prior to AD 1150 while after AD 1300 they remain wet until close to AD 1550. No real trend is evident from the indicator taxa at Liffey Head Bog.

The three sites provide contrasting results to each other with respect to this time period. The regional pollen scenario appears to agree at each site where relatively stable conditions in the surrounding landscape of each site are suggested. These appear to reflect the historical events of the time period. This was also found to be the case from the DCA analysis as explained in Chapter VI. The local pollen scenario is not as simple however. Evidence from Liffey Head Bog suggests that no significant change in local wet or dry conditions occurred at this site during this time period while data from All Saint’s Bog may hint at slightly increasing wet conditions between AD 1150 and AD 1300 compared to previous times (see Table 9.1). Evidence from Ballygisheen Bog suggests that this time period may have been drier compared to before AD 1150 and after AD 1300. The fungal spore and testate amoebae data provide disparities with respect to this time period also where definite clear local wet conditions are suggested by the results at All Saint’s Bog and Ballygisheen Bog but slight decreasing wet conditions are suggested at Liffey Head Bog.

At each site either the beginning or end of the time period under investigation corresponds with a zone line as decided by the CONISS analysis (see Chapter III). AD 1150 corresponds with the zone line from the All Saint’s Bog fungal spore assemblage which separates ASF1 from ASF2 and the zone line from the Ballygisheen Bog fungal spore assemblage which separates BGF 1 from BGF 2. Similarly AD 1300 corresponds with the zone line from the Liffey Head Bog local pollen assemblage which separates LHL 1 from LHL 2. The fact that these dates coincide with the zone lines suggests that there was a definite change in the components of each of the profiles at this time which may well be attributed to a type of climatic change.

Overall it would appear that this time period in Ireland was one of wet conditions (see Table 9.1). If this period corresponds to the Medieval Warm Period as experienced in Britain, then it would seem that this time period may well have been warmer than previous
Table 9.1 Table of general vegetation and climatic changes inferred from both pollen and fungal spore data that occurred at each site over the last 1,200 years

<table>
<thead>
<tr>
<th>Time (AD)</th>
<th>Regional Pollen</th>
<th>Local Pollen</th>
<th>Fungal Spores</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LHB</td>
<td>ASB</td>
<td>BGB</td>
<td>LHB</td>
</tr>
<tr>
<td>1900-1997</td>
<td>↑ Woodland</td>
<td>Dry</td>
<td>Wet</td>
<td>Dry</td>
</tr>
<tr>
<td>1700-1900</td>
<td>↓ Trees esp. Coryloid</td>
<td>Wet</td>
<td>Dry</td>
<td>Wet</td>
</tr>
<tr>
<td>1550-1700</td>
<td>↓ Trees</td>
<td>Dry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1300-1550</td>
<td>↑ Trees</td>
<td>Wet</td>
<td>Wet</td>
<td>Dry</td>
</tr>
<tr>
<td>1150-1300</td>
<td>↑ Plantago</td>
<td>Wet</td>
<td>Dry</td>
<td>Wet</td>
</tr>
<tr>
<td>700-1150</td>
<td>↑ Cereals</td>
<td>Wet</td>
<td>Wet</td>
<td>Dry</td>
</tr>
</tbody>
</table>
but it does not appear to have been drier as suggested by Lamb (1977), Berendsen and Zagwijn (1984), Roberts (1991) and Stine (1994). The evidence found in this investigation suggests that if Ireland did experience the Medieval Warm Period overall it may well have been wetter that previous years but on a more local scale, different areas appear to have experienced different climatic conditions or may have just reacted and responded to them in a different manner. Evidence from the Irish annals for this time period (see Table 1.1) suggests that this period was warmer in Ireland compared to previous times but was also a time of bad weather which caused the death of most livestock in 1172 (Kelly, 1997). Documentary evidence of historical events suggest that cereal production was high during this period (as suggested by the Annals of Connacht in 1252 (Kelly, 1997)) but if indeed it was wetter in Ireland during this time period then the growing and harvesting of cereals would have been very difficult despite warmer conditions. The climatic signal appears to be more pronounced in the most westerly site at Ballygisheen Bog where clear changes are occurring in the profile between 1150 and 1300, especially with respect to the fungal spore record. Similar changes are less pronounced in the other two sites especially at Liffey Head Bog where only a slight and gradual trend of decreasing wetness is evident from the fungal spore record. This may well be due to the close proximity of Ballygisheen Bog to the Atlantic, it being most subject to sea surface temperature changes that may occur, coupled with the lack of human disturbance at this site over time. Results from data from sites across northwestern Europe suggest that a change to wetter mire conditions occurred at several places around AD 1150 (800BP) such as White Moss South in England, Draved Mose in Denmark and several bogs in Norway (Hughes et al., 2000). Research by Barber et al., (2000) also found implications of high wet conditions on Moine Mhor in Scotland between AD 990-1200 which they claim may point to higher rainfall in the Scottish mountains during the Medieval Warm Period. Evidence from the USA also concludes that this time period was one of warm and wet conditions (Petersen, 1994). The $^2\text{H}/^1\text{H}$ results of van Geel and Middeldorp (1988) from Carbury Bog in Co. Kildare suggest that this area experienced local dry conditions between AD 1130 and AD 1280. Due to the seemingly conflicting evidence of palaeoclimatic data and their $^2\text{H}/^1\text{H}$ ratios van Geel and Middeldorp (1988) call into question the correlation between the climatic events in central England and the climatic development in Ireland but they conclude that although the present climatic regime in Ireland is subject to more modest extremes in most respects than England or continental Europe, it is not reasonable to suggest that Ireland’s climatic history was very different to that of England. Blackford and Chambers (1995) suggest that climatic change at the oceanic margin of the northeast Atlantic largely corresponds to inferred variations in
solar output. They investigated peat humification at Letterfrack on the west coast of Ireland and found that it was drier/warmer from AD 1050 to AD 1300.

As discussed in the previous paragraph, the results found in this investigation for the time period AD 1150 to AD 1300 agree with some but contrast with other published data for the same time period. This would fit in with suggestions by Bradley (2000) who claimed that changes in the frequency or persistence of circulation regimes may account for the unusual nature of the period and this may have led to anomalous warmth in some (but not all) areas.

9.3 The Little Ice Age

The onset and duration of the Little Ice Age has received much attention in the past (see Chapter I). According to Lamb (1977) this climatic period lasted approximately 150 years in Britain, from 1550 until 1700. This time period in Ireland is full of documented historical events and increasing anthropogenic influences and impacts on the land which means that the disentanglement of climatic change and anthropogenic influences is very difficult. From Figure 9.1 it can be seen that all three sites experienced a steady loss of total tree cover in the surrounding landscapes between 1550 and 1700. The major tree taxa such as *Alnus*, *Betula* and *Quercus* all decrease in abundance over time. Part of this period coincides with Cromwellian rule when a lot of destruction occurred in Ireland (Curtis, 1950). Between 1540 and 1800 Irish woods were exploited by plantation settlers to build houses and ships and were used in the iron works industries where large quantities of charcoal were required (Mitchell and Ryan, 1997). Co. Offaly was still well wooded at the time of its plantation in the late 16th Century (Aalen, 1978) which is reflected in the pollen record from All Saint’s Bog, but deforestation was the official policy in Ireland during the 17th Century with increasing industries being introduced (Dunlevy, 1994) and for military-strategic reasons (Aalen, 1978). The Coryloid curve appears to decline a little at Liffey Head Bog but remains stable at the other two sites. This suggests that woodland clearance was primarily for wood rather than land for agriculture. The population of Ireland did not rise significantly until after this time period where by 1830 it was close to nine million (Whelan, 1997). Gramineae percentages appear to increase, particularly at Ballygisheen Bog during this time period. A similar scenario is evident from the *Plantago* curves suggesting an increase in pastoral agriculture. Cereal-type pollen is present at all sites but
at percentages similar to those between AD 1150 and AD 1300; again the least amount was found at Ballygisheen Bog.

The local pollen from this time period (Figure 9.2) again suggests fairly stable local vegetation conditions at the three sites. *Calluna* percentages are highest at Ballygisheen Bog; the highest values of *Calluna* at this site occur in this time period. The Ericaceae-type curves are similar to those of *Calluna*, being mainly stable, but that of Ballygisheen Bog increases as time progresses. Together these two taxa suggest local dry conditions at Ballygisheen Bog during this time. This is also evident from the *Narthecium* curve at Liffey Head Bog as it gradually declines towards 1700. Values of *Narthecium* are higher at Liffey Head Bog prior to AD 1550. *Sphagnum* remains fairly stable at Liffey Head Bog and Ballygisheen Bog but tends to fluctuate at All Saint’s Bog.

Local dry conditions are also evident from the fungal spore data between 1550 and 1700 (Figure 9.3) especially from Ballygisheen Bog. Here the dry signal is very definite and continues on into the 18th Century. This is in contrast to the clear wet signal visible prior to AD 1550. Dry indicator taxa also appear high at Liffey Head Bog but tend to be lower than those prior to AD 1550 while there is no trend visible at All Saint’s Bog with its fluctuating curves.

Unlike the scenario of matching dates and zone lines associated with the time period AD 1150 to AD 1300 (see Section 9.2), no similar account is evident for the time period 1550 to 1700. Two zone lines do appear very close to the cessation of the time period at 1700 – that which separates LHF 1 and LHF 2 and that which separates ASF 2 and ASF 3. No corresponding dates and zone lines were found in the Ballygisheen Bog profile with respect to 1550 and 1700. This would suggest that the changes associated with these zone lines are not as closely linked to climatic changes as those found in Section 9.2 but may be more likely to be due to other factors such as anthropogenic influences.

Overall it would appear that between 1550 and 1700 Ireland experienced local dry conditions especially in the south west of the country (see Table 9.1). According to various published papers (Grove, 1972; Lamb, 1977) this time period was one of mainly global cool and wet conditions. However Bradley (2000) suggests that it was a time with a great deal of temperature variation in both time and space. Some areas were warm at times when others were cold and visa versa, and some seasons may have been relatively warm
while other seasons in the same region were anomalously cold. Cool temperatures may well have prevailed in Ireland during this time (as is suggested by daily observations made in Northern Ireland which are consistent with the Little Ice Age climate of Britain (Van Geel and Middeldorp, 1988)) but evidence clearly suggests that wet conditions were not especially prevalent. Similar to the scenario with respect to the time period AD 1150 to AD 1300, the climatic signal between 1550 and 1700 appears to be more distinct at Ballygisheen Bog, the most westerly and wet site. Here very clear local dry conditions are inferred from both the local pollen and fungal spore records. Again this signal is far less obvious at the other two sites. Similar reasons for this phenomenon of such a strong signal to those suggested in Section 9.2 are proposed. DCA of plant macrofossil data carried out by Barber et al. (2000) on two distant UK bogs suggest that there is clear evidence of wet conditions during the Little Ice Age from both records. The fact that both bogs, with different species composition, showed such a similar response to the Little Ice Age indicates that this is most probably due to a response to the spatially and temporally coherent temperature changes rather than the incoherent rainfall fluctuations of the records reconstructed (Barber et al., 2000). Collated data from northwestern Europe indicate that many sites experienced a change to wetter mire conditions around this time (AD 1550; 400BP) such as Walton Moss in England, Kirkpatrick Fleming in Scotland, Draved Mose in Denmark and several bogs in Norway (Hughes et al., 2000). Blackford and Chambers (1995) suggest that there is a relationship between peat humification data from Letterfrack on the west coast of Ireland and sunspot records, especially between 1650 and 1900, representing evidence of the Little Ice Age, which suggests a link between climate and solar variability. Research by van der Molen (1988) suggests that the period 1689 to 1733 was one of overall high moisture conditions surrounding Woodfield Bog in the midlands of Ireland.

9.4 20th Century Warming

The phenomenon of a global 20th Century warming has been well documented (Wigley and Kelly, 1990; Briffa et al., 1995; Nicholls et al., 1996; Mann et al., 1999). Warming appears to be more significant in some locations than in others; it has been suggested that temperatures in some areas in Europe during the last century are within the threshold of normal variability (Pfister et al., 1998) whereas others appear to be warmer during this recent period than in any other century in the last 1,000 years (Nicholls et al., 1996). However estimates of global temperature change, based largely on meteorological data,
show global average surface temperatures increasing by c.0.5°C for the past century (Chambers et al., 1999).

The last century has been marked on each of the Figures 9.1 to 9.3 and from these various conclusions can be made. It is very difficult and almost impossible to distinguish any climatic signals from the regional pollen data as these are dominated by anthropogenic influences. They almost exclusively reflect the effects of humans on the landscape such as the increase in Pinus due to its reintroduction by man, the increase in exotic tree taxa such as Fagus, Carpinus and Juglans into the landscape, the decline in Plantago due to the intensification of agriculture and the high Gramineae values reflecting the abundance of pastoral agriculture. Therefore disentangling climate and anthropogenic signals for this recent time period on a regional scale remains extremely difficult.

The last 100 years see an increase in tree abundance surrounding each of the coring sites (Figure 9.1). All tree taxa increase (with the exception of Fraxinus at Liffey Head Bog) especially Pinus. It is really only within the last 100 years that Pinus increases at Ballygisheen Bog while at All Saint’s Bog it appears to have started in the 1860s. The earliest increase in Pinus occurred in the landscape surrounding Liffey Head Bog in the late 1700s. Therefore it occurred earliest in the east and latest in the west which may reflect its closeness to Britain and large centres of human occupation. Coryloid also increases during this time period especially at All Saint’s Bog. Gramineae values appear highest in the last 100 years at all three sites than in any other parts of the profiles. This is most likely to reflect the increase in agriculture especially that of pastoralism that has occurred to the present day. Cereal-type pollen tends to increase around All Saint’s Bog but is still low at the other two sites reflecting the predominance of pastoral agriculture in Ireland over tillage. Plantago declines at each site reflecting the intensification of agriculture as previously mentioned.

Again, the last 100 years as reflected by the local pollen is naturally going to have had some anthropogenic impacts due to drainage influencing its signal of local wet and dry conditions. The taxa suggest that local dry conditions prevailed at Liffey Head Bog and Ballygisheen Bog while the opposite is true of All Saint’s Bog (Figure 9.2). The DCA plot of Axis 2 local pollen (Figure 7.18) for All Saint’s Bog suggests that no significant wet or dry conditions prevailed at this site in the last 100 years. However in the last 30 years local dry conditions appear to be somewhat favoured.
The fungal spore data of the last 100 years suggest local dry conditions at All Saint’s Bog and in particular at Ballygisheen Bog. These data suggest that the driest period at Ballygisheen Bog occurred in the last 100 years than in any other period covered by this investigation. A clear decline in local dry conditions is evident at Liffey Head Bog during the 20th Century in contrast to its local pollen signal. From the fungal spore and testate amoebae diagrams in Chapter VIII *Assulina seminulum* (Type 32B) appears to increase significantly from 1900 at all three sites compared to previous levels in the profiles. Tolonen (1986b) suggests that this type may be indicative of drier habitats on the bog surface and therefore if it was included in the dry indicator taxa curve, it may well increase the local dry signal for this period.

In general the three sites agree with one another in that all reflect (either local and/or fungal spores) an increase in dry conditions during the last 100 years (see Table 9.1). Definite trends of local dry conditions are visible from the local pollen at both Liffey Head Bog and Ballygisheen Bog and from the fungal spore data from All Saint’s Bog and Ballygisheen Bog. Although the fungal spore data from Liffey Head Bog exhibit a decreasing dry indicator taxa curve there is no corresponding increasing wet curve and also with the addition of *Assulina seminulum* (Type 32B) this decrease in dryness may not be very significant. The increasing wet conditions as suggested by the local pollen at All Saint’s Bog do not agree with the corresponding fungal spore data. Evidence of dry conditions would be expected during the last century from All Saint’s Bog as approximately 20% of the bog has been cut away recently (Cross et al., 1991). As explained in Section 7.4.3 this signal of local wet conditions as suggested by the local pollen may be due to water movement through the bog system which may well mask the impact of drainage with associated peat cutting. This would not account for the definite signal of dry conditions as illustrated from the fungal spore data for the same time period.

Similar to the time period AD 1150 to 1300 (see Section 9.2), matching dates and zone lines occur for this time period. The beginning of the last century corresponds to the zone line which separates LHL 3 from LHL 4. This suggests that there was a definite change in the components of the local pollen at Liffey Head Bog at this time which may well be attributable to a change in climate.

Overall it would appear that this time period in Ireland has been one of increasing dry conditions. Certainly at Ballygisheen Bog the last 100 years appear to have been the driest
in the entire last 1,000 year history of the bog. Again, the most pronounced signal of a change in hydrological conditions is evident from the most westerly site, closest to the Atlantic, again for similar reasons as given in Section 9.2. Initially it was thought that dry conditions at the top of a bog could be due to increasing anthropogenic pressures on peat as fuel and increased drainage schemes to aid in the utilisation of the bog but this does not appear to be the case at Ballygisheen Bog as it is one of the least disturbed and most intact lowland blanket bogs remaining in Co. Kerry. Drainage has only taken place in the most easterly portion of the bog. However, as explained in Section 7.4.2, a combination of drainage and frequent fires may well be responsible for the vegetation community present on Liffey Head Bog for the last 100 years. An increase in local dry conditions were also found from other research carried out in the Wicklow Mountains (Bowler and Bradshaw, 1985) which may suggest that such local dry conditions were in fact of a more regional nature which may be partially due to climate. Meteorological observations were made on a regular basis at an increasing number of locations from approximately 1800 onwards but it was not until 1880 that homogeneity was achieved in the recording of instrumental observations (Rohan, 1986). Those for temperature of the last 100 years suggest that in general Ireland has experienced higher temperatures in the 20th Century (Van der Molen, 1988) which is what is suggested by most of the proxy records from the three sites investigated for this time period.

Van Geel and Middeldorp (1988) found evidence of dry conditions in the top 6cm of Carbury Bog from pollen data but not from the $^{18}$O/H ratios they calculated. Van der Molen (1988) also concluded that relatively dry conditions prevailed on Woodfield Bog in Co. Offaly between 1958 and 1983 and after 1980 temperatures rose along with rainfall. Barber et al., (2000) found that both of the bogs they investigated exhibited signs of local dry conditions in the last century. These are more pronounced at Moine Mhor in Scotland and appear to be the driest signal ever in the profile (which is almost 2,000 years old) whereas the dry signal of the last century from Fallahogy Bog in Northern Ireland appear to be within the threshold of normal variability of the profile. Mann et al., (1999) found that Northern Hemisphere mean annual temperatures for three of the past eight years are warmer than any other year since AD 1400. They also suggest that although both solar and greenhouse-gas forcings play some role in explaining 20th Century warming, greenhouse gases appear to play an increasingly dominant role during this century.
9.5 The Success of the Multiproxy Approach

The various methods used in this investigation are detailed in Chapter III. Each one was chosen to provide information to add to the bigger picture in the elucidation of past climate and vegetation changes over the last 1,200 years at each site. Most of the methods proved successful in their results.

Pollen analysis, along with loss on ignition and charcoal analysis (as discussed in Chapters V, VI and VII) provided a valuable insight into the vegetation changes and anthropogenic influences both in the surrounding landscapes and on the bog surfaces of each site studied. Regional pollen analysis did not prove to be particularly successful in the elucidation of recent climate change in Ireland. The influence of humans stretches right throughout the time span covered in this investigation and so if recent climate change did take place, its effects on the regional pollen rain are likely to be concealed by the larger effects brought about by humans. The temperature changes associated with the Medieval Warm Period and Little Ice Age are only in the range of 1°C to 1.5°C and so may not have been dramatic enough or of a long enough duration to have caused a mass change in the vegetation. It has been suggested that these climatic periods were not continuously warm or cold but varied in their climatic characteristics (see Chapter I) and so such variability may have been too subtle to have caused a change in the regional pollen record.

Both radiocarbon dating and tephrochronology resulted in the satisfactory construction of a time-depth curve for each site covering the entire lengths of the sediments analysed. Tephra from the eruption of Hekla in 1947 was found at each site; this layer has not been recorded from Ireland before.

The fungal spore and testate amoebae analysis provided conflicting results to the local pollen in places and was not as successful as it was originally thought it would. The testate amoebae counted from the pollen slides did not provide a true representation of the fossil faunal component of each site. The identification of more wet and dry indicator taxa would aid in establishing a more precise and accurate local wet and dry record from each site. The assumed problems with this technique, especially in regards to this investigation, are discussed at the end of Section 8.4.4.
9.6 Where Ireland fits in with Recent Climate Changes

The results from this study have shown that recent palaeorecords from Ireland do in fact reveal climatic signals over the last 1,200 years. When the typical dates of the Medieval Warm Period, Little Ice Age and 20th Century Warming (Lamb, 1977) are superimposed on the data it would appear that in general Ireland experienced wet, dry and increased dry conditions respectively (see Table 9.1). For each of the three climatic periods investigated Ballygisheen Bog (the most westerly site) illustrates the most pronounced and clear signals in terms of changing hydrological conditions. Therefore Ballygisheen Bog, in the southwest of the country, appears to be more sensitive to changing hydrological conditions which is most likely due to a combination of its close proximity to the Atlantic Ocean (being most subject to any changes that may occur in sea surface temperatures) and also to the fact that it has undergone the least amount of human interference over time being furthest away from mainland Europe, Britain and major Irish centres of human occupation such as Dublin out of all three sites investigated.

When these results from Ireland are compared to those from Britain and Europe it can be seen that some similarities can be found. As already explained in Section 9.2, the overall wet conditions experienced in Ireland between AD 1150 and AD 1300 correspond to a change to wet conditions in several mires both in Britain and Europe (Barber et al., 2000; Hughes et al., 2000). Wet conditions are also reported from the USA during this time period (Petersen, 1994). A similar scenario is evident for the period 1550 to 1700 where the data from this study suggest that Ireland experienced a predominance of local dry conditions especially in the south west of the country. Much research from Britain suggests this time period was one of wet conditions (Blackford and Chambers, 1995; Barber et al., 2000; Hughes et al., 2000). Most European records indicate warm conditions in the 16th and 18th Centuries (Jones and Bradley, 1992; Nicholls et al., 1996) while Spanish records indicate frequent occurrences of severe drought seasons during the Little Ice Age (Lamb, 1977). Increased dry conditions are suggested from all three sites studied from 1900 to the present day. The warm climate of the late 20th Century is anomalous in the context of at least the past millennium and counters a millennial-scale cooling trend which is consistent with long term astronomical forcing (Mann et al., 1999). Overall it appears that the 20th Century has been at least as warm as any century since at least AD 1400 (Nicholls et al., 1996) which appears to be the case at both All Saint’s Bog and Ballygisheen Bog.
Overall however the climatic signals inferred from the data during these particular time periods are not synchronous between sites; climatic variability appears to exist within Ireland for similar time periods. Such a scenario is not a strange phenomenon and tends to reflect the present train of thought on recent climate especially with respect to the Medieval Warm Period and Little Ice Age in that both were not global in occurrence and that their characteristics were different in a variety of areas and were not continuous warm and dry and cool and wet periods respectively (Bradley, 2000). Briffa et al. (1995) describe how northern Fennoscandia experienced predominantly warm summers during the 11th and 12th Centuries while the northern Urals were mainly cool. Similarly Matthews et al. (1996) found no evidence to suggest the Little Ice Age in western Norway while Selsing et al. (1991) report on a climatic deterioration in the period AD 1300 to 1800 in south west Norway.

Therefore it would appear that Ireland is not particularly different to other areas in both Europe and the rest of the globe with respect to its climatic signals of the Medieval Warm Period and Little Ice Age. Definite changing signals are suggested by the data but variability is also certainly evident which seems to be very common among datasets throughout the globe for these time periods. Hughes et al. (2000) have suggested that the relationship between climate and peat stratigraphy may be more complex than was previously recognised and that mires may react in phase to a spatially coherent temperature signal and asynchronously to a zonal precipitation signal.
This thesis has dealt with the palaeoecological and palaeoclimatic history of Ireland over the last 1,200 years using a multiproxy approach. One of the major problems associated with such an investigation is obtaining an accurate chronology in order to determine changes in the vegetation and climate over decadal time spans. Radiocarbon dating is far from ideal for this type of dating due to the recent nature of the sediments and therefore most dating was carried out using tephrochronology. Successful time-depth chronologies were established for each of the three sites from tephrochronology; an otherwise impossible task using radiocarbon dating only. Among other tephra layers identified from Iceland, Hekla 1947 was detected at each site; its first finding in Ireland and together these tephra layers have aided in successfully correlating the three sites investigated.

The multiproxy approach taken has resulted in the production of the most detailed records to date of landscape and local bog surface changes in Ireland for the last millennium. The palaeoecological history of the last 1,200 years in Ireland presented here suggest that humans have played an increasing role in the moulding of the landscape to what it stands at now as time has progressed. The palaeoecological record, as reconstructed from pollen analysis, loss on ignition and charcoal analysis, reflects many of the major historical events that have happened in Ireland during this time period such as the mass clearance of trees from the landscape as pressure for agricultural land increased, the commercial exploitation of trees in the 17th Century, the significant decline in Coryloid pollen reflecting the increasing pressure on land prior to the Great Famine as a result of the prodigious rise in human population, the effects of the Great Famine itself, the introduction of new exotic tree species from the mid 18th Century onwards with the establishment of demenses and estates and the Economic War between 1932 and 1938. The palaeoecological record from each site also reflects the individual happenings occurring in their surrounding landscapes over the past 1,200 years.

The inferred palaeoclimatic record, as reconstructed from pollen, fungal spore and testate amoebae analyses, for the same time period suggests that Ireland may have experienced significant changes in the periods AD 1150 to AD 1300, 1550 to 1700 and 1900 to the present day. In general it is thought that between AD 1150 and AD 1300 wet conditions prevailed while dry conditions predominated between 1550 and 1700 in Ireland. These changes are not completely unanimous between sites and tend to reflect instead the present
train of thought on recent climatic change in that both the Medieval Warm Period and Little Ice Age were not global in occurrence and that their characteristics were different in different areas and were not continuous warm and dry and cool and wet periods respectively. Increased dry conditions are suggested at all three sites from 1900 to the present day from both the local pollen and fungal spore records. Whether this increase in dry conditions is due to increasing temperatures or due to anthropogenic impacts on the bog surface is unknown. Both may well have played a significant role in creating this trend.

For each of the climatic time periods investigated, the most westerly site studied, Ballygisheen Bog, illustrates the most pronounced signals in terms of changing hydrological conditions. This is most likely due to a combination of its close proximity to the Atlantic Ocean, being most subject to any changes in sea surface temperatures, and also to the fact that out of all three sites investigated it has undergone the least amount of human interference over time.

The regional pollen record does not really aid in the elucidation of climatic changes in the profile. The influences of humans are very strong in this record and so leaves the disentanglement of climatic changes from anthropogenic influences very difficult. The climate changes experienced may not have been severe enough to have caused any significant regional vegetation changes of a lengthy duration to be picked up in the pollen record. If such changes were actually recorded by the regional pollen their effects would more than likely be masked over by signals of anthropogenic influences.

A more detailed multiproxy approach is needed to clarify recent climate change in Ireland involving more methods such as humification and testate amoebae analysis separate to pollen analysis. A greater number of sites need to be investigated at closer intervals within the climatic gradient of increasing wetness across Ireland. Solar activity should also be taken into consideration as recent research has suggested that it has a significant, if not vital, role to play in climate change on decadal to centennial time scales. Only by understanding how and why climate has changed in the past and the effects it has had on the landscape can predictions be made and models constructed to shed light on future climate change.
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Appendix I

Plants recorded at Liffey Head Bog, Co. Wicklow

<table>
<thead>
<tr>
<th>Calluna vulgaris</th>
<th>Erica tetralix</th>
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</thead>
<tbody>
<tr>
<td>Narthecium ossifragum</td>
<td>Molinia caerulea</td>
</tr>
<tr>
<td>Drosera rotundifolia</td>
<td>Andromeda polifolia</td>
</tr>
<tr>
<td>Eriophorum angustifolium</td>
<td>Scirpus caespitosus</td>
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<td>Sphagnum sp.</td>
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Plants recorded at All Saint’s Bog, Co. Offaly

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<thead>
<tr>
<th>Calluna vulgaris</th>
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<tr>
<td>Narthecium ossifragum</td>
<td>Drosera rotundifolia</td>
</tr>
<tr>
<td>Drosera intermedia</td>
<td>Eriophorum vaginatum</td>
</tr>
<tr>
<td>Andromeda polifolia</td>
<td>Scirpus caespitosus</td>
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<tr>
<td>Menyanthes trifoliata</td>
<td>Sphagnum sp.</td>
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<td>Cladonia sp.</td>
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Plants recorded at Ballygisheen Bog, Co. Kerry

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<td>Drosera intermedia</td>
</tr>
<tr>
<td>Rhynchospora alba</td>
<td>Eriophorum vaginatum</td>
</tr>
<tr>
<td>Menyanthes trifoliata</td>
<td>Molinia caerulea</td>
</tr>
<tr>
<td>Schoenus nigricans</td>
<td>Sphagnum sp.</td>
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### Individual shard analysis (EDMA) of the Lipari standard

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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Mean</th>
<th>Stdev</th>
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<td>100.76</td>
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