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Farming and woodland dynamics in north Sligo
during the Holocene
based on lake-sediment investigations

Beatrice Ghilardi
Laurea magistrale (Università degli Studi di Milano)

A thesis submitted to the National University of Ireland Galway
for the degree of
Doctor of Philosophy

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Supervisor: Professor Michael O’Connell

Ionad Taighde Comhshaoil Ársa
Scoil na hEolaiochtaí Nádúrtha (Luibheolaiocht)
Ollscoil na hÉireann Gaillimh
Gaillimh
Éire

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Galway
Ireland
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ABSTRACT

Detailed pollen-analytical investigations were carried out on lake sediment cores from two lakes, namely Lough Dargan and Cooney Lough, in north County Sligo close to the Cúil Irra peninsula. North Sligo was chosen as a study area on account of the wealth of archaeological evidence relating especially to the Neolithic, i.e. first farming peoples. Cúil Irra peninsula is particularly rich. It has the largest passage tomb cemetery of Ireland, namely Carrowmore and also the archaeologically rich and conspicuous mountain, Knocknarea. Evidence for early Neolithic activity includes Magheraboy causewayed enclosure that is possibly the earliest Neolithic causewayed enclosure known from Britain and Ireland.

The investigations reported on here reconstruct early farming activity, woodland dynamics and the land-use, based mainly on detailed pollen analysis. Macrofossils analysis, magnetic susceptibility and loss-on-ignition measurements were also carried out. Age/depths models for the pollen profiles were constructed on the basis of the results from AMS radiocarbon dates. Attention has also been paid to early Holocene climate change, and human impact and woodland history in the later post-glacial (Bronze Age to recent times).

From L. Dargan, east of Ballygawley, parallel cores of ca. 7.5 m were collected. Most of the main core (DRG1) was pollen analytically investigated. The resulting pollen profile spanned the interval ca. 7800 BC–AD 1700. From Cooney L., west of Ballysadare, parallel cores were also taken. A pollen profile, based mainly on the 6 m long core CNY1, spanned the interval ca. 7450–790 BC, i.e. most of the early and mid Holocene.

The results from the two high-resolution pollen diagrams show that tall canopy woodland characterized the first half of the Holocene. There is little or no evidence for human impact on the primeval woodlands but there are clear pointers, especially in the pollen profile CNY1, for climate anomalies in the early Holocene. The main anomaly (CA-3) is regarded as corresponding to the 8.2 ka event as known mainly for Greenland ice-core records. This is the first securely dated, published record for the 8.2 ka event in Irish or British pollen records.

A well defined Elm Decline is recorded in both profiles. The earliest indication of farming (cereal growing) in both profiles coincides with the Elm Decline (ca. 3750 BC). After a delay of some decades, a distinct Landnam is recorded in both profiles that involved
woodland clearance by early Neolithic farmers. Landnam at L. Dargan lasted from ca. 3700–3000 BC and was considerably longer than at Cooney L. where it had largely ceased by ca. 3400 BC. At both sites there appears to have been little or no activity in the mid Neolithic (ca. 3000 BC) but by 2700 BC farming impact again registers but the impact is not as high as during the main Landnam. Neolithic farming was mainly pastoral based but there is clear evidence for cereal growing at both sites.

Major human impact registers again at ca. 2150 BC in both profiles. This is regarded as reflecting early Bronze Age impact that involved both pastoral and arable farming. Three main farming phases are recorded in both profiles. These are associated with a strong increase in micro-charcoal, mainly in the DRG1 profile. In both profiles, the strongest impact registers in the late Bronze Age (ca. 1000 BC) but that in CNY1 is of shorter duration. Profile DRG1 records developments in the Iron Age and the historical period (to ca. AD 1700), including woodland and farming dynamics. A distinct lull in pastoral farming is recorded in the late Iron Age (ca. 80 BC–AD 350) that facilitated limited woodland regeneration. This is regarded as the Late Iron Age Lull. Substantial woodland clearance, and farming that included a considerable arable component, characterised the Medieval and later periods.

The results obtained in the course of these investigations are discussed in the context of palaeoecological investigations carried out by others in Co. Sligo and in western Ireland generally.
ACKNOWLEDGEMENTS

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Publications arising from this research

**Papers** (peer reviewed in international journals)


Referred to in the thesis as:


**Chapter in book**


Referred to in the thesis as:


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<td>AD</td>
<td>Anno Domini (after Christ)</td>
</tr>
<tr>
<td>AMS</td>
<td>Acceleration mass spectrometry</td>
</tr>
<tr>
<td>AP</td>
<td>Arboreal pollen</td>
</tr>
<tr>
<td>BC</td>
<td>Before Christ (where BC is used, calibrated years should be understood)</td>
</tr>
<tr>
<td>BP</td>
<td>Before present (AD 1950) (non-calibrated $^{14}$C timescale)</td>
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<tr>
<td>ca.</td>
<td>circa</td>
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<tr>
<td>IPPT</td>
<td>Irish Passage Tomb Tradition</td>
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<tr>
<td>LOI</td>
<td>Loss-on-ignition</td>
</tr>
<tr>
<td>NAP</td>
<td>Non-arboreal pollen</td>
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<tr>
<td>NPP</td>
<td>Non-pollen palynomorphs</td>
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<tr>
<td>PAZ</td>
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Chapter 1

Introduction

1.1 Project aims and objectives

The present research is part of a larger ongoing programme of mainly palaeoecological research on the Neolithic in Co. Sligo that has been carried out in the Palaeoenvironmental Research Unit (PRU), NUI Galway in collaboration with Christian-Albrechts-Universität (CAU), Kiel, Germany (Ghilardi and O’Connell 2012c).

The research programme has focussed particularly on reconstructing the impact by Neolithic cultures on the natural environment in Co. Sligo. The research carried out in the PRU has focused on north Sligo with particular reference to Cúil Irra and its immediate surrounds while that based in the CAU focused on south Sligo and especially Carrowkeel. As regards the temporal span of the investigations, those carried out in the CAU has focussed more or less exclusively on the Neolithic (Stolze et al. 2012; Stolze 2012a, 2012b). The investigations carried out in the PRU, and which form the basis of this thesis, have also focussed on the Neolithic but, in addition, attention has been given to early Holocene woodland dynamics and climate change (Ghilardi and O’Connell 2012a) as well as farming impact and woodland history in later prehistory and the historical period (Ghilardi and O’Connell 2012b, 2012c; also this thesis).

County Sligo is widely acknowledged for its rich archaeological heritage. In particular the county is well known for its high concentration of megalithic monuments and especially megalithic tombs. Two of the four major passage tomb cemeteries in Ireland are located in this county, i.e. Carrowmore on the Cúil Irra peninsula, and Carrowkeel (including Bricklieve/Keashcorran), towards the south of the county. The recent discovery of a Neolithic causewayed enclosure (ca. 2 ha) at Magheraboy emphasises the importance of Co. Sligo and especially Cúil Irra as regards the early Neolithic in Ireland. The excavations, carried out in advance of the N4 Sligo inner relief road, have yielded exciting new evidence of early Neolithic activity including some of the earliest dates for causewayed enclosures in Britain and Ireland (Danaher 2007). On Cúil Irra peninsula are also other important
archaeological features such as the large cairn of Miosgán Meadhbha (Queen Maeve) and several passage tombs and hut sites on Knocknarea (Bergh 1995, 2002). Substantial additional archaeological evidence for Neolithic and Bronze Age activity has also been revealed during the excavations connected with the N4 roadworks at Caltragh (Danaher 2007; details in Archaeological background below).

Prior to initiation of this project various potential sites were examined (Ghilardi and O’Connell 2012c). Originally, the intention was to find a suitable place to core close to Carrowmore and/or Magheraboy in order to obtain a detailed palynological record from the Cúil Irra peninsula. Sites investigated include Carrowmore Lough, Cloverhill Lough, Punchbowl Lake and a peaty deposits near Magheraboy. None of the sites were regarded as suitable. Hence, Lough Dargan was chosen and cored in July 2008. This lake is adjacent to Cúil Irra peninsula and contiguous with the area considered by Bergh (1995) to be part of the Irish Passage Tomb Tradition in north Sligo.

A second lake was chosen to extend the scope of the palaeoecological investigation. The area between Ballysadare Bay and the Ox Mountains was now the primary focus. Two lakes were investigated as to suitability, i.e. Lough Doo and Cooney Lough (7.6 and 2.2 km to the west of Ballysadare, respectively). The lakes are of similar size (ca. 3 ha) and maximum depth (5.9 m and 8.6 m, respectively). L. Doo, however, has an uneven bathymetry (shallow at edges and rapidly deepening at several points towards the centre along a N-S axis). It has an inflowing stream which appears to input a considerable volume of water to the lake and there is an outflowing stream more or less directly opposite and on the northern end of the lake. Cooney L. was regarded as preferable because of its saucer-like bathymetry and the absence of inflowing and outflowing streams (further details in Chapter 3).
1.2 County Sligo: geography, geology and land-use

County Sligo is a maritime county on the north-west coast of Ireland (Fig. 1.01). It lies wedged between Co. Mayo to the west and Cos. Leitrim and Donegal to the north-west. To the south, it has a rather long boundary with County Roscommon.

Co. Sligo has a variety of landscapes, varying from coastal to inland and from lowland to distinctly upland. The northern part of the county is characterized mainly by coastal landscape, adjoining Sligo Bay. This bay subdivides into Ballysadare Bay and Sligo Harbour. These water bodies constitute the southern and northern boundaries to Cúil Irra peninsula (Fig. 1.02). The administrative capital and main urban area, namely Sligo town, is situated near the mouth of the Garavogue River close to where it enters Sligo Harbour at the north-east corner of Cúil Irra. Cúil Irra itself is dominated by Knocknarea, a large hill that reaches 327 m asl. Close to the centre of the peninsula is the main passage tomb complex of Ireland, namely Carrowmore passage tomb cemetery.

From Cúil Irra peninsula, looking north-eastwards, is the massif of Benbulbin (Ben Bulben) (527 m asl) and Truskmore (647 m asl). The Ox Mountain range, which in Sligo runs more or less west to east, is an extension of the main southwest to northeast-oriented part of the range in east Co. Mayo. These mountains, in reality uplands, separate the mainly lowlying coastal part of north Sligo (south of Sligo town) from the lowlands to the south. The southern part of the county is characterized largely by lowland with much glacial deposit, including drumlins, from the last glaciation (Weichelian/Midlandian). To the west of Lough Arrow the Bricklieve Mountains form a major upland. On top of these mountains another important megalithic complex overlooks the lowlands, namely Carrowkeel passage tomb cemetery. L. Arrow, together with L. Gill and L. Gara, are the major lakes of Co. Sligo. L. Arrow and L. Gara are important from an archaeological context (see below) and L. Gill is important in that in the woodlands at L. Gill northernmost station in Europe for the natural occurrence of Mediterranean species, *Arbutus unedo* is found (Sealy 1949).
**Fig. 1.01.** Relief map of Co. Sligo and adjoining areas based on Google Maps.
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Fig. 1.02. Aerial photograph of the most relevant part of north Mayo.
Co. Sligo is characterized by an oceanic climate with annual rainfall averages in the range 1100 to 1200 mm. In the upland precipitation can be greater than 2000 mm (MacDermot et al. 1996). The number of rain days, i.e. days with ≥ 1 mm precipitation, ranges between 175 and 200 per year, higher values pertaining in the uplands. Mean daily maximum air temperature for July is ca. 18°C and mean daily minimum air temperature for January is ca. 2°C. The mean daily air temperature is 7°C. Mean annual wind speed is ca. 5 m sec⁻¹ (Rohan 1975; 1931–1960 averages).

From the geological viewpoint, Co. Sligo is quite varied (Fig. 1.03A). The dominant bedrock is Carboniferous limestone, formed about 355-310 million years ago. This is the main bedrock in coastal areas and the lowlands generally. The Ox Mountain range includes igneous (granite) and metamorphic rocks including schist and gneiss. Gneiss dominates in that part of the Ox Mountains in Co. Sligo. During the last Ice Age (Weichselian/Midlandian), Co. Sligo, like all of Ireland and especially the northern part, was severely glaciated (Fig. 1.03B). The glaciers largely denuded the uplands and left extensive drift deposits in the form of drumlins, moranes and esker ridges in the lowlands (MacDermot et al. 1996).

Grey-brown podzolics and brown-earth soils dominate the coastal parts of Co. Sligo. On the Ox Mountains the soils consist of blanket peat and skeletal soils with rock outcrop, suitable for rough grazing. The southern lowlands are dominated by grey brown podzolic, with a high clay content (Walsh et al. 1976). As regards present-day farming potential about 50% of the county is regarded as consisting of moderate to very good farmland, mainly on the coastline and the lowlands; 29% is regarded as having a low potential for agricultural production and the 21% has the potential for significant improvement as regards agricultural output (Walsh et al. 1976).
Fig. 1.03. Maps showing geological features and ice-flow patterns in Sligo-Leitrim.
Evidence for woodland cover in Co. Sligo in the late historical period is presented by McCracken (1971, p. 42). The author writes: “In north Sligo the Leguy woods of oak, hazel, yew, and holly lay between the lower slopes of the Ox mountains and the sea, and stretched to Lough Gill, whose twenty-three islands, including the Lake Isle of Innisfree, were wooded. The Loughs Gara, Key, and Arrow were surrounded by woods, in which Sir Conyers Clifford was defeated by Irish forces in 1598. They were described as ‘tall, thick woods’ but by 1633 they had been despoiled by tenants who sold the timber in Sligo town”. Much of the woodland today is associated with estates and hence was probably planted. Exotic (non-native) trees and especially *Castanea sativa* are common in these parcels of woodland. There are also some extensive conifer plantations such as at Slish Wood where there are also rather old *Quercus* trees that are presumably relict trees from an Atlantic oak woodland that presumably formed the main vegetation on the Ox Mountains until some time in the historical period.
1.3 Archaeological overview for Co. Sligo

Mesolithic

Human presence is first recorded in Mesolithic times. There is no secure evidence for Palaeolithic activity for Co. Sligo or indeed for Ireland as a whole (Woodman 1985).

Mesolithic activity in Co. Sligo was recorded along the shore of Lough Gara, south Co. Sligo, near the border with Co. Roscommon (Fredengren 2002). In this area, important evidence for hunter-gatherer communities related to the latest phase of the Mesolithic has been discovered. Chert ‘Bann’ flakes and other artefacts were found (Condit & Gibbons 1991). In Ireland the early Mesolithic spans from ca. 8000 to 7000 BC and it is characterised by use of the microliths. The later Mesolithic spans from ca. 6000 to 4000 BC which is characterised by the use of the long-blade and blade-like flint flakes (Woodman 1978; Costa et al. 2005).

In Ireland Mesolithic sites were located close to the coast, on river valleys or on lake shores (Woodman 1978; Costa et al. 2005). The diet was based mainly on marine and riverine sources (e.g. salmon, eel, small fish and shell fish) and only limited mammals (e.g. wild pig) (cf. Costa et al. 2005). Interestingly the Irish name of Sligo is Sligeach, which means shelly or rich in shellfish (Bergh 1995, p. 26). The evidence for Mesolithic peoples (hunter-gathering economy) in Ireland has been rather limited until recent times. Probably during the maximum marine transgression, which occurred about 4000 BC, many coastal sites were submerged. One such is the submerged peat at Strandhill on the Cúil Irra peninsula.

The earliest Irish Mesolithic settlement found to date is that at Mount Sandel, near Coleraine, Co. Derry. This is dated to between 7750–7670 BC and was excavated by Peter Woodman between 1973 and 1977 (Woodman 1985; Waddell 2010). Peter Woodman has been responsible for many of the more recent records of Mesolithic presence in Ireland including the important site at Ferrriter’s Cove, Dingle, Co. Kerry. At this site, cattle remains were recorded in a late Mesolithic context. The cattle bones have given the $^{14}$C dates 5510±70 BP (OxA-3839) and 5825±50 BP (OxA-8775) (Woodman et al. 1999) which
places them prior to the Elm Decline (usually dated to ca. 5100 BP) and in what is regarded in Ireland as late Mesolithic rather than early Neolithic.

**Neolithic**

During the Neolithic, important changes occurred in human society that resulted in considerable modification of the landscape for the first time. The economy of the prehistoric people changed greatly. The Neolithic saw a transition from a hunting-fishing-foraging lifestyle to an economy based on stock-raising and cereal cultivation (barley and wheat) and a more permanent settlement. The cultivation and the domestication of animals (cattle, sheep, goats and pigs) led to the first substantial anthropogenic impact on the vegetation with clearance of the forest at different degrees (O’Connell and Molloy 2001; Waddell 2010).

The society also changed involving new traditions and behaviour, in particular linked with the cult of the death, as the many megalithic tombs suggest (Cooney 2000). Different types of Neolithic tombs were built during this period in Ireland as follows (Fig. 1.04; main tomb types only considered).

**Court tombs.** These tombs are considered the earliest type of megalithic tomb in Ireland. They are predominantly distributed in the northern part of the country and a high concentration is recorded in Mayo, Sligo and south-west Donegal and the distribution extend across Ulster. This tomb type is generally on lowlands, on light and well drained soils suitable for agriculture, but they are also recorded from upland locations where they are often at least partially covered by bog (Mitchell and Ryan 1997). The court tombs are characterized by a trapezoidal cairn of 20-30 m long, a burial gallery, two to four chambers, and by an open court, often U-shaped (Mitchell and Ryan 1997; Bergh 1995). Schulting et al. (2012) suggest that the court tombs were built between 3700–3570 BC.

**Portal tombs.** They are regarded as being closely related to court tombs. They are composed of a rectangular chamber with an entrance flanked by two tall slabs and covered by a large roof slab. Portal tombs occur more commonly as a single monument, but they can also occur in clusters (Mitchell and Ryan 1997; Bergh 1995).
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Fig. 1.04. Maps showing the distribution of the four main megalithic tomb types in Ireland.
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*Passage tombs.* This type of tomb constitutes the third major Neolithic category of Irish megalithic tomb. A characteristic of the passage tomb is that the chamber can be reached by a passage of parallel set slabs. The chamber can have either a rectangular, polygonal or the most common cruciform plan. The passage tomb is often covered by a circular cairn. The tombs are generally clustered in a so-called cemetery but occasionally tombs may be located on hill tops (Mitchell and Ryan 1997; Bergh 1995). The most spectacular examples of this tomb type are at Carrowmore and Carrowkeel in Co. Sligo, and at Loughcrew and the Boyne valley in Co. Meath. Newgrange, in the Boyne valley, is the largest of three large passage tombs situated in the so-called Bend of the Boyne. Bergh (1995, p. 12), because of the variation within this monument type, refers to the passage tombs as the ‘The Irish Passage Tomb Tradition’ (IPTT).

*Wedge tombs.* This tomb type relates to the late Neolithic/early Bronze Age. Wedge tombs are the most numerous megalithic tomb type in Ireland. They occur commonly as a single tomb and they are rather evenly distributed from the lowlands to the uplands. The chamber consists of a narrow gallery of orthostats covered by a flat roof slabs. The wedge tombs are often covered by a D-shaped cairn (Mitchell and Ryan 1997; Bergh 1995). The densest concentration of wedge tombs is to be found in the Burren, Co. Clare. County Sligo is considered to have one of the most dense concentration of megalithic tombs in Ireland, with ca. 218 (15%) megalithic tombs out of ca. 1448 recorded in Ireland (Bergh 1995).

Table 1.01. Megalithic tombs in Sligo in relation to the Irish total (numbers of tombs based on Ó Nualláin, 1989; after Bergh 1995).

<table>
<thead>
<tr>
<th>Type of monuments</th>
<th>Ireland (total)</th>
<th>Sligo (total)</th>
<th>Sligo (%)</th>
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<tr>
<td>Court tombs</td>
<td>391</td>
<td>59</td>
<td>15</td>
</tr>
<tr>
<td>Passage tombs</td>
<td>229</td>
<td><strong>90</strong></td>
<td><strong>39.3</strong></td>
</tr>
<tr>
<td>Portal tombs</td>
<td>174</td>
<td>11</td>
<td>6.3</td>
</tr>
<tr>
<td>Wedge tombs</td>
<td>465</td>
<td>35</td>
<td>7.5</td>
</tr>
<tr>
<td>Unclassified</td>
<td>189</td>
<td>23</td>
<td>12.1</td>
</tr>
<tr>
<td>Total</td>
<td>1448</td>
<td>218</td>
<td>15</td>
</tr>
</tbody>
</table>
Chapter 1: Introduction

The passage tombs are the most common tomb type in Co. Sligo (ca. 90 tombs, Table 1.01). From the Cúil Irra peninsula alone 75 passage tombs (30% of the total in Ireland, i.e. the highest concentration in Ireland or indeed in Europe) have been recorded. Much evidence for Neolithic activity has been found on this peninsula which is now briefly summarised.

Knocknarea. The flat-topped mountain of Knocknarea (320 m asl) is located at the western side of the Cúil Irra peninsula. During the Neolithic, Knocknarea was one of the major cultural and ritual centres in Ireland (Bergh 2002). On the flat summit of this mountain a large cairn is placed Queen Maeve’s tomb or ‘Miosgán Meadhbha’ (Fig. 1.05, 1 and 2). Queen Maeve, according to legend, was the Queen of Connacht in the fifth century AD. This important cairn (60 m diameter and 10 m high) is considered to be probably contemporaneous with Newgrange, i.e. ca. 3200 BC (Bergh 1995, 2002; Burenhult 2009) or relating to the final stage of the Irish Megalithic Tradition. On the summit are five passage tombs and several hut-sites (ca. 20) (Bergh 1995, 2000, 2002). Along of the eastern side of Knocknarea there is a complex field system of banks which probably also relate to the Neolithic (Bergh 2002).

Miosgán Meadhbha overlooks the megalithic cemetery tombs of Carrowmore and much of the countryside in the wider region including all of the lowlands to the north and west of the Ox Mountain range in Co. Sligo.

Fig. 1.05. Photographs from Cúil Irra peninsula.
1: Knocknarea photographed from Carrowmore passage tomb cemetery (all photographs, except No. 2, taken on 26/09/2008). The large cairn (Queen Maeve’s tomb) on the summit is clearly visible. 2: Close-up of Queen Maeve’s tomb, Knocknarea (24/11/2011); 3-9: passage tombs at Carrowmore; 3, Carrowmore 56 and 57; 4, Carrowmore 13; 5, Carrowmore 54; 6, Carrowmore 4; 7, Carrowmore 7 (including enclosing circle of large boulders); 8 and 9, Carrowmore 51 (also referred to as Listoghil). The cairn (reconstructed after excavation) and the tomb within the cairn are shown.
**Fig. 1.05.** Photographs from Cúil Irra peninsula.
Carrowmore passage tomb cemetery (Ceathrú Mór: Great Quarter) (Fig. 1.05, 3–9). This passage tomb complex is the largest single cluster of megalithic tombs in Ireland (Cooney 2000), covering an area of ca. 1 km² (Burenhult 2009) and coincides with the geographical centre of the Cúil Irra peninsula (Bergh 2002). The largest tomb in Carrowmore is tomb 51, also referred to as Listoghil, which is at the centre of the complex. This structure consists of a cairn of about 35 m in diameter and contains a sub-rectangular orthostatic chamber, with a large capstone on top (Fig. 1.05, 8-9). It is believed that originally about 200 tombs were present in the area but most of them have been destroyed. The first survey of the complex was undertaken far back as 1739 by Rev. Henry and, in 1779, the antiquarian and artist Gabriel Beranger visited the site. Over the years other surveys and studies were undertaken including a book on passage tombs in Ireland by Herity (1974). A major research programme that involved excavation of a number of tombs was carried out by a Swedish multidisciplinary team between 1977 and 1982. This was led by the Swedish archaeologist Göran Burenhult (Burenhult 1984, 2009; Burenhult and Westergaard 2003).

The chronology of Carrowmore has yet to be fully understood. The first $^{14}$C dates obtained suggest that the earliest monument was erected by about 5000 BC and that most of the monuments were erected and used between 4300 and 3500 BC. The reliability and context of some of these dates, and especially the early dates, in the meantime have been questioned (Caulfield 1983; Bergh 1995; Waddell 2010). A new series of $^{14}$C dates based on antler pens from within the Carrowmore tombs will provide new and hopefully more reliable evidence for the chronology of the tombs (Bergh and Hensey, forthcoming).

Magheraboy (Fig. 1.06). This site, located immediately to the south-west of Sligo town, has been excavated by Danaher (2007) as part of the excavations prior to the construction of the N4 Sligo Inner Relief Road. The main discovery is an early Neolithic causewayed enclosure of ca. 2 ha. It probably had ritual and other significance. The $^{14}$C dates from this enclosure suggest that it may be the earliest known Neolithic monument in Britain and Ireland. Stone axes, broken arrowhead, lithic (stone tool), sherds of Carinated Bowl pottery, which are indicative of early Neolithic activity, were found during excavation of the site (Danaher 2007).
Fig. 1.06. Reconstruction of the Magheraboy causewayed enclosure.
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According to Cooney et al. (2011) the preferred model for Magheraboy shows that the enclosure was built between 4115–3850 cal. BC (95% probability; start of Magheraboy), most probably between 4065–3945 cal. BC (68% prob.), and that activity ended between 3615–3355 cal. BC (95% probability), 3520–3410 cal. BC (53%).

Culleenamore. On the coastline of the peninsula several shell middens were discovered, in particular at Culleenamore, southern Cúil Irra peninsula, in the shell midden was recorded mainly oyster, with some cockles, mussels, periwinkle, scallop and limpet. This shell midden produced a fourth-millennium BC $^{14}$C date and was continuously used from the Neolithic to the Early Iron Age (Burenhult 2009; Danaher 2007).

Bronze Age

This cultural period is characterized by the introduction of the metalworking which had an important impact on society and economy. Monuments linked with this period are wedge tombs (regarded as relating to the Neolithic/Bronze Age transition; for description see above), barrows (barrows may also relate to the Neolithic), stone circles, standing stones and fulacht fiadh and burnt mounds (fulacht fiadh and burnt mound more or less synonymous; a key feature of a fulacht fiadh is a trough; both will have much charcoal; Danaher 2007).

In Co. Sligo ca. 111 barrows, with wide variety of types and location, are recorded. Relatively few standing stones, stone alignments and stone circles have been recorded (Condit and Gibbons 1991). Several fulacht fiadh (also burnt mounds and charcoal spreads that may in fact be fulacht fiadh) have been recorded in recent years (Condit and Gibbons (1991) give ca. 20; Egan et al. (2005) indicate ca. 37). During the recent excavation of the N4 road at Caltragh, south Sligo town, three fulacht fiadh associated with three round houses were discovered (Danaher 2007). From the $^{14}$C dates associated with the three houses it is possible to link this activity with the first mid Bronze Age (House 1, 3220±80 (Beta-194432), (1540–1410 cal. BC 1σ, 1680–1320 cal. BC 2σ); House 2, 3140±70 (Beta-194433), (1490–1380 cal. BC 1σ; 1530–1260 cal. BC 2σ); House 3, 3210±40 (Beta-194434), (1520–1430 cal. BC 1σ, 1530–1410 cal. BC 2σ); Danaher 2007, p. 157). At Magheraboy three (possibly four) fulacht fiadh were recorded. The available evidence
suggest that they span the interval from the late Neolithic/Early Bronze Age to the Late Bronze Age (Danaher 2007).

Iron Age and medieval period

The Iron Age is often considered to be an obscure period due to the little archaeological evidence relating to the period (Danaher 2007; Fredengren 2000, 2002). In 1999, crannógs, i.e. man-made islands, were investigated at Lough Gara (Fredengren 2000, 2002). The $^{14}$C dates obtained from crannógs KILA 16 and KILA 46 confirmed that there was Iron Age activity in the surroundings of this lake. There is also a record of a bog body from this area that has been $^{14}$C dated to the early Iron Age. Other Iron Age artefacts have also been found in the vicinity of L. Gara (Fredengren 2002).

At Rathdowney Beg, there is a pair of Iron Age barrows which, based on $^{14}$C dating, were constructed ca. 380 BC–AD 80. These provide good evidence for Iron Age activity in mid Co. Sligo (Mount 1998, 1999).

The most common archaeological evidence for early medieval presence is represented by ringforts. A total of 1703 ringforts are recorded in Co. Sligo. These are located mainly on fertile ground, e.g. near L. Dargan and also Cooney L. (cf. Danaher 2007).
1.4 Review of palaeoecological investigations in Co. Sligo

Despite the wealth of this archaeological area few palaeoecological investigations have been undertaken in Co. Sligo, and in the Cúil Irra peninsula in particular (Fig. 1.02).

The first pollen analytical investigations carried out in Co. Sligo are those by Jessen (1949) and Mitchell (1951). In those times, the main focus was on arboreal pollen (AP) and little attention was given to non-arboreal pollen (NAP). So these investigations are now mainly of historical interest. The earliest pollen analytical investigation employing modern methods were those undertaken by Göransson (1984; republished 2002). These investigations were carried out in connection with the major research programme by a Swedish team led by G. Burenhult and referred to above. The focus of Göransson’s investigations was on vegetation change associated with the construction and use of the passage tombs, i.e. during the Neolithic. To accomplish this, Göransson investigated a core from Cloverhill Lough, a short monolith from a submerged peat layer at Strandhill, both located in the Cúil Irra peninsula, a core from Ballygawley Lough, close to the Cúil Irra peninsula, and a core from Treanscrabbagh Bog in the Bricklieve Mountains beneath the Carrowkeel passage tomb cemetery.

At Cloverhill L., in the south-east part of the Cúil Irra peninsula, a core ca. 1 m long was recovered. The core extended back less than 2000 years, so the Neolithic period is not included. \textit{P. lanceolata} and Poaceae dominated the profile, with a substantial cereal-type curve and few \textit{Secale} grains were recorded in the upper part of the profile. The micro-charcoal record is notable. According to Göransson the pollen diagram from Cloverhill reflects an open landscape where \textit{Corylus} was the main AP contributor. In the upper part of the diagram exotic AP (arboreal pollen) were found, such as \textit{Tilia}, \textit{Fagus} and \textit{Picea}. The pollen profile appears to span the historical period (early first millennium AD to recent times).

At Strandhill, at the western side of the Cúil Irra peninsula, a short profile from a submerged peat layer was pollen analysed and two $^{14}$C dates were obtained (5210±60 BP and 5680±60 BP; the profile is referred to as Strand Hill). The diagram is characterized by high percentages of \textit{Pinus}, but the curve was omitted because, according to the author, the pollen of \textit{Pinus} probably was thrown up by the waves on the shores of Sligo Bay during peat
formation. The diagram reflects not only the shore plant communities, but also the nearby woodland. The profile opens with high values of *Corylus* and *Ulmus*. The decline in *Ulmus* occurs at the same time of the initiation of the *P. lanceolata* (ribwort plantain) curve. Two grass pollen grains were recorded with a diameter of 40 µm and 44 µm which may be regarded as cereal-type pollen. However, only four samples were pollen analytically investigated. There is also the possibility that the peat is not in situ but may have been washed in from elsewhere in the Sligo Bay area (M.A. Timoney, pers. comm.).

At Ballygawley L., situated at ca. 6 km south-east from Carrowmore, a core 6 m long was recovered. Although the lake is rather distant from Carrowmore, the large size of the lake (ca. 57 ha) may potentially provide a pollen diagram that represents a useful record for the reconstruction of the Neolithic at regional level. This core was pollen analytically investigated between 100 and 275 cm and two $^{14}$C dates were obtained (2490±110 BP and 3850±85 BP). The diagram opens with a low *Alnus* representation, suggesting that the record begins at the end of the Boreal or the beginning of the Atlantic period (ca. 8000 cal. BP). The Atlantic woodland consisted of *Corylus*, *Ulmus*, *Quercus* and *Pinus*. The *Pinus* curve declines strongly before the Elm Decline. The Elm Decline event occurs at the transition between algal gyttja and a black gyttja, where a hiatus of at least 1000 years was assumed by the investigator. In this profile Göransson recorded *P. lanceolata*, cereal-type pollen (>43 µm; mounted in glycerine) and charcoal in pre-Elm Decline contexts.

At Treanscrabbagh Bog, in the Bricklieve Mountains, G.F. Mitchell analysed a long core (ca. 10 m) in 1951, in the bog north of L. Availe. This core covers most of the post-glacial period. Mitchell’s diagram was redrawn by Göransson (1984). Göransson also cored in the marginal part of Treanscrabbagh Bog, with the help of M.A. Timoney and M. Thelaus, in 1981. The core was 116 cm long and consisted of minerogenic peat. Five samples were $^{14}$C dated (4010±55 BP; 4250±60 BP; 5270±60 BP; 5640±65 BP; 5830±65 BP) (Göransson (1984). This profile covers a period between ca. 4680 BC and 2550 BC.

In neither Mitchell’s nor Göransson’s pollen diagrams, the Elm Decline was not well defined. In Göransson’s profile the $^{14}$C date from the relevant level is 5270±60 BP. In this profile the pre-Elm Decline woodland was dominated by *Ulmus*, *Corylus* and *Quercus*. A peak in micro-charcoal was found in a pre-Elm Decline context, together with an increase
in Poaceae and *Pteridium* spores indicating an opening-up of the landscape. At what is regarded as the Elm Decline, *P. lanceolata* expands probably reflecting grazing activity in the area. The subsequent decline in *P. lanceolata* is associated with the increase in AP indicating a woodland regeneration phase.

From the records of *P. lanceolata*, cereal-type pollen (>43 µm; mounted in glycerine) and charcoal in pre-Elm Decline contexts, Göransson developed a working hypothesis called the “Early Neolithic fire-grazing phase” (Göransson 1984, p. 174). The author rejected Iversen’s (1941) model of woodland clearance to facilitate farming, known as Landnam which, according to Göransson, signifies “a colonist takes land”. Again, according to Göransson the Atlantic forest was transformed into a coppice wood by girdling the trees. The wood was then stimulated to produced large quantities of pollen and provided fodder for grazing animals. After coppicing the subsequent increase of light allowed the cultivation of cereal on a small scale (Göransson 1984, 2002). However, the cores analysed were not completely satisfactory for testing his hypothesis because of the lack of detail and chronological control.

Dodson and Bradshaw (1987) carried out pollen analytical investigations in north-west Sligo at Slish Lake, Slish Wood (south L. Gill) and Lough Arquilla (they refer to this lake as Union Wood lake). The main focus of this study was to investigate fire history and human impact. The authors emphasised the positive correlation between high levels of human impact, use of fire and the expansion of heath in the later part of the post-glacial. From Lough Arquilla, two cores were taken. Core 1 profile spans from ca. 6600 BP to ca. 1900 BP (four 14C dates were obtained), while core 2 spans from ca. 3500 BP to the present (two 14C dates were obtained). In core 1 the diagram opens with a closed woodland structure. The main trees/shrubs were pine, hazel, oak and elm. The *Alnus* curve started at the base of the profile and its increase was accompanied by a decline in *Pinus*. At ca. 4400 BP *Ulmus* declines together with an increase in Poaceae and *P. lanceolata*. From Slish lake a core of 2.25 m long was taken. The profile spans from ca. 1900 BP to the present (three 14C dates were obtained). The diagram opens with high values of *Sphagnum* and Poaceae, which decline in the following zone at the rise of *Corylus*. In the upper part of the profile *Corylus* declines somewhat and an increase in Poaceae and in micro-charcoal particles was recorded. At Slish Wood a sample of 54 cm thickness (dark brown humus) was recovered (no 14C
dates were obtained). Three zones were identified. In zone 1 Pinus and Alnus dominated. Zone 2 records an expansion in Myricoid, Calluna, Poaceae and micro-charcoal. Zone 3 shows a decline in NAP but Betula expands.

An interesting feature is the record of Arbutus unedo (strawberry tree) pollen, a Mediterranean species. The pollen of this species was recorded in Slish Lake and Slish Mor diagrams, as far back as ca. 1900 BP. This plant is still present along the shore of L. Gill (Sealy 1949) and in Co. Kerry (Killarney and other sites) and also west Cork (e.g. Glengarriff). In Killarney, pollen of A. unedo was recorded as far back as ca. 4000 BP (Mitchell 1988). The sampling resolution and the chronological control (the error value in the $^{14}$C dates is large) of those diagrams is, however, rather poor.

At L. Alanteen, north of L. Gill, a low resolution pollen diagram provides an overview of the Holocene vegetation dynamics in the region (Turbayne 1985). The profile spans from 950 cm to 450 cm and opens shortly after the Late-glacial in an open landscape environment. A large number of NAP taxa is recorded, in particular Poaceae and Cyperaceae. Subsequently, AP increases and Corylus after an initial peak declines gradually until the upper part of the profile. The Elm Decline is well defined. Unfortunately, the diagram does not have radiocarbon dates.

Recently, the results of pollen analytical investigations carried out in the CAU on cores from Loughmeenaghan and L. Availe have been published ((Stolze et al. 2012 and Stolze 2012b, respectively; there are also other investigations but these are unpublished; see Stolze 2012a). The focus has been on Neolithic human impact and climate change. Loughmeenaghan lies at 3 km north from Carrowkeel Passage Tomb cemetery, south Co. Sligo. A strong correlation between human development and climatic oscillations during the Neolithic is suggested (Stolze et al. 2012). The Atlantic woodland, composed mainly of hazel, oak, elm and alder, experienced a period of transformation coinciding with the Elm Decline (ca. 3800 BC). The shift towards pastoral and arable farming took place with the establishment of exceptionally dry and warm condition between 3650 and 3560 BC. The authors argue that during the transition between the early and mid Neolithic, when a decline in farming activity is recorded, the onset of cool and wet conditions caused the abandonment of the area by the first farmers.
The pollen profile from L. Availe is from near where Mitchell (1951) and Göransson (1984; 2002) carried out their investigations (see above). The profile opens during the Atlantic, where the woodland was mainly composed of hazel and elm. After 4110 BC and before the onset of the Elm Decline (4020 BC) *P. lanceolata* and *Pteridium* pollen were recorded. A piece of charred wood was also noted in this part of the core. These records are interpreted as evidence for human interference and the disturbance was linked to burning. During the early Neolithic it is suggested the establishment of dry conditions. At ca. 3260 BC, the increase in *Alnus* and pollen of aquatic plants suggests a shift towards particularly wet conditions, associated with woodland regeneration phase. In the case of both Loughmeenanaghan and L. Availe the chronology is based on 14C dates.

At Rathdowney Beg, material from an early/mid Neolithic ditch fill (14C dates suggest ca. 3600 BC) and Iron Age barrows have been investigated by D. Weir (in Mount 1998, 1999). At the base of the ditch (Neolithic) high values of grasses (70-77%) were recorded, in particular *P. lanceolata, Ranunculus acris*-type and *Rumex*-type. Cereal-type pollen was also recorded. *Quercus* and *Ulmus* were the main trees recorded and *Corylus* was the main shrub. This record suggests that an open grassland prevailed locally during the Neolithic. Pollen analytical investigations at the nearby Iron Age mounds suggest a major opening-up of the woodlands occurred during the Iron Age.

At Culleenamore, southern Cúil Irra peninsula, charcoal from a Neolithic kitchen midden was investigated by T. Bartholin (1984). The analyses showed that *Corylus* was the most common species. *Quercus, Ulmus, Salix, Prunus* and *Cornus* were also recorded. The records appear to span much of prehistory (from the Neolithic to the early Iron Age). The presence of *Prunus* and *Cornus* suggest that the woodland structure was not closed.

The above is the background against which the present investigations were undertaken. My investigations aimed especially to provide detailed, high temporal-resolution records for north Co. Sligo. It was hoped that the records would be such as to provide the basis for the reconstruction of vegetation and land-use dynamics during the greater part of the Holocene. It was also the aim to pay particular attention to prehistoric human impact and especially farming.
Chapter 2

Post-glacial environmental change at Lough Dargan

2.1 Introduction

The prestige of Co. Sligo comes from its rich archaeological heritage and in particular from the megalithic tombs related to the Neolithic period (Cooney 2000; Waddell 2010). Indeed, in this county the total number of known megalithic monuments is ca. 220, i.e. 15% out of ca. 1450 present in Ireland (Bergh 1995; Ó Nualláin, 1989). Recent excavations have brought to light new prehistoric monuments and other evidence of Neolithic activity. Despite the importance of this area few detailed palaeoecological investigations have been carried out.

This project is part of a larger ongoing palaeoecological research programme which focuses on the Neolithic in Sligo (cf. Stolze et al. 2012; Ghilardi and O’Connell 2012a, c). In this chapter the results from the palaeoecological investigations at L. Dargan are presented.

L. Dargan is located close to the Cúil Irra peninsula (Fig. 2.01). This peninsula is well known for its wealth of archaeological sites. In contains several monuments relating to the Neolithic, in particular the impressive Carrowmore passage tomb cemetery (Burenhult 1984, 2009; Bergh 1995, 2002). The peninsula has the largest cluster of passage tombs in Ireland; 75 out of a total of 230 in Ireland (Bergh 1995, 2002). The recent excavation and survey carried out by Danaher (2007) along the N4 road, south of Sligo town, further highlighted the importance of the Neolithic in this part of Ireland. In particular the Magheraboy causewayed enclosure (ca. 2 ha) has yielded some of the earliest dates for causewayed enclosures in Britain and Ireland. These are also some of the earliest dates for the Neolithic in Ireland (Danaher 2007; the chronology for this site and its significance for dating the Neolithic in Ireland are considered by Cooney et al. 2011; see Discussion).

Details of earlier palaeoecological research in this area by Göransson (1984; republished 2002), Dodson and Bradshaw (1987) as well as other minor studies are reviewed in Chapter 1.
**Fig. 2.01.** Site maps, L. Dargan.

**A.** Main map showing location of the coring position in L. Dargan, sites with published pollen diagrams and the main archaeological features. 1: Slish Wood (lake sediments and mor humus deposit) and 2: L. Arquilla (Union Wood Lake) (Dodson & Bradshaw 1987), and 3: Ballygawley L. (Göransson 1984, 2002).

Other features as follows (probable cultural period in parentheses): BM, burnt mound (Bronze Age); CDH: Castle Dargan Hotel; DC: Dargan Castle; Fs, field system (unknown); H, earthen-banked enclosure/henge (mid/late Neolithic); MB, mound barrow (Bronze Age/Iron Age); and SR, SS: stone row, standing stone (Bronze Age). Ringforts (not shown; Iron Age/early Medieval period) are common, especially in lowland to the west of L. Dargan.

Inset shows selected features in the wider region including: Passage Tomb cemeteries at Carrowmore and Carrowkeel, Magheraboy Neolithic enclosure, Rathdooney Beg (Rb) and Loughmeenaghan (Lm). Sligo and adjoining counties, Mayo, Roscommon and Leitrim, are indicated (county boundaries indicated by broken lines). The area delimited by a rectangle (the dot indicates L. Dargan) is shown in the large-scale map.

**B.** First edition (ca. 1838) of the OSI 6" map of the L. Dargan area. On the right side a photograph of the second court tomb from L. Dargan (indicated as “Druid’s Altar” in the OSI map). Photo: B. Ghilardi, 10.09.2010.
**Fig. 2.01.** Site maps, L. Dargan.
2.2 Site description

Before the project proper commenced, various sites close to Carrowmore and Magheraboy were tested in order to identify a suitable site within the Cúil Irra peninsula. Carrowmore Lough, Cloverhill Lough and Punchbowl Lake, and also peat deposits near Magheraboy were examined (M. O’Connell, pers. comm.). These sites were considered unsuitable for this investigation. L. Dargan, on the other hand, fulfilled the various requirements and was therefore selected as the main study area.

Lough Dargan (45 m asl) is a medium sized lake (area 10 ha) and circular in shape (diameter 300 m) with a narrow projection (170 m long) to the south-east (Fig. 2.01). The maximum depth recorded (by echo sounder) is 11.2 m. It lies in a sheltered position at the base of the Ox Mountains outliers (Slieve Dargan and Slieve Daene; 260 m asl). These mountains are orientated east-west and form a barrier between L. Dargan and the Cúil Irra peninsula. This barrier is interrupted by the Ballysadare/Collooney corridor through which the N4, i.e. the main Dublin/Sligo road, now runs. Nowadays, and probably also in the past, this corridor favours communication between the peninsula and the area around Castle Dargan. At the north-west side of the lake there is a small inflowing stream, which rises from the uplands. To the south of this there is a small outflowing stream.

From a geological point of view L. Dargan lies in a narrow strip of sandstone (Moy Sandstone Formation). The Ox Mountains, which lie to the north, consist of metamorphic rocks, in particular pelitic and semi-pelitic paragneiss. To the south, Carboniferous limestone dominate the lowlands (MacDermot et al. 1996).

North-west Ireland is characterized by an oceanic climate with rainfall higher than 1250 mm, and the number of rain days exceeding 200 per year (Rohan 1975). The uplands are covered mainly by blanket bog, which spread in western Ireland during the late Neolithic/early Bronze Age (O’Connell 1990). The Ox Mountains have a skeletal soil (brown podzolics and brown earths) with a high proportion of rock outcrops, and support rough grazing (Walsh et al. 1976). On the lowlands there are grey brown podsolic soils, which often have slowly permeable subsoils, gleys and some peaty soils. Due to poor permeability the soil is suitable for grassland farming and limited tillage.
Nowadays the landscape in the area around Castle Dargan is mainly treeless, although several mature trees are present at the southern edge of the lake. Up until the 17th century in north Sligo the Leguy woods of oak, hazel, yew and holly covered the lower slopes of the Ox Mountains down to the sea and stretched to Lough Gill. However, at the end of the 17th century and during the 18th century the woodlands were strongly exploited for their timber resources, and as a consequence the landscape was left relatively deforested (McCracken 1971). Nowadays a few patches of woodland, some planted with oaks like Union Wood close to Ballygawley Lough, are still present on the slopes of the Ox Mountains outliers.

The wetland flora in the vicinity of the lake includes *Potentilla anserina, Potentilla palustris, Galium palustre, Hydrocotyle vulgaris, Epilobium palustre, Ranunculus flammula, Lythrum salicaria, Lychnis flos-cuculi, Caltha palustris, Iris pseudacorus, Sparganium sp. and Juncus articulatus*. *Lemma trisulca* and *Potamogeton polygonifolium* are partially submerged plants. On the western side of the lake *Schoenoplectus lacustris* (*Scirpus lacustris*) forms a band 2-3 m wide in a water depth of 1m. At the edge of the lake *Phragmites australis* and *Carex rostrata* are also present, and *Typha latifolia* is recorded at the south-western side of the lake. *Fraxinus* is the main tree found in the vicinity of the lake, mainly close to the Castle. *Acer pseudoplatanus, Fagus sylvatica* and *Salix* spp. are also present (higher plant nomenclature follows Parnell and Curtis 2012). Smith (2004) and Watson (1981) were referenced in connection with moss identification. Moss nomenclature follows the former.

From a palaeoecological perspective several field monuments in the vicinity of L. Dargan give indications of past human activity (Fig. 2.01). There are four court tombs near L. Dargan, two of which are within 200 and 720 m of the lake. A portal tomb to the south-east is located within 1 km. On the uplands, towards the north-west, four cairns overlook the lake (two are known to be passage tombs; all four are regarded as belonging to the Irish Passage Tomb Tradition (IPTT) sensu Bergh 1995; further details in Bergh 1995; Egan et al. (2005); National Monuments Service (http://www.archaeology.ie/ArchaeologicalSurveyofIreland); Ó Nualláin 1989). A substantial earthen-banked enclosure (henge), possibly mid to late Neolithic in age, lies a kilometre to the south of L. Dargan (Danaher 2007).
Fig. 2.02. Photographs at L. Dargan.
Megalithic monuments associated with later periods include a wedge tomb (Neolithic/Bronze Age transition), standing stones and a stone row (Bronze Age). Several ringforts in the fertile lowlands to the south and west, and crannògs (lake-dwelling sites) in L. Dargan and Ballygawley L. point to considerable activity during the Iron Age and/or Medieval period. Evidence for substantial activity during the historic period includes Dargan Castle (early fifteenth century; now in ruins) which stands on a limestone rock outcrop at the southern edge of L. Dargan; a dugout boat recovered during the lake drainage in 1970 ($^{14}$C dated to the early sixteenth century; M. Timoney, pers. comm) and a demesne house (mid-eighteenth century; now Castle Dargan Hotel), situated a kilometre to the east.
2.3 Methods

2.3.1 Fieldwork

L. Dargan (ca. 50 m asl) was cored in July 2008. Parallel cores, DRG1 and DRG2 both ca. 7.5 m long, (grid refs. N54° 12.113', W08° 25.461' and N54° 12.103', W08° 25.467', respectively) were taken near the centre of the lake in water depth of ca. 8.2 m using an Usinger piston corer fitted with an 80 mm diameter steel coring tube (cf. Mingram et al. 2007) (Fig. 2.02). Highly minerogenic sediments were reached so it is assumed that DRG1 and 2 cores include more or less a full sedimentary sequence.

During the fieldwork the 2 m-long core segments were extruded in 1 m lengths (subsegments) into PVC half-pipes. Subsequently the subsegments were sliced lengthwise to give half cores (subsegments A and B). The half cores were photographed in the field then securely wrapped before being transported to the laboratory where they were stored in a cool environment.

2.3.2 Laboratory investigations

In order to ensure a correspondence in sediment depths between subsegment A and B a scaled adhesive tape was attached to the exterior of each core tube. Photographs and stratigraphical descriptions of the core subsegments were made (see Results).

Investigations were carried out on core DRG1 are as follows.

Magnetic susceptibility

Magnetic susceptibility is used to identify allochthonous sediment influx into the lake by measuring the concentration of magnetic minerals. Measurements were carried out using the split-core logging method (Nowaczyk 2001). A Bartington magnetic susceptibility meter MS2 with a high resolution surface scanning sensor MS2E was used in conjunction with Multisus ver. 2.31 software for calibrating and logging the data. The MS2 meter sensitivity
was set to x0.1, which is more sensitive than x1. Drift was corrected for taking an air reading (zero reading) before and after each measurement.

Pollen preparation and counting

Core DRG1 was used for pollen analysis. Standard procedures were used for pollen preparation. Samples of approximately 1 cm\(^3\) from 1 cm-thick slices of sediment were taken. Each sample was weighed as it was easier to accurately determine sample weight. The weight was regarded as directly equivalent to the volume (the sediment was highly organic throughout; the assumption that the density was approximately 1 or slightly greater is therefore justified) and was used as divisor when calculating pollen concentration. *Lycopodium clavatum* spore tablets were added to each sample at the commencement of preparation, in order to facilitate estimation of pollen concentration (*Lycopodium* spore batch no. 483216 and batch 177745 (for the last 11 samples) from the Department of Geology, University of Lund; three and five tablets added, i.e. 55752 spores and 92920 respectively; [http://www.geol.lu.se/personal/tsp/Ly177745.pdf](http://www.geol.lu.se/personal/tsp/Ly177745.pdf)). The preparation of the samples followed the procedure implemented in the Palaeoecological Research Unit (PRU; NUI Galway). This involves the following steps:

10% KOH. Samples were boiled for 10 minutes in 10% potassium hydroxide to remove humid acid.

They were then sieved through a 100 µm mesh to remove larger material. This was retained and stored in distilled water for macrofossil analysis.

60% HF. Samples were placed in plastic tubes in a 60% hydrofluoric acid solution and either left overnight in a fume cupboard or heated gently in a bath for ca. 30 minutes. The HF treatment removes any siliceous material.

Acetolysis. Samples were treated with acetic anhydride/sulphuric acid (9:1) and heated for 4 minutes in a boiling water bath. Acetolysis treatment is applied to remove cellulose.

At the end of the procedure samples were sieved in an ultrasonic bath through 5 µm mesh in order to remove small particles. Samples were stored in vials and mounted for counting in glycerol.
A Leica DM LB2 microscope fitted with x10 oculars and a x50 objective lens was used for counting samples. Pollen were routinely checked using a x40 phase contrast objective. Critical grains were checked using a x100 phase-contrast oil immersion objective. Identification of the pollen grains was carried out using various keys and illustrations that included Fægri and Iversen (1989), Moore et al. (1991), Reille (1992, 1995) and Beug (2004). The PRU pollen reference collection was used. Pollen nomenclature generally follows Moore et al. (1991). Cereal-type pollen were distinguished following Beug’s (2004) criteria. However, grains <40 µm in size were classified as Poaceae, i.e. non-cultivated grasses. Cereal-type pollen were routinely assigned during counting to a size class: 40–44 µm, 45–49 µm and >50 µm. Secale pollen were recorded separately. For the saccate grains of Pinus the individual air sacs were counted and subsequently divided by two, in order to estimate the number of grains.

Non-pollen palynomorphs (NPP) were also counted including Pinus stomata, micro charcoal fragments (>37 µm) and fungal spores. Publications such as van Geel (1978), Pals et al. (1980), van Geel et al. (1981), Bakker and van Smeerdijk (1982), van der Wiel (1982), van Geel et al. (1989) and Feeser and O’Connell (2009) were consulted.

Generally a pollen sum of at least 1000 pollen, based on total terrestrial pollen (TTP), was achieved in most samples. In the TTP the aquatic taxa, Sphagnum spores, algae, micro charcoal and the NPPs are excluded. A “+” symbol was used for the pollen types encountered outside of the routine counting.

The program CountPol (ver 3.3; author I. Feeser) was used to calculate the percentage and concentration values and to plot the pollen diagrams.

The equation for the percentage values is as follows:

\[ P_x = \left( \frac{C_x}{P} \right) \times 100 \]

where \( P_x \) corresponds to the percentage representation of the specific taxon, \( C_x \) the count for that taxon x and P is the pollen sum. The equation for the concentration values is as follows:

\[ T_x = \left( \frac{C_x \times T_m}{C_m} \right) \]

where \( T_x \) represents the concentration for the particular taxon, \( C_x \) the count for the taxon x, \( T_m \) is the number of Lycopodium spores initially added and \( C_m \) represents the number of
Lycopodium spores counted. The pollen diagrams are colour coded as follows: blue for arboreal pollen, orange for tall shrubs, green for grassland indicators, red for disturbed habitat indicators, brown for bog/heath taxa, bright blue for aquatic/wetland taxa, brown for ferns and black for NPPs and micro-charcoal.

The zonation boundaries were identified by eye and subsequently drawn, using CorelDraw ver. X4, where substantial changes in pollen taxa representation (percentages and concentrations) occurred.

**Macrofossils analysis**

The material retained in the 100 µm mesh sieves during the initial stages of pollen sample preparation was scanned using a Leica MZ 125 stereo-microscope. Photomicrographs of the macrofossils were taken using a Leica DFC32 digital camera. Estimates of quantity were recorded as follows: rare (+); occasional (1); frequent (2) and abundant (3). Fruits, seeds and nutlets were identified using mainly Cappers et al. (2006) and Beijerinck (1947), and Körber-Grohne (1964) for Juncus seed and Poaceae caryopses. The nomenclature of the higher plants follows Parnell and Curtis (2012). For moss identification, Smith (2004) and Watson (1981) were consulted. Moss nomenclature follows Watson (1981).

**Radiocarbon dating**

Eighteen sediment samples consisting of 2 cm-thick slices of material (wet weight ca. 50 g) were sieved using a 125 µm-mesh sieve. The material retained in the sieve was investigated using the same procedures as for the macrofossil samples. Macrofossils suitable for AMS $^{14}$C dating were submitted to the $^{14}$Chrono Centre (QUB) and to the Centre for Isotope Research (CIO), Groningen. For calibration see Results.

**Loss-on-ignition (LOI)**

Sediment samples with a volume of ca. 2 cm$^3$ were taken from depths corresponding to those sampled for pollen. The samples were first dried in a heating cabinet for 24 h at 105°C
(DW$_{105}$) and subsequently transferred to porcelain crucibles and ashed for four hours at 550°C. This was done in order to oxidise the organic matter to carbon dioxide (DW$_{550}$) (cf. Heiri et al. 2001). Loss-on-ignition (LOI), ash content (inverse of LOI) and water content were calculated as indicated below.

\[
\% \text{ water} = \left(\frac{W_{\text{wet sample}} - DW_{105}}{W_{\text{wet sample}}} \right) \times 100
\]

\[
\text{LOI}_{550} = \left(\frac{DW_{105} - DW_{550}}{DW_{105}} \right) \times 100
\]

$W$ = weight (g); $DW$ = dry weight (after drying/ashing at the temperature indicated)
2.4 Results

2.4.1 Stratigraphy

A photograph of the split core segments, core DRG1, is shown in Fig. 2.03. Stratigraphical descriptions as made in the laboratory are given in the Appendix (Table A2.01) and an overview is given in Table 2.01.

Table 2.01. Summary of stratigraphy, core DRG1 (L. Dargan)

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–53</td>
<td>Watery fine gyttja (noticeably less consolidated); no visible plant remains; orange colouration in parts</td>
</tr>
<tr>
<td>53–627.5</td>
<td>Dark fine gyttja. Following features noted</td>
</tr>
<tr>
<td>180–204</td>
<td>Several tiny plant remains;</td>
</tr>
<tr>
<td>203</td>
<td>Flat leaf-like material;</td>
</tr>
<tr>
<td>229.5</td>
<td>Light grey material c. 3 mm of diameter;</td>
</tr>
<tr>
<td>230–233</td>
<td>Fainter and lighter coloured sediment</td>
</tr>
<tr>
<td>627.5–659</td>
<td>Dark fine gyttja but lighter in colour then above, presumably because it contains more silt and clay</td>
</tr>
<tr>
<td>659–664</td>
<td>Transitional sediment</td>
</tr>
<tr>
<td>664–694</td>
<td>Dark grey, highly minerogenic (i.e. silt and clay) sediment</td>
</tr>
<tr>
<td>694–696</td>
<td>It is assumed that the Holocene begins at 664 cm (664 cm this is the transition Late-glacial/Holocene)</td>
</tr>
<tr>
<td>694–698</td>
<td>Medium brown, organic-rich gyttja. Sharp transition on top and bottom (interstadial Bølling-Allerød) (note: sloping boundary; above depths regarded as best approximation</td>
</tr>
<tr>
<td>696–740</td>
<td>Light coloured sediment, upper cm distinctly light in colour could be because of marl Sharp upper and lower boundary. (Bølling-Allerød interstadial)</td>
</tr>
<tr>
<td>698–740</td>
<td>Highly minerogenic (silt, clay and gravel) dark gray in colour. 698 cm is regarded as the end of the Pleniglacial</td>
</tr>
<tr>
<td>740–746</td>
<td>Silt, clay and large stones</td>
</tr>
</tbody>
</table>

Note: Above in 4, 2 m-long drives, i.e. segments, I, II, III and IV; in I, 20 cm of water so segments II–IV ran 180, 380, 580 (top measurements).
Fig. 2.03. Photograph of split core segments, core DRG1.
Chapter 2: L. Dargan

The stratigraphy suggests that the core spans the whole Holocene and part of the Late-glacial. The bottom part of the core shows the distinctive tripartite Late-glacial sequence. Clay/silt/sands and gravel at the base was presumably deposited at the end of the last glaciation some 15,000 years ago (divisions based on lithology). Between 698 and 694 cm light brown sediment suggests the Bølling/Allerød interstadial period. The dark grey highly minerogenic (silt and clay) sediment recorded from 694–664 cm, indicative of severe solifluxion and a substantial drop in temperature, probably represents the Younger Dryas. At 664 cm the sediment changes in colour. It becomes darker brown and consists mainly of uniform fine dark gyttja, i.e. organic-rich lake sediment up until 53 cm. This change in sedimentation represents the Late-Glacial/Holocene transition. Plant remains are recorded from 180–204 cm. Faint and light bands of sediment are present between 230 and 233 cm. In the upper part of the core, from 53 cm upwards, the sediment is less consolidated and extremely watery, particularly as the water/sediment interface is reached.

2.4.2 Radiocarbon dating

The results of radiocarbon dating are presented in Table 2.02 and an age/depth curve is shown in Fig. 2.04A. Of the eighteen samples submitted for dating, one sample had insufficient material and so a date was not returned, four dates showed reversals (substantial in the case of three dates from the upper sediments) and a further four dates had large to very large error values but were otherwise regarded as acceptable. In all, thirteen $^{14}$C dates were regarded as of use for constructing an age/depth model.

Several methods to obtain an age/depth model were tried. Various age/depth models were generated by OxCal ver. 4.1.7 (Ramsey 2009) using the IntCal09 calibration curve (Reimer et al. 2009) and the P_Sequence model. In the age/depth curve given in Fig. 2.04B all the radiocarbon dates were included, outliers were designated as such, the $k$ parameter was equal to 0.5 and boundary conditions were placed at 506 cm, 354 cm and 306 cm. The latter were identified according to the changes in concentration. Other conditions specified included that the uppermost watery sediment (0 cm) represents the sediment/water interface at the time of coring (AD 2008), and that a change to highly minerogenic sediment at 664 cm near the base of the core represents the Late-Glacial/Holocene transition and hence dates...
to 9700±50 cal. BC (cf. Walker et al. 2008, 2009). While the curve may be acceptable there are sharp slope changes in sedimentation rate.

The age/depth curve adopted as best estimate is a combination of different curves. From the bottom part a linear interpolation was used due to the absence of radiocarbon dating starting from 664 cm (Late-Glacial/Holocene transition) up until 578 cm. Thereafter until 332 cm a polynomial of third degree was applied. From 332 cm to the top, a spline smoothing function gave the best estimate.
Fig. 2.04. A Age-depth model for core DRG1, L. Dargan
**Fig. 2.04.** B Age-depth model for core DRG1, L. Dargan
<table>
<thead>
<tr>
<th>Lab code</th>
<th>Depth (cm)</th>
<th>^14C date (BP)</th>
<th>$\Delta^{13}C$ (‰)</th>
<th>Age range $^1$ (1σ; 68.3%)</th>
<th>Age range $^1$ (2σ; 95.4%)</th>
<th>Median age $^1$</th>
<th>Description</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>UBA-15776</td>
<td>190</td>
<td>3482±29</td>
<td>-24.4</td>
<td>1877–1753</td>
<td>1889–1699</td>
<td>1811</td>
<td>Sphagnum leaf; dark leaf strongly reticulated; insect remains; fruit (broken fragment); Betula bud scales</td>
<td>Reversal; not used</td>
</tr>
<tr>
<td>UBA-15777</td>
<td>250</td>
<td>4860±32</td>
<td>-27.8</td>
<td>3695–3636</td>
<td>3708–3537</td>
<td>3652</td>
<td>Sphagnum leaf fragment; insect remains; Betula fruit (1) and bud scales (4); charred leaves; leaf fragments cf. Salix</td>
<td>Reversal; not used</td>
</tr>
<tr>
<td>UBA-15778</td>
<td>330</td>
<td>1944±41</td>
<td>-17.2</td>
<td>18–121</td>
<td>45–134</td>
<td>-56</td>
<td>Insect remains (c. 30), bud scales of Betula (2) and dark scale-like material</td>
<td>Accepted; beginning of LIAL</td>
</tr>
<tr>
<td>UBA-15779</td>
<td>362</td>
<td>3945±106</td>
<td>-46.8</td>
<td>2580–2233</td>
<td>2861–2139</td>
<td>2442</td>
<td>Bud scales of Betula (6), insect remains (c. 70), charred leaves (3) and other unidentified plant remains</td>
<td>Reversal; not used; exceptionally negative $\Delta^{13}C$</td>
</tr>
<tr>
<td>GrA-45432</td>
<td>400</td>
<td>2530±370</td>
<td>-31.0</td>
<td>1117–202</td>
<td>1606–215</td>
<td>675</td>
<td>Betula fruit (1, broken), bud scale fragments (3), charred leaf fragments (a few small pieces) and insect remains (several)</td>
<td>Error very large but accepted</td>
</tr>
<tr>
<td>UBA-15780</td>
<td>408</td>
<td>2651±86</td>
<td>-34.6</td>
<td>927–670</td>
<td>1013–525</td>
<td>822</td>
<td>Insect remains (c. 30), bud scale of Betula (3) and charred material (several)</td>
<td>Accepted</td>
</tr>
<tr>
<td>GrA-45433</td>
<td>420</td>
<td>2820±130</td>
<td>-26.9</td>
<td>1189–831</td>
<td>1386–788</td>
<td>1021</td>
<td>Bud scale (1) and bud scale fragments (2, charred) of Betula, charred plant fragments (2) and insect remains (several)</td>
<td>Error large but accepted</td>
</tr>
<tr>
<td>GrA-45435</td>
<td>440</td>
<td>2910±45</td>
<td>-29.1</td>
<td>1192–1020</td>
<td>1263–976</td>
<td>1107</td>
<td>Large leaf fragment, Pinus bud scales (1) and Betula fruit (1)</td>
<td>Accepted</td>
</tr>
<tr>
<td>GrA-45437</td>
<td>460</td>
<td>3075±220</td>
<td>-30.0</td>
<td>1605–1013</td>
<td>1877–814</td>
<td>1317</td>
<td>Leaf fragments, unidentified bud scales (3, charred) and insect remains (several)</td>
<td>Error large but accepted</td>
</tr>
<tr>
<td>UBA-15781</td>
<td>470</td>
<td>3366±41</td>
<td>-29.8</td>
<td>1737–1612</td>
<td>1747–1531</td>
<td>1657</td>
<td>Insect remains and charred material (occasional)</td>
<td>Accepted</td>
</tr>
<tr>
<td>GrA-45439</td>
<td>478</td>
<td>3440±205</td>
<td>-30.0</td>
<td>2022–1505</td>
<td>2398–1292</td>
<td>1781</td>
<td>Betula fruit (1), unidentified bud scales (2, charred) and insect remains (several)</td>
<td>Error large but accepted</td>
</tr>
<tr>
<td>GrA-45442</td>
<td>500</td>
<td>3850±40</td>
<td>-27.3</td>
<td>2449–2210</td>
<td>2461–2205</td>
<td>2324</td>
<td>Betula fruit (1, broken), possible wall of a fruit (1), insect remains (several)</td>
<td>Reversal (fruit may be an aquatic); not used</td>
</tr>
<tr>
<td>GrA-45443</td>
<td>520</td>
<td>3780±105</td>
<td>-27.8</td>
<td>2400–2036</td>
<td>2487–1922</td>
<td>2217</td>
<td>Betula fruit (2), bud scale unidentified (1) and several insect remains</td>
<td>Error large but accepted</td>
</tr>
<tr>
<td>UBA-15782</td>
<td>522</td>
<td>3889±29</td>
<td>-30.0</td>
<td>2458–2344</td>
<td>2468–2292</td>
<td>2383</td>
<td>Bud scales of Betula (8) and leaf remains (several)</td>
<td>Accepted</td>
</tr>
<tr>
<td>GrA-45444</td>
<td>540</td>
<td>4150±60</td>
<td>-25.1</td>
<td>2872–2636</td>
<td>2889–2577</td>
<td>2736</td>
<td>Bud scales (4) and fruit (1) of Betula</td>
<td>Accepted</td>
</tr>
<tr>
<td>GrA-45446</td>
<td>560</td>
<td>4665±110</td>
<td>-27.0</td>
<td>3634–3347</td>
<td>3658–3091</td>
<td>3439</td>
<td>Betula fruit (1), Pinus bud scales (1 and a few fragments)</td>
<td>Error large but accepted</td>
</tr>
<tr>
<td>GrA-45449</td>
<td>578</td>
<td>5110±50</td>
<td>-27.8</td>
<td>3970–3805</td>
<td>4036–3786</td>
<td>3879</td>
<td>Betula bud scales (5) and fruit (1); Pinus bud scale (1)</td>
<td>Accepted; below PAZ 2/3 boundary (576/574 cm)</td>
</tr>
</tbody>
</table>
2.4.3 Macrofossil analysis

The macro-remains recorded from the initial sievings (entities ≥100 µm) of the pollen samples and from the sieving carried out to obtain material for 14C AMS dating are presented in Fig. 2.05.

The higher abundance of macro-remains recorded in samples analysed for radiocarbon dates reflects the greater quantities of sediment analysed. Most of the samples contained little material. Insect remains, chironomid head capsules and Bryozoa statoblasts were commonly present. Zones 2, 3 and 4 are richest in macrofossil remains. Pinus bud scales are recorded in five samples from the bottom part of the core, below 561 cm. Betula bud scales and fruits are identified mainly in the 14C samples. Leaf fragments with fibrous material and roots are more frequent in zones 3 and 4. Fern annuli and Potamogeton fruits were recorded mainly in the first half of the profile. Juncus effusus/conglomeratus seeds are more or less consistently recorded from 430 cm upwards. Sphagnum leaves were detected at 588, 536, 409 and 251 cm. In zone 1 leaves of Neckera complanata and some unidentified Hypnaceous mosses are recorded. Thuidium tamariscinum, Hypnum cupressiforme and Bryales leaves are present in zone 2. Brachythecium velutinum and Hypnum cupressiforme are present in zone 3. Fontinalis antipyretica although present in zone 3 is more frequent in zone 4 where Drepanocladus cf. revolvens, Neckera complanata (in only one sample), Thuidium tamariscinum, Hypnum cupressiforme and Cratoneuron commutatum (in only one sample) are recorded. Records for moss leaves are much reduced in zone 5 and 6. In zone 5 occasional leaves of Brachythecium velutinum, Hypnum cupressiforme and Fontinalis antipyretica are present. In zone 6 in addition to Hypnum cupressiforme and F. antipyretica, Calliergon cuspidatum and Fissidens adiantoides are recorded. No moss leaves are recorded in zone 7.

Charred material is detected throughout the core, although only between 441 and 401 cm does it show an almost continuous and substantial record. Pieces of mineral matter are recorded only in zones 2 and 3.

Fig. 2.05. Macro-remains, charred material, mineral matter and mosses, profile DRG1, from the sieving. Counts are converted as follows: 1, 2 or 3 individual converted into 0.5; 4-10 individuals into 1; 10-20 converted into 2; >20 converted into 3. Mosses with only one record in the profile are grouped in the last curve. Abbreviation used: lf.: leaf; fr.: fruit; s.: seed; bs.: bud scale; br.: bract.
Fig. 2.05. Macro-remains, charred material, mineral matter and mosses, profile DRG1.
2.4.4 Loss-on-ignition and magnetic susceptibility

The complete curves for the magnetic susceptibility and ash content, i.e. the inverse of LOI, curves are presented in Fig. 2.06. In the pollen concentration diagram only part of the curves related to the pollen profile are shown.

The bottom part of the core is characterized by high values for both curves, which are followed by a steady decline until subzone 1e. The magnetic susceptibility curve peaks at the end of this subzone, whereas the ash content values reach a peak only at the end of the following zone (zone 2). Both curves show high values between the end of subzone 4c until the middle of subzone 4e. Here the magnetic susceptibility values decrease, whereas the ash content values increase. In subzone 5a both curves show high values and from about subzone 6b they rise steadily to the top of the profile, with a small decrease in values at the beginning of subzone 6b.
**Fig. 2.06.** Magnetic susceptibility, ash content and stratigraphy of core DRG1.
2.4.5 Pollen analysis

For core DRG1 a total of 154 samples were pollen analytically investigated. Sampling began at 636 cm and ended at 116 cm (the core was not sampled above this point). Sampling was carried out every 2 cm between 620–608 cm and 592–420 cm. Elsewhere sampling was carried out every 4 cm, except between 300 and 116 cm where it was every 8 cm.

A percentage pollen diagram showing the main curves is presented in Fig. 2.07. A secondary percentage pollen diagram shows additional taxa not included in Fig. 2.07 are given in Fig. 2.08. Concentration curves with magnetic susceptibility, ash content and selected pollen accumulation rate (PAR) curves for *Pinus*, *Ulmus*, *Quercus*, *Corylus*, *Alnus*, Poaceae and *P. lanceolata* are shown in Fig. 2.09. PAR is a function of the pollen concentration and the sediment accumulation rate. The central part of the pollen profile is also presented to better illustrate the changes where close-interval sampling was carried out (Fig. 2.10). A pollen sum (PS) of 1000 pollen grains is generally achieved except for the uppermost part of the profile (the top six samples: 156, 148, 140, 132, 124, 116 cm), where the pollen concentration is low. Aquatic taxa, *Sphagnum*, spores and micro-charcoal curves are excluded from the PS. These are based on the PS plus the sub-sum of each group, e.g. total aquatic taxa. Silhouetted curves are magnified on the x axis. The zones are placed where major changes in the pollen spectra are recognized. Subzones and sub-subzones are used to highlight small but still substantial changes.

A total of seven pollen assemblage zones are distinguished for DRG1. The main features of the pollen profile are now considered and summarized in Table 2.03.

**Fig. 2.10.** Detail of pollen profile, DRG1, showing selected percentage curves for the mid Holocene including the Neolithic and the Bronze Age. Ash and magnetic susceptibility values (broken line: original data; solid line: running mean of 3) are displayed on the right of the diagram. Non-filled background curves show values exaggerated by 10 (in case of relatively high values the curves are truncated).
**Fig. 2.10.** Detail of pollen profile, DRG1, showing selected percentage curves for the mid Holocene including the Neolithic and the Bronze Age.
Chapter 2: L. Dargan

PAZ DRG1-1; 636–590 cm; ca. 7800–4600 BC

The profile opens with high percentage representation of AP (average 93.8%). The main taxa represented are Pinus (pine), Quercus (oak), Ulmus (elm), Betula (birch) and in particular Corylus (hazel). Pinus stomata are recorded throughout the zone, except for the basal part of it, where they are unrecorded. Among the NAP taxa only Polypodium and Hedera curves are well expressed. However, AP percentage and concentration values are not steady during this period. For this reason zone 1 is divided into five subzones, with the following characteristics:

Subzone 1a. At the onset of this subzone pollen concentration and PAR increase sharply. Corylus attains its highest percentage representation for the profile (67%). Pinus and Betula decline somewhat in the middle part of the subzone. Ulmus is consistently recorded, whereas the Quercus curve shows a steady rise starting from 3.6% and reaching 12.2% at the upper part of the subzone. Leaves of Neckera complanata are recorded at 628, 624, 620 and 618 cm. At 616 cm a cereal-type pollen of 50 µm diameter (annulus 13 µm; pore 5 µm) was recorded (photomicrographs presented in Fig. 2.11A and B). The exine surface pattern as viewed under phase contrast showed fine punctae with a clumped pattern that is typical of Triticum-type pollen.

Subzone 1b. In this subzone Pinus and Betula values increase. This increase corresponds with a decrease in Corylus and Quercus, and with an overall decline in arboreal concentration. Polypodium and Botryococcus curves decline.

Subzone 1c. Quercus percentage values increase in this subzone. Corylus values peak initially then decline somewhat whereas Pinus shows an opposite trend. Bud scales of Pinus are recorded.

Subzone 1d. Pinus values increase steadily (from 11.8 to 15.8%) whereas records of Pinus stomata and Betula values peak in the middle part of this subzone. Corylus values decline to 50% in the upper part of the subzone. During this period Alnus is represented by a slender curve (0.8%) and a few grains of Fraxinus pollen are detected. Micro-charcoal particles are consistently recorded.
Fig. 2.11. Photomicrographs of early cereal-type, profile DRG1.
Subzone 1e. *Pinus* reaches its maximum percentage value for the profile (25.9%) in conjunction with a peak in *Pinus* stomata. *Corylus* and *Ulmus* values decline while *Quercus* increases slightly. Concentration values, in particular for the AP, decline drastically. *Potamogeton* pollen is recorded for the first time and also a fruit is detected at 590 cm. Micro-charcoal particles show an increase at the end of this subzone.

**PAZ DRG1-2; 588–576 cm; ca. 4600–3760 BC**

The lower boundary of zone 2 is marked by a drastic decline in *Pinus*. Percentage values drop from 25.9% in the previous zone to 9% at the beginning of this zone and 1.5% at the end of it. At the same time AP taxa expand (both concentration and percentage values), in particular *Ulmus* (14.8%) and *Alnus* (6.8%). *Quercus* values also show a steady increase throughout the zone, whereas *Polypodium* values decrease substantially. At 580 cm *Ilex* pollen is recorded for the first time. The AP concentration curves show an overall substantial increase in values.

**PAZ 3; 574–510 cm; ca. 3760–2120 BC**

In order to provide a higher temporal resolution and greater detail as regards pollen taxa, close interval sampling (every other centimetre) was undertaken in this part of the core. Three main subzones are identified as follows:

Subzone 3a. The lower boundary of this subzone corresponds to the Elm Decline. NAP diversity increases. The main AP taxa are *Quercus*, *Corylus*, *Alnus*, *Salix* and *Betula*. *Ilex* is almost consistently represented, albeit by a slender and interrupted curve. The *Pinus* curve shows low values, although its stomata are still recorded. The micro-charcoal curve shows a small increase. In the first part of this period, sub-subzone 3aa, the *Ulmus* curve declines within 2 cm from 21% to 11% at 574 cm. The concentration values and PAR of *Ulmus* also decline. *P. lanceolata* expands in the following spectrum (572 cm), reaching 3.4%, corresponding with the expansion of Poaceae. Cereal-type pollen are recorded although not consistently. It is notable that a large cereal-type grain (size 80 µm, annulus 16 µm and pore 8 µm) identifiable due to its clumped punctae surface as *Triticum*-type (wheat), was detected at the beginning of zone 3 (photomicrographs Fig. 2.11 C and D). At the end of this sub-
subzone *Ulmus* reaches the lowest value (3.4%) for this period. In the second half of the zone, sub-subzone 3aβ, the *Ulmus* curve rises to 18.3%. NAP taxa decrease, in particular *P. lanceolata* and Poaceae. Cereal-type is poorly represented.

**Subzone 3b.** Percentage values for AP rise with *Fraxinus* in particular increasing in importance. The *P. lanceolata* curve is interrupted and Poaceae representation is very low.

**Subzone 3c.** Another expansion of herbaceous taxa is recorded. *Ulmus* values decline for the second time, whereas *Fraxinus* continues to expand. At the beginning of this subzone, six pollen grains of *Taxus* are recorded. This subzone is divided into two sub-subzones, 3ca and 3cβ. In the second subzone, the cereal-type curve resumes.

**PAZ 4; 508–384 cm; ca. 2120–550 BC**

Sampling every other centimetre was carried out until 420 cm. The upper part of this zone was sampled every four centimetres. This zone is characterized by a higher representation of NAP herbaceous taxa than in the previous zone and by a constant, albeit fluctuating, record of cereal-type pollen, Poaceae, *P. lanceolata* and micro-charcoal particles. Due to this fluctuation zone 4 is divided into six subzones, characterized as follows:

**Subzone 4a.** This subzone records a sizeable drop in AP percentage and concentration values. *Ulmus, Corylus* and *Quercus* curves decrease, whereas *Fraxinus* representation increases. An important expansion of pastoral and arable taxa has occurred, in particular Poaceae and *P. lanceolata*. Cereal-type display the highest peak recorded in this zone (4%). Bog/heath taxa such as *Calluna* and Cyperaceae expand. *Pteridium* values and micro-charcoal particles increase in representation. A few *Taxus* pollen are recorded as well as *Viburnum opulus* and *Myriophyllum*. The curve for Type 91 spore rises at the end of this subzone. Micro-charcoal particles increase substantially. Type 91, Equisetum-like (val Geel 1978), was identified as *Peridinium* (a dinoflagellate) in Holmes et al. 2007 as per F. McCarthy, pers. comm.

**Subzone 4b.** In this subzone, AP expand alongside an overall reduction in NAP, including pastoral and arable indicators. The *Pteridium* and micro-charcoal particle curves decline.

**Subzone 4c.** Another expansion of NAP is recorded although the cereal-type pollen curve, after an initial peak, has reduced representation. The Poaceae and *P. lanceolata* curves are
well expressed. *Pteridium*, micro-charcoal particles and *Peridinium sp.* values increase, in particular the latter records a noteworthy expansion.

**Subzone 4d.** AP percentage and concentration values rise, although a small increase in NAP is recorded in the middle of the subzone. Several pastoral taxa are still detected. The *Peridinium sp.* curve shows high values, in particular at the end of the subzone where it displays a substantial peak.

**Subzone 4e.** A major expansion of NAP, in particular of taxa indicative of grassland, is recorded with a maximum of 34.3% at 428 cm. AP declines and *Pteridium* and micro-charcoal expand. The *Peridinium sp.* curve drops drastically.

**Subzone 4f.** Another expansion of AP follows, although several herbaceous taxa are still recorded. An increase in NAP and micro-charcoal particles is recorded at the end of this zone, where *Pediastrum* is also consistently detected.

**PAZ DRG1-5; 380–316 cm; 550 BC–AD 350**

A strong expansion in bog taxa, corresponding with a substantial increase in NAP (pastoral and arable), and a substantial decrease in *Corylus* characterize this zone. Three subzones are identified as follows:

**Subzone 5a.** *Fraxinus*, *Corylus* and *Quercus* values decline (both percentage and concentration). The expansion of Cyperaceae values, together with the expansion of Poaceae, *P. lanceolata* and *Pteridium* is notable. A large number of pastoral taxa increase in representation, such as *Filipendula*, *Liguliflora*, *Ranunculus acris*-type and *Rumex*-type. In addition, arable indicators increase, e.g. cereal-type pollen, Chenopodiaceae, *Artemisia* and *Hornungia*-type. *Pediastrum*, *Botryococcus* and *Nymphaea* curves rise. High values of micro-charcoal particles are recorded. *Glomus* spores, *Peridinium* cysts and *Filinia* eggs are recorded in this subzone.

**Subzone 5b.** At the beginning of the subzone there is a negative peak in AP (47%) which corresponds with high values of Poaceae and cereal-type pollen. Towards the end of this subzone AP taxa increase, in particular *Fraxinus*. Although the Poaceae curve maintains high values, *P. lanceolata* decreases. The cereal-type pollen curve shows a weak decline at the end of the subzone. Cyperaceae, *Pediastrum*, *Botryococcus* and micro-charcoal particle
curves maintain high values. Glomus spores, Peridinium cysts and Filinia are also recorded in this subzone.

Subzone 5c. A strong decline in NAP is recorded, in particular in Cyperaceae, P. lanceolata and Poaceae, although the cereal-type curve remains more or less steady. Among the AP Fraxinus increases notably and a small expansion in Taxus is recorded. Micro-charcoal particles and Pediastrum curves decline.

PAZ DRG1-6; 312–164 cm; AD 350 –1480

At the basal part of subzone 6a AP decline in both percentage and concentration values, particularly Fraxinus which falls from 3.7% to 0.4% in subzone 6b. Taxus pollen is recorded only in the lower part of the zone. Pinus increases in representation, particularly in subzone 6c, and Pinus stomata are inconsistently recorded throughout the zone. NAP taxa expand notably (both classical farming indicators and bog taxa) throughout the zone. However, P. lanceolata values generally do not exceed those attained during the Bronze Age (zone 4) and much of the Iron Age (zone 5), despite the more open landscape. A Secale pollen is recorded at 276 cm. Ferns are also well expressed, particularly Pteridium which achieves the highest value of the entire profile in subzone 6b (8.4%). A substantial expansion in micro-charcoal particles and Pediastrum values is recorded in zone 6.

PAZ DRG1-7 156–116 cm; AD 1480–1680?

The upper part of the diagram is characterized by a major rise in NAP taxa (both pastoral and arable) and the lowest percentage and concentration values of AP (27%) for the whole profile. The Fraxinus curve is interrupted, Quercus and Alnus are poorly represented and Corylus decreases substantially. Pinus is represented by a slender curve and its stomata are recorded. A Secale pollen grain is detected at 148 cm. During this period notable expansions of Pediastrum, micro-charcoal and Filinia eggs are recorded. The magnetic susceptibility curve and ash content have high values.
Table 2.03. Summary of pollen profile DRG1 (L. Dargan)

<table>
<thead>
<tr>
<th>PAZ DRG1</th>
<th>Spectra/depth(cm)</th>
<th>Age range*</th>
<th>Cultural period</th>
<th>Main features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Zone 7</strong></td>
<td>116 – 156</td>
<td>-1680 – -1480</td>
<td>Post-Medieval</td>
<td>Strongest human impact is recorded. Poaceae, cereal-type, Cyperaceae, <em>Pediastrum</em> and micro-charcoal achieve their maximum values. High values of ash content and magnetic susceptibility are also recorded</td>
</tr>
<tr>
<td><strong>Zone 6</strong></td>
<td>164 – 312</td>
<td>-1480 – -350</td>
<td>Medieval</td>
<td>Steady increase of human impact</td>
</tr>
<tr>
<td>6d</td>
<td>164 – 192</td>
<td>-1480 – -1310</td>
<td></td>
<td>Slow but constant increase in arable and pastoral indicators in conjunction with an increase in micro-charcoal and <em>Pediastrum</em> values</td>
</tr>
<tr>
<td>6c</td>
<td>200 – 236</td>
<td>-1310 – -1070</td>
<td></td>
<td>Weak woodland regeneration (<em>Corylus, Alnus, Fraxinus</em> and <em>Salix</em>)</td>
</tr>
<tr>
<td>6b</td>
<td>244 – 300</td>
<td>-1070 – -530</td>
<td></td>
<td>High values of Cyperaceae, Poaceae, <em>Pteridium</em> and <em>Pediastrum</em></td>
</tr>
<tr>
<td>6a</td>
<td>304 – 312</td>
<td>-530 – -350</td>
<td></td>
<td>Increase in human activity. A substantial decrease in <em>Fraxinus</em> values and a second expansion in Cyperaceae values are recorded</td>
</tr>
<tr>
<td><strong>Zone 5</strong></td>
<td>316 – 380</td>
<td>-350 – 550</td>
<td>Iron Age</td>
<td>AP initially decrease but subsequently increase their representation</td>
</tr>
<tr>
<td>5c</td>
<td>316 – 340</td>
<td>-350 – 80</td>
<td></td>
<td>Increase in AP pollen suggest woodland regeneration. High values of cereal-type are still recorded. This period is referred to as the Late Iron Age Lull (LIAL)</td>
</tr>
<tr>
<td>5b</td>
<td>344 – 364</td>
<td>80 – 380</td>
<td></td>
<td>Increase in NAP. High values of Poaceae and cereal-type are recorded</td>
</tr>
<tr>
<td>5a</td>
<td>368 – 380</td>
<td>380 – 550</td>
<td></td>
<td>Intense increase in human activity, in particular pastoral indicators. Strong increase in Cyperaceae and also in micro-charcoal and <em>Pediastrum</em> values</td>
</tr>
<tr>
<td><strong>Zone 4</strong></td>
<td>384 – 508</td>
<td>550 – 2120</td>
<td>Bronze Age</td>
<td>Three phases with substantial activity farming are recorded</td>
</tr>
<tr>
<td>4f</td>
<td>384 – 422</td>
<td>550 – 970</td>
<td></td>
<td>Reduced farming activity and woodland regeneration phase.</td>
</tr>
<tr>
<td>4e</td>
<td>424 – 434</td>
<td>970 – 1100</td>
<td></td>
<td>High impact on woodland with an substantial increase in Poaceae and <em>P. lanceolata</em>. High values of micro-charcoal are recorded</td>
</tr>
<tr>
<td>4d</td>
<td>436 – 464</td>
<td>1100 – 1450</td>
<td></td>
<td>Woodland regeneration phase</td>
</tr>
<tr>
<td>4c</td>
<td>466 – 480</td>
<td>1450 – 1670</td>
<td></td>
<td>Increase in farming activity, mainly pastoral. High values of micro-charcoal are recorded</td>
</tr>
<tr>
<td>4b</td>
<td>482 – 486</td>
<td>1670 – 1760</td>
<td></td>
<td>Woodland regeneration phase</td>
</tr>
<tr>
<td>4a</td>
<td>488 – 508</td>
<td>1760 – 2120</td>
<td></td>
<td>Increase in farming activity with a strong arable component (cereal-type max value 4.2%). High values of micro-charcoal are recorded. AP concentration values drop substantially</td>
</tr>
<tr>
<td>Zone 3</td>
<td>510 – 574</td>
<td>2120 – 3760</td>
<td>Neolithic</td>
<td>First farming activity (pastoral and arable) recorded at L. Dargan</td>
</tr>
<tr>
<td>--------</td>
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<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>3eβ</td>
<td>510 – 520</td>
<td>2120 – 2360</td>
<td></td>
<td>Cereal-type curves resume</td>
</tr>
<tr>
<td>3ca</td>
<td>522 – 536</td>
<td>2360 – 2710</td>
<td></td>
<td>Renewal of the farming activity. Pastoral indicators are recorded</td>
</tr>
<tr>
<td>3b</td>
<td>538 – 548</td>
<td>2710 – 3000</td>
<td></td>
<td>Woodland regeneration phase. Peak in ash content and magnetic susceptibility</td>
</tr>
<tr>
<td>3aβ</td>
<td>550 – 562</td>
<td>3000 – 3390</td>
<td></td>
<td>Decline in the farming activity</td>
</tr>
<tr>
<td>3aα</td>
<td>564 – 574</td>
<td>3390 – 3760</td>
<td></td>
<td>Elm Decline is recorded. Evidence of farming activity is recorded (P. lanceolata and cereal-type)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Zone 2</th>
<th>576 – 588</th>
<th>3760 – 4600</th>
<th>Mesolithic</th>
<th>Atlantic woodland. Pinus values drops substantially. A relevant presence of Alnus (max value 12.4%) is recorded. Peak in ash content at the end of the zone, with a strong increase in AP concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>590 – 636</td>
<td>4600 – 7800</td>
<td>Mesolithic</td>
<td>Boreal woodland composed mainly by oak, hazel, elm and pine</td>
</tr>
</tbody>
</table>

| 1e | 590 – 592 | 4600 – 4940 |           | Pinus values record the highest peak. Increase in magnetic susceptibility and ash content are recorded |
| 1d | 596 – 604 | 4940 – 5760 |           | Gradual increase in Pinus and decrease in Corylus. Alnus curve appears forming a slender curve |
| 1c | 608 – 610 | 5760 – 6100 |           | Re-establishment of AP values pre-perturbation |
| 1b | 612 – 614 | 6100 – 6370 |           | Increase in Pinus and Betula values and decrease in Quercus and Corylus. Decline in AP concentration values. Climate anomaly interpreted as the 8.2 ka event |
| 1a | 616 – 636 | 6370 – 7800 |           | High Corylus and Ulmus values with high representation in Pinus and Betula are recorded. At the same time Quercus values increase |

* Ages in AD/BC (calibrated); negative indicates AD.
2.5 Interpretation

2.5.1 General considerations

Lake sediment provides an excellent environment for pollen preservation. This quality makes it possible for pollen grains deposited through time to be analysed for the purpose of recording past vegetation change. Therefore lakes are considered to be a good source of material for palaeoenvironmental reconstruction. However, the interpretation of a pollen profile is very complex and several factors have to be borne in mind, such as the lake size, landscape topography, the size and shape of the pollen grains, dispersal capacity, etc., in order to establish the pollen source area.

L. Dargan is a medium-sized lake (ca. 10 ha) which reflects a source area of about 1–2 km. However, the source area is also influenced by atmospheric conditions, topography, dispersal capacity of particular pollen types and variable pollen production. The main factor that plays an important role for the atmospheric condition is the wind. In Sligo it comes from west south-west, hence in L. Dargan is expected to receive pollen coming mainly from this direction. The landscape topography is another important element to be considered. The Ox Mountains located to the north of the lake are an important input of pollen coming from the air and from inflowing streams. This further complicates the interpretation of the pollen source area because allochthonous pollen from these uplands may be brought into the lake by inflowing streams. The size and shape of the pollen grains play another important role. Indeed large and heavy pollen, like cereal-type, have a poor dispersal capacity compared with hazel and birch, which are smaller and lighter, or pollen like pine, which has two air-sacks. Moreover, anemophilous plants with an high pollen production, such as hazel, will be over represented in the pollen profile whereas entomophilous species, such as Liguliflorae and Rosaceae, will be more silent or under- represented (Jacobson and Bradshaw 1981). Fægri and Iversen (1989) divided the pollen type into three groups (A, B and C). Group A is composed of high pollen producer plants e.g. (in northern Europe) Pinus, Betula, Corylus and Alnus, which will be over-represented in the pollen diagram. Group B includes moderate pollen producer plants, such as Quercus, Fraxinus, Fagus, Tilia and Hedera. In group C pollen types with a low pollen productivity are included, where many of them are either entomophilous or autogamous species. However, taxa belonging to this
group may represent important indicators, such as the pollen of cereals. For this reason it is
important to reach a high pollen sum (PS) in order to detect them. Furthermore, herbaceous
plants can have a high pollen productivity comparable to trees, but because of their
proximity to the ground they have a much lower dispersal capacity, e.g. Calluna (Fægri and
Iversen 1989).

Many scientists (Calcote 1995; Broström et al. 1998; Sugita et al. 1999; Sugita 2007a, b)
have tried to define the ‘relevant pollen source area’ (RSA) sensu Sugita (1994). This is the
area beyond which the correlation between the pollen loading and the distance weighted
plant abundance will not increase as the vegetation sampling area increases, but will
approach an asymptote. However, it has been seen that another important factor to bear in
mind, which influences the RSA, is the vegetation patch size and spatial distribution of the
patches (Bunting et al. 2004; Broström et al. 2005). Indeed an open landscape favours
higher dispersal capacity (Hellman et al. 2009). For this reason the estimation of local,
regional and extra-regional is difficult to assess and the relative proportions change over
time. Indeed, the long-distance-transported AP has been shown to increase in relative
importance as the input from local woodland diminishes or ceases (Feeser and O’Connell
2010). The long-distance component becomes more obvious towards the top of profiles,
assuming, of course, that the profile extends to the top.

All of these factors must be taken into account if an accurate interpretation of past
vegetation recorded in pollen diagrams is to be made.

Another important consideration to be borne in mind in the interpretation of L. Dargan
pollen profile is concerned with chronology. Some of the radiocarbon dates obtained for the
profile have large standard deviations due probably to the small amounts of dateable
material in the material submitted for dating (macrofossils were generally scarce in the
sediment). Furthermore, four of the samples returned an older age than expected (see
Results). In particular some of the dates that show an age reversal, i.e. suggest a date that
is older than a date from lower in the profile, hint at reworked organic material that has
washed in from the catchment. However, in the central part of the profile there is a good set
of radiocarbon dates, which make it possible to establish a reliable chronology for that
period of time. Indeed, a good number of radiocarbon dates relate to the Neolithic period.
These radiocarbon dates make it possible to reconstruct the chronology of early farming activity in considerable detail, which is the main focus of this research.

The terms Boreal and Atlantic are used *sensu* Mitchell (1956) as convenient labels to indicate post-glacial time periods. They are not intended to imply climate change nor are they used to convey a chronology.

**2.5.2 Palaeoenvironmental reconstructions**

*Pre-Elm Decline environment: (PAZ DRG1-1; 636–590 cm; ca. 7800–4600 BC and PAZ DRG1-2; 588–576 cm; ca. 4600–3760 BC)*

The profile opens during the Boreal period, at ca. 7800 BC (9750 cal. BP), where the main elements of the vegetation in order of importance were hazel, pine, elm, oak and birch. Hazel shows a substantial presence at the beginning of the profile. It reaches its maximum value at 7250 BC (9200 cal. BP), although it gradually decreases in importance. Nowadays, shrublands with hazel dominated communities are common in the Burren, north Clare (Kelly and Kirby 1982). Hazel may have formed similar shrubland communities in Co. Sligo in the early Boreal. The subsequent expansion of oak could have caused a reduction of space and light inside the woodland thereby reducing the pollen production capacity of hazel. In subzone 1a *Neckera complanata* is recorded. This moss is common in calcareous woodlands in Britain and Ireland. It grows on the tree trunks and also walls and rocks (Watson 1981; Porley and Hodgetts 2005). In the Burren it is particularly common on hazel (Ivimey-Cook and Proctor 1966). The low presence of NAP suggests that the woodland had a closed canopy structure. The high representation of *Polypodium* and *Hedera* may be explained by their ecology, being epiphytes of trees. In particular *Polypodium* is a fern which grows on the branches of oak trees.

The detection of a cereal-type grain identified as *Triticum-type* at the end of subzone 1a, at 616 cm (ca. 6440 BC), presents a difficulty because the beginning of arable farming in Ireland did not start until the Neolithic period (ca. 3800 BC). Whether this pollen is the result of contamination has to be considered. Sampling in the field (July 2008) and sample preparation in the laboratory (from October 2008) were carried out carefully in order to
avoid any contamination. During the extruding phase in the field the core segment was split from the bottom towards the top and immediately wrapped in strong plastic sleeves. Also during laboratory preparation the samples were taken from the bottom of the core upwards. This eliminates the possibility of transferring younger pollen towards the lower and older part of the core. Also, there is little or no cereal cultivation in the vicinity of Galway city and also in western Ireland generally in present times so there is not a possibility of contamination by contemporaneous pollen. Furthermore, the sample in question was prepared with another eight samples from the bottom part of the core. During counting no other cereal-type pollen was detected. The most likely explanation is that this large pollen is a large non-cultivated grass like Glyceria. However, this pollen does not reach 50 µm and it is characterized by a narrow annulus in relation to a large pore size (Beug 1961, 2004).

In addition Glyceria is belongs to Hordeum-type, which has a different surface structure. Hordeum-type displays a punctae patterned structure on the exine, uniformly distributed and rarely in groups of 2–3. The probability that the pollen grain was transported from the continent is also low. The Neolithic, at that time, was still developing in the eastern part of the Mediterranean basin (Berger and Guilaine 2009). That this is the source is highly unlikely given the distances involved and the poor dispersal capacity of large pollen grains. Many palynologists have found and discussed the origin of cereal-type grains in pre-Elm Decline contexts in Ireland and Great Britain (Edwards and Hirons 1984; O’Connell 1987; Hall et al. 1993; Molloy and O’Connell 2002). However, most of the grains are dismissed as large Poaceae pollen produced by non-cultivated grasses (O’Connell and Molloy 2001).

At the beginning of the zone pollen concentration and PAR show high values, probably reflecting the increase in pollen productivity as the temperature increased. High ash content suggests a considerable amount of soil erosion, which can also be supported by the magnetic susceptibility curve. However, both curves decline significantly towards the middle and upper part of the zone suggesting soil stabilisation. This situation may be due to either a reduction in precipitation or a change in vegetation cover which would have decreased the run-off.

The peaks in Pinus, Betula and Ulmus in subzone 1b, which correspond with the decline in Corylus and Quercus and reduction in AP concentration values, may suggest a climatic perturbation. Pine and birch are more cold tolerant trees than oak and hazel, which are
thermophilous (Paus 2010; Tallantire 2002). The decline in *Polypodium* spores is probably due to the decrease in the oak population. According to the chronology (6370–6100 BC; 8320–8050 cal. BP) this period coincides with the so-called 8.2 ka event, which involved a sharp climatic deterioration (Alley *et al.* 1997; Alley and Ágústsdóttir 2005; Hede *et al.* 2010; Ghilardi and O’Connell 2012a). The magnetic susceptibility shows a weak increase at the end of this subzone but ash content remains steady. There seems to be little or no soil instability.

In subzone 1c the pollen representation reverts to values similar to those prior to the perturbation. AP concentration curves, in particular *Corylus* and *Quercus*, show high peaks. It is likely that the return to warmer temperatures stimulated pollen production. The low values in ash content and magnetic susceptibility may suggest a stabilization of the soil in the catchment.

During subzone 1d (5760–4940 BC; 7710–7030 cal. BP) the *Pinus* curve increases substantially, reaching the highest peak in subzone 1e (it reaches 26%) (4600–4940 BC; 6550–6890 cal. BP). This coincides with another pronounced decline in AP, where *Corylus* (both percentage and concentration values) seems most affected. The presence of pine in the area surrounding the lake is proved by the peak recorded in *Pinus* stomata and the bud scales identified during the macrofossil analysis. Indeed leaves (needles) of pine are quite large and heavy (poor dispersal capacity) and after decay the stomata are left in place. Their presence shows that pine was present close to the lake margin. The increase of pine in conjunction with the decrease of *Corylus* and the low level of ash content and magnetic susceptibility may be an indication of a climatic shift towards cooler conditions.

At the onset of subzone 1e *Pediastrum* increases somewhat suggesting in-washed material from the catchment. This idea is reinforced by the peak in magnetic susceptibility in the middle of the zone. A substantial increase in *Pinus*, which reaches 26%, is also recorded in this subzone. AP concentration drops dramatically and among the trees *Corylus* seems the most affected. In this period a major shift in woodland composition took place mainly in favour of pine.

Zone 2 is characterised by high values in AP (it reaches 97.3%), which suggests a closed canopy, and a substantial change in woodland composition. Pine declines significantly becoming a relatively minor component of the woodlands. This decline is not only at
regional level as the decrease in pollen suggests, but also in the immediate vicinity of the lake. The decrease at local level is suggested by the decline in frequency of pine stomata. The *Alnus* curve starts at the onset of subzone 1d (5760 BC; 7710 cal. BP) and increases its representation in subzone 1e (2.5%). However, it is only in zone 2 that alder (*Alnus glutinosa*) expands rapidly probably occupying the wet habitat around the lake. Alder physiology allows the plant to grow in wet, or very damp areas and it is recognised as one of the trees of Britain and Ireland most tolerant to water logging (cf. Bennett and Birks, 1990). Pine, on the other hand, is more competitive, forming stable communities, on nutrient-deficient soils (Carlisle and Brown 1968; Roche *et al*. 2009). This shift in woodland composition can be interpreted as a climatic shift towards wetter conditions. The possibility that the shift in vegetation could be caused by human interference is unlikely as there is no firm evidence for a Mesolithic presence during this period (Waddell 2000; Berg 1995). The peak in pine followed by a substantial decline in conjunction with the expansion of alder is recorded in many pollen diagrams from north-west Ireland: L. Doo (Co. Mayo; O'Connell *et al*. 1987); L. Sheeauns (Co. Galway; Molloy and O'Connell 1991); L. Corrib (Co. Galway; Bingham 2011). In these profiles the expansion of pine was interpreted as due to a probable decrease in water table level, which allowed the conifer to expand at the margin of the lake. The subsequent fall of pine can be due to the rise of the lake surface, which increased the availability of wet areas that was to the advantage of alder. Alder lives in a symbiotic relationship with nitrogen-fixing actinomycete (*Frankia*), which is a factor that enables alder to exploit wet habitats (Hall 2011).

In L. Dargan a shift in limnic conditions is suggested by the low values of *Botryococcus* algae and also by the peak in ash content. These factors hint at an increase in soil erosion which may be due to an increase in precipitation.

In Ireland, generally this shift in pollen representation, in particular between pine and alder, marks the Boreal/Atlantic transition. It is not possible, however, to define a precise date for this event. The Boreal/Atlantic transition is placed at the base of zone 2, where *Alnus* expands to substantially more than 1% for the first time. Alder was almost certainly growing in the vicinity of L. Dargan at this time.

The decrease in *Polypodium* representation may be due to the closed nature of the canopy, which reduced its dispersal capacity. During this period a further expansion of *Ulmus* is
recorded, which suggests that elm played an increasingly important role in the woodland composition, becoming more dominant than oak. It must be borne in mind that the pollen productivity of elm is lower than oak (Andersen 1973; Broström et al. 2008), hence pollen diagrams underestimate elm relative to oak. It is notable, however, that Quercus representation also increases gradually throughout the zone.

Another important feature of this zone is the presence of Ilex (holly). Holly is an insect-pollinated plant, hence its representation in pollen diagrams is underestimated. Due to its expansion during the Atlantic period it has been recognised as a climatic indicator (Iversen 1944). Molloy and O’Connell (1991) suggested that the spread of holly was facilitated by the presence of perturbations, although the causes that generated the perturbations are still to be understood. In the L. Dargan profile the expansion of Ilex corresponds with the expansion of Sorbus. However, an opening up of the woodland has not been recorded. Among the pastoral taxa only Filipendula increases in representation. Perturbations are definitely taking place but it is difficult to pinpoint the factors involved.

*The Elm Decline and human impact during the Neolithic (PAZ 3; 574–510 cm; ca. 3760–2120 BC)*

The Neolithic period is represented in this zone (the upper part of the zone may include the beginning of the Bronze Age). At the beginning of subzone 3a (3760 BC; 5710 cal. BP) the classical Elm Decline is recorded (*Ulmus* drops from 21% to 11% across the boundary). Percentage, concentration and PAR values for *Ulmus* decline. In L. Dargan the expansion of *P. lanceolata*, which is regarded as an indicator of pastoral farming, although in particular circumstances it may also be indicative of arable/fallow (Behre 1981), occurs 2 cm after the Elm decline. This suggests, that at least initially, the decline of elm is not due to clearance. If the clearance was caused by human activity a rapid expansion of *P. lanceolata* into the opening would have been expected. However, in other detailed Irish pollen profiles *P. lanceolata* is recorded in pre-Elm Decline contexts, like at L. Sheeauns in Connemara (Molloy and O’Connell 1991) and especially An Loch Mór, Inis Oírr (Molloy and O’Connell 2004).

The Dutch Elm disease, that recently adversely affected the elm population, was probably the most likely primary cause of the initial decline in *Ulmus* (cf. Molloy and O’Connell
1987; Parker et al. 2002). The cause of this disease is due to *Ophiostoma (Ceratocystis) ulmi*. The vector that causes the infection and leads to a drastic decline in elm productivity is the beetle *Scolytus scolytus*.

The beetle remains (*Scolytus scolytus* and *Scolytus* sp. *elytron*) were recorded in two lowland raised mires in Scotland for the period between 8800 and 5660 cal. BP by Clark and Edwards (2004). The disappearance of the beetles after the Elm Decline was interpreted as a sign that the tree was under unbearable stress and after its death the insect could not find another suitable habitat to live in.

Because of the synchronicity of this north-west European event (Parker et al. 2002), the Elm Decline is used as a stratigraphical marker for the transition between the Atlantic and the Sub-Boreal periods. Further evidence which suggests that the primary decline of elm was not caused by anthropogenic clearance has been found in the pollen profiles from Co. Clare; Caheraphuca Lough (Molloy and O’Connell 2011, 2012) and Mooghaun Lough (Molloy 2005). In these two Irish sites the Elm Decline is well expressed, although there is no evidence for a Neolithic Landnam (farming phase). Parker et al. (2002), in their review of the Elm Decline, concluded that the spread of the elm bark beetle was probably facilitated by woodland clearance in conjunction with a shift towards a more continental climate.

In L. Dargan, from the beginning of zone 3 cereal-type pollen grains were recorded suggesting the presence of Neolithic farming activity. The largest cereal-type grain was identified as *Triticum* type (see Results). The cereal-type pollen records strongly suggests that cereal growing was important but pastoral farming seems to have predominated. However, it must be borne in mind that cereal pollen has poor dispersal capacity and is under-represented in pollen diagrams. The subdivision in zone 3, namely 3aα and 3αβ, is made because of the difference in intensity of farming activity. The first, which spanned ca. 370 years, is characterized by a more intense human activity and by the decline in *Ulmus* values. The sub-subzone 3αβ, which spanned almost another four centuries, is characterized by the gradual decline of farming activity, which facilitated the regeneration of elm. The increase in NAP is due to the opening up of the woodland. Probably the farming activity of the first Neolithic peoples led to the development of grasslands though grazing for cattle. Use of wood for houses and fires undoubtedly contributed to woodland decline. Elm, which is usually present on fertile soils, seems to be more or less exclusively affected by the...
clearance. Oak (\textit{Quercus} curve decreases only slightly) may have formed separate stands, though this is rather unlikely particularly if \textit{Q. robur}, which has ecological preferences similar to elm, was the main oak tree and not \textit{Q. petraea}. This latter was probably present but most likely would have been largely confined to the Ox Mountains where soils would have been acidic. Oak was probably purposely spared because it was a valuable source of mast for pigs, the bones of which have been recorded from Neolithic contexts at both Carrowmore and Rathdooney Beg (Persson and Persson 1984; P. Lynch in Mount 1999).

The interruption of the \textit{P. lanceolata} curve and the substantial decrease of Poaceae during subzone 3b (3000–2710 BC) suggest that farming activity ceased. Woodland cover reverted to the pre-Elm decline state but ash started to make a greater contribution (4.5%). In this period magnetic susceptibility values increase notably, whereas ash content, after an initial decline, rises and peaks in the central part of the subzone. These changes may indicate soil erosion (but \textit{Pediastrum} does not increase as might be expected) or within-lake changes such as an increase in the diatom population but this would not be reflected in the magnetic susceptibility values. Soil erosion appears to be the most likely cause and this raises the possibility that increased runoff as a result of increased rainfall was responsible (cf. Stolze \textit{et al}. 2012).

A renewal of farming activity is recorded in subzone 3c (2710–2120 BC), however it does not show the same intensity as in sub-subzone 3aa. The small decline in AP, where in particular \textit{Ulmus} is most affected, and the small increase in Poaceae and \textit{P. lanceolata} shows that the impact on woodland cover was quite modest. This subzone is distinguished by two sub-subzones, 3ca and 3cb, in order to emphasize the shift in farming practise. The latter sub-subzone records cereal-type pollen after a long interruption, although the curve does not show a substantial expansion. The increase in micro and macro-charcoal, ash content and magnetic susceptibility also hint at a more intensive farming that included an arable component. The farming activity affected in particular \textit{Quercus} and \textit{Corylus}. At the end of this sub-subzone a decrease in human activity is suggested by the increase of \textit{Ulmus} and \textit{Fraxinus}, although \textit{Quercus} decreases. This situation is probably due to a shift in woodland composition rather than a change in the extent of woodland cover. At the end of this zone the sedimentation rate is increased to ca. 0.55 mm yr$^{-1}$ (ca. 18 yr cm$^{-1}$). The
increase might be due to the re-establishment of the farming activity which caused the woodland clearance.

In the pollen profile from Céide Fields, Co Mayo, during the late Neolithic and the beginning of the Bronze Age an expansion of *Pinus* values was recorded. In recent years peat cutting in the area has exposed several pine stumps. Pollen from these pines are undoubtedly reflected in the increase in *Pinus* (GLU IV-6b; Molloy and O’Connell 1995). Molloy and O’Connell (1995) suggest that dry conditions at the end of the Neolithic facilitated the colonization of the bog by pine. However, in L. Dargan, a similar expansion of pine was not recorded (note: a *Pinus* stoma was recorded at 522 cm; this suggests a pine presence in the vicinity of the lake). But in-wash, that included reworked material, cannot be excluded. The small increase of *Calluna* and the low values of ash content and magnetic susceptibility may also indicate a drier climate. In the Neolithic field system of Céide Fields the subsequent decline of pine was related to the expansion of blanket bog, which may be due to a wetter climate (Molloy and O’Connell 1995).

*Farming and woodland dynamics in the Bronze Age and early Iron Age (PAZ 4; 508–384 cm; ca. 2120–550 BC)*

This zone spans about 1570 years and describes the vegetation dynamics during the Bronze Age. This part of the pollen profile is distinctive in that NAP pastoral indicators (e.g. Poaceae and *P. lanceolata*) have distinctly increased representation, and there is a more or less continuous record of cereal-type pollen (several ≥45 µm). Arable farming activity probably became more important during the Bronze Age compared with the Neolithic. The elevated values of micro-charcoal associated with the classical anthropogenic indicators, such as *P. lanceolata*, indicate substantial human activity. The substantial decrease in pollen concentration, mainly AP, is probably due to the overall reduction in pollen production and also the increase in sedimentation rate (ca. 0.61 mm yr⁻¹; ca. 16.6 yr cm⁻¹; average subzone 4a). Magnetic susceptibility is particularly elevated between the end of subzone 4a and the beginning of subzone 4f. The ash content curve shows generally high levels, particularly at the top of the zone. Indeed, the decline in woodland cover (less evapotranspiration) could have increased the soil erosion from the catchment and hence the runoff. Alternatively
increased erosion may be caused by a shift towards a wetter climate (ca. 2400–2000 BC according to Barber 2006).

The pollen profile reflects three main farming phases (subzones a, c and e). The first subzone (4a) spans almost four centuries (2120–1760 BC) and is differentiated on the basis of rather high cereal-type pollen (maximum peak 4.2%, average 1.2%), suggesting a substantial arable activity close to the lake. Anthropogenic indicators and especially Poaceae, *P. lanceolata* and *Pteridium* expand suggesting woodland clearance. The opening of the woodland is also confirmed by the expansion of herbaceous taxa such as *Rumex*-type, *Ranunculus acris* type, *Cerastium*-type, and *Filipendula*. The more frequent record of *Viburnum opulus*, *Prunus*-type and *Crataegus*-type pollen (under-represented in the pollen records) suggest that shrubby vegetation also developed. The expansion of Cyperaceae and *Calluna* reinforce the idea of a rather open landscape. The main trees affected by the clearance are hazel, oak and elm. A stoma of *Pinus*, at 498 cm, may indicate either that pine was present, probably at the edge of the lake with a rather small population, or reworked sediment. Yew was probably present at regional level, but it did not expand in the source area. The increase of *Filinia*, *Tetraploa aristata*, *Keratella* and in particular *Peridinium* cysts in combination with the expansion of *Botryococcus* and a small increase in *Pediastrum* suggest an increase in trophic status of the lake. In addition the presence of *Glomus* spores indicates soil erosion (van Geel et al. 1989; van Geel et al. 2003).

A decline in farming activity is reflected in subzone 4b (1760–1670 BC), where the anthropogenic indicators decline and the AP, in particular *Corylus* expand. However, human activity is still present in the pollen source area although somewhat weaker.

Another increase of NAP and the anthropogenic indicators, especially *P. lanceolata*, in subzone 4c (1670–1450 BC), suggest the onset of another intense period of farming activity. Charred material found during the macrofossil analysis, at 479, 472 and 471 cm, suggests that fire was probably used close to the lake. The elevated values of ash and magnetic susceptibility may suggest a considerable increase in in-washed material into the lake catchment during this period. The presence of *Peridinium* cysts, a dinoflagellate, at An Loch Mór was regarded as indicative of a decline in lake level (Holmes et al. 2007). However, in the L. Dargan profile there is no evidence for lake-level change during this period. The expansion of *Peridinium* cysts occurred at the beginning of the Bronze Age, when a strong
and consistent farming activity took place. This might indicate an algal bloom in connection with eutrophication of the lake. However, in the upper part of the profile the curve decreases notably.

After this period (subzone 4d, 1450–1100 BC) farming activity (both pastoral and arable) is much lower, facilitating woodland regeneration especially of hazel and ash. The high percentage of *Peridinium* cysts may suggest a continued high level of eutrophication of the lake probably due to an increase of soil erosion caused by precipitation. Indeed high levels of magnetic susceptibility and ash content suggest an increase of in-washed material into the lake. A *Pinus* bud scale at 441 cm may either suggest the presence of pine trees in the vicinity of the lake, although the discontinuous and low values indicate that pine was rare, or perhaps the reworking of the sediment.

The most intensive farming phase is reflected in subzone 4e (1100–970 BC), in particular by the high levels of Poaceae and *P. lanceolata*. The lower percentage of cereal-type pollen compared with subzone 4a, suggests that the farming activity during the late Bronze Age was mainly pastoral, but cereal growing was also important. During this period the woodland was subjected to substantial clearance, where AP fall to 55.5%. The disturbance is also reflected by the increase in *Pteridium*. The high level of micro-charcoal particles points again to a substantial human activity in the region (micro-charcoal tends to be well dispersed; cf. Patterson *et al.* 1987) and the presence of *Glomus* spores suggests an increase of soil erosion. Macrofossils of *Juncus effusus/conglomeratus* are consistently recorded from this period onwards to the top of the profile. This suggests the onset of a substantial presence of rushes in the area surrounding the lake and hence increased openness.

The increase of AP mainly *Corylus*, *Fraxinus* and *Quercus* in subzone 4f suggests that a decrease in farming activity and hence a phase of woodland regeneration took place (970–550 BC). At the end of this zone the rise in ash content values indicates soil destabilisation. A weak increase in *Pediastrum* may suggest an increase of mineral input into the lake, confirmed by the rise in ash content. The increase in soil destabilisation may be due to an increase in precipitation. Indeed, during this period in Europe a shift towards wetter/colder conditions sometimes referred to as the 2.8 event (850 BC) is recorded (Barber 2006). However, in Ireland the abrupt shift to wetter conditions, which is preceded by a dry
climate, may have been somewhat later at ca. 2700 cal. BP (750 BC) (Plunkett and Swindles 2008; Swindles et al. 2007; Plunkett 2006).

The expansion of the *Peridinium* cyst curve suggests a second, although more modest, algal bloom. Sedimentation rates at the end of zone 4 have doubled compared to the beginning (1 mm yr⁻¹; 9 yr cm⁻¹). An almost continuous record of macro-charcoal from 441 to 401 cm (subzones 4e and f) suggests a more intense and prolonged use of fire close to the lake and also at regional level during the late Bronze Age. Micro-charcoal shows a high positive correlation with the anthropogenic indicators such as *P. lanceolata* which points to human activity. It is noteworthy that a substantial number of *fulachta fiadh* (burnt mounds) associated with this period are listed in “The Archaeological Inventory of County Sligo”. During the N4 archaeological investigation, south of Sligo town at Caltragh and Magheraboy, several *fulachta fiadh* and burnt mounds were discovered (cf. Danaher 2007).

**Mid/late Iron Age (PAZ DRG1-5; 380–316 cm; 550 BC–AD 350)**

This zone spans about nine centuries and is characterised by a pronounced period of woodland clearance followed by a regeneration phase known as the Late Iron Age Lull (LIAL). At the beginning of the Iron Age the farming activity seems to be more pastoral based. However, during subzone 5b and 5c there is a shift towards more arable activity (respectively 380–83 BC and 83 BC–350 AD; mid and late Iron Age).

Subzone 5a is marked by a strong increase in human activity, which is reflected by an expansion in NAP. The substantial expansion of Cyperaceae, Poaceae and *P. lanceolata* suggest a wide woodland clearance which affected ash, hazel and oak more intensively. The high level of *Pteridium* also hints at a woodland perturbation and the high percentage of micro-charcoal suggests the substantial use of fire at a regional level. The rise in *Pediastrum* suggests an increase of in-washed material into the lake, which is confirmed by the high level of ash content and magnetic susceptibility. The high level of *Pediastrum* and micro-charcoal particles continue until the end of subzone 5b, at which point the two erosion indicator curves decrease (magnetic susceptibility and ash content). The decline in *P. lanceolata* and an increase in cereal-type pollen may suggest a change in the level of farming activity during the Iron Age. The increase in *Nymphea*, *Myriophyllum* and *Equisetum* may suggest a decrease in water table level.
A steady rise of *Fraxinus* is recorded throughout the subzone with its major expansion occurring in subzone 5c. During this period the increase in AP hints at a woodland regeneration phase. The *Taxus* curve increases slightly. In many Irish pollen profiles such developments are regarded as corresponding to the Late Iron Age Lull, i.e. a lull in farming activity in the early centuries of the first millennium AD, leading to a recovery of the woodland (Molloy 2005; Overland and O’Connell 2010). However, in the L. Dargan area human activity does not cease completely as cereal-type and Poaceae continue to be well represented. The low values for micro-charcoal suggest that the regional impact on the vegetation decreases. Also the decrease in *Pediastrum* hints at a reduction of nutrient input into the lake.

**Historical period (PAZs DRG1-6 and 7; 312–116 cm; AD 350–1680?)**

From the basal part of zone 6 a strengthening of human activity, with regard to both arable and pastoral farming, is recorded. This period of intense clearance adversely affected ash in particular. The substantial representation of *Pediastrum* coupled with the increase in magnetic susceptibility and ash content suggest an increase of in-washed material into the lake. This period of erosion is also supported by a continuous record of *Glomus* spores. The level of erosion seems to be directly connected with the increase in farming activity. At 276 cm and also at 148 cm two *Secale* pollen grains are recorded. Rye produces a substantial quantity of pollen and has a good dispersal capacity. However, the detection of only two pollen grains suggests that rye was not so important in the area close to L. Dargan. Probably it was present as a weed amongst other cereals (Overland and O’Connell 2011).

A further and more intensive phase of farming activity took place during zone 7, which involved a reduction of the woodland. During this period the increase in indicators of soil erosion is noteworthy.

This part of the profile does not have independent chronological controls. The results from two radiocarbon dates obtained at 250 and 190 cm are reversals. This may have resulted from in-washing of reworked material from the catchment. However, it is possible to assign this part of the profile to the medieval period. This period is characterized by substantial woodland clearance in the context of significant levels of farming with an increasingly arable component. The profile does not include the so-called secondary rise of *Pinus* (the
re-introduction of pine on a wide scale is datable to ca. AD 1750 in Ireland) and pollen of other exotics such as beech (only occasional records of *Fagus*). The *Pinus* curve is slender (average value: 1.1%). In an open landscape situation pollen such as *Pinus*, which has high dispersal capacity, would have been strongly represented in pollen profiles. However, during this period pine was extremely scarce and largely extinct in Ireland, hence long distance dispersal alone does not adequately account for the presence of *Pinus*. The presence of *Pinus* stomata suggest that reworked organic material (e.g. from the nearby uplands) that contained *Pinus* pollen and stomata from an earlier period, is the most likely source. The age reversals obtained from AMS dating for this part of the diagram supports this hypothesis.

It is reasonable to assume that the top of the profile (116 cm) extends beyond the medieval period, i.e. into the seventeenth century.

### 2.6 Discussion

#### 2.6.1 Pre-elm decline environment

The pollen record from L. Dargan spans most of the post-glacial. The basal part of the profile (zone 1 and 2), which begins at ca. 7800 BC, shows the vegetation dynamic during the period that precedes the first substantial human impact prior to the commencement of Neolithic farming.

Evidence for Mesolithic activity in Ireland is scanty. The Mesolithic people had a hunter-gathering economy; hence they had only a minor impact on their environment including the natural vegetation. For this reason to prove the presence of early human occupation through a palaeoecological investigation, such as pollen analysis, is difficult. In addition, in Ireland the rising of sea level could have hidden several coastal Mesolithic sites. The first site to produce evidence of early Mesolithic settlement in Ireland was Mount Sandel, near Coleraine, Co. Derry; and was dated to between 7750–7670 cal. BC (Woodman 1985; Waddell 2010). One of the most convincing pieces of evidence that domesticates were present in a late Mesolithic context comes from Ferriter’s Cove, Co. Kerry. From this site cattle bones have yielded the following dates: 5510±70 BP (OxA-3839) and 5825±50 BP (OxA-8775) (Woodman *et al.* 1999). In southern Co. Sligo, near the Roscommon border, evidence of Mesolithic activity was found along the shore of Lough Gara. Important
evidence for hunter-gatherer communities related to the latest phase of the Mesolithic was discovered in this area (Fredengren 2002; Woodman 1978).

Hence, according to the archaeological record, there is some evidence for a Mesolithic economy in Co. Sligo, relating mainly to the later Mesolithic period. It is unlikely, however, that Mesolithic peoples interfered to any great extent with the vegetation. Vegetational changes are thus more than likely due to natural causes, i.e. climate change, competition, edaphic changes and other factors.

The Lough Dargan profile, from a palaeoenvironmental point of view, provides an important record which reflects in detail the changes in the vegetation that occurred in the pollen source area, i.e. within an estimated 1–2 km radius of the lake. In this area, during the Boreal, woodland was mainly dominated by pine, oak, hazel and elm. Pine played an important role, in particular during the early Holocene (up to ca. 4600 BC) (average 14% in zone 1). A similar woodland composition is reflected by other pollen profiles, such as L. Arquilla (Union Wood) (Dodson and Bradshaw 1987) and Ballygawley L. (Göransson 1984). However, at L. Anelteen, pine does not seem to play a part in the main woodland composition (Turbayne 1985). This difference is probably due to local factors.

The high representation of fern spores, in particular of Polypodium and Pteridium (also fern annuli are common) and Hedera suggest that the woodland structure around L. Dargan was quite open. In zone 2 four pollen grains of Ilex are recorded. The dispersal and productivity of this plant are favoured by open conditions. Holly was probably quite rare as in Union Wood (Dodson and Bradshaw 1987). Viburnum opulus was at least locally important, especially where calcareous soils prevailed (cf. Watts 1984; O’Connell and Molloy 2005; Stolze et al. 2012). V. opulus pollen seems not to have been widely recognised and therefore probably largely unrecorded in Irish pollen diagrams.

During the early Holocene the main climate anomaly is the “8.2 ka event”. This event is characterized by a sharp climatic deterioration which is recorded in many proxies and especially in the Greenland ice-core δ¹⁸O (GRIP and NGRIP cores). This event was probably caused by a very large outburst flood from Lake Agassiz and Lake Ojibway, North America, after the decay of the Laurentide Ice Sheet into the North Atlantic Ocean (Barber et al. 1999). This event changed the strength of the Atlantic meridional overturning circulation (AMOC) which is a major regulator of the heat at high latitudes in the North Atlantic (Alley
et al. 1997; Alley and Ágústsdóttir 2005; Ellison et al. 2006; Hede et al. 2010). In the L. Dargan profile the 8.2 ka may be reflected in subzone 1b (6370–6100 BC; 8320–8050 cal. BP). This event mainly adversely affected oak and hazel in favour of pine and birch. *Ulmus* also increased during this period. From the present-day distribution of *Ulmus glabra* (the only native species of *Ulmus* in Ireland) in Fennoscandia, *Ulmus* is more continental in character than *Corylus*. Indeed, elm is present in parts of the interior of Fennoscandia whereas hazel hugs the Atlantic coast at its northernmost limits in western Norway (cf. Giesecke et al. 2008). It is possible that during cold conditions such during the 8.2 ka event, elm, being more cold-resistant than hazel, may have had a competitive advantage.

Another and stronger vegetational change is recorded at the transition to zone 2 (ca. 4600 BC; 6650 cal. BP). *Pinus* after a major expansion (subzone 1e) declines in favour of *Alnus* and *Ulmus*. AP concentration drops substantially in subzone 1e, even compared to the 8.2 ka event. In zone 2 a decrease in *Pteridium* and NAP suggest a closed woodland structure, now mainly composed of deciduous trees. High magnetic susceptibility values at the end of zone 1 and high ash content in zone 2 suggest soil instability. Studies of lake-level change suggest an increase in lake levels at ca. 4500 BC in continental Europe and especially in the Alpine region (Magny 2004; Magny et al. 2006). The data from Ireland are more limited. Holmes et al. (2007) suggest that for An Loch Mór, Inis Oírr, the lake level began to rise at about that time. The rise of the lake levels may be due to an increase in precipitation which involves runoff and therefore soil erosion. Elevated temperatures and especially winter temperatures (Holocene Climatic Optimum) may have been reached at about this time (Huntley et al. 2002). The decline of *Pinus* and the increase of *Alnus* at the transition between zone 1 and 2 may be the result of a loss of competitiveness of pine caused by climate change that occurred during this period (continentality declining).

The shift between alder and pine is usually used to mark the Boreal/Atlantic transition. The key feature for this transition is the rise of alder (O’Connell and Molloy 2005). However, it is difficult to establish where it occurs in L. Dargan profile. Indeed *Alnus* pollen starts to be continuously recorded from 604 cm and the values increase in subzone 1e but rise substantially in zone 2, when the drop in *Pinus* values occurs. The lack of $^{14}$C dates for the lower part of the diagram makes the interpretation more difficult. It was decided that the best
solution was to place the Boreal/Atlantic transition at the base of zone 2 (4600 BC; 6550 cal. BP).

In zone 2 there is no evidence to support the presence of Mesolithic or pre-Elm Decline Neolithic activity in the area surrounding L. Dargan.

2.6.2 Early farming impact during the Neolithic

To visualize the temporal variation in vegetation at L. Dargan during the mid and the late Holocene pie charts have been prepared (Fig. 2.12A). These charts are related to zones 2–7 and show the average values of the various pollen components included in the PS. To better highlight the vegetational changes and land-use during the Neolithic, the relevant palynological data are summarized in the histograms in Fig. 2.12B. Comparison with other Neolithic pollen diagrams from western Ireland are presented in Fig. 2.13. The level of pastoral-based farming (mainly Poaceae and *P. lanceolata*) and cereal cultivation, based on the data from L. Dargan, Loughmeenaghan, in Co. Sligo, (Stolze et al. 2012), Céide Fields (Molloy and O’Connell 1995) and Garrynagran (O’Connell and Molloy 2001) in north Mayo, and L. Sheeauns (Molloy and O’Connell 1991) and Connemara National Park (O’Connell et al. 1988) in Co. Galway, are presented in this figure. On the left side of the figure are plotted: (a) the chronology associated with early Neolithic rectangular houses in Ireland, (b) Round Mound (Rathdowney Beg, Co. Sligo; Mount 1999), (c) the start and end of the activity at Magheraboy enclosure, (d) two models (model 2 and 3) for the start of the Irish Neolithic and the Magheraboy activity (details of the chronology are given in Cooney et al. 2011). In addition (e) the model for the initial use of Irish court tombs (Schulting et al. 2012) and (f) the charred cereals chronology for Ireland and Britain (Brown 2007) are reported. Zone 2, which precedes the Elm Decline (3760 BC) is characterized by a closed woodland structure.
Fig. 2.12. Pie charts for PAZs 2-7 and histograms for PAZ 3 (Neolithic), profile DRG1.
Fig. 2.13.

A. The chronology of early Neolithic in Ireland based on: rectangular houses of Ireland (a), round mound (Rathdowney Beg) (b), the start and the end of the activity at Magheraboy enclosure (c), two models (model 2 and 3) for the start of the Irish Neolithic and the Magheraboy activity (d) (for details of the chronology see Cooney et al. 2011), initial use of Irish court tombs (e) (Schulting et al. 2012) and the charred cereals chronology for Ireland and Britain (f) (Brown 2007).


The duration of pine growing in a blanket bog context is based mainly on pine pollen records and also pine stomata, and $^{14}$C-dated pine timbers from within peat and on mineral soils beneath peat. A question mark indicates uncertainty as to the duration of the earlier pine flush in the Glenulra basin, Céide Fields (GLU IV). The dry/wet curve for Céide Fields relates to the basin bog where core GLU IV was taken (after O’Connell and Molloy 2001).
Fig. 2.13. Summary of main data: pollen and archaeology.
The opening-up of the woodland cover started during the Neolithic. Although the Elm Decline is used as a marker in the pollen diagram for the lower boundary of the Neolithic, a delay between the Elm Decline and the beginning of the Neolithic Landnam may be present. Indeed, in many Irish pollen diagrams this interval can last from many decades to centuries as it is possible to observe in Fig. 2.13 (cf. O’Connell and Molloy 2001). The pollen profile from L. Dargan shows a delay of about 60 years. Elsewhere in Co. Sligo the duration of this interval is supported by the pollen data from Loughmeenaghan. This lasted for about 40 years (Stolze et al. 2012). As it has been largely argued the most satisfactory explanation for the Elm Decline, which is widespread in north-western Europe, remains the disease hypothesis (see Interpretation). Human activity inevitably played a role in the spread of the disease and the clearance of woodland during the Neolithic. However, in two Irish sites, Caheraphuca Lough (Molloy and O’Connell 2011, 2012) and Mooghaun Lough (Molloy 2005) in Co. Clare, the Elm Decline is well marked, although there is no evidence for Neolithic farming. These diagrams show that woodland clearance through human activity was not directly related to the Elm Decline. This supports the view that disease was the most likely cause of the Elm Decline phenomenon.

The L. Dargan profile shows an important cereal-type pollen record. In particular at the base of zone 3, before the P. lanceolata expansion, a large pollen grain identifiable as Triticum-type is recorded (Fig. 9; see Results). Large pollen grains have been frequently recorded in pre-Elm Decline contexts in both Ireland and Britain (O’Connell 1987; Edwards and Hirons 1984). In Co. Sligo, for instance, Göransson (1984, 2002) in his investigations at Cúil Irra peninsula found charcoal, P. lanceolata and cereal pollen grains in a pre-Elm Decline context at Ballygawley Lough. For this reason Göransson concluded that Neolithic people were in Sligo before the Elm Decline and they transformed the forest into coppice woodlands probably using fire for clearance. This phase was called by the author “the early Neolithic Fire-Grazing Phase” (Göransson 1984, p. 174).
These early records cannot prove the presence of crop cultivation. An absolute distinction from the pollen of wild grasses and cereals is not possible, hence independent collaborative evidence, such as well-dated cereal macrofossils or appropriate archaeological evidence, are needed (Behre 2007). Brown (2007), in a study of charred cereal remains from 63 sites between Britain and Ireland, suggests that the onset of the crop cultivation occurred no earlier than 3950 BC. A small number of dates fall between 4000/3950 and 3800 BC, whereas the majority of dates lie between 3800–3000 BC. Brown (2007) considers it more probable that the cereal pollen grains found earlier than 4000 BC derive from wild grasses rather than cultigens.

Archaeological evidence, including $^{14}$C dates, from Co. Sligo confirms an early Neolithic presence. In particular the recent excavation carried out by Danaher (2007) at Magheraboy brought to light some of the earliest dates for causewayed enclosures in Britain and Ireland. According to Cooney et al. (2011) the preferred model for Magheraboy shows that the enclosure was built between 4115–3850 BC (95% probability; start of Magheraboy), most probably between 4065–3945 BC (68% prob.), and the activity ended between 3615–3355 BC (95% probability), 3520–3410 BC (53% probability). The chronology for Magheraboy is significantly earlier than any other Neolithic element so far dated in Ireland (Cooney et al. 2011; Danaher 2007).

In order to establish a date for the beginning of the early Neolithic in Ireland, Cooney et al. (2011) developed two main models, using the early dates from Magheraboy. In models 2 and 3 the following elements were considered: the chronology of the rectangular timber houses, evidence for other occupation (spread of artefacts, pits, etc.), court tombs, portal tombs, other monuments, field systems, the Linkardstown burial (group of inhumations in cist graves), passage tombs, trackways and undiagnostic pottery. The two models differ in the order of the components. In the analysis, the five radiocarbon dates from Croaghaun, Glen (a passage tomb on the Ox Mountains, Co. Sligo; excavated by S. Bergh in 1986), were excluded. From those radiocarbon dates three have a large standard deviation (4680±675 BP (St-10452), 3280±295 BP (St-10454) and 2025±285 BP (St-10455) (Bergh 1995)) and the other two (6680±100 BP (Ua-713) and 5685±85 BP (St-10453) (Bergh 1995)), being pine charcoal, were considered to have probably derived from bog pine (Cooney et al. 2011).
In model 2 (Tab. 2.04), houses and other occupation material associated with Bowl pottery define the early Neolithic. Portal and court tombs, other related monuments, field systems, trackways and undiagnostic pottery provide the *termini ante quos* for the start of the Neolithic. The Linkardstown burial sequence and passage tombs provide the *terminus ante quem* for the end of the early Neolithic (with the Linkardstown burials and passage tombs as successive or overlapping phases).

**Table 2.04.** Model 2 for the start of the Irish Neolithic and the Magheraboy activity (Cooney *et al.* 2011).

<table>
<thead>
<tr>
<th>Model 2</th>
<th>Age range (cal. BC; 95% probability)</th>
<th>Age range (cal. BC; 68% probability)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of the early Neolithic in Ireland</td>
<td>3840–3730</td>
<td>3810–3750</td>
</tr>
<tr>
<td>Beginning of the activity at Magheraboy</td>
<td>3830–3715</td>
<td>3795–3730</td>
</tr>
</tbody>
</table>

In model 3 (Table 2.05) rectangular houses, other occupation levels and the diagnostic early Neolithic material are considered to be earlier than the Linkardstown burials and passage tombs, but contemporary with court and portal tombs, other related monuments, field systems, trackways and undiagnostic pottery.

**Table 2.05.** Model 3 for the start of the Irish Neolithic and the Magheraboy activity suggested by Cooney *et al.* (2011).

<table>
<thead>
<tr>
<th>Model 3</th>
<th>Age range (cal. BC; 95% probability)</th>
<th>Age range (cal. BC; 68% probability)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of the early Neolithic in Ireland</td>
<td>4000–3830</td>
<td>3935–3850</td>
</tr>
<tr>
<td>Beginning of the activity at Magheraboy</td>
<td>3980–3820</td>
<td>3910–3835</td>
</tr>
</tbody>
</table>
In the second model the beginning of the Neolithic in Ireland appears to be more in agreement with the pollen diagrams presented. However, the start of the activity in Magheraboy proposed by this model is not in tune with the preferred model for the building of the Magheraboy enclosure. On the other hand, in model 3 the beginning of the Neolithic and the onset of cereal cultivation as presented by Brown (2007) are in good agreement. There is also a short overlap between the start of Neolithic activity at Magheraboy and the building of the enclosure. The models are only models and as such are only approximations (but probably the best we have) of the reality.

Other early dates from Co. Sligo come from the Round Mound at Rathdowney Beg (Mount 1999) where the basal date, i.e. when the monument was constructed, is 3775–3645 cal. BC (95% probability) probably 3710–3660 cal. BC (68% probability) (Cooney et al. 2011). The analysis of the pollen present in the ditch fill suggests that open grassland prevailed locally during the Neolithic. These early dates coincide with the beginning and the expansion of the Neolithic Landnam recorded in the L. Dargan profile and the other pollen diagrams from western Ireland. The recent dates for the initial use of court tombs, ranging between 3700–3570 BC, also fall within this period (Schulting et al. 2012).

In the L. Dargan profile the early Neolithic is characterized by a Landnam, i.e. ‘taking of land’ (Iversen 1941). This term is used to define woodland clearance in the context of a prehistoric farming economy (Molloy and O’Connell 1987). The Landnam in L. Dargan exhibits two phases which differ in the intensity of human impact. The highest level of human impact is recorded in sub-subzone 3a±, and has a duration of ca. 370 years. During this period the early Neolithic rectangular houses were in use (Smyth 2010).

The chronology for the beginning of the rectangular houses is 3730–3660 cal. BC (98% probability) and 3715–3680 cal. BC (68% probability) and the end of their use is 3640–3605 cal. BC (98% probability) and 3635–3615 cal. BC (68% probability) (Cooney et al. 2011). Sub-subzone 3aβ (ca. four centuries) shows a decline in farming intensity until ca. 3000 BC at the end of which the curve of the anthropogenic indicator P. lanceolata ceased. The farming activity is concentrated during the early Neolithic, not only in L. Dargan but also other Irish pollen profiles (cf. O’Connell and Molloy 2001). The L. Dargan profile does not show high levels of pastoral farming when compared to Loughmeenaghan, Céide Fields or
L. Sheeauns. However, the profile shows a long Landnam phase which lasted approximately seven centuries. At Loughmeenaghan, for instance, the most intensive period of farming activity lasted for around two centuries (3770–3550 BC). At this site a decline in human activity is recorded from 3550 BC until 3330 BC and the P. lanceolata record is short. At Loughmeenaghan the Landnam lasted for ca. 440 years (Stolze et al. 2012).

At L. Dargan the period that follows the Landnam is characterized by a distinct lull in activity which led to a woodland regeneration (3000–2710 BC). A similar development is recorded in other Irish pollen diagrams such as Loughmeenaghan, Céide Fields and Garrynagran suggesting a regional and national significance (O’Connell and Molloy 2001). High values in ash content and in magnetic susceptibility may indicate an increase in soil erosion. Stolze et al. (2012) suggest an increase of wetter conditions between 3520 and 3170 BC. A different interpretation was suggested by Molloy and O’Connell (1995) for the same period at Glenulra basin in Céide Fields. The authors interpreted the growth of pine in the area towards the north and east of the basin, the presence of pine stumps and the increase in Calluna and Empetrum (GLU IV profile) as indicating a shift towards drier conditions.

During the late Neolithic at L. Dargan (ca. 2700 BC) a renewal of farming activity is recorded. In contrast, the evidence for renewed activity is lacking in the profile from Loughmeenaghan but this profile may not extend into the late Neolithic (Ghilardi and O’Connell 2012a).

The presence of cereal-type pollen in sub-subzones 3aα and 3aβ (0.20% and 0.27%, respectively of TTP) is of high significance given the poor dispersal capacity of cereal pollen, which would have also been limited by the largely wooded landscape. This record is one of the longest for cereal pollen during the Neolithic in western Ireland. At Loughmeenaghan cereal-type (Triticum-type) pollen were recorded between ca. 3780–3640 BC (Stolze et al. 2012). In this profile a Hordeum-type curve is also presented. The authors suggest that the source of this pollen is Glyceria, an aquatic grass, and not barley or other cultivated grasses. This appears to be a conservative view. Glyceria pollen can be distinguished from the other Hordeum-type pollen by the narrow annulus in relation to the large pore size (Beug 1961, 2004). In L. Dargan Glyceria-type pollen were not recorded.

At L. Dargan, during the late Neolithic, yew failed to expand. O’Connell and Molloy (2001) suggested that the general low level of human impact in the second half of the Neolithic led
to a woodland regeneration, which included the expansion of yew. In the pollen diagrams from Co. Sligo a *Taxus* expansion is not recorded (Dodson and Bradshaw 1987; Turbayne 1985; Stolze *et al.* 2012) suggesting that yew was not important in the post-glacial woodlands of this county. However, records of yew charcoal were found in a shell midden at Culleenamore, Cúil Irra, from a Neolithic context (Bartholin 1984).

### 2.6.3 Early farming impact during the Bronze Age

The Bronze Age at L. Dargan (cf. zone 4; 2120–550 BC) is characterized by substantial farming activity, both pastoral and arable. This period records a high level of human impact on the woodland and an abrupt drop in AP concentration. This results in a more open landscape compared to the Neolithic (see Fig. 11) with a substantial increase in NAP due to a pronounced woodland clearance. From this period an expansion of bog taxa is recorded which also suggests an opening-up of the landscape.

The record of *Fontinalis antipyretica*, an aquatic moss, in the DRG1 profile from the upper part of zone 3 and in zone 4 is notable. *F. antipyretica* usually grows attached to wood or rocks in streams and around the edges of lakes, but seldom in deep water (Watson 1981; Porley and Hodgetts 2005). The record of this moss does not necessarily indicate low lake levels because the large and often plentiful leaves often become detached from the stems, especially in rapid flowing water (Porley and Hodgetts 2005).

During the Bronze Age there are three main distinctive phases of major farming activity recorded in subzones a, c and e. Throughout the Bronze Age the strong representation of cereal–type pollen is noteworthy. This suggests that farming at L. Dargan had a considerable arable component. The low dispersal capacity of cereal pollen has to be considered although the dispersion can also be favoured by increased landscape openness. In particular during the early Bronze Age (subzone 4a; 2120–1760 BC) cereal-type pollen achieves the highest values for the prehistoric period. The three farming phases show a positive correlation with the increase in micro-charcoal particles which suggest the use of fire in the region. The record of macro-charcoal in subzone e and f also suggests a more intense use of fire in the L. Dargan area. In this regard the large number of *fulacht fiadh* (burnt mounds) recorded in Co. Sligo (Egan *et al.* 2005) is noteworthy. Although in subzone 4c the magnetic susceptibility values record a substantial increase, the rise in ash content and *Pediastrum*
representation are modest suggesting little soil erosion. Record of *Glomus* spores, however, hint at soil erosion in the catchment.

A more intensive phase of human activity during the late Bronze Age is not unusual in the Irish pollen records (cf. Molloy 2005; Molloy and O’Connell 2011; Overland and O’Connell 2008; Plunkett 2009). Interestingly, in Mooghaun L. (Molloy 2005), Co. Clare, the early and middle Bronze Age farming activity is not well expressed, whereas the late Bronze Age records a major impact. The increase of the anthropogenic indicators coincides with a decrease in *Corylus* values of ca. 60%. Also at Caheraphuca (Molloy and O’Connell 2011, 2012), Co. Clare, the human activity is more concentrated during the late Bronze Age, although the impact is not as intense as that indicated in the Mooghaun L. profile. Unfortunately other detailed pollen diagrams from Co. Sligo relating to the Bronze Age are not available (but see Cooney L., Chapter 3).

The L. Dargan profile shows a distinct early and mid Bronze Age farming activity, whereas in other Irish sites the middle Bronze Age is characterized by varying degrees of intensity in mixed farming (Plunket 2009). Archaeological evidence from the Cúil Irra peninsula supports intense activity for much of the Bronze Age. At Caltragh, Danaher (2007) discovered the first middle Bronze Age clustered settlement for north–west Ireland. At this site three round houses were discovered. The radiocarbon dates for the three houses are: House 1, 3220±80 BP; House 2, 3140±70 BP; House 3, 3210±40 BP (Danaher 2007, p. 157). The main focus of the activity is postulated to have changed from the megalith-based monumental culture of the Neolithic to an integrated settlement. Danaher (2007) maintains that at Caltragh the spatial organization of the houses and the associated boundaries, the placing of the burials and the *fulachta fiaidh* (three) suggest that people from this area developed a strong localized sense of identity grounded in an acute awareness of place with strong ties to the past (Danaher 2007).

Bronze Age activity is also recorded from Magheraboy. This is indicated by the presence of three (possibly four) *fulachta fiaidh* which may span the period from the late Neolithic/Early Bronze Age to the Late Bronze Age (Danaher 2007). Hence archaeological evidence supports an intense use of fire in this period, which is also confirmed by the high values of micro-charcoal recorded in the L. Dargan profile.
2.6.4 Farming and woodland dynamics during the Iron Age and the historic period

In the L. Dargan profile, zone 5 (555 BC–AD 350) may cover the period related to the Iron Age, although the beginning and the ending dates of this period are still uncertain (Waddell 2010). The pollen diagram indicates a large and largely sustained openness in the landscape. The main trees affected by this intensive clearance are oak, ash and hazel. The increased representation of Cyperaceae and Filipendula suggests an increase of wet habitat suitable for sedges and other plants that tolerate wet soils. The increase in ash content and the substantial expansion of Pediastrum suggest soil erosion, probably due to the expansion of pastoral and arable farming, was taking place in the vicinity of the lake. This phase of high level human impact is reflected also in the expansion of micro-charcoal particles. The late Iron Age (subzone 5c; 80 BC–AD 350) is characterized by a decline in pastoral farming, which facilitated woodland regeneration (a minor expansion of Taxus is recorded). Interestingly, cereal representation shows high values, suggesting that arable farming is still important in the L. Dargan area. The characteristics as described are indicative of the Late Iron Age Lull (LIAL), which spans the first three/four centuries of the first millennium AD in many Irish pollen diagrams (cf. Overland and O’Connell 2011).

From ca. AD 350 (subzone 6) a large-scale woodland clearance associated with intense farming activity is recorded. This important increase in human impact is demonstrated also by the elevated values for ash content and magnetic susceptibility as a result of severe soil erosion. A major increase in cereal-type pollen representation is recorded from ca. AD 800 (mid subzone 6b). From this point onwards crop cultivation assumed an increased importance in Ireland (Overland and O’Connell 2011). In the study from L. Kinale, in particular from the Ballywillin Crannog core, after AD 800 Hordeum-type pollen achieved 50% (Selby et al. 2010). Other evidence for the increased importance of cereals during this period comes from the recently excavated watermill at Kilbegly, Co. Roscommon and increased importance of mills generally in Ireland (Overland and O’Connell 2011). Two further increases of cereals are recorded. The first at the base of subzone 6d (AD 1300; Norman period) and the second at the base of zone 7. This last zone covers the period from the early 16th century and the mid/late 17th century. The decrease of cereal-type pollen at the top of the zone may be related to the adoption of potato cultivation. Solanum pollen is not,
however, recorded. The dispersal capacity of this species is limited, therefore the pollen is silent in the pollen record.

In zone 6 and 7 woodland was mainly dominated by hazel, oak, (although *Quercus* declines steadily), ash (*Fraxinus*, however, shows an increase in subzone 6c), alder, birch and willow.

Pine began to be commonly planted in Ireland from ca. AD 1750. The absence of the second rise of *Pinus* suggests that the top of the pollen diagram pre–dates this period. Reversal of radiocarbon dates and the record of *Pinus* pollen and stomata in the upper part of the profile are suggestive of high levels of farming activity, in particular arable. This situation could have been caused by inwash of reworked material into the lake. Intense soil erosion is also highlighted by the increase in ash content and magnetic susceptibility values and also by the record of *Glomus* spores. In zone 7 the notable rise of *Filinia* may suggest an increase in the eutrophication of the lake, which is supported by the high values of *Pediastrum*.

In north Sligo, the Leguy woods, which were composed of oak, hazel, yew and holly existed until the seventeenth century. The wood lay between the lower slopes of the Ox Mountains and L. Gill. At the end of the seventeenth century and during the eighteenth century a strong exploitation drastically reduced the forest (McCracken 1971). The woodland clearance may be reflected in zone 7 with the decline in AP.

Dodson and Bradshaw (1987) recorded *Arbutus* pollen at Slish Lake and Slish Mor (ca. 1 AD), where the strawberry tree grows today, and at L. Arquilla (Union Wood, core 2). A single pollen grain is recorded at Loughmeenaghan (Stolze *et al.* 2012) from the Neolithic (ca. 3500 BC). The absence in the L. Dargan profile does not indicate the absence of this plant because *Arbutus* pollen is under-represented in pollen records (Mitchell 1988).
2.7 Conclusions

The detailed palynological investigation carried out at L. Dargan contributes substantially to our understanding of woodland dynamics and land use in the vicinity of L. Dargan. Close interval sampling was carried out in order to obtain a detailed record of early farming (Neolithic and Bronze Age).

The pollen diagram spans most of the Holocene (ca. 7800 BC–AD 1680). The profile opens in the Boreal period, when the woodland was mainly composed of pine, oak, hazel and elm. There is evidence for two woodland perturbations. The first perturbation is recorded in subzone 1b (6370–6100 BC) which may correspond to the so called 8.2 ka event. A second perturbation involved a shift that favoured elm and alder at the expense of pine (ca. 4600 BC). It is suggested that these may be due to an increase in precipitation and elevated temperatures (especially in summer).

A well-defined Elm Decline is dated to 3760 BC. At the same time the first two cereal-type pollen are recorded. In particular a *Triticum*-type pollen (wheat) was identified. The expansion of *P. lanceolata* occurred ca. 60 years after the Elm Decline. At L. Dargan the earliest part of the Neolithic is characterized by pastoral farming with a distinct cereal growing component (Landnam lasted ca. 760 years). The early part of the Landnam is the most pronounced (3760–3390 BC). A woodland regeneration phase took place after the Landnam (3000–2710 BC). This phase is followed by a renewal of farming activity. During the late Neolithic a renewal of pastoral farming is recorded from ca. 2700 BC, whereas the arable indicators resume from ca. 2360 BC.

The data obtained from the L. Dargan profile, relating to the Neolithic, are compared with archaeological field evidence for the early Neolithic in Co. Sligo. The early Neolithic is, indeed, characterized by considerable farming and other activity. This is supported by proposed chronologies for the Neolithic (Bergh 1995; Danaher 2007; Cooney *et al.* 2011) and also by other sources such as the Neolithic rectangular house (Cooney *et al.* 2011), cereal macrofossils in Britain and in Ireland (Brown 2005) and the Irish court tombs (Schulting *et al.* 2012).

The Bronze Age is characterized by intense human impact. During this period three major phases of farming activity are recorded. Bronze Age farming had an important arable
component and exhibited a positive correlation with the rise in micro-charcoal. Evidence for considerable human activity and the use of fire during the Bronze Age has been discovered to the south of Sligo town (burnt mounds, *fulachta fiadh* and also houses; Danaher 2007).

During the Iron Age a substantial opening-up of the landscape occurred between 550 BC and 80 BC. This period is followed by a woodland regeneration phase which lasted until ca. AD 350, although cereal-type pollen continues to be well represented.

From zone 6 onwards, farming activity increases constantly. The uppermost part of the diagram (AD 450–1680) is characterized by major woodland clearances in the context of intense agricultural and pastoral farming activity. This situation led to substantial soil erosion, including input of old organic material that led to $^{14}$C reversals.
Chapter 3

Post-glacial environmental change at Cooney Lough

3.1 Introduction

In this chapter the results of a detailed pollen-analytical investigation of a core from Cooney Lough, a small lake in north Co. Sligo, western Ireland, are presented.

Cooney L. is located immediately to the south of one of the most prestigious Neolithic regions of Ireland, namely the Cúil Irra peninsula. This area hosts the impressive Carrowmore passage tomb cemetery, one of the four major passage tomb cemeteries of Ireland, and Knocknarea, a prominent hill with Queen Maeve’s tomb (a large cairn, probably with a passage tomb) on the summit (Burenhult 1984, 2009; Bergh 1995, 2002). The recent excavation along the N4 roadway south of Sligo town has produced new evidence of Neolithic occupation (Danaher 2007). The causewayed enclosure at Magheraboy (ca. 2 ha), on the eastern side of the peninsula and immediately to the south of Sligo town, has yielded some of the earliest dates for causewayed enclosures in Britain and Ireland (Danaher 2007; the chronology for this site and its significance for dating the Neolithic in Ireland is considered in detail by Cooney et al. (2011). The N4 roadway also yielded substantial archaeological evidence for Bronze Age activity including fulacht fiadh and three round houses. Seven grinding stones and saddle quern fragments recovered from these houses (Danaher 2007) highlight the importance of cereal growing in this area.

Cooney L. lies to the north of the Ox Mountains and so lies well within the area belonging to the Irish Passage Tomb Tradition (IPTT) as defined by Bergh (1995).

3.2 Site description

Cooney Lough (36 m asl) (Fig. 3.01) is a small and closed lake, more or less circular in shape. It lies in a sheltered depression in the low-lying coastal strip between the Ox Mountains and the inner part of Ballysadare Bay (Fig 3.01). Cooney L. has a saucer-like bathymetry, it is steep sided and flat bottomed with a maximum recorded depth of 8.6 m.
The area of the lake is ca. 3 ha. It measures ca. 180 m from east-west and 150 m from north-south.

The fertile coastal strip consists of drift-covered Carboniferous limestone (Ballyshannon Limestone Formation; MacDermot et al. 1996) which today supports mainly pastoral farming. In this area, from the west of Ballysadare up to the border with Co. Mayo, the soils are grey brown podzolic (Walsh et al. 1976; Egan et al. 2005). This soil has good drainage, the structure is moderately well formed and the depth can vary from 60 to 100 cm. It is considered good for tillage and grassland farming (Walsh et al. 1976).

The Ox Mountains, which define the area to the south, consist of metamorphic rock. In the area immediately to the south of Cooney L. the bedrock is psammitic paragneiss and has skeletal soils. To the south-southwest of Cooney L. there is a narrow strip of semi-pelitic biotite schists (MacDermot et al. 1996).

The Ox Mountains in this area form a chain of east-west orientated low-lying hills (tallest nearby peak is Slieveward at 189 m asl) that support mainly wet heath and provide rough grazing.

Nowadays the landscape in the study area has very little woodland (there are only a few low trees and tall shrubs scattered in the vicinity of Cooney L.). Up until the 18th century, however, there was extensive woodland associated with the Ox Mountains in Co. Sligo and referred to as the Leguy woods. McCracken (1971, p. 42) describes the Leguy wood as consisting of oak, hazel, yew and holly and stretching between the Ox Mountains and the sea (Sligo Bay). There are records of exploitation for charcoal (for ironworks) as late as 1768 (McCracken 1971).

The steep fields surrounding Cooney L., on the northern, eastern and southern side, are used for grazing (mainly cattle and horses). On the western side of the lake several trees of Alnus glutinosa and Salix spp. are present, whereas to the south a large band of Ulex europaeus shrubs occupy more steeply sloping ground. Close to the edge of the lake in low water depths Carex rostrata form a semi-continuous band 5 m wide, together with Schoenoplectus lacustris (Scirpus lacustris), Phragmites australis, Caltha palustris, Iris pseudacorus and Menyanthes trifoliata. At the edge of the lake Juncus effusus, Juncus articulatus, Epilobium palustris, Veronica beccabunga, Rorippa nasturtium-aquaticum, Senecio aquaticus,
Filipendula ulmaria, Angelica sylvestris and Equisetum fluviatile were recorded. On sloping ground close to the lake Cirsium vulgare, Cardamine pratensis Taraxacum officinalis, Ranunculus repens and Ranunculus acris were recorded.

From the archaeological point of view Cooney L. is located in a very interesting area, not only due to its proximity to Carrowmore, but also on account of three megalithic tombs recorded within the vicinity of the lake. A ruined court tomb ‘Corhawnagh’ lies to the east, at ca. 700 m from the lake (Ó Nualláin 1989, tomb no. 77, Egan et al. 2005, tomb no. 61).

From the Ox Mountains, a passage tomb and a cairn overlook the landscape. The passage tomb ‘Glen’ is located to the south-west of Cooney L. on the summit of Croaghaun, at ca. 180 m asl and 1.5 km from the lake. It was excavated in 1986 by Bergh (Ó Nualláin 1989; Bergh 1995; Egan et al. 2005, tomb no. 66). Further west, on the Ox Mountains, there is a circular cairn ‘Mullanashe/Rathosey’ which possibly includes a passage tomb which, like Croaghaun, is probably orientated towards Knocknarea (cf. Bergh 1995). It is located at ca. 4 km from Cooney L. on the top of Doomore Mountain, at 273 m asl (Ó Nualláin 1989; Bergh 1995; Egan et al. 2005, tomb no. 82).

During the coring a fulacht fiadh, i.e. a cooking place, datable to the mid/late Bronze Age, was noted on the southern lake shore. Ancient field boundaries were noted on steeply sloping ground bounding the northern side of the lake. There are several ringforts in the lowlands about Cooney L. and especially to the west. These probably relate to the Iron Age and/or Medieval periods.

Fig. 3.01. The large aerial photograph includes the Ox Mountain range and the lowlands to the north. The area delimited by a rectangle is shown in the larger scale aerial photograph (bottom right) (BING map; downloaded 1/10/2012). The following are indicated: core CNY1 (dot), a fulacht fiadh beside the lake and a large ringfort (arrows), and a hut site and ancient field boundaries (square).

Inset, top left, shows selected features in the wider region including passage tomb cemeteries at Carrowmore and Carrowkeel, Magheraboy Neolithic enclosure, L. Dargan (LD), Rathdooney Beg (RB), Loughmeenaghan (Lm) and L. Availe (LA). Sligo and adjoining counties, Mayo, Roscommon and Leitrim, are indicated (county boundaries indicated by broken lines). The area delimited by a rectangle is shown in the large aerial photograph. A dot marks the position of Cooney L. (map is after Google Maps).
Fig. 3.01. Map and aerial photographs relating to the study area, Cooney Lough.
3.3 Methods

3.3.1 Fieldwork

Prior to coring (August 2009) the bathymetry of Cooney Lough was established using a GPS (Garmin GPSMAP 450s) with a depth sounder attached (Garmin Transom transducer). Parallel cores, CNY1 and CNY2 (grid. ref. N 54° 12.236', W 08° 32.490', and N 54° 12.236', W 08° 32.486', respectively; water surface ca. 36 m asl) were taken in April 2010 from near the centre of the lake in water depth of ca. 8.3 m using an Usinger piston corer fitted with an 80 mm diameter steel coring tube (cf. Mingram et al. 2007). In CNY1, the uppermost 20 cm of sediment was very watery which suggests that sampling began at or close to the surface of the sediment (depth measurements support this). Highly minerogenic sediments were reached so it is assumed that the 6 m-long core includes more or less a full sedimentary sequence. At CNY2, coring began 50 cm deeper with respect to CNY1. A core 4 m long was taken, i.e. neither the uppermost nor the basal sediments were recovered.

The 2 m-long core segments were extruded in 1 m lengths (subsegments) into PVC half-pipes. The subsegments were sliced lengthwise to give half cores (subsegments A and B). The half cores were labelled, photographed, securely wrapped and transported to the laboratory where they were stored in a cool environment.
Fig. 3.02.

A. Photograph showing preparation for coring at Cooney Lough. The photograph was taken near the land station where extrusion took place at the north-east corner of the lake. The tripod, used for lowering the casing and lowering and raising the core tube with its extension rods during coring, has been erected. The casing (2 m lengths of aluminium pipe) lies on the raft. Low hills, outliers of the Ox Mountains, are in the background on the left hand side (Photo: B. Ghilardi 28/04/2010).

B–D. Series of photographs showing the recovery of the core CNY1 using an Usinger piston corer. B. The corer containing lake sediment is being pulled up through a hole in coring platform. C. Ingo Feeser holds the corer containing a 2 m segment of the lake sediment. D. I. Feeser and Péter Majkut remove the transition rod from the corer head prior to core extrusion at the land station (Photo: B. Ghilardi 28/04/2010).

E. Panoramic view of Cooney L. The platform is anchored at the coring location CNY1. In the background (to the north) is Knocknarea with its distinctive shape. The large cairn (Maeve’s cairn) which may cover a passage tomb is visible right of centre at the top of Knocknarea. Carrowmore lies at the foot of Knocknarea. In the foreground Ulex europaeus (furze) is flowering. (Photo: M. O’Connell 28/04/2010).
Fig. 3.02. Photographs relating to coring at Cooney Lough and cores retrieved.
3.3.2 Laboratory investigations

An adhesive tape with a scale was attached to each core holder to facilitate sampling and to ensure correspondence in sediment depths between subsegments A and B. The subsegments were photographed and stratigraphical descriptions were made.

The investigations that follow were carried out mainly on the A subsegments as these generally had more sediment.

Magnetic susceptibility

Measurements were carried out on half-cores using the split-core logging method (Nowaczyk 2001). This involved using a Bartington magnetic susceptibility meter MS2 with a high resolution surface scanning sensor MS2E and Multisus ver. 2.31 software for calibrating and logging the data. The MS2 meter sensitivity was set to x0.1 rather than x1 which is less sensitive. Drift was corrected for by taking an air reading (zero reading) before and after each measurement.

Pollen preparation and counting

Core CNY1 was mainly used for pollen analysis. Samples of ca. 1 cm³ from 1 cm-thick slices of sediment were taken at regular intervals (every 2 cm; in parts, continuous sampling was carried out) between 302 to 500 cm (see Chapter 2 for further details regarding sampling procedures). Additional samples were taken from the parallel core CNY2 with a view to filling in a possible gap in the sediment record between segments CNY1-II and CNY1-III, i.e. at depth 400 cm (Table 3.01).

Standard procedures were used for pollen preparation. Lycopodium clavatum spore tablets were added at the commencement of preparation to facilitate estimation of pollen concentration (Lycopodium spore batch no. 177745 from the Department of Geology, University of Lund; http://www.geol.lu.se/personal/tsp/Ly177745.pdf). For each sample three tablets, i.e. 55752 spores, were used. Samples were treated with 10% KOH, sieved through a 100 μm mesh to remove large matter, treated with 60% HF and acetyolysed (cf. Fægri and Iversen 1989; Moore et al. 1991). At the end of the preparation procedure, the
pellet containing the pollen was sieved in an ultrasonic bath using a mesh size of 5 μm to remove small particles. Samples were stored in vials and mounted for counting in glycerol (for a more detailed description of the laboratory procedure see Chapter 2).

The samples were counted using a Leica DM LB2 microscope fitted with x10 oculars and a x50 objective. Pollen were routinely checked using a x40 phase contrast objective and critical grains were checked using a x100 phase-contrast oil immersion objective. Pollen identification was carried out using various keys and illustrations that included Fægri and Iversen (1989), Moore et al. (1991), Reille (1992, 1995) and Beug (2004). The pollen reference collection in the Palaeoenvironmental Research Unit was extensively used. Pollen nomenclature generally follows Moore et al. (1991). Cereal-type pollen were distinguished following Beug’s (2004) criteria. Pollen that otherwise fitted these criteria, but having size 37–40 μm, were classified as Poaceae, i.e. non-cultivated grasses. Cereal-type pollen were routinely assigned during counting to the following class sizes: 40–44 μm, 45–49 μm and ≥50 μm. Secale pollen were distinguished separately. Non-pollen palynomorphs (NPP) were also counted including Pinus stomata, micro-charcoal fragments >37 μm and fungal spores. Towards this, publications such as van Geel (1978), Pals et al. (1980), van Geel et al. (1981), Bakker and van Smeerdijk (1982), van der Wiel (1982), van Geel et al. (1989) and Feeser and O’Connell (2009) were consulted.

Generally a pollen sum of at least 1000 pollen (excluding aquatic taxa, Sphagnum, micro-charcoal and NPP) was achieved in most samples. A ‘+’ was used for pollen types encountered outside routine counting.

For pollen data calculations and plotting pollen diagrams the program CountPol (ver 3.3) by I. Feeser was used. Zone boundaries were placed where substantial changes in pollen representation and concentration occur.
Table 3.01. Table showing the correlation of pollen samples in cores CNY1 and CNY2 and the depth adjustments that were made.

<table>
<thead>
<tr>
<th>Depth* CNY1</th>
<th>Depth* CNY2</th>
<th>Comments</th>
<th>Depth* CNY1</th>
</tr>
</thead>
<tbody>
<tr>
<td>398</td>
<td></td>
<td></td>
<td>398</td>
</tr>
<tr>
<td>424</td>
<td></td>
<td>This sample is very similar to 398 in CNY1; it is regarded as contiguous with and below 398 cm in CNY1</td>
<td>399</td>
</tr>
<tr>
<td>426</td>
<td></td>
<td></td>
<td>401</td>
</tr>
<tr>
<td>428</td>
<td></td>
<td></td>
<td>403</td>
</tr>
<tr>
<td>430</td>
<td></td>
<td></td>
<td>405</td>
</tr>
<tr>
<td>432</td>
<td></td>
<td>This sample is v. similar to 404 cm (non-adj. depth); it is regarded as contiguous with and above 404 cm in CNY1</td>
<td>407</td>
</tr>
<tr>
<td>404</td>
<td></td>
<td></td>
<td>408</td>
</tr>
</tbody>
</table>

* Depths in centimetres; * Depths adjusted after filling ‘gap’ in CNY1. Samples from CNY2 are italicised. To avoid undue complication, the profile with these five samples from CNY2 continues to be referred to as CNY1.

Macrofossils analysis

The material retained in the 100 μm mesh sieves during pollen-sample preparation was scanned using a Leica MZ 125 stereo-microscope and photomicrographs were taken using a Leica DFC32 digital camera. Estimates of abundance were recorded as follows: rare (+); occasional (1); frequent (2) and abundant (3). Seeds, fruits and nutlets were identified using mainly Beijerinck (1976, 1988) and Cappers et al. (2006), and Körber-Grohne (1964) for Juncus seed and Poaceae caryopses. Higher plant nomenclature follows Parnell and Curtis (2012). For moss identification, Smith (2004, 1978) and Watson (1981) were consulted. Moss nomenclature follows the former.

Radiocarbon dating

Eleven sediment samples consisting of 2 cm-thick slices of half-cores (wet weight ca. 50 g) were sieved using a 125 μm-mesh sieve. The material retained in the sieve was investigated using the same procedures as in the case of the macrofossil samples (see above). Macrofossils suitable for AMS 14C dating were submitted to the 14Chrono Centre, QUB.

Loss-of-ignition (LOI)

Sediment samples with a volume of ca. 5 cm³ were taken from depths corresponding to those sampled for pollen. Recommendations by Heiri et al. (2001) as to the procedures to...
be carried out were followed to ensure consistency. The samples were initially dried for 24 h at 105°C and subsequently transferred to porcelain crucibles and ashed for four hours at 550°C. Water content, LOI and ash content were calculated (for details of calculations see Chapter 2). A second series of analyses was required in order to obtain a sufficient amount of ash for geochemical analysis. The core was resampled using a sediment volume of ca. 10 cm³.

**Multivariate analysis**

Multivariate analysis, using the software PC-ORD ver. 5 (McCune and Mefford 2011), was carried out on the data set for core CNY1 in order to identify trends and influencing factors in the palaeoecological data.

Nonmetric Multidimensional Scaling (NMS) with Sørensen distance measure was used. NMS is an ordination method that suits data that are non-normal or are on arbitrary, discontinuous or questionable scales. It is an iterative search for the best position of n entities (spectra) on k dimensions (axes) that minimises the stress of the k-dimensional configuration. The calculations are based on an n x n distance matrix calculated from the n x p-dimensional data matrix, where n is the number of rows and p is the number of columns (taxa) in the data matrix. ‘Stress’ is a measure of departure from monotonicity in the relation between the dissimilarity in the original p-dimensional space and distance in the reduced k-dimensional ordination space (McCune and Mefford 2011).

The matrix consisted of taxa that were included in the pollen sum and with a frequency equal and higher than four, i.e. columns with less than four non-zero values were removed. For the analysis, data from spectra in zones 3 to 7 were included (for details regarding NMS analysis carried out on pollen data relating to zones 1 and 2 see Ghilardi and O’Connell 2012a). The matrix consisted of percentage values for 76 spectra and 43 taxa. A slow and thorough option was selected with autopilot function (250 runs of real data and 250 runs with randomized data for a Monte Carlo test significance) to check the consistency of the results and assess the dimensionality of the data set.
3.4 Results

3.4.1 Stratigraphy

Stratigraphical descriptions of cores CNY1 and CNY2 are presented in Tables 3.02 and 3.03, respectively, and the original data as recorded in the laboratory are presented in Tables A3.01 and A3.02, respectively.

**CNY1.** The core (Fig. 3.03), ca. 6 m long, mainly consists of uniform fine dark gyttja. The uppermost 20 cm is much less consolidated due to high water content. Below 88 cm the sediment becomes gradually more consolidated and some faint lines of marl are recorded. Below 519 cm the sediment becomes gradually grey due to the increased presence of silt and clay. This change in sedimentation probably represents the beginning of the Holocene. Between 521 cm and 539 cm the core is characterised by silty clay-rich sediments with sand. From 546 cm to 604 cm the sediment becomes mainly sandy, in particular coarse sand is recorded from 594 downwards. However, the distinctive tripartite Late-glacial sequence, i.e. Bølling/Allerød-Younger Dryas, is not recorded in this core. At 400 cm, the upper part of core segment IIIa, the sediment is partly disturbed by the presence of a stone (4.5 cm long) which made it impossible to sample for pollen analysis. It was therefore decided to sample this part of the sequence from the parallel core CNY2.

**CNY2.** This core spans the interval 50 cm to 457 cm. The sediment is similar to CNY1. It consists of fine dark gyttja which gradually becomes more consolidated with depth. The basal minerogenic sediment was not reached. Light faint lines of marl are recorded at 377 cm and 368 cm, and a very thin line of marl was recorded at 393 cm. Marl bands, 1–2 mm thick, were recorded between 450–451.3 cm.
Fig. 3.03. Photographs of cores CNY1 and CNY2.
### Table 3.02. Summary of the stratigraphy, core CNY1.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–88</td>
<td>Sediment not very consolidated; high water content</td>
</tr>
<tr>
<td>88–519</td>
<td>Dark fine gyttja. Light coloured gyttja (due to marl) recorded at: 342.5 cm, 368 cm and between 428–429 cm</td>
</tr>
<tr>
<td>519–604</td>
<td>Grey sediment (interpreted as silt rather than marl) to 521 cm; beneath (until 546 cm) highly minerogenic silty sediments with sand; below 546 cm mainly sand (coarse sand from 594–604 cm); bedrock not reached; it was assumed the drive almost reached bedrock. This interval probably includes Late-glacial (but the typical Late-glacial tripartite sequence was not present) and end phase of the Pleniglacial</td>
</tr>
</tbody>
</table>

Note: adjusted depths are used above, i.e. 4 cm were added below 400 cm.

### Table 3.03. Summary of the stratigraphy, core CNY2.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>50–150</td>
<td>Fairly consolidated dark fine gyttja with high water content</td>
</tr>
<tr>
<td>150–557</td>
<td>Rather consolidated dark fine gyttja. Light coloured faint lines (due to marl) recorded at: 377 cm, 368 cm and 393 cm, and between 450–451.3 cm</td>
</tr>
</tbody>
</table>
3.4.2 *Radiocarbon dating*

The radiocarbon dates are presented in Table 3.04. The $^{14}$C dates were calibrated using Calib 6.0 (Stuiver *et al.* 2005) and IntCal09 calibration curve (Reimer *et al.* 2009). To obtain an age-depth model, a variety of methods were investigated including constructing a curve based on joining the median value of the calibrated dates by simply joining the points and also fitting curves using a cubic spline and polynomials of various orders. For curve fitting, the add-in function XlXtrFun.xll of Microsoft excel (Scott Allen Rauch, Advanced Systems Design and Development 1993–1999; [www.xlxtrfun.com/XlXtrFun/XlXtrFun.htm](http://www.xlxtrfun.com/XlXtrFun/XlXtrFun.htm)) was used. The software OxCal ver. 4.1.7 (Ramsey 2009), using IntCal09 calibration curve (Reimer *et al.* 2009) and the P_Sequence model (various $k$ values were tried; $k=1$ seems to give the best result; cf. Ramsey 2008), was also employed to calibrate the dates and generate age/depth models. Boundary conditions experimented with included specifying a change in sedimentation rate at 388 cm, i.e. the base of PAZ 4a (sustained decrease in pollen concentration begins here) and also at 484 cm (pollen concentration values increase). Other conditions included that the top of the profile is close to present time (AD 2010) and that the Late-glacial/Holocene transition occurs at 519 cm and is datable to 9700±50 BP (cf. Walker *et al.* 2008, 2009). The boundary at 388 cm was excluded because it created an abrupt change in the curve which did not seem realistic. The best fit obtained with OxCal is presented in Fig. 3.04 and the spline-fitted curve is also shown (red line). These two curves are very similar although the main differences occur near the base and the top, where the suggested dates for the cubic spline are somewhat older (ca. 100 years), but accord better with the uppermost $^{14}$C date. The curve is also smoother and so is regarded as being more appropriate in this situation.
Fig. 3.04. Age-depth model for core CNY1, Cooney Lough, based on 11 AMS $^{14}$C dates.
Table 3.04. Radiocarbon dates, core CNY1 (Cooney Lough).

<table>
<thead>
<tr>
<th>Lab code</th>
<th>Depth (cm)</th>
<th>C date (BP)</th>
<th>δ13C (%)</th>
<th>Age range* (1σ; 68.3%)</th>
<th>Age range* (2σ; 95.4%)</th>
<th>Median age*</th>
<th>Description (numbers in parentheses refer to the number of items included in the sample)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UBA-17011</td>
<td>302</td>
<td>2609±34</td>
<td>-25.7</td>
<td>810–781</td>
<td>835–670</td>
<td>797</td>
<td>Sphagnum leaf and <em>Betula</em> fruit</td>
</tr>
<tr>
<td>UBA-15784</td>
<td>326</td>
<td>2846±24</td>
<td>-26.2</td>
<td>1045–944</td>
<td>1112–924</td>
<td>1005</td>
<td>Fragment of leaves cf. <em>Salix</em></td>
</tr>
<tr>
<td>UBA-15785</td>
<td>350</td>
<td>3001±29</td>
<td>-32.2</td>
<td>1310–1135</td>
<td>1374–1129</td>
<td>1254</td>
<td><em>Betula</em> fruits (2), <em>Betula</em> scales (4), <em>Betula</em> bract (1) and leaves cf. <em>Salix</em></td>
</tr>
<tr>
<td>UBA-15786</td>
<td>372</td>
<td>3379±26</td>
<td>-24.1</td>
<td>1730–1634</td>
<td>1742–1617</td>
<td>1674</td>
<td>Leaf of <em>Salix</em>, leaf cf <em>Salix</em>, bud scales of <em>Betula</em> (2) and <em>Betula</em> fruits (3)</td>
</tr>
<tr>
<td>UBA-17010</td>
<td>394</td>
<td>3917±32</td>
<td>-33.6</td>
<td>2470–2347</td>
<td>2479–2295</td>
<td>2405</td>
<td>Leaf fragment (ca. 20)</td>
</tr>
<tr>
<td>UBA-15787</td>
<td>420</td>
<td>4653±30</td>
<td>-27.5</td>
<td>3500–3369</td>
<td>3518–3364</td>
<td>3456</td>
<td>Bud scales of <em>Betula</em> (8), big bud scales (2), <em>Pinus</em> scales (4) and <em>Betula</em> fruits (3)</td>
</tr>
<tr>
<td>UBA-17008</td>
<td>428</td>
<td>4928±32</td>
<td>-31.8</td>
<td>3756–3654</td>
<td>3772–3650</td>
<td>3698</td>
<td>Large leaf fragments; Bud scales of <em>Betula</em> (4) and <em>Pinus</em> (2)</td>
</tr>
<tr>
<td>UBA-15788</td>
<td>444</td>
<td>5502±28</td>
<td>-25.9</td>
<td>4362–4333</td>
<td>4446–4269</td>
<td>4350</td>
<td><em>Pinus</em> periderm (5 large, 7 small), bud scales of <em>Pinus</em> (ca. 50) and leaves fragment (3)</td>
</tr>
<tr>
<td>UBA-15789</td>
<td>464</td>
<td>6481±32</td>
<td>-30.8</td>
<td>5482–5381</td>
<td>5508–5369</td>
<td>5433</td>
<td>Large leaf (cf. <em>Salix</em>), <em>Pinus</em> periderm (3 large pieces, ca. 30 small pieces) and bud scales of <em>Pinus</em> (ca. 30)</td>
</tr>
<tr>
<td>UBA-15790</td>
<td>476</td>
<td>7077±38</td>
<td>-23.2</td>
<td>6006–5915</td>
<td>6025–5885</td>
<td>5952</td>
<td>Bud scales of <em>Pinus</em> (ca. 60), <em>Pinus</em> periderm (6 large pieces) and <em>Pinus</em> leaf (1)</td>
</tr>
<tr>
<td>UBA-17009</td>
<td>486</td>
<td>7792±36</td>
<td>-31.8</td>
<td>6652–6593</td>
<td>6688–6509</td>
<td>6621</td>
<td>Container A: <em>Pinus</em> scales (ca. 50); Scales unidentified (7); Container B**: <em>Pinus</em> periderm (10 pieces about 2 cm long)</td>
</tr>
</tbody>
</table>

Sample depths are given with reference to the upper depth; e.g. 302 cm included sediment from 302–304 cm; radiocarbon dates were calibrated using OxCal ver. 4.1.7 (Ramsey 2009a) and IntCal09 calibration curve (Reimer et al. 2009).

* Age ranges and median range, as reported by OxCal, are quoted in calibrated AD/BC.

**Container B was submitted in case of insufficient material in container A (not included in the material dated).
3.4.3 Macrofossil analysis

Macro-remains were detected from the retained material after the initial phase of sieving using 100 μm-mesh sieves. The macro-remains were identified after the sieving of the sediment. The higher abundance of macro-remains recorded in samples analysed for radiocarbon dates reflects the greater quantities of sediment analysed. The results are presented in Fig. 3.05.

Insect remains, bryozoan statoblasts, chironomid capsule heads and fern annuli are generally present in all samples. *Pinus* bud scales and *Pinus* periderm fragments are concentrated at the lower part of the profile, in particular between 440 and 490 cm. Two leaves of *Pinus* were identified at 444 and 476 cm from sediment analysed for 14C dating. *Betula* bud scales and fruit are consistently recorded between 429 cm and 350 cm. *Juncus effusus/conglomeratus* seeds are recorded only at the upper part of the core, i.e. from 330 cm upwards. A high frequency of macro-charcoal is recorded between 330 and 342 cm. Macro-charcoal was frequent in sample 477 cm (14C sample). Ostracod shells are recorded at 477, 429, 424, 421, 395 and 327 cm whereas mollusc shells are recorded at 421 and 395 cm. Mineral matter (quartz) is recorded in particular in the lower part of the profile. In the upper part there are occasional records.

Unidentified hypnaceous mosses are recorded in the majority of the samples whereas *Sphagnum* leaves are detected only at 302, 372, 378 and 470 cm. The aquatic moss *Fontinalis antipyretica* is consistently recorded mainly from 394 cm upwards. *Neckera complanata* is recorded at 454 and 448 cm. The presence of *Hylocomium splendens*, a moss with preference for acidic habitats and frequent today in western Ireland, is recorded at 474 cm.
3.4.4 Loss-on-ignition and magnetic susceptibility

The results of ashing (inverse of LOI) are presented in Fig. 3.06. In Fig. 3.06A, the first set of results (LOI-1) based on small sample size and the second set (LOI-2) based on large sample size are presented. In Fig. 3.06B, the two sets of results are drawn on the same graph so that the result can be more easily compared. The magnetic susceptibility curve for more or less the complete core is shown in Fig. 3.07. The lower part of the pollen profile is characterized by high values of ash. Values start to decline at ca. 490 cm and have fallen to relatively low values by ca. 483 cm. The values remain steady until 430 cm, where they begin to increase to give a remarkable peak at 427 cm. This peak is followed by a rapid decrease. Low values are recorded until 344 cm. At 342 cm and at 326 cm there are two modest peaks. There is a gradual decline towards the top of the profile.

The magnetic susceptibility curve shows low values between 422 and 414 cm but then an increase, reaching a peak at 398 cm. From 388 cm the values are low until the upper part of the diagram.
Fig. 3.06. Ash content values, profile CNY1.
Fig. 3.07. Magnetic susceptibility and stratigraphy of core CNY1.
3.4.5 Pollen analysis

The percentage pollen profile is presented in Fig. 3.08. Additional taxa not included in Fig. 3.08 are presented in Fig. 3.09. Concentration curves with magnetic susceptibility, ash content and pollen accumulation rate (PAR) curves for *Pinus, Ulmus, Quercus, Corylus, Alnus, Fraxinus*, Poaceae and *P. lanceolata* are shown in Fig. 3.10. PAR is a function of the pollen concentration and the sediment accumulation rate. PAR curves show a similar trend to the pollen concentration curves (see Fig. 3.10). For this reason PAR values will be described together with the concentration values. The middle and the upper part of the profile are also presented in Fig. 3.11.

In general a pollen sum (PS) of 1000 pollen grains was achieved. Aquatic taxa, *Sphagnum* spores and micro-charcoal are excluded from the PS. In one instance (428 cm), the PS reached 2235 pollen. This high count was made in order to confirm the high value of *P. lanceolata* (see also below).

The short pollen diagram from core CNY2 is presented in Fig. 3.12. Using spectra 424, 426, 428, 430 and 432 cm, the gap in CNY1 was bridged. These samples were inserted into CNY1 and assigned to the following depths 399, 401, 403, 405 and 407 cm. The samples below 404 cm were accordingly adjusted by adding 4 cm to each depth.

The pollen diagrams are divided into pollen assemblage zones based on important changes in the percentage pollen curves. Smaller variations in the pollen curves within the various zones are used to differentiate subzones and sub-subzones.

Seven pollen assemblage zones were identified. The main features are now considered and summarised in Table 3.05.
Fig. 3.11. Minor percentage pollen cores, profile CNY1.
Fig. 3.12. Percentage pollen diagram, with selected curves, for profile CNY2.
Chapter 3: Cooney Lough

PAZ CNY1-1; 500–481 cm; ca. 7760–6160 BC

Zone 1 is sampled every other centimetre, except for the first spectrum (500 cm). The pollen profile opens with a high percentage in AP, which reach in this zone the highest values recorded (98.4%). Corylus, Quercus, Pinus, Betula and Ulmus are the major contributors, whereas NAP are poorly represented. Pinus stomata are recorded throughout the zone. Salix and Hedera values are also well expressed.

Three subzones were identified:

In subzone 1a (ca. 7760–6990 BC) high values of Corylus are recorded and Quercus values show a steady increase. The first spectrum (500 cm) records low AP concentration values, but in the second spectrum the values increase substantially to give the highest peak of the whole diagram. This peak is followed by a decline in AP concentration, although the values are not constant but show a jagged trend. Betula values present a small peak in the middle of the subzone, in conjunction with a smaller peak in Pinus and an expansion in Ulmus. One pollen grain of P. lanceolata and Chenopodiaceae are recorded at 495 cm.

Subzone 1b (ca. 6990–6510 BC) is characterized by initial low AP concentration values. The Pinus curve rises steadily whereas Corylus values, after an initial decline, rise towards the upper part of the subzone. An increase in Polypodium and Cyperaceae representations are recorded. Micro-charcoal values peak near the top of the subzone. Glomus chlamydospores are also recorded.

In subzone 1c (ca. 6510–6160 BC) a decrease in Corylus and Quercus is recorded. At the same time Pinus and in particular Betula show relevant peaks near the end of the zone. Ulmus values are generally high. Two pollen grains of Alnus are recorded at the top of the zone (482 cm). Low values of AP are recorded in the pollen concentration diagram; although at the transition with subzone 2a another important peak is recorded. A weak expansion in Poaceae values is recorded towards the top of the zone and a P. lanceolata pollen grain is recorded at 481 cm. Polypodium and Cyperaceae show high values. Dryopteris filix-mas, Pteridium and Calluna increase in representation. A small increase in Pediastrum is also recorded at the end of the subzone.

PAZ CNY1-2; 480–442 cm; ca. 6160–4160 BC

In this zone the main taxa are Pinus, Quercus, Ulmus, Betula and in particular Corylus. Alnus pollen is consistently recorded from 479 cm. Pinus stomata are recorded throughout the zone. NAP present low values.

Zone 2 is divided into four subzones with the following features:
In subzone 2a (ca. 6160–5850 BC) the lower boundary is characterized by a sharp drop in *Betula* and by a peak in AP concentration. The *Alnus* curve is initiated at 479 cm.

In subzone 2b (ca. 5850–5130 BC) high values of *Corylus* are recorded in the lower part of the subzone, whereas low values are recorded in the upper part. *Pinus* values and also pine stomata records increase in the middle of the subzone and at the same time *Polypodium* values increase.

In subzone 2c (ca. 5130–4790 BC) the percentage and concentration values of *Pinus* and *Pinus* stomata increase substantially. *Ulmus* values show a small peak in the middle of the subzone, whereas *Betula* values increase at the end of it. *Pediastrum* representation increases in particular towards the upper part of the subzone.

In subzone 2d (ca. 4790–4160 BC) *Pinus* values decline gradually and at the same time *Alnus* increases. *Ulmus* increases gradually towards the top of the subzone. *Pediastrum* representation is still considerable, although it declines near the top of the zone. Few *Glomus* chlamydospores are recorded at the base of this subzone.

**PAZ CNY1-3; 440–430 cm; ca. 4160–3710 BC**

In this zone *Alnus* representation increases gradually and at the same time *Pinus* values decline (from 12% at the beginning of the zone to 2% at the end of it). Also there are only a few records of pine stomata. *Betula* peaks in mid zone and at the same time *Corylus* decreases. *Ulmus* increases in representation near the top of the zone (max value 19.2%). In the uppermost spectrum *Ulmus* declines to 14.4% and 12 pollen grains of *P. lanceolata* were recorded. A modest increase in NAP is recorded, in particular Poaceae, *Rumex acetosa*-type and *Ranunculus acris*-type. Tall shrubs such as *Ilex* (more or less the first record) and *Sorbus* increase. *Pediastrum* values rise in mid zone.

**PAZ CNY1-4; 429–390 cm; ca. 3710–2170 BC**

Close interval sampling every other centimetre was carried out between 430 and 420 cm. This zone is characterized by the increase in NAP and the presence of cereal-type pollen. *Fraxinus* and *Taxus* are also recorded. Four different subzones are differentiated.

Subzone 4a (ca. 3710–3440 BC) is further differentiated by the recognition of three sub-subzones. The main features are now presented.

Sub-subzone 4aa (ca. 3710–3680 BC), which corresponds to a single spectrum (429 cm), is characterized by the decline in *Ulmus* values. *Ulmus* values drop from 14.4% (last spectrum of the previous zone, 430 cm) to 9.3% at 429 cm. *P. lanceolata*, Poaceae,
Ranunculus and Rumex-type are recorded. Ilex and Hedera values decrease. In this spectrum two large cereal-type pollen are recorded (46 \text{µm} and 52 \text{µm}).

In sub-subzone 4aβ (ca. 3680–3530 BC) NAP expand. P. lanceolata values achieve 5.2% and Poaceae 6.4%. After the initial peaks the two curves gradually decline. In the middle of the sub-subzone Ulmus records the lowest value (1.3%) at 426 cm. Quercus values decline towards the upper part of the sub-subzone in conjunction with the rise in Betula. Corylus values record an initial negative peak but then increase in representation. Fern spore curves are well expressed together with Cyperaceae and Botryococcus. Micro-charcoal values increase slightly. Pediastrum and Glomus chlamydospores are also recorded.

In sub-subzone 4aγ (ca. 3530–3440 BC) pastoral indicator curves decrease together with the increase in Ulmus values. Cereal-type pollen are still recorded. Quercus values increase whereas Corylus values decline. Pinus declines to 0.8% and no stoma is recorded.

Subzone 4b (ca. 3440–3000 BC) is characterized by a decline of NAP values in favour of AP values that achieve 98.1%. A cereal-type pollen is recorded at the base of the subzone. High values of Ulmus and Quercus are recorded. The Fraxinus curve begins to be more distinct and continuously recorded from 416cm. Alnus and Salix decline somewhat. Tall shrubs increase in representation. The Polypodium curve records a small peak at the base of the subzone.

In subzone 4c (ca. 3000–2700 BC) P. lanceolata ceases to be recorded until 403 cm. Poaceae form a slender curve. A cereal-type pollen is recorded at the basal part of the subzone. From the beginning of this subzone Taxus is consistently recorded. Corylus values increase but at the same time Ulmus declines. Polypodium, Cyperaceae and Botryococcus values expand.

In subzone 4d (ca. 2700–2170 BC) a moderate increase in NAP (pastoral and arable) is recorded. Cereal-type pollen starts to be recorded at 398 cm (ca. 2530 BC). Taxus, Fraxinus and Alnus curves expand alongside the decrease in Corylus. Micro-charcoal increases in the upper part of the subzone. The Polypodium, Cyperaceae and Botryococcus curves are well expressed. Pteridium, Calluna and Myrica values increase. A Glomus chlamydospore is recorded at the top of the subzone (392 cm).

PAZ CNY1-5; 388–344 cm; ca. 2170–1160 BC

This zone is characterized by a continuous and important record of cereal-type pollen and P. lanceolata. Taxus pollen is also continuously recorded. Six subzones are identified as follows.
Subzone 5a (ca. 2170–1840 BC) shows an expansion in NAP. Poaceae and *P. lanceolata* representation expand and cereal-type peaks near the beginning of the zone. *Quercus* values slowly decrease whereas *Fraxinus* increases. Ferns, *Polypodium*, Cyperaceae and *Botryococcus* curves increase in representation. At the base of this zone the micro-charcoal particles curve increases slightly. *Glomus* chlamydospores are recorded at the basal part. 

Subzone 5b (ca. 1840–1730 BC) is characterized by the decline of pastoral taxa and an increase in AP representation. The cereal-type curve is still well expressed.

In subzone 5c (ca. 1730–1530 BC) a substantial increase in *P. lanceolata* and cereal-type pollen is recorded. Shrubs such as *Hedera* and *Sorbus* expand. AP decline except for *Betula* and *Salix*. *Betula* in particular achieves a notable peak in the mid subzone. A weak increase in micro-charcoal values is recorded. Pollen grains of *Tilia* and *Carpinus* were recorded.

In subzone 5d (ca. 1530–1380 BC) an increase in AP representation at the same time as the decline of pastoral and arable pollen is recorded. *Corylus*, *Ulmus* and *Fraxinus* values increase. *Quercus* values decline somewhat. Tall shrubs are still well represented and *Ilex* values expand. Ferns and bog taxa decline.

In subzone 5e (ca. 1380–1310 BC) a further increase in AP is recorded. Poaceae, *P. lanceolata* and cereal-type decrease notably.

In subzone 5f (ca. 1310–1160 BC) a moderate increase in NAP representation at the expense of AP is recorded. The *Taxus* curve reaches the highest peak whereas *Ulmus* declines. Towards the top of this subzone ferns, bog taxa and micro-charcoal increase in representation.

**PAZ CNY1-6; 342–320 cm; ca. 1160 –940 BC**

This subzone is characterized by the highest expansion of NAP recorded in the profile. In subzone 6a (ca. 1160–1100 BC) a rapid increase in NAP is recorded. In Subzone 6b (ca. 1100–940 BC) high values of Poaceae (29.3%), *P. lanceolata* (5%) and cereal-type (1.9%) are recorded. AP values decrease to 53.7%. In particular, the *Taxus* curve declines until it disappears altogether. *Ulmus* shows a slender curve. Few *Pinus* pollen are recorded and stomata are present at 338 and 326 cm. Not only pastoral and arable indicator values increase, but also ferns, bog, aquatic (in particular *Nymphaea*), algae and spore taxa. *Glomus* chlamydospores values form a well defined curve. The micro-charcoal curve is well expressed up until the end of the zone. Pollen grains of *Fagus* and *Tilia* are recorded.
PAZ CNY1-7; 318–302 cm; ca. 940–790 BC

After the noteworthy expansion of NAP recorded in the previous zone, zone 7 shows an increase in AP, in particular at the basal part of this zone (subzone 7a; ca. 940–880 BC). Subzone 7b (ca. 880–790 BC) records a moderate increase of pastoral and arable curves together with the expansion of bog taxa, *Botryococcus* and *Peridinium*. In this subzone *Taxus* is only recorded in the last spectrum at the top of the profile. *Quercus* values, after an initial increase, decline towards the top of the zone, whereas at the same time *Fraxinus* and *Corylus* increase. In zone 7 micro-charcoal values are low.

### 3.4.6 Multivariate analysis

Two dimensional solutions were recommended by the NMS analysis.

The proportion of variance explained by the ordination axes ($r^2$ values), calculated as a proportion of the variation in the reduced matrix relative to that in the original matrix, by NMS ordination on axis 1 is 64.2%. Axis 2 explained an additional 30.9% of the observed variability.

The final stress for the 2-dimensional solution is 10.65. For most ecological community data a final stress of about 10 is considered a good ordination with no real risk of drawing false inferences (McCune and Mefford 2011).

The scores of the spectra on the main axis (axis 1) are presented as a curve (see Discussion).
Table 3.05. Summary of pollen zonation, profile CNY1, Cooney Lough.

<table>
<thead>
<tr>
<th>PAZs (CNY1-)</th>
<th>Spectra/depth (cm)</th>
<th>Age range (BC)</th>
<th>Period</th>
<th>Main features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Zone 7</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 7</td>
<td>302–318</td>
<td>790–940</td>
<td>Late BA/early IA</td>
<td>Modest increase in NAP</td>
</tr>
<tr>
<td>7b</td>
<td>302–314</td>
<td>790–880</td>
<td></td>
<td><em>P. lanceolata</em> shows a modest increase that is not, however, sustained. Decline in ash content.</td>
</tr>
<tr>
<td>7a</td>
<td>314–318</td>
<td>880–940</td>
<td></td>
<td>Low NAP values; modest recovery in AP.</td>
</tr>
<tr>
<td><strong>Zone 6</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 6</td>
<td>320–342</td>
<td>940–1160</td>
<td>BA</td>
<td>Strongest increase in NAP</td>
</tr>
<tr>
<td>6a</td>
<td>338–342</td>
<td>1100–1160</td>
<td></td>
<td>Strong expansion of NAP. Ash content peaks.</td>
</tr>
<tr>
<td><strong>Zone 5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 5</td>
<td>344–388</td>
<td>1160–2170</td>
<td>BA</td>
<td>Increase in NAP, incl. Poaceae, <em>P. lanceolata</em> and cereal-type</td>
</tr>
<tr>
<td>5f</td>
<td>344–354</td>
<td>1160–1310</td>
<td></td>
<td>Gradual increase in Poaceae, <em>P. lanceolata</em> and cereal-type pollen. Peak in <em>Taxus</em> and decline in <em>Ulmus</em>.</td>
</tr>
<tr>
<td>5e</td>
<td>356–358</td>
<td>1310–1380</td>
<td></td>
<td>AP increase. <em>Corylus, Fraxinus</em> and <em>Ulmus</em> are well represented. <em>P. lanceolata</em> and cereal-type values decline.</td>
</tr>
<tr>
<td>5d</td>
<td>360–366</td>
<td>1380–1530</td>
<td></td>
<td>Gradual decline in pastoral and arable taxa. Increase in <em>Corylus, Ulmus</em> and <em>Fraxinus</em>. <em>Quercus</em> decline somewhat. <em>Ilex</em> values expand and bog taxa decline.</td>
</tr>
<tr>
<td>5c</td>
<td>368–374</td>
<td>1530–1730</td>
<td></td>
<td>Increase in NAP. <em>P. lanceolata</em> peaks and cereal-type are well represented. A substantial peak in <em>Betula</em> is recorded. <em>Sorbus</em> and <em>Hedera</em> values expand.</td>
</tr>
<tr>
<td>5b</td>
<td>376–378</td>
<td>1730–1840</td>
<td></td>
<td>AP increase. <em>P. lanceolata</em> and Poaceae decrease but cereal-type values remain steady.</td>
</tr>
<tr>
<td>5a</td>
<td>380–388</td>
<td>1840–2170</td>
<td></td>
<td>NAP increase, in particular Poaceae and cereal-type are represented by a continuous curve. Cereal-type peaks near the beginning of the zone.</td>
</tr>
<tr>
<td><strong>Zone 4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 4</td>
<td>390–429</td>
<td>2170–3710</td>
<td>Neol.</td>
<td>Anthropogenic indicators, including <em>P. lanceolata</em> and cereal-type pollen, important for the first time.</td>
</tr>
<tr>
<td>4d</td>
<td>390–401</td>
<td>2170–2700</td>
<td></td>
<td>Moderate increase in pastoral and arable taxa. <em>Taxus, Fraxinus</em> and <em>Alnus</em> expands. Micro-charcoal increase; <em>Polypodium</em>, <em>Cyperaceae</em> and <em>Botryococcus</em> well expressed. Magnetic susceptibility peaks.</td>
</tr>
<tr>
<td>4c</td>
<td>403–408</td>
<td>2700–3000</td>
<td></td>
<td><em>P. lanceolata</em> curve ceases. Poaceae form a slender curve. <em>Taxus</em> is consistently recorded. Increase in magnetic susceptibility values.</td>
</tr>
<tr>
<td>4b</td>
<td>410–420</td>
<td>3000–3440</td>
<td></td>
<td>AP expand. <em>Fraxinus</em> is continuously recorded from 416 cm. A cereal-type pollen is recorded near the base of the zone. Decrease in magnetic susceptibility.</td>
</tr>
</tbody>
</table>
### Chapter 3: Cooney Lough

<table>
<thead>
<tr>
<th>Subzone</th>
<th>Time Period</th>
<th>Neolithic Landnam (sub-subzones highlight the different intensity)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Zone 3</strong></td>
<td>440–430 3710–4160</td>
<td>Shift between <em>Alnus</em> and <em>Pinus</em>. Increase in <em>Ulmus</em>.</td>
</tr>
<tr>
<td><strong>Zone 2</strong></td>
<td>442–480 4160–6160</td>
<td>High values of AP, in particular <em>Corylus</em>, <em>Quercus</em>, <em>Pinus</em>, <em>Betula</em> and <em>Ulmus</em> with a gradual increase in <em>Alnus</em>.</td>
</tr>
<tr>
<td><strong>2d</strong></td>
<td>430–452 4160–4790</td>
<td>Gradual decline of <em>Pinus</em> and increase of <em>Alnus</em> and <em>Ulmus</em>. <em>Pediastrum</em> decline at the end of the zone. <em>Glomus</em> is recorded near the beginning of the subzone.</td>
</tr>
<tr>
<td><strong>2c</strong></td>
<td>454–458 4790–5130</td>
<td><em>Corylus</em> values decrease and an expansion of <em>Pinus</em>, <em>Quercus</em> and <em>Ulmus</em> is recorded. <em>Pediastrum</em> values increase.</td>
</tr>
<tr>
<td><strong>2b</strong></td>
<td>460–476 5130–5850</td>
<td><em>Corylus</em> records high values at lower part of the subzone. <em>Pinus</em> values and stomata expand in mid subzone.</td>
</tr>
<tr>
<td><strong>2a</strong></td>
<td>477–480 5850–6160</td>
<td><em>Betula</em> drops sharply. At the beginning of the subzone a peak in pollen concentration is recorded. <em>Alnus</em> curve is initiated.</td>
</tr>
<tr>
<td><strong>Zone 1</strong></td>
<td>481–500 6160–7760</td>
<td>High values of AP, in particular <em>Corylus</em>, <em>Quercus</em>, <em>Pinus</em>, <em>Betula</em> and <em>Ulmus</em>.</td>
</tr>
<tr>
<td><strong>1c</strong></td>
<td>481–485 6160–6510</td>
<td>Decrease in <em>Corylus</em> and <em>Quercus</em>. <em>Pinus</em> increases in the mid subzone and <em>Betula</em> values peak towards the end of it.</td>
</tr>
<tr>
<td><strong>1b</strong></td>
<td>486–491 6510–6990</td>
<td>Decline in <em>Corylus</em> is conjunction with a steady increase in <em>Pinus</em> is recorded. <em>Polypodium</em> shows high values. A weak expansion of NAP towards the end of the zone is recorded. Micro-charcoal peaks near the top of the subzone. <em>Glomus</em> chlamydospores are recorded.</td>
</tr>
<tr>
<td><strong>1a</strong></td>
<td>492–500 6990–7760</td>
<td>High AP values. High values of <em>Corylus</em> and a steady increase in <em>Quercus</em> are recorded. Small peak in <em>Betula</em> and increase in <em>Pinus</em> are recorded in the mid subzone.</td>
</tr>
</tbody>
</table>

Periods refer to prehistoric cultural periods.
Table 3.06. Results of two separate counts (Count 1 on 13/10/2010; Count 2 on 11/03/2011) for sample 428 cm, core CNY1. Percentage values and difference between the percentage values are also given.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Count 1</th>
<th>Count 2</th>
<th>Count 1 (%)</th>
<th>Count 2 (%)</th>
<th>Difference (count 1-count 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quercus</td>
<td>174</td>
<td>180</td>
<td>15.05</td>
<td>16.66</td>
<td>-1.61</td>
</tr>
<tr>
<td>Pinus</td>
<td>28.5</td>
<td>24.5</td>
<td>2.46</td>
<td>2.27</td>
<td>0.20</td>
</tr>
<tr>
<td>Ulmus</td>
<td>62</td>
<td>53</td>
<td>5.36</td>
<td>4.91</td>
<td>0.46</td>
</tr>
<tr>
<td>Alnus</td>
<td>143</td>
<td>142</td>
<td>12.36</td>
<td>13.14</td>
<td>-0.78</td>
</tr>
<tr>
<td>Betula</td>
<td>22</td>
<td>23</td>
<td>1.90</td>
<td>2.13</td>
<td>-0.23</td>
</tr>
<tr>
<td>Salix</td>
<td>3</td>
<td>3</td>
<td>0.26</td>
<td>0.00</td>
<td>0.26</td>
</tr>
<tr>
<td>Corylus</td>
<td>529</td>
<td>511</td>
<td>45.74</td>
<td>47.29</td>
<td>-1.55</td>
</tr>
<tr>
<td>Myrica</td>
<td>4</td>
<td>5</td>
<td>0.35</td>
<td>0.46</td>
<td>-0.12</td>
</tr>
<tr>
<td>Ilex</td>
<td>1</td>
<td>1</td>
<td>0.09</td>
<td>0.00</td>
<td>0.09</td>
</tr>
<tr>
<td>Hedera</td>
<td>4</td>
<td>4</td>
<td>0.35</td>
<td>0.00</td>
<td>0.35</td>
</tr>
<tr>
<td>Sorbus</td>
<td>1</td>
<td>1</td>
<td>0.00</td>
<td>0.09</td>
<td>-0.09</td>
</tr>
<tr>
<td>Fern spores (no perine)</td>
<td>11</td>
<td>7</td>
<td>0.95</td>
<td>0.65</td>
<td>0.30</td>
</tr>
<tr>
<td>Pteridium</td>
<td>2</td>
<td>2</td>
<td>0.17</td>
<td>0.19</td>
<td>-0.01</td>
</tr>
<tr>
<td>Polypodium</td>
<td>3</td>
<td>7</td>
<td>0.26</td>
<td>0.65</td>
<td>-0.39</td>
</tr>
<tr>
<td>Dryopteris filix-mas-type</td>
<td>2</td>
<td>1</td>
<td>0.17</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>Poaceae</td>
<td>85</td>
<td>57</td>
<td>7.35</td>
<td>5.28</td>
<td>2.07</td>
</tr>
<tr>
<td>Plantago lanceolata</td>
<td>67</td>
<td>49</td>
<td>5.79</td>
<td>4.53</td>
<td>1.26</td>
</tr>
<tr>
<td>Rumex acetosa</td>
<td>4</td>
<td>5</td>
<td>0.35</td>
<td>0.46</td>
<td>-0.12</td>
</tr>
<tr>
<td>Filipendula</td>
<td>1</td>
<td>1</td>
<td>0.09</td>
<td>0.09</td>
<td>-0.01</td>
</tr>
<tr>
<td>Succisa</td>
<td>1</td>
<td>1</td>
<td>0.09</td>
<td>0.00</td>
<td>0.09</td>
</tr>
<tr>
<td>Ranunculus acris</td>
<td>1</td>
<td>1</td>
<td>0.00</td>
<td>0.09</td>
<td>-0.09</td>
</tr>
<tr>
<td>Lotus-type</td>
<td>1</td>
<td>1</td>
<td>0.00</td>
<td>0.09</td>
<td>-0.09</td>
</tr>
<tr>
<td>Liguliflorae</td>
<td>1</td>
<td>1</td>
<td>0.00</td>
<td>0.09</td>
<td>-0.09</td>
</tr>
<tr>
<td>Cereal-type 40-44 (µm)</td>
<td>1</td>
<td>1</td>
<td>0.09</td>
<td>0.09</td>
<td>-0.01</td>
</tr>
<tr>
<td>Cyperaceae</td>
<td>9</td>
<td>6</td>
<td>0.78</td>
<td>0.56</td>
<td>0.22</td>
</tr>
<tr>
<td>Calluna</td>
<td>1</td>
<td>1</td>
<td>0.00</td>
<td>0.09</td>
<td>-0.09</td>
</tr>
<tr>
<td>Potentilla-type</td>
<td>1</td>
<td>1</td>
<td>0.00</td>
<td>0.09</td>
<td>-0.09</td>
</tr>
<tr>
<td></td>
<td>Pollen sum</td>
<td>1156.5</td>
<td>1080.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sphagnum</td>
<td>1</td>
<td></td>
<td>0.00</td>
<td>0.09</td>
<td>-0.09</td>
</tr>
<tr>
<td>Pediastrum</td>
<td>1</td>
<td>2</td>
<td>0.09</td>
<td>0.18</td>
<td>-0.10</td>
</tr>
<tr>
<td>Botryococcus</td>
<td>7</td>
<td>19</td>
<td>0.60</td>
<td>1.72</td>
<td>-1.12</td>
</tr>
<tr>
<td>Pinus stomata</td>
<td>2</td>
<td>1</td>
<td>0.17</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>Peridinium (HdV-91)</td>
<td>2</td>
<td>2</td>
<td>0.17</td>
<td>0.18</td>
<td>-0.01</td>
</tr>
<tr>
<td>Filinia (HdV-603)</td>
<td>6</td>
<td>4</td>
<td>0.51</td>
<td>0.37</td>
<td>0.15</td>
</tr>
<tr>
<td>Diporotheca (HdV-143)</td>
<td>2</td>
<td>2</td>
<td>0.17</td>
<td>0.18</td>
<td>-0.01</td>
</tr>
<tr>
<td>Glomus (HdV-207)</td>
<td>2</td>
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<td></td>
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<tr>
<td>Charcoal</td>
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<td>19</td>
<td>2.12</td>
<td>1.73</td>
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<td>Lycopodium counted</td>
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<tr>
<td>Lycopodium added</td>
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<td></td>
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</tr>
<tr>
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<td>1.37</td>
<td></td>
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<td>No. of taxa (all)</td>
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<td>No. of taxa in PS</td>
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<td>Min percentage difference</td>
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3.5 Interpretation

3.5.1 General considerations

Cooney Lough is a rather small lake (3 ha) located in a depression between the Ox Mountains and Ballysadare Bay to the north. On the basis of its size and its setting within a depression, the pollen source area is assumed to be rather small. As indicated in Chapter 2, the pollen source area is dependent on many factors and especially the openness of the landscape and the patchiness of the woodland cover (Bunting et al. 2004; Hellman et al. 2009; Sugita 2007a, b; Sugita et al. 1999; Broström et al. 1998, 2005). For Cooney L. the pollen source area for the period under consideration, during which there was either full or substantial woodland cover, was probably within a kilometre of the lake. Assuming that the prevailing winds were, like today, from the west/south-west, the area to the west and south-west is probably also differentially represented in the pollen record.

There are no inflowing or outflowing streams so that stream input of pollen does not have to be taken into account. Surface water runoff, however, was probably important given the steepness of the surrounding slopes to the north, east and south. In terms of water and hence pollen input, the influence of the southern catchment which includes the Ox Mountain uplands should not be underestimated.

Most of the lower part of the profile, i.e. from 496–440 cm (most of zone 1 and all of zone 2), has been evaluated in Ghilardi and O’Connell (2012a). Spectrum 500 cm was not included in that publication because there was a gap of 4 cm between it and the next spectrum at 496 cm. The pollen concentration is lower than the spectra immediately above but the percentage pollen values are similar. The profile described in Ghilardi and O’Connell (2012a) spans from ca. 9400–6000 cal. BP (7450–4050 BC). Five shifts in the pollen data were ascribed to climatic anomalies, CA-1 to CA-5 (Fig. 3.13). The most pronounced anomaly is CA-3, which spans the interval 8450–8200 cal. BP (6500–6250 BC). This anomaly is related to the 8.2 ka event recorded in many proxies and especially in the Greenland ice-core δ¹⁸O records. Expansion of Betula and Pinus (cold tolerant trees) together with the decline in Corylus and Quercus (thermophilous taxa) suggest a more continental climate (colder winter, low summer temperature and reduced precipitation). The
anomalies CA-1 and CA-2 precede the 8.2 ka event. The former probably corresponds to the 9.2 ka event and the latter, which is more pronounced, to an anomaly at 8.8 ka. After the CA-3, at about 7.5 ka, another anomaly (CA-4) is recorded that is of minor intensity compared with CA-5 (initiated at ca. 7.1 ka) which probably involved a fall in temperature.
Fig. 3.13. Summary of pollen data based on non-metric multidimensional scaling (NMS).
3.5.2 Palaeoenvironmental reconstructions

Atlantic woodland dynamics: zone 3 (ca. 4160–3710 BC)

A vegetational shift in favour of alder and at the expense of pine is recorded in zone 3. Alder thrives in moist soils facilitated by its symbiotic relationship with nitrogen-fixing actinomycete (*Frankia*), which provides nitrate required for the plant (McVean 1953; Bennett and Birks 1990; Alloisio *et al.* 2010; Hall 2011). Pine, on the other hand, is more competitive on nutrient-deficient soils (Carlisle and Brown 1968; Roche *et al.* 2009). This gradual shift is probably due to a slow change in lake level. The decrease in pine may be caused by a rise in the lake level that favoured alder over pine. At An Loch Mór (Inis Oírr, Aran Islands) lake level started to rise at ca. 6400 cal. BP (4450 BC) and accelerated at ca. 5600 cal. BP (3650 BC) (Holmes *et al.* 2007) which suggests a shift in the precipitation-/evapotranspiration regime towards wetter conditions.

In Cooney L. the change in pine and alder representation is very gradual in comparison with other Irish pollen diagrams. Perhaps during this time, there was a general shift towards more oceanic conditions and lower seasonal contrasts which would be expected to disadvantage pine which today is regarded as a continental species (cf. Ghilardi and O’Connell 2012a).

At Cooney L. a possible explanation for the more gradual shift between the two species is the steepness of the slopes that surround the lake, in particular at the north, east and south sides. The steep slopes mean that an increase in lake level would not have led to a greatly increased wet area at the edge of the lake. The wet area around the lake continued to be limited, so there was limited opportunity for alder to expand. This scenario may also help to explain the persistence of *Pinus* on the drier slopes, evident from the records of stomata, bud scales and periderm in zone 3.

An important feature at the top of zone 2 is the initiation of the *Ilex* curve. Holly has long been noted as a climatic indicator, together with *Hedera* (ivy) and *Viscum* (mistletoe) (Iversen 1944). Ivy can only flower and set seed in oceanic regions (Jessen 1949). The ability of ivy to tolerate low winter temperatures declines with the summer temperatures and vice versa. The mean coldest monthly temperature that ivy can tolerate is ca. -1.5°C (Iversen 1944; Jessen 1949; Troels-Smith 1960). Holly behaves in a similar way. It tolerates mean coldest monthly temperatures only as low as -0.5°C (Iversen 1944; Jessen 1949). Ivy,
although present since the Boreal in Ireland, achieves highest percentage representation during the sub-Boreal in Irish and other north-west European pollen diagrams (Molloy and O’Connell 1991; Jessen 1949; Iversen 1944). The expansion of *Ilex* started during the Atlantic period in north-west Europe (Mitchell *et al.* 1996; Molloy and O’Connell 1991; Jessen 1949; Iversen 1944). In Cooney L. the *Ilex* curve is not continuous and the maximum value reached in zone 3 is only 0.6%. It should be borne in mind that *Ilex* is an insect pollinated plant, hence the pollen is poorly represented in pollen diagrams. Increased values for *Ilex* may be the result of opening up of the woodland which facilitated the flowering and the dispersal of its pollen. The small increase in *Hedera* along with the modest expansion of Poaceae and the increase in NAP taxa are hints that there was disturbance in the surroundings of the lake. At L. Sheeauns (Molloy and O’Connell 1991) and L. Doo (O’Connell *et al.* 1987) the presence of *Ilex* is also recorded in the Atlantic period, where it achieves maximum representation. Molloy and O’Connell (1991) suggested that the expansion of holly is facilitated by the occurrence of perturbations. These authors suggest the following possible causes for these perturbations that led to opening in the woodland and consequently better flowering and dispersal of *Ilex*: the frequency of windthrows, onset of podsolization or mor humus formation and the possibility of human interference. In the case of L. Sheeauns, the authors favoured the last hypothesis as an explanation for the increase in *Ilex* in the Atlantic period. This view was supported by a slender *P. lanceolata* curve. However, at Cooney L. there is no additional evidence for human interference, such as recorded at L. Sheeauns. Human impact is unlikely as the main cause of the changes recorded at Cooney L.

The magnetic susceptibility curve shows a modest increase in the mid zone, suggesting an increase in inwash. The rise in *Pediastrum* values is another indicator of increased lake productivity caused possibly by increased soil inwash. There is also an increase in the sediment accumulation rate (1 cm represents 39 years) at this time.

*Woodland dynamics and farming activity during the Neolithic: zone 4 (ca. 3710–2170 BC)*

This zone opens with a distinct decline in *Ulmus* (3710 BC). *Ulmus* percentage values drop from a maximum value of 19.2% at 432 cm in zone 3 (zone 3 average = 16.6%) to a
minimum of 1.3% at 426 cm in zone 4 (zone 4 average = 5.9%) with a sharp decline observed at the transition between the zones from 14.4% at 430 cm to 9.3% at 429 cm. 

*P. lanceolata*, which has long been regarded as an important anthropogenic indicator, expands at 428 cm (3670 BC) and achieves a maximum value (5.2%) for zone 4. The gap between the Elm Decline and the expansion of *P. lanceolata* suggests that, at least initially, the Elm Decline was not caused by human clearance; otherwise we would have expected a simultaneous expansion of *P. lanceolata* at the same time as *Ulmus* is declining. Several pollen analytical investigations carried out in Ireland and Great Britain support the hypothesis which suggests that elm was affected by an epidemic disease at this time (Molloy and O’Connell 1987, 1991; O’Connell and Molloy 2001; Peglar and Birks 1993; Parker et al. 2002; Clark and Edwards 2004). The recent Dutch elm disease caused by *Ophiostoma (Ceratocystis) ulmi*, which has as a vector the bark beetle *Scolytus scolytus*, shows how the disease caused by *O. ulmi* can bring about a drastic decline in the pollen productivity of elm (Perry and Moore 1987). Clark and Edwards (2004) found, in two lowland raised mire sites in Scotland, the presence of beetle remains (*Scolytus scolytus* and *S. elytron*) over a prolonged period (8800–5660 cal. BP). The presence of these beetles neither proves nor disproves the disease hypothesis. The absence of these beetles following the Elm Decline indicates a lack of a suitable host for the beetles thus suggesting a dependence of the beetle on *Ulmus* (Clark and Edwards 2004). However, as this does not conclusively prove that the beetles were responsible for the decline in *Ulmus*, climatic, edaphic or anthropogenic causes cannot be completely excluded as possible causes (Clark and Edwards 2004).

A review of the mid-Holocene Elm Decline in the British Isles carried out by Parker et al. (2002) on 138 sites across England, Scotland, Wales and Ireland suggests synchronicity of the Elm Decline. The overall average date suggested for the Elm Decline is 5036±247 BP (between 6347 and 5281 BP at 95% of the sites). In western Ireland an approximate date for the Elm Decline is 3800 BC (O’Connell and Molloy 2001). At Cooney L. the Elm Decline is dated to ca. 3710 BC, which falls inside the range given by Parker et al. (2002) and is close to the date given by O’Connell and Molloy (2001) and by Ghilardi and O’Connell (2012b) from L. Dargan.

Selective clearances to facilitate farming on fertile soils where elm thrives would have been slow, patchy and non-synchronous (Parker et al. 2002). Human clearance of elm whether
by ring-barking or girdling or the use of elm as fodder by pollarding the branches (practices still in use in Norway and Switzerland (Troels-Smith 1960; Rackham 2003)) is a slow and geographically patchy process. Such clearances cannot explain the Elm Decline.

Soil deterioration as a cause of the Elm Decline was also considered by Parker et al. (2002). However, the Elm Decline was rapid and widespread in different types of soils; therefore this hypothesis was rejected (Troels-Smith 1960; Parker et al. 2002). In addition a particular case is presented by two Irish sites located in Co. Clare, Caheraphuca Lough (Molloy and O’Connell 2011, 2012) and Mooghaun Lough (Molloy 2005). At these sites although the Elm Decline is well expressed in the pollen diagrams, there is no evidence for a Neolithic Landnam. These studies reinforce the idea that the woodland clearance alone cannot be a primary cause of the Elm Decline (Molloy and O’Connell 2011; Molloy 2005).

Parker et al. (2002) also analysed possible climatological changes as a mechanism that could have led to the Elm Decline. The reduction of species such as ivy and holly, which are considered frost-sensitive plants, was used as marking the beginning of the sub-Boreal period by Iversen (1941). However, the climate changes during the Atlantic/sub-Boreal transition are not fully understood. The Elm Decline was more likely due to a combination of several factors. The spread of the elm bark beetle was probably facilitated by the woodland clearances caused by human activity. Climate instability may also have had a role. Elm is susceptible to harsh winters and late frost and therefore it would have been at a disadvantage (Parker et al. 2002). Drier conditions during this period are suggested by Stolze et al. 2012, but Ghilardi and O’Connell (2012 b) (also Molloy and O’Connell 1995) suggest that the opposite may be true, i.e. there was increased wetness. The pollen profile CNY1 does not provide any clear indications as to climate change at this point.

In sub-subzone 4a the weak reduction of Quercus values is recorded, which may suggest that a modest woodland clearance took place. At the beginning of Landnam, AP concentration and PAR decline although the relative contribution of Corylus increases. This rise could be due to an opening up of the woodland, so that hazel pollen productivity increased.
Fig. 3.14. *Corylus* and *Alnus* percentage curves of zone 4 (Neolithic) plotted to an age scale.
Corylus and Alnus percentage curves show a negative correlation throughout zone 4. At every positive peak of Corylus, Alnus records a negative peak and vice versa (Fig. 3.14).

The possibility of mistakes and inconsistencies during counting has to be taken into consideration. Sample 429 cm was initially counted on 13/10/2010 and it was recounted five months later on 11/03/2011, the main aim being to check the validity of the P. lanceolata peak. The results from the two counts are presented in Table 3.06. The counts for P. lanceolata are more or less the same (count 1: 67 (5.8%); count 2: 49 (4.5%)). Overall the results for the two counts of 429 cm are similar and the ratios of Corylus and Alnus remain constant (ratio in count 1: 3.7; ratio in count 2: 3.6). Therefore the possibility of an error during counting seems unlikely.

The use of hazel from the Neolithic times onwards for wattle-work (hurdle, wattle-and-daub and woven fences) is documented by Rackham (2003). He suggests that hazel is best coppiced on short rotation, because after twelve to fifteen years growth it becomes more difficult to work, losing its flexibility and ability to be twisted. Hazel was used extensively during the prehistoric period as rod for trackways. In Walton Track (Rackham 2003, pp. 106-7), for instance, 5000 rods were produced mainly by coppicing and occasionally by pollarding. These were almost all hazel rods with some ash and birch. The age of the rods varied from four to ten years growth suggesting that selective stems were chosen rather than by felling the whole area at once. In the Neolithic trackways at Corlea and Cloonbony, Co. Longford, oak was used for the structural elements (see Cooney 2000, p. 59). Oak and hazel charcoals were the most common charcoals frequently recorded in the timber palisade at Magheraboy (Danaher 2007).

These examples show that hazel and oak were frequently used in various structural contexts during the Neolithic. The jagged curve of Corylus during the Landnam may be indicative of coppicing of hazel in the vicinity of Cooney L. However, it is difficult, and probably impossible, to identify a short coppicing cycle given that each sample integrates ca. 30 years of pollen production and, furthermore, coppicing at any one time would probably be taking place in a small proportion of the pollen source area.

Subzone 4a (3710–3440 BC), which spans ca. 270 years, records the first phase of farming activity including Landnam, i.e. woodland clearance. In sub-subzone 4aa (3710–3680 BC) two cereal-type pollen were identified. These were 46 μm and 52 μm, respectively. On the
basis of their large size and well defined pore and annulus (cereal: 46 μm; pore: 6 μm; annulus: 12 μm; cereal: 52 μm; pore: 6 μm; annulus: 14 μm), these are regarded as of cereal origin. It is assumed that cereal growing was taking place in the vicinity of the lake.

In sub-subzone 4ab (3680–3530 BC, ca. 150 years) NAP increases substantially. There is a peak in *P. lanceolata* (5.2%) and Poaceae (6.4%). In this sub-subzone the most intensive farming phase of the Neolithic is recorded, but it declines towards the top. In sub-subzone 4ag (3530–3440 BC), there is still modest farming activity. The low representation of cereal-type pollen suggests that farming activity was predominantly pastoral based.

In subzone 4b (3440–3000 BC) a decline in NAP, in particular in *P. lanceolata* and Poaceae, suggests a substantial reduction in farming. However, small values of *P. lanceolata* are still recorded. In subzone 4c (3000–2700 BC) the *P. lanceolata* curve is interrupted for a period of about 130 years, which suggests that farming may have ceased completely during this period.

Another farming phase began in the late Neolithic (subzone 4d; 2700–2170 BC). *P. lanceolata* and Poaceae show a gradual increase and a few cereal-type pollen indicate arable activity (at 398 cm; ca. 2530 BC). The increase in pastoral indicators, such as Liguliflorae, *Succisa*, *Ranunculus* and *Rumex*-type, indicates a new expansion of grassland.

During the Neolithic oak was the main tall canopy tree, while pine was of minor importance. Elm re-established its importance in the woodland during the decline in farming activity. The records of *Betula* bud scales in sub-subzone 4aα and *Betula* fruits and bud scales in sub-subzone 4aγ indicate the presence of birch close to the edge of the lake. During the Neolithic ash and yew became part of the woodland composition. First a modest expansion of *Fraxinus* is recorded from the middle of subzone 4b, although some pollen grains are recorded from zone 1 onwards. During the mid/late Neolithic a modest expansion of *Taxus* (yew) is recorded (ca. 2960 BC). In many Irish pollen diagrams, in particular in western Ireland, a strong expansion of yew is recorded during the late Neolithic, showing a sharp peak followed by a drastic decline (L. Doo, Co. Mayo; O’Connell *et al.* 1987), and An Loch Mór (Molloy and O’Connell 2004). In Cooney L. yew shows a different trend, expanding gradually during the Bronze Age. During the Neolithic hazel was the main tall shrub. The interruption in the *Hedera* curve at the beginning of sub-subzone 4aβ and its resumption at the end of sub-subzone 4aγ could have anthropogenic causes. A possibility is the use of ivy
as fodder for cattle, as shown by Troels-Smith (1960, 1984) with reference to Switzerland. The gathering of ivy as fodder for cattle may have results in a decrease in the ivy population in the surroundings of the lake. Another possibility may be that ivy was affected by strong grazing pressure. Given that flowering of ivy and pollen dispersal are favoured by the opening-up of woodland, ivy was presumably under pressure (due probably to grazing; it may also be affected by lower temperatures but the required depression in temperature is unlikely) at this time.

At the transition between sub-subzone 4aα and 4aβ a notable peak in ash content is recorded. The ash curve starts to rise at 430 cm (zone 3; ca. 3730 BC), peaks at 428 cm (ca. 3670 BC) and declines until about 420 cm (ca. 3420 BC). Therefore the expansion of ash started a spectrum before the Landnam phase. The peak in ash coincides with the peak in *P. lanceolata* suggesting a substantial farming activity in the lake catchment which probably caused a substantial contribution of minerogenic material into the lake. The record of *Glomus* chlamydospores indicates an increase in soil erosion in the lake catchment (van Geel *et al.* 1989; van Geel 2003). Also *Diporotheca* sp. (*Diporotheca rhizophila* a parasitic fungus of the Solanaceae; van Geel *et al.* 2003), *Peridinium* sp, a dinoflagellate cyst, and *Filinia* sp., rotifer egg, expand during the Landnam. Lake eutrophication probably favoured their expansion. The micro-charcoal curve shows a small increase suggesting the use of fire by the Neolithic people at regional level. Sediment accumulation rate increased during Landnam. In zone 3, each sample integrates about 40 years (average), whereas in subzone 4a, about 30 years are represented. This situation may reflect an increase in soil erosion, probably due to the farming impact. In subzone 4c, when the woodland regeneration took place and the farming activity ceased, 1 cm spans 43 years.

At 400 cm a large stone (4 cm) was present in core CNY1, which coincides with a peak in magnetic susceptibility. The magnetic susceptibility suggests soil inwash to the lake. However, the low ash values suggest that soil erosion was not very strong. Two factors should be taken into account: the large size of the stone and the location of the core, i.e. close to the centre of the lake. The stone may have been laterally transported by a mud slide. However, given the saucer-shaped lake morphometry, a mud slide is unlikely and there is no evidence (pollen data, 14C dates, etc.) to support this. That it is a drop stone, i.e. transported by ice which melted and dropped the stone at this location, is a possibility. But
whether winter conditions were cold enough at this time in the Holocene is very much debatable. Given the size and weight of the stone, it is quite likely that it sunk in the sediments, therefore the time of deposition may be over-estimated if based on the age attributed to depth 400 cm. On the other hand, there is also the possibility that the stone lay in sediment above 400 cm but was dislodged during that particular coring drive (or while recovering the previous core segment) and so is older than the age/depth model would suggest. The most that can be said is that it suggests human activity in the late Neolithic (or younger) in or at the edge of the lake. Indeed, it may be connected with the fulacht fiadh at the lake edge.

Woodland and land use during the Bronze Age: zone 5 (ca. 2170–1160 BC); zone 6 (ca. 1160–940 BC); zone 7 (ca. 940–790 BC)

Zone 5 is regarded as spanning the early and mid Bronze Age. The increase of anthropogenic indicators in subzone 5a (2170–1840 BC), such as cereal-type pollen (maximum value 1%), *P. lanceolata* (maximum value 1.4%) and Poaceae (maximum value 10.8%) indicates a substantial rise in farming activity.

The beginning of the Bronze Age is also marked by a more intense woodland clearance compared to Neolithic Landnam. The steady increase in sediment accumulation (1 cm represents 34 years), is probably due to increased nutrient inputs as farming pressure increased. AP concentration decreases drastically from 8.9 x 10^5 grains cm^-3 at 390 cm to 3.1 x 10^5 grains cm^-3 at 388 cm.

In subzone 5b (1840–1730 BC) the increase in AP representation indicates a period of woodland regeneration, which is followed by another phase of farming activity recorded in subzone 5c (1730–1530 BC). This time Poaceae values remain low, whilst *P. lanceolata* peaks (5.5%). Cereal-type values are steady between 0.5 and 1% for a period lasting about 200 years (ca. 1730–1530 BC). This suggests considerable emphasis on arable farming, in which case the high *P. lanceolata* values may result largely from *P. lanceolata* growing on fallow ground which provides a particularly favourable habitat for ribwort plantain (cf. Behre 1981; Ghilardi and O'Connell 2012a). The decrease in AP such as *Fraxinus, Ulmus*
and *Corylus* corresponds with a peak in *Betula* (10.5%). The increase in *Betula* could be due to its colonizing ability of open space in woodland clearances.

In subzone 5d (1530–1380 BC) a decline in human impact is recorded. In subzone 5e (1380–1310 BC) *P. lanceolata* and cereal-type representations reach their lowest values during the Bronze Age. This decline suggests reduced farming in the vicinity of Cooney L. Not only the anthropogenic indicators decline; but also ferns, shrubs and Cyperaceae. A more closed woodland cover probably limited pollen dispersal of NAP and also fern spores and pollen of shrubs. The reduced human activity undoubtedly facilitated the regeneration of trees and shrubs such as elm, ash and hazel. *Taxus*, on the other hand, achieved maximum values in subzone 5f (3.7%, ca. 1240 BC) when there was moderate farming. Pollen production of yew probably increased with increased availability of light so the yew population was probably quite small.

Zone 6 (1160–940 BC) corresponds to the late Bronze Age. Increased farming drastically altered the landscape. Poaceae and *P. lanceolata* values reach 29.3% and 5%, respectively. Many herbaceous taxa have increased representation, indicating opening-up of the woodland. The substantial increase in cereal-type pollen suggests that the arable farming became important in the Cooney L. area. Bog taxa (cf. Cyperaceae, *Calluna* and *Sphagnum* curves) increase notably. The woodland disturbance is also reflected by the increase in *Pteridium* and shrubs, and in particular *Hedera*. The ash content shows two peaks. The first peak is recorded near the beginning of zone 6 (subzone 6a; 1160–1100 BC) and the second in mid subzone 6b (1100–940 BC). Ash indicates an increase in soil erosion that is supported by records of *Glomus* chlamydospores and *Pediastrum*. In addition sediment accumulation increases notably (1 cm represents ca. 9 years). During this period an expansion in *Diporotheca* and *Filinia* is also recorded, which suggests an increase in nutrient input to the lake. The increase in micro-charcoal and records of macro-charcoal, are indicators that fire played an increasingly important role during the late Bronze Age, presumably in settlement contexts (Ghilardi and O’Connell 2012b). The presence of a *fulacht fiadh* (usually dating to the mid-late Bronze Age) close to the lake, and also the many *fulachta fiadh* found during the recent excavation of the N4 Sligo roadworks (Danaher 2007) supports this.
This intensive farming period is followed by a woodland regeneration phase (zone 7), with a duration of ca. 55 years. During this phase most of the AP taxa recovered. At the upper part of the diagram from 880 to 790 BC another farming phase took place, although of modest intensity. This new phase records a substantial increase in *Peridinium* spores (a dinoflagellate) and *Botryococcus*. 
3.6 Discussion

Cooney L. is situated in an critical location for the investigation of early prehistoric farming activity. Northwards across Ballysadare Bay, lies Cúil Irra with the iconic Knocknarea Mountain. On the mountain top is Queen Maeve’s cairn and at its foot lies Carrowmore megalithic cemetery. To the south, on the top of the Ox Mountains, there is a cairn with a passage tomb on Croaghaun (180 m asl) and another cairn which may also contain a passage tomb on Doomore (272 m asl) (these features are regarded as part of the IPTT by Bergh (1995)). A court tomb (Corhawnagh) has been recorded ca. 700 m to the east of the lake in the lowlands which today are under pasture. The main concentration of megalithic tombs (predominantly court tombs) begins at Beltra, 5.5 km to the west of Cooney L., and extends from there to Easkey. The tombs are mainly concentrated in the lowlands between the N59 and the Ox Mountains. To the south of the Ox Mountains, there is a cluster of megalithic tombs (mainly wedge tombs; also court tombs) in the vicinity of Coolaney which is situated 5.5 km to the south-west of Cooney L. Overall, Cooney Lough lies within the area that was probably strongly influenced by the IPTT culture but rather distant from the main concentration of court and wedge tombs. The nearest known portal tomb is that near L. Dargan.

What appear to be reliable results have been obtained from the 11 samples submitted for $^{14}$C dating. The $^{14}$C dates are well spaced in the pollen profile: four in the pre-Elm Decline period (Boreal and Atlantic), three during the period that represents the Neolithic and four during the Bronze Age. Furthermore, the high precision of the dates and the lack of reversals facilitate the establishment of what is regarded as a reliable age/depth model.

The lower part of the pollen diagram has been published in Ghilardi and O’Connell (2012a) (Fig. 3 and 4). The part of the diagram published spans 9400–6000 cal. BP (7450–4050 BC). This high resolution diagram provides a detailed record for early Holocene woodland dynamics. Continuous or sub-continuous (every other cm) sampling, from 496 to 440 cm, was applied. Vegetational changes due to human interference were excluded, given that the population levels in most parts of Ireland during the Mesolithic were low (cf. Bergh 1995; Waddell 2010). Pedogenesis was also excluded given the calcareous character of the soils in the catchment of the lake and the unlikelihood that podzolisation was of major importance during the early Holocene. Therefore, climate change was considered the most
likely factor responsible for many of the changes recorded in this part of the pollen diagram. During this period woodland was composed mainly of hazel, which was the major contributor to the vegetation, together with elm and oak. Pine was also important, its local presence being vouched for by stomatal records as well as macrofossils including pine bud scales, pine periderm fragments and also two pine leaves. Other woody plants present in the local vegetation included birch, willow and ivy. The expansion of *Alnus* was recorded in the upper part of this short profile.

Five climate anomalies (CA-1 to CA-5) (Fig. 3.13) were suggested and compared with other proxies including the Greenland ice-cores (GRIP and NGRIP $\delta^{18}$O) (see Ghilardi and O’Connell 2012a, Fig. 3). Key features of these anomalies are the increase in *Betula* and *Pinus* (cold tolerant trees) alongside the decrease in *Corylus* and *Quercus* (thermophilous plants), which suggest establishment of a more continental climate (colder winter, low summer temperature and reduced precipitation). There was also a reduction in pollen productivity.

The anomalies CA-1 and CA-2 probably correspond to the 9.2 ka and 8.8 ka events. The most pronounced anomaly, CA-3, is recorded in subzone 1c which spans the interval 8450–8200 cal. BP (6500–6250 BC). This event has been associated with the so-called 8.2 ka event. This climatic oscillation was probably caused by the collapse of the north-eastern American ice sheet that resulted in pulses of freshwater into the N. Atlantic off Canada. This brought about a weakening of the Atlantic meridional overturning circulation (AMOC). This climatic deterioration, i.e. onset of cold and dry conditions, affected in particular the North Atlantic region (Wiersma and Renssen 2006; Alley et al. 2007; Alley and Ágústsdóttir 2005; Barber et al. 1999). In CNY1 profile the most pronounced change occurred towards the end of the subzone 1c (ca. 100 years centred on 8200 cal. BP). This, the 8.2 ka event, has been recorded not only as anomalies in the Greenland ice-core but also in other proxies from different locations in the N. Atlantic region (see Ghilardi and O’Connell 2012a, Figs. 3 and 4).

Interestingly the early Mesolithic in Ireland, characterized by microliths, ended ca. 9000 cal. BP and the Later Mesolithic (non-microlithic, ‘Bann-flake’ culture) began around or before 8000 cal. BP (Woodman et al. 1999). This lull during the Mesolithic could have been
brought about by the intensity of the 8.2 ka event. This climatic anomaly probably had negative consequences for the human population in Ireland (Ghilardi and O’Connell 2012a).

At about 7.5 ka, another anomaly (CA-4) was recorded that involved a two-step decline in *Corylus* values. The last anomaly, CA-5, initiated at ca. 7.1 ka, is defined largely by an increase in *Pinus*. *Betula* also increases. These changes suggest colder, more continental conditions that may have continued until ca. 6450 cal. BP.

The base of subzone 2b (7900 cal. BP; 5950 BC), where *Alnus* is consistently recorded (more or less consistently >0.2%), may be regarded as the Boreal/Atlantic transition.

The high resolution pollen data set from Cooney L. offers an important insight into how climate impinged on the vegetation dynamic during the early Holocene. In the mid and later part of the Holocene the effects of climate are not so obvious because during much of this time human interference is much stronger.

To get an overview of the pollen data from the mid Holocene onwards, the pollen data have been summarised in pie charts (Fig. 3.15). The late Atlantic period (zone 3), prior to the Elm Decline event, shows that a tall canopy woodland dominated (96%) with little evidence for disturbance. Records of *Ilex*, *Sorbus* and Poaceae may hint at opening of the canopy either due to human or natural causes. In this part of the diagram, however, there is no clear evidence for a human presence in a pre-Elm Decline context. The hypothesis of Göransson (1984; 2002) that coppicing and cereal cultivation took place before the Elm Decline seems to be most unlikely (Ghilardi and O’Connell 2012a).

The recent excavation carried out by Danaher (2007) at Magheraboy has given some of the earliest dates for Neolithic causewayed enclosures in Britain and Ireland. According to Cooney *et al.* (2011) the preferred model for Magheraboy shows that the enclosure was built sometime between 4115–3850 BC (95% probability; beginning of Magheraboy), probably in 4065–3945 BC (68% probability). Those dates mainly pre-date the Elm Decline. The pollen profile from Cooney L. does not give support for a Neolithic presence as the dates from Magheraboy suggest. Magheraboy is rather distant from Cooney L. (ca. 8 km), and a small lake, such as Cooney L., has a pollen source area of about 1 km. So there may be a Neolithic population at Magheraboy whose activities do not necessarily find expression at Cooney L.
Fig. 3.15. Pie charts showing the contribution of the various terrestrial pollen components in PAZs 3–7, profile CNY1.
In Cooney L. profile a distinct phase of human impact is recorded from the beginning of zone 4 (regarded as the beginning of the Neolithic), although the intensity varies throughout the zone. To show this variation, histograms were created for the periods that represent the Neolithic and the Bronze Age (Fig. 3.16A and Fig. 3.16B, respectively).

In zone 4, where a distinct Elm Decline is recorded (ca. 3710 BC), the pie charts show an opening up of the woodland (94%) while the histograms emphasize more detailed changes during the Neolithic. Farming activity is registered since sub-subzone 4aa (3710–3680 BC), where two large cereal-type pollen (46 and 52 µm), regarded as of cereal origin, are also recorded. This suggests arable farming, i.e. a Neolithic presence, in the vicinity of Cooney L.

The most intensive farming phase is recorded in 4aβ (3680–3530 BC), where *P. lanceolata* performs a notable peak achieving 5.2% and Poaceae expands to 6.4%. The decline in farming is recorded in 4ay (3530–3440 BC). This period of farming activity may be referred to as a Landnam and lasted ca. 270 years. The rather high *P. lanceolata* values suggest that early Neolithic farming in the vicinity of Cooney L. was mainly pastoral but there was a minor arable component.

Subzone 4b (3440–3000 BC) records a drastic decline in farming activity which ceased completely in subzone 4c for a period of 300 years (3000–2700 BC). During the late Neolithic, in subzone 4d (2700–2170 BC), there was a modest renewal of farming activity.

A more sustained opening up of the woodland is recorded in zone 5 (early/mid Bronze Age; 2170–1160 BC), where AP decreases to 90.5% while the pastoral and arable reach 6.1% and 0.3% respectively (zone average). This part of the diagram is characterized by a continuous record of anthropogenic indicators (*P. lanceolata* and cereal-type pollen), showing a prolonged period of farming activity, both pastoral and arable. This period of farming activity presents, however, different phases of human impact. During the late Bronze Age (zone 6; 1160–940 BC) the highest level of human impact is recorded. In this zone the AP values fall to ca. 70% (average) and NAP taxa expanded considerably. The high representation of cereal-type pollen suggests that arable activity had a considerable importance in the area close to Cooney L. The increase in soil erosion during this period is supported by the rise in ash content, *Pediastrum* and *Glomus* chlamydospores. There is also increased representation of *Nymphaea*, algae, NPP and micro-charcoal. The micro-charcoal
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record, together with the macro-charcoal record, suggests use of fire in local and regional contexts during the late Bronze Age. This is supported by the presence of a *fulacht fiadh* (an ancient cooking place) near the eastern shore of the lake. These monuments are generally dateable to the mid/late Bronze Age. A substantial number of *fulachta fiadh* are recorded from Co. Sligo (Egan *et al.* 2005) and several *fulachta fiadh* were recorded and excavated during the recent excavations connected with the N4 Sligo roadworks (Danaher 2007). Presumably fire was being used mainly in settlement contexts rather than for woodland clearance.

In zone 7 (940–790 BC) farming declined though there is still a modest level of farming activity, particularly in subzone 7b (880–790 BC). In this subzone there is a continuous cereal-type pollen record which suggests that cereal cultivation was taking place, possibly in the general vicinity of the lake.

The diagram presented in Fig. 3.17 (plotted to a time scale) serves to summarize the changes in vegetation and land use during the mid Holocene. In this diagram the following curves are presented: sediment accumulation time, palynological richness (measure of the pollen diversity) based on (a) the number of taxa recorded in each spectrum (includes taxa that are within the pollen sum) and (b) rarefaction analysis (see below), the NAP/AP ratios (indicator of landscape openness) and the NMS scores for the main axis (axis 1) (mainly indicating landscape openness, the result of human impact). Percentage pollen curves of AP (*Corylus* is also shown), shrubs, ferns, NAP (pastoral), cereal-type, bog and aquatic taxa are also plotted. Rarefaction analysis was carried out using psimpoll (ver. 4.27) by Bennett (http://www.chrono.qub.ac.uk/psimpoll/psimpoll_manual/4.27/ppmen.htm). Using this program, the estimated number of pollen taxa (*E(T*)*) is based on a standardized pollen count, i.e. the smallest pollen count within the data set. In this case the smallest pollen sum is 916. The palynological richness can be used as a measurement of the past floristic diversity (Tipper 1979; Birk and Line 1992; Odgaard 1994,1999, 2001; Seppä 1998; Weng *et al.* 2006; Berglund *et al.* 2008).
Fig. 3.16. Histograms relating to PAZ 4 (cf. Neolithic), and similar histograms relating to PAZs 5–7, profile CNY1.
Fig. 3.17. Summary diagram plotted to a time scale (calibrated year).
Zone 3 (cf. Atlantic) is characterized by low pollen diversity and a closed woodland structure. The number of taxa and the NAP/AP ratio increase at the beginning of subzone 4a and decline as the subzone ends. Both curves peak near the beginning of zone 4. Those peaks are related to a strong increase in pastoral taxa (in particular, *P. lanceolata*). The NMS curve and the palynological richness show a jagged trend, probably reflecting the changes in *Corylus* and *Alnus* values. Subzone 4a corresponds to Neolithic Landnam. In subzone 4b the curves decline indicating a reduction of open landscape due to a lower anthropogenic pressure, which reaches the minimum for this zone in subzone 4c. This subzone coincides with a lull in activity during the Neolithic. In the following subzone (4d), which represents the late Neolithic/early Bronze Age, the increase in pollen taxa and in NAP/AP ratio indicates a new opening-up of the landscape, due to a renewal of farming activity. From zone 5 (cf. early/mid Bronze Age) a rather high pollen diversity and an increase in landscape openness are reflected by the data. The greatest farming pressure occurs in subzones 5a, 5c and 5d. In zone 6 (cf. late Bronze Age), the curves indicated the overall highest levels of human impact and maximum landscape openness. In zone 7, a distinct decline in farming and consequently a regeneration of woodland are recorded.

The sediment accumulation time curve is positively correlated with levels of human impact. Sedimentation increases during Neolithic Landnam and declines as human impact decreases in the mid Neolithic. The highest sedimentation rate is achieved during the late Bronze Age when human impact on the terrestrial environment is at its maximum.
3.7 Conclusions

The pollen analytical investigations at Cooney L. provide a detailed record of the woodland dynamics and land-use for the early and the mid Holocene. The pollen diagram is associated with a reliable age/depth model based on eleven high quality AMS \(^{14}\)C dates.

Evidence for five climatic oscillations (CA1–CA5) is recorded in the lower part of the profile (7450–4050 BC) and published in Ghilardi and O’Connell (2012a). The most pronounced anomaly, CA-3, dated 8450–8200 cal. BP (6500–6250 BC) is associated with the so-called 8.2 ka event. During this period (cf. Boreal) hazel, oak, pine and elm were the main woodland components.

During the Atlantic period, i.e. in a pre-Elm Decline context, pine declines in importance and alder slowly expands. An increase in Poaceae and the initiation of an \(Ilex\) curve suggests some perturbation of the oak, elm and hazel dominated woodlands.

During the mid Holocene a well-defined Elm Decline is recorded at ca. 3710 BC. Two large cereal-type pollen grains, recorded at the beginning of the Elm Decline, indicate arable farming in the vicinity of Cooney L. A gap of about 30 years exists between the Elm Decline and the expansion of farming activity (ca. 3680 BC). This expansion starts with a notable peak in \(P. lanceolata\) (5.2\%) and in ash content. The main Landnam phase (subzone 4a) spans ca. 270 years. Farming was mainly pastoral-based but there was an arable component. This is followed by another ca. 500 years during which farming levels and human impact continued but at a low level (subzone 4b; 3440–3000 BC). Human impact ceased completely for a period of about 300 years (subzone 4c; 3000–2700 BC). A renewal of farming activity, of modest intensity compared with the Landnam phase, took place in the later Neolithic (subzone 4d; 2700–2170 BC).

During the early and the mid Bronze Age (2170–1160 BC) there is considerable farming activity, both pastoral and arable, although this is not as intense as in L. Dargan profile (Ghilardi and O’Connell 2012b). The strongest human impact is recorded during the late Bronze Age (1160–940 BC). Micro-charcoal and macro-charcoal records during the late Bronze Age indicate the importance of fire, probably for domestic use.
Chapter 4

Discussion and final conclusions

In this chapter the overall results are first discussed and final conclusions are drawn.

4.1 Discussion

The lakes selected for this study, namely L. Dargan and Cooney L., are both situated in an area of high prestige from the archaeological point of view. Both lie immediately outside the Cúil Irra peninsula which is among the most archaeologically rich area — especially as regards the Neolithic — in Ireland. Cooney L. is situated at the northern side of the Ox Mountains (Slieveward and Croaghaun peaks) and thus lies within the IPTT area as defined by Bergh (1995). The lake is only 5 km from Carrowmore and 7.5 km from Magheraboy enclosure. It is overlooked by Knocknarea to the north. On the top of this hill is Maeve’s Cairn (presumably with passage tomb within), five passage tombs have been recorded close to the cairn and several hut sites and other evidence of Neolithic activity are known from the slopes of Knocknarea (Bergh 2002).

Close to Cooney L. (ca. 700 to the east) there is a court tomb where today there is pasture, and overlooking the lake on the Ox Mountains are two cairns. That on Croaghaun, 1.5 km to the south-west of Cooney L., contains a passage tomb (Bergh 1995). The cairn on Doomore, 2.6 km further to the west, probably also contains a passage tomb but this has not been confirmed (Bergh 1995). During coring a fulacht fiadh, which is generally dated to the mid/late Bronze Age, was noted close to the southern lake shore. An ancient field wall and a hut site were noted towards the top of the large field at the north-east side of the lake.

L. Dargan is separated from the Cúil Irra peninsula by the Ox Mountains outlier (nearby peaks Slieve Dargan and Slieve Daene). This barrier is interrupted by the Ballysadare/Collooney corridor which facilitates connection with the peninsula. The lake lies less than 9 km from the Carrowmore passage tomb cemetery (Burenhult 1984, 2009; Bergh 1995, 2002) and the early Neolithic causewayed enclosure at Magheraboy (Danaher 2007). Situated on the Ox Mountains and overlooking the lake are four cairns (megalithic
tombs confirmed in two of these cairns) that are regarded as belonging to the IPTT (Bergh 1995). L. Dargan is also close to a cluster of lowland megalithic tombs including four court tombs (two within 720 m), a portal tomb within 1 km to the south-east (Egan et al. 2005; Ó Nualláin 1989) and a wedge tomb.

Both lakes are small to medium sized. Cooney Lough is a small lake with an area of ca. 3 ha. It lies in a sheltered depression in the low-lying coastal strip between the Ox Mountains and Ballysadare Bay to the north. The lake is in a closed basin, i.e. there is no inflowing or outflowing stream. Stream input of pollen is therefore not a factor that has to be taken into account. However, the surface water runoff undoubtedly transports pollen to the lake. Given the various considerations outlined above and especially the rather small lake size, pollen source area is probably also small, i.e. within a radius of 1 km.

L. Dargan, has an area of ca. 10 ha and has one small inflowing stream that drains the lower slopes of the Ox Mountains and flows into the lake a short distance from the small outflowing stream. In effect, the lake is therefore close to being enclosed. Its catchment includes the southern slopes of the Ox Mountains and the more fertile lowlands in which it lies. As a small to medium sized lake, its pollen source area lies probably within a radius of 1–2 km.

Two pollen profiles were constructed, DRG1 from L. Dargan and CNY1 from Cooney L. The former spans the interval 7800 BC–AD 1700, i.e. most of the Holocene. The latter profile spans the interval 7500–790 BC, i.e. the early and mid Holocene. Note: dates are based on the age/depth models; in other words, they are the best available approximations; the quoted precision should be viewed accordingly.

In the case of each profile, an independent chronology has been constructed based on AMS $^{14}$C dates. For Cooney L. organic material from 11 sediment samples were used for AMS $^{14}$C dating. Suitable material of terrestrial origin was relatively common, so what appears to be reliable $^{14}$C dates with low error values were obtained. These are also well distributed through the pollen profile.

From L. Dargan, material from 18 sediment samples were submitted for AMS $^{14}$C dating. One sample contained insufficient material and so no date was returned. Four other dates, mainly from the upper part of the profile, showed age reversal. This appears to be due to
reworked organic material that was washed in from the catchment due to high levels of human activity. A further four samples showed a large error value but the dates returned appear to be reliable and so, unlike the dates referred to above, these were used in the construction of the age/depth model. Most of the $^{14}$C dates relate to the central part of the diagram where early farming impact is recorded so that, despite these difficulties referred to above, this important part of the record is regarded as being chronologically well constrained and the chronology of the other parts of the profile may also be regarded as the best available approximations given the various difficulties involved.

The main focus of these palaeoenvironmental investigations was to reconstruct vegetation dynamics and farming impact in the prehistoric period. These and other findings of importance from the research are now discussed.

### 4.1.1 Early Holocene

The basal part of the two pollen profiles are shown in Fig. 4.01. Profile CNY1 spans from 7450–4010 BC and profile DRG1 from 7800–4260 BC (cf. Boreal). The late Mesolithic to the late Bronze Age pollen diagrams (CNY1: 4110–790 BC; DRG1: 4260–700 BC) are shown in Fig. 4.02.

Most of the trees except alder were already present when the profiles open. The early Holocene woodland was composed by pine, oak, hazel and elm. The large number of *Pinus* stomata, in both cores, indicates that pine played an important role. In particular several *Pinus* bud scales and periderm fragments and two leaves recorded in CNY1 highlight the importance of this tree in the immediate vicinity of Cooney L.

From the lower part of the profile, evidence of Mesolithic activity is lacking. In the archaeological record the main evidence for Mesolithic activity comes from the shores of Lough Gara, near the border with Co. Roscommon, south Co. Sligo. Here evidence for hunter-gatherer communities relating mainly to the late Mesolithic period have been recorded (Fredengren 2002; Woodman 1978; O’Sullivan 1998). Evidence for a Mesolithic presence in Cúil Irra also came to light in the course of Burenhult’s (1984) excavations of passage tombs at Carrowmore and the shell middens that were excavated at Culleenmore.
on the south-west coastal area of Cúil Irra appear to relate mainly to the Neolithic and Bronze Age, but activity in the late Mesolithic cannot be excluded.

Given that Mesolithic peoples relied mainly on fishing, gathering and hunting, it is unlikely that they created a substantial impact on vegetation such as might be reflected in the pollen record. It is more likely therefore that vegetation changes were due to natural causes, i.e. climate change, species competition, edaphic changes and other factors.

In CNY1 during the early Holocene five climate anomalies (CA-1 to CA-5) have been identified (Ghilardi and O’Connell 2012a). In Fig. 4.01, the vegetational changes during the early Holocene as recorded in profiles CNY1 and DRG1 are shown and also the Greenland ice-core δ¹⁸O records from GRIP and NGRIP. The climate anomalies as identified in the CNY1 profile are also shown.

Though the level of detail in profile DRG1 is less than that achieved in profile CNY1 (dating control might also be better), it is nevertheless possible to identify some common features. In subzone DRG1-1b (6370–6100 BC; 8320–8050 BP), the increase in Betula and Pinus occurs at the same time as a decrease in Quercus and Corylus. According to the age/depth model, this subzone coincides with CA-3 as recorded in Cooney L. (6500–6250 BC; 8450–8200 cal. BP), the upper part of which (CA-3b) corresponds with the 8.2 ka event as recorded in the Greenland ice cores. This climate anomaly was probably caused by a large outburst flood from Lake Agassiz and Lake Ojibway, i.e. the large lakes that formed as the Wisconsin ice sheet melted. This outburst (several may be involved) probably changed the strength of the Atlantic meridional overturning circulation (AMOC), which is the major vehicle for the transfer of heat to high latitudes in the North Atlantic (Alley et al. 1997; Alley and Ágústsdóttir 2005; Ellison et al. 2006; Hede et al. 2010). This climatic anomaly resulted in colder and dry conditions in the N. Atlantic region, including Ireland (Wiersma and Renssen 2006; Alley et al. 2007; Alley and Ágústsdóttir 2005; Barber et al. 1999; Ghilardi and O’Connell 2012a).

The early Mesolithic in Ireland, which is characterized by microlithics, ended at ca. 9000 cal. BP. The late Mesolithic, i.e. the so-called Bann-flake culture, started 8000 cal. BP (Woodman 2009). Thus there appears to be a gap of about a thousand years between the
early and the late Mesolithic. It is quite likely that the 8.2 ka anomaly had negative consequences for the Mesolithic population in Ireland (Ghilardi and O’Connell 2012a).

After the 8.2 ka event a gradual increase of *Alnus* is recorded in both pollen profiles. This increase is usually regarded as marking the Boreal/Atlantic transition (Jessen 1949; Mitchell 1951; O’Connell and Molloy 2005). However, to identify a specific moment for this transition is not so straightforward. In Cooney L., the base of subzone 2b (5850 BC) is regarded as the Boreal/Atlantic transition, i.e. where *Alnus* is consistently recorded. The first substantial expansion of *Alnus* is, however, recorded in subzone 2d (4790 BC) where *Pinus* begins to decline. In DRG1 *Alnus* starts to be continuously recorded from the base of subzone 1d (5760 BC), and increases at the base of zone 2 (4600 BC), where *Pinus* representation falls substantially. The base of zone 2 is regarded as the Boreal/Atlantic transition.

Holmes *et al.* (2007) suggest that at about 4500 BC lake levels at An Loch Mór began to rise. Similar lake-level changes have been noted in continental Europe and especially in the alpine region (Magny 2004; Magny *et al.* 2006). This probably corresponds with the ‘Holocene Climatic Optimum’, which is characterized by elevated temperatures, especially winter temperatures, and high precipitation (Huntley *et al.* 2002). Such a shift in climate would be expected to favour alder and disadvantage pine, which is a species favoured by continental-type climate.

During the late Atlantic, before the Elm Decline event, tall canopy trees that gave woodlands with a closed structure characterized the landscape (AP: 96% in CNY1; 97% in DRG1; Fig. 4.02). In Cooney L. records for *Ilex*, *Sorbus* and Poaceae suggest some disturbance of the woodland. At L. Dargan, there is also some evidence for woodland perturbation (cf. *Ilex* and *Sorbus*). Evidence for such minor disturbances are now known from several pollen profiles (O’Connell and Molloy 2001; Molloy and O’Connell 2004; Plunkett *et al.* 2008) but it is uncertain if human or natural factors such as climate change are responsible.
**Fig. 4.03.** Pie charts relating to the mid Holocene at Cooney L. and L. Dargan.
4.1.2 Mid Holocene (including Elm Decline and human impact in the Neolithic and Bronze Age)

The mid Holocene is characterized by several vegetational changes. From the beginning of the Neolithic, human populations started to impinge to varying degrees on both vegetation and landscape.

As well as presenting summary percentage pollen diagrams drawn to a time scale from Cooney L. and L. Dargan (Fig. 4.02), the pollen data from both sites are summarised in pie charts (Fig. 4.03). These charts show the values achieved by the various pollen components included in the PS.

To further highlight and compare vegetational changes and land-use during the Neolithic and Bronze Age the relevant palynological data from the two sites are summarized in histogram format in Figs. 4.04 and 4.05, respectively.

In Fig. 4.06, palaeoenvironmental reconstructions relating to the Neolithic based on profiles CNY1 and DRG1 are shown schematically. Other reconstructions and related information brought together in this figure include Loughmeenaghan (Stolze et al. 2012) from north of Carrowkeel, Co. Sligo, Céide Fields (Molloy and O’Connell 1995; O’Connell and Molloy 2001) and Garrynagran (O’Connell and Molloy 2001) from N. Mayo and L. Sheeauns from W. Connemara, Co. Galway (Molloy and O’Connell 1991). These have been selected as they are the main detailed pollen records from W. Ireland and therefore usefully serve as comparisons to the available detailed pollen profiles from Co. Sligo. Chronological data from archaeological investigations into the Neolithic are also shown for the following: (a) early Neolithic rectangular houses in Ireland (McSparron 2008; Cooney et al. 2011), (b) round mound at Rathdowney Beg, Co. Sligo (Mount 1999), (c) the start and end of the activity at Magheraboy enclosure, (d) two models (model 2 and 3) for the start of the Irish Neolithic and the Magheraboy activity (Cooney et al. 2011), (e) initial use of Irish court tombs (Schulting et al. 2012) and (f) charred cereals from Ireland and Britain (Brown 2007).

The Elm Decline has traditionally been considered the marker for the beginning of the Neolithic. In CNY1, the beginning of this event is recorded at 3710 BC and in DRG1 at 3760 BC. The Elm Decline in these two profiles may therefore be regarded as broadly contemporaneous.
Fig. 4.04. Histograms relating to zones CNY1-4 and DRG1-3 (Neolithic).
Fig. 4.05. Histograms relating zones CNY1 5–7 and zone DRG1-4 (cf. Bronze Age).
In CNY1, *Ulmus* percentage values decline from a maximum value of 19.2% at 432 cm (3800 BC) in zone 3 (zone 3 average =16.6%) to a minimum of 1.3% at 426 cm (3610 BC) in zone 4 (zone 4a average = 5.9%). At the Elm Decline itself (zone boundary), *Ulmus* values decline from 14.4% at 430 cm (3730 BC) to 9.3% at the next sample (429 cm; 3698 BC).

In DRG1, the maximum value reached by *Ulmus* in zone 2 is 21.8% at 578 cm (3860 BC) (zone 2 average =18.8%) and a minimum value of 3.4% is reached at 566 cm (3480 BC) in zone 3 (zone 3a average = 10.5%). At the Elm Decline itself (zone boundary), *Ulmus* values decline from 21% 576 cm (3850 BC) to 11% at the next sample (574 cm; 3725 BC).

The Elm Decline occurs more rapidly and is more severe at Cooney L. This may be related to the smaller pollen source area at Cooney L. and so the buffering effect on the pollen components that might arise from a larger pollen source area, as at L. Dargan, does not come into play.

In many Irish pollen diagrams there is often a delay between the onset of the Elm Decline and the beginning of Landnam (see Fig. 4.06; cf. O’Connell and Molloy 2001). In Cooney L. profile the expansion of farming activity occurs at the beginning of 4aβ (3680 BC), where the *P. lanceolata* curve shows a notable peak (it achieves 5.2%) and Poaceae expands to 6.4%. At this site, there is a delay of ca. 30 years between the Elm Decline and the beginning of Landnam. At L. Dargan, the delay is about 60 years (3700 BC) and farming impact seems to be rather modest (maximum value for *P. lanceolata* is 3.4% and for Poaceae is 4.7%; but differences in pollen source area need to be taken into account). At Loughmeenaghan a delay of 40 years is recorded (Stolze *et al.* 2012). In Co. Sligo, therefore, a few decades appear to separate the Elm Decline and the beginning of Landnam. The delay lends support to the idea that woodland clearance by Neolithic farmers (Neolithic Landnam) was not the main cause of the Elm Decline but rather that it was disease, analogous to the present-day Dutch Elm disease.
Fig. 4.06.

A. The chronology of early Neolithic in Ireland based on \(^{14}\)C dates derived from: (a) Neolithic rectangular houses, (b) Neolithic mound at Rathdowney Beg, (c) the start and the end of Neolithic activity at Magheraboy enclosure, (d) two models (models 2 and 3) for the start of the Irish Neolithic and Neolithic activity at Magheraboy (for details of the chronology see Cooney et al. 2011), (e) initial use of Irish court tombs (Schulting et al. 2012), and (f) charred cereal chronology for Ireland and Britain (Brown 2007).

B. Schematic depiction of farming activity based on data from Cooney L. and L. Dargan (Chapters 3 and 2, respectively) and Loughmeenaghan (Stolze et al. 2012), Céide Field and Garrynagran in north Co. Mayo and L. Sheeauns in Co. Galway (O’Connell and Molloy 2001).

The duration of pine growing in a blanket bog context is based mainly on pine pollen records and also pine stomata. A question mark indicates uncertainty as to the duration of the earlier pine flush in the Glenulra basin, Céide Fields (GLU IV). The dry/wet curve for Céide Fields relates to the basin bog where core GLU IV was taken (after O’Connell and Molloy 2001).
Fig. 4.06. Summary of archaeological and pollen data relating to the Neolithic.
Differences and similarities between Cooney L. and L. Dargan during the Neolithic are now discussed by reference to the histograms presented in Fig. 4.04. In both profiles, Landnam takes place in the early Neolithic. In Cooney L. Landnam and the main farming activity phase is recorded in 4a\(\beta\) (3680–3530 BC; note: 4a\(\alpha\) includes only a single spectrum) and in 4a\(\gamma\) (3530–3440 BC) a notable decline in activity has set in. In L. Dargan, according to the age/depth model, the early phase of Neolithic activity lasted ca. 750 years, with the Landnam phase lasting ca. 700 years; i.e. all but the earliest part of DRG1-3a\(\alpha\) and all of 3a\(\beta\) (3700–3000 BC). At Cooney L., on the other hand, early Neolithic impact lasted ca. 270 years with Landnam having a duration of ca. 240 years (CNY1-4a\(\beta\) and 4a\(\gamma\)). So, while early Neolithic impact begins to register at about the same time in both profiles, i.e. at 3700 BC, it ends much earlier at Cooney L., i.e. at 3440 BC vs. 3000 BC at L. Dargan. The very slender curve for *P. lanceolata* in CNY1-4b may well be reflecting farming in the wider region, at a time when there is little activity in the vicinity of Cooney L.

In both CNY1 and DRG1, cereal-type pollen are recorded at about the same time (3750 BC) and in the same palynological context, as the Elm Decline is well underway. In L. Dargan the largest cereal-type pollen was identified to *Triticum*-type, and so more than likely derives from wheat. Two large pollen grains were also recorded in CNY1 at the point where the Elm Decline was taking place. The cereal-type record during the early Neolithic is longer and better expressed in DRG1 (from 3730 BC to 3000 BC). In Cooney L., on the other hand, occasional cereal-type pollen are recorded in the interval 3700–3420 BC; otherwise, there are few cereal-type pollen in the interval ascribed to the Neolithic. Arable farming was probably not very important in the vicinity of either lake but it seems to have greater importance at L. Dargan but here also the overall levels of farming activity were higher.

At Loughmeenaghan, southern Co. Sligo, the record for the cultivation of *Triticum* started at 3780 BC and lasted until 3640 BC. In this pollen diagram there is also a *Hordeum*-type curve. The authors suggest that the source for the *Hordeum*-type is *Glyceria*, an aquatic grass. This seems to be a conservative view, because it excludes the possibility that this pollen could refer to barley or other cultivated grasses. The pollen of *Glyceria* can be recognized from the other *Hordeum*-type by the narrow annulus in relation to the large pore size (Beug 1961, 2004). In Cooney L. and L. Dargan pollen profiles *Glyceria*-type pollen was not recorded. *Glyceria*, though a grass of wet habitats, is usually not particularly
frequent at the margins of lakes so it is not surprising that there are no records of *Glyceria*-type pollen in these profiles. Overall, the cereal-type pollen records from Cooney L., L. Dargan and Loughmeenaghan suggest that arable farming took place in Co. Sligo during the early Neolithic. The Neolithic farming economy was, however, mainly based on pastoral activity with a minor arable component.

Göransson (1984, 2002) recorded cereal pollen, *P. lanceolata* and charcoal in a pre-Elm Decline context in lake core he investigated from Ballygawley L. On this basis, he suggested that Neolithic people were present in Sligo in a pre-Elm Decline context, transforming the forest into coppice woodlands and probably using fire for clearance. Göransson called this hypothesis “the early Neolithic Fire-Grazing Phase” (Göransson 1984, p. 174). However, in the profiles from Co. Sligo (including also the diagrams from Union Wood lake (Dodson and Bradshaw 1987) and Lough Anelteen (Turbayne 1985)) there is no evidence for cereal-type pollen that pre-date the Elm Decline. In a recent pollen profile from Lough Availe, Transcrabbagh Bog, Carrowkeel, Stolze (2012b) gives records for *P. lanceolata* pollen in a pre-Elm Decline context and also charred wood. The author suggests that this is evidence for human interference during the late Mesolithic (at/after 4110 BC) and that the disturbance was linked to burning. However, this may be a rather simplistic conclusion because *P. lanceolata* does not necessarily prove human interference and charred wood could have originated through a natural fire. At L. Sheeauns, on the other hand, not only is *P. lanceolata* recorded in an immediate pre-Elm Decline context, but there are also *Triticum*-type pollen. Thus the evidence is much stronger for Neolithic activity (O’Connell and Molloy 2001; Molloy and O’Connell 1991).

In other parts of Ireland, as in Co. Sligo, the most intensive farming activity is recorded during the early Neolithic (Fig. 4.05; Ghilardi and O’Connell 2012b; Stolze et al. 2012; O’Connell and Molloy 2001; Plunkett et al. 2008; Brown et al. 2005). Archaeological evidence, supported by $^{14}$C dates, corroborate this statement. In Co. Sligo the basal date from the Round Mound at Rathdowney Beg (Mount 1999), i.e. indicative of when the monument was constructed, is 3775–3645 cal. BC (95% probability) probably 3710–3660 cal. BC (68% probability) (Cooney et al. 2011). The results of pollen analysis of the ditch fill suggests that open grassland prevailed locally during the Neolithic. The radiocarbon dates for the beginning of rectangular houses during the Neolithic in Ireland (McSparron
2008), according to the recent chronology suggested by Cooney et al. (2011), is 3730–3660 cal. BC (98% probability) and 3715–3680 cal. BC (68% probability) and the end of their use is 3640–3605 cal. BC (98% probability) and 3635–3615 cal. BC (68% probability). The recent dates for the initial use of the Irish court tombs range from 3700 to 3570 BC (Schulting et al. 2012). Brown (2007) in a study of 63 sites between Britain and Ireland with charred cereal remains, reports that most of the dates lie between 3800–3000 BC. The recent archaeological evidence from Magheraboy supports the presence of an early Neolithic activity. This site yields some of the earliest dates for causewayed enclosures in Britain and Ireland. The preferred model for Magheraboy, according to Cooney et al. (2011), indicates that the enclosure was built between 4115–3850 BC (95% probability; start Magheraboy), probably in 4065–3945 BC (68% probability) (Danaher 2007; Cooney et al. 2011; see Fig. 4.05). The pollen profiles CNY1 and DRG1 show no evidence of activity so early in the Neolithic period.

A distinct lull in activity in approximately the mid Neolithic is a feature of both profiles (CNY1: 3440–2700 BC; DRG1: 3000–2700 BC) and is followed by a renewal of farming activity during the late Neolithic/early Bronze Age. The lull in the mid Neolithic seems to have not only local/regional significance (see Fig. 4.05; Ghilardi and O’Connell 2012b; Stolze et al. 2012) as it is recorded in several pollen diagrams from different parts of Ireland (cf. O’Connell and Molloy 2001). The possible causes of this decline in farming activity are still to be understood. Stolze et al. (2012) suggest a possible climatic deterioration (cool and wet conditions) at the transition between the early and the mid Neolithic, causing the abandonment by the first farmers. Evidence for this climatic downturn, however, is not particularly strong (cf. Ghilardi and O’Connell 2012b). For instance the high frequency of bog timbers (both pine and oak) and the dry bog surfaces in Glenurla and north Mayo, where pine was growing in the blanket bogs, suggest dry conditions (O’Connell and Molloy 2001).

At Cooney L., the Taxus curve initiated during the woodland regeneration phase, expanded to a minor degree in the late Neolithic and early Bronze Age. The expansion is, however, modest compared to other pollen diagrams from western Ireland (O’Connell et al. 1987; Molloy and O’Connell 2004). In contrast, at L. Dargan Taxus failed to expand which is also the case in other pollen diagrams from Co. Sligo (Dodson and Bradshaw 1987; Turbayne 1985; Stolze et al. 2012). This suggests that yew was not important during the mid Holocene.
in Co. Sligo. Nevertheless, at Culleenamore, Cúil Irra, yew charcoal was recorded from a Neolithic context in a shell midden (Bartholin 1984). O’Connell and Molloy (2001) suggest that the expansion of yew in the later Neolithic was a decidedly western/south-western phenomenon in Ireland. In a pollen profile from Muckross, Killarney, *Taxus* was recorded since the beginning of the Boreal, and the expansion occurred after the Elm Decline (Mitchell 1988) but this seems to be the only profile from Ireland where there is an early record for *Taxus*. The present-day yew wood on Muckross peninsula, Killarney, is one of the best yew woods in Britain and Ireland. Clearly, yew has a long history in Killarney and this seems to be rather exceptional in Irish and British contexts.

The pie charts for Cooney L. and L. Dargan (Fig. 4.03) emphasise the major opening up of woodland that occurred in the Bronze Age. This period is characterized by three substantial farming phases, where each phase is followed by reduced farming activity and woodland regeneration. During the Bronze Age, woodland was mainly composed of hazel, oak, ash, alder and elm, although elm is only a minor component by the late Bronze Age (CNY1-6, 1160–940 BC; DRG1-4d, e and f, 1450–550 BC). Yew was better represented at Cooney L. (cf. *Taxus* peak in zone CNY1-5f of 3.7%; 1240 BC; at L. Dargan the curve is discontinuous). At the beginning of the Bronze Age the concentration diagrams, from both profiles, show a pronounced decline in AP, with a correspondingly large expansion of indicators of open habitat and also of human activity. During this period different levels of human impact are recorded. There are continuous records for anthropogenic indicators (*P. lanceolata* and cereal-type pollen) in both pollen diagrams which suggests sustained farming at both sites. The three farming phases, in both cases, are characterized by well established pastoral and arable farming activity. The three main farming phases are now compared.

The first farming phase (cf. early Bronze Age) at Cooney L. is recorded in subzone CNY1-5a and spans from 2170 BC to 1840 BC. In L. Dargan, there is a corresponding phase recorded in subzone DRG1-4a that spans 2120–1760 BC. At both sites this farming phase lasted about three centuries. The main differences involve higher values for Poaceae, *P. lanceolata* and cereal-type pollen in L. Dargan. In DRG1, the high cereal-type values are particularly noteworthy (the highest values for the prehistoric period). This suggests that arable farming was important. Also noteworthy is the importance of micro-charcoal in the
Chapter 4: Discussion and conclusions

DRG1 profile (more or less throughout the Bronze Age) while in the CNY1 profile it achieves importance only in the late Bronze Age. Fire was clearly more important in the L. Dargan area.

The second farming phase (cf. mid Bronze Age) in Cooney L. spans the interval 1730–1530 BC (subzone CNY1-5c and d) whereas at L. Dargan there is a farming phase in the interval 1670–1450 BC (subzone DRG1-4c). This farming phase lasted about two centuries at both sites, but it occurred earlier at Cooney L. began and ended a century earlier. This second farming phase has similar intensity at both sites.

The third farming phase (cf. late Bronze Age) in Cooney L. spans 1160–940 BC (zone CNY1-6). The most intense farming activity in the profile is recorded during this interval. That human impact was substantial is seen in the strong expansion of NAP and the decline of AP to 70% (zone average). The high cereal-type pollen values highlight the considerable importance of arable activity. Fire also was of importance for the first time in the Cooney L. area. At L. Dargan the third farming phase spans 1100–970 BC (zone DRG1-4e) and is also characterized by a substantial opening up of the landscape (AP falls to 63.5% (zone average)). At Cooney L. high impact farming seems to have begun somewhat earlier but, at both sites, the high level of farming activity had largely ceased by the second half of the 10th century BC. The third farming phase (cf. late Bronze Age) was undoubtedly of major importance at both sites.

A distinct increase in human impact during the late Bronze Age is recorded also in many Irish pollen records (Molloy 2005; Molloy and O’Connell 2011, 2012; Overland and O’Connell 2008; Plunkett 2009). In Co. Clare two sites show a well expressed farming activity centred during the late Bronze Age: Mooghaun L. (Molloy 2005) and Caheraphuca (Molloy and O’Connell 2011, 2012). The former presents a more severe and prolongated farming phase, which lasted almost four centuries (1100–700 BC) and involved total woodland clearance. The farming phase recorded at Caheraphuca spans ca. 250 years (1200–950 BC). This corresponds closely with the records from Cooney L. and L. Dargan. Clearly the late Bronze Age was a period of major importance. The high level of activity involving elaborate metal working, etc. that is known from the archaeological record (cf.
Waddell 2010), was obviously underpinned by intensive farming that probably supported a large population.

### 4.1.3 Late Holocene (Iron Age and the historical period)

This time interval is represented only in profile DRG1 which continues to near present time (it is estimated to reach AD 1700). This part of the record is discussed in Chapter 2 and the main details are summarised in Final conclusions (see below). Ghilardi and O’Connell (2012b) also give this part of the record detailed consideration.
4.2 Final conclusions

The pollen analytical investigations carried out at two lakes in northern Co. Sligo, i.e. Cooney L. and L. Dargan, provide fine-resolution records (profiles CNY1 and DRG1, respectively) of Holocene woodland and land-use dynamics.

The two pollen diagrams open shortly after tall canopy woodland with pine, hazel, oak and elm was established but alder had not yet expanded (cf. Boreal period). The CNY1 profile reaches the late Bronze Age (790 BC), whereas the DRG1 profile extends close to present day (AD 1700).

In the high resolution early post-glacial pollen record from Cooney L., which has a secure chronology based on AMS $^{14}$C-dates, five climate anomalies (CA-1 to CA-5) were identified (Ghilardi and O’Connell 2012a). These climate anomalies, and especially CA-3 which is regarded as equivalent to the 8.2 ka event as recorded in many proxies from the northern Hemisphere (Wiersma and Renssen 2006; Alley et al. 2007; Alley and Ágústsdóttir 2005; Barber et al. 1999), are characterized by the increase in Betula and Pinus (cold tolerant trees) in conjunction with a decrease in Corylus and Quercus (thermophilous plants). During the 8.2 ka event, the climate in N. Sligo was more continental climate (colder winter, low summer temperature and reduced precipitation). In profile DRG1, although the chronology is poorly constrained and there is not continuous sampling in this part of the profile, what appears to be an 8.2 ka event also registers, even if less clearly.

Human impact prior to the Elm Decline has not been identified with certainty in the pollen profiles. There is, however, evidence of some disturbance/perturbation in the woodlands that is suggested by an Ilex curve and records from Sorbus and Poaceae. P. lanceolata, however, is not recorded until immediately prior to the Elm Decline. Pre-Elm Decline disturbances were therefore minor and were greatest immediately before the Elm Decline.

The Elm Decline is well defined in both profiles (CNY1, 3710 BC; DRG1, 3760 BC). The differences between the dates are not significant in a statistical sense and so it seems acceptable to regard the event at the two sites as being broadly synchronous. Disease of elm is regarded as the main factor that brought about the decline of elm at the Elm Decline and possibly also in later declines of elm.
In both pollen profiles, Neolithic activity is concentrated in the early part of the Neolithic. Neolithic farmers seem to have been present as the Elm Decline was taking place (this based on cereal-type pollen records in both profiles). Landnam, involving the expansion of farming, and especially pastoral farming, and woodland clearance starts some few decades after the Elm Decline. At Cooney L. higher values of *P. lanceolata* suggest that early Neolithic impact may have been more intense than at L. Dargan, though this may be partly an impression due to a small pollen source area at Cooney L. At Cooney L. the main farming phase spanned from 3680 BC to 3530 BC and declined between 3530 BC and 3440 BC. *P. lanceolata* values are very low in the interval 3440–3000 BC. At L. Dargan the main farming phase stretched from 3760 BC to 3390 BC and farming activity declined between 3390 BC and 3000 BC.

During the early Neolithic there was cereal growing at both sites. At L. Dargan the cereal-type record is better expressed and cereal-type pollen are recorded over a longer period in the early Neolithic.

In several Irish pollen diagrams Neolithic Landnam is concentrated in the early part of the Neolithic (Stolze et al. 2012; O’Connell and Molloy 2001; Plunkett et al. 2008; Brown et al. 2005). Taken in conjunction with the archaeological evidence at a national level (McSparron 2008; Cooney et al. 2011; Brown 2007), it points to a substantial rise in population, farming and overall impact on the landscape during the early Neolithic.

Neolithic Landnam is following by a lull and possibly a cessation in farming activity. This is particularly well defined in the DRG1 profile (DRG1-3b, 3000–2710 BC). In the CNY1 profile, a corresponding feature is recorded in CNY1-4c (3000–2700 BC) but at this site the lull may have started much earlier (CNY1-4b, 3440–3000 BC). Closed canopy woodland reestablished itself and yew expanded to a limited degree at Cooney L.

In the late Neolithic (from 2700 BC onwards), both profiles and especially DRG1 suggest renewed farming, again mainly pastoral but with an arable component. This renewal in activity is especially evident in the DRG1 profile.

The Bronze Age is characterized by much higher levels of farming activity, both pastoral and arable. The woodland was mainly composed of hazel, oak, ash and alder. Elm was greatly reduced during the late Bronze Age. Yew achieved importance only at Cooney L.
but only to a limited degree (maximum expansion at 1240 BC). Three main farming phase were identified at both sites. These involved woodland clearances followed by woodland regeneration.

The first farming phase (cf. early Bronze Age) in CNY1 spans 2170–1840 BC and in DRG1 it spans 2120–1760 BC. In DRG1, cereal-type pollen achieves the highest representation for the prehistoric period. In Cooney L. the farming phase is less pronounced.

The second farming phase (cf. mid Bronze Age) in Cooney L. spans 1730–1530 BC whereas in L. Dargan it spans 1670–1450 BC. At L. Dargan human impact may have been stronger than at Cooney L. In CNY1, however, *P. lanceolata* and cereal-type are better represented than during the first farming phase.

The third farming phase (cf. late Bronze Age) in CNY1 spans 1160–940 BC and in L. Dargan it spans 1100–970 BC. Both profiles show a high level of human impact and considerable use of fire. This is the first time that fire assumes importance at Cooney L. At Cooney L. this farming phase is longer; mainly because it starts somewhat earlier.

Pollen profile DRG1 continues to AD 1700, i.e. it includes the Iron Age and most of the historical period. During the interval 550 BC–AD 350, which is considered to represent the Iron Age, there was initially a considerable increased in human impact that resulted in a substantial opening of the landscape (increase in NAP) and pastoral and arable farming were important. There was also increase in micro-charcoal, indicative of increased firing presumably a consequence of increased human activity. The main trees affected by the intensive clearance were oak, ash and hazel. A decline in pastoral farming is recorded during the late Iron Age (80 BC–AD 350), when a woodland regeneration took place (a minor expansion of *Taxus* is recorded). During this period, however, arable farming was still important in the L. Dargan area. This period is referred to the Late Iron Age Lull (LIAL), recorded also in other Irish pollen diagrams (cf. Overland and O’Connell 2011).

A large-scale woodland clearance associated with an intense farming activity started from AD 350. Three main expansions of the cereal-type curve are recorded at AD 800, 1330 and 1500. This points to increased cereal growing at these times. The record of *Pinus* pollen and stomata (pine was extinct in this period) and the reversal of $^{14}$C dates in this part of the
diagram suggest that reworked material was brought into the lake, again suggesting a high level of human impact.

A decrease in farming activity is recorded at the top of the profile. This decrease may be related to the adoption of potato cultivation, although *Solanum* pollen is silent in the pollen diagram because of the poor dispersal capacity.

Hazel, oak and alder were the main trees in the historical period. McCracken (1971) describe an old woodland, Leguy woods, which lay between the lower slope of the Ox Mountain and the sea and stretched to Lough Gill. These woods were present until the seventeenth century and, according to the historical sources, were composed of oak, hazel, yew and holly. At the end of the seventeenth century and during the eighteenth century a strong exploitation drastically reduced the forest. This woodland clearance is probably reflected in the reduction in AP near the top of the pollen profile.

The results from these detailed palaeoecological investigations, carried out on lake sediments from Cooney L. and L. Dargan, offer an important insight for the understanding of woodland dynamics and land-use during much of the Holocene. In particular, this research provides important new information on the economy and the impact created by early prehistoric farmers in north Co. Sligo. Those farmers not only produced the first meaningful impact on the vegetation, but they left behind important megalithic monuments that still characterize the landscape today.
Fig. 1.01. Relief map of Co. Sligo and adjoining areas based on Google Maps (1/10/2012). The main archaeological sites are indicated, i.e. the Carrowmore (Cm) and Carrowkeel (Ck), and also Céide Fields, north Mayo. The location of the lakes, Cooney L. and L. Dargan, that were cored for the investigations reported on here are shown (filled circles), the location of the published pollen studies carried out at CAU, Kiel (open circles), i.e. L. Availe (LA) and Loughmeenaghan (Lm), and Rathdooney Beg (open polygon; RB) where pollen investigations have been carried out by D. Weir (see text). Inset shows a map of Ireland. BB: Ballysadare Bay; SH: Sligo Harbour. The area enclosed by a rectangle is shown in the relief map.
Fig. 1.02. Aerial photograph of the most relevant part of north Mayo (from Google Maps; 1/10/2012). The location of the coring sites Cooney L. and L. Dargan, and the main archaeological sites, are marked. Published pollen profiles are indicated as follows. 1: Slish Wood (lake sediments and mor humus deposit) (Dodson & Bradshaw 1987); 2: Union Wood Lake (L. Arquilla) (Dodson & Bradshaw 1987); 3: Ballygawley L.; 4: Cloverhill L.; 5: Strand Hill. Sites 3–5 in Göransson (1984, 2002). Magheraboy (Mb) and Caltragh (Ct) are also indicated.
Fig. 1.03. A. Map showing the main geological features of Sligo-Leitrim. B. Map showing ice-flow patterns during the last glaciation in Sligo-Leitrim (source: MacDermot et al. 1996).
Fig. 1.04. Maps showing the distribution of the four main megalithic tomb types in Ireland (main source: Ó Nualláin 1989).
Fig. 1.05. Photographs from Cúil Irra peninsula (further details on previous page).
Fig. 1.06. Reconstruction of the Magheraboy causewayed enclosure, drawn by John Murphy (source: Danaher 2007).
Fig. 2.01. Site maps, L. Dargan (further details on previous page)
Fig. 2.02. Photographs at L. Dargan. The position of the platform indicates the coring location. An Usinger piston corer was used for coring. Dargan Castle is visible in the background. In the inset, extrusion of a core segment is shown (photos: O. Nelle and M. O’Connell 12/07/2008).
Fig. 2.03. Photograph of split core segments, core DRG1 (drives DRG1-I to DRG1-IV, i.e. the complete sequence is shown). A toothpick is used to mark the main stratigraphical changes (mainly small changes in colour and texture in the case of the Holocene sediments). A broken line with an arrow indicated what is regarded as Younger Dryas sediments; Allerød/Bølling sediments are indicated by an unbroken line; below this are highly minerogenic, Pleniglacial sediments Photo: M. O’Connell, 30.09.2008.
Fig. 2.04 A. Age-depth model for core DRG1, L. Dargan. The curve segments are calculated as follows: a. straight line; b. 3rd order polynomial curve obtained by fitting a curve to the calibrated ^14C dates ( ^14C dates are cited as years BP; median calibrated ages are plotted); c. straight line; d. spline curve.
**Fig. 2.04 B.** Age-depth model curve generated by OxCal ver. 4.1.7. P sequence with k= 0.5 was used. Boundaries due to change in pollen concentration are applied at 306 cm, 354 cm and at 506 cm. Late Glacial-/Holocene transition (9700±50 BC) is placed at 664 cm.
Fig. 2.05. Macro-remains, charred material, mineral matter and mosses, profile DRG1, from the sieving. (further details on previous page)
Fig. 2.06. Magnetic susceptibility, ash content (inverse of loss-on-ignition (LOI) at 550°C) and stratigraphy of core DRG1. The red curves show the running mean (3 point moving average). The lithology and PAZs are shown. Stratigraphy and zone boundaries are represented in two the vertical bars at the centre of the figure.
Fig. 2.07. Main percentage pollen diagram, with selected curves, for profile DRG1 (L. Dargan). The ecological groups are differentiated using colour coding. A “+” symbol indicates records made after routine counting was completed. Dots are used to emphasise small values. Individual pollen curves that are not shaded are magnified (magnification indicated at the base of each curve). Non-filled background for Pinus curve is magnified by 10 (the curve is truncated where the values are relatively high).
Fig. 2.08. Minor percentage pollen diagram for profile DRG1 (L. Dargan) showing curves excluded from Fig. 2.07. The percentage composite diagram is also shown. Conventions followed are as in Fig. 2.07.
Fig. 2.09. Pollen profile DRG1 showing composite percentage diagram, selected pollen concentration curves, magnetic susceptibility values and ash content (black line original data, red line running mean of 3). Pollen accumulation rate (PAR) curves for selected taxa are also shown. In the pollen concentration curves ‘+’ symbol is utilized to indicate records made after routine counting was completed and dots are used to emphasise small values. Individual pollen curves that are not shaded are magnified (magnification indicated at the base of each curve).
Fig. 2.10. Detail of pollen profile, DRG1, showing selected percentage curves for the mid Holocene (further details on previous page).
Fig. 2.11. Photomicrographs of A and B show a cereal-type pollen from sample 616 cm (c. 6400 BC) of 50 μm with annulus 13 μm and pore 5 μm. In A a Corylus pollen grain is included. B shows the details of pore and exine surface. Photomicrographs of C and D show a cereal-type pollen of 80 μm (Triticum-type) from 574 (c. 3730 BC). C shows the cereal-type pollen (annulus 16 μm; pore 8 μm) and an Alnus pollen (included for size reference). D shows the surface pattern (fine, partially clumped punctae).

A Leica microscope with objectives x40 and x100 (oil immersion for detail of the exine) was used with phase contrast illumination.
Fig. 2.12.
A. Pie charts for PAZs 2-7 showing the contribution of the various terrestrial pollen components.
B. Histograms for PAZ 3 (Neolithic) showing the relative contribution of the main pollen components. Estimated ages are also indicated.
Fig. 2.13. Summary of main data: pollen and archaeology (further details on previous page).
Fig. 3.01. Map and aerial photographs relating to the study area, Cooney Lough (further details on previous page).
Fig. 3.02. Photographs relating to coring at Cooney Lough and cores retrieved (further details on previous page).
Fig. 3.03. The complete sequence of CNY1 and CNY2 are shown.

A. Photograph of split core segments, core CNY1 showing side A and B coupled together. A broken line with an arrow indicates Late-glacial sediment.

B. Photograph of split core segments, core CNY2 (side A). The basal minerogenic-rich sediments (Late-glacial) were not recovered.
### Figure 3.05

Macro-remains, charred material, mineral matter and mosses, profile CNY1, from the macrofossil sieving. The small "C" in red indicates the radiocarbon date samples. Abundances are as follows: 0.5 = rare, i.e. 1, 2 or 3 specimens; 1 = frequent, i.e. 4 to 10 specimens; 2= occasional, i.e. 10 to 20 specimens; 3= frequent, i.e. >20 specimens.
Fig. 3.06. Ash content values, i.e. the inverse of loss-on-ignition (LOI) at 550°C. Two series of analyses, based on two sets of samples, were carried out. These are referred to as LOI-1 and LOI-2, respectively (A). Both sets of samples are from the same depths but smaller samples were used in LOI-1 and some additional samples were measured from sediments close to the base of core in LOI-2. A broken line is used to show the results of individual measurements; a solid line indicates a running mean (3-point moving average). The data (results of individual measurements) are also shown on a single graph (B).
Fig. 3.07. Magnetic susceptibility and stratigraphy of core CNY1. Pollen zones and cultural periods are also indicated.
Fig. 3.08. Main percentage pollen diagram, with selected curves, for profile CNY1. The ecological groups are differentiated using colour coding. A ‘+’ symbol is used to indicate records made after routine counting was completed. Dots are used to emphasise small values. Individual pollen curves that are not shaded are magnified (magnification indicated at the base of each curve). Non-filled background for *Pinus* curve is magnified by 10 (the curve is truncated where the values are relatively high).
Fig. 3.09. Pollen profile CNY1 showing composite percentage diagram, selected pollen concentration curves, magnetic susceptibility values and ash content curves (LOI-1 and LOI-2, see Fig. 3.06). Pollen accumulation rate (PAR) curves for selected taxa are also shown. Conventions followed are as in Fig. 3.08.
Fig. 3.10. Detail of pollen profile, CNY1, showing selected percentage curve for the mid Holocene including the Neolithic and the Bronze Age. A silhouette, values magnified by 10, is used in the case of Pinus (high values are truncated). Abbreviations: T, Tilia; C, Carpinus. Conventions followed are as in Fig. 3.08.
Fig. 3.11. Minor percentage pollen curves, profile CNY1. This shows curves excluded from Fig. 3.08. The percentage composite diagram is also shown. Conventions followed are as in Fig. 3.08.
Fig. 3.12. Percentage pollen diagram, with selected curves, for profile CNY2. Conventions followed are as in Fig. 3.08. Samples marked in red were used to fill in the gap in CNY1.
Fig. 3.13. Summary of pollen data based on non-metric multidimensional scaling (NMS) carried out by PC-ORD (ver. 6.06) (McCune and Mefford 2011). The results suggest that the concentration, PAR and percentage data are optimally summarised on the single axis and two axes, respectively, as presented here. The spectra are plotted to a depth scale. Climate anomalies (CA) are suggested by shading. An arrow and darker shading is used to highlight the 8.2 ka anomaly (from Ghilardi and O’Connell 2012a).
Fig. 3.14. Corylus and Alnus percentage curves of zone 4 (Neolithic) plotted to an age rather than a depth scale. The two curves show strong negative correlation. Horizontal lines are added to help see the main correspondences in the curves.
Fig. 3.15. Pie charts show the contribution of the various terrestrial pollen components in PAZs 3–7, profile CNY1.
### CNY1-4 (Neolithic)

<table>
<thead>
<tr>
<th>Zonation</th>
<th>Age (BC)</th>
<th>Duration (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4d</td>
<td>2170–2700</td>
<td>530</td>
</tr>
<tr>
<td>4c</td>
<td>2700–3000</td>
<td>830</td>
</tr>
<tr>
<td>4b</td>
<td>3000–3440</td>
<td>300</td>
</tr>
<tr>
<td>4ay</td>
<td>3440–3530</td>
<td>440</td>
</tr>
<tr>
<td>4ab</td>
<td>3530–3680</td>
<td>90</td>
</tr>
<tr>
<td>4ac</td>
<td>3680–3710</td>
<td>150</td>
</tr>
</tbody>
</table>

Total duration: 1380 years

### CNY1-5, 6 and 7 (Bronze Age)

<table>
<thead>
<tr>
<th>Zonation</th>
<th>Age (BC)</th>
<th>Duration (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>790–940</td>
<td>150</td>
</tr>
<tr>
<td>6</td>
<td>940–1160</td>
<td>220</td>
</tr>
<tr>
<td>5</td>
<td>1160–2170</td>
<td>1010</td>
</tr>
</tbody>
</table>

Total duration: 1380 years

---

**Fig. 3.16.**

A. Histograms showing the relative contributions of the main pollen components in the various subdivisions of pollen zone 4 (cf. Neolithic).

B. Histograms showing the relative contributions of the main pollen components in pollen zones 5, 6 and 7 (cf. Bronze Age). Estimated ages are rounded up to the nearest 10 years.
Fig. 3.17. Summary diagram plotted to a time scale (calibrated year). The following curves are presented: sediment accumulation time, number of taxa in the pollen sum (N. taxa in PS), palynological richness, NAP/AP ratio, non-metric multidimensional scaling (NMS) scores of the pollen spectra on the main axis (axis 1, proportion of variance 64.2%), carried out by PC-ORD (ver. 5) (McCune and Mefford 2011), and percentage pollen curves of AP (the Corylus curve overlaps the AP), shrubs, ferns, pastoral, cereal-type, bog and aquatic taxa.
Fig. 4.01. A. Summary percentage pollen diagrams from Cooney L. and L. Dargan (selected curves and lower part of profiles; plotted to an age scale) to illustrate woodland dynamics during the early Holocene. The usual conventions are followed. B. Summary percentage pollen diagrams from Cooney L. and L. Dargan (few curves than in A) and corresponding GRIP and NGRIP δ¹⁸O data (20 year averages and a running mean of 3). The climate anomalies (CA) suggested for CNY1 (Ghilardi and O’Connell 2012a) are reported.
Fig. 4.02. Percentage composite diagram and individual percentage pollen curves from Cooney L. and L. Dargan. The diagrams are plotted to a time scale. In the case of each profile, spectra from shortly before the Elm Decline (ca. 4200 BC) until the late Bronze Age (ca. 700 BC) are plotted. The usual conventions are followed.
Fig. 4.03. Pie charts showing the percentage contribution of the various terrestrial pollen components in the mid Holocene at Cooney L. and L. Dargan.
Fig. 4.04. Histograms showing the percentage contributions of the main pollen components in the various subdivisions of zones CNY1-4 and DRG1-3 (both regarded as spanning the Neolithic). Estimated ages are rounded up to the nearest 10 years.
Fig. 4.05. Histograms showing the percentage contributions of the main pollen components in the subdivisions of zone CNY1 5–7 and zone DRG1-4 (cf. Bronze Age). Estimated ages are rounded up to the nearest 10 years.
Fig. 4.06. Summary of archaeological and pollen data relating to the Neolithic (further details on previous page).
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Appendix

Chapter 2: Lough Dargan

Table A2.01. Stratigraphical description of core DRG1 as made in the laboratory.

<table>
<thead>
<tr>
<th>Core segments</th>
<th>Description</th>
</tr>
</thead>
</table>
| DRG1-Ia       | Subsegment length 100 cm  
The top of the core was regarded as containing the most recent sediment  
0–35 cm: watery, unconsolidated sediment; no obvious plant remains  
35–100 cm: fine gyttja, relatively consolidated |
| DRG1-Ib       | Subsegment length 80 cm; sediment depth: 100–180 cm  
Dark fine gyttja; no layers or mottling noted |
| DRG1-IIa      | Subsegment length 100 cm; sediment depth: 180–280 cm  
Dark fine gyttja. The following additional features noted:  
180–204 cm: dark fine gyttja with plant remains  
230–233 cm: a fainter, lighter coloured (presumably due to marl) sediment |
| DRG1-IIb      | Subsegment length 102 cm; sediment depth: 280–382 cm  
Dark fine gyttja (as above). Small elongated holes resulting from presence of small woody remains and air pockets |
| DRG1-IIIa     | Subsegment length 100 cm; sediment depth: 382–478 cm (uppermost 4 cm regarded as contaminated)  
Dark fine gyttja (as above) |
| DRG1-IIIb     | Subsegment length 102 cm; sediment depth: 478–580 cm  
Dark fine gyttja (as above) |
| DRG1-IVa      | Subsegment length 100 cm; sediment depth: 580–680 cm  
580–627.5 cm: dark fine gyttja  
627.5–659 cm: dark fine gyttja but lighter in colour than above, presumably because it contains more silt and clay  
659–664 cm: transitional between sediment above and below  
664–680 cm: dark grey, highly minerogenic sediment, i.e. silt and clay components were obvious |
| DRG1-IVb      | Subsegment length 65 cm; sediment depth: 680–645 cm  
680–694 cm: dark grey, highly minerogenic sediment (as above)  
694–696 cm: medium brown organic-rich gyttja; sharp transition at top and bottom  
696–698 cm: light coloured sediment, upper cm distinctly light in colour (cf. more marl, i.e. CaCO3 ); sharp upper and lower boundary  
Note: difficult to place the boundaries because the layers slope (about 1 cm difference across the core); above depths are the best approximation.  
698–740 cm: dark grey, highly minerogenic sediments (silt, clay and gravel); at 729 cm a stone, 1 cm in diameter  
740–746 Silt, clay and large stones  
Further penetration was not possible; end of coring tube damaged by a stone/rock  
The basal sediments of DRG1-IV are interpreted as follows: Younger Dryas (664-694 cm), a short Bølling/Allerød (694-698 cm) sequence, followed by clay/silt/sands and gravel at the base (presumably relating to the end of the Pleniglacial)
# Chapter 3: Cooney Lough

Table A3.01. Stratigraphical description of core CNY1 as made in the laboratory.

<table>
<thead>
<tr>
<th>Core segments (CNY1-)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia (20–116)</td>
<td>Dark gyttja gradually more consolidated especially below 88 cm. The uppermost 20 cm of sediment was very watery. A piece of wood between 82–82.5 cm</td>
</tr>
<tr>
<td>Ib (116–203)</td>
<td>Dark fine medium-consolidated gyttja. At 135.5 cm a seed was noted</td>
</tr>
<tr>
<td>IIa (203–294)</td>
<td>Dark fine consolidated gyttja. The uppermost 8 cm of sediment was excluded from consideration as it was considered secondary, i.e. the subsegment was regarded as beginning 8 cm below the top of the sediment in the core holder</td>
</tr>
<tr>
<td>IIb (294–400)</td>
<td>Dark fine consolidated gyttja. Faint lines of probably marl at 342.5 cm and 368 cm</td>
</tr>
<tr>
<td>IIIa (400–500)</td>
<td>Dark fine consolidated gyttja. Faint lines grey/brown of marl (?) at 424–425 cm. Large stone (4.5 cm long) found at 400 cm. The top 4 cm of the sediment are disturbed by the stone. The stone may have been originally at 409 cm; on cutting the core segment horizontally it may have been pushed towards the top. A lens of grey sediment, 4 mm thick x 10 mm long was present between 411–411.5 cm. Plant material noted throughout the segment. Depth 484 cm, i.e. beginning of subzone 1b, is used as the boundary depth. The ash content also decreases substantially at 484 cm</td>
</tr>
<tr>
<td>IIIb (500–600)</td>
<td>500–515: dark consolidated gyttja (the base of this layer is regarded as the beginning of the Holocene) 515–517: grey sediment (grey may be due to silt) 517–535: dark grey silty sediment with some sand 535–539.5: lighter grey sediment, especially between 537 and 539.5 cm 539.5–542: dauby blue silty clay sediment 542–600: mainly sand; additional features noted: clay rich between 548–554.5 cm; and between 565–567 cm; sand coarse from 590 cm downwards; a large stone recorded at 560 cm</td>
</tr>
</tbody>
</table>

* Depths are also given (centimetres from the water/sediment interface as originally recorded). All depths are as originally recorded. Pollen analysis showed that there was a gap of c. 4 cm between subsegments Ib and IIa. To allow for this, 4 cm was subsequently added to sample depths below 400 cm (details in Table 3.01). Adjusted depths only are used in the text.
**Table A3.02.** Stratigraphical description of core CNY2 as made in the laboratory.

<table>
<thead>
<tr>
<th>Core segments (CNY2-)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia (50–150 cm)</td>
<td>Fairly consolidated dark fine gyttja. Breaks present (arose during extrusion) 3 mm at 99.5 cm and 5 mm at 112.5 cm</td>
</tr>
<tr>
<td>Ib (150–252 cm)</td>
<td>Dark fine rather consolidated (especially in comparison to subsegment Ia) gyttja</td>
</tr>
<tr>
<td>Ila (252–357 cm)</td>
<td>Dark fine gyttja. Sediment increasingly consolidated with depth</td>
</tr>
<tr>
<td>I Ib (357–457 cm)</td>
<td>Dark fine gyttja. Faint lines of marl at 377 cm, 368 cm and a very thin line at 393 cm. More obvious marl bands, 1–2 mm thick, present between 450–451.3 cm</td>
</tr>
</tbody>
</table>

Note: basal minerogenic-rich sediments were not recovered.