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People, Land-use and Time

Linking Multi-Proxy Palaeoenvironmental Data to the Archaeological Record of Prehistoric Co. Clare, Ireland

Submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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Abstract

The aim of this thesis is to understand the nature of changing human-environment interactions through prehistory (from the Neolithic to the Late Bronze Age) in two neighbouring regions of western Ireland. The first is the study site of Lough Inchiquin, located to the south of the Burren, Co. Clare, and specifically near to the landscape of Roughan Hill known for its dense concentration of Chalcolithic – Early Bronze Age sites. The second study site is Rosroe Lough, Co. Clare, situated to the east of the Late Bronze Age site of Mooghaun hillfort. Sediment cores were extracted from both lakes in order to carry out palaeoenvironmental analysis. Through the establishment of robust chronologies for the sediment cores it is possible to compare the archaeological and palaeoenvironmental data with regard to human-environment interactions in the two study areas.

A range of techniques were applied to the sediment core extracted from Lough Inchiquin. Pollen, macrofossil and palaeolimnological analysis including chironomid (non-biting midge) sub-fossil analysis, organic and inorganic geochemistry was undertaken. The local archaeology is contextualised in its landscape setting leading to a discussion of human-environment interactions through time based primarily on pollen data and including comparisons with previous palaeoenvironmental research in the area. The results highlight the impact of the Neolithic *Landnam* on the catchment and subsequent periods of increased farming activity. Interestingly, this is revealed to be most intensive during the Late Bronze Age, a period when the known archaeological evidence for human activity in this area is limited. The nutrient enrichment of the lake through time has been identified through palaeolimnology (chironomid and organic geochemistry) which can be linked to land-use in the surrounding catchment and demonstrates localised pastoral farming activity in the Late Bronze Age. In addition, inorganic geochemistry highlights a period of significant erosion from the Burren into Lough Inchiquin.

Pollen and macrofossil analyses were undertaken on the sediment core extracted from Rosroe Lough, twenty six kilometres to the south-east in the Mooghaun Landblock. Human-environment interactions, with an increasing intensity of farming activity through time, and comparison with previous palaeoenvironmental research in the area, are discussed. The palaeoenvironmental evidence correlates well with the archaeological record – with the lack of a Neolithic *Landnam* in the pollen profile supported by the scarcity of archaeological

remains from this period and an intensification of human activity seen in the Late Bronze Age.

Multi-proxy analyses are vital to this study and the application of palaeolimnology to the Lough Inchiquin sediment core, in particular, demonstrates the additional information that can be gained by applying a multi-proxy approach to palaeoenvironmental investigations. The final analysis consists of a comparison, through time, of human-environment interactions in these two neighbouring but contrasting landscapes. This provides a more holistic interpretation of the prehistory of Co. Clare than has been possible in the past with the two data sets, palaeoenvironmental and archaeological, allowing for the further development of the archaeological narrative of these two prehistoric landscapes.

Acknowledgements

I would like to take the time to thank all those who have contributed, in whatever way, to the completion of this PhD.

To my supervisor, Dr Carleton Jones I would like to express my gratitude for his guidance and support during this project, and for his enthusiasm for the archaeology of Co. Clare which I hope has shone through in this thesis. Having had not one, but two supervisors, I must also thank Dr Aaron Potito for his encouragement and enthusiasm over the past four years and for always being there to help. I have learnt a great deal more from him than how to identify tiny insects and will always be grateful for his support and teaching. A huge thank you goes to Dr Karen Molloy for her excellent and very patient pollen training, kind words, enthusiasm and support with this project.

I must also thank Dr Carlos Chique for always being happy to help in the pollen lab and to Dr Karen Taylor for taking the time to look through photo after photo of 'unknown' chironomids. To everyone who helped core Lough Inchiquin and Rosroe Lough, especially Dr Aaron Potito, Dr Karen Molloy, Pat O'Rafferty and Siubhán Comer – thank you. It was no mean feat to take the 'deepest core in Ireland' and to everyone who came along to help, (you know who you are), this project couldn't have gone ahead without you!

To our American colleagues, Dr Anna Martini, Henry Frentzel and all those involved in the geochemical analysis at Amherst College, the University of Massachusetts and the University of California – thank you for your interest in this project which has allowed us to follow new avenues of research. Thank you to all those who helped with laboratory work here in Galway, namely Svenja Dobbert, Liam Conaghan and Michelle Moore-Temple. Your hard work made this project happen. For help and patience with making GIS maps, thank you to Joe Fenwick and Dr Benjamin Thébaudeau.

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Thank you to Dr Ros Ó'Maoldúin for giving me the chance to excavate the chamber of two wedge tombs in my study area, and the much-needed escapism from the office that this provided! To everyone I have shared an office with over the past four years, thank you for your kindness, laughter and support, especially to Lynda McCormack and Chelsea Ryan! A big thanks to my friends (especially Kate, Ruble and Monica) and housemates for providing me with a safe haven filled with laughter, happiness and gin!

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I would also like to thank Graham Roberts and Prof Mike Parker Pearson who each played a vital role in me becoming an archaeologist and whose passion for the subject and encouragement to pursue it has led me to where I am today.

This PhD is dedicated to my grandad, Brian Forshaw, who would have been enthralled by the archaeological adventures I have been on over the years and whose contribution to my education has made them all possible.

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Chapter 1 – Introduction

1.1 Background and Rationale

Archaeological investigations in Co. Clare have led to the discovery of a large quantity of sites of prehistoric date, including the earliest dated megalith in Ireland – Poulnabrone portal tomb (Lynch, 2014). Located on the Burren, an upland karst region of north-west Co. Clare, the dating of this monument and the concentration of other Early Neolithic sites across the wider Burren suggests that this landscape was of particular importance in early prehistory. Due to the upstanding remains of prehistoric occupation, the Burren has been a focus of research, both historically (Westropp, 1898; Westropp, 1905), and over recent decades (Jones and Walsh, 1996; Jones et al., 2015; Jones, 1998; 2003; 2016; in press). The results of such work have demonstrated a high level of prehistoric activity on the Burren from the Early Neolithic which appears to intensify during the Chalcolithic – Early Bronze Age. Wedge tombs, a monument type confined to the period c. 2500 – 2150 BC, are particularly prolific on the Burren, and a small upland area named Roughan Hill hosts the densest concentration of this tomb type in Ireland (Jones, 1998). This area is also host to intensive settlement activity in the Chalcolithic with a number of habitation sites and field systems identified (Jones, 1998; Jones and Gilmer, 1999). Archaeological evidence for later prehistoric activity on the Burren is limited, and a potential shift of prehistoric communities from this upland landscape towards the more southerly lowland landscape of Co. Clare has previously been proposed (Grogan, 1996; Jones et al., 2010; Grogan, 2005b).

This narrative is supported by archaeological and palaeoenvironmental evidence that has demonstrated little to no human presence in south-east Co. Clare during the Neolithic. That this is not a product of archaeological bias is suggested by intensive investigations carried out by the Discovery Programme as part of the North Munster Project which covered a total area of c. 9000km^2 including south Co. Clare, as well as north Co. Kerry, Co. Limerick and west Co. Tipperary (Grogan, 2005a; 2005b). The specific area investigated by this project in Co. Clare was the Mooghaun Landblock, an area of 286km^2 surrounding Mooghaun hillfort (Grogan, 2005b). These investigations demonstrated a scarcity of early prehistoric activity in the Mooghaun Landblock, while in the later prehistoric period there was an intensification of settlement (Grogan, 2005b). The construction of wedge tombs in the Mooghaun landscape demonstrates an increased human presence in the Chalcolithic but the greatest intensity of activity occurred during the Late Bronze Age (Grogan, 2005b). The hillfort at Mooghaun, in addition to a proliferation of prestigious metalwork finds, including the Mooghaun gold hoard, has led to the interpretation of this landscape as being an elite territory by the Dowris phase of the Late Bronze Age (c. 1000 BC) (Grogan, 2005b).

The archaeology, then, suggests the location of two important focal areas of prehistoric activity in Co. Clare. The first, the Burren, was a focal point during early prehistory while the second, the Mooghaun Landblock, was central to later prehistoric occupation. While recent research in the north Burren (Ó'Maoldúin and McCarthy, 2016) indicates that this, and possibly other currently undetected areas may also have been important foci, these two relatively well-researched archaeological landscapes will form the regional study areas for this project, with Roughan Hill forming a refined study area within the wider Burren (Figure 1.1). Debate regarding this apparent shift identified in the archaeological record between the two areas has been on-going (Grogan, 1996; Grogan and Condit, 2000; Grogan, 2005b). It has been suggested that, as the population increased from the Neolithic to the Chalcolithic in the Burren landscape, there may have been a gradual decrease in the quality or fertility of land, potentially as a result of over-exploitation (Grogan, 1996). This model is supported by the evidence of preserved soil horizons suggesting the Burren was once vastly more fertile than at present (Grogan, 1996), and previous suggestions that large-scale Holocene erosion likely led to the now largely exposed limestone landscape (Drew, 1983; Feeser and O'Connell, 2009). This model suggests that land degradation may have necessitated the movement of communities out of this area with abandonment of the Burren (Grogan, 1996).

Alternatively, the increased human presence indicated by the archaeological record for south-east Co. Clare may have been the result of a settlement *expansion* from the Burren and development of another sub-regional base, while settlement continued in the lowland Burren towards Lough Inchiquin (Grogan, 1996; Grogan and Condit, 2000). More recently, a change of use of the Burren landscape in the Late Bronze Age, rather than a specific reduction in human activity, has been proposed by Jones et al. (2010). Specifically, the suggestion has been put forward that the Burren may have become a specialised producer landscape engaged in potentially seasonal pastoralism, within a network of power relationships that linked the Burren with the prominent power-base of the Mooghaun territory at this time (Jones et al., 2010). Despite suggestions of a continued high population density on the Burren into the Early Bronze Age (Grogan and Condit, 2000) and continued exploitation into the Late Bronze Age (Jones et al., 2010), there has been little research focus on the Late Bronze Age of this area.

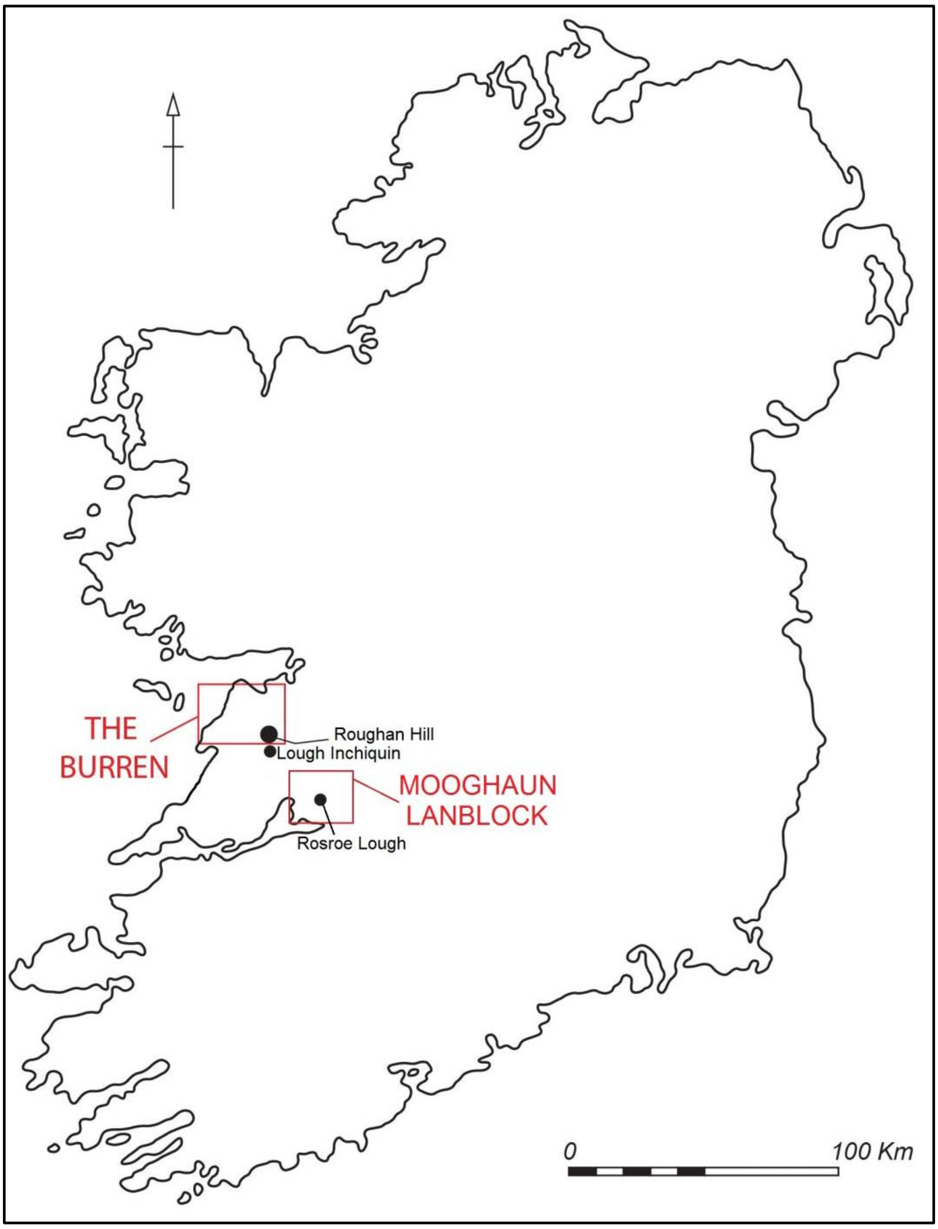

Figure 1.1: Location of the two refined study areas within Co. Clare, Ireland. The location of the lake sites, Lough Inchiquin immediately south of the Burren and Rosroe Lough in the centre of the Mooghaun Landblock, has been indicated. After Jones (forthcoming-a).

Based on the integration of archaeological and palaeoenvironmental datasets the project, which was the subject of this PhD thesis, aims to develop an in-depth understanding of human-environment interactions within and between these two areas of Co. Clare during prehistory, from the Early Neolithic to the Late Bronze Age. During the course of this project, lake sediment cores were extracted from Lough Inchiquin and Rosroe Lough, which are situated immediately south of the Burren, and in the centre of the Mooghaun Landblock, respectively. At the core of this study are palaeoenvironmental investigations based on the systematic analysis and interpretation of a range of environmental indicators within the lake sediments. These multi-proxy investigations focus on fossil pollen, chironomid (non-biting midge) sub-fossils, and organic ($\delta^{15}N$, $\delta^{13}C$ and C:N) and inorganic (elemental concentrations of Ti, Fe, Mn and S) geochemistry.

1.2. Aims and Objectives

The overarching aim of this PhD project is to understand the nature of changing human-environment interactions in two regions of Co. Clare, throughout prehistory, via an examination of archaeological and palaeoenvironmental data. This study is primarily concerned with interaction via farming activity which will register in the palaeoenvironmental record. Although ritual interaction with the landscape will be seen in the archaeological record, this will be used as a measure of human activity or presence within the landscape rather than assessing how the changing environment may be related to ritual practices. Similarly, while social interaction may form part of the resulting interpretation when combined with the archaeological record, it will not be the main focus. When considering human-environment interactions, 'the environment' is considered to be 'the natural world, in a particular geographical area, especially as affected by human activity' (Oxford Dictionaries, 2019). A palaeoenvironmental account of changing land-use dynamics from the Early Neolithic to the Late Bronze Age will be provided by the analyses, and an assessment of the interpretations provided by each dataset, and their correspondence with each other, will allow for a more detailed understanding of land-use and human activity. The integration of a palaeolimnological study at Lough Inchiquin will provide a detailed assessment of the impacts of human activity on the lake system itself which will be contextualised by the pollen data. While the two study areas will be discussed separately, the final discussion will allow for an integration of the data to examine land-use change and human activity across Co. Clare in prehistory.

The focused palaeoenvironmental objectives of this project are as follows.

1. To provide a detailed account of human-environment interactions in the Burren and within the Mooghaun Landblock, via the production of a high resolution pollen

record for each lake site spanning from the Early Neolithic to the Late Bronze Age. Attention will be focused on markers of human activity in the pollen records such as decreases in arboreal pollen (AP) and increases in non-arboreal pollen (NAP), specifically pastoral indicators (NAPp) and cereal-type. Macrofossil analysis will supplement pollen data where possible.

2. To provide a robust chronology for the pollen records through the acquisition of ^{14}C dates of lake sediment material from which a Bayesian age-depth model can be produced. This will allow for a direct comparison between the palaeoenvironmental data and the archaeological record.
3. To provide a more regional signal of land-use and human activity across a wider area of each study landscape than has been previously undertaken. Primary comparisons will be made between Lough Inchiquin and Molly's Lough (Thompson, 1997; Lamb and Thompson, 2005), and Rosroe Lough and Mooghaun Lough (Molloy, 2005).
4. To produce a high resolution chironomid record for Lough Inchiquin demonstrating both the response of chironomid communities to prehistoric farming within a large lake system, and the effect such activity had on Lough Inchiquin. In the resulting chironomid stratigraphy attention will be focused on taxa associated with increasingly eutrophic conditions, and those associated with pastoral agriculture in previous studies (cf. Potito et al., 2014).
5. To obtain high resolution organic geochemical data ($\delta^{15}N$, $\delta^{13}C$ and C:N) from Lough Inchiquin through which the anthropogenic impact upon the lake system can be assessed via eutrophication. Through objectives 4 and 5 the impact of prehistoric farming on the lake system can be examined, and will be contextualised by the new pollen data for this site.
6. To obtain high resolution inorganic geochemical data (Ti, Fe, Mn and S) from Lough Inchiquin with which to identify any periods of increased erosion into the lake system which may have led to the development of this exposed karst landscape. If identified, an assessment of any correspondence between periods of increased erosion and increased human activity from the archaeological record will be made.

The degree to which the palaeoenvironmental records, provided by the analyses of the current study, correspond with or diverge from the evidence provided by the archaeological record alone will also be examined through a comparison of the datasets. A number of focused archaeological objectives will be used to evaluate the archaeological record at specific time periods, from the Early Neolithic to Late Bronze Age.

The focused archaeological objectives of this project are as follows:

1. Can instances of correspondence or disagreement between the palaeoenvironmental and archaeological records be explained by issues of bias, visibility or the quality of the archaeological record?
2. Do periods of high visibility in the archaeological record reflect periods of intensive human activity and farming activity within the palaeoenvironmental records?
3. Do periods of low visibility in the archaeological record reflect decreases or changes in subsistence strategy reflected in the palaeoenvironmental records?
4. Does the type of archaeological data from specific periods, (i.e. ritual and burial monuments, habitation sites, stray artefactual finds) influence the degree of correspondence between the records?
5. Overall, is there a high degree of correspondence or divergence between the archaeological and palaeoenvironmental datasets?

The palaeoenvironmental objectives outlined above will combine to form a detailed multi-proxy investigation into human-environment interactions in prehistoric Co. Clare, which through comparison with the archaeological record via the archaeological objectives will address the main aim of this thesis, namely to understand the nature of changing human-environment interactions in the two sub-regions of Co. Clare from the Early Neolithic to the Late Bronze Age.

1.2.1 Archaeological Methodology

The existing archaeological narrative of Co. Clare, based primarily on the archaeological evidence, will be examined to provide the contextual background for this study. A critical analysis of both the archaeological and palaeoenvironmental records of the refined study areas will be carried out to determine the quantity, quality and limitations of the existing data (Chapter 3). The data for the study area will also be contextualised within wider trends in Irish data. The study will obtain and analyse new palaeoenvironmental data with the specific palaeoenvironmental methodologies detailed in Chapter 5. The relationship between the archaeological record of the study area and palaeoenvironmental records from Lough Inchiquin and Rosroe Lough will be analysed, in addition to a comparison of the pollen records from the two lake sites. The new analyses of the current study will allow the existing narrative of human-environment interactions in prehistoric Co. Clare to be re-examined regarding both the interpretations of the new palaeoenvironmental data, and the relationship between the archaeological and palaeoenvironmental records.

1.3 Thesis Structure

This thesis is divided into ten separate chapters. This structure allows for the evidence chapters (6 – 8) to be readily transformed into manuscript (article) format for future publication in relevant journals. The main focus of each chapter is as follows:

Chapter 1: A short, introductory chapter introducing the aims, objectives and rationale behind this PhD project.

Chapter 2: This chapter provides a detailed introduction to the study areas.

Chapter 3: This chapter provides an in-depth contextual background to the current study. This includes an overview of human-environment interactions in Ireland in the following periods; Early Neolithic, Middle – Late Neolithic, Chalcolithic – Early Bronze Age, Middle Bronze Age and Late Bronze Age. After each section focusing on the wider palaeoenvironmental evidence, an overview of the archaeology of that period within Co. Clare is provided. This is followed by a brief summary of palaeoenvironmental evidence from Co. Clare which provides additional context for the results of Chapters 6 and 8.

Chapter 4: A brief examination of the development of studies focused on human-environment interactions with regard to archaeological theory is provided. This is followed by a discussion on the theoretical background of each technique which will provide a greater understanding to the reader on the specific results of the evidence chapters, especially regarding the interpretation of the data.

Chapter 5: This chapter provides a broader and more detailed description of the methods used in this study than given in the specific evidence chapters.

Chapter 6: Pollen data from the Lough Inchiquin core is presented and interpreted in this chapter. Interpretation includes comparison with the archaeological record and previously published pollen sequences in the Burren region.

Chapter 7: Palaeolimnological data from the Lough Inchiquin core is presented and interpreted. This is inclusive of chironomid data and organic and inorganic geochemical data. The interpretation incorporates palynological evidence provided in Chapter 6.

Chapter 8: Pollen data from the Rosroe Lough core is presented and interpreted in this chapter. This chapter follows a similar format to that of Chapter 6 making comparisons with both the archaeological record and previous pollen data from the study area.

Chapter 9: This chapter integrates the different components of this multi-proxy investigation and aims to place the results within the wider framework provided, in the most part, in Chapter 3. An explicit comparison is made between the palaeoenvironmental data and the archaeological record of each study area. A new archaeological narrative based on the data produced by this project is provided. This is followed by a comparison of the two new pollen sequences from Co. Clare with regard to the archaeological narrative provided in Chapters 1 and 3.

Chapter 10: The concluding chapter focuses on new perspectives on the prehistory of Co. Clare provided by this new data. It summarises the major findings of this research project and recommendations for future research are provided.

Chapter 2 – Study Sites

2.1 Study Region

This research focuses on human activity and landscape change within the boundaries of Co. Clare and the most southerly part of Co. Galway. The area of Co. Clare encompasses 3400km^2 of the mid-west of Ireland and is characterised by the exposed Atlantic coastline to the west, the sheltered coast of Galway Bay to the north, and the estuarine environments of the Rivers Shannon and Fergus to the south. Co. Clare has been chosen as the study region because of the large number of prehistoric archaeological sites as discussed in Chapter 3. The study region has been extended to include a small portion of south Co. Galway encompassing the low-lying karstic terrain that stretches eastwards away from the Burren, in light of recent archaeological discoveries ahead of the M18 motorway (cf. Delaney et al. 2012). Geologically, the majority of the study region consists of Lower Carboniferous limestone, with Devonian sandstone in the east, and Upper Carboniferous shales and sandstones to the south and west (Figure 2.1). The varied topography, climate and geology has allowed for the formation of fifty-six soil series across the county and a simplified map is provided in Figure 2.2 (Finch et al., 1971). The apparent clustering of the archaeological sites in the north and south-east of Co. Clare has led to the development of two more refined study areas – Roughan Hill and the wider Burren, and the Mooghaun Landblock (Figure 1.1; Figure 2.4; Figure 2.6).

The majority of lakes are located in the north-central and in the south-east of the county. For the purpose of palaeoenvironmental analysis a lake has been chosen, within each area, in close proximity to archaeological remains. The first is Lough Inchiquin located to the south of Roughan Hill and the second is Rosroe Lough located to the south-east of Mooghaun hillfort. Lake sediment cores were extracted from both lakes to provide material for analysis in this study.

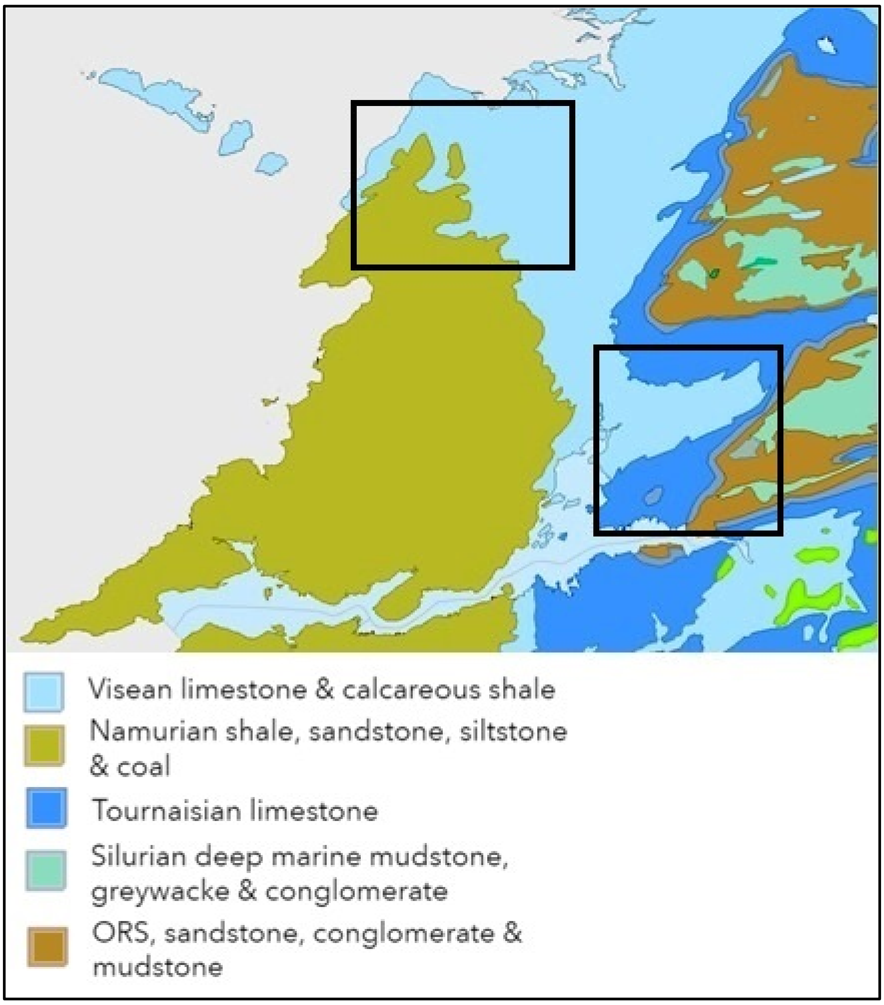

Figure 2.1: A geological map of Co. Clare, Ireland that shows the limestone nature of the bedrock in both refined study areas (Geological Survey Ireland, 2018 Last accessed 15/06/2018).

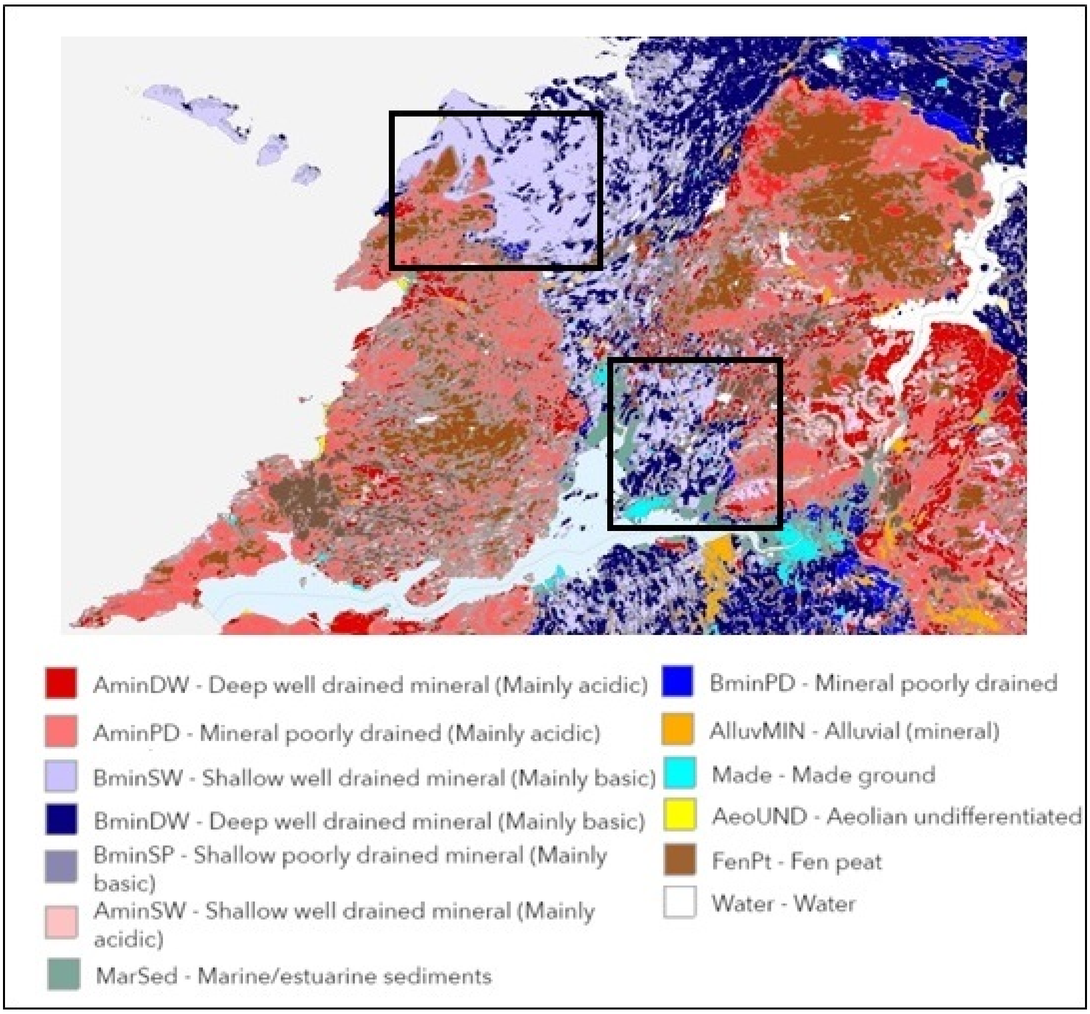

Figure 2.2: A simplified soils map of Co. Clare, Ireland (Geological Survey Ireland, 2018 Last accessed 15/06/2018).

2.1.2 Study Site 1: Roughan Hill and the wider Burren

The Burren is an upland region in north-west Co. Clare characterised by exposed expanses of carboniferous limestone which form a glaciated karst landscape - the region being one of the best examples of such in the world (National Parks and Wildlife 2017). The Burren is bounded to the north by Galway Bay and to the west by the Atlantic, with the Aran Islands off the western shore an extension of the Burren geology. The southern boundary of the Burren is provided by the transition to overlying Clare shales while to the east there is a transition to the drift-covered Tournaisian limestone of the Irish Central Plain (Ivimey-Cook and Proctor, 1964). The exact area is hard to delineate and has been proposed by Drew and Magee (1994) as an area of c. 367km^2 while Jones (1998) suggests a greater area of c. 550km^2 (Figure 2.3). The actual area of exposed limestone is slightly smaller at c. 250km^2

with the majority designated as a Special Area of Conservation and the Burren National Park encompassing 15km^2 of the south-east Burren (National Parks and Wildlife 2017).

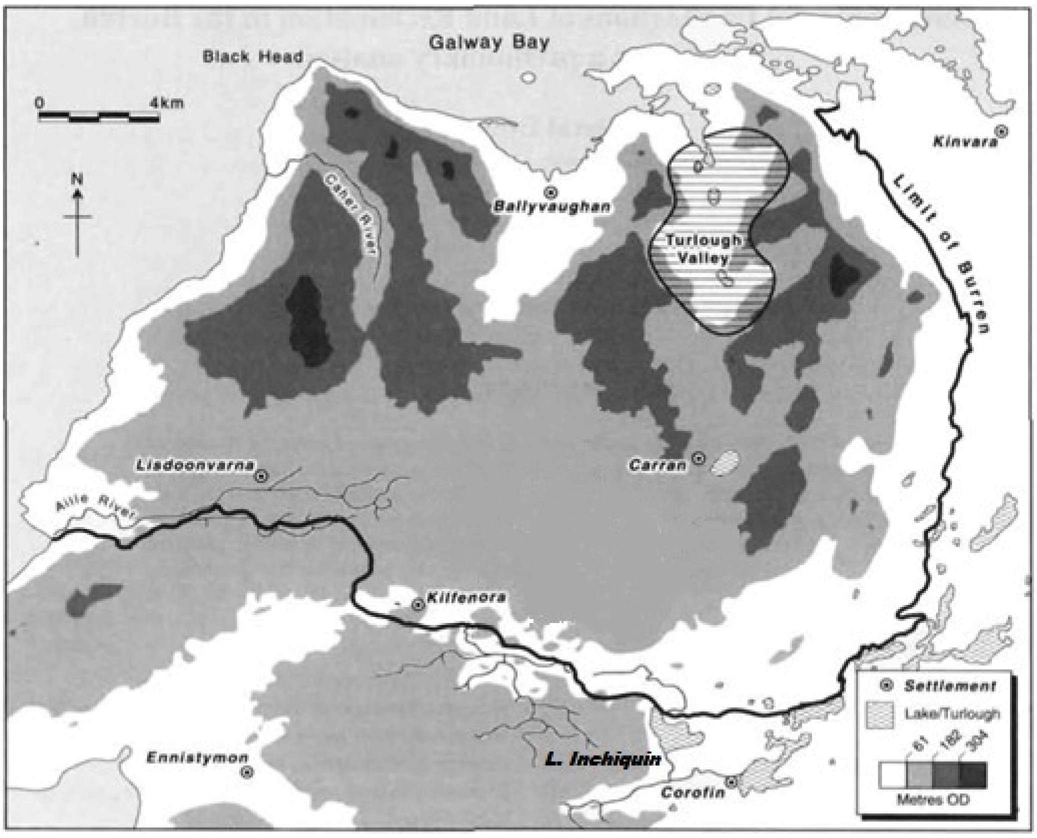

Figure 2.3: The delineation of the Burren in north Co. Clare. The study site of Lough Inchiquin has been marked along with modern settlements. After Drew and Magee (1994).

The glacial and fluvioglacial deposits that cover the bedrock of the Burren are incomplete, proposed to be, in part, because of Holocene erosion (Moles and Moles, 2002; Moles et al., 1999; Drew, 1983). The soils on Roughan Hill are thin rendzinas (shallow soils derived from carbonate bedrock) which are especially suited to extensive grazing (Finch et al., 1971). As such, many of the upland Burren areas, including Roughan Hill, are still used for modern cattle winterage (Jones et al., 2015). The limestone pavement is characterised by extensive fissures (grykes) between flat slabs of limestone (clints) that express a number of solutional features (karren). The subterranean nature of the drainage across the Burren means there are underground rivers, turloughs (disappearing lakes) and depressions (dolines) (National Parks and Wildlife 2017). The largest of these underground river systems is the River Fergus which then rises to the south of Roughan Hill and flows into Lough Inchiquin, one of the sample sites for this study (McNamara and Hennessy, 2010). Topographically, the very north and eastern edge of the Burren is characterised by high peaks such as Mullaghmore, Slieve Rua and Knockanes.

Roughan Hill is located on the south-eastern edge of the Burren c. 3km north of Lough Inchiquin. This low ridge rises to c. 130m situated on a north-east/south-west axis providing extensive views of the River Fergus valley and Lough Inchiquin to the south (Jones and Walsh, 1996). The name Roughan Hill is derived from the original townland name of *Roughan* and is now located within the townland of Parknabinnia, extending into Commons North and, at its highest point, Leana (Jones and Walsh, 1996). As Jones et al. (2015) note, Roughan Hill marks a topographical divide between the Burren uplands to the north and the lowland valley of the River Fergus (which flows c. 100m below the crest of the hill) to the south in which Lough Inchiquin is situated.

Detail of the lake site of Lough Inchiquin is provided in Chapter 6.

Archaeological Setting

Fig 2.4 provides an account of archaeological features within the catchment area of Lough Inchiquin and extending into the wider Burren to the north. These will be discussed in detail in Chapter 3. The majority of prehistoric archaeological sites of interest to this study are concentrated in the southern half of the region and form one of the highest densities of sites in the country (Jones 1988, Lynch 2014). There is a significant amount of Early Neolithic activity in the immediate surroundings of Lough Inchiquin. This includes the Ballycasheen portal tomb located just upstream from the lake, at the base of Roughan Hill, with another likely portal tomb close-by and the court tomb located on Roughan Hill itself (Mercer, 2014; Jones, 1998; Jones, in press). Later prehistoric activity includes fifteen wedge tombs (Chalcolithic), four habitation sites (Chalcolithic – Early Bronze Age) and associated contemporary field-systems (Jones, 2016). This suggests that human occupation began in the Early Neolithic but was at its most intensive during the Chalcolithic – Early Bronze Age. A number of burnt mounds, presumed prehistoric, are located within the catchment but have not been dated. A later prehistoric presence is attested to by secondary activity at earlier monuments within the wider landscape e.g. Poulnabrone (Lynch, 2014) and the more recent discoveries of Late Bronze Age dates at Teeskagh, Carran and Turlough Hill, also at some remove from the lake itself.

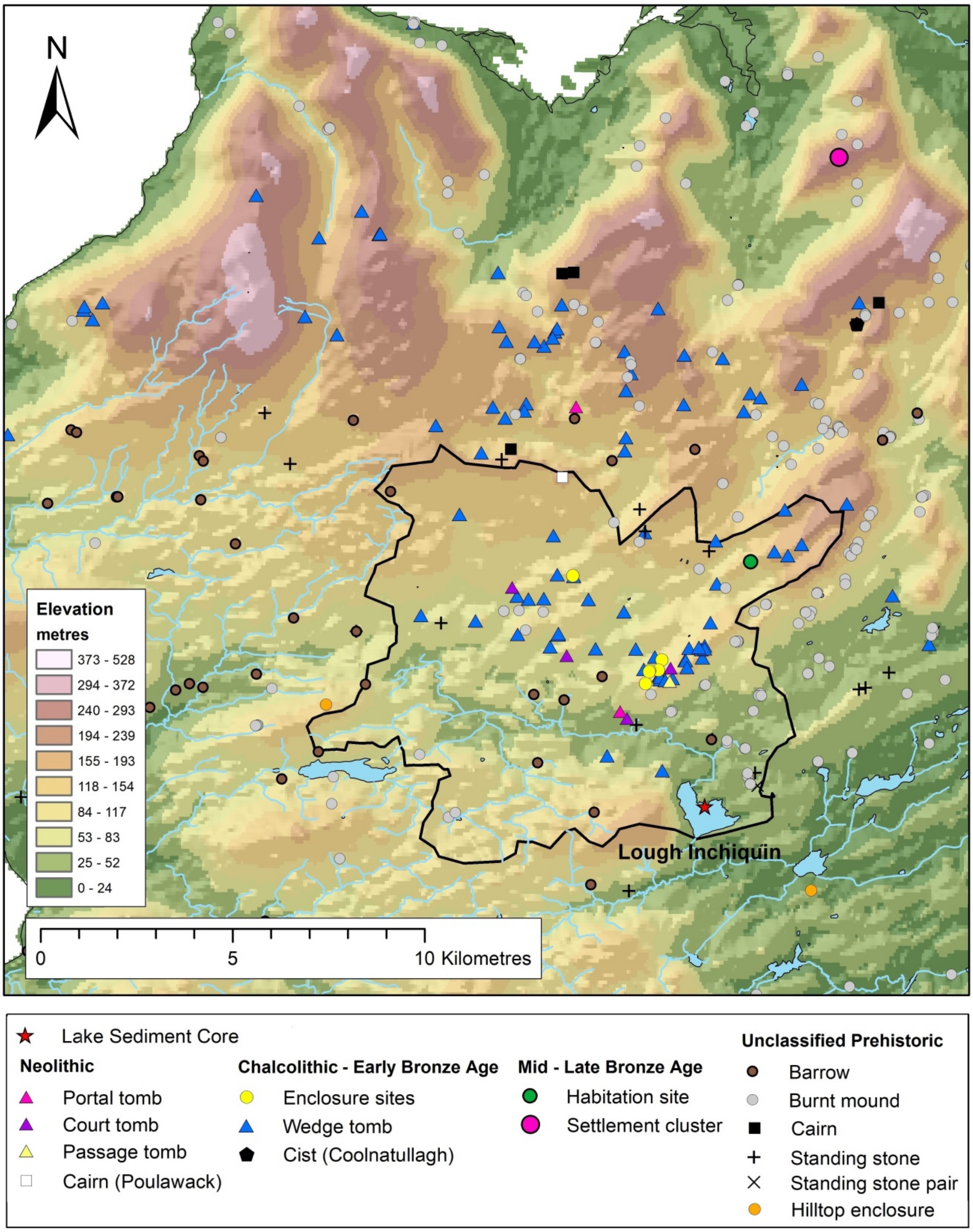

Figure 2.4: The distribution of relevant archaeological sites in the Burren. Lough Inchiquin is labelled and the red star indicates the coring location. The black line denotes the catchment area of Lough Inchiquin which covers a large area (c. 93.2km^2) of the Burren uplands. The dense concentration of sites c. 3km north of Lough Inchiquin is the area of Roughan Hill. Source: author.

Previous Palaeoenvironmental Research

Fifteen pollen records are available from the Burren, including one profile from Co. Galway on Inis Oírr which geologically is an extension of this region (Table 2.1). Of these, seven are pertinent to the study and will be examined in detail. Two profiles (Illauncronan and Poulroe) cover only the late-glacial period and so will not be discussed. The remaining six records do contain Holocene sediments but do not cover the period under investigation. The location of the seven profiles is given in Figure 2.5. As the map illustrates there are two profiles located in the northern Burren – a monolith taken from heath at Cappanawalla (Feeser and O’Connell, 2009) and one from blanket bog at Lios Lairthín Mór (Jeličić and O'Connell, 1992). Just off-shore, on the small island of Inis Oírr, Aran Islands, a record was obtained from An Loch Mór (Molloy and O'Connell, 2007; Molloy and O’Connell, 2004). Three records come from the south-eastern edge of the Burren which includes Loch Gaeláin (Feeser, 2009), Gortlecka and Rinn na Mona Loughs (Watts, 1984; Watts, 1963). An additional record from this area, taken from the Carron depression will be discussed when possible but the resolution of the data is not sufficient for a full comparison. The most relevant record for the current study is that from Molly’s Lough, the small lake (c. 30 x 70m) immediately west of Lough Inchiquin (Thompson, 1997; Lamb and Thompson, 2005). The central Burren area is unsuitable for palaeoenvironmental studies of this kind with little surface water and no lakes or bogs from which to sample, which accounts for the bias to the north and south-eastern edge where the nearest lakes can be found (Feeser, 2009).

Table 2.1: Available pollen records from the Burren and including one from Inis Oírr, Aran Islands. Pollen records used for comparison in this study are highlighted in bold.

Site	Co-ords	Site type	Time span	^{14}C dates	Reference
Molly's Lough	**52°56'43" 9° 5'48"**	**Lake**	**AD1950-10050BC**	**4**	**Thompson (1997); Lamb & Thompson (2005)**
Loch Gaeláin	**52°59'58" 9°1'16**	**Lake**	**AD1950 – 9560BC**	**10**	**Feeser (2009)**
An Loch Mór	**53° 3'32" 9°30'30"**	**Lake**	**AD1950-9650BC**	**33**	**Molloy & O'Connell (2004; 2007)**
Gortlecka	**53° 0'6" 9° 0'54"**	**Lake**	**AD1950-9550BC**	**6**	**Watts (1963)**
Rinn na Mona	**52°59'40" 9° 2'54"**	**Lake**	**AD1950-7050BC**	**0**	**Watts (1984)**
Cappanawalla	**53° 7'3" 9°11'48"**	**Heath**	**AD1950-1550BC**	**4**	**Feeser & O'Connell (2009)**
Lios Lairthín Mór	**53° 4'56" 9°13'29"**	**Blanket bog**	**AD1950-1250BC**	**8**	**Jeličić & O'Connell (1992)**
Carron	53° 2'1" 9° 4'2"	Fen peat	AD1950-9550BC	0	Crabtree (1982)
Gortaclare	53° 4'56" 9° 2'6"	Grykes	AD1950-50BC	3	Feeser & O'Connell (2009)
RUA	53° 0'53" 8°59'40"	Grykes	AD1950-950BC	1	Feeser & O'Connell (2009)
Rockforest	53° 0'17" 8°57'35"	lake	AD1950-350BC	6	Roche
Lough Goller	53° 0'30" 9°18'1"	Lake	7050-11050BC	0	Watts (1963)
Garrannon Wood	52°41'39" 8°44'46"	Mor humus	AD1950-1300	1	Bohan (1997)
Illauncronan	52°56'49" 8°51'36"	Lake	8050-12550	0	Andrieu et al (1993)
Poulroe	53° 4'0" 8°58'0"	lake	Late-glacial	0	Watts (1977)

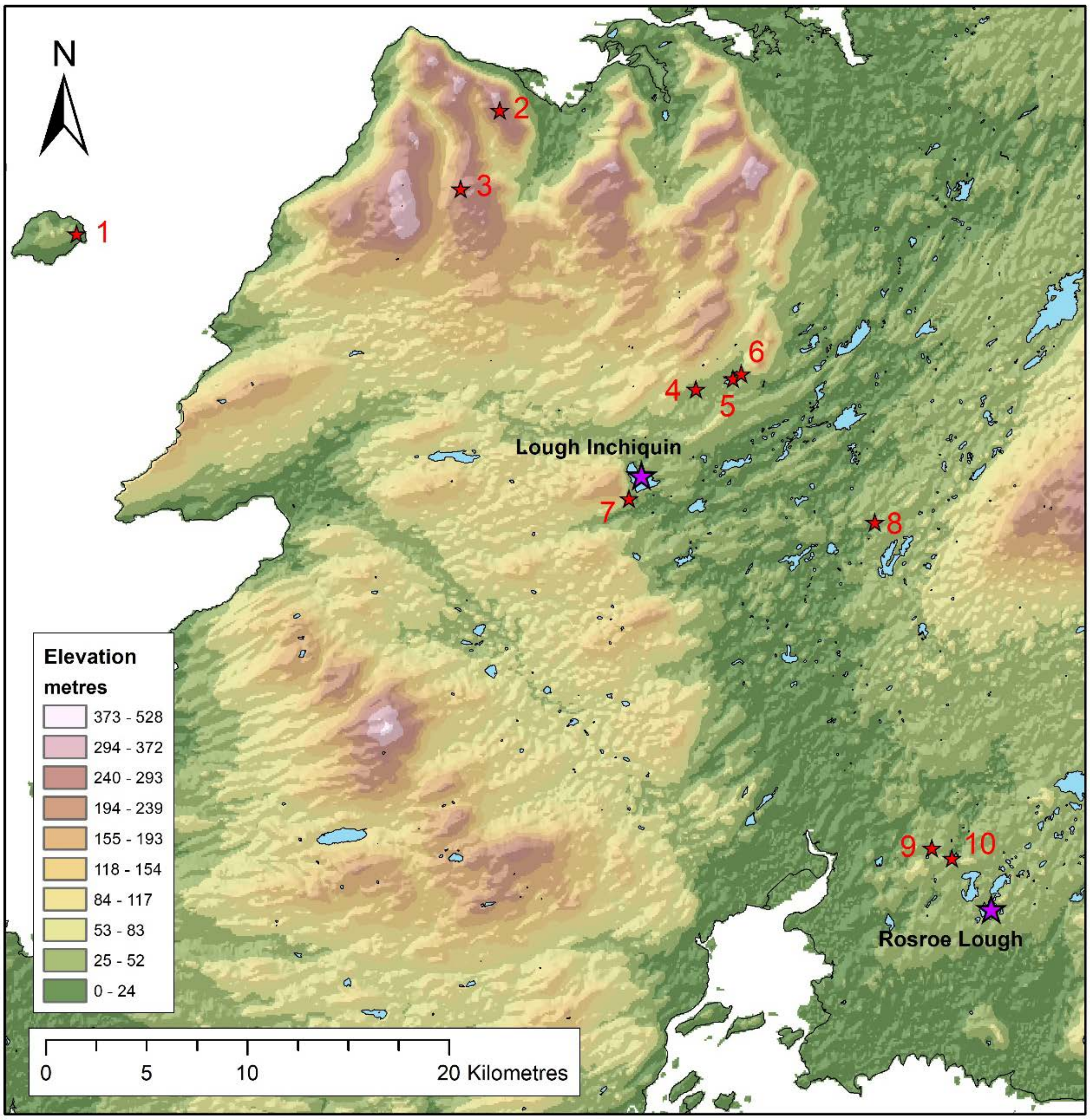

Figure 2.5: The location of previous pollen investigations in Co. Clare and those from the current study. Numbers relate to sites as follows: 1 = An Loch Mór, Aran Islands; 2 = Cappanawalla; 3 = Lios Lairthín Mór; 4 = Rinn na Mona Lough; 5 = Loch Gaeláin; 6 = Gortlecka Lough; 7 = Molly's Lough; 8 = Caheraphuca Lough; 9 = Mooghaun Lough; 10 = Caherkine Lough. The current study sites of Lough Inchiquin and Rosroe Lough are indicated by the purple stars. Source: author.

2.1.3 Study Site 2: Mooghaun Landblock

The landscape surrounding Mooghaun hillfort was first termed the 'Mooghaun Landblock' during the course of investigations as part of the North Munster Project carried out by The Discovery Programme (Grogan, 2005b). The area encompasses 286km^2 of the central Clare lowlands and eastern uplands with the River Fergus and its estuary providing a boundary to the west, and the Shannon estuary to the south (Figure 2.6) (Grogan, 2005b). The geology of the area is mostly Carboniferous limestone with a small region of higher ground in the south-east corner made up of Devonian and Silurian geologies, where the high peaks of Woodcock Hill and Knockaphunta are located (Grogan, 2005b). For the most part the catchment of Rosroe Lough hosts either Grey-brown Podzolic soils or that of the Burren-Ballinacurra complex (low potential) with these being the location of the majority of archaeological sites across the landblock (Grogan, 2005b). Grey-brown Podzolic soils have a B-horizon characterised by high clay content and are moderately drained, such that under management they can be agriculturally productive and are well suited to grazing (Finch et al., 1971). The modern landscape for the most part is agricultural grassland but with some exposed limestone pavement occurring in the north and east. A number of lakes run from the north-east to south-west, of which Rosroe Lough, the second study site, is one of the largest. Detail on Rosroe Lough itself is provided in Chapter 8.

Archaeological Setting

Figure 2.6 provides an account of archaeological features within the Mooghaun Landblock which will be discussed in detail in Chapter 3. Archaeological sites specifically within the catchment area of Rosroe Lough include two wedge tombs, one located on a ridge immediately east of the lake and another to the north which attests to localised Chalcolithic activity. Burnt mounds are present, while just outside of the delineated area one such site situated by Mooghaun Lough has been dated to c. 1250 BC (Molloy, 2005). An embanked barrow, attributed to the Middle Bronze Age (Grogan, 2005b) is located in the north of the catchment. The Knocknalappa lake settlement is located on the eastern shore of Rosroe Lough dating to c. 1033 – 848 BC associated with an enclosure and the recovery of two log-boats (Grogan et al., 1999; Raftery, 1942). Lying just outside of the western edge of the catchment is the Late Bronze Age site of Mooghaun hillfort constructed in the late 10th Century BC and nearby is the find-spot of the Mooghaun gold hoard; the largest assemblage of gold items found in Ireland (Grogan, 2005b; Eogan, 1983; Condit, 1996).

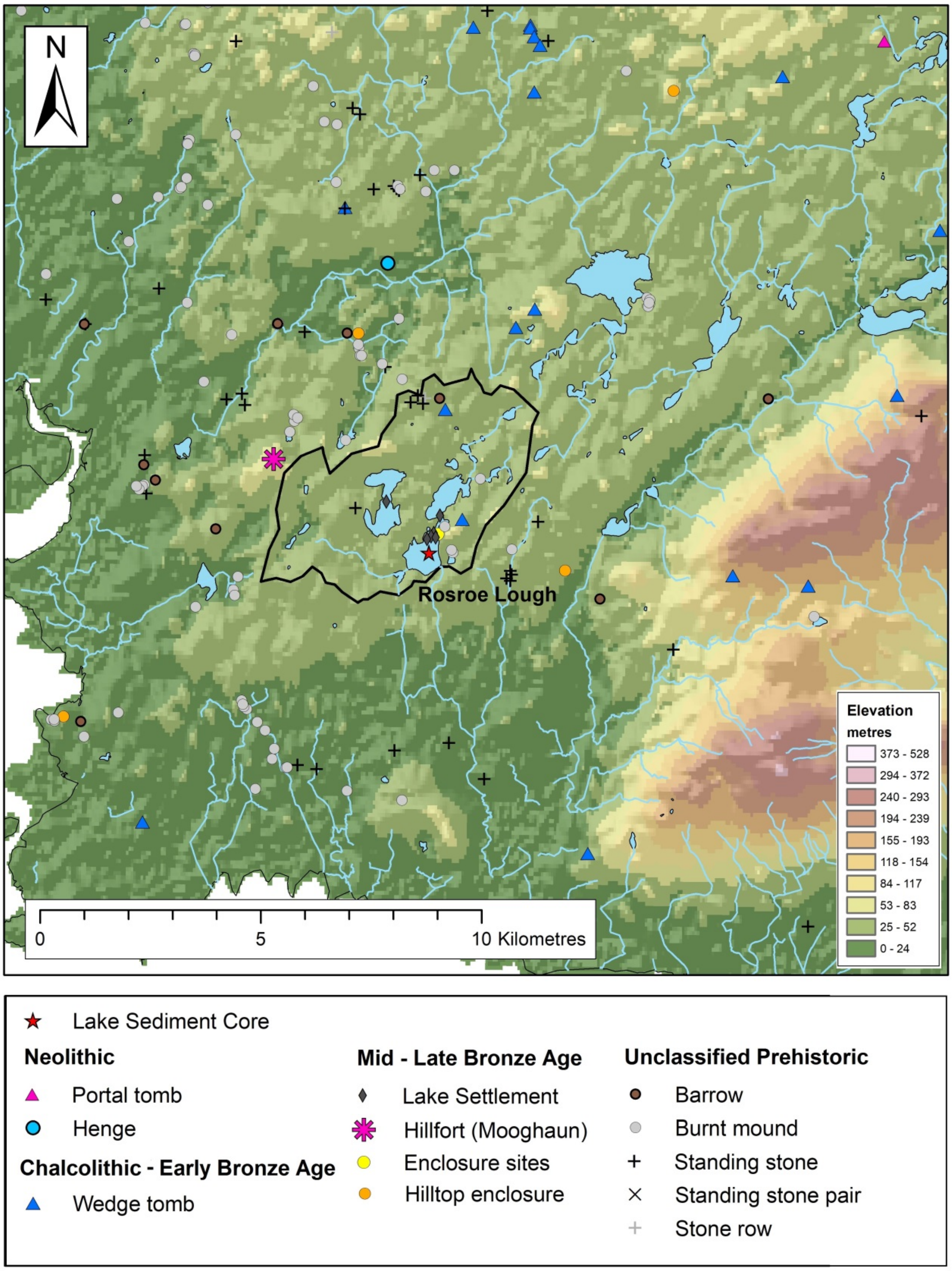

Figure 2.6: The distribution of relevant archaeological sites in the Mooghaun Landblock. Rosroe Lough is labelled and the red star indicates the coring location. The black line denotes the catchment area of Rosroe Lough which covers an area of c. 19.3km^2. The lake settlement site of Knocknalappa is situated on Rosroe Lough. Mooghaun hillfort and much of the archaeological activity is to the north-west of the lake. Source: author.

Previous Palaeoenvironmental Research

Previous palaeoenvironmental research in this area has been limited despite the presence of a large number of lakes across the landscape. Three pollen records will be examined in detail (Table 2.2). As Figure 2.5 illustrates, two of these profiles are located in close proximity to Rosroe Lough within the Mooghaun Landblock. Mooghaun Lough is a small lake located c. 3.7km to the north-west of Rosroe Lough, c. 750m from Mooghaun hillfort (Molloy, 2005) and Caherkine Lough is located c. 2.6km to the north-west of Rosroe Lough (O'Connell et al., 2001). Caheraphuca Lough is at a greater distance of c. 19km north but is included in this comparison due to the similarity of this record with that of Mooghaun and Caherkine, in contrast to those from the Burren (Molloy and O'Connell, 2012; Thompson, 1997; Feeser and O'Connell, 2009). These records all provide local pollen signals due to their basin characteristics; Mooghaun Lough is a small, closed basin and Caheraphuca Lough is surrounded by a low, glacial ridge. Detail of the Caherkine catchment is provided in Figure 8.2. None of the previous pollen records have a particularly robust chronology with dating programmes being problematic in all cases, including at Rosroe Lough.

Table 2.2: Available pollen records relating to the Mooghaun Landblock

Site	Co-ords	Site type	Time span	^{14}C dates	Reference
Mooghaun	52°47'28"8°52'12"	Lake	AD1950-9550BC	2	Molloy (2005)
Caherkine	52°47'12" 8°51'18"	Lake	AD1950-9550BC	0	O'Connell *et al* (2001)
Caheraphuca	52°56'10" 8°54'54"	Lake	1050-8050BC	1	Molloy & O'Connell (2011)

Chapter 3 – Human-Environment Interactions in Irish Prehistory with a Focus on Co. Clare

3.1 Early Neolithic (c. 4000 – 3600 BC)

One of the main research agendas concerning Early Neolithic Ireland has been the origin and adoption of the Neolithic way of life. This has encompassed debate over immigration versus indigenous adoption (Sheridan, 2007; 2010; Schulting and Richards, 2002; Thomas, 2004), the proposed dietary shift from marine to terrestrial resources (Schulting, 2010; Richards and Schulting, 2006; Schulting and Richards, 2002; Milner et al., 2003; Milner et al., 2006) and the application of new techniques such as ancient DNA (Cassidy et al., 2016). Further research agendas have focused on stone axe exchange (Cooney and Mandal, 1995; Mandal and Cooney, 1996; Mandal et al., 1997; Mandal, 1997; Curran et al., 2001; Cooney et al., 1998) and early monumentality (Lynch, 2014; Mercer, 2015; Schulting et al., 2012; Bergh and Hensey, 2013).

In recent years the increase in large-scale developer-funded archaeology in Ireland has led to an upsurge in the recovery of settlement evidence from the Early Neolithic and demonstrated a distinct period of early house construction (Armit et al., 2003; Smyth, 2014a; 2013; McSparron, 2003; Purcell, 2002; Danaher, 2009; O'Donovan et al., 2003; Logue, 2003; Moore, 2003; Dunne, 2003; O'Drisceoil, 2003). Bayesian statistical modelling of ‘gold standard’ AMS ^{14}C dates has confirmed the existence of a distinct house-horizon between c. 3720 – 3620 BC (Whitehouse et al., 2014; Smyth, 2014b; McSparron, 2008; Grogan, 2002) which suggests a greater concern with the concept of ‘place’ within the Irish landscape at this time. The most fundamental change with the onset of Early Neolithic agriculture was the changing interaction between people and their environment with an overall trend for decreasing woodland and increasing landscape openness. As such palaeoenvironmental investigations have been an important focus of research in this period.

3.1.1 Human – Environment Interactions: Wider Trends

Palaeoenvironmental analysis is an excellent tool with which to assess the changes that occurred in landscapes with the onset of agriculture. Ireland during the Mesolithic was a mixed-deciduous woodland environment composed of elm, oak, hazel and lesser amounts of pine (e.g. Molloy, 2005). In Britain, research by Woodbridge et al. (2014) has indicated that >75% of the land cover was woodland but that levels started to decrease from c. 4050 BC. A prominent feature of Holocene pollen diagrams is the Elm Decline which can be synchronously dated across mid-western Ireland to c. 3890 BC and is broadly contemporary in Britain (O'Connell and Molloy, 2001; Edwards, 2004). The cause of the decline is heavily debated but it is thought to have been exacerbated by the combined effects of elm-specific disease, potential climatic factors and human activity (O'Connell and Molloy, 2001; Edwards, 2004). A widely accepted contributor to the Elm Decline is disease associated with the elm bark beetles *S. scolytus* in disturbed woodland which would account for the rapid decline seen in the majority of records (Parker et al., 2002). Figure 3.1 shows the variation in start date for the Elm Decline at sites across Ireland.

The period immediately after the Elm Decline in the majority of Irish pollen records is characterised by anthropogenically induced vegetation changes, i.e. a reduction in woodland concurrent with a rise in disturbance indicators which is described as a *Landnam* (Iversen, 1941). Generally in the Irish record there is the establishment of the first open areas within the landscape characterised by species-rich grassland inclusive of herb taxa such as ribwort plantain (*Plantago lanceolata*), and in some instances cereal-type pollen is detected in the record (Behre, 1981; Molloy and O'Connell, 2016). Whitehouse et al. (2014) describe this as the '*Plantago* rise', which when numerous sites from across Ireland were examined, with the exclusion of poorly dated sites, appears to have occurred no earlier than c. 4050 BC and more generally from c. 3900 BC (Figure 3.2). *Landnam* periods have been identified in both local (e.g. Glenulra Basin, Céide Fields, Co. Mayo) and regional (e.g. Garrynagran, Co. Mayo) pollen records in mid-western Ireland suggesting that substantial pastoral farming was the general trend at the time across large expanses of the landscape (O'Connell and Molloy, 2001). The duration of Early Neolithic *Landnam* are variable, however, identified as a period of five centuries in the Céide Fields landscape but as a shorter three centuries of farming activity at Lough Sheeauns, Connemara (O'Connell and Molloy, 2001).

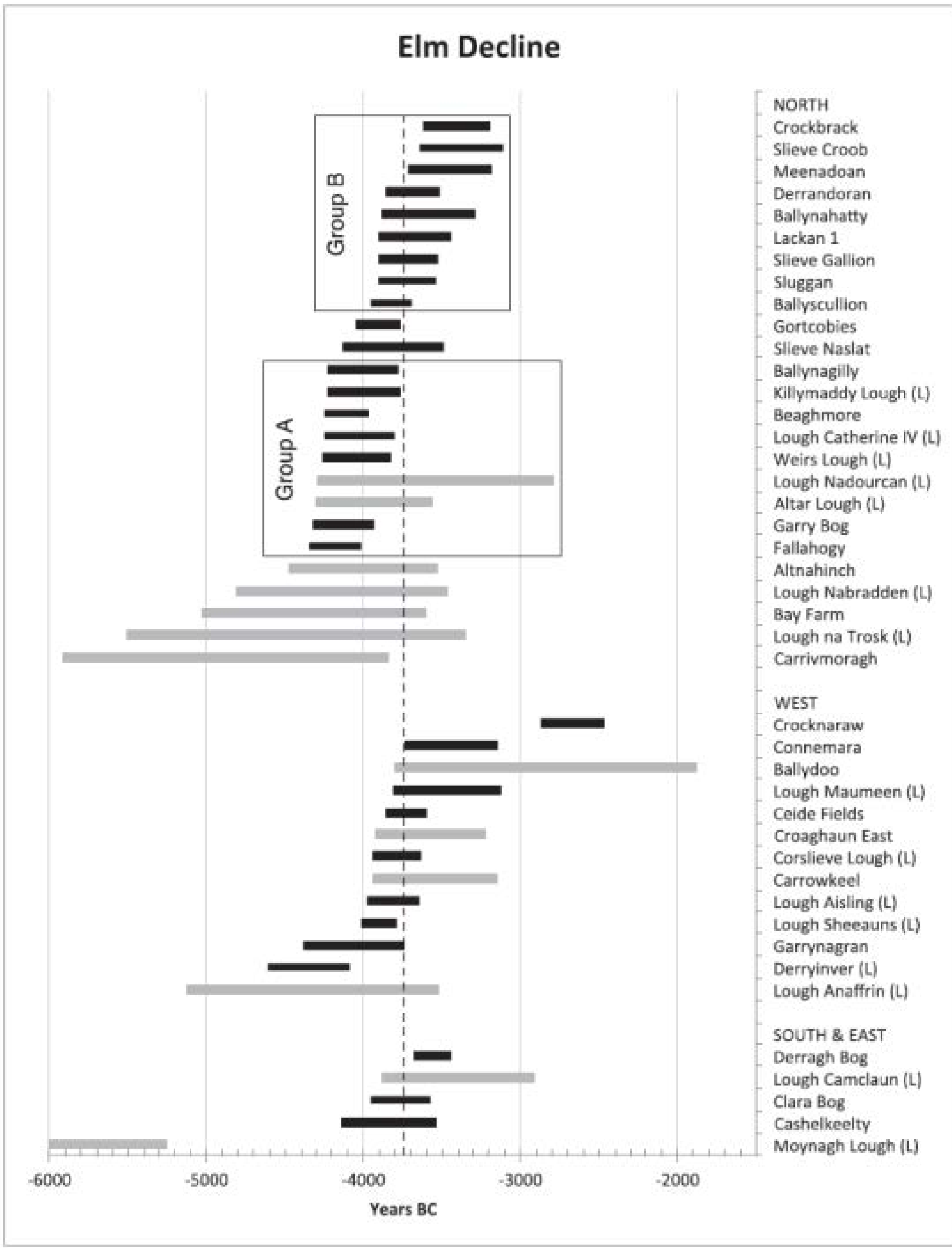

Figure 3.1: The timing of the Elm Decline across Ireland. Sites from which pollen records have been obtained are listed on the right and the x-axis represents calibrated years BC. Bars indicate the date range for this feature with more precisely dated records shown in black. Group A = pre-4000 BC start date while group B = post-4000 BC for northern sites (Whitehouse et al., 2014).

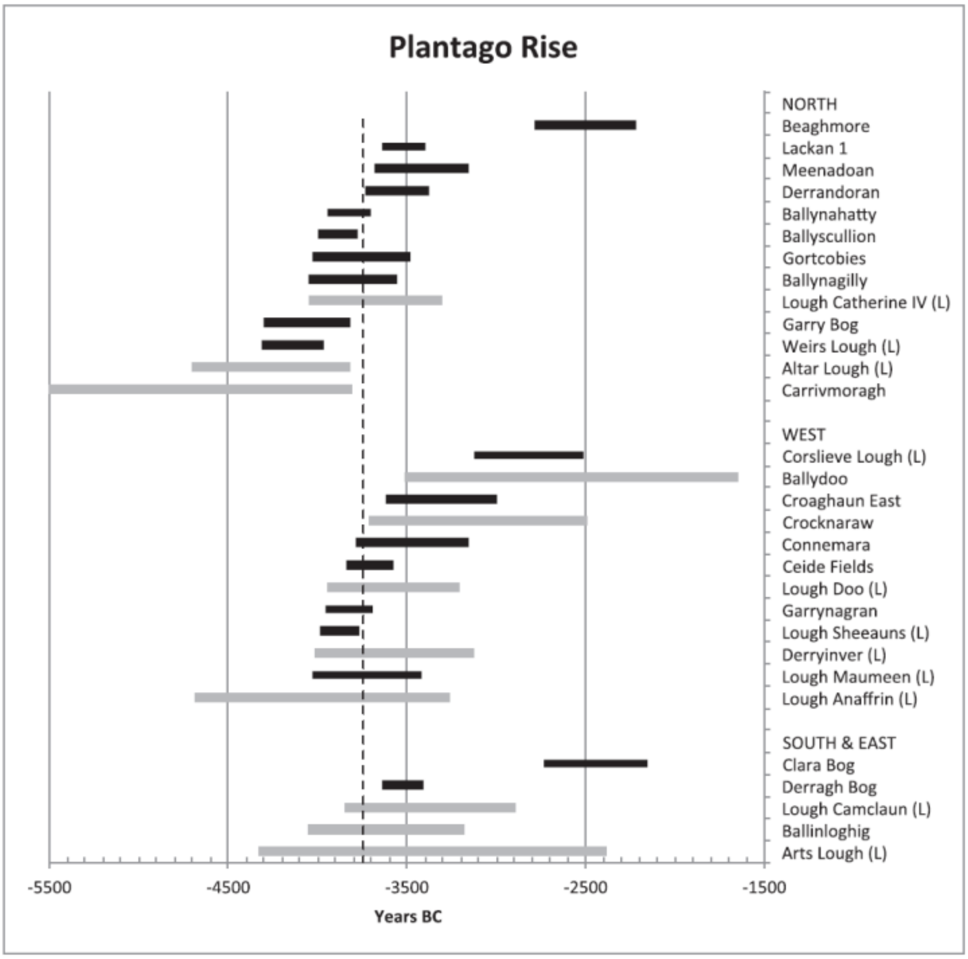

Figure 3.2: The timing of the expansion of *Plantago lanceolata* which is associated with Neolithic *Landnam* activity from the North, West, South and East of Ireland. Pollen records are indicated on the right of the diagram and the x-axis represents calibrated years BC. Bars indicate the date range for this feature with more precisely dated sites shown in black. The dashed line indicates the start of the Neolithic (Whitehouse *et al*, 2014).

Due to the extensive woodland that was established by the Early Neolithic, the pollen of anthropogenic indicators may not register strongly in a record unless there was significant land clearance (O’Connell and Molloy, 2001). The trend does appear to be for a strong pastoral and limited arable component within the initial agricultural economy of the Neolithic in mid-western Ireland (O'Connell and Molloy, 2001). Figure 3.3 demonstrates the trends in Neolithic farming from the Irish pollen record and the concentration of activity in the Early Neolithic.

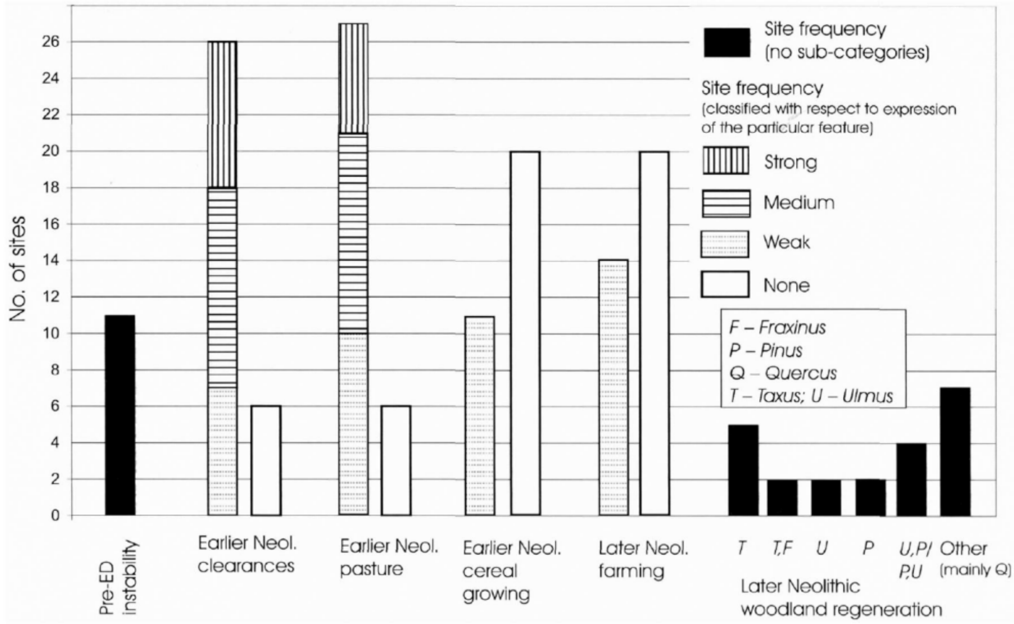

Figure 3.3: Trends in Neolithic farming from the Irish pollen record; pre-elm decline instability, Early Neolithic clearance, pasture, cereal and later Neolithic farming from twenty six pollen records across Ireland. The frequency of woodland regeneration in the Neolithic is indicated with the main tree species indicated (O'Connell and Molloy, 2001).

It was also in the Early Neolithic that the first fieldsystems were established in the landscape, with Céide Fields being the earliest and most well known in Ireland and the subject of recent debate (Whitefield, 2014; 2017). The traditional interpretation of Céide Fields suggests that an intensive period of pastoral activity c. 3700 – 3200 BC included the clearance of >1000ha of land and the demarcation of two large, conjoined, coaxial field systems (Cooney, 2000; Waddell, 2010). Pastoral farming is thought to have been predominate at the site but with some evidence for small scale cereal cultivation (O'Connell and Molloy, 2001). Further fieldsystems have been identified in the Belderrig Valley and at Rathlackan, Co. Mayo (Cooney, 2000; Smyth, 2013). A recent re-examination of dating evidence, however, has called into question the Early Neolithic date assigned to these fieldsystems (Whitefield, 2014; 2017). If the established chronologies are to be accepted then the bounding of the landscape, in western Ireland at least, was a process that began in the Early Neolithic.

Combined with pollen data which demonstrates intensive, primarily pastoral, farming this suggests a commitment to the new agricultural economy. Cattle are thought to have been the most important domesticate at this time which has been interpreted in Britain, at least, as supporting a subsistence strategy based on seasonal mobility (Cooney, 2000). Early

Neolithic settlement evidence and potential fieldsystems, however, suggests cattle husbandry may have taken a more sedentary form in Ireland (Cooney, 2000).

An arable component appears to have been concentrated within the first two centuries after the Elm Decline, which has been identified between c. 3780 – 3640 BC, for example, at Lough Meenaghan, Co. Sligo (O'Connell and Molloy, 2001; Stolze et al., 2012). Recent studies (Whitehouse et al., 2014; McClatchie et al., 2014) have demonstrated the presence of cereals at 86% of Irish Early Neolithic sites (sample size = 52) while Bogaard and Jones (2007) have proposed that the scale of cereal cultivation in Britain and continental Europe was similar at this time. Cereal assemblages are a persistent occurrence at Early Neolithic sites corresponding with the first appearance of cereal-type grains in pollen records (Whitehouse et al., 2014; O'Connell and Molloy, 2001). Emmer wheat was the dominant crop but with additional evidence for significant levels of naked and hulled barley (Whitehouse et al., 2014). The combined evidence suggests that Irish Early Neolithic farmers were not engaged in shifting cultivation but had a more permanent economic base in the form of small garden plots (Whitehouse et al., 2014; McClatchie et al., 2014) which combined with the house-horizon evidence suggests Early Neolithic communities were becoming concerned with creating a sense of place.

Climate

It has been proposed that the beginnings of agriculture may have been contemporary with climatic amelioration which is indicated in several Irish records (Turney et al., 2006). Warmer/drier periods are suggested from records at Lough Meenaghan, Co. Sligo (c. 3770 BC), Templevanny Lough, Co. Sligo (c. 3710 – 3670 BC), Achill Island, Co. Mayo (c. 3850 – 3250 BC) and Derragh Bog, Co. Longford (c. 4330 – 3950 BC) (Stolze et al., 2012; Stolze et al., 2013; Caseldine et al., 2005; Langdon et al., 2012). Correspondence with the beginnings of human activity suggests a possible regional response to climatic amelioration (Stolze et al., 2013). That the majority of arable cultivation appears to be concentrated in the Early Neolithic lends supports to this interpretation but any correlation is unclear (Tipping and Tisdall, 2004; Bonsall et al., 2002). That the climate of north-western Europe, in general, was becoming more continental is suggested by numerous studies (Bonsall et al., 2002; Girling, 1979; Parker et al., 2002). A lack of consistency at British sites, however, has led Schulting (2010) to propose that climatic impacts may have been of marginal importance at this time. Similarly, Woodbridge et al. (2014) note that the relationship between climate and changing land-use is far from straightforward with few clear links observed and a lack of chronological precision. Furthermore, it is important to remember that "*correlation does not equal causation*" and that people in the past would not have reacted to climate change *per se* but to the resulting environmental conditions brought about by such change (Schulting, 2010).

3.1.2 Human-Environment Interactions in Co. Clare – The Story So Far

Archaeological Evidence

The main focus of Early Neolithic settlement in Co. Clare appears to have been centred in the Burren. The earliest evidence occurred in the central Burren with the construction of the Poulnabrone portal tomb, one of the most iconic monuments in Ireland (Figure 3.4) (Grant, 2010; Lynch, 2014). Although there is no date for its construction, depositional activity has been modelled by Bayesian statistics to between c. 3885 – 3720 BC and c. 3355 – 3135 BC, which can be interpreted as successive internments over a period of six centuries or as two distinct phases of use (Schulting, 2014; Lynch, 2014). The unburnt and disarticulated remains of at least thirty five individuals, both males and females, were deposited (Beckett and Robb, 2006). It had originally been proposed that the assemblage may have represented the secondary deposition of older bones but taphonomic analysis by Beckett (2011) suggests this was not the case. It is likely that the monument was used as a repository for whole bodies with decomposition occurring *in situ* with the subsequent manipulation and removal of certain bones (Beckett and Robb, 2006). Isotopic signatures suggest the majority, bar one, had their origins in a limestone area, likely on the Burren itself (Lynch, 2014). The mixed bone assemblage attests to secondary manipulation and the removal of certain bones after burial (Lynch, 2014; Beckett, 2011). Human activity closer to Lough Inchiquin is attested to by the Ballycasheen portal tomb, 2.4km north-east of the lake, on the southern end of Parknabinnia ridge (De Valéra and O' Nuallain, 1961). It is situated on the edge of the Burren located between the southern end of Roughan Hill and the River Fergus, possibly marking the location of this water source (Lynch, 2014; Jones, 2004; Mercer, 2014). The large portal tomb of Moyree Commons is also close to the River Fergus and c. 8.5km from Lough Inchiquin, on the low-lying limestone landscape that stretches eastwards from the Burren (Mercer, 2014). A number of stone axes (46), likely dating to the Neolithic have been found around Lough Inchiquin itself, in the landscape towards Roughan Hill which attests to early human activity (Grogan and Condit, 2000).

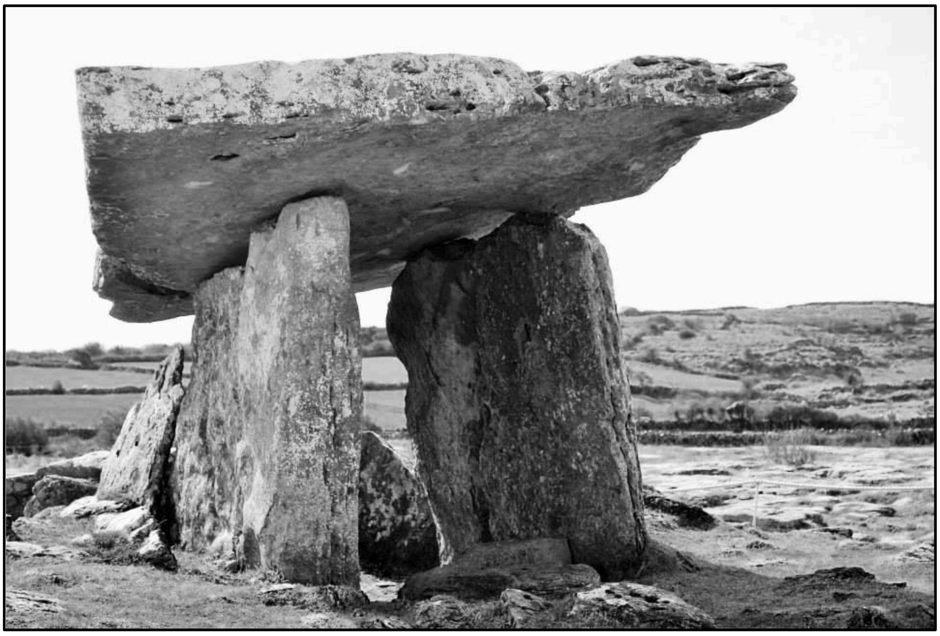

Figure 3.4: Poulnabrone portal tomb, the earliest dated megalith in Ireland, which is located on the Burren c. 10km north-west of Lough Inchiquin. Source: author.

Activity began on Roughan Hill in the Early Neolithic with the construction of Parknabinnia chambered 'atypical' court tomb (Cl.153) in addition to a similar but ruined tomb (Cl.154) (Jones, 2003). Bayesian modelling has placed the initial use of Irish court tombs at c. 3700 – 3570 BC (Schulting et al., 2012). Situated north of the crest of Roughan Hill, Cl. 153 exhibits a number of unusual features while the gallery of two chambers is similar to that of a court tomb (Jones, 2003). Material culture recovered through excavation suggest an Early Neolithic date with this later confirmed by a series of twelve ^{14}C determinations from human bone within chambers 1 and 2, which provided one of the earliest dates from a court tomb (c. 3693 – 3376 BC) (Schulting et al., 2012). The alkaline nature of the soils on the Burren allowed for a detailed examination of human remains with cremated and inhumed remains of at least eighteen individuals (male and female) preserved (Jones, 2003; 2004). Manipulation of the remains has been proposed with earlier burials rearranged during episodes of tomb cleaning (Beckett and Robb, 2006; Beckett, 2011).

Approximately 3.5km to the west of Roughan Hill are two further chambered court tombs; Ballyganner North (Cl.34) and Leamaneh North (Cl.135), both of which are morphologically similar to Cl.153. These three monuments, together with Shanballeyedmond (Ti. 7) in Co. Tipperary (dated to c. 3938 – 3542 BC), have been assigned to a regional tradition labelled the 'North Munster atypical court tombs' (Jones, 2016; Schulting et al., 2012; Jones, Forthcoming-b). While these tombs share some features characteristic of court tombs in general, they also possess distinctive architectural features that set them apart (e.g. narrower forecourts, short heel-shaped cairns and pseudo-jamb stones) (Jones, Forthcoming-b). With the exception of Shanballeyedmond, which is c. 70km to the south-east, these atypical court tombs cluster within c. 5km of each other, at some distance from the main concentration of court tombs in North Connacht and Ulster (Jones, 2016; Jones, Forthcoming-b). The court tombs are positioned with two to the east (Roughan Hill) and two to the west (Ballyganner/Leamaneh) with Jones (2004) suggesting the two distinct areas may represent two clans within a territory defined by the position of the portal tombs; Poulnabrone to the north, and Ballycasheen to the South. The evidence suggests that, although there was intense activity in this area in later periods, it was built upon a tradition of Early Neolithic monument building in the area (Jones, 2003). Multiple forms of expression were open to the Early Neolithic inhabitants of the Burren, and although portal tombs predate court tombs slightly, they remained in contemporary use (Mercer, 2014). The initial use of Parknabinnia court tomb is contemporary with the house-horizon, while deposition in Poulnabrone portal tomb continued throughout that period, suggesting that activity in the Burren was part of a much larger intensification of human activity seen throughout Ireland at this time. Jones (2003) suggested the possibility of settled farmers in the Burren during the Early Neolithic, and Neolithic ceramic sherds have been found at a habitation site at Teeskagh, c. 5.8km north of Lough Inchiquin (Gibson, 2016).

Further south in the landscape of the Mooghaun Landblock a single portal tomb (Clogher) is located, c. 14km from Rosroe Lough, which attests to limited activity at this time (Mercer, 2014; Grogan, 2005b). The find-spots of Neolithic artefacts (twenty stone axes, three arrowheads and one cylindrical stone object) within a c. 10km radius of Rosroe Lough confirms a limited presence, although Grogan (2005b) and O'Sullivan (2001) have both proposed that south-east Co. Clare did not see significant activity in the Early Neolithic. A concentration of c. 750 stone axes, some of which may be later in date, have been found at Killaloe in the River Shannon, c. 26km north-east of Rosroe Lough, suggesting that a ritual focus was emerging in this area (Grogan, 2005a).

Palaeoenvironmental Evidence

In the Burren region, seven pollen records have previously been investigated; two from the northern Burren (Cappanwalla and Lios Lairthín Mór), four from the south-eastern edge

(Loch Gaeláin, Gortlecka, Rinn na Mona and Carron), one from the southern lowlands (Molly's Lough) with an additional record from An Loch Mór, on the nearby offshore island of Inis Oírr also considered relevant. Further detail of these records will be provided in Chapter 6. An overview of main trends in pollen data from these records will be provided in this chapter. The Elm Decline was identified in all of the pollen records in this area, identified at Molly's Lough at c. 4050 BC with the timing of this feature in the additional records consistent with the generally accepted timing of c. 3850 BC for mid-western Ireland (Thompson, 1997; Lamb and Thompson, 2005) (Molloy and O'Connell, 2001, 2004; Feeser, 2009; Watts, 1984). In all instances, shortly after the Elm Decline, an expansion of anthropogenic indicators was recorded suggestive of pastoral farming (Thompson, 1997; Feeser, 2009; Molloy and O'Connell, 2004; Watts, 1963, 1984). Despite wider Irish evidence suggesting cereal cultivation occurred during the Early Neolithic, no cereal-type pollen has been identified from this period from across the Burren (Thompson, 1997; Feeser, 2009; Molloy and O'Connell, 2004; 2007; Watts, 1963; 1984). It has been proposed (e.g. Thompson, 1997; Lynch, 2014) that the megalithic monuments in the Burren were likely constructed by the same communities responsible for Early Neolithic woodland clearance represented in the pollen record.

In contrast, the pollen records of south-east Co. Clare suggest very little human activity in the Early Neolithic. In this area, three pollen records have been investigated; two less than 4km to the north-west of Rosroe Lough (Mooghaun and Caherkine Loughs) and one c. 19km to the north (Caheraphuca). Again, further details will be discussed in Chapter 8. The Elm Decline registers in all of the records but was not followed by an Early Neolithic *Landnam* (Molloy, 2005; Molly and O'Connell, 2012; O'Connell et al., 2001). In all cases, the representation of anthropogenic indicators remained low suggesting little to no human activity in this area in the Early Neolithic (Molloy, 2005; Molly and O'Connell, 2012; O'Connell et al., 2001), thus supporting the archaeological interpretation.

3.1.3 Summary

The Early Neolithic can be characterised as the first period in which human activity increased to a level substantial enough to alter the environmental record. The dating of the house-horizon and the proposed concentration of cereal cultivation in the earlier part of this period suggests a concern with the creation of a sense of place within the landscape. There was an intensification of settlement and a new engagement with the landscape that is borne out in both the archaeological and palaeoenvironmental record. The identification of the Elm Decline in the majority of Irish pollen profiles (O'Connell and Molloy, 2001) and the contemporaneous decline in woodland seen across northern Europe indicates that this was the general trend at the time. The identification of significant *Landnam* events in most Irish pollen records subsequent to the Elm Decline suggests a strong pastoral farming economy. The contrast between the pollen records of the Burren and the Mooghaun Landblock in this regard, however, attests to local differences in population densities and settlement occupation.

3.2 The Middle – Late Neolithic (c. 3600 – 2500 BC)

The Irish Middle- Late Neolithic can be viewed as a period of declining levels of human activity compared to the preceding period. The strong settlement evidence that characterised the Early Neolithic is no longer found, although settlement architecture has become a focus of Late Neolithic research (Smyth, 2013; 2014a; Richards, 1993; Pearson et al., 2008; Pearson, 2007; O'Drisceoil, 2009; Grogan, 2002). Interactions between Ireland and Britain have been a major research agenda for the Late Neolithic concerned primarily with Grooved Ware pottery (Richards, 1993; Brindley, 1999; Sheridan, 2004; Eogan and Roche, 1999). There was still a great concern for monumentality and research has focussed on mortuary practices specific to the period (Brindley et al., 1989; Dowd, 2015) while the timber circles of Ireland and the henges of Britain have received most attention (O'Drisceoil, 2009; Eogan and Roche, 1999; Plunkett et al., 2008; Noble, 2006). There was a strong component of woodland regeneration which may suggest declining population levels at this time within Ireland. The Irish climate from c. 3550 BC appears to have been one of increased instability inferred from various proxy records, although the impact this would have had on human-environment interactions is unclear. As such, palaeoenvironmental research of this period is quite well established.

3.2.1 Human-environment Interactions: Wider Trends

The Middle – Late Neolithic in Irish pollen records was at first characterised by a continuation of Early Neolithic *Landnam* activity but later there was a decline in this farming activity allowing for the regeneration of woodland (O'Connell and Molloy, 2001). This has been identified in pollen records from the Glenulra basin and Garrynagran, Co. Mayo from c. 3450 BC and c. 3150 BC, respectively (O'Connell and Molloy, 2001). Similarly, at Lough Sheeauns, Connemara, no farming activity was identified in the pollen record from c. 3480 – 3180 BC (O'Connell and Molloy, 2001). Fieldsystems in Co. Mayo were abandoned such as Belderrig Beg (c. 3425 BC) and Céide Fields (c. 3200 BC) although the date of peat growth that may have led to abandonment has been the subject of recent debate (O'Connell and Molloy, 2001; Whitefield, 2017; Whitefield, 2014). In general, arboreal representation increased significantly with the regeneration of hazel and oak in the landscape (O'Connell and Molloy, 2001). Research in the south-west of Ireland demonstrated that arboreal representation reached c. 90-95% in this period at Cashelkeelty, Co. Kerry (Lynch, 1981). Woodland regeneration appears to have been the general trend at this time and is seen as being spatially extensive across the country (Whitehouse et al., 2014; O'Connell and Molloy, 2001). Concurrent with the rise in arboreal taxa in Irish pollen records is a decrease in the anthropogenic indicators that defined the *Landnam* period, especially grass and ribwort plantain (O'Connell and Molloy, 2001; Whitehouse et al., 2014). Whitehouse et al. (2014) propose this decline occurred no earlier than c. 3500 BC based on a dataset of twelve precisely dated sites from across Ireland (Figure 3.5).

Similarly, in Britain, pollen data indicates increased re-afforestation from c. 3350 BC at a large number of sites with arboreal representation increasing by up to 35% (Whitehouse and Smith, 2010). The changing intensity of farming from the Early Neolithic into the Middle Neolithic has been compared with proposed demographic changes inferred from the ^{14}C distribution of archaeological sites. The density of sites from the first centuries of the Middle Neolithic infers high population levels, with a subsequent decline suggested from c. 3350 BC (Woodbridge et al., 2014). This corresponds with the re-establishment of woodland between c. 3450 – 3050 BC when arboreal representation was up to 80% (Woodbridge et al., 2014). The data suggests that there was an intrinsic link between population dynamics and land-cover change during the Neolithic in Britain (Woodbridge et al., 2014). With the Irish pollen data also demonstrating increased woodland at this time, it is possible that decreased population levels were a factor in the reduction of farming activity in the Middle Neolithic which has been proposed by Whitehouse et al. (2014).

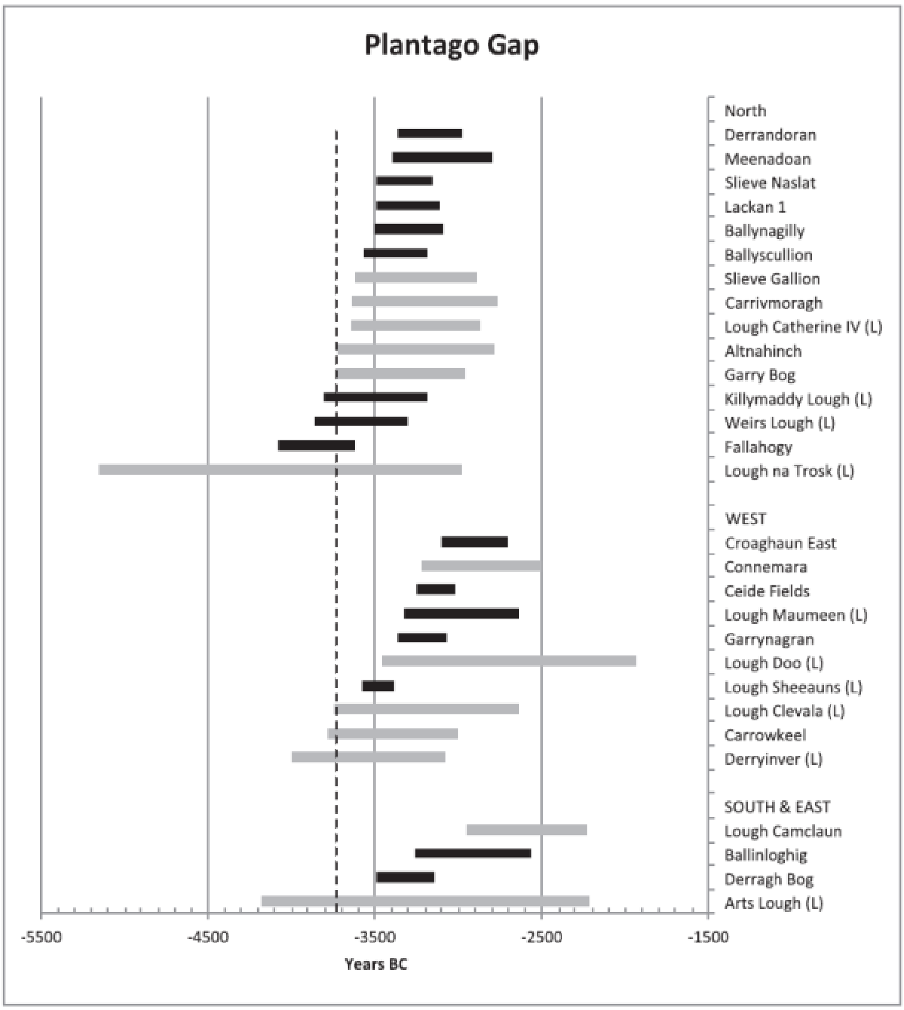

Figure 3.5: The timing of the '*Plantago* Gap' which has been linked to a period of reduced farming and woodland regeneration across Ireland during the Middle Neolithic. Pollen records are listed on the right with the x-axis representing calibrated years BC. Bars represent the date range for this feature with more precisely dated sites shown in black. The dashed line marks the start of the Middle Neolithic in Ireland (Whitehouse et al., 2014).

Across the Irish landscape the reduced pressure from farming activity allowed elm to regenerate (O'Connell and Molloy, 2001). Changes in woodland dynamics also occurred in this period with the expansion of both ash and yew, the latter reaching up to 20 – 30% in several pollen records (O'Connell and Molloy, 2001). The yew expansion appears to be a phenomenon of the west of Ireland evident in pollen records from the counties of Clare, Galway and Mayo, although slender curves have been identified elsewhere (O'Connell and Molloy, 2001). A climatic factor is proposed for the general synchronicity of yew expansion across Ireland which peaked at c. 2900 BC (O'Connell and Molloy, 2001). After a rapid expansion this species then declined, likely due both to a failure to regenerate under its own canopy (Perrin et al., 2006) and its sensitivity to grazing pressure with the re-initiation of farming activity in the Late Neolithic (O'Connell and Molloy, 2001). O'Connell and Molloy (2001) note that there is a strong bias of Irish Neolithic pollen records to the north and west of the country which may not allow for a full impression of land-use dynamics across Ireland as a whole. This is especially true for areas of increased importance in the mid-later Neolithic such as the Boyne Valley where the archaeological record would suggest a continued human impact upon the landscape at this time, with the continued use and elaboration of passage tombs complexes (O'Connell and Molloy, 2001; Hensey, 2015).

In terms of the arable component there appears to have been a reduction in the frequency of cereal remains from Irish Middle Neolithic sites (Whitehouse et al., 2014). During the first few centuries when *Landnam* activity was still occurring, arable activity continued at sites such as Céide Fields, Co. Mayo and Lough Sheeauns, Co. Galway (O'Connell and Molloy, 2001). Later, however, there appears to have been a cessation of arable farming during the phase of woodland regeneration, although there is some evidence of farming from the Garrynagran record (O'Connell and Molloy, 2001). Figure 3.6 demonstrates the reduction in farming activity in this period implied from the pollen record of western Ireland. The relative importance of crops in the Irish Middle Neolithic is harder to determine due to a smaller dataset of dated assemblages, but emmer wheat and barley still appear to dominate (Whitehouse et al., 2014). In Scotland, an increase in the use of wild plant resources was noted c. 3300 BC in addition to a preference for barley – a crop more tolerant to cooler and wetter conditions (Whitehouse et al., 2014). Crops, in particular, may have been vulnerable to climatic change given the short length of time since their adoption to Ireland in the earlier Neolithic (Whitehouse et al., 2014).

Towards the end of this period, farming appears to have been re-initiated at most sites demonstrated for mid-western Ireland in Figure 3.6. An increase in pastoral indicators in mid-western Ireland started to occur during the last century of the Late Neolithic (O'Connell and Molloy, 2001). Farming was re-initiated on Inis Oírr from c. 2950 BC after a particularly strong period of woodland regeneration had occurred (Molloy and O’Connell, 2004). Similarly at Lough Dargan, Co. Sligo, grassland increased from c. 2705 BC after a period of woodland regeneration which began c. 3390 BC and was particularly pronounced from c. 3005 – 2705 BC (Ghilardi and O'Connell, 2013a). The ‘*Plantago* Gap’ comes to an end at most sites by c. 2700 BC, which suggests the re-initiation of farming activity across Ireland by the end of the Late Neolithic (Whitehouse et al., 2014).

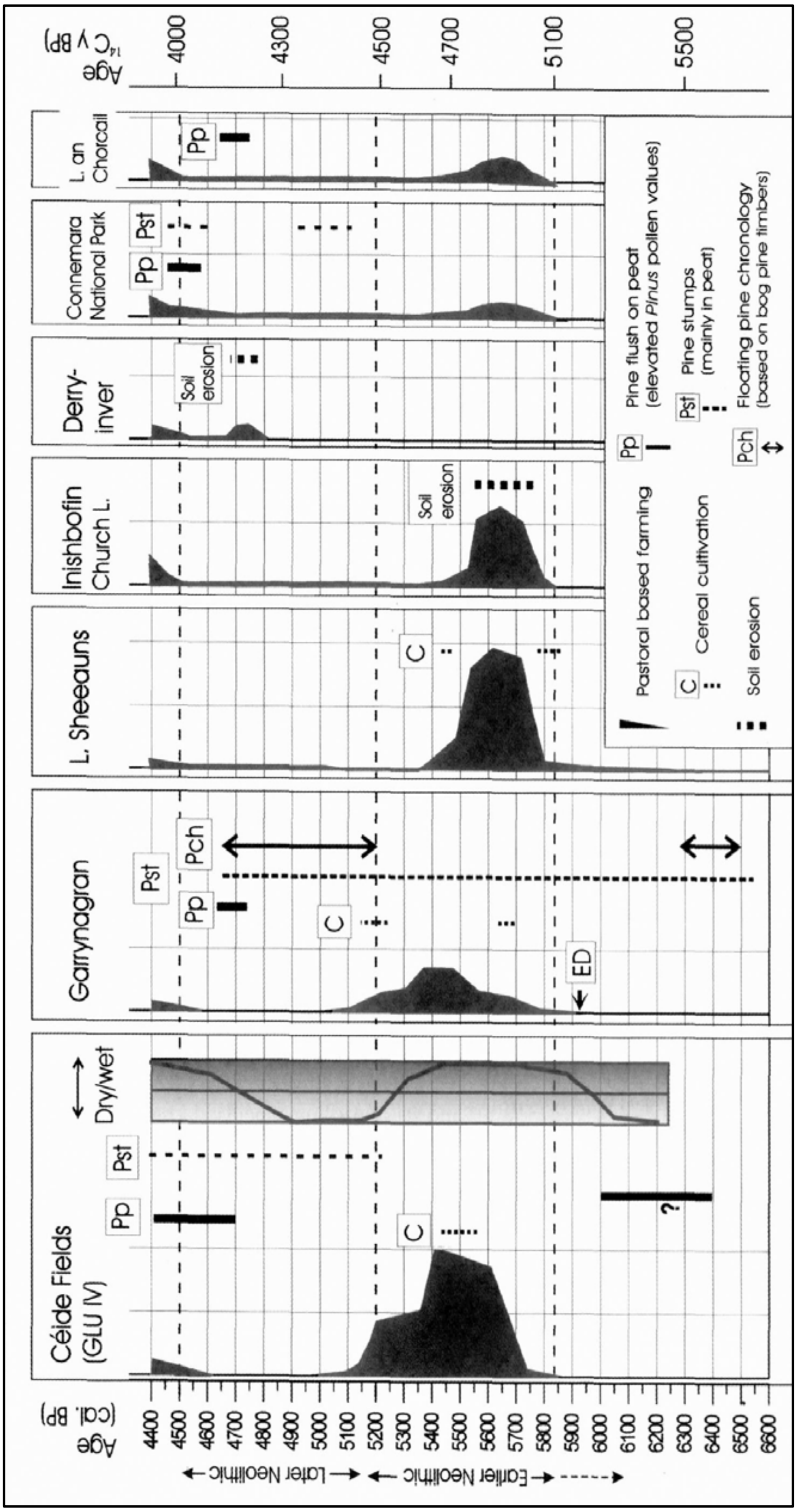

Figure 3.6: Schematic depiction of land-use change from selected sites in Co. Galway and Co. Mayo from the Early to Late Neolithic. Periods of pastoral farming are shown as a black area. The first dashed line indicates the Elm Decline, the second the transition from earlier – later Neolithic and the third the transition to the Chalcolithic. Pollen records are listed at the top and the y-axis represents calibrated years BP (O'Connell and Molloy, 2001).

Climate

Ireland may have become climatically unsettled from c. 3500 BC, characterised by substantial climatic oscillations, although the effect this may have had on human activity and subsistence is unclear (Whitehouse et al., 2014; Stolze et al., 2013). This is especially true as the chronological resolution of comparable datasets is often low (Whitehouse et al., 2014). Evidence for cooler/wetter conditions in the Irish record includes increased bog surface wetness at Derragh Bog, Co. Longford from c. 3550 BC, speleothem evidence from Crag Cave Co. Kerry from c. 3260 BC and multi-proxy high resolution records from Loughmeenaghan and Templevanny Lough, Co. Sligo from c. 3670 BC (Langdon et al., 2012; McDermott et al., 2001; Stolze et al., 2012; Stolze et al., 2013). Additionally, a storm (or series of storms) has potentially been identified in peat profiles from Achill Island, Co. Mayo c. 3250 – 3150 BC (Caseldine et al., 2005). Similarly, evidence from Britain has suggested worsening conditions at this time (Langdon et al., 2004; Langdon et al., 2003; Hughes et al., 2000). In Europe a rise in the level of Lake Constance, Switzerland, has been identified c. 3870 BC, while on a global scale a cooler period has been proposed from c. 3650 – 3050 BC (Magny et al., 2006). Later, a period of drier conditions has potentially been identified in Scottish bog pine records c. 3200 – 3000 BC and in the Irish bog oak record c. 3050 BC (Turney et al., 2006; Moir et al., 2010), while a narrow tree ring event at c. 3190 BC suggests cooler conditions (Whitehouse et al., 2010; O'Connell and Molloy, 2001; Stolze et al., 2012).

3.2.2 Human-Environment Interactions in Co. Clare – The Story So Far

Archaeological Evidence

Human activity in Co. Clare still appears to be concentrated in the Burren landscape. Poulawack cairn, located 5.5km to the north-west of Roughan Hill, was excavated in 1934 and although originally thought to be a Bronze Age monument was later recognised as a Linkardstown cist – a monument type specific to the Middle Neolithic (Hencken and Movius, 1935; Ryan, 1981). Three phases have since been identified at the site, with the primary phase of activity (the principal burial graves 8/8A) dated to c. 3350 BC (Brindley and Lanting, 1991a). Fragments of four skeletons were found within graves 8/8A identified as an infant of c. 1 year, two females c. 21 and c. 40 – 45 years and a male c. 40 -45 years (Hencken and Movius, 1935). The burial consisted of two individual cists surrounded by a number of limestone slabs set on edge with a surrounding cairn up to 2m in height contemporary with it (Brindley and Lanting, 1991a). Linkardstown cists are known to incorporate complex depositional practices and a re-examination of the human remains, which demonstrated a higher representation of robust bones, led Beckett (2011) to propose that secondary manipulation may have occurred at the site. Combined with its prominent position within the landscape this would have reinforced the importance of the site within society (Beckett, 2011). Earlier monuments, such as Poulnabrone portal tomb and Parknabinnia court tomb would have been visible within the landscape at the time of construction. Deposition continued at Parknabinnia court tomb, with nine of the twelve ^{14}C dates from human bone dating to the Middle Neolithic (Schulting et al., 2012). There was, in fact, an overlap in the use of these three monuments in a small area of the southern Burren in this period, highlighted in Figure 3.7 (Schulting et al., 2012; Brindley and Lanting, 1991a).

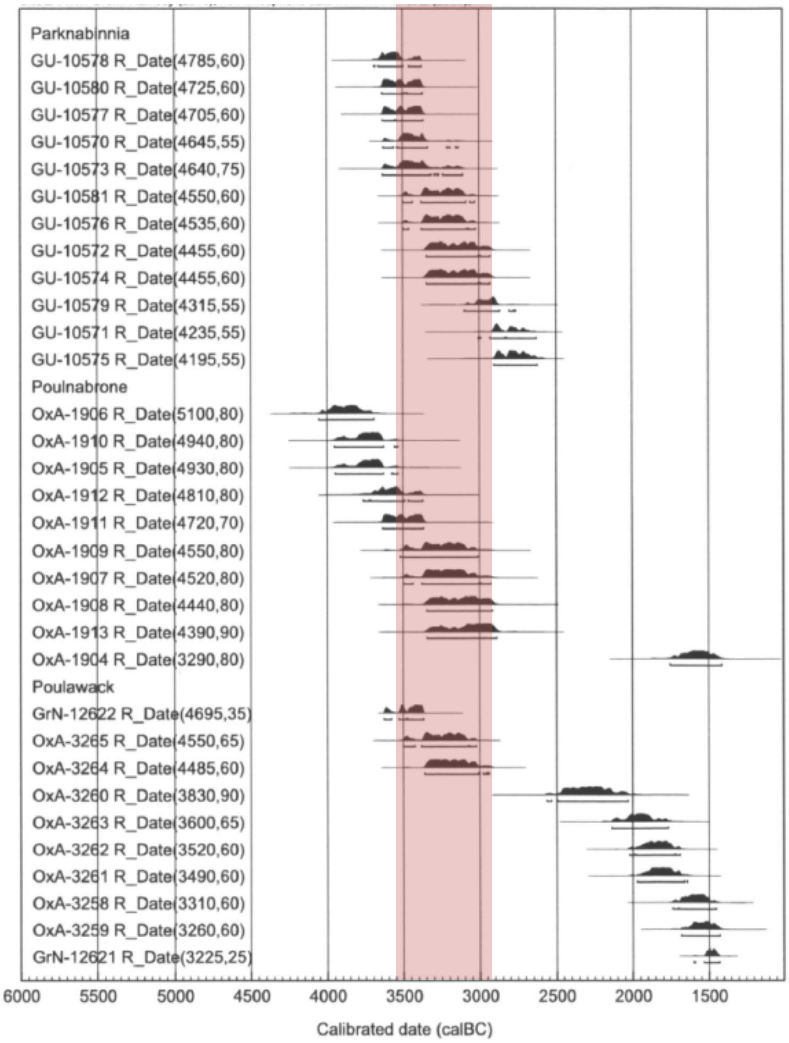

Figure 3.7: ^{14}C-AMS determinations on unburnt human bone from Parknabinnia, Poulnabrone and Poulawack, Co. Clare. The red shaded area indicates the overlap in use of these three monuments during the Middle - Late Neolithic (after Schulting et al.*,* 2010).

In the Late Neolithic, chamber 2 of Parknabinnia court tomb was blocked by four large slabs wedged in front of the jamb and sill stones that divided the chamber, and a femur found between these was dated to c. 3095 – 2765BC (Jones, 2016). Despite the rear chamber now being inaccessible, deposition continued until c. 2900 – 2640 BC in chamber 1 which is late in terms of the general use of court tombs in Ireland (Cooney et al., 2011; Jones, 2016). Schulting et al. (2012) identified Late Neolithic activity in only two other court tombs (Ballyglass 2 and Rathlackan, Co. Mayo) causing Jones (2016) to suggest society in the west of Ireland may have been more traditional and less open to changing ideologies. The blocking of the chamber, however, may have been a reaction to, or at least an awareness of, the elaboration of monumentality occurring in the east of Ireland with the construction of the large passage tombs (Jones, 2016). There is also settlement evidence from a habitation site at Teeskagh (c. 5.8km north of Lough Inchiquin) where a ^{14}C determination of c. 3080 BC was obtained (Gibson, 2016). There appears to be only limited human activity within south-east Co. Clare but a recent discovery of a henge at Coogaun, within the Mooghaun Landblock, attests to limited ritual activity here in the Late Neolithic (Jones, 2018; Condit and Grogan, 1998).

Palaeoenvironmental Evidence

The pollen records from the Burren region correspond with the wider Irish trend for woodland regeneration in this period. Across the south-eastern Burren this increase in woodland was identified at Molly's Lough, Loch Gaeláin, Gortlecka and Rinn na Mona in the Middle Neolithic (Thompson, 1997; Feeser, 2009; Watts, 1984). Similarly a period of woodland regeneration was identified in the more distant An Loch Mór record on Inis Oírr (Molloy and O'Connell, 2007; Molloy and O'Connell, 2004). The evidence suggests a distinct decline in the levels of farming activity across this landscape with a decrease in all pastoral indicators (Thompson, 1997; Feeser, 2009; Watts, 1984; Molloy and O'Connell, 2004). The scale of afforestation led Thompson (1997) to propose that the communities responsible for Early Neolithic farming activity may have abandoned the area during this period, although continued human activity from the archaeological record complicates this assumption. For the most part, this woodland regeneration continued into the Late Neolithic with the exceptions of Loch Gaeláin and An Loch Mór, where farming was re-initiated in the Late Neolithic (Feeser, 2009; Molloy and O'Connell, 2004). Further south in Co. Clare, a woodland environment continued in the catchments of Caheraphuca, Mooghaun and Caherkine Lough's (Molloy, 2005; Molloy and O'Connell, 2012; O'Connell et al., 2001). The combined pollen evidence suggests very low levels of human activity within Co. Clare during the Middle – Late Neolithic which saw pastoral farming diminish and woodland expand across the landscape, before a re-initiation in the latter stages at some sites.

3.2.3 Summary

The Middle – Late Neolithic is characterised from the palaeoenvironmental data as a period of reduced human activity. After the initial farming phase, the evidence for pastoral farming declined from c. 3500 BC and a period of woodland regeneration occurred across Ireland and Britain. This may have been influenced by climatic instability or the vulnerability of new farming regimes. A decline in population has been proposed which may explain both the regeneration of woodland environments and the lack of settlement evidence that was so prolific in the Early Neolithic. In general across Ireland this woodland regeneration occurred after a period of increased and sustained human activity in the Early Neolithic and so can be viewed as a dramatic, and often rapid, change in land-use and landscape composition. There is a lack of settlement evidence within Co. Clare but activity continued at monuments in the Burren, particularly at Poulawack and Parknabinnia. This area continued to be a focus of human activity.

3.3 The Chalcolithic (c. 2500 – 2150 BC) – Early Bronze Age (c. 2150 – 1600 BC)

Since the publication of Allen et al. (2012), the use of the term 'Chalcolithic' to represent an important transitional period starting at c. 2500 BC has become more accepted. A 'transitional copper period' within Ireland was proposed early in the 20th Century by Coffey (1901) but it was O'Brien (2012a) who made the case for a distinct Chalcolithic period within Ireland. A major research focus has been on the adoption of the Beaker package within Ireland (Fokkens, 2012; Sheridan, 2012; Carlin, 2006), with modern scientific techniques including isotopic analysis and ancient DNA helping to elucidate issues of innovation and migration (Cassidy and Bradley, 2015; Cassidy et al., 2016; Jay et al., 2012). With roughly half of the dated burnt mounds belonging to the period c. 2500 – 1900 BC, this has also formed a major research agenda (Hawkes, 2014; McLaughlin et al., 2016; Carlin, 2011) together with the main monument type of the Chalcolithic, the wedge tomb

(Brindley and Lanting, 1991b; O'Sullivan and Downey, 2010; O'Brien, 1999; Schulting et al., 2008; Jones et al., 2015; Ó Maoldúin, 2015). Research spanning both periods has focused on Beaker pottery (Carlin, 2006; 2011), metallurgy and mining (O'Brien, 2012a; O'Brien, 2004; O'Brien, 1994; O'Brien, 2013; Roberts, 2013), gold-working (Eogan, 1994; O'Brien, 2012a; Sheridan, 2012; Cahill, 2015; Warner et al., 2009; 2010; Standish et al., 2015) and settlement (Carlin, 2006; Sweetman et al., 1985; McLaughlin et al., 2016; Brück, 1999; Cleary, 2005; Cleary, 2006; McQuade et al., 2009).

Human-environment interactions, by comparison, have not seen intensive investigations, partly due to the profound changes seen in the archaeological record and partly due to the lack of palaeoenvironmental data with sufficiently robust chronologies for the Chalcolithic, in particular (Fitzpatrick, 2015; Allen and Maltby, 2012).

3.3.1 Human –Environment Interactions: Wider Trends

It is generally proposed that by the Chalcolithic period, there had been a return to a farming economy based on cattle and pig pastoralism with arable cultivation (O'Brien, 2012a). The extent to which this was a fully mixed farming economy is debated but it has been proposed that cultivation began to increase in Ireland in the latter part of the 3rd millennium, and in Britain from c. 2300 BC (Fitzpatrick, 2015). In the north of Ireland, at Lough Muckno, Co. Monaghan, three periods of increased farming activity have been identified in pollen data from c. 2590 – 2460 BC, c. 2330 – 2150 BC and c. 1970 – 1750 BC (Chique et al., 2017). A small-scale arable component was suggested throughout this period until c. 1710 BC when a possible lull in arable farming occurred concurrent with a lower representation of pastoral indicators (Chique et al., 2017). At Ballynagilly, Co. Tyrone, low-level farming activity was re-initiated from c. 2350 BC with occasional cereal-type pollen recorded (Pilcher and Smith, 1979). In the north-midlands pollen data from raised bog peats at Corlea, Co. Longford, similarly suggests that pastoral indicators increased from c. 2600 BC (Caseldine and Hatton, 1996).

In the west, pollen data from Lough Dargan, Co. Sligo, suggests renewed farming activity during the period c. 2705 – 2125 BC, although at a lesser intensity than the Neolithic *Landnam* (Ghilardi and O'Connell, 2013a). Farming activity subsequently became more intensive during the Early Bronze Age with a substantial arable component (Ghilardi and O'Connell, 2013a). After approximately four centuries of farming in this landscape there does appear to have been a decline from c. 1755 – 1670 BC (Ghilardi and O'Connell, 2013a), corresponding with the situation at Lough Muckno for the final century of the Early Bronze Age. Similarly, at Cooney Lough, Co. Sligo, pollen data suggests that farming resumed in the Chalcolithic but did not increase substantially until the Early Bronze Age c. 2175 BC when a mixed farming economy was represented in the data (O'Connell et al., 2014). Pollen investigation at Ballinphuill bog, Co. Galway, during the development of the M6 road scheme, determined that woodland was still prominent in this period but that pastoral farming activity registered c. 2300 – 2050 BC with a small-scale arable component (Molloy et al., 2014; Molloy and O'Connell, 2016).

In the south-west of Ireland, at Cashelkeelty, Co. Kerry, anthropogenic indicators began to rise from c. 2508 BC, corresponding with the large number of Chalcolithic wedge tombs in the area, and subsequently increased again from c. 2015 BC (Lynch, 1981). In the record from Barrees, Beara Peninsula, woodland continued for a little longer with arboreal pollen remaining high until c. 2400 BC with only low representation of pastoral indicators from c. 2400 – 1600 BC (Overland and O'Connell, 2008). Despite variations in the timing and intensity of farming activity during the Chalcolithic – Early Bronze Age across Ireland, it can in general be considered as a period of renewed farming activity.

The extent of cereal cultivation in comparison with pastoral agriculture is hard to determine from the available data (Fitzpatrick, 2015). In Britain, evidence of ard marks have been found within Beaker period soils and tillage has been confirmed by soil micromorphology or the presence of charred plant remains (Fitzpatrick, 2015; Waddell, 2010; Allen and Maltby, 2012). Wheat and barley have been identified but also large quantities of wild foodstuffs discovered at Cloghers, Co. Kerry, suggests the exploitation of natural resources (Fitzpatrick, 2015). A shift to the predominance of barley cultivation has been proposed for continental Europe, but the Irish data is not sufficient to determine if this also occurred here (Allen and Maltby, 2012). An excavated example is that of the Beaker period settlement site, identified at the periphery of the mound at Newgrange. Here, the charred remains of barley and emmer were preserved together with a large animal bone assemblage that was dominated by cattle (58%), followed by pig (34%) with sheep and goat poorly represented (3%) (Allen and Maltby, 2012; van Wijngaarden-Bakker, 1974). In general, however, there is a lack of well-dated palaeoenvironmental datasets from non-funerary contexts with which to deduce the relative importance of domestic animals and crops in this period (Allen and Maltby, 2012).

Climate

The 4.2ka event occurred towards the end of the Chalcolithic c. 2200 BC and has been examined recently by Meller et al. (2015) in terms of its impact upon prehistoric communities. This period of abrupt climate change manifested itself as drier conditions in low latitudes of the Northern hemisphere with cooler/wetter conditions proposed for higher latitudes, although this is less clear (Roland et al., 2014). Difficulty in comparing climatic data with the archaeological record at this time arises due the shape of the calibration curve which can cause uncertainties in ^{14}C dating (Fitzpatrick, 2015). Although multi-centennial climate change at c. 2200 BC appears to have been identified across several regions of the world, it has not been identified in multi-proxy palaeoclimatic records from Ireland and Britain (Fitzpatrick, 2015; Roland et al., 2014). It has been associated with the collapse of numerous early civilisations including the Mesopotamian urban centres which are proposed to have collapsed due to severe drought at this time (Roland et al., 2014). Table 3.1 shows the evidence thus far that has been used to support the manifestation of the 4.2ka event in Ireland and Britain, proposed to have caused wetter conditions.

Table 3.1: The current evidence used to support the manifestation of a 4.2ka event in Ireland and Britain with references indicated in the first column (Roland *et al,* 2014).

Study	Site(s)	Proxy (stats)	Proposed nature of change	Proposed age of change; chronological control (2.5–6.5 ka)
Hughes et al. (2000)	Walton Moss, northern England	Plant macrofossils (DCA)	Major wet event	4.41–3.99 ka; 2 radiometric ^{14}C dates of bulked material from 8 cm stratigraphic depth, no tephrochronology.
Barber et al. (2003)	Abbeyknockmoy Bog, central Ireland	Plant macrofossils (DCA)	Major change to wetter/ cooler conditions	4.4 ka; 6 radiometric ^{14}C dates of bulked material from 2 cm stratigraphic depth, no tephrochronology.
	Bolton Fell Moss, northern England	Plant macrofossils (DCA)	Major change to wetter/ cooler conditions	4.4 ka; 10 radiometric ^{14}C dates of bulked material from 3 to 8 cm stratigraphic depth, no tephrochronology.
Barber (2007)	Review of studies (1976–2005) from a number of sites across Ireland and northern Great Britain, as well as elsewhere in NW Europe	Plant macrofossils (DCA), testate amoebae (TF), humification (%T)	Changes to cooler/wetter conditions	Range from 4.62 to 3.99 ka; high variability in chronological strategy between studies, tephrochronology limited to one study
Mauquoy et al. (2008)	Butterburn Flow, northern England	Testate amoebae (TF); plant macrofossils (DHI)	Moderate wet shift	c. 4.15 ka; 14 AMS ^{14}C dates, no tephrochronology.
Daley and Barber (2012)	Walton Moss, northern England	Testate amoebae (TF), plant macrofossils (DCA/NMDS/DHI), humification (%T)	Rapid shift to wetter conditions	c. 4.2 ka; 13 AMS ^{14}C dates, no tephrochronology.

Roland et al. (2014), however, have cited insufficient ^{14}C dating, poor coherence between records, disagreements with key regional trends and the common use of a single proxy or site, to call into question the accuracy of these Irish and British records. Roland et al. (2014) themselves examined high resolution, multiproxy palaeoclimatic data from two ombrotrophic raised bogs (Sluggan Moss, Co. Antrim and Fallahogy Bog, Co. Derry) situated in an area known for its climatic sensitivity which was supported by a robust chronology. Of the three proxies examined (peat humification, plant macrofossil and testate amoebae), only the latter showed consistent coherence regarding climate, allowing a record spanning the period c. 4550 – 550 BC to be produced (Roland et al., 2014). Although a slight increase in water table depth was identified at c. 2300 – 1800 BC in both bogs this was not distinguishable from variations along the sequence as a whole (Roland et al., 2014). Roland et al. (2014) suggest that because the Irish climate is known to be heavily influenced by one of the proposed factors of the 4.2ka event, (the North Atlantic ocean-atmosphere circulation systems), that had change occurred at this point it should be recognisable in this record. No compelling evidence for this was identified, however, and comparisons with further peat records showed no indication of a significant sustained increase in wetter/colder conditions at this time across Ireland or Britain (Roland et al., 2014).

Contrary to this, Baillie and McAneney (2015) identified a climatic anomaly in the Irish oak tree-ring chronology with a rapid and sustained downturn in tree-ring growth between c. 2206 – 1890 BC. A previous downturn in tree-ring growth was also identified at c. 2354 – 2345 BC (Baillie and McAneney, 2015). Analysis of wood samples from trees located near Lough Neagh, Northern Ireland suggest that lake levels rose during this period indicating that tree-ring growth had been affected by wetter conditions (Baillie and McAneney, 2015). With no consensus over the driving factors of the 4.2ka event, Baillie and McAneney (2015) used documentary sources, the Irish palaeoclimatic record and an anomalous layer of dust at Tell Leilan, Syria c. 2350 BC to propose that meteoric debris were a factor – the dust from which could have caused global climate/atmospheric circulation patterns to change. As Fitzpatrick (2015) states, the correlation between climate and archaeological change should be approached with caution in the Irish record as there is little consensus on the significance of this event in Ireland and it is even harder to deduce how societies may have responded to it.

3.3.2 Human-Environment Interactions in Co. Clare – The Story So Far

Archaeological Evidence

Human activity appears to have been concentrated in the Burren, and in particular at Roughan Hill in this period, with habitation sites and a dense concentration of wedge tombs identified. Through surveys carried out in the 1990s, an extensive secular landscape was identified on Roughan Hill extending over 370 acres (Jones, 1998). A system of fields and habitation enclosures, four of which appear to be Chalcolithic – Early Bronze Age in date (RH1, RH2, RH5 and RH7), have been identified (Figure 3.8 and 3.9) (Jones, 2016). The mound walls create a fieldsystem defined by small, irregular fields that orientate both north-west/south-east and south-west/north-east (Jones, 2016). Settlement RH1 is a kidney shaped enclosure and excavation in the centre revealed a circular house c. 6 – 7m in diameter (Jones, 2004). The most intensive occupation of the site occurred during the Chalcolithic with evidence of Beaker material culture including Beaker pottery, concave-based arrowheads, convex scrapers, a possible hone stone, quern stones, hammer stones and a bone awl tip (Jones and Walsh, 1996; Jones et al., 2010; Jones and Gilmer, 1999; Jones, 1998; 2004). Additionally, six ^{14}C determinations were obtained on excavated animal bone dating to c. 2400 – 1460 BC (Jones, 2016).

Settlement RH2 is a small (<1 acre) roughly circular enclosure with three smaller, rectilinear fields adjoining the western side of the enclosure. Artefacts uncovered in the western section of the enclosure included convex scrapers, chert and flint debitage, a copper or bronze fragment and sherds of Vase Food Vessel pottery, all indicating a Chalcolithic – Early Bronze Age date (Jones et al., 2010). This is supported by two ^{14}C dates on animal bone from the same context suggesting occupation between c. 2275 – 1945 BC, and sub-wall bedrock pedestal heights similar to that of RH1 (Jones, 2016). That this occupation occurred once the enclosure wall was built is suggested by the distribution of occupation material only on the inside of the wall (Jones, 2016). Settlement RH5, consists of three oval enclosures and artefacts are indicative of prehistoric occupation (Jones, 1998). On the basis of sub-wall bedrock pedestal heights a Chalcolithic date has been proposed for RH5 and RH7 (c. 0.2km south) (Jones, 1998; Jones et al., 2010).

Sub-wall bedrock pedestals have been referred to above and these have been used on Roughan Hill as a means to date the ancient walls. A method based on the observation that the limestone bedrock beneath would be more sheltered from erosion and so result in a higher pedestal of bedrock under the wall has been applied; the general concept being the higher the bedrock pedestal the older the wall (Jones and Gilmer, 1999; Jones, 1998; 2004; Jones, 2016). The process relied upon the use of independently dated 'fixed points' in order to assign dates to varying pedestal heights, which in this study were settlements RH1 and RH2 (of Chalcolithic date) and settlement RH3 (of historic date) (Jones, 1998; Jones and Gilmer, 1999; Jones, 2016). Through stratigraphically comparing mound and slab walls, and through the use of fixed dates, this data has led to the conclusion that the majority of the mound walls on Roughan Hill date to the Chalcolithic period (Jones, 2016).

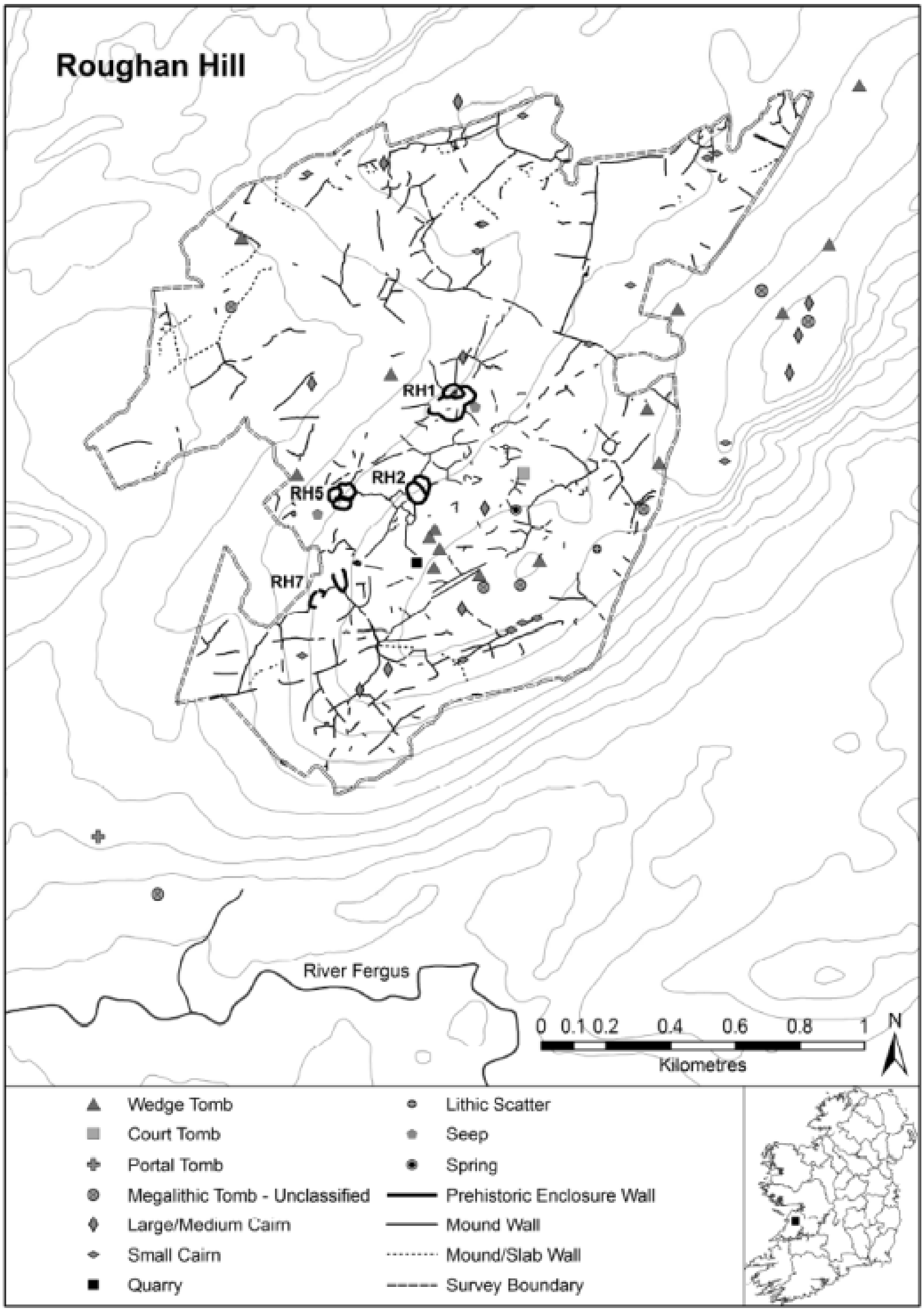

Figure 3.8: The distribution of archaeological sites on Roughan Hill, in the Burren, which represents intensive settlement and subsistence in the Chalcolithic – Early Bronze Age. Roughan Hill settlement enclosures can be seen embedded within contemporary field systems. The distribution of wedge tombs and other monuments is also indicated. Lough Inchiquin is located to the south of the map area shown (Jones, forthcoming-a).

Figure 3.9: A Chalcolithic habitation enclosure (RH5) on Roughan Hill, c. 3km to the north of Lough Inchiquin, looking west towards Knockloon Hill which can be seen on the horizon. Source: author.

This was further refined to c. 2350 BC by using a calculated rate of bedrock lowering for the River Fergus drainage that provides an estimated age for the mound walls (Jones, 2016).

The similarity, both in construction and pedestal height, of the fieldsystem mound walls and enclosure walls of RH1, RH2, RH5 and RH7, which are seemingly embedded within the fieldsystem, suggest they are contemporary (Jones, 2016). Therefore the prehistoric evidence on Roughan Hill represents *"a distinct era of farming activity"* of Chalcolithic – Early Bronze Age date (Jones, 2016). Radiocarbon dates from the habitation enclosures range from c. 2402 – 2148 BC to c. 1665 – 1464 BC and Bayesian modelling using 12 ^{14}C determinations has confirmed activity on Roughan Hill to be between c. 2300 – 1550 BC (Jones, 2016; Jones, forthcoming-a). This occupation, however, may not have been necessarily continuous over this period of c. 800 years (Jones, 2016). In addition, a flat copper axe (Lough Ravel type) was found to the south of Roughan Hill demonstrating that this area remained within wider networks of exchange into the Early Bronze Age (Jones et al., 2010; Harbison, 1969). In the wider region this was demonstrated by the discovery of a gold lunula close to the south-west corner of the Burren, at Carrowduff (Jones et al., 2010; Taylor, 1970).

Mound walls have been identified in the Coolnatullagh Valley in the eastern Burren, which are thought to be contemporary with those on Roughan Hill due to the similar height of sub-wall bedrock pedestals (Jones et al., 2010). A wedge tomb is located at Coolnatullagh and three habitation sites (or farms) have been identified, c. 0.5 – 1km apart, within individual fieldsystems (Jones et al., 2010). Farm C1 consists of a C-shaped enclosure located at the south-western end of the valley embedded in a fieldsystem (Jones et al., 2010). This is dated by the Coolnatullagh cairn which is embedded within the fieldsystem and consists of a central cist containing the partial remains of an adult and infant inhumation in addition to cremation deposits (Jones, 2004; Eogan, 2002). The burials date to c. 2460 – 2140 BC which is likely the time of its construction (Jones, 2004; Eogan, 2002). Farm C2 is an enclosure at the eastern end of the valley and farm C3, the largest enclosure, is located on the lower slope of Gortaclare Mountain with a large field attached to its southern side (Jones et al., 2010). A fieldsystem covers the mountain itself, oriented by a long mound wall which runs along the summit (Jones et al., 2010). Another area which has been investigated is the Carran Plateau, located roughly equidistant between Roughan Hill and Coolnatullagh. Here, some of the mound walls have similar pedestal heights to Roughan Hill and thus may be of Chalcolithic date (Jones et al., 2010).

The dense concentration of wedge tombs on Roughan Hill (Figure 3.8), when combined with the settlement evidence, suggests intensive human activity during the Chalcolithic (Jones, 1998). Jones (1998) comments upon the density of this activity with farmsteads only c. 250 – 300m apart from each other, with wedge tombs located within c. 150m of settlement sites potentially indicative of competition for land (Jones, 2004). The fifteen wedge tombs on Roughan Hill and the adjacent uplands (Leana townland) are located within an area of just c. 2.5 x 1.75km (Jones, 2003). This represents the densest concentration of wedge tombs in the country (O'Sullivan and Downey, 2010; Jones, 1998; 2003). Such a proliferation of wedge tombs was perhaps related to a breakdown of Neolithic society which led to smaller social groups asserting claims to the locale, in a similar way that ethnographically, tomb building can be a manifestation of competition (Island South-East Asia) and the acquisition of power (West Sumba) (Jones, 2004; Jones et al., 2015). It is possible that Roughan Hill was an important ancestral or origin place in the Chalcolithic with its concentration of fifteen wedge tombs set within a wider distribution of approximately eighty on the Burren suggesting a nested social structure (Jones et al., 2015; Ó Maoldúin, 2014). It is in this vein that Jones et al. (2015) see the wedge tombs of Roughan Hill as belonging to smaller groups that would be united through tradition, kinship and ritual, with the act of tomb building a way of maintaining strong linkages with a core area, as population dispersed more widely in the landscape (Jones et al., 2015).

Until recently, dating evidence of Burren wedge tombs was confined to a single date from a human bone collected from Baur South wedge tomb dating to c. 2033 – 1897 BC (Ó Maoldúin, 2014). The Irish Fieldschool of Prehistoric Archaeology has since undertaken the excavation of three Roughan Hill wedge tombs (Figure 3.10 and 3.11). The first to be excavated was wedge tomb CL017 – 180002 which was discovered through intensive survey in the 1990s as only partial stones of the chamber could be seen (Jones and Walsh, 1996, Site E). It is a small tomb, c. 2m long and c. 1m wide and the post-excavation plan and section can be seen in Figure 3.10 which shows the substantial cairn present around the chamber. A large amount of both cremated and inhumed bone was recovered from the chamber amounting to a minimum of thirty five individuals (Ó Maoldúin, 2015; Ó Maoldúin, 2017 pers. comm.)

Two ^{14}C dates have been determined from cremated bone within the chamber providing Chalcolithic dates from both context 21 and context 10 (Figure 3.10) (Ó Maoldúin, 2017 pers. comm.). The succession of the dating evidence suggests continued deposition of remains throughout this period (Ó Maoldúin, 2017 pers. comm.). Although dating evidence is not yet available, a further two wedge tombs, CL016 – 061002 and Parknabinnia wedge tomb (CL017 – 180008), have been excavated and are thought to be contemporary with CL017 - 180002. The megalithic slab quarry for the construction of the Roughan Hill wedge tombs has also been identified through the identification of negative voids from stone removal (Jones, 2016).

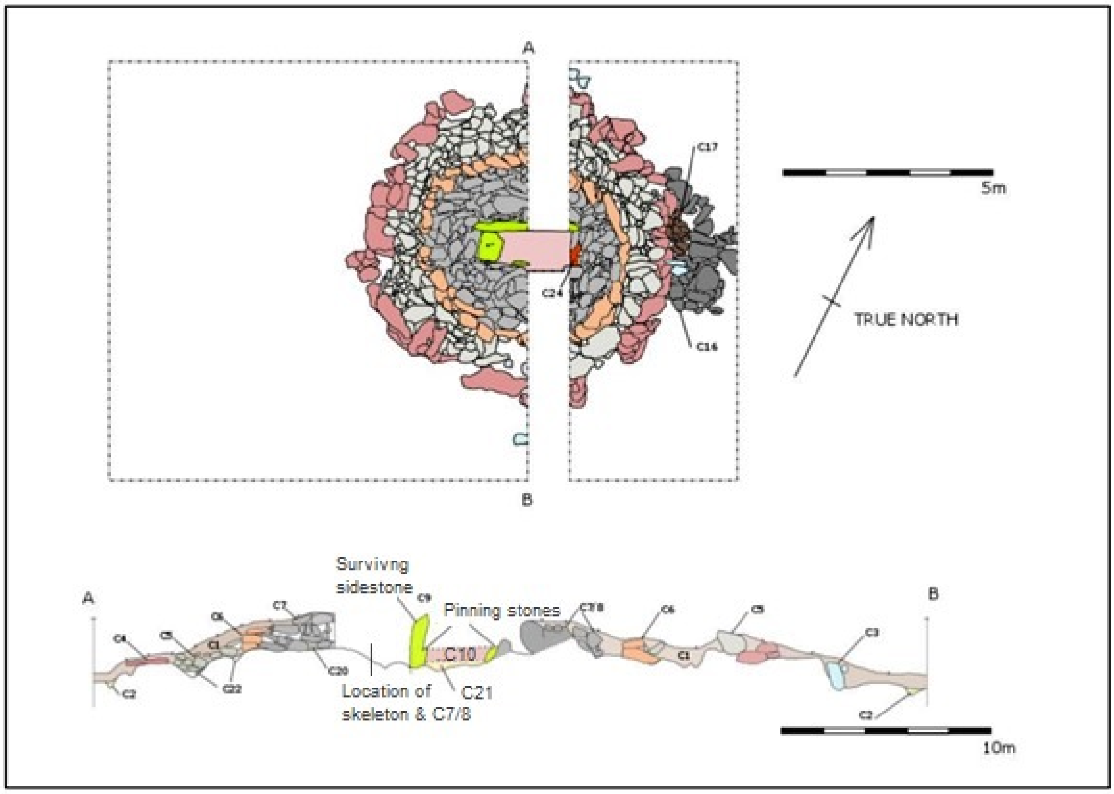

Figure 3.10: Site plan of one of the excavated wedge tombs on Roughan Hill, CL017 – 180002 .The plan shows the chamber of the tomb (in yellow) surrounded by cairn material with potential kerb revetments (orange and pink). Below is the west-southwest facing section that indicates the contexts from which the dating evidence was obtained. After Ó Maoldúin (2015).

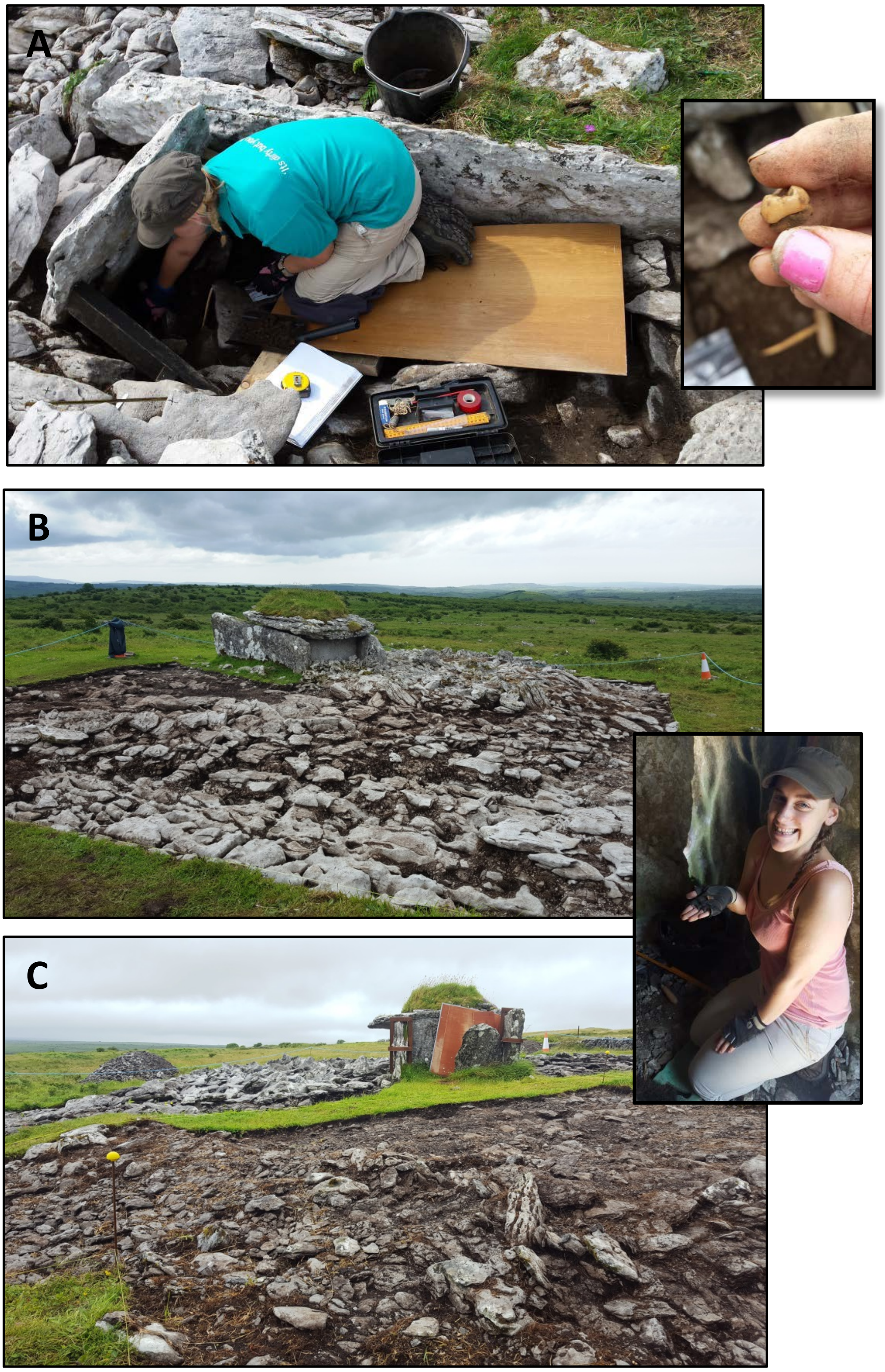

Figure 3.11: The excavations undertaken on two Roughan Hill wedge tombs. (A) Excavation of the chamber of wedge tomb CL017 – 180002 by the author which has provided the first ^{14}C date from this dense concentration of tombs. (inset) Image of a human tooth from within the chamber (B) Excavation trench at Parknabinnia wedge tomb (C) Front view of trench at Parknabinnia wedge tomb (inset) The author excavating within the chamber of Parknabinnia wedge tomb from which a human tooth had just been found. Source: author.

A cluster of at least six wedge tombs is located c. 3.5km to the west within an area c. 2.5 x 2km on the south-western slopes of Ballyganner/Leamaneh (Jones, 2003). Jones (2003) noted the presence of mound walls in this area which are likely contemporary with those on Roughan Hill. The third cluster of wedge tombs in the Burren is located at the Poulnabrone depression where at least eleven tombs are situated within an area c. 4.3 x 3.5km (Jones, 2003). Again, the presence of mound walls in addition to the concentration of wedge tombs has led Jones (2003) to suggest the Poulnabrone depression was another focus of Chalcolithic activity. Further mound walls in the wider Burren region are likely contemporary (Jones, 1998; Jones, 2003). Approximately 3.8km north-east of Roughan Hill in the northern part of the townland of Teeskagh, a narrow plateau is divided into small rectilinear fields by a series of mound walls and overlooked by a further wedge tomb (Cl.133). A habitation site which saw earlier activity was again used for settlement activity during the Chalcolithic with a ^{14}C date of c. 2233 - 1946 BC (2σ) derived from bone associated with an enclosure wall (Gibson, 2016).

The re-use of earlier monuments in the Burren also occurred with a secondary burial at the Coolnatullagh cairn dating to c. 1880 – 1610 BC associated with a concentration of pig and cattle teeth (Jones, 2004). Similarly, Poulawack cairn was re-used as an Early Bronze Age cemetery cairn with three cists inserted c. 2000 BC (Brindley and Lanting, 1991a). Recent dating evidence from Parknabinnia court tomb has identified the insertion of two cremations inserted in the Chalcolithic (c. 2456 – 2415 BC) and the Early Bronze Age (c. 1971 – 1687 BC) (Snoeck et al., Forthcoming). Offshore, on the island of Inis Oírr, the flat-topped circular mound of Cnoc Raithní is thought to have originated as an Early Bronze Age cemetery mound with two cremation burials contained within a circular cist (Jones, 2004). The presence of a cordoned urn associated with one of the cremation burials suggests a date of c. 1730 – 1500 BC (Jones, 2004; Brindley, 2007).

Away from the Burren, the presence of Knocknalappa wedge tomb immediately east of Rosroe Lough, and Knopoge c. 2.8km to the north, is indicative of Chalcolithic activity in the catchment of the lake (De Valéra and O' Nuallain, 1961). A total of seventeen wedge tombs are located within the Mooghaun landblock with two, Craggaunowen and Deerpark North, situated within c. 6km of the lake (De Valéra and O' Nuallain, 1961; Grogan, 2005b). Beaker pottery was identified at what would later become Area C within Mooghaun hillfort (Ó Maoldúin, 2014; Carlin, 2011) and Early Bronze Age artefacts have been found in the north of the area (Grogan, 2005b; Grogan and Condit, 1994). Further to the east at O'Brien's

Bridge an Early Bronze Age cist burial containing cremated bones and a small pottery vessel was discovered (Waddell, 1970). This suggests a significant increase in human activity in this area given the lack of archaeological evidence from the preceding periods.

Recent investigations in advance of the M18 Ennis bypass and the N85 relief road (which runs west c. 11km south of the Burren) have identified a number of Chalcolithic – Early Bronze Age sites. A burnt mound at Cahircalla Beg (AR126) produced a date of c. 2550 – 2300 BC with contemporary dates obtained from burnt spreads around the site (Bermingham et al., 2012b). Additional burnt spreads at Cahircalla More (AR127) and Clareabbey (AR122; AR124) also produced Chalcolithic and Early Bronze Age dates while a cremation cemetery at Manusmore (AR100) was in use between c. 2450 – 2150 BC (Bermingham et al., 2012b). A Chalcolithic habitation site was found at Rathwilladoon just north of the Co. Clare border c. 13km north-east of Lough Inchiquin. An arrangement of pits, post-holes and stake-holes have been tentatively assigned to a north-south aligned oval or sub-rectangular structure (Lyne, 2011). Occupation is proposed for the Chalcolithic with finds of Beaker pottery and a ^{14}C date of c. 2280 – 2042 BC from a charred hazelnut within a pit (Lyne, 2011). In the wider region, a cist grave was identified during investigations along the M6 Galway to Ballinasloe (to the north of the study area in Co. Galway) at Treanbaun 3 where a large inverted Beaker vessel contained a cremation burial (Muñiz-pérez et al., 2011; Muniz-Perez, 2014). This was found in the vicinity of a proposed Early Bronze Age lead mine pit where charcoal from the primary fill produced a date of c. 2570 – 2130 BC and a deposit overlying a hearth produced a date of c. 1880 – 1660 BC suggesting continued use into the Early Bronze Age (Muniz-Perez, 2014; Muñiz-pérez et al., 2011). Excavations carried out ahead of the Gort – Crusheen section of the M18 to the east of the Burren, (c. 12km east of Lough Inchiquin), identified fourteen burnt mounds that saw activity during the Chalcolithic – Early Bronze Age (Delaney et al., 2012).

These discoveries suggest that widespread human activity was becoming more common in this period throughout Co. Clare but that there was still a strong focus of activity in the south-east Burren at this time (Jones, 2003). Three concentrations of human activity can be proposed, at Roughan Hill, Ballganner/Leamenah and the Poulnabrone Depression. It has been noted that the Chalcolithic period saw an expansion of agriculture into upland areas throughout Ireland and Britain (Jones et al., 2010), and so the focus of activity in the Burren uplands at this time fits with the wider nature of prehistoric activity. Jones et al. (2010) further argue that such agricultural intensification was used to finance developing political economies at this time, which with regards to the Burren may have been in the area southwards along the River Fergus towards the River Shannon and the Mooghaun Landblock.

Palaeoenvironmental Evidence

The pollen evidence from the Burren suggests that pastoral farming activity was increasing during the Chalcolithic in the local catchments of Molly's Lough, Loch Gaeláin, Gortlecka and Rinn na Mona (Thompson, 1997; Feeser, 2009; Watts, 1984) and further afield at An Loch Mór (Molloy and O'Connell, 2007; Molloy and O'Connell, 2004). At Molly's Lough pastoral farming continued to increase from the start of the Early Bronze Age with an arable component identified for the first time (Thompson, 1997). Further evidence for arable cultivation comes from Loch Gaeláin while all of the Burren pollen records suggest an intensification of pastoral farming activity during the Early Bronze Age (Feeser, 2009; Watts, 1984; Molloy and O'Connell, 2007; 2004).

A similar situation is evident further south in Co. Clare but this increase in human activity is all the more noteworthy as it is the first time such activity has registered in the pollen records of Mooghaun, Caherkine and Caheraphuca, at a significant level (Molloy, 2005; Molloy and O'Connell, 2012; O'Connell et al., 2001). Additionally, cereal-type pollen appears in all of the records from this area suggesting arable cultivation had been initiated (Molloy, 2005; Molloy and O'Connell, 2012; O'Connell et al., 2001). On the whole, the records suggest an increase in human activity and farming intensity especially from the Early Bronze Age (Molloy, 2005; Molloy and O'Connell, 2012; O'Connell et al., 2001).

3.3.3 Summary

The Chalcolithic – Early Bronze Age was a time of change within Ireland with the introduction of Beaker pottery, new burial customs and copper metallurgy at the start of this period. The Irish archaeological record remained distinctive, however, with burial taking the form of wedge tombs during the Chalcolithic and the Ross Island copper mine allowing the development of metallurgy and prestige items. Later, the funerary tradition changed again with megalithic monuments going out of use, replaced by single burial. The focus of studies in this period has not on the whole been on human-environment interactions but on the artefactual and burial material and the ways in which these were adopted. Progress in this area will require the acquisition of off-site palaeoenvironmental data in long, chronologically robust sequences (Allen and Maltby, 2012). A general trend, however, in the palaeoenvironmental data appears to be one of increasing human activity and farming across Ireland from the latter part of the 3rd millennium. The increased levels of disturbance indicators indicate a predominantly pastoral farming economy at this time with a minor arable component suggested by the finds of cereal-type pollen and charred grains.

Within Co. Clare this renewed farming activity occurred at a time when the dense concentration of wedge tombs were established on Roughan Hill in addition to four habitation sites in a landscape of contemporary field systems (Jones, 2016). There appears to have been an expansion of human activity in this upland area with Bayesian modelling of the ^{14}C dates from Roughan Hill suggesting the settlements were occupied between c 2300 – 1550 BC (Jones, forthcoming-a). More widespread human activity is indicated through the presence of wedge tombs in the Mooghaun Landblock, supported by pollen data which suggests the beginnings of human activity. Pastoral farming activity intensified in both areas with the onset of the Early Bronze Age suggesting that these areas were perhaps more densely populated and exploited than in previous periods. To what extent the c. 2200 – 2000 BC global climatic anomaly affected the human-environment interactions of the Irish Chalcolithic is currently a topic of debate (Roland et al., 2014; Baillie and McAneney, 2015). Why such an anomaly, if it did cause cooler/wetter conditions in Ireland, would favour the establishment of intense human occupation of an upland area such as Roughan Hill (from c. 2300 BC) has been examined by Jones (forthcoming-a), and the Burren is known for its cattle winterage to this day.

3.4 The Middle Bronze Age (c. 1600 – 1200 BC)

Studies on the Irish Middle Bronze Age have concentrated on metallurgy, with division into the Killymaddy (c. 1600 – 1400 BC) and Bishopsland (c. 1400 – 1200 BC) phases, and the Irish gold industry (Eogan, 1994; Roberts, 2013). Developer-funded archaeology has also led to an increase in evidence relating to settlement (McQuade et al., 2009; Gillepsie and Kerrigan, 2010) and burial (Lynch and O'Donnell, 2007; Grogan et al., 2007; Grogan, 2004). Further research has focused on burnt mounds (Hawkes, 2014; Ó Néill, 2003) and monumentality including the development of the ‘stone circle complex’ (O'Brien, 2012b). Less emphasis has been placed on the specific study of palaeoenvironmental evidence during this period but studies such as Plunkett (2009) have attempted to integrate the archaeological and available pollen records for the Middle and Late Bronze Age.

3.4.1 Human-environment Interactions: Wider Trends

The general trend for this period appears to have been one of a mixed farming economy practiced with varying degrees of intensity throughout the period leading to woodland regeneration in some landscapes (Plunkett, 2009). As such the development of the Bishopsland metalworking industry occurred within the framework of a widespread and thriving agricultural economy, although there is little evidence for increased intensification at this transition c. 1400 BC (Plunkett, 2009). Towards the end of the Middle Bronze Age there appears to have been a decline in farming activity in some areas (Plunkett, 2009). It is in the Middle Bronze Age that extensive fieldsystems were initiated in England, for example at Barleycroft Farm and Flag Fen, East Anglia and at Dartmoor, Devon, although parallels in Ireland have not been identified (Roberts, 2013).

Intensified farming was identified in the pollen record from Lough Dargan, Co. Sligo, where the first two centuries of the Middle Bronze Age (c. 1670 – 1450 BC) were characterised by a high representation of pastoral indicators and a reduction in elm (Ghilardi and O'Connell, 2013b). For the remainder of the Middle Bronze Age, however, there appears to have been a reduction in farming allowing for the regeneration of woodland, although the continued presence of cereal-pollen attests to limited farming activity (Ghilardi and O'Connell, 2013b). Similarly, the start of this period saw the continuation of an intense farming phase in the catchment of Cooney Lough, Co. Sligo, which then reduced from c. 1530 BC towards a distinct lull c. 1375 – 1310 BC (O'Connell et al., 2014).

In Co. Mayo, in the catchment of Owenduff bog, woodland expanded from c. 1620 BC and persisted throughout the Middle Bronze Age (Plunkett, 2009). This woodland regeneration also occurred further east in the catchment of raised bog peats at Corlea, Co. Longford, c. 1550 – 1330 BC (Caseldine and Hatton, 1996). Conversely, in the catchment of Ballinphuill bog, Co. Galway, substantial pastoral farming activity occurred c. 1620 – 1250 BC, likely with a wood-pasture-type economy accounting for the continuation of high arboreal pollen, and a small arable component (Molloy et al., 2014; Molloy and O’Connell, 2016). In Co. Limerick pollen data from Moyreen bog suggests moderate levels of pastoral farming activity c. 1610 – 1450 BC which then began to decline for the remainder of the period (Plunkett, 2009). Pollen analysis undertaken on a profile from Derryville bog, Co. Tipperary, suggests the landscape between c. 1640 – 1310 BC was predominantly grassland in the drier areas with some cereal cultivation occurring on higher ground; this activity being more intensive than in preceding periods (Caseldine et al., 1996). The settlement site at Chancellorsland, Co. Tipperary, gives some indications of the components of the pastoral economy at this time with animal remains suggesting an emphasis on meat production while residue analysis provided evidence of dairy products (Waddell, 2010).

Despite a reduction in farming in some areas of Ireland towards the end of the Middle Bronze Age, in Northern Ireland substantial human activity appears to have continued. Intensive pastoral and arable farming occurred in the landscape at Loughnashade, Co. Armagh c. 1409 – 1265 BC (Plunkett, 2009). Further north the pollen data from Garry Bog, Co. Antrim, suggests a low level of human activity occurred from c. 1640 BC which then increased substantially from c. 1440 BC (Plunkett, 2009). Similarly, at Sluggan bog, Co. Antrim, an expansion of pastoral indicators did not occur until c. 1390 BC continuing to c. 1260 BC, while at Glen West bog, Co. Fermanagh, farming occurred c. 1370 – 1210 BC (Plunkett, 2009). Although farming activity did occur in earlier periods at Lough Muckno, Co. Monaghan, there was a substantial expansion of farming c. 1490 – 1300 BC which remained at a relatively high level throughout this period (Chique et al., 2017). In contrast, a profile from Claraghmore, Co. Tyrone, indicates declining farming during the Middle Bronze Age with little to no human activity by c. 1300 BC (bar one cereal-type grain) (Plunkett, 2009).

It was not until the Middle Bronze Age that farming began to increase in the extreme south-west of Ireland, at the Beara peninsula, when pastoral indicators and cereal-type pollen represented the first agricultural activity which became particularly intense from c. 1400 BC (Overland and O'Connell, 2008). Similarly, at Cashelkeelty, Co. Kerry, an intensification of farming activity occurred from c. 1500 BC evidenced through woodland clearance and a rise in anthropogenic indicators (Lynch, 1981). The evidence from across Ireland suggests that the Middle Bronze Age was characterised by varying degrees of agricultural intensity, occurring at different times in different landscapes which Plunkett (2009) relates to the apparent expansion of human activity across Ireland as indicated by the archaeological record.

Climate

There is thought to have been a climatic downturn at the beginning of this period across Europe potentially related to the Thera (Santorini) eruption of 1613 ± 13 BC (Risch and Meller, 2015). Narrow tree-rings are proposed to be related to wetter/cooler conditions and a link between volcanic eruptions and this growth phenomenon has been proposed (Baillie and Munro, 1988). Grudd et al. (2000), however, note that as climatic cooling is a secondary effect any linkages can only be circumstantial. In the Irish data narrow growth-rings have been identified on Irish oak trees including at Garry Bog, Co. Antrim (Baillie and Munro, 1988; Baillie, 1989). Similarly reduced growth-rings have been identified on oak trees in England and Germany (Grudd et al., 2000; Baillie and Munro, 1988) and on pine in Sweden, proposed to be related to climatic cooling from the Thera eruption, far to the north of the Mediterranean (Grudd et al., 2000). Evidence from further afield includes frost-rings in the bristlecone pine record in America c. 1627 BC and a peak in acidity in the Greenland ice cores (GISP2 and Dye 3) c. 1645 ± 20 BC (Baillie and Munro, 1988; Baillie, 1989; Pearson et al., 2009).

Cooler/wetter conditions were identified in marine cores from the eastern Mediterranean from c. 1600 BC proposed to be due to cycles of solar activity and atmospheric circulation that caused a more unstable climate at this time (Risch and Meller, 2015). Although the 16th Century BC saw a period of social transformations, (e.g. the transition from Early – Late Palace periods on Crete and the end of the El Argar and Unetice polities), Risch and Meller (2015) do not see climate as a primary cause. In Ireland Plunkett (2006) identified a period of increased wetness in the humification record of Irish bogs dated to c. 1300 – 1250 BC, which potentially ties in with decreased farming in some areas of Ireland towards the end of the Middle Bronze Age.

3.4.2 Human-Environment Interactions in Co. Clare – The Story So Far

Archaeological Evidence

Human activity in the Burren was characterised by the re-use of earlier monuments during the Middle Bronze Age. The Poulnabrone portal tomb was re-used with the burial of a foetus and associated pottery dated to c. 1754 – 1411 BC. This secondary burial was found within the portico feature and it is possible that this structural element was also added at this time (Lynch, 2014). Four burials were inserted into the Poulawack cairn (one containing a crouched inhumation) with burial activity in two phases, c. 1610 – 1554 BC and c. 1486 – 1452 BC, which also included the enlargement of the cairn and the addition of a kerb (Brindley and Lanting, 1991a). Further activity occurred at wedge tomb CL017 – 180002 where a Middle Bronze Age secondary inhumation was discovered beneath the cairn (Ó Maoldúin, 2017 pers. comm.). It is, therefore, possible that all of the cairns on the Roughan Hill wedge tombs were later additions (Ó Maoldúin, 2017 pers. comm.) which would increase evidence for human activity significantly in this period with such a dense concentration of monuments.

There is a dense concentration of burnt mounds particularly in the eastern Burren (Figure 2.4 Chapter 2), which while they cannot be interpreted as settlement evidence *per se,* Ó'Drisceoil (1988) suggests that their distribution may signal the settlement distribution of their users. In the case of Co. Clare this would be principally the eastern Burren and more southern lowlands. One of these, Fahee South, has been excavated and is located c. 8.5km north of Lough Inchiquin (Ó'Drisceoil, 1988). Wood from the trough was dated to c. 1408 – 1219 BC suggesting that others in the area may also date to the Middle Bronze Age (Ó'Drisceoil, 1988; Brindley et al., 1989). In the wider landscape, to the south of Ennis, a burnt spread at Cahircalla Beg (AR126) was dated to c. 1440 – 1280 BC (Bermingham et al., 2012b). Analysis of c. 93 dates from Irish burnt mounds suggests a clear concentration in the Middle Bronze Age (Hawkes, 2014) meaning it is quite likely that more of those on the Burren date to this period. During the course of investigations ahead of the M18 Gort – Crusheen road scheme, nine of the burnt mounds excavated were used during the Middle Bronze Age (Delaney et al., 2012). There is a further concentration of burnt mounds in south-east Co. Clare, to the west and north of Rosroe Lough (see Figure 2.6 Chapter 2). Two are located very close to the eastern shore of Rosroe Lough while a further two are situated on the shores of Knocknalappa Lough (Grogan, 2005b). A further three are located around Mooghaun Lough, c. 3.8km to the north-west (Molloy, 2005). A series of radiocarbon determinations were obtained from the northernmost burnt mound at Mooghaun Lough, which Molloy (2005) used to propose a construction date and initial use period at c. 1250BC.

Standing stones in the area may be Middle Bronze Age in date and five are located c. 2km to the east of Rosroe Lough with a further five to the north (Grogan, 2005b). There are eleven barrows across the Mooghaun Landblock which Grogan (2005b) attributes to the Middle Bronze Age although undated, one of which (an embanked barrow) is located within the catchment, 2.9km north of Rosroe Lough. Artefacts dating to the Middle-Late Bronze Age include two palstaves, two spearheads (a basal-looped and a socket-looped) and two wing-flanged axe-heads occurring within this Lakeland zone (Grogan et al., 1995). It was in this period that the formal deposition of bronze artefacts increased in the River Shannon paralleled in Britain by a contemporaneous concentration of deposits in the River Thames (Waddell, 2010; Bradley, 2007; Roberts, 2013; Bourke, 2001). Sixty-four specifically Middle Bronze Age metalwork depositions have been recovered from the River Shannon which suggests that this area was becoming a major focus of ritual activity (only twenty two of Early Bronze Age date have been identified) (Bourke, 2001). Six items were recovered from the River Shannon within Co. Clare, five from Killaloe and one from Ballyvally, both located c. 26km to the east-north-east of Rosroe Lough (Bourke, 2001). A dirk/rapier was also recovered from the River Shannon in Co. Limerick, likely within c. 15 – 20km of Rosroe Lough due to the location of the Shannon within the county (Bourke, 2001). Taken together, the archaeological evidence suggests a potential diminishing of activity at this stage in prehistory in the northern part of the study area and a contemporary increase in archaeological evidence in the southern part of the study area.

Palaeoenvironmental Evidence

A predominantly pastoral economy with a small-scale arable component continued in the catchment of Molly's Lough to the south of the Burren during the Middle Bronze Age (Thompson, 1997). Similarly, at Loch Gaeláin and Gortlecka farming activity remained high for the majority of the Middle Bronze Age, but a period of woodland recovery began c. 1300 BC in the former (Feeser, 2009; Watts, 1984). In the northern Burren, the pollen record from Cappanawalla is not suggestive of particularly intensive farming activity, but rather, suggests an open woodland environment (Feeser and O'Connell, 2009). An additional profile from the north at Lios Lairthín Mór opens towards the end of this period and suggests a high level of activity (Jeličić and O'Connell, 1992; Feeser and O'Connell, 2009). On Inis Oírr, the Middle Bronze Age was characterised by a period of reduced farming which actually began c. 1740 BC and continued throughout this period with pastureland reverting back to woodland (Molloy and O'Connell, 2004).

Further to the east at Caheraphuca Lough, the Middle Bronze Age period was characterised by woodland regeneration with limited evidence for human activity throughout this period (Molloy and O'Connell, 2012). Further south at Mooghaun Lough the pollen record suggests more intensive human activity with woodland clearance occurring at this time but with decreased faming activity towards the end of this period (Molloy, 2005). Cereal-type pollen was also identified suggesting low-level cultivation, specifically of wheat and barley, in the latter stages of the Middle Bronze Age (Molloy, 2005). At Caherkine Lough, however, woodland regeneration again characterised this period (O'Connell et al., 2001). The combined evidence suggests varying levels of farming intensity throughout Co. Clare in this period. This does not seem to be of a particularly high level in the Mooghaun Landblock despite Grogan (2005b) suggesting this area was becoming more densely occupied at this time.

3.4.3 Summary

The evidence surrounding human-environment interactions during the Middle Bronze Age suggests a sustained human presence and the practice of a mixed farming economy, although carried out with varying degrees of intensity throughout this period. For example, some sites show a reduction in human impact for the first few centuries of this period with a subsequent increase, whereas others show the reverse. A possible climatic shift to wetter/cooler conditions may have occurred with evidence of narrow growth-rings identified > 1628 BC in Garry Bog, Co. Antrim, included amongst the evidence for this (Baillie and Munro, 1988). In Co. Clare the main focus of human activity appears to be concentrated further south than in preceding periods with evidence of burnt mounds, artefact find spots, standing stones and barrows dating to the Middle Bronze Age being the main sources of evidence for human activity here at this time. The increasing importance of the area is evidenced through an increase in the deposition of metalwork into the River Shannon. Despite a reduction in the archaeological evidence for human activity across the Burren, the pollen data is still indicative of continued activity, particularly at Molly’s Lough and Loch Gaeláin (Thompson, 1997; Feeser, 2009). Further south increased human activity is most evident in the pollen record of Mooghaun Lough with both pastoral and arable farming registering in the data (Molloy, 2005). Here there was some woodland regeneration towards the end of the Middle Bronze Age, in keeping with the overall Irish data, which can also be seen across the Burren.

3.5 The Late Bronze Age (c. 1200 – 600 BC)

Research on the Irish Late Bronze Age has placed emphasis on material culture focusing on metallurgy (Roscommon c. 1200 – 1000 BC and Dowris c. 1000 – 600 BC phases), hoards (O'Brien, 2012b; Waddell, 2010) and gold-working (Eogan, 1994; O'Brien, 2012b). Settlement evidence has again increased through developer-funded investigations (McQuade et al., 2009) with wetland sites and crannogs being a development of settlement hierarchy in this period (O'Sullivan, 1997; Raftery, 1942). The development of hillforts has been a particular focus of attention in recent years (O'Driscoll, 2016; 2017; O'Brien and O'Driscoll, 2017; Cotter, 2012a; 2012b; Grogan, 2005a; 2005b). Specific to the Late Bronze Age is an increasing concern with warrior identity (Treherne, 1995; Frieman et al., 2017). Evidence for human-environment interactions in this period suggests a sustained presence in the landscape with an intensification of pastoral agriculture seemingly contemporary with the onset of the Dowris phase c. 1000 BC (Plunkett, 2009).

3.5.1 Human Environment Interactions: Wider Trends

The Late Bronze Age was characterised by fluctuating levels of human activity within the landscape but in general farming activity was intensive at this time. During the Roscommon phase (until c. 1000 BC) woodland regeneration occurred in some areas, while others demonstrated an increase in activity, which Plunkett (2009) suggests may indicate a contraction of populations into more prominent settlement areas associated with the emergence of centralised socio-political territories. As such Plunkett (2009) would view this phase as one of important political re-organisation. With the onset of the Dowris phase (c. 1000 BC) there appears to have been a more widespread intensification of predominantly pastoral agriculture across Ireland, at a time when the archaeological record suggests more extensive human activity (Plunkett, 2009). Plunkett (2009) suggests this is perhaps the diffusion of socio-political control and de-centralisation of society seen through the palaeoenvironmental record. In general the final century or so of the Late Bronze Age was characterised by reduced farming activity allowing for some woodland regeneration (Plunkett, 2009). Pollen data for the Irish Late Bronze Age corresponds well with demographic fluctuations identified by Armit et al. (2014), which highlighted a peak in human activity c. 1050 – 900 BC that subsequently declined by c. 800 BC and fell rapidly for the remainder of the period.

At Lough Dargan, Co. Sligo, substantial farming activity (pastoral and arable) occurred from c. 1100 – 950 BC before declining (Ghilardi and O'Connell, 2013b). Similarly, in the catchment of Cooney Lough intensive mixed farming was identified c. 1095 – 935 BC (O'Connell et al., 2014). The remainder of the Late Bronze Age saw fluctuating levels of farming with woodland regeneration c. 953 – 885 BC followed by a small rise in activity by c. 790 BC (O'Connell et al., 2014). In the catchment of Owenduff bog, Co. Mayo, intensification occurred c. 1130 – 910 BC and c. 720 – 650 BC (Plunkett, 2009); at Ballinphuill bog, Co. Galway, from c. 1050 BC (Molloy et al., 2014; Molloy and O'Connell, 2016) and at Moyreen, Co. Limerick, from c. 1110 BC (Plunkett, 2009). The intensity of activity varied for the remainder of the period, decreasing from c. 870 BC followed by an increase c. 780 BC, but as in other records human activity was negligible by the end of the period c. 620 BC (Plunkett, 2009).

In Northern Ireland the start of the Late Bronze Age saw a period of reduced human pressure on the landscape with some woodland regeneration at Garry bog (c. 1210 – 950 BC) and Sluggan bog (c. 1290 – 910 BC), Co. Antrim, and Claraghmore bog (c. 1200 – 990 BC), Co. Tyrone (Plunkett, 2009). In all cases, more intensive farming followed this with subsequent woodland regeneration in the latter stages of the Late Bronze Age (Plunkett, 2009). Conversely, in the far south-west of Ireland the pollen data from the Beara peninsula suggests intensive pastoral and arable farming from the start of the Late Bronze Age until c. 1050 BC, at which point there was a recovery of woodland from c. 1050 – 850 BC (Overland and O'Connell, 2008). For the final centuries of the Late Bronze Age, farming activity once again increased with a predominantly pastoral economy (Overland and O'Connell, 2008). Similar trends were also evident in two records from Cashelkeelty, Co. Cork (Lynch, 1981).

Further examples from across Ireland where trends of initial Late Bronze Age woodland regeneration have been identified include Beaghmore, Co. Tyrone; Céide Fields, Co. Mayo; Achill Island, Co. Mayo and Derryville bog, Co. Tipperary (Plunkett, 2009; Pilcher, 1969; Caseldine et al., 1996). The subsequent substantial farming activity during the Dowris phase (from c. 1000 BC) has also been identified at Red Bog and Essexford Lough, Co. Louth, An Loch Mór, Co. Galway; Oldcroghan, Co. Offaly; Derryville bog, Co. Tipperary and within north-east Co. Mayo (Plunkett, 2009; O'Connell, 1990; Caseldine et al., 1996; Molloy and O'Connell, 2004). Similarly, the woodland regeneration at the end of the Late Bronze Age is also suggested at Lough Sheeauns, Co. Galway; Red Bog, Essexford Lough and Whiterath Bog in Co. Louth; and Lough Muckno, Co. Monaghan (Plunkett, 2009; Chique et al., 2017).

While the Late Bronze Age often sees the highest representation of anthropogenic indicators in Irish prehistoric pollen records, the intensity of such activity fluctuates during this period across Ireland, with phases of woodland recovery between intensive farming phases. Relating changes in human-environment interactions to the archaeological record led Plunkett (2009) to conclude that strong agricultural bases allowed the metalworking industries of the Bishopsland and Dowris phases to develop, but that downturns in industry did not appear to have been due to agricultural failures. On the whole the Late Bronze Age was a time of intensive farming within the landscape with a possible shift to more pastoral agriculture towards the later phases in areas where activity continued.

Climate

A short downturn in environmental conditions, as suggested by an anomaly in the growth pattern of Irish oaks c. 1159 – 1140 BC has been proposed to be linked to the eruption of Hekla 3 in Iceland (Plunkett, 2009; Baillie, 1989; Baillie and Munro, 1988). An acid layer in the Greenland ice core and contemporary tephra have been found at South Uist, Shetland Isles, confirming the far reach of the eruption (Baillie, 1989; Baker et al., 1995). Further tephra layers in the raised bogs of Fallahogy Mire, Ballynahore Bog and Sluggan Bog, Co. Antrim, and Claraghmore, Co. Tyrone, are thought to be related to the Hekla 3 eruption providing evidence for the eruption's reach within Ireland (Pilcher and Hall, 1992; Plunkett, 2006). Baillie (1989) notes a number of proposed consequences including the collapse of the Mycenaean civilisation, flooding in the Hungarian Plain and rise of the Caspian Sea in the 12th Century BC. In Ireland it is possible that the emergence of hillforts may reflect a response to a deterioration of climate, whereby times of stress may lead to a more visible archaeological record (Plunkett, 2009). Plunkett (2009) notes, however, that in landscapes that saw high levels of human activity contemporary with the Icelandic eruption there appears to have been no adverse effect on the subsistence strategy. If Hekla 3 was the cause of the anomaly in Irish oak growth in the middle of the 12th Century BC, its effects appear to be undetected in Irish pollen diagrams for this period (Plunkett, 2009).

Additional palaeoclimatic data includes a potential dry phase c. 1250 – 800 BC, and a shift to wetter/cooler conditions c. 750 BC (Swindles et al., 2013). The latter may relate to the woodland regeneration seen in some pollen records at the end of the Late Bronze Age. Climatic deterioration in Ireland has been identified in testate-amoebae and peat humification records from three raised bogs – Dead Island and Slievanorra, Co. Antrim, and

Glen West bog, Co. Fermanagh where it has been dated through Bayesian modelling to 748 BC (Swindles et al., 2007; Armit et al., 2014; Plunkett and Swindles, 2008). Similarly, in Britain this climate shift registers in peatland records in addition to a period of river flooding at c. 780 BC (Swindles et al., 2007).

3.5.2 Human-Environment Interactions in Co. Clare – The Story So Far

Archaeological Evidence

Late Bronze Age archaeology from the Burren is severely limited. There is, of course, the possibility that some of the burnt mounds date to this period, with six of those excavated as part of the Gort – Crusheen section of the M18, to the east of the Burren, providing evidence of Late Bronze Age activity (Delaney et al., 2012). A Late Bronze Age sword was found in close proximity to Lough Inchiquin in the townland of Nooan (Figure 3.12), with another sword found c. 1km to the north (Clare County Library, 2017). Further artefactual evidence includes weapons discovered at Noughaval and Ballyconnoe South and the Gleninsheen gold collar or gorget, dated to c. 700 BC, which was discovered in a grike close to Poulnabrone portal tomb (Figure 3.12) (Gleeson, 1934; Lynch, 2014). The discovery of the Gleninsheen gorget, in particular, with parallels in the lower Shannon region (towards the Mooghaun Landblock) suggests that the Burren was incorporated into wider political networks at this time (Jones et al., 2010).

Figure 3.12: Late Bronze Age artefacts discovered in the Burren landscape. (Left) The Late Bronze Age sword found close to Lough Inchiquin (Clare County Library, 2017 Last accessed 15/06/2018). (Right) The Gleninsheen gorget discovered close to Poulnabrone portal tomb (An Post, 2017 Last accessed 15/06/2018). The objects suggest this area was incorporated into networks of exchange in this period.

Late Bronze Age settlement evidence was discovered at Teeskagh (c. 6km to the north of Lough Inchiquin), where a habitation enclosure has produced dates of c. 1208 – 976 BC and 1043 – 835 BC for activity within the site (Gibson, 2016). A further c. 2km north, investigation of the western half of the central Carran plateau led to the identification of five enclosures (Jones et al., 2010). While the date of four of these is unknown, ^{14}C determinations from one have provided Late Bronze Age dates for its construction at c. 1071 BC and c. 929 BC, and is the only enclosure not to have associated mound walls (Jones et al., 2010). Two further enclosures have internal hut sites suggesting habitation, and to the north-east of the enclosures is a surveyed area c. 300m x 300m where further hut sites have been identified with mound walls forming small sub-rectangular fields (Jones et al., 2010). These two sites suggest some settlement occupation of the Burren in the Late Bronze Age perhaps concentrated in this north-east region.

Further north, c. 17km from Lough Inchiquin, is the proposed Late Bronze Age nucleated settlement of Turlough Hill in the eastern range of the Burren Mountains (Bergh, 2015; Ó Maoldúin and McCarthy, 2016). A detailed survey undertaken in 2008 identified c. 140 circular house foundations on the western summit over a relatively flat area 300 x 100m (Bergh, 2015). In addition to the house foundations, there is a large cairn and a multi-vallate enclosure, with the siting of the houses respecting these features (Bergh, 2015). The siting of the houses is viewed as critically important by Bergh (2015), as although other flat areas were available, it was the very summit of the mountain that was chosen, suggesting this area held a special significance. Bergh (2015) does not view these, albeit domestic-scale structures, as having a purely domestic/functional purpose, but instead takes their prominent position on one of the highest and most readily recognisable summits in the Burren to indicate a ritual aspect to the site, in a similar way to the Middle Neolithic site of Mullaghfarna, Co. Sligo. Excavation was carried out across four of the hut sites in 2016 and produced Late Bronze Age dates (Ó Maoldúin, 2018 pers. comm.).

For the most part, however, the settlement focus appears, from the archaeological record, to have shifted south-eastward towards the Mooghaun Landblock by the Late Bronze Age (Grogan et al., 1994). O'Sullivan (2001) argues that this area was now the focus for a wealthy, hierarchical society evidenced through hoards, hillforts and hilltop enclosures. In the wider landscape, to the north-west of Rosroe Lough by the route of the M18, Late Bronze Age activity is evidenced at the Killow burnt mound (c. 1280 – 1010 BC) and at the Manusmore cremation cemeteries (Bermingham et al., 2012b). Single find spots of four socketed axe-heads, a sword, a bronze rivet, gold dress-fastener and a gold bracelet have all been identified in the Mooghaun Landblock (Grogan et al., 1995). The gold pennanular bracelet is thought to have been recovered from the earlier Knocknalappa wedge tomb immediately east of Rosroe Lough (Grogan et al., 1995).

Situated on the eastern shore of Rosroe Lough (in the northern area of the southern basin) is the Late Bronze Age lake settlement site of Knocknalappa, which was identified through drainage in 1936 with excavation of the site carried out in 1937 (Figures 3.13 and 3.14) (Grogan et al., 1999; Raftery, 1942). The site covered an area of c. 1000m^2 with a platform formed from nine half-split trunks surrounded by a palisade consisting of a series of posts and stakes (Grogan et al., 1999; Raftery, 1942). Although no structures or hearths were identified, the associated artefact assemblage indicated that this was an important habitation site within the landscape (Grogan, 2005b). Finds included >400 pottery sherds, amber beads, a polished stone axe-head, lignite bracelet, saddle querns, a bronze flange-hilted sword, a possible horse harness, sunflower pin and a bronze ring that clearly indicates settlement activity of a relatively high status (Waddell, 2010; O'Sullivan, 1997; Grogan et al., 1999; Raftery, 1942). Additionally an animal bone assemblage was recovered with red deer, cattle, sheep, pig, horse and dog identified (Raftery, 1942). The first phase of activity on the site is represented by a layer of brushwood on which a plank floor was laid which produced an Early Bronze Age date of c. 1887 – 1701 BC (Grogan et al., 1999). The second phase was represented by a spread of stony material and associated timbers which were separated from the brushwood floor by a layer of peat (Grogan et al., 1999; Raftery, 1942). The majority of finds were recovered from this context over an area of at least 400m^2 with the main period of occupation dated by the artefactual assemblage to the Late Bronze Age, with an additional ^{14}C date of c. 1033 – 848 BC derived from accretion on a pottery sherd (Grogan et al., 1994; 1999; Raftery, 1942).

A further three associated sites have since been identified by Grogan et al. (1999). These include a settlement platform (c. 20m in diameter) on the lake edge next to the main excavated site, a small circular platform of stone (c. 5 – 6m in diameter) in the lake shallows, and a large stone and wooden structure, potentially a platform, in the middle of this section of the lake (Grogan et al., 1999). The site is comparable to other Late Bronze Age lake settlement sites such as Clonfinlough and Ballinderry 2 in Co. Offaly; Cullyhanna, Co. Armagh; and Moynagh Lough, Co. Meath (Grogan et al., 1999). Two dug-out canoes were found on the shores of Rosroe lough and a further eight dug-out canoes have been found across the Mooghaun Lakeland zone including on the south-eastern side of Finn Lough c. 800m to the west where another lake settlement site is situated (Grogan et al., 1995; 1999).

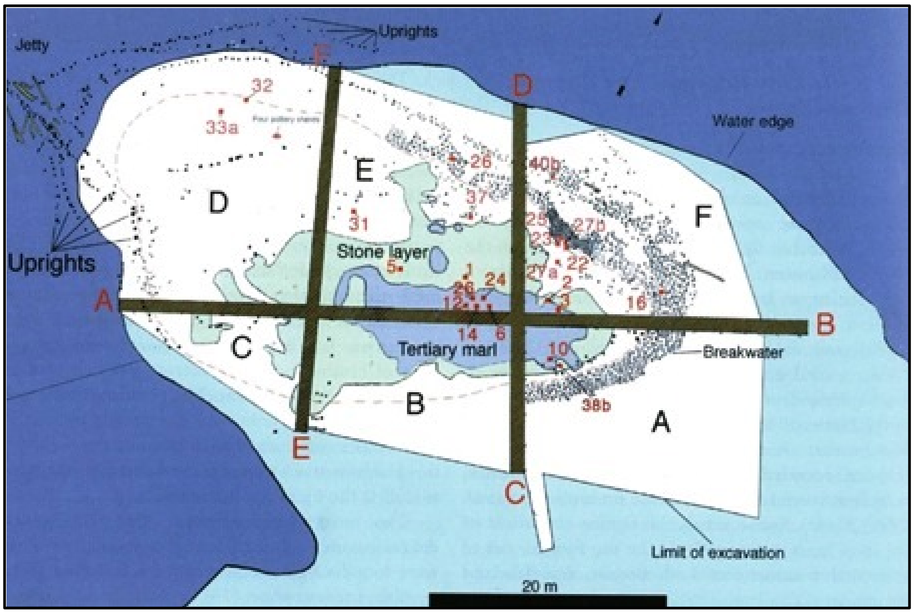

Figure 3.13: Site plan of the Late Bronze Age platform at Knocknalappa lake settlement site located on the shore of Rosroe Lough. The plan indicates the limit of excavation and structural elements of the site itself. The site was divided into sections during investigation, of which only the western side of section A was fully excavated. (Grogan et al., 1999).

Figure 3.14: The excavated area of Knocknalappa lake settlement site from original excavation report. The wooden planks seen on the left of the image were part of the platform within section A and the brushwood layer can be seen in the remainder of the image (Raftery, 1942).

Mooghaun trivallate hillfort is the most prominent monument in the area located c. 3.6km west of Rosroe Lough in an area so as to command extensive views of the River Shannon (Grogan, 2005b; Grogan et al., 1995). Identified in 1840 the site was excavated in the 19th century but saw little further investigation until an intensive survey carried out by the Discovery Programme as part of the North Munster Project (Grogan, 2005b; 2005a). The hillfort is composed of three sub-circular stone ramparts which enclose an area of c. 11ha (Figure 3.15) (Grogan, 2005b). The ramparts, though not necessarily militarily defensive, were substantial, being in general c. 1.5 – 2.4m wide and made up of a core of internal limestone walling and compact rubble (Grogan, 2005b). Differences in the construction of segments of the ramparts suggests that their construction represents the collaboration of various different groups which would have required extensive planning and organisation of the residents of this landscape (Grogan, 2005b). A ditch over 5m wide and almost 2m high surrounded the site and when originally constructed the ramparts would have been particularly impressive suggesting that a primary concern was the impact of the hillfort on the surrounding landscape (Waddell, 2010; Grogan, 2005b).

Two ^{14}C determinations from animal bone, from contexts relating to the inner and middle rampart, suggest construction c. 915 – 905 BC (Grogan, 2005b). The outer rampart appears to have been constructed prior to this potentially c. 1255 – 917 BC suggested from a charcoal sample (Grogan, 2005b). ^{14}C determinations suggest occupation c. 925 – 915 BC in the area of the middle enclosure with further occupation suggested c. 905 – 842 BC (Grogan, 2005b). All of the occupation evidence discovered thus far, however, appears to pre-date the final completion of the hillfort (Grogan, 2005b). The evidence for settlement was found on the southern and eastern slopes of the hillside concentrated in Site C within the middle enclosure and less so, but still evident, in Site A11 on the western side of the inner rampart and Site G to the south-east of Site C within the middle enclosure (Figure 3.16) (Grogan, 2005b). The foundations of two, possibly four, circular house sites measuring c. 3.5 – 5m in diameter were identified against the inner face of the middle rampart (Grogan, 2005b). Associated with the structures were occupation debris, paved and compacted floors, hearths, fireplaces and pits (Grogan, 2005b). As such the evidence suggests occupation within the middle rampart for c. 50 – 75 years during the construction of the rampart itself over an area of 200m^2, with settlement then abandoned after the finalisation of the rampart and hillfort construction (Grogan, 2005b).

Site A within the inner enclosure produced evidence of metalworking activities with iron slag, clay crucibles and mould fragments recovered (Grogan, 2005b). The on-site production of bronze artefacts may have been taking place at Mooghaun indicated by the crucibles, moulds and fragments of waste bronze (Grogan, 2005b). Mooghaun was clearly built as a focal monument within the landscape, and must have demanded a considerable expenditure of resources to perhaps provide an assembly place of ritual significance for the society (Waddell, 2010). Sited on the highest part of the local terrain Mooghaun dominates the landscape and is seen by Grogan (2005b) as the symbolic capital of the region with a territory extending west to the Fergus estuary, south to the River Shannon and east to the Cratloe Hills encompassing c. 450km^2.

Figure 3.15: Aerial photograph of Mooghaun hillfort taken in the 1970s. The three ramparts can be seen clearly because of the lack of woodland over much of the site at this time. The continuation of the outer rampart through the wooded area can be seen as a lighter band. The two cashels located on the outer and middle enclosure are not contemporary with the hillfort (Grogan, 2005b).

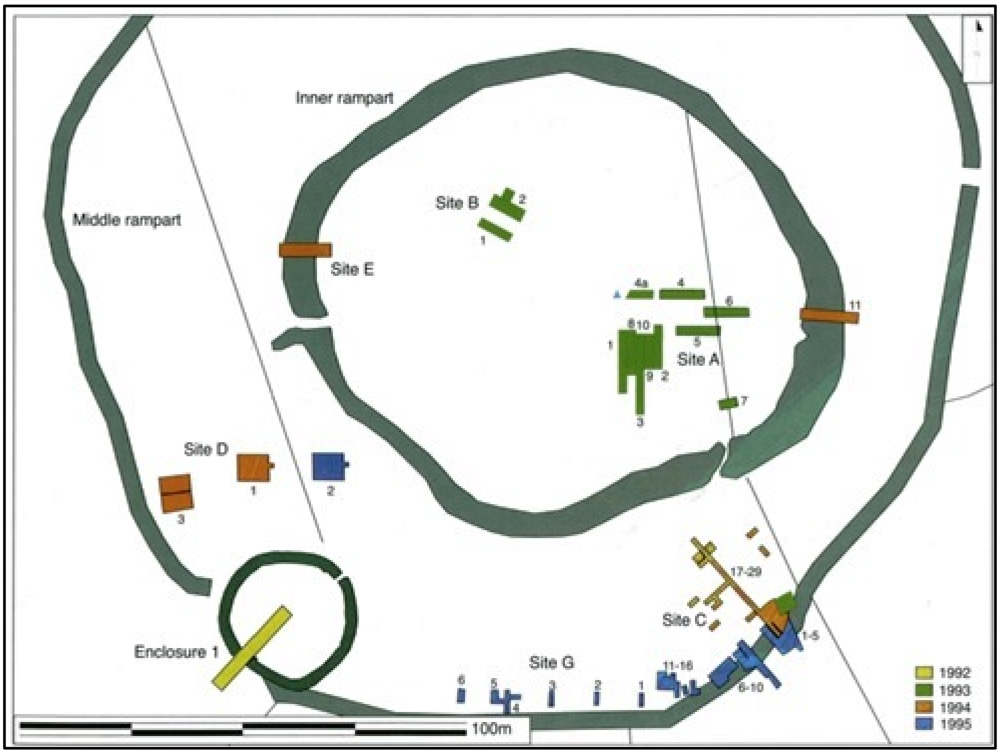

Figure 3.16: Site plan of the inner and middle enclosures of Mooghaun hillfort showing the areas under excavation as part of the North Munster Project in the 1990s. The settlement evidence was concentrated in Site C and to a lesser extent in Site A and G (Grogan, 2005b).

This 450km^2 area has been termed the Mooghaun chiefdom and is proposed to have supported a population of c. 9000 people presumably centrally controlled by an elite in residence at Mooghaun hillfort (Grogan, 2005b), although occupation after completion has not, as yet, been identified. Thirteen hilltop enclosures have been identified by Grogan (2005b) within the landscape (ten of which are definite) and are suggested to be defended settlements. This includes Clenagh c. 8.5km to the south-west of Rosroe Lough which was excavated in 1994 (Grogan and Daly, 2005; Grogan and Daly, 1996). The site consists of an enclosure with a defensive rampart and evidence of habitation in the form of post-holes and stake-holes (Grogan and Daly, 2005). The only dating evidence, however, was a date of AD 405 – 561 from a post-abandonment ditch fill suggesting the site had long been abandoned by the end of the Iron Age (Grogan and Daly, 2005). Despite a lack of dating evidence, Grogan (2005b) assigns a Late Bronze Age date to the hilltop enclosures in this landscape based on similarities with hillforts and contrasts with later ringforts. Grogan (2005b) describes the area surrounding Mooghaun hillfort as densely occupied in this period with settlement enclosures, burnt mounds, standing stones and barrows.

The distinctiveness of this area emerges in the Dowris phase of the Late Bronze Age with the territory producing huge quantities of prestigious metalwork that characterises this region in the Late Bronze Age (Grogan, 2005b; Eogan, 1993). The production and control of valuables may have allowed this area to become a regional political centre in the same way that O'Brien (2012b) proposes for Late Bronze Age society in general. Deposition in the River Shannon was prevalent at this time with a significant number of bronze artefacts recovered. Condit and O'Sullivan (1999) note an emphasis on Late Bronze Age weaponry deposition, with at least five spearheads and five swords recovered from the River Shannon at Killaloe in addition to possible Late Bronze Age agricultural tools. A flourishing gold industry emerged during the Late Bronze Age with the production of gorgets, lock-rings, bowls and boxes concentrated in the Mooghaun Landblock (Grogan, 2005b; Eogan, 1994; Waddell, 2010). The difficulty in producing such items suggests the presence of an elite society able to control a developing industry (Eogan, 1994; Waddell, 2010). A hoard of six gold items was discovered in 1948 at Gorteenreagh, c. 17km north east of Rosroe Lough, which consisted of personal ornaments (gorget, lock rings, bracelets and ear spool), thought to be the jewellery of a single individual (Wallace and O'Floinn, 2002). In Late Bronze Age Denmark gold discs were worn as symbols of high status males and the personal ornaments of the Mooghaun chiefdom may have been used in a similar way (Eogan, 1994).

Much of the gold material has been recovered from hoards and the Mooghaun hoard (also known as the Great Clare Find) is the largest assemblage of gold objects ever found in Ireland (Figure 3.17) (Eogan, 1983; Waddell, 2010). Discovered in 1854 in advance of the Limerick to Ennis railway it consisted of 146 pieces of lavish goldwork (Eogan, 1983; Waddell, 2010). This included 137 pennanular gold bracelets, five gorgets, two neck rings and two ingots but unfortunately much of this was melted down (Eogan, 1983; Condit, 1996). While the exact find-spot is unknown it has been proposed by Condit (1996) that it was originally deposited in the, now dated, burnt mound situated c. 10m from the south-western side of Mooghaun Lough. Contemporary accounts and a depression (c. 2 x 1.7 x 0.5m) within it suggest that this is a likely candidate (Condit, 1996). Comparison has been made between Mooghaun Lough and Mooghaun hillfort, and the King's Stables artificial pond and Haughey's Fort, Co. Armagh, which was a known site of ritual deposition (Condit, 1996). There are contemporary descriptions of further, now missing, items such as lock-rings, that may have changed the original character of the hoard perhaps to the stock of a major gold workshop that would be consistent with the emerging gold industry in the Shannon region (Grogan et al., 1995).

Figure 3.17: The Mooghaun Gold Hoard which contained 146 pieces of goldwork discovered in 1854 during railway works. (National Museum of Ireland, 2018 Last accessed 15/06/2018). (inset) The location of Mooghaun Lough where it is thought the hoard was deposited at a burnt mound. Source: author.

Three additional Late Bronze Age hoards have been found in this landscape including an assemblage of weapons, tools and domestic items on the shores of Rosroe Lough associated with the Knocknalappa lake settlement site (Grogan et al., 1995). A tool hoard was found c. 5km to the east of Rosroe Lough at Enagh East (which also included four small rings), and a hoard of tools and ornaments thought to have been a votive deposit at Lahardaun c. 10km north-east of Rosroe Lough (Grogan et al., 1995). It is thought that the hoard at Enagh East may be representative of settlement activity in that area in the Late Bronze Age (Grogan et al., 1995). Gold specifically from the Mooghaun Landblock includes the Mooghaun hoard, a gold dress-fastener from the River Fergus , the bracelet recovered from Knocknalappa wedge tomb, two further bracelets from Dromoland (c. 5km west) and a collar from near to Newmarket-on-Fergus (Grogan et al., 1995). Other Dowris phase hoards in Co. Clare include the Gorteenreagh hoard, and the bronze hoards of Booltiaghadine, Boolybrien, Lahardan, Moyarta and Teernagloghane (Eogan, 1983).

It is clear that this area of south-east Co. Clare was becoming increasingly important in the Late Bronze Age and it has been argued that a hierarchical, elite society with an enormous wealth of prestige items was located here (Grogan, 2005b). O'Brien (2012b) proposed that the circulation and control of prestigious material culture can allow for the concentration of power, and it was perhaps this control of metal, specifically gold, that allowed the regional territory of the Mooghaun chiefdom to arise. There appears to have been an increase in high status settlement sites and artefacts during the Late Bronze Age in the Mooghaun Landblock with this area of south-east Co. Clare incorporated into the North Munster metalworking region (Grogan et al., 1995). The technological innovation of the Dowris phase in Ireland is a reflection of the long distance networks of communication that existed between Ireland, Britain and mainland Europe, with the transmission of objects and ideas (Eogan, 1993). These networks were increasingly used from the Chalcolithic period and the dominance of the south-west of Ireland due to the existence of the Ross Island copper mine (O'Brien, 2004) may have led to its unique trajectory of development and ultimately its position of power in the Late Bronze Age.

With an abundance of native gold, Ireland became a major European centre of gold production, with the North Munster region stimulated both by Irish industries and the wider Atlantic zone, such that access to the sea would be desirable – the River Shannon providing an important trade and communication route (Eogan, 1993). It is therefore possible that the control of such trade via this route, by societies adjacent to the Shannon estuary, would have led to prosperity and to the emergence of a small number of powerful families (Eogan, 1993) who may have established themselves in prominent sites such as Mooghaun hillfort. Jones (2009) has noted the siting of Mooghaun hillfort close to one of the five great roads of Ireland, the Slighe Dhala. Although these route-ways were documented in the early Medieval period, it is possible that their origins lie in prehistory as given the topography of the landscape, these route-ways would have provided the easiest way through the landscape in any period (Jones, 2009). The positioning of Mooghaun hillfort at such a location would have enabled the control of trade not only east along the Slighe Dhala and on to Britain, but via the Atlantic seaway to Europe (Jones, 2009). It is, therefore, interesting that the main concentration of gold objects is within the landscape of the Mooghaun chiefdom, and certainly gives credence to the idea that the control of trade, once a sophisticated North Munster gold industry emerged, led to the development of an elite society in the lower Shannon region.

Palaeoenvironmental Evidence

The pollen data from Molly's Lough to the south of the Burren indicates substantial farming activity at the start of the Late Bronze Age which then declined from c. 1030 BC, leading Thompson (1997) to propose a lull in human activity. Similarly, the profile from Loch Gaeláin in the south-east Burren suggests reduced activity throughout the Late Bronze Age until c. 750 BC (Feeser, 2009). Contrary to this, in the small catchments of Gortlecka, Cappanawalla and Lios Lairthín Mór, intensive farming activity was identified (Watts, 1984; Feeser and O'Connell, 2009; Jeličić and O'Connell, 1992). Off-shore on Inis Oírr, substantial farming was also detected in the pollen record from An Loch Mór (Molloy and O'Connell, 2004; 2007). This suggests that although Thompson (1997) proposes that farming activity diminished in the catchment of Molly's Lough, this was perhaps spatially limited, with increased activity occurring across other parts of the Burren landscape in the Late Bronze Age.

Thompson (1997) used sediment accumulation rates to propose a period of significant erosion into Molly's Lough c. 1218 – 639 BC. It is thought that originally the Burren region was more extensively covered by soil and diamicton (poorly sorted terrigenous sediment) which has eroded throughout the Holocene to the karst, often bare, landscape that can be seen today (Moles et al., 1999; Moles and Moles, 2002; Jeličić and O'Connell, 1992; Drew, 1983). Drew (1983) used the identification of karren (solutional features) on the side stones of wedge tombs (which showed sub-soil erosion) in addition to soil evidence to support this theory, with the suggestion that soil was removed in late prehistory. Moles and Moles (2002) identified changes in soil texture downslope, widespread mixing of shale- and granite-bearing soils and the presence and location of certain depositional horizons to be features associated with erosion. At Knockanes Mountain, c. 10km from Lough Inchiquin, a date of c. 1390 BC has been determined from charcoal buried beneath diamicton on the south-eastern flank (Moles et al., 1999; Moles and Moles, 2002). Moles et al. (1999) propose that because the diamicton cannot be the result of original glacial deposition, this is evidence of mass movement in the Bronze Age, which covered the charcoal shortly after its formation by at least 1.75m in a single episode, likely associated with anthropogenic activity. Further similar patches of diamicton occur on the eastern flanks of Slieve Rua and

Mullaghmore and so could be further evidence of this prehistoric soil erosion (Moles et al., 1999; Moles and Moles, 2002). Additionally, speleothem analysis in caves in the Burren has shown a cessation of growth and colour change that could be indicative of soil erosion proposed through Uranium-Thorium series dating to have occurred in the 2nd millennium BC (Drew, 1983).

In the pollen record further south in Co. Clare at Caheraphuca Lough, the Late Bronze Age was characterised by a significant increase in human activity. A *Landnam* event occurred from the start of this period with intensive pastoral and arable farming which subsequently declined from c. 950 BC (Molloy and O'Connell, 2012). In the Mooghaun Landblock a significant *Landnam* was identified in the Mooghaun Lough record c. 1000 – 750 BC, indicative of a strong mixed farming economy (Molloy, 2005). Reduced pressure on the landscape occurred for the remainder of the period (Molloy, 2005). It was during the main *Landnam* period that Mooghaun hillfort was constructed, and Molloy (2005) proposes that the fertile pastureland surrounding the basin of Mooghaun Lough would support cattle on year-round grazing. Molloy and O'Connell (2012) comment upon the similarity between the Caheraphuca and Mooghaun Lough pollen profiles which emphasise the regional importance of this area of central Clare in later prehistory. Plunkett (2009) proposes that the emergence of socio-economic centres, such as at Mooghaun during the Dowris phase of the Late Bronze Age, corresponds well with the palaeoenvironmental record for intensive farming. In the case of Caheraphuca, however, the data shows that high levels of human activity at this time were occurring in landscapes that were not dominated by such high status sites (i.e. the hillfort at Mooghaun) (Molloy and O'Connell, 2012).

While there was an increase in farming activity in the catchment of Caherkine Lough, the substantial *Landnam* seen in the other pollen records is not expressed (O'Connell et al., 2001). This contrast suggests that the main focus of Late Bronze Age settlement and subsistence in south-east Co. Clare was perhaps concentrated around Mooghaun Lough (O'Connell et al., 2001). The idea of a contraction of population to major areas of settlement in the Late Bronze Age, proposed by Plunkett (2009), could be said to be represented in this data. The scale of activity appears to be much more intensive in the Mooghaun Landblock in contrast to the Burren, although high levels of activity do register in some of the more northerly profiles. On the whole, the pollen records from Co. Clare relate to the wider Irish trend of varying intensities of pastoral and arable farming with some woodland regeneration towards the end of this period.

3.5.3 Summary

The Late Bronze Age in Ireland was a period of development with the transition from the Roscommon to Dowris phase of metalwork occurring c. 1000 BC, and with it an intensification of the bronze and gold industries. This allowed for the development of a more hierarchical society which in Co. Clare can be seen through lake settlement sites and hillforts such as Mooghaun. In terms of human-environment interactions there appears to have been some woodland regeneration during the initial Roscommon phase in some areas of Ireland which Plunkett (2009) views as evidence for the contraction of the population to prominent areas allowing socio-political territories to form. The Dowris phase was subsequently characterised by an intensification of agriculture across Ireland which in the final century or so either declines entirely or shifts to a pastoral farming base. In the Burren, the archaeological evidence for human activity in the Late Bronze Age is more limited than the preceding periods, although some areas such as Carran, Teeskagh and Turlough Hill appear to see a continuation of activity.

Contrary to this, the Late Bronze Age was a period of substantially increased human activity in the Mooghaun Landblock evidenced both through the archaeological record and the palaeoenvironmental data. Activity may have been concentrated around Mooghaun Hillfort constructed c. 915 – 902 BC forming the symbolic capital of a territory encompassing c. 450km^2 (Grogan, 2005b). This area became increasingly important throughout the Late Bronze Age with a concentration of prestigious gold and metalwork including the Mooghaun hoard. In the pollen data *Landnam*-type events registered for the first time in two of the three pollen records in this area, which suggest a strong pastoral economy in the region on which this elite society may have thrived. Current palaeoenvironmental data supports the intensification of human activity in this area in the Late Bronze Age.

3.6. Development of Archaeological Objectives

This chapter has provided a critical analysis of the archaeological record available from the Burren and Mooghaun Landblock from the Early Neolithic to Late Bronze Age. As such, it has allowed for the development of the archaeological objectives outlined in Chapter 1 regarding the correspondence between the archaeological record and the new palaeoenvironmental data. Specifically, this chapter has identified periods, within both refined study areas, of high and low visibility in the archaeological record which allows more detailed questions to be examined:

1. Is the high archaeological visibility of the Early Neolithic in the Burren a true reflection of early farming levels in the region?
2. Is the low archaeological visibility of the Early Neolithic in the Mooghaun Landblock a reflection of an actual lack of human activity in the region or a result of archaeological bias?
3. Does the concentration of archaeological sites (wedge tombs and settlement evidence) dating from the Chalcolithic – Early Bronze Age on Roughan Hill represent a distinct phase of farming activity, more apparent on the Burren than in south-east Co. Clare, or is it due to the nature of previous archaeological investigations?
4. Is the low visibility of Middle – Late Bronze Age archaeology in the Burren an accurate reflection of past settlement or a result of archaeological bias or a lack of research focus on this time period?
5. Is the high visibility of the Late Bronze Age archaeological record in the Mooghaun Landblock reflective of a phase of significant agricultural activity reflected in the palaeoenvironmental record?

Chapter 4 – Theoretical Background

4.1 Theoretical Approaches to Human-Environment Interactions

Environmental archaeology, rooted in the biological and earth sciences, has been a named sub-discipline of archaeology for the past three decades (Turney et al., 2014). The development of environmental archaeology, however, arguably stems back as far as the 18th and 19th Centuries when geologists, biologists, archaeologists and anthropologists were making both theoretical and practical advancements in the study of the ancient past, which was beginning to highlight the importance of understanding human-environment interactions with regard to cultural change (Turney et al., 2014). The interpretation of environmental data is largely based on the concept of uniformitarianism (Turney et al., 2014). For example, with regard to the current study, particular plant species representative of a specific modern environment such as pastureland, would be used to identify that environment in prehistory through the identification of its fossil pollen. In this way environmental archaeology is rooted in scientific philosophy but it must be remembered that human agency is always a factor when considering past human-environment interactions (Turney et al., 2014).

The development of environmental archaeology, and so studies focused on human-environment interactions, has been influenced by aspects of wider archaeological theory, in tandem with that of 'landscape archaeology'. As processual archaeology became more popular in the 1960s, the scientific rationale behind environmental archaeology allowed it to epitomise the increasingly popular approach of explaining rather than describing cultural change (Turney et al., 2014). The primary concern of environmental archaeology at the time was to define the biophysical environmental characteristics and processes within which socio-economic interactions took place (Butzer, 1982). The term 'landscape archaeology' came about in the mid-1980s and was, in its beginnings, firmly focused upon the human impact on the environment – as such sharing much of the same theoretical approaches as environmental archaeology (David and Thomas, 2008). With the subsequent emergence of post-processual archaeology, landscape archaeology developed a more social approach (Albarella, 2001; David and Thomas, 2008) and it has been argued that it is now the challenge of investigations into human-environment interactions to maintain scientific rigour while allowing for the complexity of interpretation strived for in a more post-processualist agenda (Turney et al., 2014). As such Bell and Walker (2005) suggest that it is necessary for environmental archaeology to distance itself from the false dichotomy between people and the environment and favour a more integrated approach in such discussions.

The relationship between human societies and the environment is of course fundamental to archaeology as a whole (Albarella, 2001; Adams, 1988). This interaction between humans and the natural environment can be seen as an on-going cultural process (Turney et al., 2014). With the onset of agriculture in the Neolithic, this interaction was heightened to such an extent that the environment started to be significantly altered by human action such that changes in vegetation can be intrinsically linked to human activity in pollen records. Most human-induced interactions can be defined as short term processes such as deforestation, burning, crop cultivation and animal husbandry (Turney et al., 2014). Taken together, these processes represent the cultural modification of the natural environment (Turney et al., 2014) with which this study is primarily concerned. It is important to remember that the natural and cultural elements of ancient landscapes would have been hard to disentangle, where natural features may also have held important social meanings throughout prehistory (Albarella, 2001; Chapman and Geary, 2013). Through the integration of both a scientific and social perspective a more in-depth understanding can be developed of the ways in which humans have altered their environment (Bell and Walker, 2005), and systems theory is one model through which this can be illustrated (Figure 4.1) (Redman, 1999).

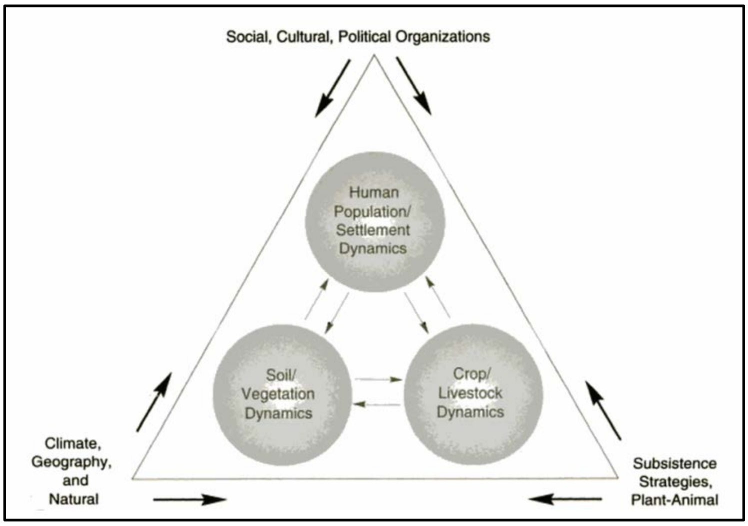

Figure 4.1: A system diagram representing the influence of various factors relating to natural and cultural processes on an ecosystem (Redman, 1999).

Often the study of past environments, and in particular those that encompass climatic factors, can lead to a view of environmental determinism, i.e. that certain environmental factors would have given rise to a single human response (Bell and Walker, 2005). While it is certainly true that climatic change would have impacted past societies, to take such a dogmatic approach is perhaps unhelpful to studies of human-environment interactions in archaeology. A change in environmental conditions may create the necessity or opportunity for societal change but will not determine the specific outcome (Bell and Walker, 2005). The challenge of human adaptation throughout prehistory is linked to strategies of resilience rather than the creation of any sort of equilibrium-centred system of cause and effect with the environment (Adams, 1988).

A useful perspective is provided by Bell and Walker (2005) when they define a landscape as the product of interactions between the environment and the human populations living within it and as such, a product of human agency. Bell and Walker (2005) argue that through the creation of various places within an environment such as settlements, fields or sacred places, the natural environment has been transformed into a socially constructed landscape. The emergence of a more social archaeology in the mid-1980s, which saw the archaeological record as a product of socially interacting people engaging with their surroundings, soon impacted upon landscape archaeology (David and Thomas, 2008; Shanks and Tilley, 1987) and can be applied to human-environment interactions. Landscapes were now seen as socially engaged places that, through their structuring could be related to cultural aspects such as social order, territorial spaces and social and personal experience, with people lying at the core of the approach (David and Thomas, 2008; Knapp and Ashmore, 1999). In these more socially-focussed approaches the foundation for understanding cultural landscapes is provided through social theory while the techniques utilised in environmental archaeology, such as those employed in this study, allow for an understanding of the physical environment and the interactions of human populations with it (Chapman and Gearey, 2000). This is particularly relevant to the current study which is utilising palaeoenvironmental techniques in order to investigate two socially constructed or cultural landscapes; these landscapes being material manifestations of complex human-environment interactions (Torrence, 2002).

4.2 Theoretical Background to Palaeoenvironmental Analyses

Palaeoenvironmental investigations can, as carried out in this study, take advantage of the continuous sedimentary record provided by lake sediments. Lake sediments essentially act as an archive of environmental change containing within it the fossil/sub-fossil remains of various biological, chemical and isotopic indicators (Edwards and Whittington, 2001; Diefendorf et al., 2008). These include, but are not limited to, pollen grains, chironomid sub-fossil remains, plant macrofossils, diatoms and algae (Edwards and Whittington, 2001). As demonstrated in Figure 4.2 these indicators can be linked to anthropogenic processes, and can also include minerogenic and elemental records preserved within the sediment matrix. Sediment accumulation is generally a constant, undisturbed process leading to a stratigraphic sequence of such indicators that have the potential to be related to changes in the local and regional environment over time (Davidson and Jeppesen, 2013). Lake sedimentation is thought to be especially efficient in deep lake basins, like those used in this study, with less effect of within-lake processes and wind turbulence on the sediment accumulation area than in shallower systems (Kalff, 2002; Faegri and Iversen, 1989).

Once material reaches the lake system, by whatever means, it drifts into the central part of the basin and is re-deposited in deep water causing a focus in the profundal zone (Faegri and Iversen, 1989). When choosing a location for sampling it is important to take into consideration any physical turbulence that may be caused by currents or the in/out-flow of a river, which could cause mixing of the sediment and thus disturb the stratigraphic sequence, although this is more common in shallower lakes (Faegri and Iversen, 1989). To avoid such effects it is normally sediment in the deepest part of the lake that is sampled which will also avoid any erosion of sediment that may have occurred in the littoral zone (Moore et al., 1991; Faegri and Iversen, 1989). By establishing a chronology for lake sediment via ^{14}C dating, changes can be assessed over both prehistoric and historic timescales (Edwards and Whittington, 2001). These multi-proxy records are one of the main sources of evidence examined for investigations into long-term environmental change (O'Connell et al., 2014).

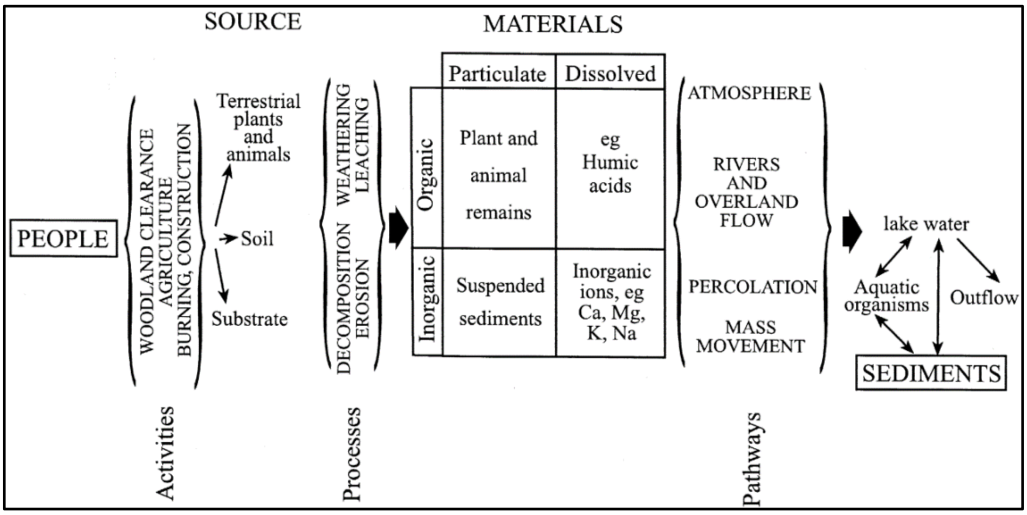

Figure 4.2: A simplified model of lake catchment processes and sedimentation influenced by human activity (Edwards and Whittington, 2001).

4.2.1 Pollen Analysis

Pollen analysis (palynology) is the primary technique used for the reconstruction of past vegetation and includes the study of fossil pollen grains and spores (Bennett and Willis, 2001; Moore et al., 1991). The examination of pollen grains has applications across a wide range of fields including taxonomy, palaeoclimatology, phytogeography, conservation biology and most relevant to the current study, that of palaeoecology (Moore et al., 1991; Birks and Berglund, 2018). Quaternary pollen analysis was developed over a century ago in Scandinavia, with analysis initially carried out on peat deposits. During its 'pioneer phase' (1916 – 1950) important conceptual developments were realised such as the impact of prehistoric people on vegetation change (Birks and Berglund, 2018). The development of ^{14}C dating occurred during what has been termed the 'building phase' of palynology (1951 – 1973) and it was during this time that the potential of lake sediments for analysis was realised (Birks and Berglund, 2018). The spatial scale and resolution of the pollen data produced was also recognised (Birks and Berglund, 2018). Major advances in the 'modern phase' (1974 – present day) include the development of AMS ^{14}C dating, which due to the very small sample size required (c. 2 mg), allows for the establishment of robust age-depth models for lake sediments (Birks and Berglund, 2018; Sugita, 2007a). With a strong link between pollen analysis and archaeology, research into prehistoric diet and food production, site function, and the effects of climate on human populations has been carried out (Bennett and Willis, 2001; Hevly, 1981). Valuable information regarding human-environment interactions in the past can be gained through such analysis especially if the sediments analysed are in close proximity to archaeological sites (Hassan, 1978; Moore et al., 1991; Mitchell et al., 2013).

Principle of Pollen Analysis

Pollen is produced annually, in large quanties, within plants and is dispersed as part of their reproduction (Moore et al., 1991). During dispersal, a uniform pollen rain including arboreal pollen (AP) and non-arboreal pollen (NAP) is formed through the mixing of pollen within the atmosphere from various environmental components (e.g. trunk space, canopy, rain, local) which is then deposited within a context and preserved as a unit (Bennett and Willis, 2001; Broström et al., 1998). The outer walls of pollen grains contain the polymer sporopollenin, a very stable structure, which allows them to withstand most forms of chemical and physical degradation (bar oxidation) (Bennett and Willis, 2001). As such, the grains are well preserved under anaerobic conditions which enable them to survive across archaeological timescales (Moore et al., 1991; Bennett and Willis, 2001). It is this resistant exine structure that exhibits the unique sculpturing features that form the basis of pollen identification keys and on which the identification of fossil pollen is based (Figure 4.3 and 4.4). The apertures consist of two types, pores (*pori*) and furrows (*culpi*), and it is the number and location of these that is used during identification. The majority of pollen grains are spherical or elliptical in shape and between 20 – 30µm (Moore et al., 1991). Through comparison with a reference collection and aided by the experience of the researcher, the fossil pollen grains can be identified to genus and species level under the microscope and the number of pollen grains from each taxa are enumerated (Bennett and Willis, 2001).

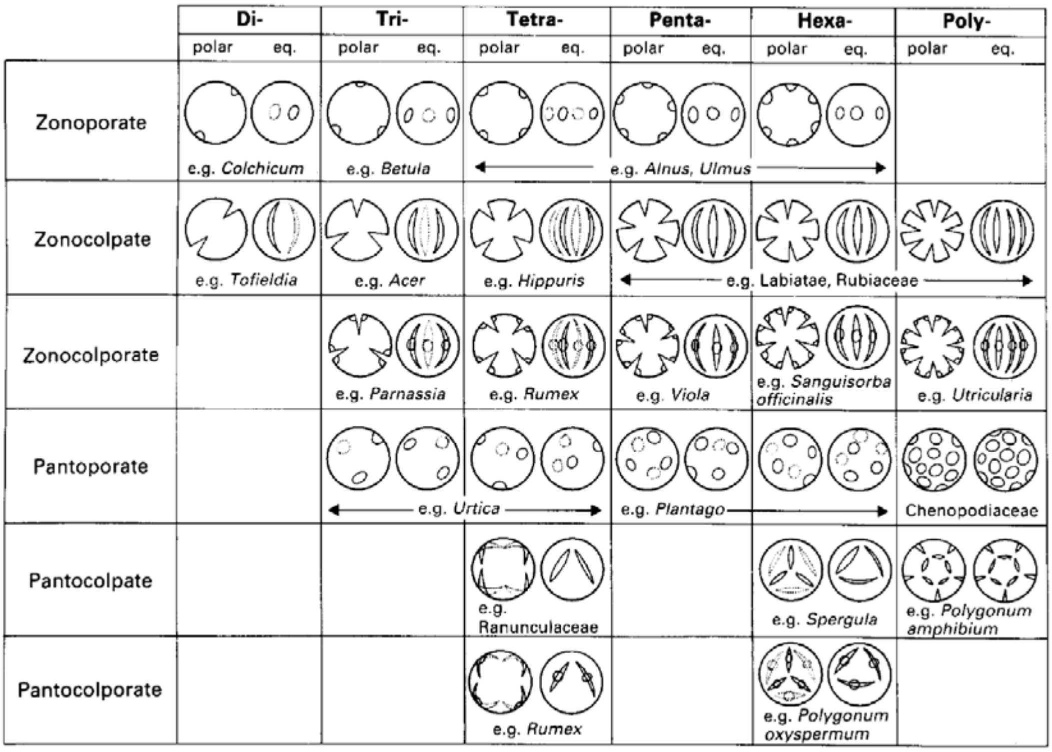

Figure 4.3: The number and position of apertures (pores and furrows) that are used in the classification of pollen types. The range presented is not limited to Irish flora (Moore et al., 1991).

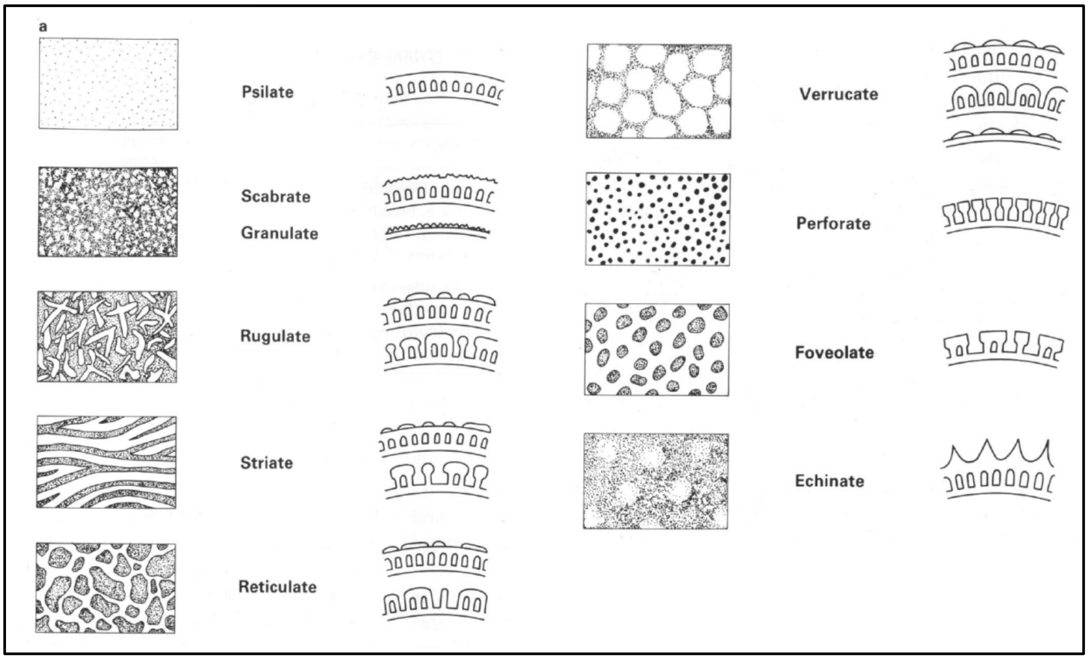

Figure 4.4: Examples of sculpturing types upon the surface of pollen grains that are used in pollen classification and identification. The types are shown both in surface view and optical section (Moore et al., 1991).

Interpreting Pollen Data

It is important to consider the nature of the depositional context when interpreting the pollen record with research undertaken on lake sediments, peat sediments and archaeological deposits. For pollen analysis, lake and peat sediments are the most suitable due to maintained anaerobic conditions (Bennett and Willis, 2001; Moore et al., 1991; Faegri and Iversen, 1989). In archaeological deposits, sediments may have been disturbed and can also become dry, subjecting fossil pollen grains to decay (Moore et al., 1991). A relationship between the pollen preserved in sediment and the vegetation that produced it is assumed, and it is on this principle that the interpretation of pollen analysis is based (Birks and Birks, 2000). There are caveats, however, such as differences in the production, dispersal and preservation of pollen taxa that can complicate the interpretation of pollen profiles (Bennett and Willis, 2001; Birks and Birks, 2000; Broström et al., 1998). For example, wind-dispersed plant species normally produce more pollen than those that rely on insect dispersal (Bennett and Willis, 2001; Moore et al., 1991; Hevly, 1981). Furthermore, Hevly (1981) proposed that wind transported pollen can travel over tens to hundreds of kilometres whereas insect dispersed pollen will remain much closer to the producer plant. The terminal settling velocity of pollen grains, determined by their size, bulk density and atmospheric conditions, will also determine their dispersal, with smaller pollen grains generally travelling greater distances, in addition to those that employ air-sacs (Bolinder et al., 2015; Hall and Walter, 2011; Moore et al., 1991). Similarly, the height of pollen dispersal, i.e. distance from the ground, can be a determining factor in its overall dispersal, with low-lying species such as grassland herb taxa not able to travel great distances (Sjögren et al., 2015).

Taken together, there is a greater production and dispersal of tree pollen when compared to taxa associated with grasslands and this can directly affect the likelihood of pollen grains of certain taxa being present in the fossil pollen record (Behre, 1981; Moore et al., 1991; Hellman et al., 2009). This can cause an under-representation of NAP within pollen records which in turn can lead to an underestimate of the openness of a landscape, especially when factors such as the 'glade effect' (i.e. the increased flowering of tree species due to increased landscape openness) are considered (Hellman et al., 2009; Feeser and Dörfler, 2014). As such there is no simple 1:1 relationship between pollen percentages and vegetation percentages (Birks and Berglund, 2018; Hellman et al., 2009). An understanding of how vegetation is reflected in the pollen record can be aided by modern observations of the relationship between vegetation and pollen preserved in sediment (Bennett and Willis, 2001; Broström et al., 1998). Useful examples include research by Sjögren et al. (2015) that aimed to determine the dispersal-deposition properties of grasses and Vuorela (1973) that assessed pollen dispersal around a cultivated field.

A fossil pollen sample typically contains poorly dispersed pollen from the local area and widely dispersed pollen from a greater distance, with each pollen taxon having its own source area (Bennett and Willis, 2001; Broström et al., 1998). The size of the site to be sampled will determine the catchment area of the pollen rain. Research has focused on the relevant pollen source area (RPSA), which has allowed for a greater understanding of local versus regional pollen signals, with RPSA increasing with basin size (Sugita, 1994; 2007a; 2007b). Regional estimates of vegetation abundance for large sites (REVEALS) is also a focus of research, with Sugita (2007a) proposing that vegetation reconstruction over an area $10^4 – 10^5 km^2$ could be determined from large lake sites. The degree of heterogeneity of landscape areas would also affect RPSA and is a further area of research (Hellman et al., 2009). It has been suggested that only c. 30 – 45% of total pollen will be derived from the RPSA, but due to the homogenous nature of the remainder, this is enough to reflect local vegetation (Sugita, 1994; Birks and Berglund, 2018).

When lake sediment is examined, additional pollen will reach the lake via water transport (i.e. from rivers that flow into the lake), and from contemporary soil that has been washed into the system (Moore et al., 1991; Brown et al., 2007). There has been little research, however, into fluvial pollen transport despite it being an important source of pollen into lake sediments (Brown et al., 2007). The ratio of fluvial to airborne pollen input is determined by factors such as the catchment area, lake surface area, topography and catchment vegetation (Brown et al., 2007). Previous research has demonstrated that a high percentage of pollen input (>85%) to lake systems is fluvial (Brown et al., 2007; Bonny, 1978; Peck, 1973). Similarly, a more recent study demonstrated that 88% of the total pollen influx was transported by water into a lake system, suggesting that the pollen source area is composed of three parts; an aerial component, a fluvial river-borne component and a waterborne surface run-off component (Xu et al., 2012).

Interpreting Human – Environment Interactions from Pollen Data

Through pollen analysis, questions on the arrival, expansion and contraction of different species can be investigated both in relation to natural succession and human influence (Moore et al., 1991). For example, through the examination of large pollen datasets, the location of oak refugia during the last glacial period, and its subsequent spread across Europe has been traced (Brewer et al., 2002). Similarly, the decline of species can be investigated, such as the mid- Holocene Elm Decline (Edwards, 2004; Parker et al., 2002; Lamb and Thompson, 2005; Stolze et al., 2013). The influence of humans on the development of post-glacial vegetation was originally considered largely inconsequential with factors such as soil development and climate deemed more important (Faegri and Iversen, 1989). Pioneering work in the 1930s and 1940s, however, led to both an acceptance that human populations had a strong influence on the environment, both past and present, and to the methods with which to demonstrate this (Faegri and Iversen, 1989). With regard to human-environment interactions it is the ability of pollen analysis to elucidate the transition from natural undisturbed landscapes to those that have been anthropogenically altered that is of great importance (Faegri and Iversen, 1989).

Furthermore the capacity to reconstruct both the timing and causal relationships of such change can allow for a deeper interpretation of cultivated landscapes (Faegri and Iversen, 1989). The calibration of radiocarbon dates acquired on pollen sequences allows changes within the landscape to be directly compared with archaeological records – an essential pre-requisite of in-depth investigations into human-environment interactions (Grant and Waller, 2017). It is not feasible to date every point along a pollen sequence which has led to the production of age-depth models, ranging from the simplest 'classical age-depth models' which aim to fit a curve to a series of points based on calibrated radiocarbon dates (linear interpolation), to Bayesian age-depth models which can statistically produce interpolated age estimates for every depth (cm) of a sediment core (Grant and Waller, 2017). Figure 4.5 shows the number of Holocene pollen sequences across Ireland and the number of ^{14}C dates obtained from these sequences.

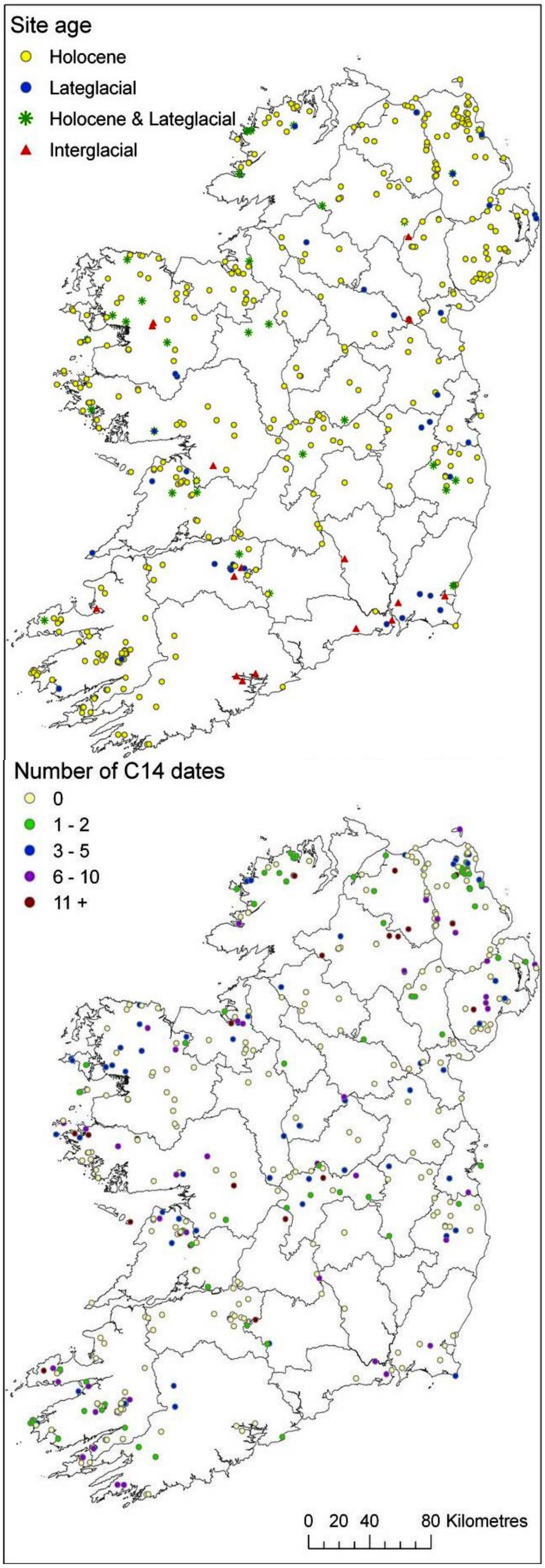

Figure 4.5: The distribution of pollen sequences, and the number of ^{14}C dates obtained from the sediment cores, across Ireland which have been submitted to the Irish Pollen online database (IPOL) (Stefanini and Mitchell, 2011 Last accessed 15/06/2018).

Certain horizons appear to occur synchronously across multiple pollen sequences and as such can provide tentative chronological markers, as well as signifying widespread human-environment interactions. The Early Neolithic *Landnam* was first identified by Iversen (1941) who coined the term *landnám,* taken from the Old Norse word for 'land-take' in relation to the Danish Neolithic. Since this early publication the influence of prehistoric people on vegetation structure has been widely accepted (Birks and Berglund, 2018; Iversen, 1941). The ability of pollen analysis to examine the impact of human populations on 'pristine' undisturbed environments in this way has led to much research on the initial Norse colonisation of Iceland, for example (McGovern et al., 2007; Dugmore et al., 2005). The interaction of the first agricultural communities on the Irish environment (e.g. O'Connell and Molloy, 2001) is, of course, of great interest within palaeoenvironmental research and especially in archaeology. Other major palaeoenvironmental changes within Ireland include the Late Iron Age Lull c. 200 BC – AD 200 (Newman et al., 2007; Molloy and O'Connell, 2004; Feeser and O'Connell, 2010; Coyle McClung, 2013) and the later introduction of *Secale* (rye) cereal cultivation in the Medieval period (c. 8th Century AD) (Molloy and O'Connell, 2004; Behre, 1981).

While pollen analysis can easily identify changes in vegetation through time, it is the cause of such change that is of greater interest within archaeological investigations. Fundamentally and at a rudimentary level pollen data provides an image of an environment in which humans lived (Moore et al., 1991). The archaeological evidence and social dynamics which make up the 'lived-in' landscape can then be overlaid on to the backdrop created by the palaeoenvironmental data. As agricultural practices can be detected in the pollen record (pastoral and arable indicators) the technique can provide information on prehistoric economies (Whitehouse et al., 2014). Interpretations made on the structure and openness of a landscape (AP/NAPp) in addition to the recognition of such indicators allows for interpretations on agricultural activity and land-use dynamics over time (Edwards and Whittington, 2001). Pollen analysis can allow for the detection of human activity in areas where no human presence is known archaeologically, while also allowing for an enhanced understanding of prehistoric land management and land-use in the absence of documentary evidence (Moore et al., 1991).

Anthropogenic Indicators

Human impact within a pollen diagram registers as a decrease in the proportion of AP concurrent with an increase in pastoral indicators, which are distinguished from NAP in a separate category (NAPp), and as such interpretations should be based on both negative and positive indicators (Faegri and Iversen, 1989). Certain indicator species have been recognised that thrive in environments affected by human activity and thus can be regarded as anthropogenic indicators (Moore et al., 1991). Interpretation is based on the ecological tolerance of these indicators, i.e. whether they thrive in pasture or cultivated land, for example (Faegri and Iversen, 1989; Behre, 1981). These include species linked to disturbed soils, open landscapes devoid of dense woodland and land that is nutrient enriched (Moore et al., 1991). It can be useful to examine the full pollen spectra and make comparisons with modern culturally influenced landscapes, but it must be taken into consideration that the strict division between arable and pastoral land in modern agriculture may have been more fluid in the prehistoric past (Faegri and Iversen, 1989; Behre, 1981). A system of rotational or ley farming (with fallow periods) is deemed most likely during prehistory, which would have led to the presence of numerous perennial species (Behre, 1981). The simple farming equipment used in prehistory (mattocks and ards) would have also allowed these to thrive, when later technologies would destroy the roots and annual weeds would be favoured (Behre, 1981).

The principal and most important anthropogenic indicator is *Plantago lanceolata* (ribwort plantain) which appears in pollen assemblages indicating disturbed grassland, particularly as pastureland (Figure 4.6) (Behre, 1981). Due to its high light-dependence, this species cannot survive under woodland canopy, and so it is generally regarded as an indicator of an open landscape (Behre, 1981). The highly distinctive structure of *Plantago lanceolata* pollen grains in addition to higher levels of pollen dispersal, (compared with other herb taxa), allow it to be easily detected in the pollen record (Behre, 1981; Moore et al., 1991). Its presence in conjunction with various grass types (*Poaceae*), and its recognised association with human activity, is thus suggestive of farming activity or perhaps the abandonment of cultivated areas (Behre, 1981).

Figure 4.6: The flowering heads of *Plantago lanceolata* (ribwort plantain) within a meadow accompanied by grass and buttercup. (inset) The illustrated ribwort plantain pollen grain showing the distinctive surface of the grain (Molloy and O'Connell, 2012).

Other taxa indicative of pastureland, and often found with ribwort plantain include *Poaceae* (grass), *Rumex acetosa* (sorrel), *Rumex acetosella* (sheep's sorrel), *Liguliflorae* (dandelion) and *Ranunculus acris*-type (buttercup) (Behre, 1981). The genus *Rumex* (dock) includes two species, sorrel and sheep's sorrel, that can provide information on land-use, although it is normally the composite sum-*Rumex* curve that is used as a general indicator of a more open, cleared and cultivated landscape (Behre, 1981). *Rumex acetosella* is a perennial herb of short, open grasslands and can occur in a number of environments such as poor meadowland and fallow areas while also thriving as a weed of winter cereals (Behre, 1981; Preston et al., 2002). *Rumex acetosa* is a short-lived perennial of meadows and pastures, also able to survive in woodland glades (Behre, 1981; Preston et al., 2002). Taxa associated with arable cultivation include cereal-type (discussed further below), *Chenopodiaceae* (namely *Chenopodium album* – goosefoot) and *Artemisia* (mugwort) (Behre, 1981). Figure 4.7 indicates taxa associated with cultivated crops and different types of pastureland, which allows for the identification of pastureland over simply open, grassland areas during interpretation (Behre, 1981).

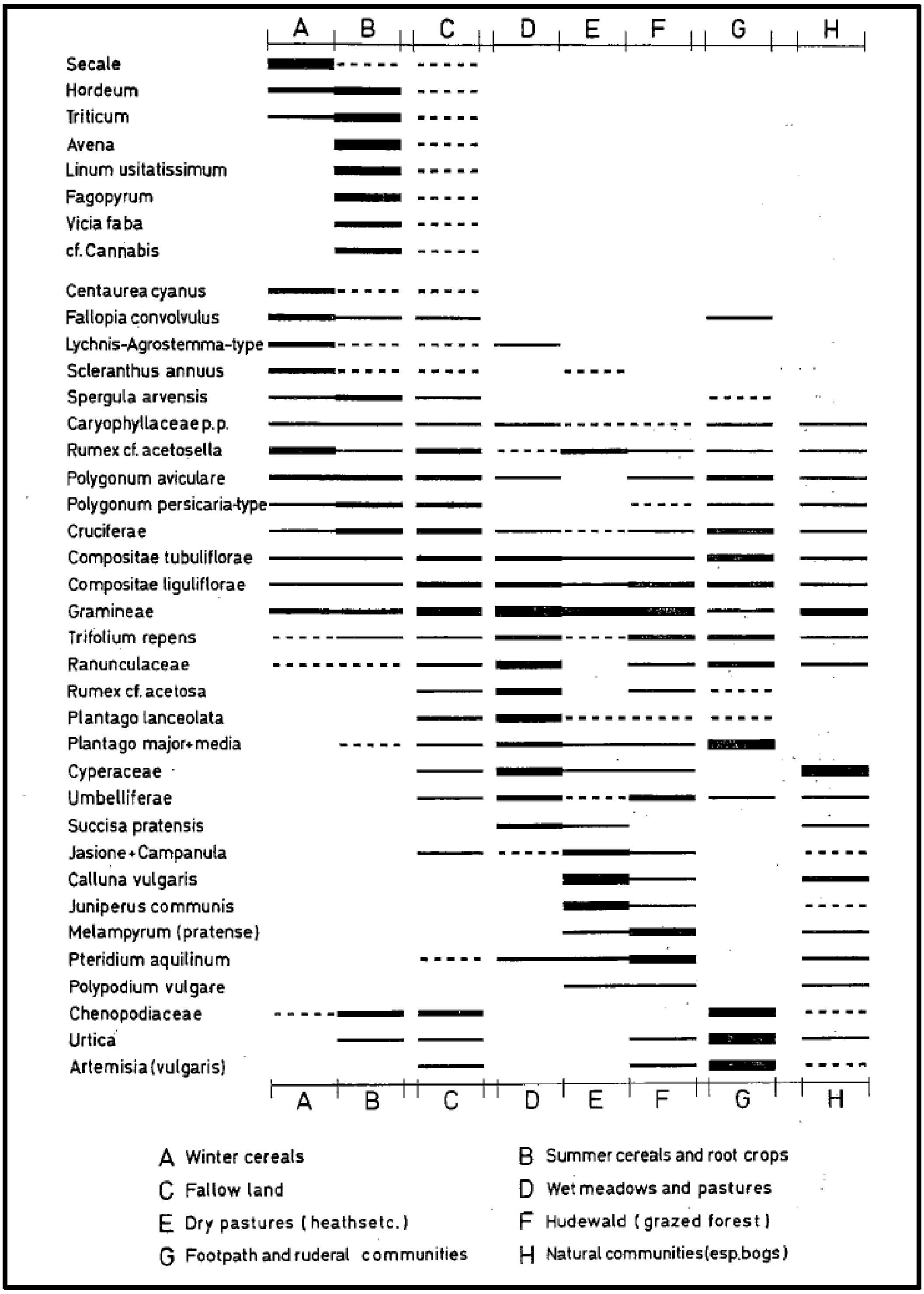

Figure 4.7: The representation of anthropogenic indicators as defined by Behre (1981) that demonstrates their association with different types of cultivated land including cultivated land, dry pastures and wet meadows/pastures.

Given that taxa can be associated with pastoral and arable environments, attempts have been made to determine the ratio of pastoral to arable land in prehistory. These have ranged from simple arable/pastoral indexes, contrasting the levels of cereal-type pollen to ribwort plantain or uncultivated grasses (Behre, 1981), to more complicated groupings (Donaldson and Turner, 1977; Turner, 1964). Such an index method can only be used to suggest the predominant type of land-use, however, as even if arable and pastoral land were of equal importance in a prehistoric community, the low dispersal of cereal-type pollen would cause it to be under-represented in the index (Behre, 1981). Interpretations can be aided by experimental research. The production and distribution of anthropogenic indicators in the immediate surroundings of a 27ha cultivated area, over a two year period, was examined by Vuorela (1973) via pollen trap and moss polster samples. Grass was found to be the dominant taxa contributing >50% of total NAP while other anthropogenic indicators were negligible (Vuorela, 1973). This is proposed to be due to the purely arable nature of the site, however, with the study also highlighting that surrounding woodland prevented more widespread dispersal (Vuorela, 1973). Similarly, grass was found to be the most well represented NAP taxa around a Neolithic clearing in Germany, while dock, daisies and ribwort plantain were dispersed to a greater distance than cereal-type pollen (Behre and Kucan, 1986). Research has also demonstrated the inverse correlation between the presence of anthropogenic indicators and distance from the site of human activity (Faegri and Iversen, 1989).

Due to the geographical limits of certain weed species such as ribwort plantain, it is possible to detect the arrival of European communities (along with their crops) into areas such as Australia and America and the subsequent commencement of agricultural practices (Moore et al., 1991; Faegri and Iversen, 1989). The geographical location of the landscape under investigation will determine which taxa are anthropogenic indicators, but for northern Europe, including Ireland, the taxa discussed are the most important (Moore et al., 1991). It should be stressed that although finer interpretations on land-use may be difficult to elucidate from these anthropogenic indicators, their presence would not occur under purely natural woodland conditions, and as such registers human activity within a landscape (Behre, 1981).

Cereal-type Pollen

Of course, the most secure indicator of arable cultivation is the presence of pollen grains from cultivated crops (Faegri and Iversen, 1989; Behre, 1981). Studies on arable farming suffer, however, from difficulties in distinguishing species and in low levels of pollen dispersal, with many cultivated crops being autogamous (self-fertilising) (Behre, 1981). This lowers the probability of cereal-type pollen being present in a pollen assemblage even if cultivation was occurring (Behre, 1981; Faegri and Iversen, 1989). The main cereals identified include *Triticum* (wheat), *Hordeum* (barley) and *Avena* (oats) and while *Secale* (rye) is the most readily identifiable, it was not cultivated during the prehistoric period (Behre, 1981). The likelihood of cereal-type pollen registering in a pollen record is determined by the distance of cultivation from the sampling location, local vegetation, density of remaining woodland and potentially certain processes such as threshing (Faegri and Iversen, 1989; Vuorela, 1973).

Single occurrences of cereal-type pollen may point to agriculture somewhere in the catchment, whereas large amounts found in conjunction with grass pollen, would be more indicative of local agriculture (Vuorela, 1973). In the experimental study by Vuorela (1973) cereal-type pollen was poorly represented varying in value from 2 – 7% of total NAP, unable to compete with the larger amounts of pollen dispersed from other anthropogenic indicators (Vuorela, 1973). Similarly, in an experimental study by Hall (1988), samples taken directly below a cereal crop produced pollen percentage values of between 9 – 23% but at a distance greater than 1.5m from the edge of the cultivated area, this dropped to c. 1%. Similarly samples taken from soil within and outside a cultivated enclosure at Carrownaglogh, Co. Mayo further demonstrated the poor dispersal of cereal-type pollen (O'Connell, 1990). Thus, while cereal-type pollen is direct evidence of cultivation, its absence within a pollen record does not automatically mean there was no cultivation occurring in the landscape (Behre, 1981). Similarly, the percentages of such taxa are not necessarily indicative of quantitative relations (Faegri and Iversen, 1989). Research has been undertaken on optimising the recovery of cereal-type grains to overcome some of these issues (Edwards et al., 2005).

Perhaps the most important methodological factor in studies of past cultivation is the ability to distinguish wild grass pollen from domesticated cereal-type pollen (Tweddle et al., 2005). Both pollen types are circular grains with a single pore, and so consideration must be given to the size of the grain in addition to the pore diameter, width and thickness of the annulus (Köhler and Lange, 1979; Tweddle et al., 2005; Beug, 1961; Beug, 2004). A general threshold of 40µm grain diameter is used while the diameter of the annulus must be at least double the width of the pore alone (Figure 4.8). Identification can be aided by classifications of overall size, pore and annulus dimensions and location of *punctae* (minute perforations on the surface) made by Beug (1961); Beug (2004). Research has demonstrated that the pore of cereal-type grains is more distinct and delimited by a protuberant annulus while that of wild grasses are much thinner and less distinct (Joly et al., 2007; Tweddle et al., 2005).

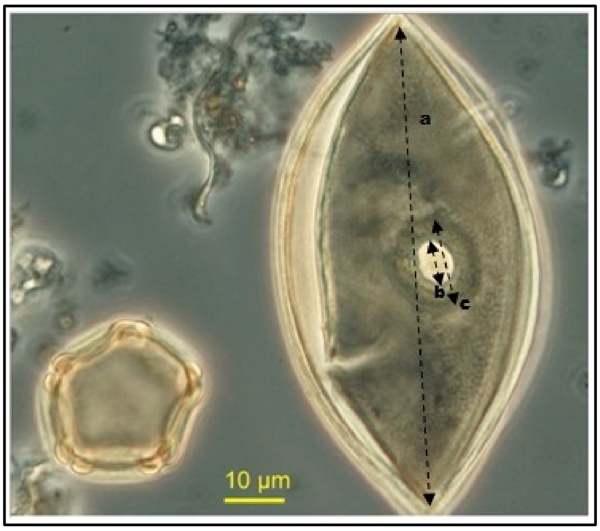

Figure 4.8: Photomicrograph of a large cereal-type pollen grain (*Triticum*). The arrows indicate measurements that are taken on cereal-type grains; (a) length (b) pore diameter (c) pore + annulus diameter. A pollen grain of *Alnus* (Alder) to the left demonstrates the large size of cereal-type pollen. After Ghilardi and O'Connell (2013).

Detailed investigation into the exine sculpturing patterns of cereal-type grains for species identification has been carried out (Köhler and Lange, 1979) but differentiation requires a high level of preservation (Joly et al., 2007). It can be possible, however, to distinguish between cultivated species in fossil pollen samples, as in Molloy (2005). The application of multivariate statistics has also demonstrated that while most cereal-types can be distinguished from each other, there remains some overlap with wild-type grasses which can complicate interpretations (Tweddle et al., 2005). Large wild grass types which may be contributing to this problem include *Agropyron repens, Bromus erectus* and *Glyceria fluitans* (Edwards and Hirons, 1984; O'Connell, 1987). It has been demonstrated that large wild grass pollen can travel a greater distance than that of cereal-type and as such may occur in greater frequency in pollen records (Hall et al., 1993). This is especially important when considering pre-elm decline arable activity (Edwards and Hirons, 1984; Hall et al., 1993; O'Connell, 1987) and that of the earliest Neolithic in Ireland (O'Connell and Molloy, 2001).

4.2.2 Macrofossil Analysis

Macrofossil analysis is often used to supplement investigations based on pollen analysis and can be incorporated into multi-proxy investigations of lake and peat sediments (Birks and Birks, 2006). An advantage of implementing such a methodology is that macrofossils can often be identified to greater taxonomic precision than fossil pollen and are representative of vegetation in close vicinity to the coring location (Birks and Birks, 2000). Thus, it provides a local scale to the vegetation reconstruction provided, generally, at a wider resolution by pollen analysis (Birks, 2014). Although less abundant than pollen, certain macrofossils may be identified from taxa unlikely to have been identified in pollen data (Birks and Birks, 2000). Macrofossil assemblages can include vegetative remains, including leaves, bud-scales, seeds and moss, but also faunal remains such as chironomid head capsules and mites (Birks, 2014). These have the potential to be related to both vegetative and climatic changes if the ecological tolerance is known (Heggen et al., 2012). When analysis is carried out on sediment cores extracted for the purposes of pollen analysis i.e. from the profundal zone, however, it may yield a low concentration of terrestrial macrofossils (Heggen et al., 2012). Similarly, as remains do not travel a great distance from parent vegetation, analysis of sediment from very large lakes may not be ideal for such purposes (Heggen et al., 2012; Birks, 2001). When used in conjunction with pollen analysis, macrofossil analysis is generally carried out on retained material from the pollen preparation process and as such, is usually of a smaller sample size than would be encouraged for studies principally employing macrofossil analysis (Heggen et al., 2012). Studies have demonstrated that macrofossil analysis is a worthwhile addition to palaeoecological investigations (e.g. Carrión and Navarro, 2002) and can be used to refine environmental interpretations (Birks and Birks, 2000).

4.2.3 Chironomid Analysis

Chironomids are non-biting midge flies belonging to the Diptera order of insects. Due to the high abundance of remains preserved in lake sediments, especially when compared to other insects, they have become a focus of palaeoecological study (Eggermont and Heiri, 2012). Chironomids are holometabolous insects and thus develop through a series of four life stages (Figure 4.9); egg, larva, pupa and adult. The larval stage is of most importance as it is the development of the larvae through four successive instars that produces the remains which ultimately survive in lake sediment (Walker, 2001). As the larvae progresses from one instar to the next a process called ecdysis is undergone in which the head capsule is shed. It is the sclerotized head capsule of the larval instars, in addition to the chitinous cuticle surrounding the thorax and abdomen, that are preserved *in situ* due to the robust nature of the material (Walker, 2001; Brodersen and Quinlan, 2006). Although head capsules are shed during each stage, those of the third and fourth larval instar are most frequent, with the resorption and differential preservation of earlier instar material causing a bias in the sedimentary record (Walker, 2001).

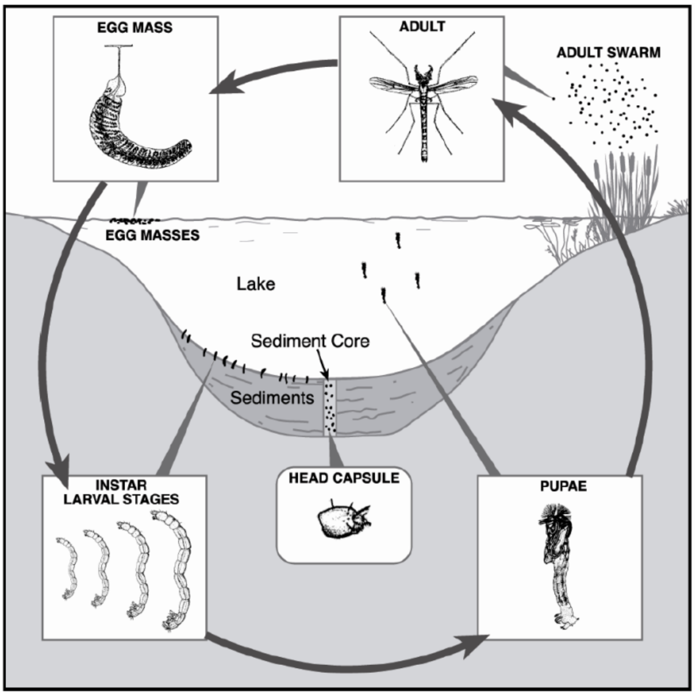

Figure 4.9: A representation of the chironomid life cycle and preservation within the lake sediment. During the development of the larval stages the process of ecdysis occurs where the head capsule is shed. This is what is preserved in the lake sediment and used in chironomid sub-fossil analysis (Porinchu and MacDonald, 2003).

Principle of Chironomid Analysis

Chironomid analysis is based on the principle that the preserved head capsules, although usually fragmented, are taxon diagnostic (Quinlan and Smol, 2001b; Langdon et al., 2004; Heiri and Lotter, 2003). Identification is based primarily on the morphology of the mentum which allows for the classification of even poorly preserved remains while other structures such as the mouthparts and ventromental plates aid identification (Figure 4.10) (Walker, 2001). Research has been undertaken on the various methods of counting preserved head capsules; total numbers, fourth instar only, second instar only or most numerous instar (Carter, 2001). While it was concluded that counting the most numerous instar within the sediment avoids issues of over-estimation, instar differentiation is rarely undertaken and so the greatest amount of information is gained by counting the total number of head capsules present with a sediment sample (Carter, 2001).

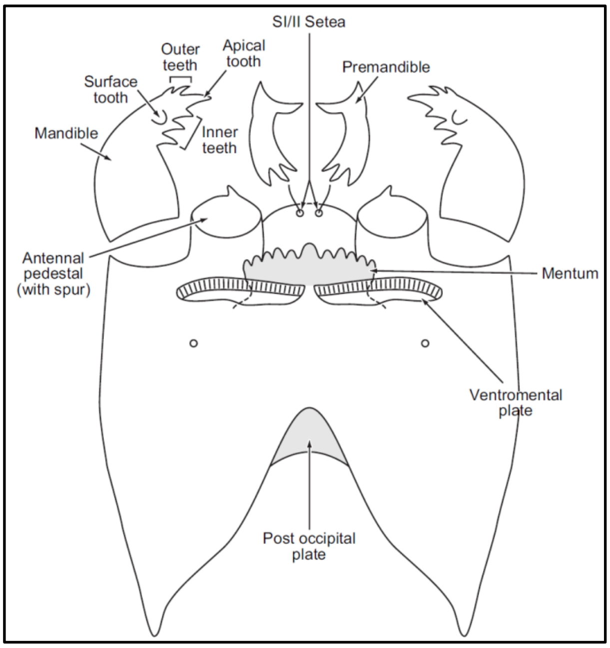

Figure 4.10: A generic chironomid head capsule showing the main parts used for identification which include the mentum, mandible, pre-mandible and occipital plate (Ruiz et al., 2006).

The subsequent interpretation of chironomid data relies on the premise that the majority of taxa are stenotopic and thus can only survive in a restricted range of environmental conditions; the fossil remains being representative of the conditions at the time of sediment deposition (Brodersen and Quinlan, 2006). Furthermore, the short life cycle of most chironomid taxa means that changes in chironomid communities initiated by environmental change is rapid and can occur at a faster rate than changes in terrestrial vegetation (Brooks et al., 1997; Francis and Foster, 2001). The ubiquitous nature of chironomid larvae in lake systems ensures a high abundance of head capsules within most lake sediments and consequently analysis can be undertaken on small samples at a high temporal resolution (Brodersen and Quinlan, 2006; Brooks et al., 1997). Walker (2001) suggests that as little as 1cm^3 of sediment will produce the required number of head capsules from a small, shallow lake, and in general 0.5 – 2cm^3 is sufficient (see also Brooks et al., 1997). There is general agreement amongst the research community that in order to infer changes in environmental conditions to a high degree of reliability from chironomid data, a minimum of fifty head capsules must be identified within each sample (Walker, 2001; Quinlan and Smol, 2001b). This relatively low number of fossil remains, when compared to other biological indicators e.g. pollen, is advantageous, keeping costs and laboratory time at an achievable level for research (Quinlan and Smol, 2001b).

The Application of Chironomid Analysis

Traditionally used for climatic research a number of studies have used this proxy to produce high-resolution chironomid-inferred temperature reconstructions (Langdon et al., 2004; Brooks et al., 1997; Bigler et al., 2002). A number of environmental variables can affect the composition of chironomid communities either directly or indirectly including summer temperature, lake water pH, depth, nutrient status, benthic substrate and dissolved oxygen (Eggermont and Heiri, 2012). As such, chironomid analysis is also successfully used to assess past conditions within lake systems such as salinity (Heinrichs and Walker, 2006), productivity (Brodersen and Quinlan, 2006; McKeown and Potito, 2016; Chique et al., 2018), oxygen conditions (Quinlan and Smol, 2001a) and nutrient status (Langdon et al., 2006; Meriläinen et al., 2000; Foy et al., 2003) with transfer functions developed through the combination of chironomid surface samples with contemporary environmental variables (Langdon et al., 2004, p. 198; Brodersen and Quinlan, 2006, p. 1999; Potito et al., 2014). Of particular interest is the recent focus on the impact of changing land-use associated with human activity that has developed within chironomid studies (Francis and Foster, 2001; Heiri and Lotter, 2003) and the new application of the technique within archaeological investigations (O'Brien et al., 2005; Ruiz et al., 2006; Taylor et al., 2013; Taylor et al., 2017b; Taylor et al., 2017a).

Human Impact and Chironomid Analysis

Known to respond to changes in lake productivity, a number of studies have focussed on the effects of lake eutrophication on chironomid taxa. Eutrophication is caused by the direct or indirect anthropogenic input of excess nutrients into a lake system (Brodersen and Quinlan, 2006). At Sägistalsee Lake, Switzerland, periods of increased anoxia were identified by chironomid data, in which the normally dominant taxa were absent from the sediment record (Heiri and Lotter, 2003). The anoxia was deemed to be the result of grazing activity and the subsequent in-wash of livestock manure (Heiri and Lotter, 2003). As such Heiri and Lotter (2003) concluded that it was human impact rather than climatic factors that were primarily influencing the composition of the chironomid communities at this site. Heiri and Lotter (2003) proposed that the scale of such activity could not be determined via this technique as minor disturbances resulted in the same change as major human activity at this site, but this has since been refuted by Taylor et al. (2013). Brodersen and Quinlan (2006) noted that with increased productivity in the Bay of Quinte, Ontario, there was a change from oligotrophic to eutrophic chironomid taxa. Similary, at Lake Lappajärvi, western Finland, increasingly eutrophic conditions occurred from AD 1936 which resulted in the establishment of a strong *Chironomus* community (Meriläinen et al., 2000).

Hypolimnetic oxygen levels are related to trophic status which has, in the past, been regarded simply as high oxygen levels in oligotrophic lakes and low oxygen levels in eutrophic lakes (Brodersen and Quinlan, 2006). Brodersen and Quinlan (2006), however, note that such a linear relationship cannot be assumed and chironomid-based interpretations should be strengthened with the use of further proxies. Temperature and trophic status also appear to be linked, with taxa such as *Chironomus* and *Procladius* indicating both high productivity and warm conditions while *Heterotrissocladius* and *Micropsectra* indicate both low productivity and cold temperatures (Brodersen and Quinlan, 2006). Langdon et al. (2006) aimed to improve understanding of the eutrophication process by examining the timing and nature of change in chironomid communities from thirteen lakes in England and southern Scotland. The assemblages revealed that *Chironomus plumosus*-type was abundant in lakes with high nutrient enrichment while *Microtendipes* and *Ablabesmyia* were more dominant in lakes with lower nutrient enrichment (Langdon et al., 2006). Chironomid response, however, was shown to be an indirect and complex process (Langdon et al., 2006).

Research has led to the recognition of the favourable conditions of various chironomid taxa. Potito et al. (2014) identified chironomid taxa relating to temperature and agricultural land cover. Similarly, relationships between chironomid taxa and trophic status were revealed in studies by van Asch et al. (2012) (Fiddaun lough, Co. Galway) and Meriläinen et al. (2000)(Lake Lappajärvi, Finland). Table 4.1 has collated this information.

Table 4.1: The relationship between chironomid taxa and various environmental conditions identified by Potito et al., (2014), van Asch et al., (2012) and Meriläinen et al., (2000).

Favourable Conditions	Chironomid taxa
Cold stenotherms	*Heterotrissocladius marcidus*-type *Micropsectra insignilobus*-type *Pseudorthocladius* *Sergentia coracina*-type *Protanypus*
Mid-temperature stenotherms	*Thienemannimyia* *Pseudochironomus*
Warm stenotherms	*Cladopelma* *Parachironomus varus*-type *Tanytarsus mendax*-type *Cladotanytarsus mancus*-type
Low levels of agriculture	*Heterotanytarsus* (associated with bog land)
High levels of agriculture	*Chironomus anthracinus*-type *Cricotopus intersectus*-type *Endochironomus albipennis*-type *Microtendipes pedellus*-type
Oligotrophic	*Micropsectra* *Paracladopelma nigritula gr.* *Heterotrissocladius subpilosus*-type *Pseudodiamesa* *Parakiefferiella nigra*-type *Paracladius* *Stictochironomus rosenschoeldi*-type
Mesotrophic	*Sergentia coracina-type coracina*
Mesotrophic – eutrophic	*Tanytarsus glabrescens*-type *Ablabesmyia* *Thienemannimyia*-type *Dicrotendipes nervosus*-type *Cricotopus cylindraceus*-type
Eutrophic	*Chironomus anthracinus*-type *Chironomus plumosus*-type

Human – Environment Interactions and Chironomid Analysis in an Irish Context

Chironomid-inferred temperature reconstructions have been carried out in Ireland (Watson et al., 2010; van Asch et al., 2012; Taylor et al., 2018). Within an Irish context there has been recent recognition, however, that because the Irish landscape has been affected by agricultural land-use since the Neolithic, the majority of lakes will not provide a robust climate signal via chironomid analysis (Taylor et al., 2013; Chique et al., 2018). Potito et al. (2014) examined the dominant influences of modern chironomid sub-fossils using surface samples from fifty lakes in western Ireland and found that from the thirty-six environmental variables considered, July temperature and percentage agriculture in the catchment, accounted for the highest variance in the data. The results encouraged caution when reconstructing temperature in lakes which have a history of agricultural land-use in their catchment (Potito et al., 2014). It has since been demonstrated that if a substantial level of agricultural activity has occurred within a lake catchment, that percentage agriculture will become the dominant control on the chironomid community composition and will overwhelm the climate signal (McKeown and Potito, 2016). This has led to an increase in studies on Irish lakes that are primarily investigating human-environment interactions within an archaeological context. The integration of pollen analysis to such studies is essential in order to contextualise changes in chironomid community composition with land-use change. The addition of further limnological techniques such as geochemistry allows for a thorough investigation of the impacts of human activity upon lake systems throughout prehistory (Taylor et al., 2017b).

A multi-proxy investigation which utilised chironomid analysis was undertaken at Ballywillin Crannog at Lough Kinale, Co. Longford where a sediment core was extracted from the outer palisade of the crannog site (O'Brien et al., 2005). Taxa associated with woody debris were identified between the 9th – 11th centuries AD which were likely associated with intensified use of the wooden crannog structures themselves (O'Brien et al., 2005; Ruiz et al., 2006). Later, the chironomid assemblage suggested an increase in macrophyte vegetation and a shallower, more eutrophic system that indicated a reduction in the use of the crannog (O'Brien et al., 2005). In 2006 the data from Ballywillin Crannog was combined with chironomid data from a further two archaeological deposits in a systematic assessment of the potential of the technique for use in archaeology. Samples were taken from the base of a palaeochannel adjacent to West Cotton multi-period site in the East Midlands, UK which had evidence of human activity during the Neolithic, Bronze Age and Medieval periods.

While Ruiz et al. (2006) noted that it was hard to decipher anthropogenic effects from the natural development of the palaeochannel, an increase in eutrophication and reduction in water quality suggested by the chironomid assemblage towards the top of the profile, may have been caused by the nearby human activity, evidenced through the prehistoric enclosures and funerary activity, and especially the Saxon period settlement. The final archaeological context examined was the fill of a Roman well within a Romano-British farmstead in Wollastan, Northamptonshire. The dominance of *Chironomus plumosus*-type is indicative of the deposition of organic waste into the well, including sewage (Ruiz et al., 2006). The presence of semi-terrestrial taxa towards the top of the profile may represent the abandonment of the well when the environment became drier (Ruiz et al., 2006). The case studies presented by Ruiz et al. (2006) certainly make a case for the use of chironomid analysis in archaeology, especially within multi-proxy investigations, with the technique able to corroborate or question interpretations produced from additional proxies.

Ruiz et al. (2006) expressed the need for further research on modern chironomid communities and studies by Potito et al. (2014) and Free et al. (2006) have certainly added to the understanding of natural conditions associated with chironomid communities which will allow anthropogenic effects to be deciphered. Chironomid analysis has the potential to elucidate questions on human-environment interactions especially when lakes close to areas of archaeological interest are investigated (Ruiz et al., 2006). A number of archaeologically significant activities could be identified such as settlement, agriculture, intensive animal management, crop processing, tanning and metalworking which would be indicated by chironomid taxa suggestive of certain environmental conditions (Ruiz et al., 2006). Although changes in land-use can be determined through pollen analysis, problems due to the differential production and preservation of pollen grains makes an additional *in-situ* palaeoindicator particularly valuable (Taylor et al., 2013). In favourable conditions (i.e. a closed system with a single settlement phase and high precision dating) it may even be possible to estimate human and animal populations by quantifying eutrophication (Ruiz et al., 2006).

Taylor et al. (2012) carried out a multi-proxy investigation of prehistoric farming at Lough Dargan, Co. Sligo using chironomid analysis as the principal technique in addition to sediment geochemistry and existing pollen data. The chironomid community were shown to respond to lake eutrophication that first occurred during the Neolithic *Landnam* and more significantly so in the Late Bronze Age, likely as a result of pastoral farming activity

(Taylor et al., 2013). A reversion to taxa indicative of mesotrophic conditions occurred during the Middle Neolithic when pollen data indicated a reduction in farming, but a second phase of reduced activity in the Middle Bronze Age was not reflected in the chironomid data (Taylor et al., 2013). This indicates that the intensive nature of agricultural activities had led to the permanent alteration of lake conditions and demonstrates the ability of chironomid analysis to elucidate the intensity of past farming activity (Taylor et al., 2013). Taylor et al. (2013) concluded that chironomid analysis is a useful and highly effective method for detecting the presence and scale of prehistoric farming within a lake catchment and when combined with additional proxy data can give a comprehensive view of an archaeological landscape.

A further two publications have since examined the impact of prehistoric farming on chironomid communities at Templevanny Lough and Cooney Lough, Co. Sligo, and in both cases the chironomid taxa were shown to respond to periods of increased agricultural activity inferred from pollen and geochemical data (Taylor et al., 2017b; 2017a). It was demonstrated that land-use within the catchments was the dominant factor influencing the chironomid community composition and statistically NAPp had a strong relationship with the chironomid data (Taylor et al., 2017b; 2017a). This is the result of nitrogen and phosphorous-rich soils, nourished by manure, washing into the lake system causing the dissolution of phosphorous into the lake and stimulating the growth of aquatic plants (Taylor et al., 2017b). The chironomids then respond indirectly to changes in the availability of food and reduced benthic oxygen conditions (Taylor et al., 2017b; 2017a). Taylor et al. (2017b) proposed that this nutrient in-wash was caused by cattle farming in the catchment of the lakes. The taxa exhibiting a strong response to farming activity in the three lakes have all been associated with either agricultural catchments or eutrophic conditions in previous studies (Potito et al., 2014; Taylor et al., 2017a). It is clear that prehistoric farming was a significant control on chironomid communities with this recent study further corroborating earlier assessments that human impact can be discerned from, and indeed overwhelm climate signals, in chironomid stratigraphies (Taylor et al., 2017a; McKeown and Potito, 2016). These recent contributions to the application of chironomid analysis to human – environment interactions have demonstrated the usefulness of the technique, which can examine both the intensity and location of prehistoric land-use (Taylor et al., 2017a).

4.2.4 Lake Sediment Organic Geochemistry

Organic geochemistry of lake sediments can be used to provide both palaeoclimatic and palaeoenvironmental information. Although they can be used as a primary indicator in their own right, geochemical data is often employed in multi-proxy studies in conjunction with other proxies such as pollen, diatom or chironomid analysis (Ito, 2001; Woodward et al., 2012). Of most significance to the current study are the elemental concentrations of nitrogen and carbon which can provide information on the productivity and nutrient status of lake systems (Talbot, 2001; Ito, 2001). Specifically, they can be used to assess the sources of lake sediment material including organic matter, nutrient cycling and temperature change (Woodward et al., 2012; Gu et al., 1996). Changing environmental conditions in the landscape that surrounds a lake during sediment accumulation will produce different geochemical signatures through time (Routh et al., 2004). For example, agricultural landscapes in particular will produce a characteristic signal that can be detected through such analysis, with increased nutrient loading of lake systems (Vander Zanden et al., 2005).

Principle of $\delta^{13}C$ and $\delta^{15}N$ Analysis

The organic components present within lake sediment can be both autochthonous (from within the lake) and allochthonous (within its catchment area) and derive for the most part from the detritus of plants (Woodward et al., 2012; Meyers and Lallier-Vergès, 1999). Therefore, the values of carbon and nitrogen isotopes are determined both by the sources of sediment accumulating within the lake, and the carbon and nitrogen cycles both within the lake and its catchment area (Woodward et al., 2012). It is important to understand the links between vegetation within a lake catchment and the $\delta^{13}C$ and $\delta^{15}N$ measurements derived from the sediment, which can be aided through studies on fractionation, carbon and nitrogen pathways and their sources (Woodward et al., 2012). If the vegetation cover of a lake catchment changes, so too will the amount of organic matter reaching the lake sediment, and the isotopic measurement there-of (Meyers and Lallier-Vergès, 1999).

The ratios of $\delta^{13}C$ and $\delta^{15}N$ can provide information on nutrient loading of lakes which can be caused by agricultural practices (Woodward et al., 2012). The analysis of $\delta^{13}C$ of lake sediment can provide information on lake productivity and the levels of dissolved organic carbon in the past (Woodward et al., 2012). A number of factors determine the values such as particulate organic carbon and dissolved organic carbon, (due to algae within the lake), and the $\delta^{13}C$ signature of organic carbon from outside of the lake system which makes its use as a proxy complicated (Woodward et al., 2012). This technique has, however, been successfully applied to a sediment core from Lough Inchiquin to interpret terrestrial landscape change and its influence on $\delta^{13}C_{calcite}$ and $\delta^{13}C_{organic}$ lake sediment values (Diefendorf et al., 2008).

Nitrogen is an essential nutrient and the determining factor in the organic productivity of lake systems (Talbot, 2001). A number of factors determine the availability of nitrogen isotopes within a lake including limnological and sedimentological conditions in addition to climate and the catchment area (Talbot, 2001). Changes in the sources of nitrogen input to a lake can alter the composition and accumulation of organic matter (Talbot, 2001). Nitrogen is contained within lacustrine organic matter including within aquatic and terrestrial plants, algae and soil humus and it is the $\delta^{15}N$ signal within this material from within and outside the lake that determines the $\delta^{15}N$ in the sediment (Talbot, 2001; Woodward et al., 2012). Nitrogen cycling within lakes includes processes such as dissolution, fixation, assimilation, remineralisation and nitrification (Talbot, 2001). Botrel et al. (2014) note that the $\delta^{15}N$ signal is complex and a number of factors will contribute.

Identifying Anthropogenically-Induced Eutrophication

The process of lake eutrophication can be identified through nitrogen analysis with numerous studies able to demonstrate that nutrient loading was due to modern land-use practices (Talbot, 2001; Botrel et al., 2014). For example, severe eutrophication was identified at Lough Neagh, Northern Ireland, which resulted in strongly increased $\delta^{15}N$ and decreased $\delta^{13}C$ (Bunting et al., 2007). Similarly, eutrophication of Lake Okeechobee in the south-eastern United States occurred post AD 1950 evidenced through a decrease in the C:N ratio and an increase in $\delta^{15}N$ values amongst other factors (Engstrom et al., 2006). Multi-proxy analysis of a sediment record from Lake Igaliku in southern Greenland showed an isotopic response to modern sheep farming and while the response to historical Norse farming was limited, likely due to lower intensity farming, slightly higher $\delta^{15}N$ values and lower $\delta^{13}C$ values were observed (Perren et al., 2012). It is in this way that modern studies can be used as analogues for investigations into the nutrient loading of lake systems due to ancient agriculture and to gain an understanding of past nitrogen cycling (Talbot, 2001).

Research in Canada, which analysed the surface sediments of sixty-five lakes, demonstrated a strong relationship between human-derived nitrogen load and the $\delta^{15}N$

signature of the lake sediment (Botrel et al., 2014). For the current study it is the input of anthropogenic nitrogen that is particularly relevant, with $\delta^{15}N$ signals derived from human and animal waste generally ranging between +10 and +20‰ due to a high degree of fractionation (Botrel et al., 2014; Vander Zanden et al., 2005). Similarly, the $\delta^{15}N$ signal of agricultural soil nitrate (including the addition of manure to soil) is known to vary between +15 to +30‰ (Botrel et al., 2014). The signal of anthropogenic nitrogen is distinct from that of atmospheric nitrogen which would range from -15 to +15‰, although it should be noted that in both cases the original signature may be altered by within-lake processes (Botrel et al., 2014). High livestock densities in pastoral farming economies can produce large amounts of manure that can lead to a surplus of nitrogen and phosphorous within the soil which subsequently leaches into downstream lakes and ecosystems (Bunting et al., 2007).

The Application of Organic Geochemistry in an Irish Context

Woodward et al., 2012 used statistical analysis to determine which environmental variables account for variations in $\delta^{13}C$ and $\delta^{15}N$ in the surface sediments of fifty lakes in western Ireland – the same lakes as used by Potito et al. (2014). The lakes chosen for the study spanned a human-impact gradient associated with changing land-cover and thus allowed the influence of anthropogenic activity and its intensification to be determined (Woodward et al., 2012). The large sample size allowed for an assessment of the effects of different landscape types and human activities on the carbon and nitrogen cycles (Woodward et al., 2012). Thirty-six environmental variables including the physical and chemical characteristics of the lake, catchment land-cover and cattle population were examined while a digital elevation model was used to delineate catchment areas (Woodward et al., 2012). The study determined that lakes within agricultural catchments had more negative $\delta^{13}C$ values compared with non-impacted catchments, caused by hypolimnetic oxygen concentrations and methane production (Woodward et al., 2012). Using the data from Woodward et al. (2012) the mean value for $\delta^{13}C$ in catchments affected by >80% agricultural land-cover is -29.7‰ compared to -27.7‰ for catchments with <75% agricultural cover. Conversely, the values of $\delta^{15}N$ in lakes surrounded by agricultural catchments is more positive than those in non-impacted catchments due to the effect of cattle manure from pastoral farming (Woodward et al., 2012). The mean $\delta^{15}N$ value for lake catchments affected by >80% agricultural cover has been calculated at 5.1‰ in contrast to a mean value of 2.8‰ for catchments with <75% agricultural cover (Woodward et al., 2012).

Significant variables affecting the $\delta^{15}N$ values included concentrations of phosphorous and nitrogen, total organic carbon and lake water conductivity (Woodward et al., 2012). Furthermore, the input from livestock manure is known to affect the $\delta^{15}N$ values of material entering the lake (Woodward et al., 2012). Decreases were also observed in the C:N ratios of productive lakes with the mean value calculated at 12.8 in lake catchments affected by >80% agricultural land-use in contrast to a mean of 16.5 for catchments with <75% agricultural cover (Woodward et al., 2012). A similar study on twenty-seven Danish lakes examined fourteen variables including livestock density and the nature of land-cover demonstrating that the number and density of animals in the lake catchment was an important driver of biotic $\delta^{15}N$ enrichment via manure (Vander Zanden et al., 2005). In this case the agricultural $\delta^{15}N$ signal was 13‰ (Vander Zanden et al., 2005). The statistical relationship observed between agricultural catchments and the values of $\delta^{13}C$ and $\delta^{15}N$ have been identified in a number of studies looking at the impact of prehistoric farming on lakes systems (Taylor et al., 2013; 2017b; 2017a).

The multi-proxy study of prehistoric farming at Lough Dargan, Co. Sligo, previously discussed in relation to chironomid analysis, also used lake sediment geochemistry. The Early Neolithic, characterised by early farming activity, led to a peak in $\delta^{15}N$ of 3.6‰ with decreased $\delta^{13}C$ values and C:N ratio (Taylor et al., 2013). When farming then declined $\delta^{15}N$ values increased, attributed to the effect of soil erosion, and $\delta^{13}C$ and C:N increased (Taylor et al., 2013). A period of intensive farming was identified during the Bronze Age which saw a contemporaneous increase in $\delta^{15}N$ (Taylor et al., 2013). $\delta^{13}C$ values, however, appear to become less negative during periods of pollen-inferred pastoral activity (Taylor et al., 2013) in contrast to the more negative values that had previously been associated with human-impacted catchments (Woodward et al., 2012). This has been attributed to an increased input of terrestrial material into the lake (Taylor et al., 2013) and $\delta^{13}C$ has been shown to be less dependable as an indicator than $\delta^{15}N$ (Taylor et al., 2017b). In this study the geochemical data responded more strongly to pastoral farming rather than arable cultivation likely due the scale of such activity or the proximity to the lakeside (Taylor et al., 2013).

Similarly, geochemical analysis of lake sediment from Templevanny Lough, Co. Sligo demonstrated increased $\delta^{15}N$ levels concurrent with the first major phase of Neolithic farming while $\delta^{13}C$ values decreased (Taylor et al., 2017b). The geochemical data, on the whole, correlated with the dynamics of farming activity throughout prehistory but with

$\delta^{15}N$ values proposed to be the most reliable for use in prehistoric agricultural studies in Ireland (Taylor et al., 2017b). The correlation between agricultural intensity and $\delta^{15}N$ values was well demonstrated in Taylor et al. (2017a) in the data from Cooney Lough, Co. Sligo. With little to no human activity in the Mesolithic – Early Neolithic the levels of $\delta^{15}N$ were particularly low, increasing with the onset of agriculture from c. 3700 BC and decreasing during a period of reduced farming in the Middle Neolithic (Taylor et al., 2017a). As farming once again increased in later prehistory, so too did the $\delta^{15}N$ values (Taylor et al., 2017a). From an assessment of the previous research on the impact of agricultural practices on the geochemical signature of lake sediments, it seems evident that $\delta^{15}N$ values are the most reliable indicator, with values consistently increasing during times of known agricultural practice – responding particularly to the pastoral component of the economy.

4.2.5 Lake Sediment Inorganic Geochemistry

Inorganic geochemistry is used within palaeolimnology to understand the chemical properties of lake sediment and in doing so understand processes occurring within the catchment of a lake system (Boyle, 2001). Similarly to the organic geochemical signal discussed above, the inorganic signal is determined by autochthonous and allochthonous components, with the latter consisting of mineral particles derived from catchment soils (Engstrom and Wright Jr, 1984). One of the first applications of lake sediment inorganic geochemistry was undertaken by Mackereth (1966) which established the initial palaeolimnological principles for fresh water lake systems regarding inorganic geochemistry. More recently, a major focus has been that of atmospheric pollution with regard to anthropogenic trace element contamination of lake sediments (Boyle, 2001) although this lies outside the scope of this overview.

When used in multi-proxy investigations of lake systems, the addition of inorganic chemical data can aid the understanding of environmental change and potentially human impact (Boyle, 2001). The application of inorganic geochemistry can be used to assess trophic status, lake redox conditions and human impact on the lake system (Boyle, 2001). Of particular relevance is the identification of long term catchment evolution, such as weathering and erosion, that can be identified via this technique (Boyle, 2001). Although investigations into inorganic geochemistry generally analyse the entire component of lake sediment (Boyle, 2001) this section will give an overview of four elements, titanium (Ti), iron (Fe), manganese (Mn) and sulphur (S), which are of particular relevance to the current study.

Principle of Inorganic Geochemistry

Stratigraphic changes in lake sediment elemental composition have been proposed to be determined by the sequence of soils accumulating from the catchment (Mackereth, 1966). This is especially true under oligotrophic systems whereas the influence of within-lake processes can be stronger under more productive conditions, such as bacterial activity, redox variations and within-lake carbon production (Engstrom and Wright Jr, 1984; Boyle, 2001). One of the principles defined by Mackereth (1966) was that high concentrations of minerogenic elements within lake sediments were related to erosional processes. Although elemental signals can be altered by redox conditions, in general increased concentrations of elements are thought to be due to an influx of enriched catchment soil (Mackereth, 1966; Engstrom and Wright Jr, 1984). Variations in elemental concentrations can also be used to determine terrigenous sediment sources (Boyle, 2001).

Iron, Manganese and Sulphur

While peaks in most elements correspond to erosion events, both processes within the catchment and within the lake system can influence the concentrations of iron, manganese and sulphur. The initial mobilisation of iron and manganese is affected by humic materials within catchment soils, soil redox and soil water retention (Engstrom and Wright Jr, 1984). The subsequent levels of iron and manganese within lake sediment are heavily affected by a number of independent environmental processes such as lake redox conditions, pH, ionic composition of the water and within-lake diagenesis (Mackereth, 1966; Engstrom and Wright Jr, 1984). The redox potential within catchment soils and within the lake itself can cause changes in the concentrations of iron and manganese ultimately preserved in lake sediment (Mackereth, 1966; O'Connell et al., 2014). Due to this it has been proposed that concentrations of such elements in lake sediments could be used to indicate the palaeo-redox conditions of soils in lake catchments (Mackereth, 1966; Engstrom and Wright Jr, 1984). Mackereth (1966) proposed that Fe/Mn ratios could aid the interpretation of changes in these elements and this is sometimes applied in palaeolimnological studies.

Once within the lake system, oxidation and reduction of the coupled pairs of iron and manganese oxides can result in either its precipitation into lake sediment or re(dissolution) into the lake water which results in the almost continuous cycling of these elements (Naeher et al., 2013). The reducing conditions needed for this to occur are the result of oxygen consumption during the remineralisation of organic matter (Naeher et al., 2013). Through subsequent mixing of the water column, iron and manganese are then re-oxidised, and as the oxidised forms of these trace metals are of very low solubility, they can precipitate and become preserved within the lake sediment (Naeher et al., 2013; Schaller and Wehrli, 1997; Granina et al., 2004; Engstrom and Wright Jr, 1984). As such, peaks in iron and manganese can indicate reducing conditions within the lake and highlight periods of anoxia, which was demonstrated by Schaller et al. (1997) with high concentrations of both elements during the transition from oxic to anoxic conditions. Despite this, these elements have been used as indicators of erosion in palaeolimnological studies, e.g. O'Connell et al. (2014) and Boyle et al. (2004). Iron is less readily mobilised via redox changes than manganese and has been proposed to be an indicator of terrigenous input if used in conjunction with other elements such as titanium (e.g. Naeher et al., 2012).

This elemental cycling that complicates the interpretation of lake sediment concentrations also applies to sulphur involving both reductive and oxidative processes (Holmer and Storkholm, 2001). Diagenetic processes within the lake can affect its preservation within a sediment (Cohen, 2003). The reduction of sulphate in lakes, which can lead to its deposition and preservation within the sediment, is controlled in part by the concentration of sulphate present (Holmer and Storkholm, 2001). This is generally low but erosion within a lake catchment may cause additional sulphates to enter a lake system increasing the concentration, and likelihood of reduction (Luther et al., 2003). The preservation of sulphur within lake sediment occurs under anoxic conditions when sulphate is reduced to hydrogen sulphate and subsequently binds with iron to form iron pyrite (FeS_2) that is deposited (Holmer and Storkholm, 2001).

The use of Titanium as an Erosion Indicator

In contrast to the complicated post-depositional contexts of the above three elements, titanium is derived from clastic material, largely unaffected by such processes and is strictly of terrigenous origin, allowing it to be a reliable indicator of erosion into lake systems (Arnaud et al., 2012). As Mackereth (1966) originally proposed for all minerogenic elements, an increased concentration of titanium is proposed to be due to the erosion of catchment soils (O'Connell et al., 2014; Doyen et al., 2016). The quantification of elements such as titanium can allow the weathering regime of lake catchments to be investigated including the timing and extent of change (Koinig et al., 2003). For example, Boyle et al. (2004) used peaks in titanium in lake sediment geochemical data to suggest the regional influx of clastic material from the catchments of a number of lakes on Svalbard. Similarly, an increase in titanium associated with the weathering of silicates (from the silt and clay fraction of catchment soils) was identified by Koinig et al. (2003) in the sediment of a Swiss alpine lake. The increase in trace metals, including titanium, was proposed to be due to erosion corresponding with deforestation (Koinig et al., 2003). Its use as an erosional indicator is widespread ranging from its use a proxy for the physical weathering of catchment soils at Lake Bourget, France to an assessment of topsoil erosion pre and post-European settlement in western Canada (Arnaud et al., 2012; de Boer, 1997).

It has been applied in an Irish context in the geochemical analysis of lake sediments from Cooney Lough, Co. Sligo (O'Connell et al., 2014). Here, geochemical analysis was used to elucidate changes in soil erosion that may be related to prehistoric farming within the lake catchment (O'Connell et al., 2014). O'Connell et al. (2014) demonstrated that increased titanium (in combination with other trace elements) occurred during periods of increased farming activity, for example, during the Early Neolithic *Landnam*, proposing that clearance and agricultural activities at this time had caused erosion to occur within the catchment (O'Connell et al., 2014). This highlighted the causal relationship between farming and erosion, and the concentration of titanium in lake sediment. As farming intensity increased during the Early Bronze Age, however, a reduction in erosional indicators occurred, with the relationship between pollen and inorganic geochemical data weaker in this section of the sediment profile (O'Connell et al., 2014). Overall, the widespread application of titanium in such studies suggests it is a robust indicator of erosional processes when high concentrations are identified within lake sediment.

Chapter 5 – Palaeoenvironmental Methodology

This section provides a broader account of the methods specific to this study than will be presented in the evidence chapters (6, 7 and 8). This provides a general context for the methods presented in those chapters as well as more specific detail of laboratory methods.

5.1 Core extraction at Lough Inchiquin

Fieldwork at Lough Inchiquin was carried out in June 2015. A Usinger piston corer was used to extract a 10.6m long sediment core (LIQ1) from the deepest part of Lough Inchiquin at GPS co-ordinates N52°57'20"N W9°5'16". A total of six drives were completed (Table 5.1). The equipment consists of a rod-operated high-precision piston coring system that enables the recovery of high integrity sediment cores from lakes up to 40m water depth (Mingram et al., 2007). The system is particularly suited to coring water-saturated sediments. A detailed description of the full components of the coring system is provided by O'Connell et al. (2004). An aluminium raft platform with a working area of 4.3 x 3m was assembled at the southern lake edge (Figure 5.1A). Four large, inflatable tubes were then securely attached to the underneath of the platform which allows it to float (Figure 5.1B). Traverses of the lake were done in a small boat with depth sounding equipment allowing the deepest part of the lake to be located. The raft was subsequently launched from the jetty, towed into the correct position and anchored in place with the aid of ropes running to the shoreline, and heavy anchor bags (Figure 5.1G). Once secured in place the process of coring began.

The process involved lowering aluminium casing through the central opening to the lake floor which then acts as a guide for the coring tube (Figure 5.1C). With the use of extension rods the coring tube, with piston head attached, was lowered to the lake sediment (Figure 5.1 D and E; Figure 5.2D). A driving rod was attached last of all which restricts the coring drive to 2m. The driving rod was pushed down allowing the coring tube to fill with sediment. With the aid of a lever and rope it was brought back up through the opening and delivered to the lakeside by boat where the sediment was extruded (Figure 5.1F). This involves a ratchet mechanism that deposits the sediment into a plastic half-tube. Sediment sections were subsequently cut into 1m segments and split into an A-half and a B-half.

The top 9.9m consisted of lake sediment and the lower 0.7m was composed of glacial clay. For the final 2m a coring tube with a narrower diameter was used, able to cope with increased frictional resistance at greater coring depths (Bingham, 2011). The sediment core extracted seemed to be of sufficient quality to fulfil the requirements of the investigation with a considerable length of Holocene sediment retrieved. The surface of the split-halves was cleaned and visual description and photography were used to document the stratigraphy of the sediment core. The segments were subsequently stored in the cold room of the Palaeoenvironmental Research Unit (PRU) at NUI Galway prior to further analysis.

Table 5.1 Details of coring drives during retrieval of sediment at Lough Inchiquin.

Drive no.	Coring Depth (m)	Sediment Depth (m)	Comments
1	30 – 32	0 – 2	Very top damaged during extraction
2	32 – 34	2 – 4	
3	34 – 36	4 – 6	
4	36 – 37.5	6 – 7.5	Could not push driving rod down full 2m
5	37.5 – 38.6	7.5 – 8.6	“
6	38.5 – 40.5	8.5 – 10.5	Thinner corer used, reached glacial clay

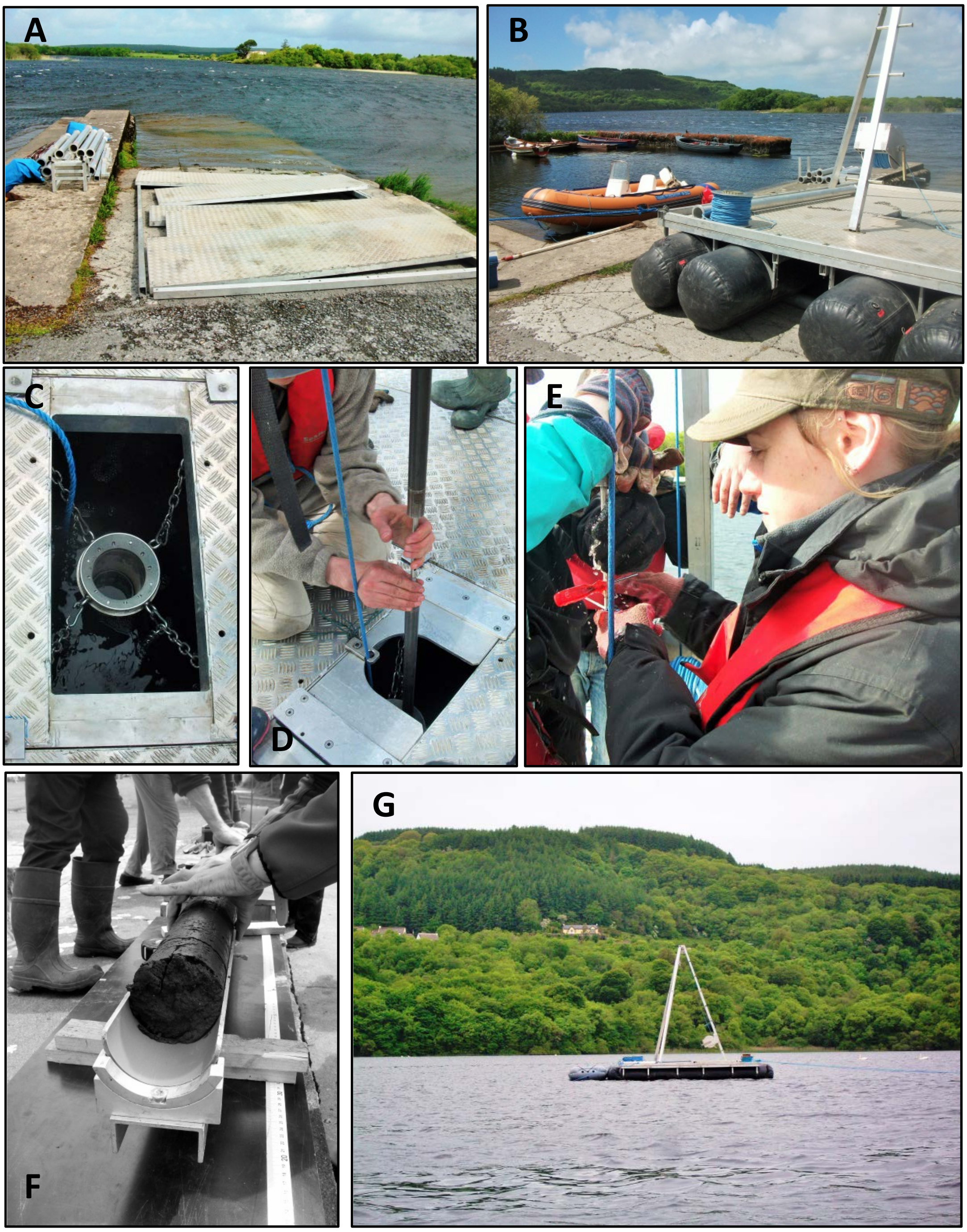

Figure 5.1: Photographs relating to coring fieldwork at Lough Inchiquin. (A) Assembling the coring platform at the lakeside (B) The assembled coring platform at Lough Inchiquin with inflatable tubes attached (C) Image of aluminium casing through central opening of platform (D) and (E) Attaching extension rods to lower the coring tube to the lake sediment (F) Extraction of sediment from tube at lakeside (G) Coring platform in position on Lough Inchiquin. Source: author.

5.2 Core Extraction at Rosroe Lough

Fieldwork at Rosroe Lough was carried out in June 2016. The Usinger piston corer, described above, was used to extract a 6.0m long sediment core (RRL1) from the deepest part of Rosroe Lough (Figure 5.2E). A total of three drives were completed (Table 5.2). The equipment was assembled at the southern edge of the lakeside where the slope of the ground allowed the assembled raft to be pushed easily into the lake (Figure 5.2 A, B, C). A boat was used to traverse the southern basin of the lake with a depth sounder to locate the deepest part. This was located at GPS co-ordinates N52°45’51” W8°49’33” with a water depth of c. 16.6m. The coring procedure followed the same steps as outlined above. The top 4m consisted of organic lake sediment and the lower 2m was composed of glacial clay. A parallel core (RRL2) was taken in this instance at a distance of c. 2m from the first coring location, at a depth of 16.4m (Table 5.2). RRL1 was deemed of sufficient quality for primary use in the analysis.

Table 5.2 Details of coring drives during retrieval of sediment cores RRL1 (above) and RRL2 (below) at Rosroe Lough.

Drive no.	Water Depth (m)	Sediment Depth (m)	Comments
1	17.5 – 19.5	0.5 – 2.5	
2	19.5 – 21.5	2.5 – 4.5	Glacial clay basal 11cm
3	21.5 – 23.5	4.5 – 6.5	All glacial clay

Drive no.	Water Depth (m)	Sediment Depth (m)	Comments
1	17.0	0 – 2	
2	19.0 – 21.0	2 – 4	Glacial clay at base

Figure 5.2: Photographs from coring fieldwork at Rosroe Lough. (A) Assembled coring platform in the shallows of Rosroe Lough (B) Getting equipment ready on board the platform (C) The boat towing the coring platform into position on the lake (D) Attaching extension rods to lower the coring tube to the lake sediment (E) Photograph taken from the lakeside during the coring process (F) Using the rope to retrieve the coring tube. Source: author and (E) Siobhan Comer.

5.3 ^{14}C- AMS Dating and Chronology for Lough Inchiquin and Rosroe Lough Records

In order to obtain material suitable for ^{14}C-AMS dating of the Lough Inchiquin record, ten samples of 2cm-thick slices of material were taken from LIQ1. Initial pollen analysis had been carried out at a sampling interval of 16cm between 788 – 364cm. This enabled a skeleton pollen diagram to be produced which provided an overview of the vegetation changes occurring in the catchment of Lough Inchiquin. Similarly, for the Rosroe record ten samples of 2cm-thick sediment were taken from RRL1 after the production of a skeleton diagram from initial pollen analysis. Certain features within these pollen diagrams such as the Elm Decline and the introduction of ash and yew provided preliminary chronological markers. In all cases, sediment samples were wet-sieved using a 125µm sieve and examined using a Leica MZ12s stereomicroscope. Fine forceps were used to retrieve known terrestrial macrofossils suitable for ^{14}C-AMS dating. Material retained included wood, charcoal, identifiable seed fragments and bud-scales. The processed material was submitted for ^{14}C dating at the ^{14}Chrono Centre, Queen's University Belfast, UK. Subsequent age-depth models for each lake were produced using Bacon v. 2.2 Bayesian age-depth modelling software (Blaauw and Christen, 2011). Bacon uses Bayesian statistics with prior assumptions on the sediment accumulation rates and the variability of such over time (Blaauw and Christen, 2013). Default prior values are based on Goring et al. (2012) and by dividing the core into several thin vertical sections (5cm), estimations of the accumulation rate in years/cm are made, which combined with an estimated starting date, form the age-depth model (Blaauw and Christen, 2013). Dates were inputted to Bacon as ^{14}C BP and produced as calibrated years BP using a default calibration curve of IntCal13 (Reimer et al., 2013). The Inchiquin age-depth model was constrained using an age for the Younger Dryas/Holocene transition of 11.7ka (Walker et al., 2009) as this transition could be easily identified in visual examination of the sediment core (Figure 5.3) and an age for the year of coring (AD 2015).

Figure 5.3: Transition from Younger Dryas to Holocene sediment in the Lough Inchiquin sediment core LIQ1.

See Chapters 6 and 8 for further details on the respective chronologies of Lough Inchiquin and Rosroe Lough.

5.4 Loss-on-Ignition

Loss-on-ignition (LOI) analysis was carried out on samples over the full length of sediment core LIQ1 from Lough Inchiquin at 4cm intervals. Similarly, the technique was carried out on samples of 2cm interval from sediment core RRL1 from Rosroe Lough. In all cases sample size was 2cm^3. The guidelines outlined by Heiri et al. (2001) were followed regarding the method of sequential heating. Crucibles of known weight were used to contain the samples which were then weighed together with the sample and dried for at least twenty four hours at 101^{o}C. Samples were subsequently ashed for four hours at 550^{o}C and two hours at 950^{o}C. Samples were weighed after each stage. The following equations were used to calculate LOI_{550} (%) and LOI_{950} (%) which produces an estimation of the organic matter and inorganic carbon content of the sample, respectively.

$$LOI_{550} = ((DW_{101} – DW_{550}) / DW_{101}) \times 100$$

$$LOI_{950} = ((DW_{550} – DW_{950}) / DW_{101}) \times 100$$

LOI_{550} = loss-on-ignition (%) at 550^{o}C

LOI_{950} = loss-on-ignition (%) at 950^{o}C

DW_{101} = dry weight (g) before combustion

DW_{550} = dry weight (g) after 550^{o}C combustion

DW_{950} = dry weight (g) after 950^{o}C combustion

5.5 Pollen Analysis

Pollen analysis was carried out on a total of ninety samples from the Inchiquin core and seventy eight samples from the Rosroe core. All samples consisted of 1cm^3 of sediment. Preparation of samples for pollen analysis followed Faegri and Iversen (1989). Processing was carried out in batches of eight samples initially and subsequently of sixteen. The standard methods followed at the PRU are outlined below:

1. Exotic spores of *Lycopodium clavatum* (3 tablets) were added to the samples and dissolution of the tablets was aided by 10% HCl (v/v; c. 5ml). The addition of exotic spores facilitates the calculation of pollen concentration (Stockmarr, 1971).
2. In order to remove humic acids the samples underwent deflocculation with 10% KOH (w/v; c. 25ml) and were heated to boiling point on metal plates for 10 minutes. Distilled water was used to ensure samples did not boil over. Samples were sieved using a 100µm mesh and centrifuged (4 minutes at 3200 revs min^{-1}) in a Megafuge 1.0 (Heraeus Instruments) centrifuge. The supernatant was decanted and the procedure repeated to ensure the sample was clear. Remaining material within the sieve was retained for subsequent macrofossil analysis.
3. Samples were treated with 10% HCl (v/v; c. 20ml) to remove the carbonate component and centrifuged (4 minutes at 3200 revs min^{-1}). This step was essential due to the nature of the bedrock (carboniferous limestone) in the catchment area of both lakes under investigation.
4. A HF solution (60% v/v; c. 10ml) was added to the samples and a water bath was used to heat the samples gently for 30 minutes to remove mineral matter. Samples were left to settle in the HF solution overnight. The HF solution was centrifuged (5 minutes at 3200 revs min^{-1}), decanted, washed with distilled water and re-centrifuged. This was carried out twice to ensure the removal of all HF acid from the remaining sample pellet.
5. Samples were washed with glacial acetic acid, stirred and centrifuged (3 minutes at 3200 revs min^{-1}). This was carried out to dehydrate samples as acids used in the next stage can react violently with water.
6. Acetolysis treatment used a 9:1 (v/v) mix of acetic anhydride and sulphuric acid. Samples were heated in a water bath at c. 100^{o}C for 4 minutes. Acetolysis treatment removes cellulose and stains the pollen grains to aid identification.
7. After centrifuging the supernatant was poured off and remaining pellets were sieved (5µm mesh) using distilled water in an ultrasonic bath to remove smaller particulate matter.
8. Glycerol (c. 2 drops) was added to the pellet to aid transfer to labelled sample tubes.
9. A drop of glycerol was placed on a microscope slide to which a drop of sample was added and mixed. A square cover slip was then placed over the sample material and moved gently until the sample spread across the entire cover slip.

Samples were counted using a Leica 4000-B microscope. Routine counting was carried out at x400 magnification along evenly spaced traverses of the slide. Phase-contrast and x630 magnification were used for detailed analysis of pollen grains if required. The PRU pollen reference collection was available for consultation and pollen and spore identification followed Moore et al. (1991) and Beug (2004). Pollen grains were identified to the lowest taxonomic level possible. Cereal-type pollen was identified based on a minimum size criterion of 40µm diameter, and classification of pore, annulus and *punctae* as defined by Beug (1961) to distinguish from wild *Poaceae* grains. Cereal-type were distinguished into three groupings; 40-44µm, 45-49µm and >50µm based on a measurement of the longest axis. A minimum of 1000 total terrestrial pollen (TTP) grains were counted in each sample in addition to micro-charcoal (>37µm) and aquatic taxa such as *Pediastrum* and *Botryococcus.* The large number of pollen grains counted allows for the identification of rare human land-use indicators in a human modified catchment and will be more representative of the sample as a whole.

Data input and manipulation was carried out using CountPol v. 3.3, a JAVA-based program in Windows (Feeser, unpublished). Pollen percentage and concentration data was exported into Microsoft Excel. Pollen diagrams produced in CountPol were exported in a graphic format which could then be imported into CorelDraw v. 12 for further modification, e.g. labelling and zonation. Pollen assemblage zones (PAZs) were established manually through interpretation of the raw pollen percentage data. The manual establishment of pollen zones (in contrast to statistical zonation) is standard practice in pollen analysis as small changes in key (often rare) taxa percentages can reflect important zone boundaries (Moore et al., 1991). The nature of percentage data means that concentration diagrams are also required to ensure that trends seen in percentage diagrams are reflective of the real situation. The pollen taxa were grouped into ecological categories and colour coded. The main pollen categories comprise arboreal pollen (AP) and non-arboreal pollen (NAP) with the latter divided into shrubs, ferns, pastoral indicators (NAPp), arable indicators, bog and aquatic. The main NAPp taxa include *Poaceae*, *Plantago lanceolata*, *Liguliflorae* (mostly *Taraxacum officinale*), *Tubuliflorae* (mostly *Bellis perennis*), *Ranunculus*-type*, Filipendula*, Rumex (*acetosa* and *acetosella*), *Trifolium*-type and *Cerastium*-type. Arable indicators include cereal-type, *Chenopodiaceae* (mostly *Chenopodium album*) and *Artemisia*.

The calculation of pollen percentage and concentration was automatically produced within CountPol but the formulae are given below. Pollen percentage values were based on total terrestrial pollen (TTP) with pollen and spores from aquatic taxa being excluded from the pollen sum.

% representation of taxon *n* = (count for taxon *n* / pollen sum) x 100

conc^{n} of taxon *n* = (count for taxon *n x* conc^{n} of *Lycopodium*) / count for *Lycopodium*

An additional calculation was used to produce the percentage representation of taxa outside the pollen sum e.g. aquatics.

% representation of taxon *x* = (count for taxon *x* / (pollen sum + sum of aquatic taxa)) x 100

The concentration of pollen within lake sediment is dependent upon both the rate of sediment accumulation and the rate of pollen deposition within that sediment (Bennett and Willis, 2001). The accumulation rate of the sediment is modelled using the radiocarbon determinations obtained from the sediment core (Bennett and Willis, 2001). Due to the high number of pollen grains in any given sample, the final pollen count is itself a sample of the total amount of pollen. Despite this, the greater the overall pollen count, the fewer statistical uncertainties there are (Bennett and Willis, 2001). For example, Bennett and Willis (2001) calculated that the uncertainty was only c. ±2% for a pollen type that equated to 50% of the pollen sum when 1000 grains had been counted.

5.6 Macrofossil Analysis

Macrofossil analysis was carried out on material retained from the 100µm sieve in the initial pollen preparation step. Material was examined at x10 to x40 magnification using a Leica MZ12s stereomicroscope. The remains of vegetation, insects, charcoal and mineral fractions were identified. Specimens identified included spores, bryophytes, statoblast, fern sporangium, chironomids, chara, shells, *Betula* seeds, *Daphnia* Sp, mites and juncus. Identification was aided by Carrión and Navarro (2002), Lacourt (1968), Van Geel (2002), Van Geel et al. (1989), Bakker and Van Smeerdijk (1982), Mauquoy and Van Geel (2007).

Abundance was based on the following scale; 0.5 = rare, 1 = occasional, 2 = frequent, 3 = abundant. The material encountered was scarce and provided little palaeoecological interpretation attributed to the deep coring depth. Generally, shallow water cores are used for such analysis due to the importance of proximity to parent vegetation (Birks and Birks, 2006).

5.7 Chironomid Analysis

Chironomid sub-fossil analysis was carried out on fifty eight samples from the Lough Inchiquin sediment core corresponding with samples depths from pollen analysis between 788 – 444cm. Chironomid head capsule methodology follows that of Walker (2001) and is outlined below:

1. Between 0.5 and 2ml of sediment was deflocculated in a KOH solution (10% w/v; c. 50ml) and heated for 30 minutes on a metal plate, stirring every 5 minutes.
2. A constant flow of distilled water was used to sieve the sample through a 90μm mesh to eliminate finer components of the sediment.
3. Once the sample size had reduced such that the finer components had been removed, a small amount of distilled water was added to the sediment concentrate which was then poured into a Bogorov plankton counting tray. Samples were left for c. 5 minutes to allow the chironomid remains to settle.
4. The material was examined using a Leica MZ12s microscope at x10 to x40 magnification. Chironomid head capsules (both full and half heads) were retrieved using fine forceps and placed on to circular cover slips using a Leica DM LB2 microscope. In general 5 – 10 heads were mounted with c. 3 cover slips per slide.
5. Entellan, a water-free mounting medium, was used to permanently mount the cover slips, with the chironomid remains, to the slides.
6. The collected head capsules were identified using a Motic B3 Professional Series microscope at x100 to x400 magnification with associated Motic camera software to further aid identification.

Taxonomic identification was based for the most part on Brooks et al. (2007), with further taxonomic detail derived on all species from Wiederholm (1983) and on tanypod identification from Rieradevall and Brooks (2001). A minimum of fifty head capsules, or whole mentum equivalents (WME), were retrieved in each sample with an average of sixty five head capsules retrieved per sample. The use of WME is beneficial because of the ease with which chironomid head capsules split in two. Split head capsules were counted as a half-head and two-halves were representative of a whole specimen. A total of eighty four taxa were identified in LIQ1 with forty eight designated as common taxa i.e. in at least two samples with an abundance of ≥2% in at least one sample.

Statistically significant chironomid assemblage zones (CAZs) were established using Psimpoll (Bennett, 2009-1993) a software program for the plotting and analysis of palaeoecological data. The chironomid data is divided using sum-of-squares partitioning to produce statistically significant zones.

The percentage calculation is as follows:

% representation of taxon *n* = (WME for taxon *n* / WME sum) x 100

Interpretation of chironomid ecology was based on Brooks et al. (2007), Vallenduuk and Pillot (2007); Moller Pillot (2009); Moller Pillot (2013) and Chique et al. (2018).

5.8 Organic Geochemistry

Sediment samples were taken at 10cm intervals along the Inchiquin sediment core from 1052cm to 5cm. Results from 785cm – 365cm will be presented. Results were interpolated to correspond with chironomid sub-sampling for subsequent ordination analysis.

The analysis of $\delta^{13}C$ values was carried out at Amherst College and the University of Massachusetts Amherst, USA. Samples were dried, pulverised with a mortar and pestle and passed through a 200µm sieve. Homogenised material was weighed into silver capsules and HCl-fumigated (Harris et al 2001) and measured for $\delta^{13}C$ values using a Piccaro $\delta^{13}C$-CO_2 analyser.

The analysis of $\delta^{15}N$ was carried out at the UC Davis Stable Isotope Lab, Department of Plant Sciences at the University of California. Separate analysis, using an Elementer Vario EL Cube or Micro Cube elemental analyser interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (IRMS) was conducted to measure $\delta^{15}N$ values of a non-acidified portion of the samples. Samples were combusted at 1080°C in a reactor packed with copper oxide and tungsten (VI) oxide. Oxides were removed in a reduction reactor and N_2 and CO_2 separated using a molecular sieve adsorption trap before entering the IRMS. During analysis, samples were interspersed with several replicates of at least two different laboratory standards (http://stableisotopefacility.ucdavis.edu/13cand15n.html - Last accessed 09/06/2018).

Stable isotope ratios of C and N were determined using a Thermo Fisher Delta V Advantage EA-IRMS at Amherst College, University of Massachusetts, Amherst.

5.9 Inorganic Geochemistry

Elemental analysis was carried out at every millimetre along the full length of the Inchiquin core. Results were averaged for each 1cm between 788 – 444cm. Geochemical data at depths corresponding to chironomid samples were used in statistical ordinations. The relative abundance of forty four elements was determined through analysis with four, sulphur (S), titanium (Ti), iron (Fe) and manganese (Mn), recognised as indicators of erosion and thus relevant to the current study.

Samples were taken from the LIQ1 core at the PRU, NUI, Galway. U-channels (long, plastic boxes) were used to take continuous, single-box subsamples of each 1m sediment core section. These were pressed into the centre of each 1m core section to avoid any contaminated material and thus provide the most representative sample for analysis. A fishing line was run underneath the underside of the U-channel to free it from the sediment during extraction.

Analysis was carried out at Amherst College, Massachusetts in association with the University of Massachusetts Amherst (UMASS), USA. Analysis was carried out using an ITRAX™ Core Scanner. The following settings were used: voltage of 50kV, current of 50mA, exposure time of 1700ms, step size of 1000microns, XRF exposure time of 10 seconds, XRF voltage of 30kV, XRF current of 55mA and a molybdenum tube. The element peak area produced reflects the element abundances within the sediment. Results were produced as a relative abundance measured in counts per second (cps).

5.10 Ordination Analysis

Principal Component Analysis (PCA) and Redundancy Analysis (RDA) were used to gain insights into associations between environmental variables, relating to pollen and geochemical results of the Inchiquin core, and the chironomid community composition. All ordination analyses were performed using Canoco v.5.0, a software program designed for multivariate data exploration, testing and summarisation on results from the Inchiquin core only. Analyses were performed on square-root transformed chironomid percentage data for all common taxa. For further details on the statistical analyses used on this data see Chapter 7.

Chapter 6 – Palaeoenvironmental Investigation of Prehistoric Land-use at Lough Inchiquin

6.1 Introduction

This chapter will discuss the results of pollen analysis undertaken on a lake sediment core from Lough Inchiquin, located immediately to the south of the karstic limestone region of the Burren, Co. Clare. As discussed in detail in Chapter 3 the Burren has a long history of human occupation which began in the Early Neolithic with the construction of portal and court tombs in the landscape (Lynch, 2014; Jones, 2003; Jones, Forthcoming-b). Close to the lake, on the low ridge of Roughan Hill, the densest concentration of archaeological remains dates to the Chalcolithic – Early Bronze Age with less known archaeological evidence for later activity in the Burren (Jones, 1998; Jones et al., 2015).

This study aims to provide a palaeoecological assessment of the large catchment of Lough Inchiquin with particular emphasis on the evidence for human activity in the form of pastoral and arable farming. Pollen analysis, loss-on-ignition and macrofossil analysis have been employed in this study. Previous pollen investigations have been undertaken in the south-east and northern areas of the Burren which will be used as comparison material (e.g. Feeser, 2009; Watts, 1984; Feeser and O'Connell, 2009). The large size of Lough Inchiquin will provide a more regional signal to evaluate if changes seen at Molly's Lough can be replicated across the wider Burren region or if differing human-environment interactions can be identified. Pollen data will be compared with the archaeological record in order to assess the degree of correspondence between the two data-sets and to allow for an in-depth interpretation of human activity throughout prehistory.

6.2 Study Site

Lough Inchiquin (N52°57'10" W9°5'16") is a large lake encompassing c. 110ha with a shoreline of 6365m (Figure 6.1) (Waemere, 2005). It is located c. 20km inland from the Atlantic Ocean at an elevation of 35m above sea level (Cullinane, 2012). The lake has an average depth of 10.8m with a maximum of 30m located in part of the central basin towards the northern shore. The shoreline shelves steadily towards the centre allowing for the regular accumulation of sediment within the deep basin (Cullinane, 2012). Thermal stratification occurs in this lake with the development of a thermocline producing a warm epilimnion (upper layer of water) and cool hypolimnion (lower layer) (Diefendorf et al., 2006; 2008). Lough Inchiquin is hydrologically open with the River Fergus entering at the northern-most shore, and exiting to the south, with a water residence time of c. 1 month (Diefendorf et al., 2008). The River Fergus is the largest of the underground systems in the Burren and rises immediately south of Roughan Hill, draining a considerable amount of the Burren plateau (McNamara and Hennessy, 2010; Drew, 2001). An estimate for the catchment of the River Fergus springs was proposed to be 115km^2 based on river flow and regional precipitation input (Drew, 1988). The inflow area is shallow at a depth of c. 2m which hosts macrophyte vegetation (Cullinane, 2012). Groundwater also forms a significant portion of the lake water with the karstic landscape, causing the short residence time of groundwater in the catchment (Diefendorf et al., 2006). Reed beds of *Phragmites* are established in the most easterly section of the lake and at the northern-most shore line. Agricultural land surrounds the lake with 40% classed as pastureland and with minimal tree cover (Waemere, 2005). The western side of the lake has more extensive tree cover and Clifden Hill (190m high) provides some shelter to the south-west. Two islands are present in the south-east corner of the lake. The current study has estimated the catchment of Lough Inchiquin to be 93.2km^2 (Figure 6.2) but it had previously been calculated as 147.1km^2 by Cullinane (2012).

Lough Inchiquin was chosen due to its proximity to the archaeologically-rich area of the Burren, and specifically the area of Roughan Hill – a low ridge which rises to c. 130m. The sedimentary record of Lough Inchiquin is expected to incorporate both regional and local pollen, with a possible over-representation of AP due to its large size. The wider archaeological setting of Lough Inchiquin has been discussed in Chapter 3 and sites within the catchment can be seen in Figure 6.2.

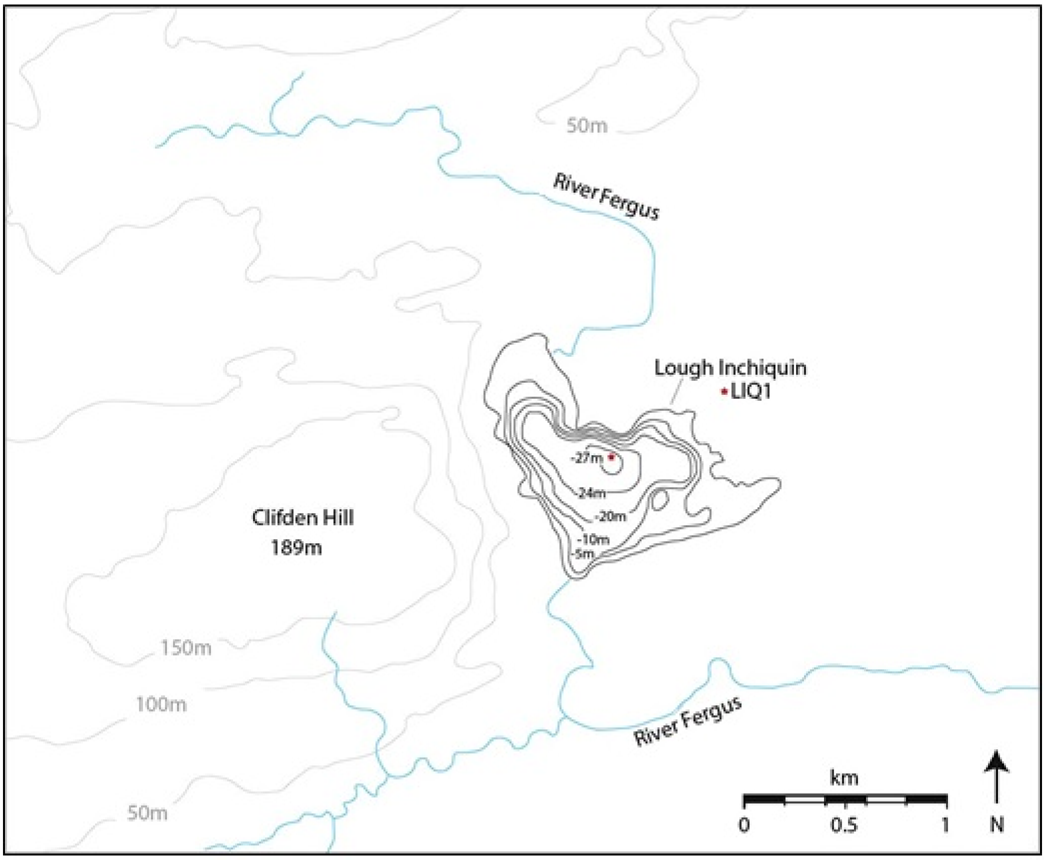

Figure 6.1: Bathymetry map of Lough Inchiquin showing water depth contours of -5, -10, -20, -24 and -27m. The coring location is marked with a red star. Lough Inchiquin is shown within its topographical setting. The River Fergus enters the lake at the northern shore. Clifden Hill provides some shelter to the south-west Roughan Hill is located to the north of the map area. Source: author (adapted from Diefendorf et al. (2006).

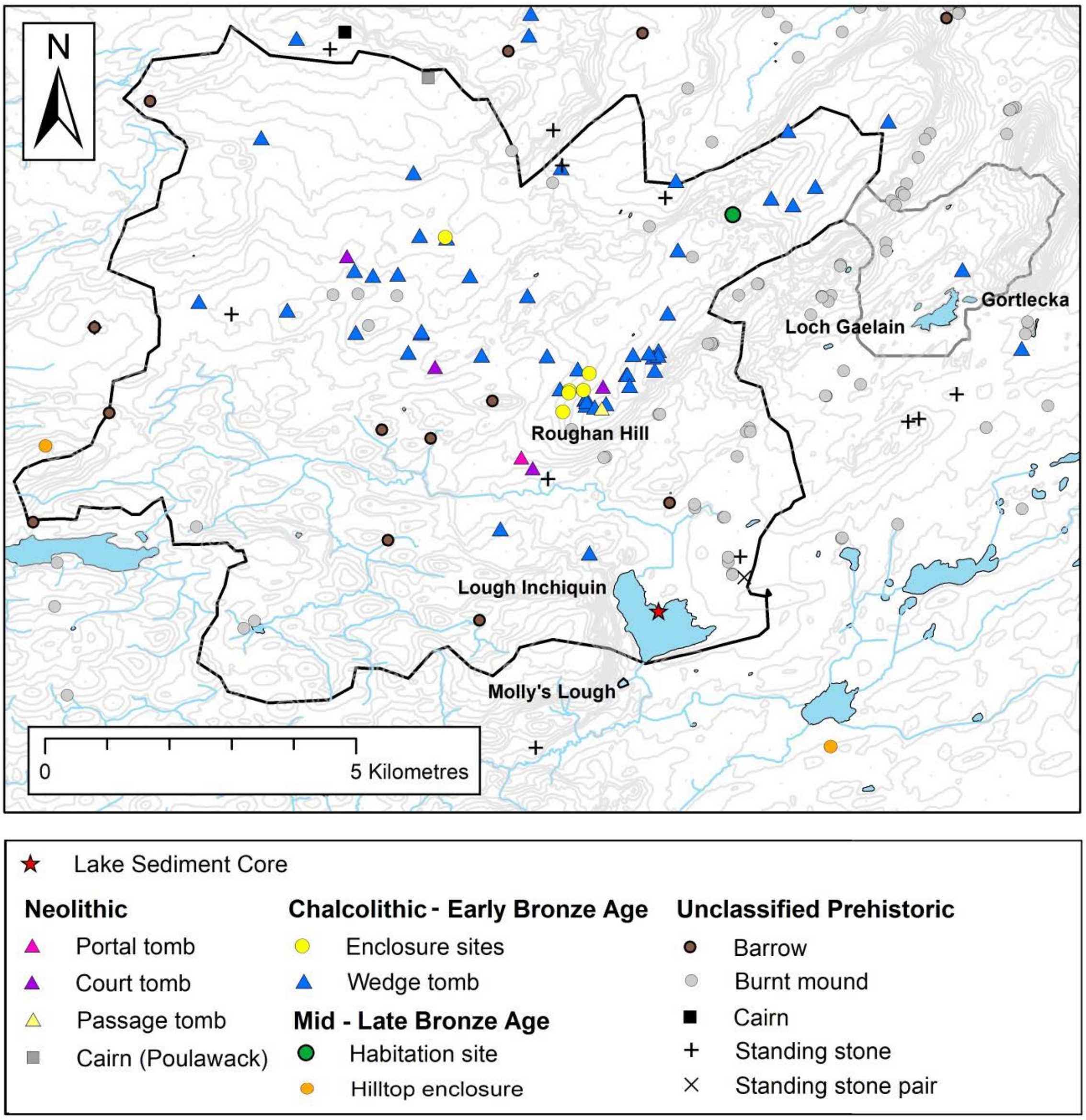

Figure 6.2: The distribution of archaeological sites within the catchment area of Lough Inchiquin as denoted by the black line. The coring location is marked by the red star. The concentration of wedge tombs, enclosures and a court tomb c. 3km to the north of the lake is the area of Roughan Hill. Two additional lake sites, discussed in the text, are labelled and the catchment of Loch Gaeláin is denoted by the dark grey line. Contours are denoted by the light grey lines to depict the topography of the landscape. Source: author.

Figure 6.3: The coring platform in position in Lough Inchiquin during fieldwork. Source: author.

6.3 Methods

The full details of all methods are given in Chapter 5. Key points are summarised below.

6.3.1 Core Extraction

A 10.6m long sediment core (LIQ1) was extracted from the deepest part of Lough Inchiquin (N52^{o}57’20”N W9^{o}5’16”) (Mingram et al., 2007) at a water depth of 30m, using a Usinger piston corer in June 2015. Figure 6.3 shows the coring platform in position on the lake.

6.3.2 Chronology

Age control for Lough Inchiquin is based on ten ^{14}C-AMS dates of which seven were accepted. Samples of 2cm-thick sediment were wet-sieved in order to retrieve suitable plant material for ^{14}C analysis. Radiocarbon AMS dating was carried out at the ^{14}Chrono Centre, Queen’s University Belfast, UK. An age-depth model was established using Bacon v. 2.2 Bayesian age-depth modelling software (Blaauw and Christen, 2011) utilising calibration curve IntCal 13 (Reimer et al., 2013). All ages produced by Bacon are expressed as calibrated years BC and rounded to the nearest ten years.

6.3.3 Loss-on-Ignition

Loss-on-ignition (LOI) analysis was carried out on samples of 2cm^3 over the full length of LIQ1 at 4cm intervals. Guidelines for the determination of organic (LOI_{550}) and inorganic (LOI_{950}) carbon contents proposed by Heiri et al. (2001) were followed. This was done in order to produce estimates for the organic matter and inorganic carbonate content of the lake sediment. Results spanning 788 – 364cm are presented with pollen data.

6.3.4 Pollen and Macrofossil Analysis

Pollen analysis was carried out on a total of ninety samples between 788 – 364cm. Basal samples were taken at depths of 788cm, 772cm, 764cm, and 754cm. Samples were taken at 4cm intervals in all cases between 748 – 452cm while a sampling interval of 8cm was used between 452 – 364cm. Preparation of samples for pollen analysis followed Faegri and Iversen (1989). In all cases sample size was 1cm^3. Pollen taxa were divided into arboreal pollen (AP) and non-arboreal pollen (NAP) with the latter divided into shrubs, ferns, pastoral indicators (NAPp), arable indicators, bog and aquatic. The main NAPp taxa include *Poaceae*, *Plantago lanceolata*, *Liguliflorae* (likely *Taraxacum officinale,* although belonging to a large group*)*, *Tubuliflorae* (likely *Bellis perennis* and *Anthemis)*, *Ranunculus, Filipendula*, *Rumex* acetosa/acetosella, *Trifolium*-type and *Cerastium*-type. Arable indicators include cereal-type, *Chenopodiaceae* (likely *Chenopodium album* and *Atriplex*-type) and *Artemisia*. The identification of cereal-type pollen was based on a minimum size criterion of 40µm and characteristics of the pore and annulus as presented by Beug (1961). Macrofossil analysis was carried out as described in Chapter 5.

6.4 Results

6.4.1 Sediment Core Description

In general, the core consisted of a uniform lake sediment/gyttja with occasional bands of shells, shell inclusions and plant material. Glacial clay was recorded from 9.9m. See Table 6.1 below for details. The full sediment core in profile is shown in Figure 6.4.

Table 6.1 Detailed description of the lithology of sediment core LIQ1 from Lough Inchiquin.

Depth (m)	Lithology
0-1.01	Light brown uniform gyttja Some iron precipitation in upper 10cm Occasional shells throughout Plant material in A and B-half
1.01-1.99	As above but with moderate shells
2.0-3.0	Light-mid brown gyttja becoming darker Occasional shells Plant material in A and B-half
3.0-4.0	Light-mid brown silt (consolidated) with banding becoming apparent Bands of shell Wood in A and B-half
4.0-5.0	Light-mid brown, slightly banded silt becoming darker from 4.5m Moderate shells throughout with sand/shell layers
5.0-6.03	Mid-light brown silt Moderate to frequent shells with sand/shell layers Wood and plant material (possibly charred) in A and B-half
6.03-7.01	Mid-dark brown silt (consolidated) with strong banding Becomes a lighter brown from 6.51m Occasional shells with sand/shell lens Plant material in A and B-half
7.01-7.60	Dark brown silt (consolidated) with lighter banding Occasional to moderate shells with thin shell bands Plant material in A and B-half
7.60-8.46	Dark brown silt (consolidated) with banding Sand/shell layers Wood in A and B-half
8.46-8.64	Mid-light brown silt (consolidated) with thin banding Sand/shell layer
8.64-9.61	Mid-light brown silt with banding becoming more grey-brown at base Sand/shell layers Plant material in A and B-half
9.61-10.59	Banded mid-light brown silt becoming lighter until 9.9m (Holocene) Occasional shells Grey clay from 9.9 – 10.4m (Younger Dryas) Yellowish-grey sediment 10.4 – 10.6m (Late glacial) becoming darker grey at base

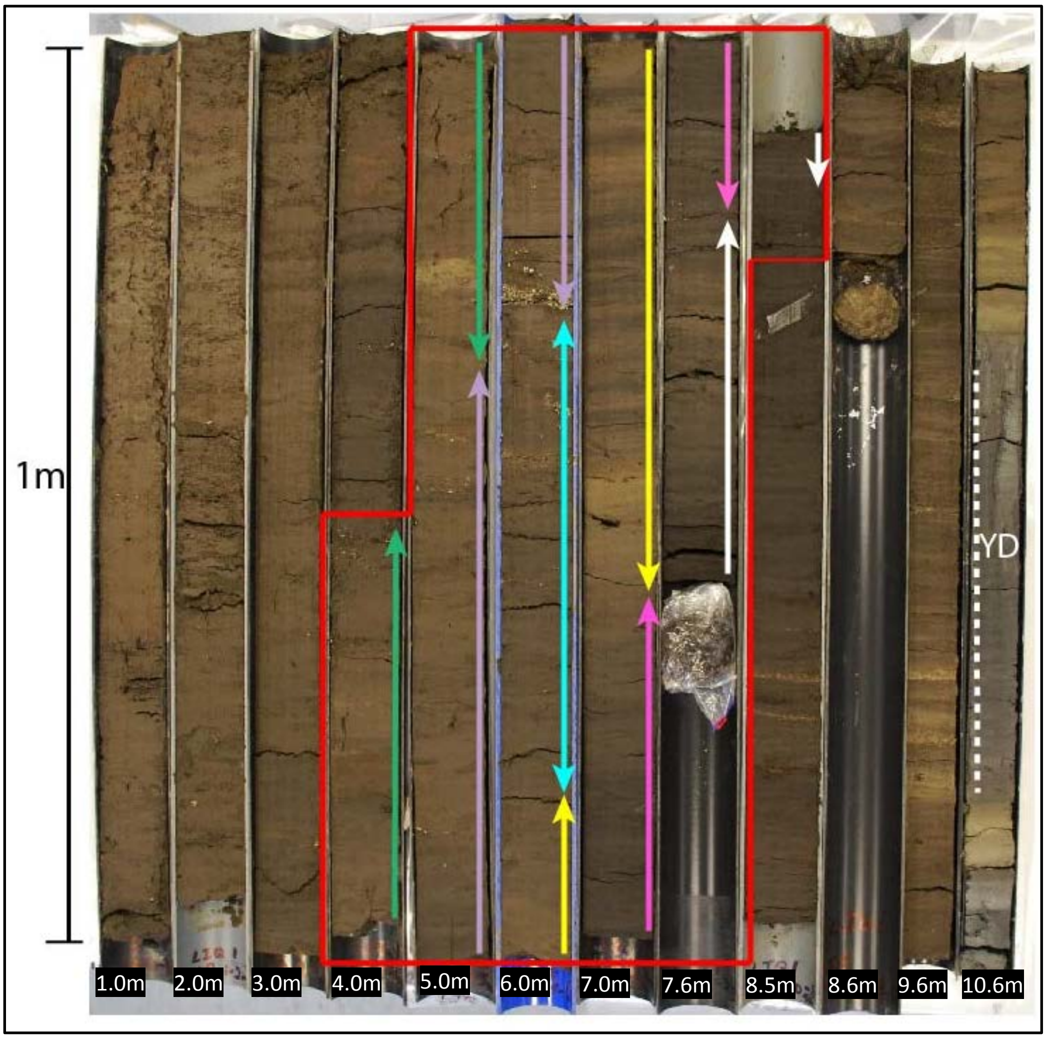

Figure 6.4: The full profile of lake sediment core LIQ1 from Lough Inchiquin. The red outline indicates the section of the core investigated during this study. Arrows indicate time periods as follow: white = Early Neolithic; pink – Middle – Late Neolithic, Yellow = Chalcolithic – Early Bronze Age; Blue = Middle Bronze Age; Purple = Late Bronze Age; Green = Iron Age. The white dashed line indicates the Younger Dryas.

6.4.2 Chronology

Obtained ^{14}C dates are presented in Table 6.2. Five samples were initially taken for ^{14}C-AMS dating. The aim of the dating programme was to provide a chronology for major changes seen in vegetation and land-use detected in the pollen data. As such the first sample (LIQ1-1) was taken at what appeared to be the Elm Decline, prior to an increase in NAPp presumed to be associated with a Neolithic *Landnam*. Dates LIQ1-2, LIQ1-3 and LIQ1-4 were chosen at points when NAPp increased in order to provide start dates for periods of increased human activity. Date LIQ1-5 was taken at the uppermost limit of the diagram. Once pollen analysis had been carried out at a higher resolution three further samples were taken. Dates LIQ1-6 and LIQ1-8 were taken at points where NAPp decreased in order to bracket two periods of increased human activity. Date LIQ1-7 was taken between two previous dates (LIQ1-3 and LIQ1-4) in an attempt to establish a robust chronology for the Chalcolithic period, a time when archaeological evidence of human activity is particularly strong. The two final samples (LIQ1-9 and LIQ1-10) were taken immediately next to LIQ1-8 and LIQ1-6 due to uncertainties in the accuracy of the original ^{14}C determinations. In all cases, sediment samples were processed for ^{14}C dating as outlined in Chapter 5.

Based on the resulting ^{14}C determinations an initial age-depth model was created to review the dating evidence (Figure 6.5). The model was constrained using an age for the Younger Dryas/Holocene transition of 11.7ka (10100 BP) based on Walker et al. (2009). Three dates were rejected on the basis of the resultant age-depth model. Dates LIQ1-8 and LIQ1-6 were rejected on the basis of ^{14}C reversals; the age determination was deemed to be too old for that particular sediment depth in relation to the other dates in the sequence. As LIQ1-6 was older in date than seven preceding dates, this was rejected from the model. Similarly LIQ1-8 was older in date than the previous accepted date provided by LIQ1-3. The rejection of LIQ1-7 was based on overlapping date ranges at 2σ between LIQ1-4 and LIQ1-7 despite being 22cm apart. LIQ1-4 was deemed reliable, in relation to the pollen data and the other dates in the sequence, which led to the rejection of the other. The rejected dates deemed to be too old may have arisen through the re-deposition of older material within the sediment or could be due to the hard-water effect, often problematic in carbonate lakes such as Lough Inchiquin, although terrestrial macrofossils were used for the dating analysis (Törnqvist et al., 1992).

Examination of the model with regard to sedimentation rates (indicated by LOI_{550} and pollen data) suggests that sedimentation rate began quite slowly but began to increase from c. 676cm concurrent with an increase in anthropogenic indicators. Similarly, an increase in both sedimentation and anthropogenic indicators occurred at c. 612cm. Sedimentation remained high until c. 456cm at which point the pollen data suggests less intensive land-use with some woodland recovery. The accepted ^{14}C determinations appear to corroborate the relative rate of sedimentation change (e.g. through increased erosion) as suggested by land-use indicators within the pollen data.

Table 6.2: Radiocarbon dates derived from material within sediment core LIQ1 from Lough Inchiquin. ^{14}C-AMS dates were obtained on plant material from wet-sieved, 2cm-thick sediment samples.

^{14}C lab code	Sample ID	Depth (cm)	^{14}C (BP)	Age range 1σ 68.3%	Age range 2σ 95.4%	Material dated	Comments
UBA – 33216	LIQ1-1	364	1933±37	AD 47 - 89	40BC – AD 137	Plant macrofossil	Accepted
UBA – 34750	LIQ1-6	454	4751±30	3632 – 3559BC	3636 – 3510BC	Wood	Reversal; rejected
UBA - 35612	LIQ1-10	456	2624±32	814 – 792BC	835 – 773BC	Wood	Accepted
UBA - 33217	LIQ1-2	524	2934±29	1208 – 1108BC	1222 – 1036BC	Plant macrofossil	Accepted
UBA – 35611	LIQ1-9	564	3195±32	1497 – 1440BC	1521 – 1413BC	Wood	Accepted
UBA – 34752	LIQ1-8	566	3601±30	1980 – 1917BC	2030 – 1889BC	Wood	Reversal; rejected
UBA – 33218	LIQ1-3	612	3429±34	1771 – 1684BC	1783 – 1639BC	Plant macrofossil	Accepted
UBA – 34751	LIQ1-7	654	4021±42	2576 – 2483BC	2638 – 2464BC	Wood	Rejected
UBA – 33219	LIQ1-4	676	4149±33	2777 – 2667BC	2876 – 2625BC	Plant macrofossil	Accepted
UBA - 33220	LIQ1-5	748	5436±36	4300 – 4262BC	4348 – 4238BC	Plant macrofossil	Accepted

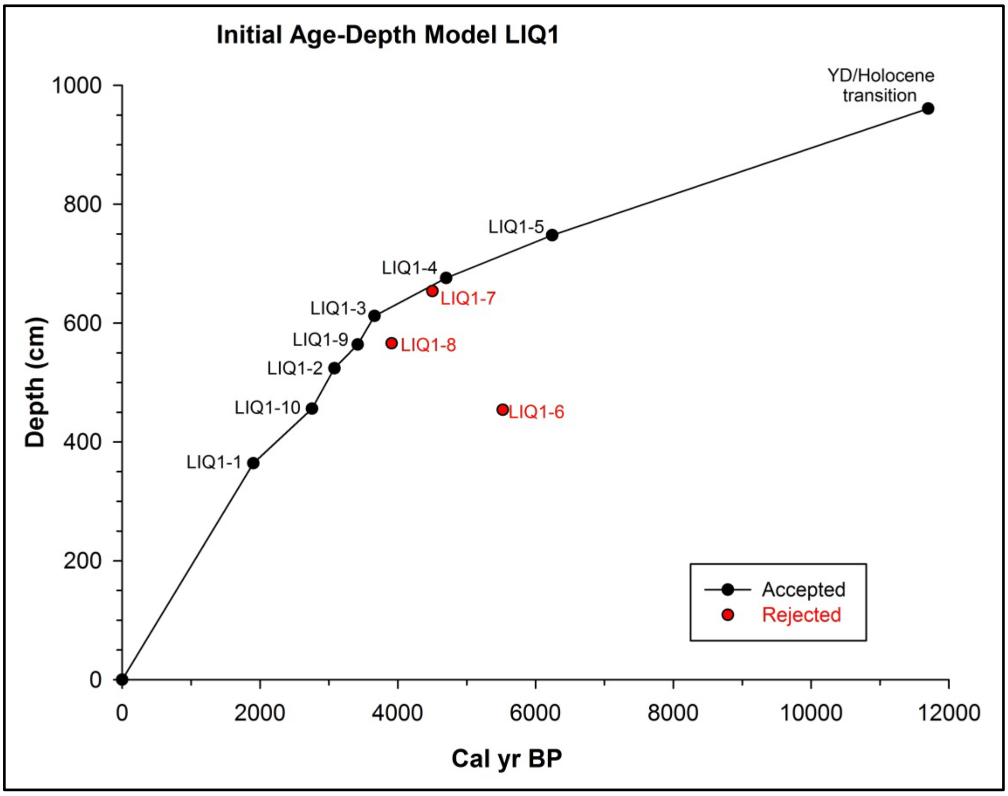

Figure 6.5: Initial age-depth model produced from radiocarbon dates of plant material retrieved from sediment core LIQ1 from Lough Inchiquin, showing both accepted and rejected dates.

An age-depth model (Figure 6.6) was produced using Bacon v.2.2 Bayesian age-depth modelling software (Blaauw and Christen, 2011). The model was constrained using an age for the Younger Dryas/Holocene transition of 11.7ka (Walker et al., 2009) and an age for the year of coring (AD 2015) which allowed a chronology to be constructed for the entire length of the lake sediment core. The chronology used in this study, however, relates to the section 788 – 364cm and runs from c. 4590 – 10 BC. The potential error within this age-depth model is not deemed problematic ranging from 160 – 740 years with the chronology being particularly robust for the Bronze Age. The potential error ranges are 260 – 670 years (Neolithic), 410 – 460 years (Chalcolithic), 220 – 410 years (Early Bronze Age), 160 – 220 years (Middle Bronze Age) and 190 – 350 years (Late Bronze Age).

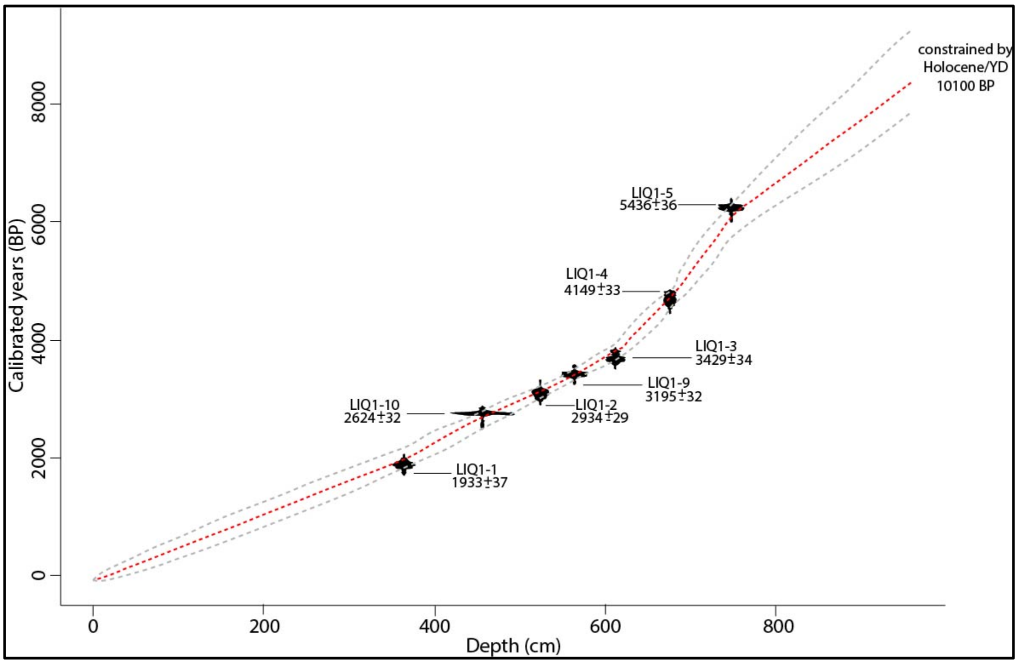

Figure 6.6: Age-depth model based on Bacon Bayesian modelling of ^{14}C dates from plant material derived from sediment core LIQ1 from Lough Inchiquin. Black symbols indicate the probability distribution for calibrated ^{14}C dates. The red dashed line follows the weighted mean age for each depth and parallel grey dashed lines indicate the 95% confidence interval.

6.4.4 Pollen Analysis

Pollen assemblage zones (PAZs) and subzones were established on the basis of significant changes in percentage and concentration pollen data across a range of pollen taxa. A time period was assigned to each PAZ based on the Bacon age-depth model produced. The pollen data is presented in Figure 6.7 and Figure 6.8. The main trends in LOI_{550} are presented for each PAZ (Figure 6.9).

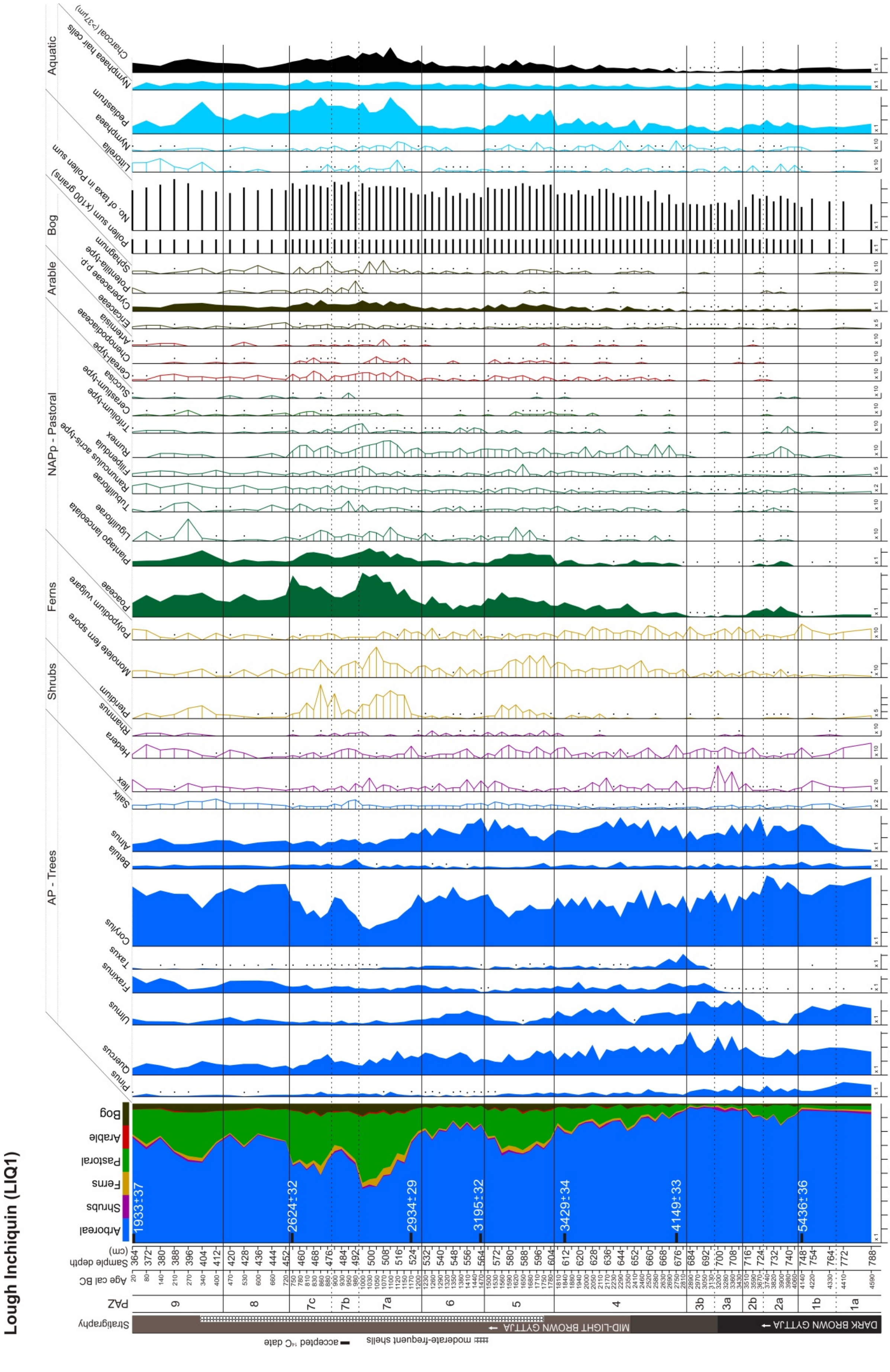

Figure 6.7: Percentage pollen diagram plotted to depth with age-scale provided in calibrated years BC. The diagram is divided into nine PAZs based on changes in the abundance of certain taxa. A simplified core stratigraphy is provided to the left. A composite diagram demonstrates the abundance of different ecological groupings - categorised and colour coded as indicated. Selected pollen percentage curves and pollen sum (x1000 grains) are then presented. Scales indicated at base of individual curves (scale of x1 = solid fill; exaggerated curves = hatched fill). Very low values are indicated by dots. Black bars indicate accepted radiocarbon dates which are displayed on the composite diagram.

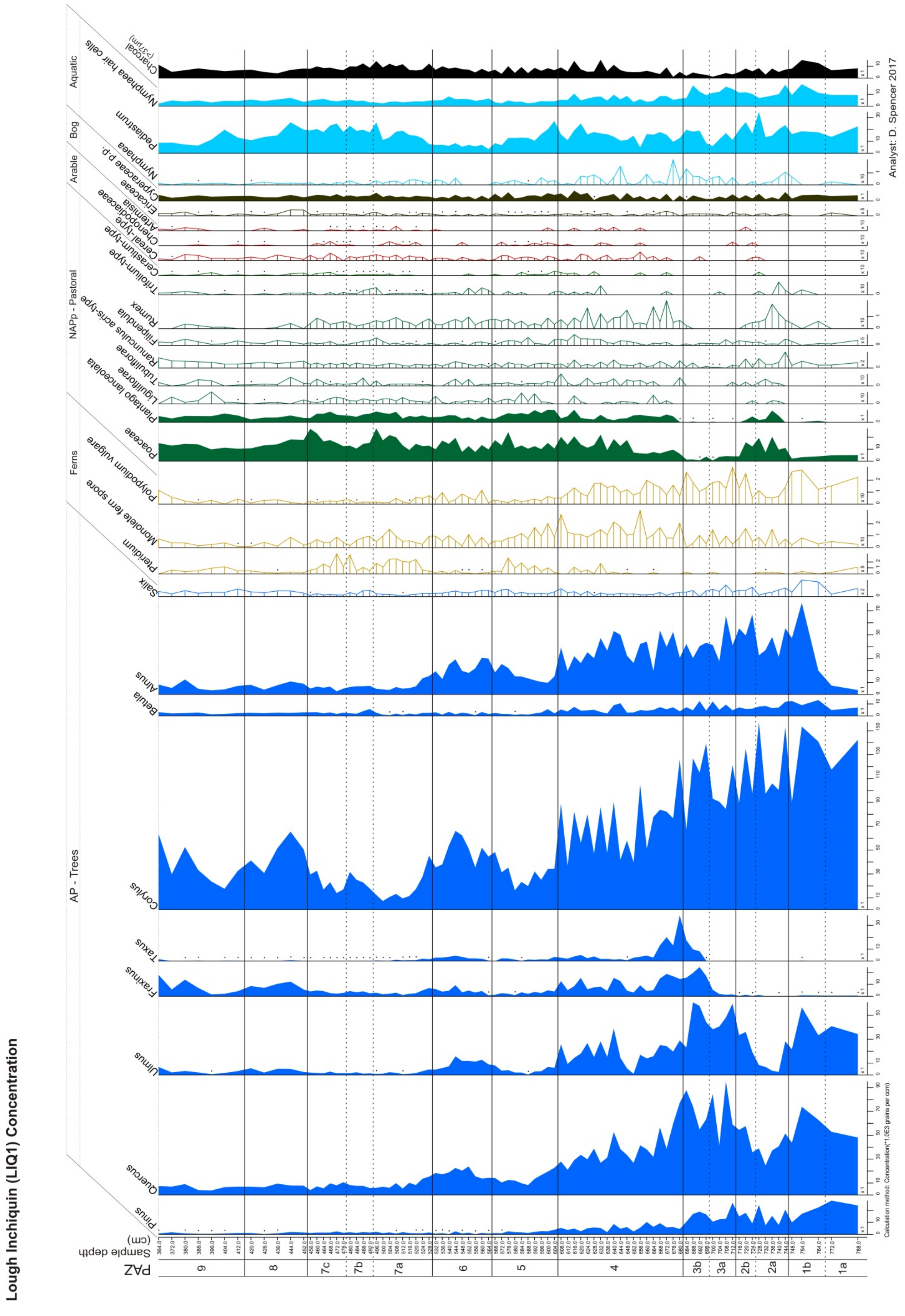

Figure 6.8: Concentration pollen diagram plotted by depth for main pollen taxa presented in Figure 6.7. The diagram is divided into the same nine PAZs as the percentage pollen diagram to aid comparison. The same ecological groups and colour coding is used as in Figure 6.7. Selected concentration curves are presented (scale of x1 = solid fill; exaggerated curves = hatched fill).Very low values are indicated by dots.

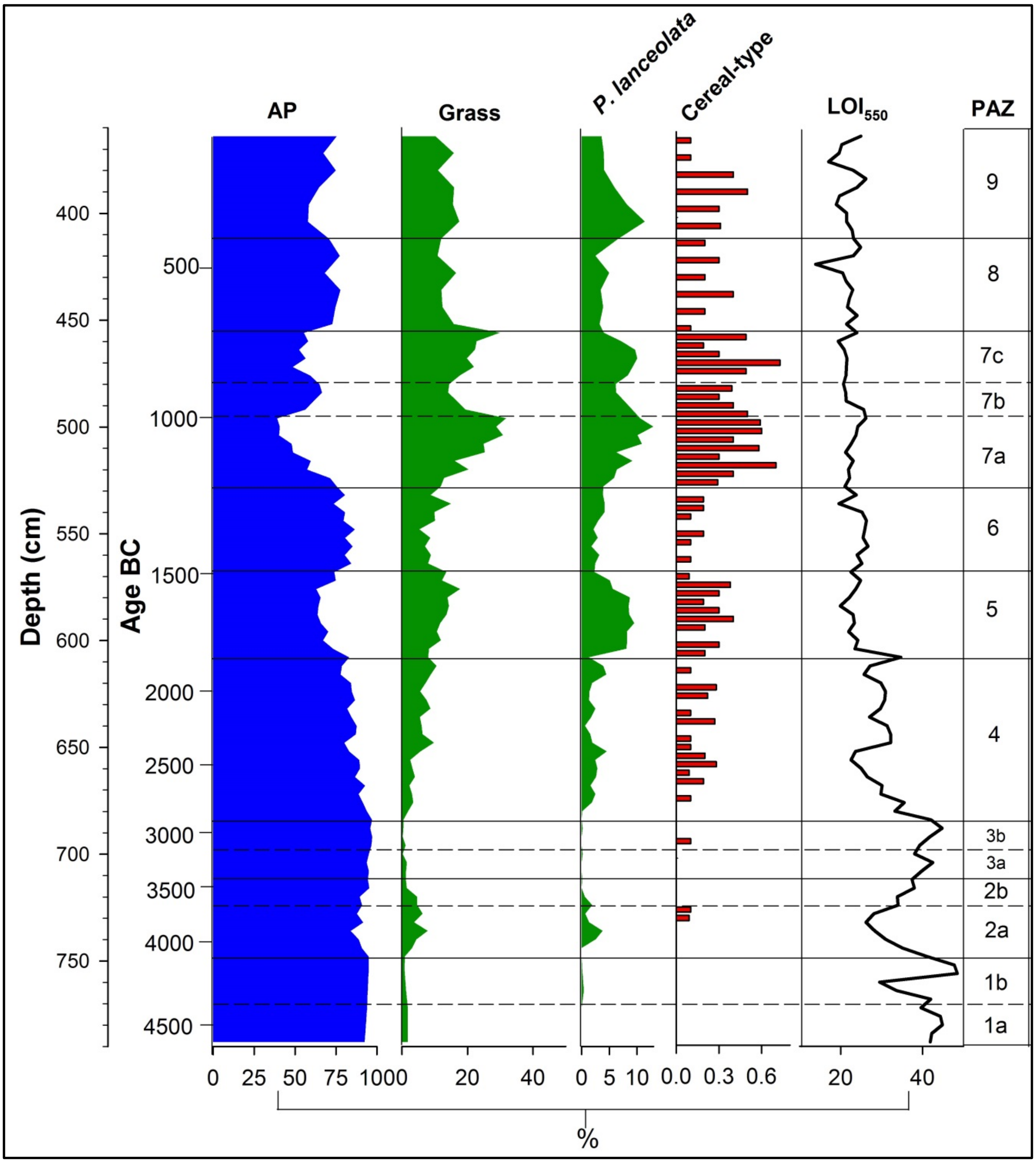

Figure 6.9: Selected percentage pollen curves representative of arboreal taxa and land-use indicators plotted by depth and presented alongside LOI_{550} data for each PAZ.

PAZ-1 (788 – 748 cm; c. 4600 – 4090 BC)

Subzone 1a (788 – 772cm; c. 4600 – 4370 BC)

AP is high throughout and accounts for 93% of TTP. The main contributors are *Corylus* (49.9 – 43.5%), *Quercus* (16.9 – 19.6%), *Ulmus* (12.0 – 15.2%) and *Pinus* (8.5 – 10.5%). NAPp values are very low (2.3 – 2.9%). *Pediastrum* and micro-charcoal are both present but at low levels. Pollen concentration values are high overall for this subzone. LOI_{550} starts relatively high at 41.8% with an average of 42.6% in this subzone.

Subzone 1b (764 – 748cm; c. 4370 – 4090 BC)

AP remains high accounting for 94.8% of TTP. *Corylus* decreases from 44.4 – 37.7% as does *Pinus* from 7.1 – 4.2%. *Alnus* increases substantially from 6.3 – 19.8% and of the shrubs *Ilex* increases from 0.4 – 0.8%. NAPp remains low at an average of 2.2%. Pollen concentration values remain high in this part of the core and the rise in *Alnus* is well expressed in this data. LOI_{550} initially decreases to 29.5% before increasing to 48.5%.

PAZ-2 (744 – 716 cm; c. 4090 – 3470 BC)

Subzone 2a (744 – 728cm; c. 4090 – 3710 BC)

AP decreases from 91.0 – 84.0% by 736cm before increasing slightly to 87.8% by the end of the subzone. *Ulmus* declines from 7.9% to a minimum of 1.2% at 740cm and it remains low (1.2 – 2.7%) throughout this subzone. *Corylus* increases from 42.9 – 50.9% while *Quercus* decreases from 14.4 – 12.6%. *Pinus* and *Alnus* remain relatively stable. NAPp increases from 3.1 – 7.9% by 736cm. *Poaceae* is present at 3.1% prior to the decline in *Ulmus* while *Plantago lanceolata* only occurs after the *Ulmus* decline. *Poaceae* reaches 7.9% and *Plantago lanceolata* 3.8%. The diversity of NAPp has increased with *Liguliflorae* registering for the first time and more significant levels of *Ranunculus, Rumex acetosa* and *Trifolium*-type. *Pediastrum* levels fluctuate but are higher than in PAZ-1. Cereal-type pollen was identified for the first time with one grain detected at 728cm (45µm). LOI_{550} values decline rapidly to 26.2% by 732cm. These changes are also reflected in pollen concentration data. LOI_{550} decreases from 35.0% to a minimum of 26.2% by 732cm.

Subzone 2b (724 – 716cm; c. 3710 – 3470 BC)

AP increases throughout this subzone from 91.0 – 95.3%. *Ulmus* recovers from 7.4 – 12.4% and *Quercus* from 13.6 – 20.2% while *Corylus* decreases from 37.0 – 33.1%. NAPp decreases from 7.4 – 2.0%. A cereal-type grain was identified at 724cm (40μm). Further arable indicators include *Chenopodiaceae* and *Artemisia*. Pollen percentage trends are mirrored in concentration data. LOI_{550} increases to 38.0% during this subzone.

PAZ-3 (712 – 684cm; c. 3470 – 2850 BC)

Subzone 3a (712 – 700 cm; c. 3470 – 3160 BC)

AP ranges from 93.8 – 95.1%. Arboreal taxa fluctuate with *Corylus* ranging from 33.5 – 40.7%, *Quercus* from 17.6 – 28.1%, *Ulmus* from 14.2 – 17.9% and *Alnus* from 11.7 – 19.4%. Of the shrub taxa *Ilex* increases to a maximum in the profile of 1.9% and *Rhamnus* registers in the profile. NAPp have declined to low levels with *Poaceae* and *Plantago lanceolata* only reaching 1.3% and 0.2%, respectively. No cereal-type pollen was detected (Figure 6.10) with arable indicators only detected in one sample (0.09% at 712cm). Pollen concentration values remain high and reflect the percentage data. LOI_{550} increases from 37.4 – 42.5% by 704cm.

Subzone 3b (696 – 684 cm; c. 3160 – 2850 BC)

AP representation has increased slightly with values ranging from 95.9 – 97.1%. *Corylus* decreases from 40.7 – 23.9% while *Quercus* increases from 18.5 – 31.2% by 684cm. *Alnus* fluctuates ranging from 8.4 – 15%. *Ulmus* declines from 16.9% at 692cm to 8.2% by the end of the subzone. *Fraxinus* expands from 1.8% at the top of subzone 3a to a high of 7.2% at 692cm. *Taxus* increases from 0.1% at the start of subzone 3b to 11.6% at the start of PAZ-4. NAPp representation remains low. A cereal-type grain was detected at 692cm (50μm). Concentration values remain high overall with the rise in *Taxus* and *Fraxinus* well pronounced. LOI_{550} values increase to a maximum of 44.8% by 688cm.

PAZ-4 (680 – 608cm; c. 2850 – 1790 BC)

AP representation has decreased by an average of 10% from the previous zone and decreases from 93.9 – 83.2% throughout PAZ-4. *Corylus* fluctuates ranging from 20.9 –

40.8%. *Alnus* increases to 24.7% at 644cm before decreasing to end the zone at 15.4%. *Quercus* decreases from 23.3 – 11.0% while *Taxus* peaks at 11.6% before declining to 0.4% by 640cm and remaining low. *Ulmus* declines significantly from 6.6 – 0.8% between 656 – 652cm and then recovers to 10.1% by the end of the zone. NAPp representation increases from 3.3% to a maximum in this zone of 16.4% at 616cm. A value of 14% is achieved at 648cm just after *Ulmus* is at its lowest level. *Poaceae* increases from 1.9 – 10.6cm at 612cm while *Plantago lanceolata* increases from 0.1 – 4.6% at 652cm and 4.4% at 616cm. Curves are established for *Ranunculus* (maximum of 1.5%), *Rumex acetosa* (maximum of 0.9%) and *Filipendula* (maximum of 0.8%). Lesser amounts of *Aster*-type and *Liguliflorae* also detected. Cereal-type is identified in all but four samples between 672 – 612cm ranging from 0.1 – 0.3% (Figure 6.11). *Chenopodiaceae* and *Artemisia* identified in six samples. *Pediastrum* and micro-charcoal values both fluctuate but see an overall increase throughout the zone. Concentration values are lower than in the previous zones. LOI_{550} values decline to a minimum of 22.5% by 656cm before increasing and ranging from 27.0 – 34.7% for the remainder of the zone.

PAZ-5 (604 – 568 cm; c. 1790 – 1480 BC)

AP representation is at 73.4% at the opening of the zone and falls to 63.7% by 588cm before returning to 74.0% at the close of the zone. This is accounted for by a decrease in *Ulmus* to 0.5% at 588cm, *Quercus* to 9.2% at 576cm and *Corylus* to 20.6% at 580cm. *Alnus* decreases from the start of the zone to 7.6% by 600cm before increasing. *Rhamnus* is present in most samples. Ferns increase to a maximum of 3.7% at 584cm with *Pteridium* reaching 2% at 576cm. An expansion of NAPp takes place increasing from 20.4 – 27.5% at 584cm and decreasing to 18.6% by the end of the zone. *Poaceae* increases to 14.3% by 584cm and *Plantago lanceolata* to 9.5% at 592cm. *Plantago lanceolata* decreases from 580cm concurrent with an increase in *Corylus*. Continuous curves are established for *Ranunculus*, *Filipendula*, *Rumex (*mostly *Rumex acetosa*), *Liguliflorae* with lesser amounts of *Tubulifloreae, Trifolium*-type and *Cerastium*-type. Cereal-type pollen forms a continuous curve ranging from 0.1 – 0.4% with associated arable indicators. *Pediastrum* increases substantially to 17.4% across the zone boundary and remains at a high representation until 580cm. Micro-charcoal has increased to 9.2% at 584cm. Concentration values are low overall. LOI_{550} values decrease to 19.9% by 584cm before increasing to 24.9% by 572cm.

PAZ-6 (564 – 532 cm; c. 1480 – 1210 BC)

AP representation has increased reaching a maximum for the zone of 86.6% (548cm). *Corylus* is the main contributor at 42.8% (548cm) with *Quercus* less pronounced increasing to 16.4% (552cm). *Ulmus* reaches 10.3% at 556cm with small increases in *Fraxinus* and *Taxus* to 4.8% and 2.6%, respectively. *Alnus* expands initially to24.3% before declining to 12.4% at 552cm. *Pinus* is now virtually absent at <1% in all but one sample. *Rhamnus* is present at low levels in most samples. *Pteridium* declines substantially to < 0.4%. Overall NAPp is very low in the first half of the zone decreasing to 9.7% at 548cm. Contributing to this are *Poaceae* decreasing to 5.3% and *Plantago lanceolata* decreasing to 1.8% while additional herb taxa (e.g. *Liguliflorae*, *Filipendula*) do not exceed 0.2%. NAPp starts to increase from 544cm increasing from 15.8 – 20.5% by 536cm. Cereal-type representation has decreased and is not present in all samples. *Pediastrum* has a much lower representation than in PAZ-5 with values of <6%. Trends are reflected in pollen concentration data with the increase in *Corylus* particularly well expressed. LOI_{550} values are relatively stable with an average of 23.3%.

PAZ-7 (528 – 456 cm; c. 1210 – 740 BC)

NAPp representation is at its highest for the profile in this zone. Based on changes in AP/NAPp PAZ-7 has been divided into three subzones. Concentration values are at their lowest for the profile throughout this zone and the main trends in percentage data are reflected in the concentration data.

Subzone 7a (528 – 496 cm; c. 1210 – 990 BC)

AP decreases rapidly from 75.6 – 39%, the lowest values in the profile. This is accounted for by reductions in *Corylus* from 41.4 – 14.4%, *Alnus* from 14.0 – 5.4% and *Quercus* from 17.5% (516cm) to 6.9%. *Taxus* does not exceed 2.1% while *Pinus* increases to 3.5% at 512cm. *Pteridium* expands from 0.4 – 4.0% by 512cm while *Polypodium* is well represented. NAPp representation rapidly expands from 18.3 – 47.5% with *Poaceae* rising from 11.8 – 31.8% and *Plantago lanceolata* from 3.9 – 10.5%. *Ranunculus*, *Liguliflorae*, *Rumex acetosa* and *Filipendula* have all increased. Cereal-type is recorded in all but the first sample with a maximum of 0.6% between 500 – 496cm. *Chenopodiaceae* and *Artemisia* increase between 508 – 504cm. *Pediastrum* expands rapidly from 4.5 – 26.5% and micro-charcoal increases to

18.3% by 512cm. Increased charcoal particles were identified through macrofossil analysis from this zone onwards (Figure 6.12). LOI_{550} values increase from 21.0 – 26.1% throughout this sub-zone.

Subzone 7b (492 – 480 cm; c. 990 – 890 BC)

In this short subzone AP increases from 56.2 – 65%. This is predominantly accounted for by the expansion of *Corylus* from 22.4 – 35.4% with lesser increases in *Betula* to 7.2% (492cm), *Salix* to 3.4% (492cm), *Alnus* to 9.1% (484cm) *Hedera* to 0.7% (488cm) and *Rhamnus* at 0.2% throughout. Of the ferns *Pteridium* decreases to 0.6% at 484cm. NAPp representation decreases from 32.9 – 23.6%. Contributing to this is decreasing *Poaceae* from 19.4 – 14.4%, *Plantago lanceolata* from 9.1 – 6.1%, *Rumex acetosa* from 0.6 – 0.3% (484cm) and *Filipendula* at <1%. Cereal-type still forms a continuous curve but at a lower level (0.5 – 0.3%). *Chenopodiaceae* and *Artemisia* do not exceed 0.1%. The peak in *Corylus* is also reflected in the concentration data. LOI_{550} values decrease from 25.6 – 20.7%.

Subzone 7c (476 – 456 cm; c. 890 – 740 BC)

AP representation declines from 59.2 – 48.6% at 472cm before increasing to 55.4% by the end of the subzone. This is accounted for by a decline in *Corylus* from 24.1 – 20.2% by 472cm before it increases to 32.7% by 456cm. *Quercus* initially increases to 15.0% across the subzone boundary before it decreases to 4.5% by the end of the subzone. *Pteridium* increases to 4.9% at 472cm when AP is at its lowest. NAPp representation increases from 31.5 – 37.4% accounted for by increases in *Poaceae* from 17.7 – 29.9% and *Plantago lanceolata* from 8.4 – 10.1% (468cm). There is an increased representation of *Rumex acetosa*, *Liguliflorae* and *Cerastium*-type. *Liguliflorae* decreases from 472cm and *Plantago lanceolata* from 468cm. The highest value for cereal-type in the profile is recorded at 0.7% (468cm) and includes larger grains (Figure 6.10) with *Chenopodiaceae and Artemisia* reaching 1.2%. *Pediastrum* declines from 26.3% (472cm) to 17.4%. LOI_{550} values initially increase to 36.9% before returning to between 19.4 – 24.0%.

PAZ-8 (452 – 420 cm; c. 740 – 430 BC)

AP representation increases from 72.7 – 77.7% by 436cm. Contributing to this is an increase in *Corylus* to 44.7% across the zone boundary which then declines to 38.4% by the end of the zone. *Fraxinus* increases from 5.0 – 8.8%, *Quercus* from 6.9 – 8.1% (436cm) and *Ulmus* from 2.3 – 4.4% (436cm). *Alnus* declines from 7.9 – 5.0% and *Hedera* increases from 0.1 – 0.4%. *Pteridium* does not exceed 0.3%. NAPp decreases from 22.7 – 18.2% by 436cm before increasing to 25.5%. Accounting for this is *Poaceae* which decreases from 15.9 – 12.0% by 436cm and *Ranunculus* which decreases from 2.5 – 1.6 (444cm). *Plantago lanceolata* starts the zone at 3.2% increasing to 5.0% by the close of the zone. Additional herb taxa such as *Rumex acetosa* and *Liguliflorae* do not exceed 0.3%. Cereal-type has reduced from PAZ-7 ranging from 0.1 – 0.4%. *Pediastrum* decreases from 14.7 – 11.3% and micro-charcoal decreases from 6.6 – 3.3% at 436cm. Concentration values have increased slightly. LOI_{550} values are relatively stable between 21.0 – 24.9% except for a decrease to 13.9% at 424cm.

PAZ-9 (412 – 364 cm; c. 430 – 10 BC)

AP representation decreases from 77.3 – 57.9% at 404cm before increasing to 75.5% at the end of the zone. This is accounted for by a decrease in *Corylus* from 41.7 – 27.3% by 396cm before increasing to 42.9%, *Fraxinus* from 8.7 – 2.5% by 404cm before increasing to 12.1% and *Ulmus* from 5.7 – 1.1% by 396cm before increasing to 4.6%. *Quercus* and *Alnus* are more stable. *Hedera* increases from 0.1% at 412cm to 1.0% at 372cm and *Rhamnus* increases in representation. *Pteridium* increases from 0.5 – 1.5% by 396cm. NAPp increases from 15.9 – 32.7% by 404cm before decreasing to 17.6% by the end of the zone. This is predominantly accounted for by an increase in *Poaceae* to 17.5% and *Plantago lanceolata* to 11.4% by 404cm. There are increased levels of *Liguliflorae*, *Tubuliflorae*, *Rumex acetosa* and *Cerastium*-type between 404 – 388cm. Cereal-type remains continuous reaching 0.5% at 388cm. *Pediastrum* expands from 9.8 – 23.1% by 404cm before declining while micro-charcoal increases to 9.9% by 396cm. Concentration values are low and then increase towards the top of the zone. LOI_{550} values increase to 26.2% by 384cm before decreasing to 17.0% at 376cm. Values then increase for the remainder of the zone.

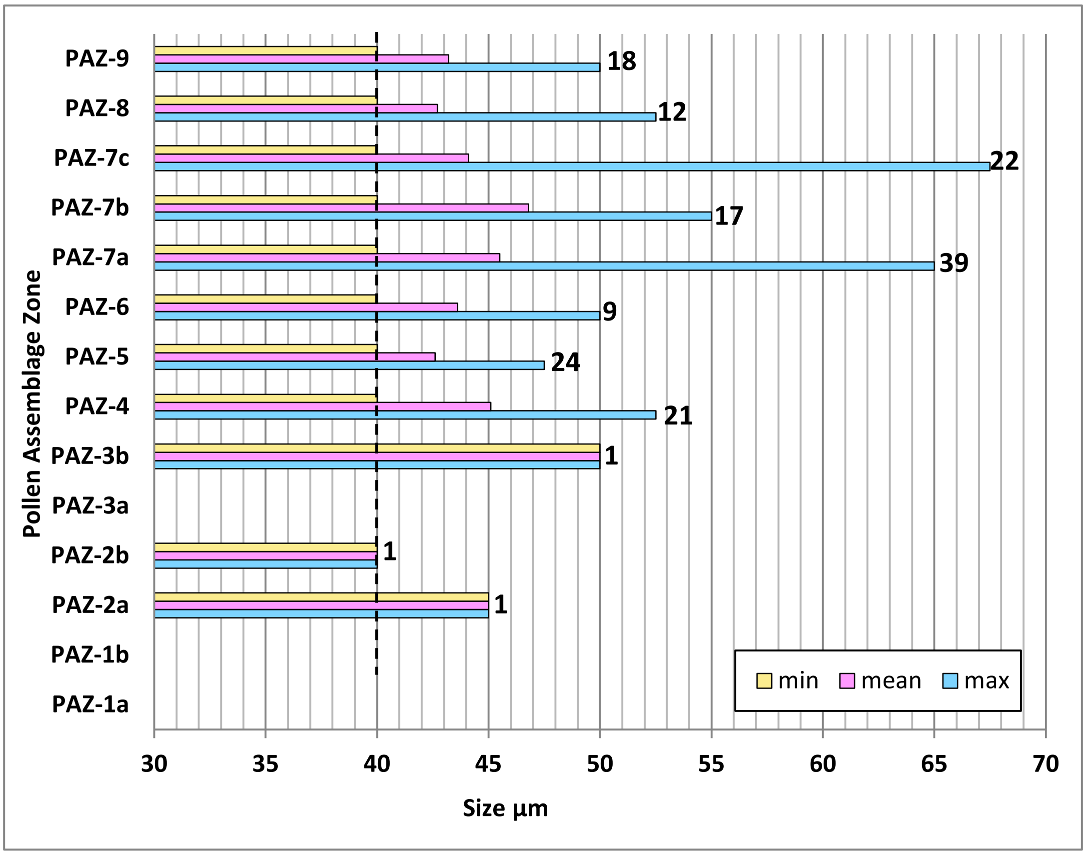

Figure 6.10: Cereal-type pollen size statistics for the Inchiquin record indicating the minimum, mean and maximum size of grains identified in each pollen assemblage zone. The vertical dashed line indicates the minimum size criterion of 40µm for categorisation as a cereal-type grain. The number to the right of the bar indicates the number of cereal-type grains identified. Results are presented by PAZ.

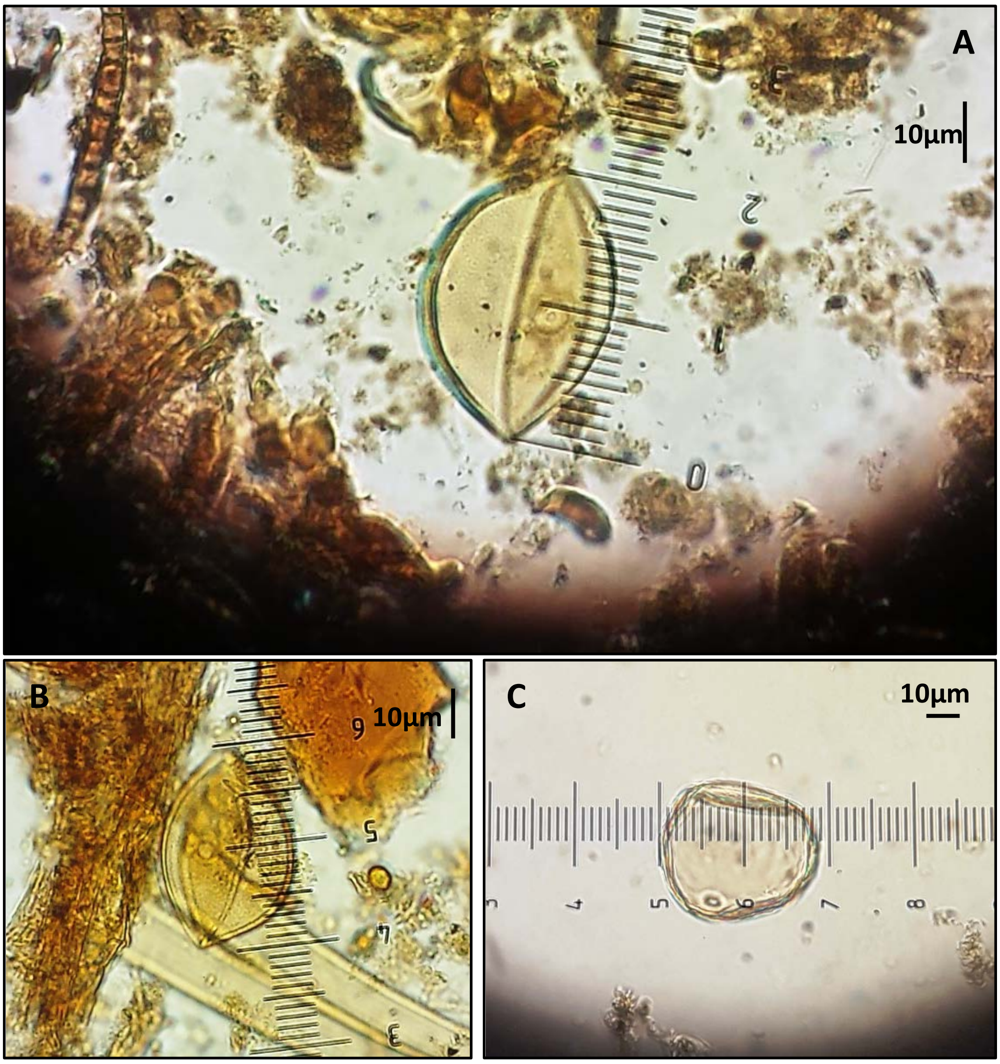

Figure 6.11: Examples of prehistoric cereal-type pollen grains from the Inchiquin record. (A) 660cm c. 2520 BC (B) 644cm c. 2290 BC (C) 472cm c. 860 BC. Source: author.

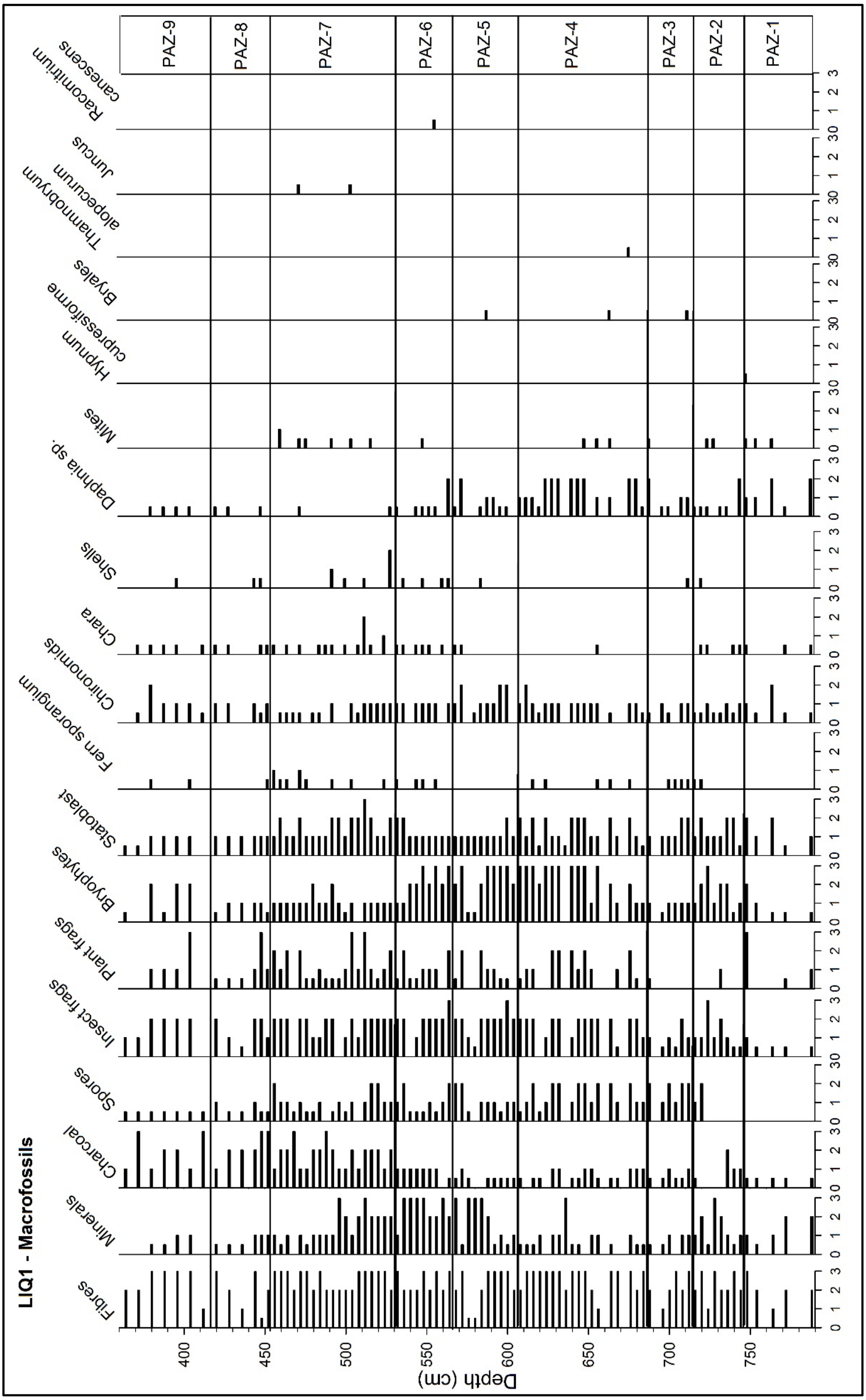

Figure 6.12: Macrofossil data from Inchiquin lake sediment material retained during pollen processing, plotted by depth. The types of material identified are indicated in the column labels. The diagram is divided into PAZ. The frequency of each macrofossil type is indicated by the length of the bar. Scale is as follows – 0.5 = rare, 1 = occasional, 2 = frequent, 3 = abundant.

Table 6.3: A summary of the main palynological features within each PAZ. Chronology follows Mesolithic (8000 – 4000BC), Early Neolithic (4000 – 3600 BC), Middle Neolithic (3600 – 3100 BC), Late Neolithic (3100 – 2500 BC), Chalcolithic (2500 – 2150 BC), Early Bronze Age (2150 – 1600 BC), Middle Bronze Age (1600 – 1200 BC), Late Bronze Age (1200 – 600 BC), Early Iron Age (600 BC – AD 400) (Waddell, 2010; Roberts et al., 2013).

PAZ	Spectra (cm)	Chronology cal BC	Period/age range	Main features and subzones
9	412-364	430 – 10	Early Iron Age	Initial decline, then increase in AP; NAPp expands – *Plantago lanceolata, Liguliflorae*, *Tubuliflorae*; subsequent decline; cereal-type
8	452-420	740 – 430	Late Bronze Age – Early Iron Age	High AP – *Corylus* and *Fraxinus*; reduced NAPp – *Poaceae*, *Plantago lanceolata* and *Rumex*; reduced cereal-type; lower *Pediastrum* and micro-charcoal
7	528-456	1210 – 740	Late Bronze Age	Lowest AP / Highest NAPp Subzone 7c: AP decreases – *Corylus*; NAPp expands; increased cereal-type Subzone 7b: AP increases – *Corylus* and *Betula*; reduced NAPp; reduced cereal-type Subzone 7a: AP decreases – *Corylus*, *Alnus* and *Taxus*; NAPp expands – *Poaceae*, *Plantago lanceolata*, *Rumex* and *Liguliflorae*; high *Pteridium*; cereal-type increases
6	564-532	1480 – 1210	Middle Bronze Age	High AP – *Ulmus* and *Corylus;* reduced NAPp; Reduced cereal-type; *Pediastrum* decreases
5	604-568	1790 – 1480	Early – Middle Bronze Age	AP declines; Expansion of NAPp – *Poaceae*, *Plantago lanceolata*; continuous cereal-type; high *Pteridium; Pediastrum* expands
4	680-608	2850 – 1790	Late Neolithic – Early Bronze Age	AP decreases – *Taxus*; 2nd Elm Decline and recovery; NAPp increases – *Poaceae*, *Plantago lanceolata* and *Rumex*; increased cereal-type; micro-charcoal increases
3	712-684	3470 – 2850	Middle – Late Neolithic	High AP Subzone 3b: Expansion of *Fraxinus* and *Taxus*; NAPp start to increase mid-subzone; cereal-type detected. Subzone 3a: High AP; peak in *Ilex*; NAPp reduced; no cereal-type
2	744-716	4090 – 3470	Early – Middle Neolithic	Elm Decline & Increased NAPp Subzone 2b: AP increases; *Ulmus* recovery; NAPp declines; 1st cereal-type. Subzone 2a: Decreasing AP; Elm Decline; NAPp increase – *Poaceae*, *Plantago lanceolata* and *Rumex*
1	788-748	4600 – 4090	Mesolithic	High AP Subzone 1b: Expansion of *Alnus* and decline in *Pinus* mid-zone (Boreal-Atlantic transition); very low NAPp. Subzone 1a: Boreal woodland of *Corylus*, *Quercus* and *Ulmus*

6.5 Discussion of Palaeoenvironmental Data

This discussion will make an assessment of changing landscape cover in the catchment of Lough Inchiquin through time (Figure 6.13) relating the palaeoenvironmental data to the archaeological record of the area to assess human-environment interactions. A comparison of the Inchiquin data with seven previously published pollen profiles from the surrounding area will be made. Details on previous pollen investigations (including the number of ^{14}C dates) were provided in Chapter 2. A summary of main pollen features of the comparison records is provided in Table 6.4. The most relevant pollen record is that from Molly's Lough located c. 415m to the south-west of the southern shore of Lough Inchiquin. Additional records from Loch Gaeláin, Gortlecka Lough, Rinn na Mona Lough and An Loch Mór commence from the Mesolithic while records from Cappanawalla and Lios Lairthín Mór relate to the Bronze Age onwards.

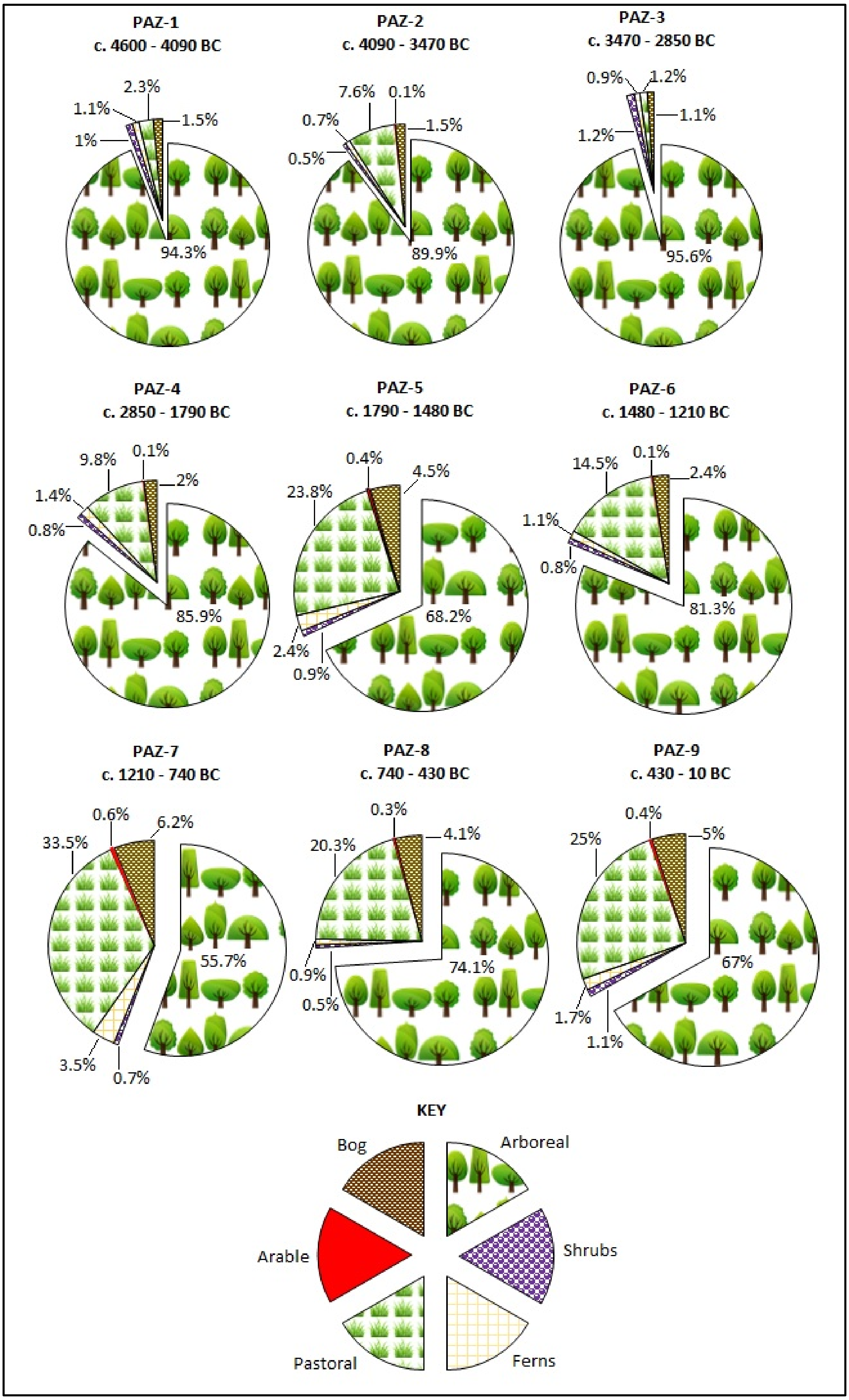

Figure 6.13: The percentage contribution of terrestrial pollen groups (as indicated in the key) from the Lough Inchiquin pollen data for each PAZ with the associated chronology provided.

Table 6.4: Summary of land-use dynamics inferred from local pollen profiles from the Burren and Aran Islands. Corresponding PAZs from the Inchiquin record are shown in the first column in addition to a chronology for comparison. Table continues on pages 160 and 161.

↑increase in human activity ↓decrease in human activity *interpolated dates ^{14}C dates from Watts (1963) were recalibrated using Calib 7.10

	PAZ, period and chronology LIQ1	Molly's Lough (Thompson 1997; Lamb & Thompson 2005)	Loch Gaeláin (Feeser 2009)	An Loch Mór (Molloy & O'Connell 2004; 2007)	Gortlecka Lough (Watts 1963; Watts 1984)	Rinn na Mona Lough (Watts 1984)	Cappanawalla peat depression (Feeser & O'Connell 2009)	Lios Lairthín Mór peat (Jelicic & O'Connell 1992; Feeser & O'Connell 2009)
	Pollen catchment signal	Local	Local	Local	Local	Local	Local	Local
1	Pre-Neolithic landscape (pre-4000 BC)	Woodland: *Ulmus, Quercus* & *Corylus*	Woodland: *Quercus, Corylus, Ulmus*; occasional *P. lanceolata*	Woodland: *Quercus, Pinus* & *Corylus*; (expansion of *P. lanceolata* 4500 BC)	Woodland: *Corylus, Pinus, Ulmus* & *Quercus*	Woodland: *Pinus, Corylus, Quercus* & *Ulmus*	N/A	N/A
2	Early – Middle Neolithic (4057 – 3511 BC)	Elm Decline 4050 BC; ↑ pastoral	Elm Decline 3750BC; ↑ expansion of *P. lanceolata*	Elm Decline 3700 BC; ↑ Neolithic *Landnam* (pastoral)	Elm Decline: 4332-3797BC (4075BC) ↑*P. lanceolata* first recorded	Possible Elm Decline *P. lanceolata* first recorded	N/A	N/A
3	Middle – Late Neolithic (3433 – 2634 BC)	↓ woodland regeneration (*Ulmus* & *Quercus*) until c. 2350 BC *Taxus* & *Fraxinus* from c. 3510 BC*	↓woodland regeneration from 3550; *Taxus* & *Fraxinus* expand c.3050; ↑ 2950 BC NAPp increase & cereal-type; ↓ 2700 – 2500 BC	↓ woodland regeneration from c. 3350 BC; AP at 95% c. 3140 BC; *Taxus* & *Fraxinus* expand; ↑ 2950 BC *Corylus* &*Taxus* decline; NAPp increase	↓ *Corylus* increases; *Taxus* peak 3949 – 2558 BC	↓ Corylus increases; Taxus peak	N/A	N/A

	PAZ, period and chronology LIQ1	Molly's Lough	Loch Gaeláin	An Loch Mór	Gortlecka Lough	Rinn na Mona Lough	Cappanawalla peat depression	Lios Lairthín Mór peat
4	Chalcolithic – Early Bronze Age (2577 – 1807 BC)	↑ pastoral farming & arable for first time	↑ pastoral farming 2500 – 2200 BC; ↓ 2250 – 1950 BC woodland regeneration; ↑ 1950 – 1300 BC increased NAPp; intensive pastoral farming with minor arable component	↑ pastoral farming until 2200 BC; ↓ until 2000 BC; ↑ intensive pastoral farming	↑pastoral farming – *Taxus* decline; increasing NAPp c. 2390 BC*	↑*Taxus* decline Increased NAPp	N/A	N/A
5	Early – Middle Bronze Age (1775 – 1496 BC)	Pastoral & arable farming continues	Intensive pastoral farming with minor arable component	↓subdued activity 1740-1050BC; *Corylus* recovery	↑NAPp increasing	N/A	Open pine-hazel woodland at 1570 BC	N/A
6	Middle Bronze Age (1465 – 1229 BC)	(as above)	↓ 1300	(as above)	↑pastoral farming – peak in NAPp; decline in *Corylus* 1250 BC*	N/A	Declining *Corylus*; stable NAPp	↑ NAPp high c. 1250 BC; *P. lanceolata* at c.20%
7	Late Bronze Age (1200 – 754 BC)	*Ulmus* increases c. 1030 BC ↓ but still NAPp & cereal present	↓until 750 BC; reduced NAPp; increased AP	↑ intensive farming from 1050 – 400 BC	↑	N/A	↑ increasing NAPp from 900 BC*	Pastoral & arable ↓slightly 1000 BC (decreasing *P. lanceolata* & increasing *Corylus*) ↑ *P. lanceolata* increasing from c.900 – 700 BC; cereal-type increasing

	PAZ, period and chronology LIQ1	**Molly's Lough**	**Loch Gaeláin**	**An Loch Mór**	**Gortlecka Lough**	**Rinn na Mona Lough**	**Cappanawalla peat depression**	**Lios Lairthín Mór peat**
8	Late Bronze Age – Early Iron Age (723 – 529 BC)	(as above)	↑ 650 – 250 BC	(as above)	↓	N/A	↑further increasing NAPp from 500 BC	NAPp remains high until 500 BC
9	Early Iron Age (465 – 17 BC)	↑NAPp Pastoral & arable farming until AD 188; *Ulmus* declines	Intensive pastoral farming until 250 BC; ↓ woodland regeneration; cessation of farming until AD 50	↓ 400BC; ↑intensive farming; ↓ 100 BC; ↑pastoral with an arable component 100 BC – AD 100 NAPp at 45%	↓rise in *Corylus*; decreased NAPp at 400 BC*; followed by ↑ until AD 735	N/A	↑ Increased arable component from 330BC*; peak of NAPp at 140 BC before ↓	↓reduced farming intensity

6.5.1 Vegetation and Land-use Dynamics through Prehistory

A discussion will be made of vegetation and land-use in archaeological time periods, rather than PAZs, with age ranges determined by the Bacon age-depth model. Latin will be used when discussing pollen taxa while common English names will be used when discussing the plant species, as is standard practice for PRU publications.

Mesolithic Woodland Dynamics (c. 4590 – 4140 BC)

As the profile opens, the landscape in the catchment of Lough Inchiquin was dominated by mixed deciduous woodland characteristic of the Boreal period (Molloy and O'Connell, 2004). A native species in limestone pavement environments (Preston et al., 2002), hazel remains the most abundant arboreal species in the Burren today, and would have formed an important understory component along with lesser amounts of alder and birch. The main tall-canopy tree was oak with lesser amounts of elm and pine. This woodland composition is similarly reflected in the small, local catchment of Molly's Lough, and across the wider Burren (Thompson, 1997; Feeser, 2009; Watts, 1963; 1984). The Boreal-Atlantic transition in European pollen diagrams from lake records is generally marked by an expansion of alder and a concurrent decline in pine, c. 7.5 kya, potentially related to environmental change although it is not considered entirely synchronous across north western Europe (Mitchell, 1954; Ghilardi and O'Connell, 2013; Smith, 1984; Bennett, 1984). These trends can be identified in the Inchiquin pollen record but the date assigned by the age-depth model (c. 4330 BC) is later than expected for this feature. This is likely because of the lack of a close ^{14}C date below this feature with only the Younger Dryas/Holocene transition constraining the age-depth model at this point. Elsewhere in the Burren it has been dated, by the first establishment of *Alnus* to consistent levels, to c. 5350 BC at Loch Gaeláin and c. 5610 BC at Gortlecka (Feeser, 2009). Similarly on Inis Oírr it was dated to c. 5310 BC in the An Loch Mór record and further afield at Cooney Lough, Co. Sligo to c. 5950 BC (Feeser, 2009; Molloy and O'Connell, 2004; Ghilardi and O'Connell, 2013). At Molly's Lough, alder expanded from c. 5050 BC but was likely established in the local catchment earlier by c. 5350 BC (Lamb and Thompson, 2005; Feeser, 2009). The data indicates that this feature was relatively synchronous across the Burren and western Ireland.

While in these local pollen records a decline in *Pinus* was not identified, which in fact maintained a relatively high representation (Feeser, 2009), this decline can clearly be seen in the Inchiquin record. This did not occur, however, with the establishment of alder in the woodland but rather at its significant expansion from 6.3 – 19.8%. If the entire confidence interval (95%) is considered, the date range for this expansion ranges from c. 4600 – 3990 BC. The Boreal-Atlantic transition has been associated with wetter conditions which would be favourable to alder, a species which colonises damp or wet soils (Preston et al., 2002), and a period of proposed increased winter precipitation has been determined from low $\delta^{18}O_{calcite}$ values at Lough Inchiquin between c. 5350 – 4750 BC (Diefendorf et al., 2006). Lower lake levels have also been proposed at Loch Gaeláin and An Loch Mór concurrent with this feature, potentially exposing moister soils favourable to alder (Feeser, 2009; Holmes et al., 2007).

It is likely that Burren soil cover at this time was more extensive than at present to support such woodland, as suggested by Moles and Moles (2002) and Moles et al. (1999). In the Inchiquin catchment, shrubs holly and ivy formed part of the woodland community probably growing at the woodland edge (Preston et al., 2002). Ferns including common polypody were also present. The presence of holly has been interpreted in some instances as suggestive of woodland instability, as suggested by O'Connell and Molloy (2001), if accompanied by a consistent record for *Plantago lanceolata.* At Lough Inchiquin, however, only grass was present prior to the Elm Decline which may simply be due to openings in the upper canopy. In the wider landscape, possible pre-elm decline woodland instability was identified at An Loch Mór on Inis Oírr, where a strong expansion of ribwort plantain at c. 4500 BC was potentially linked to climatic factors (Molloy and O'Connell, 2007; 2004). Occasional *Plantago lanceolata* were recorded at Loch Gaeláin where an additional *Ilex* curve suggests some natural openness of woodlands within this area of the Burren (Feeser, 2009).

The levels of NAPp in the Inchiquin record for this period are very low (2.3%) with only *Poaceae* and *Ranunculus* having a consistent, but low, presence in the pollen record, suggesting that open habitats were not a prominent part of the landscape at this time. Micro-charcoal was identified but while it can potentially be linked to Mesolithic human activity (Mighall et al., 2008) its presence can also be due to natural processes (Warren et al., 2014). Combined with the lack of anthropogenic indicators in the pollen profile it is more likely that charcoal originated from natural sources in this instance. Similarly, there is a lack of archaeological evidence for a human presence in this landscape. There are no known Mesolithic sites in the inland Burren area but c. 20km to the north-west of Lough

Inchiquin are two midden sites at Fanore More (Lynch, 2011; 2012; 2013). A large number of stone axes (46) have been found in the landscape immediately north of Lough Inchiquin, but while stone axes were in use in the Mesolithic, these most likely date to the Neolithic and so do not present a strong case for activity at this time (Grogan and Condit, 2000).

Early Neolithic Farming Activity (c. 4090 – 3590 BC)

The decline in *Ulmus* pollen at 744cm is thought to represent the mid-Holocene Elm Decline in the catchment of Lough Inchiquin. The Elm Decline, as recognised in pollen diagrams from the mid-west of Ireland, is generally dated to c. 3850 BC (O'Connell and Molloy, 2001). The available ^{14}C dates at Inchiquin place this event at c. 4060 BC, occurring over a period of c. 80 years, where *Ulmus* fell from 7.9 – 1.2%. The early placement of this feature corresponds reasonably well with a number of records where this feature has a pre-4000 BC start date, mostly from the north of Ireland (Whitehouse et al., 2014). The pollen record from Garrynagran in the west of Ireland also had a relatively early Elm Decline identified at c. 4000 BC (O'Connell and Molloy, 2001). Of the Burren pollen records, an early Elm Decline was identified at Molly's Lough c. 4050 BC where *Ulmus* declines from 23 – 1% (Thompson, 1997; Lamb and Thompson, 2005). Chronological resolution is poor for this record, however, with no ^{14}C dates obtained for the Neolithic period (Thompson, 1997). At Inchiquin, original elm levels were not as high as those recorded at Molly's Lough possibly due to local differences in the catchment areas. Elsewhere in the Burren the Elm Decline was recorded at Loch Gaeláin (c. 6km from Lough Inchiquin) from c. 3750 BC (Feeser, 2009) and from c. 4075 BC (midpoint) at Gortlecka Lough (Watts, 1984). It did not register in the pollen record from Rinn na Mona Lough, possibly due to the sampling interval employed (Watts, 1984). Further afield at An Loch Mór on Inis Oírr it registered at c. 3700 BC at a similar representation to the Inchiquin record (<6.0 – 0.7%) (Molloy and O'Connell, 2004; Molloy and O'Connell, 2007). The cause of the decline is heavily debated with the combined effects of disease, climate and human activity thought to have contributed to the decline (O'Connell and Molloy, 2001; Edwards, 2004).

The Elm Decline at Lough Inchiquin appears to have coincided with the first expansion of NAPp (grass and ribwort plantain) from c. 4060 BC. The rise of *Poaceae*, *Plantago lanceolata*, *Liguliflorae* (likely *Taraxacum officinale* although belonging to a larger grouping), *Tubuliflorae* (likely *Bellis perennis*) and *Rumex acetosa* is interpreted as evidence for a *Landnam* event that resulted in the opening up of the woodland. Elm and later oak and hazel were removed, facilitating the flowering of herbs which led to species-rich grassland, inclusive of ribwort plantain, dock, buttercup, clover, meadowsweet, dandelions and daisies, most likely indicative of pastoral farming. The decline in *Quercus* during this period suggests the clearance of tall-canopy trees from the landscape, which registers strongly in the concentration data as a sharp decline. *Ulmus* levels remain low for this period, only increasing from c. 3740 BC, suggesting that human activity may have been responsible for its suppression. The increase in *Corylus* concurrent with the *Landnam* was likely due to increased pollen production after the removal of tall-canopy trees (O'Connell and Molloy, 2001; Feeser and Dörfler, 2014). A decrease in *Ilex* was identified concurrent with the start of the *Landnam* and holly is known to be susceptible to browsing by animals which can affect its regeneration (Preston et al., 2002). The effects of de-forestation are represented in the LOI_{550} values which decrease as mineral material was likely eroded from the catchment, decreasing the organic component of the lake sediment.

The *Landnam* was two-phased with the most significant activity occurring between c. 4060 – 3740 BC. During this time AP representation fell and the majority of NAPp taxa were present in the pollen record suggesting the landscape was most open during the first three centuries of the *Landnam*. There was a subsequent recovery of elm and oak but fluctuations in the levels of *Corylus* due to the consistent, but reduced, presence of the main NAPp taxa. This indicates a continuation of farming activity until c. 3590 BC with the identification of cereal-type pollen at 728 and 724cm, and arable weed species (goosefoot, garden orache and mugwort), suggestive of a minor arable component. Because of the limited dispersal capacity of cereal-type pollen this was likely occurring close to the lake itself, although the influx of the River Fergus may have carried cereal-type pollen from a greater distance within the catchment (Behre, 1981; Edwards and Hirons, 1984).

At Molly's Lough the first expansion of *Poaceae* and *Plantago lanceolata* occurred simultaneously with the Elm Decline at c. 4050 BC (Thompson, 1997) but did not occur to the same extent as at Inchiquin. The expansion of herb taxa in the Molly's Lough record is thought to represent pastoral farming activity and there was an absence of cereal-type pollen during the Early Neolithic (Thompson, 1997), unlike at Inchiquin. This may suggest that any arable cultivation was not occurring in close proximity to Molly's Lough and so was only identified in the wider record from Lough Inchiquin. The first occurrence of *Plantago lanceolata* in the catchments of Gortlecka and Rinn na Mona Loughs, further to the north-east, indicates the commencement of Neolithic activity following the Elm Decline (Watts, 1984). Similarly at Loch Gaeláin the opening up of woodland is suggested following the Elm Decline with increased *Poaceae* and *Plantago lanceolata* recorded for a period of c. 200 years (Feeser, 2009). Despite increased NAPp in these additional records from the south-eastern edge of the Burren they were not described as *Landnam* events due to the lack of well-represented clearance phases. The evidence from Lough Inchiquin, however, is deemed sufficient to be a *Landnam*-type event, (AP drops; NAPp reaches 13.5%), suggesting the regional signal captured more widespread clearance occurring at this time across the Burren. It is probable that a rise in NAPp in the pollen record from the Carron depression also relates to Early Neolithic clearance although no dates are available (Crabtree, 1982). A *Landnam* signal was identified at An Loch Mór in the Early Neolithic with NAPp increasing to >24% (Molloy and O'Connell, 2004). The Inchiquin pollen record is consistent with general palynological trends identified across Ireland during the Early Neolithic, with an emphasis on pastoral farming (O'Connell and Molloy, 2001; Whitehouse et al., 2014) supported by interpretations of small-scale farming communities engaged in fixed-plot agriculture (McClatchie et al., 2014).

Although there is evidence for c. 400 years of farming in the Early Neolithic in the catchment of Lough Inchiquin, the landscape would have remained predominantly wooded with some small open areas possibly in close proximity to the lake. The first archaeological indication of human activity within the catchment comes from the construction of Ballycasheen portal tomb with Moyree Commons and Poulnabrone lying just outside of the catchment. The only dating evidence comes from Poulnabrone which was used initially at c. 3885 – 3720 BC (Schulting, 2014) and so the Inchiquin record suggests that people were active in this landscape for at least two centuries before the main use period of Poulnabrone. Court tombs were also constructed in this landscape which includes Parknabinnia (c. 3693 – 3376 BC) on Roughan Hill and three others which constitute an atypical group (Jones, 2003; Jones, Forthcoming-b) potentially used at the beginning of the second phase of the Inchiquin *Landnam*.

Middle – Late Neolithic Woodland Regeneration (c. 3590 – 2890 BC)

From c. 3590 BC there was a period of woodland recovery within the Inchiquin catchment which lasted until c. 2890 BC. The high AP representation (95% of TTP) indicates a return to full woodland conditions. AP representation was higher at this point than in the Mesolithic, although a lower sampling resolution was used for the latter. Elm increased substantially and together with oak made up the main tall-canopy component. The increase of these species likely led to a denser upper canopy and subsequently the decline of hazel, which along with alder formed the understory component at this time. Holly and buckthorn may have grown at the edges of woodland in hedgerows and areas of scrub, with buckthorn a strongly calcicolous shrub that would favour the limestone environment of the Burren (Preston et al., 2002). The woodland regeneration suggested from the Lough Inchiquin record appears to have been widespread across the Burren with all of the profiles, including the more geographically distant An Loch Mór record, indicating a recovery of woodland in the Middle Neolithic (Feeser, 2009; Watts, 1984; Molloy and O'Connell, 2004).

At Molly's Lough regeneration of elm and oak occurred from c. 3550 BC and a woodland environment persisted for a longer period of c. 1250 years (Thompson, 1997) compared with approximately seven centuries in the Inchiquin catchment. This suggests that while the local landscape in the immediate vicinity of Molly's Lough remained wooded, human activity re-commenced elsewhere on the Burren in the Late Neolithic. The representation of AP at An Loch Mór reached the same level as in the catchment of Inchiquin (95% of TTP) suggesting comparable woodland recovery but for a shorter period of four centuries (Molloy and O'Connell, 2007; Molloy and O'Connell, 2004). The cessation of farming activity at Inchiquin and across the Burren is comparable to data within a wider Irish context from c. 3350 BC identified across the country (O'Connell and Molloy, 2001; Chique et al., 2017; Molloy and O'Connell, 2016; Lynch, 1981; Caseldine and Hatton, 1996; Whitehouse et al., 2014). A comparable situation is also evident in Britain in the Middle Neolithic and in both cases a proposed link with declining population levels at this time has been suggested (O'Connell and Molloy, 2001; Whitehouse et al., 2014; Woodbridge et al., 2014).

The main change in woodland composition at Inchiquin was the expansion of ash from c. 3200 BC and the initiation of yew as a component of the woodland from c. 3130 BC. Both species increased concurrent with a slight reduction in oak canopy, perhaps allowing these species to take advantage of increased openness and light within the woodland environment. At Molly's Lough both ash and yew expanded from c. 3510 BC suggesting this trend was occurring in both the local and wider Burren environment (Thompson, 1997). Elsewhere in the Burren, yew expanded in the catchment of Rinn na Mona Lough and, similarly, at Loch Gaeláin from c. 3050 BC (Watts, 1984; 1963; Feeser, 2009). Significant expansions of *Taxus* occurred in the records from Gortlecka (22%), An Loch Mór (37% by c. 3000 BC) and further to the south-east at Caheraphuca Lough (43% by c. 2800 BC) (Watts, 1963; 1984; Molloy and O'Connell, 2004; 2007; Molloy and O'Connell, 2012). At Inchiquin it had a lower maximum of 11.6% by c. 2810 BC. A particularly strong expansion to 52% occurred in the catchment of Lough Atalia, Co. Galway, 36km north of Lough Inchiquin, where yew-dominated woodland persisted for six centuries centred on c. 2550 BC (O'Connell and Molloy, 2017). An increase in yew is thought to be as a result of a lack of grazing pressure on the landscape, but the synchronous expansion in especially the western region of Ireland may indicate an additional climatic factor (O'Connell and Molloy, 2001; Watts, 1984; Molloy and O'Connell, 2016; O'Connell and Molloy, 2017). The data indicates that the Inchiquin pollen record corresponds with what appears to have been a distinctive feature of this period, in western Ireland at least (O'Connell and Molloy, 2001; O'Connell and Molloy, 2017).

In the Inchiquin record the representation of NAPp was lower in this period than during the Mesolithic which suggests very little human activity. One cereal-type grain (50µm) was identified at c. 3050 BC, however, which may reflect the continuation of a limited arable component, or be the result of re-deposition. There may have been the continuation of some small areas of more open ground albeit within a denser woodland environment than in the Early Neolithic. Continued human occupation of the landscape at this time is evidenced through the continued deposition of remains into the Parknabinnia court tomb with nine of the twelve ^{14}C dates from human bone in chambers 1 and 2 dating to the Middle Neolithic (Schulting et al., 2012). Slightly further from the lake, 8.5km to the north-east, is the Poulawack cairn where the principal burial within the Linkardstown cist has been dated to c. 3350 BC (Brindley and Lanting, 1991a; Hencken and Movius, 1935). In fact, there is overlap in the use of three monuments within the Burren at this time; Poulnabrone, Parknabinnia court tomb and Poulawack (Schulting et al., 2012). This indicates that although the probable pastoral activity of the Early Neolithic had diminished, there was still a human presence within the landscape primarily concerned with monumentality if not subsistence in the catchment area. A habitation site, c. 5.8km to the north, at Teeskagh has provided a Late Neolithic date of c. 3080 BC which indicates possible settlement activity at this time on the Burren (Gibson, 2016).

Re-initiation of Farming Activity in the Late Neolithic (c. 2890 – 2500 BC)

From c. 2890 BC anthropogenic activity was re-initiated in the Inchiquin catchment and throughout this period the levels of NAPp taxa steadily increased as AP representation declined. That this activity represented a return to pastoral farming is indicated by the species-rich grasslands which began to increase and were inclusive of grass, ribwort plantain, dock, dandelions and buttercups with lesser amounts of clover, chickweeds and meadowsweet. The effect of this activity on the woodland is indicated by the decrease in arboreal species from the start of this period, suggesting the preferential clearance of tall-canopy trees, such as oak and pine. After the expansion of yew at Inchiquin, discussed above, this species diminished to negligible levels by the end of this period. This may suggest deliberate clearance, especially given the poisonous nature of yew foliage, although other natural factors have also been hypothesised (O'Connell and Molloy, 2001; Molloy and O’Connell, 2004). The decline of *Taxus* in the Late Neolithic of the Caheraphuca Lough record, further south in Co. Clare, would seem to corroborate this as in that case it was not accompanied by an increase in human activity and may instead relate to the species characteristics; i.e. poor regeneration under its own canopy (Perrin et al., 2006; Molloy and O'Connell, 2012). Other woodland species in the Inchiquin catchment, such as hazel and alder, appear to have been less affected by human activity. The levels of *Corylus* fluctuate in the pollen record, which may be due to phases of hazel clearance and recovery with a more open upper canopy having formed. Alder expanded slightly which may have been concentrated on moist ground close to the lake or beside rivers within the landscape (Preston et al., 2002).

The pollen record of the Late Neolithic is characteristic of steadily increasing anthropogenic activity, likely associated with small-scale pastoral farming. Increasing micro-charcoal indicates that fire may have been incorporated into clearance activities. Concurrent with the re-initiation of human activity is a decrease in LOI_{550} suggesting, as in the Neolithic *Landnam*, that woodland clearance was causing some catchment erosion of mineral material. This is also suggested by the lower concentration values from the start of this period which indicates an increase in sedimentation which would lessen the concentration of pollen within the lake sediment. A minor arable component from the Late Neolithic is indicated by cereal-type pollen from c. 2690 BC associated with arable indicators, likely goosefoot, garden orache and mugwort. Elsewhere in the Burren, at Loch Gaeláin, there was an expansion of grassland environments associated with pastoral and arable farming from c. 2850 BC (Feeser, 2009) which is particularly comparable with the Inchiquin data. Such activity did not register in additional local records from the Burren, however, where woodland appears to have continued until 2350 BC at Molly’s Lough, 2390 BC at Gortlecka and throughout the Late Neolithic at Rinn na Mona (Thompson, 1997; Watts, 1963; Watts, 1984). Further afield at An Loch Mór herb taxa expanded with a concurrent decline in AP representation from c. 2950 BC (Molloy and O'Connell, 2004; Molloy and O'Connell, 2007). The record from Inchiquin is similar to records from across mid-western Ireland that signal a return to farming practices towards the end of the Late Neolithic (O'Connell and Molloy, 2001), and across Ireland in general at this time indicated by the end of the '*Plantago* gap' as defined by Whitehouse et al. (2014).

The intensity of human activity suggested from the Inchiquin pollen record is similar to that of the Neolithic *Landnam* but there is less known archaeological evidence for a human presence in this period. Known activity within the catchment was concentrated at the Parknabinnia court tomb on Roughan Hill. Chamber 2 was blocked at c. 3095 – 2765 BC but deposition into chamber 1 did continue until c. 2770 BC (Jones, in press; Jones, Forthcoming-b) after farming had been re-established in the area. Although human interaction with the landscape increased throughout this period there is currently no further archaeological evidence of a human presence recognised.

Intensification of Farming Activity in the Chalcolithic – Early Bronze Age (c. 2520 – 1600 BC)

Throughout this period there was an intensification of farming activity which led to a decrease in AP representation by c. 20% attributed to woodland clearance prior to farming activity. NAPp representation continued to steadily increase from c. 2520 BC suggesting the expansion of species-rich grassland environments. A second Elm Decline was identified at c. 2460 BC, which while it may have been a consequence of disease, was concurrent with a peak in NAPp rising from 6.4 – 12.7%. A second Elm Decline was also identified in the Molly's Lough record at c. 2350 BC which may have been the result of disease, infestation or selective clearance (Lamb and Thompson, 2005). Given the intensity of the human occupation of the region at this time it seems likely that human activity was a contributing factor (Lamb and Thompson, 2005). Woodland clearance of oak and alder would have led to the increased openness of the woodland. Significant levels of *Pteridium*, a fern coloniser of newly-cleared areas (Marrs et al., 2000), registered in the pollen record for the first time from c. 2110 BC. The pollen record is suggestive of an expansion of pastureland inclusive of grass, ribwort plantain and dock. A near-continuous cereal-type curve was initiated at the start of this period accompanied with occasional occurrences of arable weeds (goosefoot and mugwort). As such the record indicates increasing levels of pastoral farming from the start of the Chalcolithic with a minor arable component. Palynological evidence elsewhere in the Burren is also suggestive of an increase in human activity from the start of this period with widespread pastoral farming suggested from Loch Gaeláin, Gortlecka, Rinn na Mona, and further afield at An Loch Mór (Feeser, 2009; Watts, 1984; 1963; Molloy and O'Connell, 2007; 2004). Both Loch Gaeláin and An Loch Mór, however, suggest a period of decreased activity for the final two centuries of the 3rd millennium BC, seen as a sharp decline in *Plantago lanceolata,* particularly, associated with an increase in *Ulmus* (Feeser, 2009; Molloy and O'Connell, 2004). Although perhaps not at the same magnitude, a small decrease in *Plantago lanceolata* is evident from c. 2290 BC in the Inchiquin record when *Ulmus* started to recover after the 2nd Elm Decline.

From c. 1810 BC there was a further, substantial increase in anthropogenic activity in the Inchiquin catchment with the initial removal of elm and hazel, and later of oak that allowed for the increased flowering of grassland herb taxa. The expansion of alder at this time may be due to the reduced density of the woodland canopy. NAPp representation indicative of grasslands increased to substantial levels (c. 27%), dominated by *Poaceae* (maximum of 13.9%) and *Plantago lanceolata* (maximum of 9.5%). Grassland species also included dock, dandelion, meadowsweet, buttercup, daisies, clover and chickweed. Bracken was able to colonise cleared areas of the landscape and the increased representation of herb taxa in this period indicates an intensification of pastoral farming activity within the catchment of Lough Inchiquin in the Early Bronze Age. Areas devoted to arable agriculture are also suggested from the constant presence of cereal-type pollen and goosefoot in this period. Similarly, pastoral activity in the catchment of Molly's Lough increased from the start of the Early Bronze Age when the first evidence of arable agriculture was also identified (Thompson, 1997). The evidence suggests that arable cultivation occurred slightly earlier in the catchment of Inchiquin (in the Late Neolithic) but in both cases it appears to have been practiced soon after the re-establishment of pastoral activity. All of the Burren pollen records including An Loch Mór suggest increased levels of pastoral farming activity from the start of the Early Bronze Age proper while the record from Loch Gaeláin adds to the evidence for an arable component at this time (Feeser, 2009; Watts, 1963; 1984; Molloy and O'Connell, 2004; 2007). The Inchiquin pollen record corresponds with a general increase in predominantly pastoral farming across Ireland during this period, and especially in the Early Bronze Age (Ghilardi and O'Connell, 2013a; O'Connell et al., 2014; Molloy and O'Connell, 2016; 2012; O'Connell and Molloy, 2017; Chique et al., 2017; Pilcher and Smith, 1979).

Reduced LOI_{550} and pollen concentration levels of all taxa indicate that sedimentation increased during the Chalcolithic – Early Bronze Age and is suggestive of erosion of catchment soils from this more intensive agricultural activity. Similarly, Thompson (1997) proposed an increase in catchment erosion derived from sedimentation rates in this period associated with human activity in the local area. Of interest is the significant rise in *Pediastrum* (unicellular alga) from c. 1810 BC in the Inchiquin record which suggests the lake system was now being impacted by this anthropogenic activity, resulting in nutrient enrichment (Jankovská and Komárek, 2000). This implies that some pastoral farming activity was likely occurring in close proximity to the lakeside. Increases in micro-charcoal correspond with that of pastoral indicators suggesting an anthropogenic source from woodland clearance or settlement activities.

The intensification of human activity in the landscape at this time is supported by the archaeological record. In the Roughan Hill area, fifteen wedge tombs have been identified (Jones, 1998; 2003; Ó Maoldúin, 2015; Jones et al., 2015), one of which has provided a Chalcolithic date (Ó Maoldúin, 2017 pers. comm.). There are further wedge tombs across the Burren clustered at Ballyganner/Leamaneh and the Poulnabrone depression, all likely constructed as the landscape was becoming more open which would have facilitated the construction of what is a dense concentration of monuments within a small area. Extending into the more intensive farming phase is settlement activity on Roughan Hill which includes a system of field walls and four habitation sites where activity has been identified between c. 2300 – 1550 BC (Jones, 1998; Jones and Gilmer, 1999; Jones, forthcoming-a). Current dating evidence suggests these sites were established two centuries after the re-initiation of farming activity in the catchment as determined by the present study. The pollen data would support the assertion of a distinct farming phase in this landscape (Jones, 2016), especially during the latter half of settlement activity when NAPp was particularly high. That the pollen data indicates extensive pasturelands during this time suggests the mound walls may have been associated with animal husbandry practices, with the Burren still being an important winterage site to this day.

Elsewhere within the catchment, settlement activity occurred at Teeskagh and in the Coolnatullagh valley (c. 2460 – 2140 BC) with secondary burial activity at Poulawack, the Coolnatullagh cist (c. 1745 BC) and Parknabinnia court tomb, and artefactual evidence (Jones, 2004; Taylor, 1970; Snoeck et al., Forthcoming). There is a lesser amount of known Chalcolithic – Early Bronze Age evidence in the wider landscape of the south-east Burren, suggesting human activity was perhaps concentrated in the upland Roughan Hill area, which would correspond with a wider expansion of agriculture into upland areas at this time in both Ireland and Britain (Jones, 2003; Jones et al., 2010).

Middle Bronze Age Woodland Regeneration (c. 1600 – 1230 BC)

Farming within the catchment started to decline from c. 1560 BC following the period of intensive activity. Significant woodland regeneration occurred between c. 1500 – 1320 BC when arboreal taxa reached an average of 81.5% of TTP. The most notable change in woodland composition was the expansion of hazel that occurred during this time (see expansion of *Corylus* especially in pollen concentration data). As human pressure on the landscape decreased, elm regenerated in the catchment of Lough Inchiquin. The only arboreal species to decline in this period was alder, perhaps caused by a reduction in wetter areas. From c. 1530 BC pine can no longer be considered part of the local woodland. It is likely that holly and ivy were growing on the outskirts of wooded areas, accompanied by lesser amounts of buckthorn, which can also be an undershrub in oak woodland, especially in limestone areas (Preston et al., 2002). The occurrence of *Rhamnus* was also identified in the An Loch Mór pollen record where an expansion of this species occurred in the Middle Bronze Age (Molloy and O'Connell, 2004).

Overall, the area under pastureland decreased within the catchment but herbs continue to be well expressed in the pollen record, particularly *Poaceae*, *Plantago lanceolata* and *Rumex acetosa*. *Pteridium*, however, hardly registers in the pollen record in this period suggesting a lack of newly open areas for it to colonise. As NAPp representation remains >14% for much of this period, the pollen data suggests the continuation of pastoral agriculture, albeit carried out at a smaller scale, or less intensely, within a denser woodland environment during the Middle Bronze Age. The continuation of the cereal-type curve, although reduced, indicates that arable cultivation was still occurring within the catchment. A significant decrease in the levels of *Pediastrum* is suggestive of decreased lake productivity and perhaps indicates that any continued farming activity occurred at a greater distance from the lake than in earlier periods. The level of LOI_{550} increased slightly which would be expected given the stabilisation of soils from established woodland, but further analysis (discussed in Chapter 7) suggests that LOI_{550} is likely not a reliable indicator of catchment erosion in the upper half of the pollen record.

Middle Bronze Age land-use dynamics across the Burren appear to have been variable. In the local pollen signal provided by Molly's Lough there was a continuation of both pastoral and arable agriculture at this time (Thompson, 1997). Similarly, the records from Loch Gaeláin and Gortlecka suggest continued human activity until c. 1300 and c. 1250 BC, respectively (Feeser, 2009; Watts, 1984; 1963). Although the Rinn na Mona record does not extend into this period, two additional profiles Cappanawalla and Lios Lairthín Mór, both located in the north-western Burren, are available for this period onwards. More comparable to Inchiquin is that of Cappanawalla where a pine-hazel woodland occurred, although the levels of *Plantago lanceolata* do suggest an open structure, and the dominance of *Pinus* suggests a different woodland composition to that at Inchiquin (Feeser and O'Connell, 2009). At Lios Lairthín Mór the pollen record opens towards the end of the Middle Bronze Age and suggests a rather more open landscape with high levels of *Plantago lanceolata* (c. 20%) suggestive of pastoral farming in the catchment (Jeličić and O'Connell, 1992; Feeser and O'Connell, 2009). As this begins at c. 1250 BC this is rather more comparable with the Late Bronze Age at Inchiquin.

Further afield at An Loch Mór the Middle Bronze Age was one of subdued activity which allowed hazel to regenerate (Molloy and O'Connell, 2004; 2007), as it did in the catchment of Inchiquin. It is clear that while perhaps a widespread partial recovery of woodland may have occurred in this period, there was still localised human activity occurring, and particularly so for the last century. The spatial and temporal variability of farming intensity in the Middle Bronze Age is evident in pollen profiles from across Ireland such as Lough Muckno, Co. Monaghan (Chique et al., 2017), Caheraphuca Lough, Co. Clare (Molloy and O'Connell, 2012), Lough Dargan, Co. Sligo (Ghilardi and O'Connell, 2013b), Ballinphuill bog, Co. Galway (Molloy and O'Connell, 2016) and several bog sites in Northern Ireland (Plunkett, 2009). In most instances, however, there was some resurgence of woodland towards the end of the 13th century BC (Plunkett, 2009; Pilcher, 1969; Molloy and O'Connell, 1995; Molloy, 2005).

The archaeological record for much of this period corroborates a decrease in activity with only limited evidence for a human presence within the landscape. Activity at the Roughan Hill settlement sites did continue, however, for the fifty years of the Middle Bronze Age (Jones, forthcoming-a). A secondary burial at one of the Roughan Hill wedge tombs suggests that the cairns of some, or all, of the Roughan Hill wedge tombs may have been constructed in the Middle Bronze Age (Ó Maoldúin, 2017 pers. comm.) which would increase the known archaeological presence for this period significantly. Burial activity occurred at Poulnabrone (c. 1582 BC – midpoint) and two phases of burial (c. 1610 – 1554 BC and c. 1486 – 1452 BC) have been identified at the Poulawack cairn (Lynch, 2014; Brindley and Lanting, 1991a). It is likely that some of the burnt mounds in the Burren date to this period (cf. Ó Néill, 2003; Hawkes, 2011) and the only excavated example in the Burren, Fahee South (c. 8.7km north-east of Lough Inchiquin), produced a date of c. 1408 – 1219 BC (Ó'Drisceoil, 1988; Brindley et al., 1989).

Intensive Late Bronze Age Farming Activity (c. 1230 – 600 BC)

A significant *Landnam* event occurred in the Late Bronze Age in the catchment of Inchiquin which was most intensive between c. 1230 – 1000 BC and c. 900 – 750 BC. Between these periods farming continued but at a reduced intensity, allowing for some woodland recovery within the catchment. NAPp representation reached its highest levels in the record (47.5%) by c. 1000 BC as a result of the significant expansion of species-rich grassland throughout the Late Bronze Age. Intensive human activity during this period led to the significant removal of hazel for the first time, indicating that scrub vegetation was a main target of clearances from c. 1200 BC. This suggests that the land was now being more fully cleared for agriculture, whereas in previous periods there had been a continued presence of understory shrubs. Other species affected by woodland clearance included alder, elm, ash and yew, the latter virtually absent from the record after c. 1070 BC. The increased levels of micro-charcoal in this period are likely related to the clearance of woodland or settlement activities at this time. Unusually, pine increases in the Late Bronze Age possibly reflecting long-distance transport as a result of reduced woodland canopy, although McGeever and Mitchell (2016) suggest there was a continuation of pine populations in the Burren at Rockforest Lough, 10km west of Lough Inchiquin.

The landscape was substantially more open in the catchment of Inchiquin at this time with an overall expansion of pastureland. Particularly high levels of *Poaceae* (maximum of 30.8%) and *Plantago lanceolata* (13.0%) are recorded especially during the first intensive phase. Dandelions, dock, buttercups, meadowsweet, daisies, clover and chickweed were components of the grasslands throughout the Late Bronze Age. That new areas were cleared in both intensive phases is suggested by the expansion of *Pteridium* to its highest levels (4.0% at c. 1100 BC and 5% at c. 860 BC). A slight decrease in farming intensity occurred from c. 1000 BC and lasted for a century, with a noticeable decline recorded in the *Poaceae*, *Plantago lanceolata* and *Rumex* curves. Concurrent with this was an expansion of hazel with some regeneration of birch, willow, buckthorn and ivy. Woodland cover was more open during this period with shrubs expanding and willow perhaps colonising damper land. As farming intensity increased once more, oak appears to have been preferentially cleared from the landscape in addition to hazel. The constant presence of cereal-type pollen throughout the Late Bronze Age with maximum levels for the record at c. 1070 BC (0.6%) and c. 830 BC (0.7%) indicates an arable component within the economy. Arable weed species (*Chenopodiaceae* and *Artemisia*) peaked during the two intensive phases. The pollen data of the Late Bronze Age is indicative of a largely pastoral landscape within the catchment with a prevalence of small-scale arable farming. The rapid and significant increase in *Pediastrum* implies that the lake itself was being affected by this activity and was becoming more productive as a result of anthropogenic nutrient loading. Thus, an argument can be made for farming activity in close proximity to the lake despite the regional nature of the pollen record.

The local signal provided by Molly's Lough indicates intensive activity at the start of this period which subsequently declined from c. 1030 BC (Thompson, 1997; Lamb and Thompson, 2005) when farming was at its most intense in the catchment of Lough Inchiquin. Although the dating of this record is poor, Thompson (1997) used evidence of the expansion of elm, and later of alder, ash and yew, across much of the catchment to suggest a pronounced decline in human activity, and perhaps population levels in this area in the Late Bronze Age. This is in contrast, however, to the Inchiquin record which records an intensive period of human activity lasting throughout the Late Bronze Age. Differences may lie in the characteristics of the catchment areas with the secluded basin of Molly's Lough providing only a very local signal where human activity may have indeed declined. The regional signal provided by Lough Inchiquin suggests increased activity in the wider Burren which is supported by a number of additional records, especially after c. 900 BC (Gortlecka, Cappanawalla and Lios Lairthín Mór) (Watts, 1984; Feeser and O'Connell, 2009; Jeličić and O'Connell, 1992). The situation in the catchment of Lios Lairthín Mór between c. 900 – 700 BC, when both pastoral and arable farming occurred, is especially comparable with the second phase of intensive Late Bronze Age farming at Inchiquin. In contrast, the record from Loch Gaeláin is most similar to that of Molly's Lough, where a reduction in activity continued until c. 750 BC suggesting a similar decline in activity in this local catchment during the Late Bronze Age (Feeser, 2009). The catchment of Loch Gaeláin (Figure 6.2) has been estimated by the current study to be c. 6.7km^2 compared with the

93.15km^2 encompassed by the Inchiquin data. As such, the Inchiquin pollen record is thought to be more representative of land-use across the Burren at this time, in contrast to the more local pollen records of previous investigations.

In the closing century of the Late Bronze Age, woodland in the catchment of Inchiquin became more prominent with hazel and ash in particular expanding but with some oak, elm, alder and willow regeneration. This occurred as a response to the decline of farming, and especially pastoral pressure on the landscape. Any pastoral activity was now occurring at a lower intensity and continuous records for cereal-type pollen indicate low-level arable farming. This is again in contrast with Loch Gaeláin where activity started to increase in this later stage (Feeser, 2009). The representation of NAPp also remained relatively high in the records from Cappanawalla and Lios Lairthín Mór in these later stages (Feeser and O'Connell, 2009; Jeličić and O'Connell, 1992). Some distance away at An Loch Mór, there was a period of intensive farming activity which began at c. 1050 BC and continued until 400 BC (Molloy and O'Connell, 2007; 2004).

From the combined pollen evidence, Late Bronze Age activity appears to be quite variable in terms of the timing and intensity of land-use across the Burren. It is clear that the evidence for Late Bronze Age agricultural activity is strongest at Lough Inchiquin, just to the south of the Burren in comparison with the additional pollen records from the north-eastern Burren and south-eastern edge. It could be the case that intensive Late Bronze Age activity was concentrated both close to Lough Inchiquin itself and perhaps in the more central or western region. The Inchiquin pollen record appears to correspond well with the general Irish trend at this time for intensive agricultural activity as opposed to the other Burren records. In more southerly Co. Clare, distinct Late Bronze Age *Landnam* events occurred in the catchments of Mooghaun and Caheraphuca Loughs (Molloy, 2005; Molloy and O'Connell, 2012; O'Connell et al., 2001). Elsewhere in Ireland, Plunkett (2009) has demonstrated the intensity of activity associated with both the start of the 12th and 10th centuries BC, and intensive activity has been recorded at a number of sites in the west and south of Ireland such as Lough Dargan, Co. Sligo (Ghilardi and O'Connell, 2013) Cooney Lough, Co. Sligo, (O'Connell et al., 2014), Ballinphuil Bog, Co. Galway (Molloy et al., 2014), Deryville Bog, Co. Tipperary (Caseldine et al., 1996) and in the Beara Peninsula, Co. Cork (Overland and O'Connell, 2008). Similarly, the decreased activity at Inchiquin towards the end of the Late Bronze Age is reflected in a number of records in northern and western

Ireland which led Plunkett (2009) to suggest widespread reduced pressure on the landscape at this time.

Despite the pollen record indicating that this was the most intensive period of farming activity, the archaeological evidence for human activity is limited. Grogan (2005a) suggests that the distribution of burnt mounds in the lowland area to the north-east of Lough Inchiquin may represent settlement activity into the later Bronze Age and six such features are located less than 2km from the lake with many more throughout the catchment. Artefacts including weapons and the Gleninsheen gold collar have been discovered in the Burren (Clare County Library, 2017; Lynch, 2014; Gleeson, 1934). Late Bronze Age settlement activity has been identified at Teeskagh and the find of a proposed Late Bronze Age hoe blade at the site (Gibson, 2016) confirms the possibility of arable cultivation suggested from the pollen data. An enclosure in the Carran plateau has been dated to the Late Bronze Age (Gibson, 2016; Jones et al., 2010), contemporary with the intensive farming phases. The sites of Teeskagh and Carran provide the only known archaeological evidence suggestive of settlement and/or subsistence in the catchment at this time. Outside of the lake catchment, in the wider area to the north, (c. 17km from Lough Inchiquin) recent Late Bronze Age dates have been obtained from hut sites at Turlough Hill (Ó Maoldúin, 2018 pers. comm.; Ó Maoldúin and McCarthy, 2016). Given the intensity of Late Bronze Age farming activity in the Inchiquin pollen record, more archaeological evidence from this period would be expected in the Burren. Therefore, while the lack of archaeological evidence has previously been used to suggest a lack of human activity in the Late Bronze Age Burren, the pollen data refutes this and indicates intensive land-use likely associated with settlement activity. Although the catchment of Lough Inchiquin is large, the resulting pollen diagram, which includes pollen from poorly-dispersed NAPp taxa including cereal-type, and increased levels of algae in the lake, hints at a continuation of activity in close proximity to the lakeside.

Early Iron Age Activity (c. 600 – 20 BC)

Overall, human activity decreased in this period when compared with the Late Bronze Age, with woodland regeneration occurring but combined with a continuation of some human activity. Pine was virtually absent from c. 350 BC which is the generally accepted date for its extirpation in Ireland, although there has been a recent suggestion of its continued presence in the Burren (Huntley and Birks, 1983; McGeever and Mitchell, 2016; Roche et al., 2018). AP representation was high during the start of this period with a slight decrease at c. 530 BC, especially evident in the concentration diagram, which was concurrent with an increase in *Poaceae*, *Plantago lanceolata*, *Chenopodiaceae* and *Artemisia* indicating both pastoral and arable activity. From c. 430 BC there was a more substantial decrease in *Fraxinus*, *Corylus* and *Quercus* (and micro-charcoal) coinciding with an expansion of herb taxa especially of *Poaceae*, *Plantago lanceolata* and *Liguliflorae* (likely of *Taraxacum officinale*). An intensification of a mixed farming economy in the Early Iron Age is therefore postulated. Increased *Pediastrum* at this stage hints at localised activity close to the lake itself. This is comparable with the record from Molly's Lough where there was renewed clearance, mostly of elm, but later of hazel and ash with an increase in both pastoral and arable agriculture from c. 430 BC (Thompson, 1997). Elsewhere in the Burren there were variable levels of activity expressed in the pollen records, with increased activity in the catchments of both Gortlecka and Cappanawalla for the majority of this period, and a reduction in farming intensity from c. 500 BC in the record from Lios Lairthín Mór (Watts, 1984; Jeličić and O'Connell, 1992; Feeser and O'Connell, 2009).

From c. 210 BC onwards the levels of AP increased with the recovery of both tall-canopy and understory species (oak, elm, hazel, ash and alder). Ivy and buckthorn may have expanded at the edges of woodland areas. A simultaneous decrease in overall NAPp representation occurred, most evident in the *Plantago lanceolata* curve. The reduction of activity towards the end of this period may represent the beginnings of the Late Iron Age Lull, a period of widespread woodland regeneration that occurred across Ireland; its onset generally lying between c. 200 BC and AD 200 (Coyle McClung, 2013). At Loch Gaeláin intensive pastoral farming occurred earlier than at Lough Inchiquin from c. 650 BC, but reduced at roughly the same time, at c. 250 BC (Feeser, 2009). These two records are particularly comparable in terms of the reduction in farming in the final stages of the 1st century BC suggesting a significant decrease in activity possibly associated with a Late Iron Age Lull (Feeser, 2009). The Late Iron Age Lull as identified in the Molly's Lough record occurred c. 50 BC – AD 450 (Thompson, 1997), at Lios Lairthín Mór c. AD 200 – AD 580 (Jeličić and O'Connell, 1992) and at Loch Gaeláin c. 50 BC – AD 450 (Feeser, 2009).

Archaeological evidence from this period is largely ephemeral. An iron spearhead was discovered in the nineteenth century in the River Fergus, close to where it enters Lough Inchiquin and two bridle-bits were discovered near to the modern village of Corofin, less than 2km from the lake (Jones, 2004). Artefactual evidence in the wider catchment includes two beehive-shaped quernstones found at Cohy (10km north-west) and Glencolumbkille (11km north-east) and a bridle pendant found in a bog near Lisdoonvarna (14km west) (Jones et al., 2010). Ring-barrows in the Doolin landscape (c. 20km west) have been proposed to date to this period (Jones, 2004) and four are located in the landscape to the west of Lough Inchiquin, ranging from 2 – 4km away.

6.6 Conclusion

A high-resolution palynological reconstruction at Lough Inchiquin has been presented which, through the establishment of a robust chronology, has allowed for a detailed account of landscape change and associated human activity in the Burren region of Co. Clare. The first signs of human interaction with the landscape occurred in the Early Neolithic where a *Landnam* type event registered along with archaeological evidence for monumentality in the area. Widespread woodland regeneration occurred in the Middle Neolithic despite a strong archaeological record with fewer archaeological remains dating to the Late Neolithic when low-level farming was re-initiated in the catchment. Discrepancies between the datasets are further discussed in Chapter 9 but are likely caused by variable visibility in the archaeological record reflective of the types of archaeological sites within the study area. This is in contrast to the continuous accumulation of palaeoenvironmental data which allows for a reconstruction of vegetation change regardless of other factors within the landscape. The upstanding remains of Middle Neolithic monumental burials are well preserved whereas archaeology relating to increased farming activity in the Late Neolithic, that registers in the pollen record, may now be unrecognised in the landscape.

The archaeological and palaeoecological records correspond especially well during the Chalcolithic – Early Bronze Age when a distinct farming phase was suggested both by an increased representation of pastoral and arable indicators, and evidence of settlement and occupation of the southern Burren, particularly at Roughan Hill. Some woodland regeneration then occurred in the Middle Bronze Age, when the majority of human activity is represented by the burial record. Interestingly, the most intensive phase of farming activity in the catchment occurred during the Late Bronze Age, when the known archaeological evidence for a human presence is limited. This new pollen evidence confirms the continued occupation of this area in contrast to the low visibility of the archaeological record which would suggest only a very limited presence. The capacity for pollen analysis to detect farming activity in a landscape, even when archaeological remains are absent or unrecognised is a methodological advantage of this technique. In the current study, the palaeoenvironmental data are key to the interpretation of the Late Bronze Age occupation of the Burren and the palaeoenvironmental data suggests that a profitable future focus of archaeological research on the Burren would be the Late Bronze Age.

Significant features in the Inchiquin record, e.g. the Elm Decline and Middle Neolithic woodland regeneration, correspond well with other Burren profiles and those from across Ireland. The profile from Molly's Lough is generally similar to that of Inchiquin but the lack of Middle Bronze Age woodland regeneration and the identification of a Late Bronze Age 'lull' at Molly's Lough may reflect the very local signal of this record in comparison to the regional signal provided by Inchiquin. Differences in farming dynamics, timing and intensity between the Inchiquin record and those from the south-eastern and northern Burren are likely also due to this factor. The wider regional signal of farming activity obtained from Lough Inchiquin has provided a more detailed insight into human-environment interactions across the Burren through prehistory, with the more local elements of the record providing a view of landscape change within the vicinity of this large lake, which appears to correspond with wider Irish trends.

Chapter 7 – A Palaeolimnological Study of Lough Inchiquin

7.1 Introduction

This chapter will discuss the results of a multi-proxy palaeolimnological study of the sediment extracted from Lough Inchiquin. The size of the lake is such that the catchment area encompasses the limestone karst of the Burren region which is host to a dense concentration of archaeological sites as explained in detail in Chapter 3. To summarize these range in date from the Early Neolithic to the Bronze Age and of particular interest to this study is the area of Roughan Hill (Jones and Walsh, 1996; Jones, 1998; Jones, 2003; Jones, 2016; Jones and Gilmer, 1999; Jones et al., 2015; Ó Maoldúin, 2015) (Figure 2.4 and 6.2). From the archaeological record the period of most intense human activity is that of the Chalcolithic – Early Bronze Age with fifteen wedge tombs dating to between c. 2500 – 2100 BC forming the densest concentration of such monuments in the country (Jones, 1998). Human occupation on Roughan Hill is proposed to be particularly intensive between c. 2300 – 1550 BC with a number of habitation sites and associated field systems in use at this time (Jones, 1998; Jones, forthcoming-a; Jones and Gilmer, 1999).

Chironomid sub-fossil analysis, and organic ($\delta^{15}N$, $\delta^{13}C$ and C:N) and inorganic (S, Ti, Fe, Mn) geochemistry have been applied to the lake sediment core extracted from Lough Inchiquin in order to carry out a palaeolimnological study. Palaeolimnological data will be contextualised by the pollen data, previously discussed (Chapter 6), which has identified the timing and magnitude of prehistoric farming. Chironomid analysis is an important palaeolimnological technique as chironomids are ubiquitous in lake systems and sensitive to environmental changes within the lake system, such as trophic status, clarity and food availability (Walker, 2001). Although typically used for palaeoclimatic reconstruction, recently, chironomid analysis has been successfully applied to investigations focusing on human-environment interactions including the application of the technique within archaeology (Ruiz et al., 2006; Taylor et al., 2013; 2017a; 2017b; Chique, 2017; Chique et al., 2018). The stenotopic nature of chironomid taxa means that changes in chironomid community composition can be associated with the nutrient enrichment of a lake system, which can be caused by pastoral agriculture. By examining the dominant influences that affect modern chironomid assemblages it was determined that percentage agriculture within the lake catchment was a dominant control on the variance within chironomid communities in western Ireland and could overwhelm the climate signal if a substantial level of farming had occurred within the catchment (Potito et al., 2014; McKeown and Potito, 2016). Chironomid analysis has been successfully applied to studies on prehistoric farming in western Ireland (Taylor et al., 2013; 2017a; 2017b), and with agriculture having impacted the majority of Irish landscapes since the Neolithic it is a valuable field of research.

Organic geochemistry has complemented chironomid analysis in previous studies with indicators able to provide information on lake productivity and the sources of lake-sediment organic matter (Cohen, 2003; Talbot, 2001; Woodward et al., 2012). $\delta^{15}N$, $\delta^{13}C$ and C:N ratios can be used to investigate the process of lake eutrophication which is often caused by nutrient loading as a result of modern pastoral farming activity (Talbot, 2001; Botrel et al., 2014; Bunting et al., 2007). The $\delta^{15}N$ signal of lake sediments is determined both by the $\delta^{15}N$ signature of organic matter within the lake, and in-washed material from the catchment (Woodward et al., 2012). Deforestation linked to agriculture can lead to the in-wash of material into a lake system, and if farming is occurring in close proximity to a lakeside, then leaching of nitrogen from animal manure may also reach the lake system. Increases in $\delta^{15}N$, therefore, can be caused both by the in-wash of animal manure, typically enriched in $\delta^{15}N$ (Woodward et al., 2012) and/or soil erosion (Talbot, 2001; Kendall, 1998)**.**

Further elucidation of erosion processes within lake catchments can be gained through inorganic geochemical data. Increased levels of trace elements within lake sediments have been linked to erosion and can be used to assess the weathering regime of catchment areas (Mackereth, 1966). Levels of certain elements, such as sulphur (S), iron (Fe) and manganese (Mn), although heightened by the erosional influx of material, can be affected by post-depositional within-lake processes (Mackereth, 1966; Engstrom and Wright Jr, 1984; Cohen, 2003). Titanium (Ti), on the other hand, is strictly of terrigenous origin and is largely unaffected by post-depositional processes, which allows it to serve as an erosion indicator in palaeolimnological studies (e.g. O'Connell et al., 2014; Boyle et al., 2004; Arnaud et al., 2012). The current study aims to provide a palaeolimnological assessment of the impact of prehistoric farming activity upon the lake system of Lough Inchiquin using a multi-proxy approach. It is the first to reconstruct lake response in the Burren to prehistoric farming activity using chironomid sub-fossils and lake-sediment organic geochemistry, contextualised by new pollen evidence. It is the first palaeolimnological study that provides the potential to elucidate the timing of the erosion of Burren soils, through the use of inorganic geochemistry, which is assumed to have occurred during the Holocene (Moles and Moles, 2002; Moles et al., 1999; Drew, 1983).

7.2 Methods

7.2.1 Coring

The 10.6m long sediment core was extracted from Lough Inchiquin using a Usinger piston corer, at a water depth of 30m (GPS co-ords N52°57'20" W9°05'16") as described in Chapter 5 (see Figure 6.1 for coring location).

7.2.2 Chronology

As described in Chapter 6, age control for Lough Inchiquin is based on seven accepted ^{14}C-AMS determinations that were subsequently used to establish an age-depth model using Bacon v. 2.2 Bayesian age-depth modelling software (Blaauw and Christen, 2011) with the IntCal 13 calibration curve (Reimer et al., 2013). All ages produced by Bacon are expressed as calibrated years BC and are rounded to the nearest ten years.

7.2.3 Chironomid Analysis

Chironomid sub-fossil analysis was carried out on fifty eight samples between 788 – 444cm taken at varying intervals throughout the core in order to correspond with pollen sub-sampling. Samples were taken at 8cm intervals between the depths 732 – 692cm and 552 – 456cm and 4cm intervals between 684 – 560cm. The basal five samples were not taken at a consistent interval but at depths that were consistent with the lowest pollen depths. Similarly the uppermost two samples had a 12cm interval. The methodology followed standard procedures outlined by Walker (2001) and presented in detail in Chapter 5. Chironomid identifications were made using a Motic B3 Professional Series microscope at x100 to x400 magnifications with associated Motic camera software to further aid identification. Taxonomic identification was based on Brooks et al. (2007), Wiederholm (1983) and Rieradevall and Brooks (2001).

A total of eighty four taxa were identified in the Inchiquin core with forty-eight designated as common taxa. The interpretation of chironomid ecology was based on Brooks et al. (2007), Vallenduuk and Pillot (2007); Moller Pillot (2009); Moller Pillot (2013), Potito et al.

(2014) and Chique et al. (2018). Statistically significant Chironomid Assemblage Zones (CAZs) were established using Psimpoll (Bennett, 2009-1993). Chironomid diagrams were produced in C2 v. 1.7.7 (Juggins, 2003). All further graphs were completed in SigmaPlot version 12.0.

7.2.4 Organic and Inorganic Geochemistry

Organic and inorganic geochemistry was carried out at Amherst College and the University of Massachusetts, Amherst, USA, with the exception of $\delta^{15}N$ analysis which was carried out by the UC Davis Stable Isotope Lab, Department of Plant Sciences at University of California. Details of methods were provided in Chapter 5.

The stable isotope ratios of nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) and elemental concentrations of C and N were analysed at 10cm intervals from 1052 – 5cm. Results from 785cm – 365cm will be presented. Elemental analysis was carried out at every millimetre along the full length of the Inchiquin core. The data was averaged for each centimetre between 788 – 444cm. Geochemical data at depths corresponding to the chironomid samples were used in statistical ordinations.

7.2.5 Ordination Analysis

All ordination analyses were performed using Canoco v.5 (Ter Braak and Smilauer, 1997) on square-root transformed chironomid percentage data for all common taxa. Changes in chironomid community composition through time were analysed using principal components analysis (PCA), an unconstrained linear ordination method, and redundancy analysis (RDA), a constrained linear ordination method.

A constrained RDA was carried out using sixteen environmental variables relating to geochemical and palaeoenvironmental data. Geochemical variables used were LOI_{550}, LOI_{950}, $\delta^{15}N$, $\delta^{13}C$, C:N, S, Ti, Mn, Fe. Palaeoenvironmental data (as percentage values) were NAPp, *Plantago lanceolata*, cereal-type, *Nymphaea*, *Pediastrum*, *Myriophyllum* and *Botryococcus*. These variables were chosen on the basis that they are associated with land-use, which is known to influence lake productivity. The land-use variables NAPp and *Plantago lanceolata* are known to be indicative of the extent of grassland or pasture and cereal is a direct indicator of arable cultivation representing agricultural land use. The variables *Nymphaea* and *Myriophyllum* (aquatic plants), and *Pediastrum* and *Botryococcus* (algae) can indicate the nutrient status of the lake and source of lake sediment organic content. The variables $\delta^{15}N$ and $\delta^{13}C$ can similarly indicate the nutrient status of the lake (Woodward et al., 2012) while LOI_{550} and LOI_{950} provide estimates of the percentage organic matter and percentage carbonate, respectively. The elements included as environmental variables, S, Ti, Mn and Fe are indicators of erosional activities within lake systems. Variables with high co-linearity (variance inflation factor >20 x) were removed from the dataset which led to the rejection of LOI_{950} from further analysis. Constrained analysis was re-run with the remaining fifteen variables and no further co-linearity was identified.

A constrained RDA was carried out using the fifteen environmental variables to identify the explanatory potential of the variables on chironomid community composition. Each individual variable was tested in order to identify which variables could explain a statistically significant ($p \leq 0.05$) amount of the variation in chironomid species composition. For each variable p-values were adjusted using false discovery rate, Holm correction and Boneforri correction within the Canoco program. The results of the constrained RDA led to the rejection of insignificant variables, *Botyrococcus*, *Nymphaea*, $\delta^{13}C$, S, Fe and Mn, from further analysis. The nine remaining statistically significant variables ($\delta^{15}N$, C:N, LOI_{550}, Ti, NAPp, *Plantago lanceolata*, Cereal-type, *Pediastrum* and *Myriophyllum*) were plotted passively against taxa and sample PCA plots to examine the relationships between the chironomid taxa and environmental variables. A correlation matrix was constructed to determine the relationships between the different variables.

An interactive forward selection RDA was carried out to identify which of the remaining nine variables explained the greatest amount of variance within the chironomid data. These variables were forward-selected in order of decreasing variance and selection continued until no new variables were significant predictors of chironomid assemblage data. The variables with the highest conditional effects were determined.

7.3 Results

7.3.1 Chronology

A robust chronology for the period c. 4590 – 10 BC was developed for the Inchiquin sediment core based on seven ^{14}C dates as discussed in Chapter 6 with a potential error ranging from c. 160 – 740 years throughout the prehistoric period.

7.3.2 Chironomid Analysis

The chironomid stratigraphy was divided into three statistically significant zones, CAZ-1, CAZ-2 and CAZ-3. CAZ-3 was further subdivided at 548cm into two subzones. Although the subzones are not statistically significant, the divide approximately marks the beginning of the Late Bronze Age and is useful for interpretation. The chironomid diagram is presented in Figure 7.1. Figure 7.2 presents microscope images of important indicator taxa from the Inchiquin record.

CAZ-1 788 – 680cm; c. 4590 – 2810 BC (Mesolithic – Late Neolithic)

This zone is dominated by oligotrophic taxa with the highest levels of *Micropsectra insignilobus*-type (14%) and *Heterotanytarsus* (11%) observed in this zone. The oligotrophic taxon *Pagastiella* is also most abundant in this zone with decreased levels seen in the remaining stratigraphy and *Tanytarsus lugens*-type is only present within this zone. *Sergentia coracina*-type, often used as an oligotrophic taxon in Ireland, peaks at 14% in this zone. Other well represented taxa include *Dicrotendipes nervosus*-type which attains its highest levels in this zone peaking at 20%. *Tanytarsus* undifferentiated, *Tanytarsus pallidicornis*-type and *Tanytarsus mendax*-type are well represented, peaking at 16%, 10% and 7%, respectively. Low levels of *Chironomus anthracinus*-type were observed (average of 1%) with a very slight increase peaking at 3% between 748 – 716cm. *Cricotopus intersectus*-type increases in the upper half of the zone to a maximum of 14%.

CAZ-2 676 – 636cm; c. 2810 – 2170 BC (Late Neolithic – Chalcolithic)

Mesotrophic – eutrophic taxa are more prevalent with *Chironomus anthracinus*-type peaking at 9% at the end of this zone. *Glyptotendipes pallens*-type increases in abundance. *Psectrocladius sordidellus*-type was only present in one sample in the previous zone but now peaks at 8%. *Microtendipes pedellus*-type ranges from 2 – 7%. *Polypedilum nubesculosum*-type has a much greater abundance reaching a maximum of 8% while *Parakieferiella bathophila*-type peaks at 5%. This zone sees the highest representation of *Corynoneura edwardsi*-type in the stratigraphy, attaining a maximum value of 11%. *Tanytarsus* undifferentiated and *Tanytarsus mendax*-type shows an increased abundance in this zone peaking at 24% and 8%, respectively. Other well-represented taxa include

Sergentia coracina-type which has an average value of 12%, and *Heterotanytarsus* which while it reaches a maximum of 6% only has an average of 2% throughout the zone.

CAZ-3 632 – 444cm; c. 2170 – 660 BC

Subzone 3a 632 – 552cm; c. 2170– 1380 BC (Early – Middle Bronze Age)

A further increase in levels of mesotrophic – eutrophic taxa occurs such as *Chironomus anthracinus*-type which reaches 10%. Similarly, *Microtendipes pedellus*-type (maximum of 12%), *Cricotopus intersectus*-type (maximum of 13%), *Synorthocladius* (maximum of 10%), *Stempellinella* (maximum of 4%) and *Polypedilum nubesculosum*-type (maximum of 8%) all increase in representation. *Tanytarsus* undifferentiated, *Tanytarsus pallidicornis*-type and *Tanytarsus mendax*-type are well-represented peaking at 15%, 10% and 9%, respectively. *Parakieferiella bathophila*-type achieves its highest levels with a maximum value of 9%. Two taxa, *Stictochironomus* and *Endochironomus impar*-type which are predominantly absent from the stratigraphy, are represented at low levels in this subzone at 6% and 5%, respectively. Oligotrophic taxa decrease including *Pagastiella* (present in only 3 samples), *Micropsectra insignilobus*-type (1 – 8%) and *Heterotanytarsus* (maximum of 6%). Prevalent macrophyte-dwelling taxa include *Dicrotendipes nervosus*-type (average of 8%) and *Paratanytarsus* (average of 4%). *Sergentia coracina*-type is still well represented at an average of 9%.

Subzone 3b 544 – 444cm; c. 1380 – 660 BC (Middle – Late Bronze Age)

An increase in eutrophic taxa is evident in this subzone with the highest representation of both *Microtendipes pedellus*-type (maximum of 20%) and *Crictotopus intersectus*-type (maximum of 21%). *Chironomus anthracinus*-type increases in representation with a maximum value of 11%, and *Synorthocladius* peaks at 8%. Other prevalent taxa include *Sergentia coracina-type,* which is continuously well represented maintaining an average of 9%, *Stempellina* with a maximum of 10% and *Tanytarsus* undifferentiated averaging 10%. Macrophyte-dwelling taxa are still prevalent with *Dicrotendipes nervosus*-type peaking at 11% and *Paratanytarsus* achieving its highest levels in the stratigraphy at 12%. *Ablabesmyia* reaches a maximum of 9%.

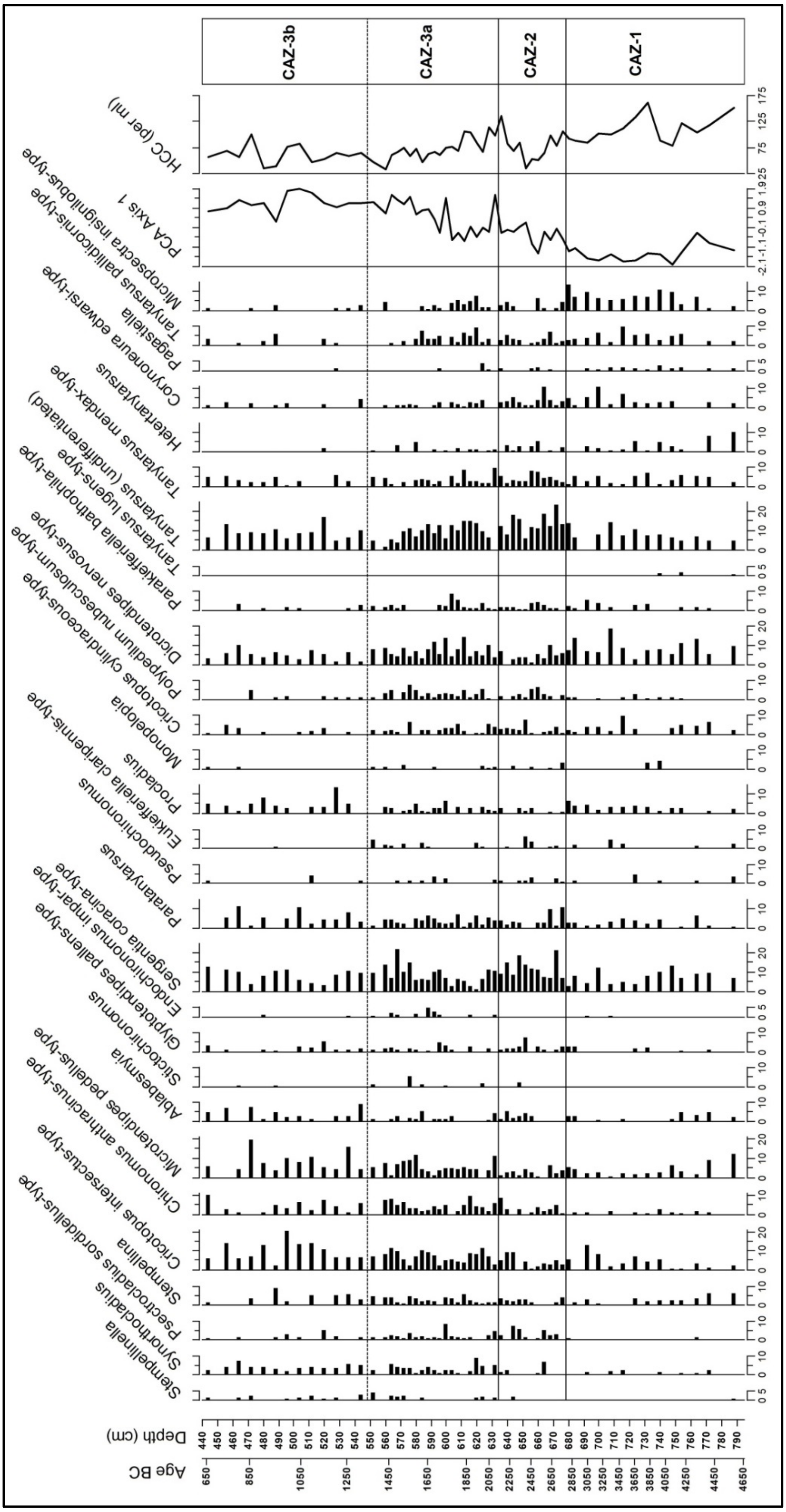

Figure 7.1: Relative percentage chironomid abundance plotted against sediment depth and divided into statistically significant CAZs. Chironomid taxa are provided at the top and are organised such that more oligotrophic taxa are to the right and more eutrophic taxa on the left. The informal subdivision of CAZ3a-b is presented as a dashed line. An age-scale is presented alongside the y-axis. Head capsule concentration (per ml) and a PCA axis-1 curve (representative of trophic conditions) are presented on the right-hand side.

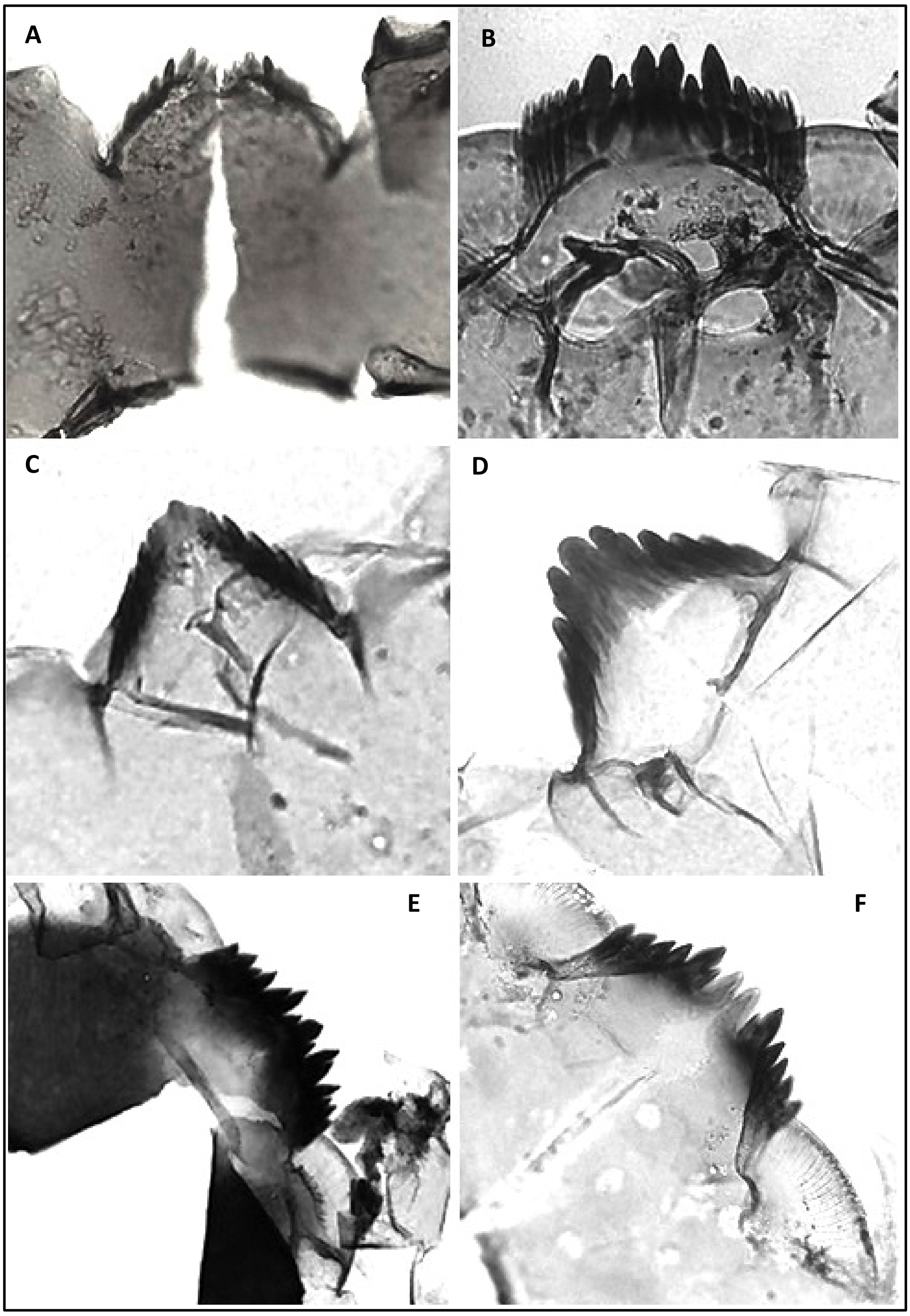

Figure 7.2: Indicator chironomid taxa from the Lough Inchiquin lake sediment. (A) Heterotanytarsus – oligotrophic/dystrophic, (B) *Polypedilum nubesculosum*-type – sandy sediments, (C) *Parakieferiella bathophila*-type – psammobiotes, (D) *Cricotopus intersectus*-type – eutrophic, (E) *Chironomus anthracinus*-type – eutrophic/agriculture, (F) *Microtendipes pedellus*-type – eutrophic/agriculture. Source: author.

7.3.3 Organic and Inorganic Geochemistry

The results of $\delta^{15}N$, $\delta^{13}C$ and C:N ratios between the depths of 785 to 445cm are presented in Figure 7.3 alongside the relative intensities of the elements sulphur, titanium, iron and manganese between the depths 788 to 444cm and LOI data.

788 – 659cm; c. 4550 – 2510 BC (Mesolithic – Late Neolithic)

At the start of this period the $\delta^{15}N$ values are low ranging from 2.8 – 3.3‰. At the start of the Neolithic, between 745 – 715cm, the $\delta^{15}N$ values increase reaching a maximum of 4.4‰. Towards the end of the Middle Neolithic, from 715cm onwards, $\delta^{15}N$ values fall slightly with a minimum of 3.8‰ at 695cm. From this time $\delta^{15}N$ values again increase rising from 3.8 – 5.4‰ by the end of the Neolithic at 665cm. At the start of this period $\delta^{13}C$ values increase from -31.7 – -30.7‰ by 735cm. For the majority of the Middle and Late Neolithic $\delta^{13}C$ values remain relatively constant before decreasing slightly to -31.1‰ at 665cm. In the Early Neolithic the C:N ratios increase from 15.2 – 16.8 and subsequently decrease between 745 – 715cm with an average of 14.4. C:N ratios then increase to 15.2 and remain relatively stable until 675cm when they decrease to 13.7.

The values for S are very low and relatively constant throughout this period averaging 0.1cps. The values for Ti are low with an average of 0.5cps between 788 – 749cm. A general increase is seen with a period of higher values between 742 – 726cm. Ti remains relatively constant averaging 0.6cps until 683cm. For the remainder of the Late Neolithic the values of Ti increase to a high of 1.2cps by 659cm. The Fe values are relatively low for this period but do see a general increase from 13.7cps to 97.5cps by c. 659cm. Mn values are low during this period with an average of 1.4cps but do see higher values between 759 – 724 cm.

658 – 632cm; c. 2590 – 2110 BC (Chalcolithic)

$\delta^{15}N$ values increase from 5.4 – 5.8‰ (665 – 655cm) before declining to 5.4‰ at 625cm. The $\delta^{13}C$ values are relatively constant with fluctuation between -30.8 – -31.1‰. C:N ratios decrease to 12.3 by 655cm before increasing to 13.9 at 645cm. C:N subsequently declines for the remainder of the period.

The values for S remain low until 647cm with an average of 0.04cps. Subsequently values steeply increase to a maximum of 2.0cps at 644cm before a sharp decrease to a low of 0.5cps at 636cm. Values then increase to peaks of 1.4cps at 635cm and 632cm. Ti values increase to a high of 1.3cps by 657cm before declining to 0.6cps by 644cm. A further increase to 0.9cps occurs at 636cm and values then decrease towards the end of the Chalcolithic with a value of 0.7cps at 632cm. Fe values rise sharply to a maximum of 164.5cps from 659 – 653cm before declining to 81.4cps by 644cm. Values increase again to a maximum of 112.9cps by 638cm and subsequently decline for the remainder of this period to a value of 91.9cps. Mn values reach a high of 9.8cps by 653cm before declining to 2.3cps by 644cm. The values then oscillate for the remainder of the period ranging from 2.3cps – 4.7cps.

631 – 582cm; c. 2110 – 1610 BC (Early Bronze Age)

$\delta^{15}N$ values steadily rise from 5.4 – 6.7‰ by 585cm. The $\delta^{13}C$ values are relatively constant with an average of -30.9‰. The decline in C:N continues in this period falling from 13.7 – 12.4 by 585cm.

A decline in S values to a low of 0.1cps at 628cm occurs at the start of this period. Values increase to a maximum of 1.1cps at 615cm before declining to 0.04cps for the remainder. Ti values see a general increase to 1.1cps by 608cm before declining to 0.7cps by 582cm. Fe values increase to a maximum of 121.9cps by 617cm before decreasing to 53.5cps by 582cm. Mn values oscillate throughout this period with an average of 2.9cps.

581 – 529cm; c. 1610 – 1210 BC (Middle Bronze Age)

From the start of this period $\delta^{15}N$ values decline to 5.7‰ by 555cm before increasing to 6.2‰ by 535cm. $\delta^{13}C$ values continue to fluctuate with an average of -31.2‰ until 535cm. C:N ratios increase initially to 13.4 by 575cm before fluctuating with an average of 13.6 until 535cm.

S values remain at low levels throughout this period with an average of 0.04cps. Ti decreases to relatively low levels averaging 0.5cps during this period. Fe values decrease with an average of 45.9cps observed in this period. Mn values are relatively constant with an average of 1.3cps.

528 – 444cm; c. 1210 – 660 BC (Late Bronze Age)

$\delta^{15}N$ values remain consistently high throughout this period with an average of 6.4%. $\delta^{13}C$ values increase to a maximum of -30.3‰ by 515cm before declining to -31.2‰ by 485cm. Values increase to -30.3‰ by 475cm before declining to -31.6‰ at the end of this period. A maximum C:N ratio is evident at 515cm with a value of 14.1 before declining to 12.4 at 485cm. An increase to 13.6 is seen by 465cm before declining to 12.4 at the end of this period.

S values remain consistently low during this period with an average of 0.04cps. Ti values remain relatively low throughout this period with an average of 0.5cps. Both Fe and Mn maintain low levels in the Late Bronze Age averaging 49.9cps and 1.3cps, respectively.

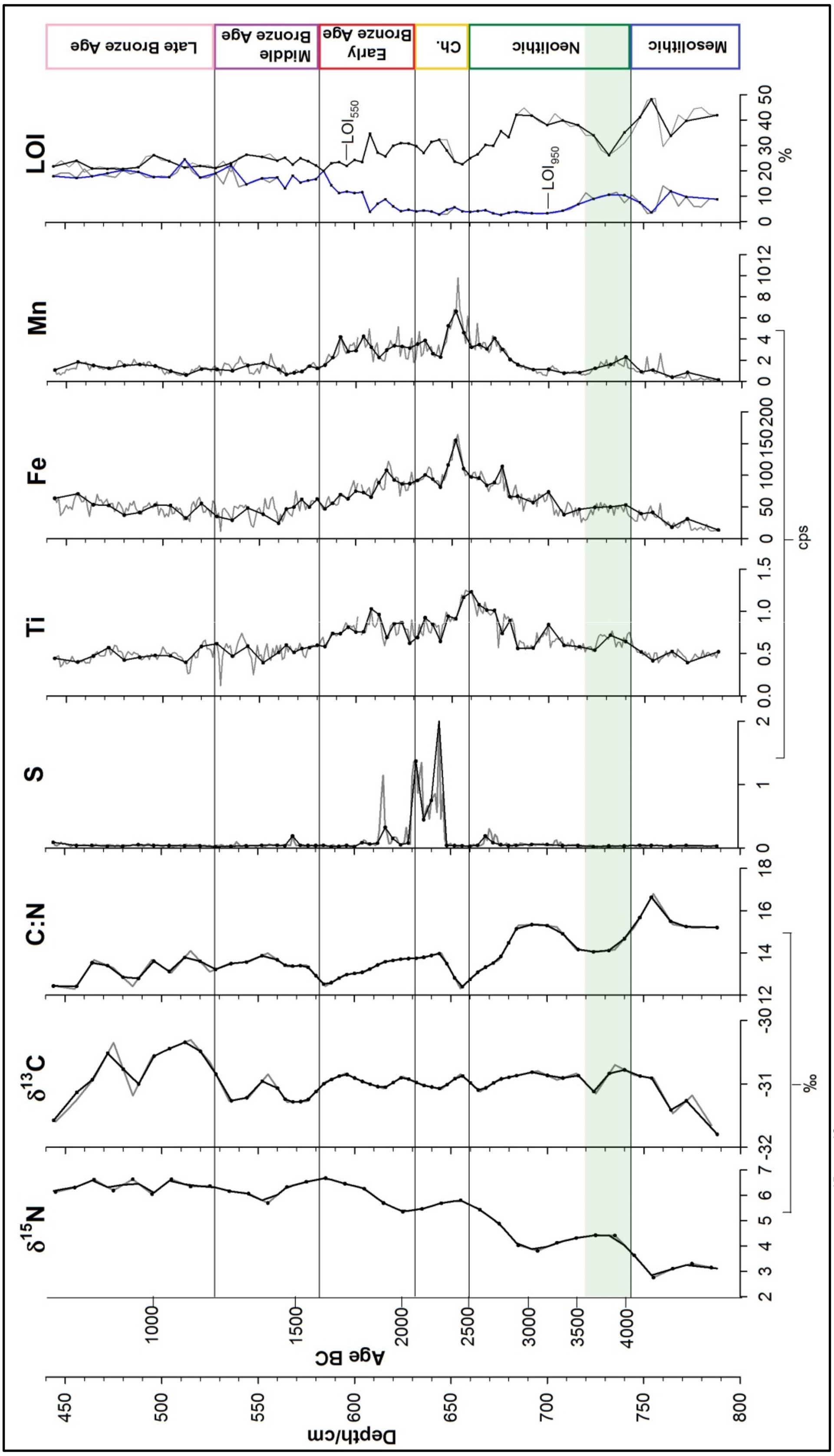

Figure 7.3: Organic ($\delta^{15}N$, $\delta^{13}C$ and C:N) and inorganic (S, Ti, Fe, Mn) geochemistry results plotted by depth but presented alongside a corresponding age axis (calibrated years BC). The full sampling resolution of each analysis is indicated by the grey line and values at chironomid depths are indicated by the black lines. Data is divided into chronological periods as discussed in the text and the Early Neolithic *Landnam* is indicated by the green shaded area.

7.3.4 Ordination Analysis

The correlation matrix of the nine environmental variables using Pearson correlation coefficients is shown in Table 7.1. It demonstrates the positive correlation between $\delta^{15}N$ and all of the land use variables which relate to farming activity whereby in statistical analyses $\delta^{15}N$ is acting as an analogue for all land-use variables, as the most powerful. Strong positive correlations in particular can be seen with NAPp, *Plantago lanceolata*, cereal and *Pediastrum*. Summary statistics for the PCA and RDA are provided in Table 7.2. Figures 7.4A and B present the passive associations of the chironomid data with nine statistically significant environmental variables ($\delta^{15}N$, C:N, LOI_{550}, Ti, NAPp, *Plantago lanceolata*, cereal, *Pediastrum* and *Myriophyllum*). The cumulative explained variance of Axis 1 was 14.2% and Axis 2 was 8.3%. All of the land use variables, ($\delta^{15}N$, NAPp, *Plantago lanceolata*, cereal, *Pediastrum* and *Myriophyllum*), group together on the right of Axis 1 except C:N because low C:N is associated with increased land-use. Directly opposite are LOI_{550} and C:N while the Ti vector is almost perpendicular to these. In the species bi-plot the samples from CAZ-1 are concentrated where LOI_{550} and C:N values are high. The samples from CAZ-2 are concentrated slightly more to the right of Axis 1 and are associated with high Ti values. Samples from CAZ-3 are concentrated where $\delta^{15}N$ and land-use indicator values are high.

Results of the interactive forward selection RDA determined that $\delta^{15}N$ was the strongest predictor of chironomid data, which when included in the analysis, led to the addition of Ti as the next significant predictor of the chironomid assemblage. Once Ti was included in the analysis no further variables were deemed significant. Figures 7.5A and B show the results of the RDA using these two statistically significant forward-selected variables ($\delta^{15}N$ and Ti). The RDA produced eigenvalues of 0.101 for Axis 1 and 0.038 for Axis 2. $\delta^{15}N$ showed the strongest relationship to RDA Axis 1 ($t = 9.06$) while Ti had the strongest relationship with Axis 2 ($t = 7.24$).

Partial RDAs show the explanatory values of the two forward selected variables, both individually and with co-variables. $\delta^{15}N$ exhibited the highest explanatory power, explaining 9.4% of the variance on its own and 7.8% with the effect of Ti partialled out. Ti was shown to explain 5.6% of the variation in the chironomid data on its own and 3.9% with the effect of $\delta^{15}N$ partialled out (Table 7.3)**.** The samples bi-plot shows a trend of movement towards high levels of $\delta^{15}N$, representative of farming activity. Initially, samples from CAZ-1 cluster in the area representative of low $\delta^{15}N$ values. Samples from CAZ-2 are associated with high levels of Ti. Samples from CAZ-3 are associated with higher $\delta^{15}N$ values, with those in CAZ-3b associated with lower Ti values than CAZ-3a. The chironomid taxa most closely associated with the different environmental variables, determined by the ordinations, can be seen in Table 7.4.

Table 7.1: Correlation matrix of environmental variables used in statistical analyses using Pearson correlation coefficients. Significant values at the 0.01 level are shown in bold and significant values at the 0.05 level are shown in italics.

Variables	Correlations								
	N15	LOI550	C:N	Ti	NAPp	Plantago	Cereal	Pediastrum	Myriophyllum
N15	_	**-0.900**	**-0.888**	0.040	**0.770**	**0.754**	**0.606**	**0.511**	**0.322**
LOI550	**-0.900**	_	**0.863**	-0.017	**-0.731**	**-0.741**	**-0.593**	**-0.527**	*-0.314*
Ti	0.040	-0.017	*-0.267*	_	**-0.354**	-0.188	-0.198	*-0.326*	*-0.288*
C:N	-0.888	0.863	_	*-0.267*	-0.592	-0.630	-0.532	**-0.405**	-0.208
NAPp	**0.770**	**-0.731**	**-0.592**	**-0.354**	_	**0.896**	**0.799**	**0.812**	**0.652**
Plantago	**0.754**	**-0.741**	**-0.630**	-0.188	**0.896**	_	**0.726**	**0.764**	**0.474**
Cereal	**0.606**	**-0.593**	**-0.532**	-0.198	**0.799**	**0.726**	_	**0.750**	**0.603**
Pediastrum	**0.511**	**-0.527**	**-0.405**	*-0.326*	**0.812**	**0.764**	**0.750**	_	**0.617**
Myriophyllum	*0.322*	*-0.314*	-0.208	*-0.288*	**0.652**	**0.474**	**0.603**	**0.617**	_

Table 7.2: Summary statistics of PCA and RDA statistical analyses. Significant t-values are marked with an asterisk (P < 0.05).

	Axis 1	Axis 2	Axis 3	Axis 4
PCA model – 8 environmental variables				
Eigenvalue	0.142	0.083	0.063	0.056
Cumulative explained variance (%)	14.20	22.46	28.70	34.31
Pseudo-canonical correlation	0.832	0.480	0.605	0.436
RDA – forward selected model				
Eigenvalue	0.101	0.038		
Cumulative explained variance (%)	10.10	13.93		
Pseudo-canonical correlation	0.874	0.782		
T values				
$\delta^{15}N$	9.06*	2.40*		
Ti	-2.83*	7.24*		

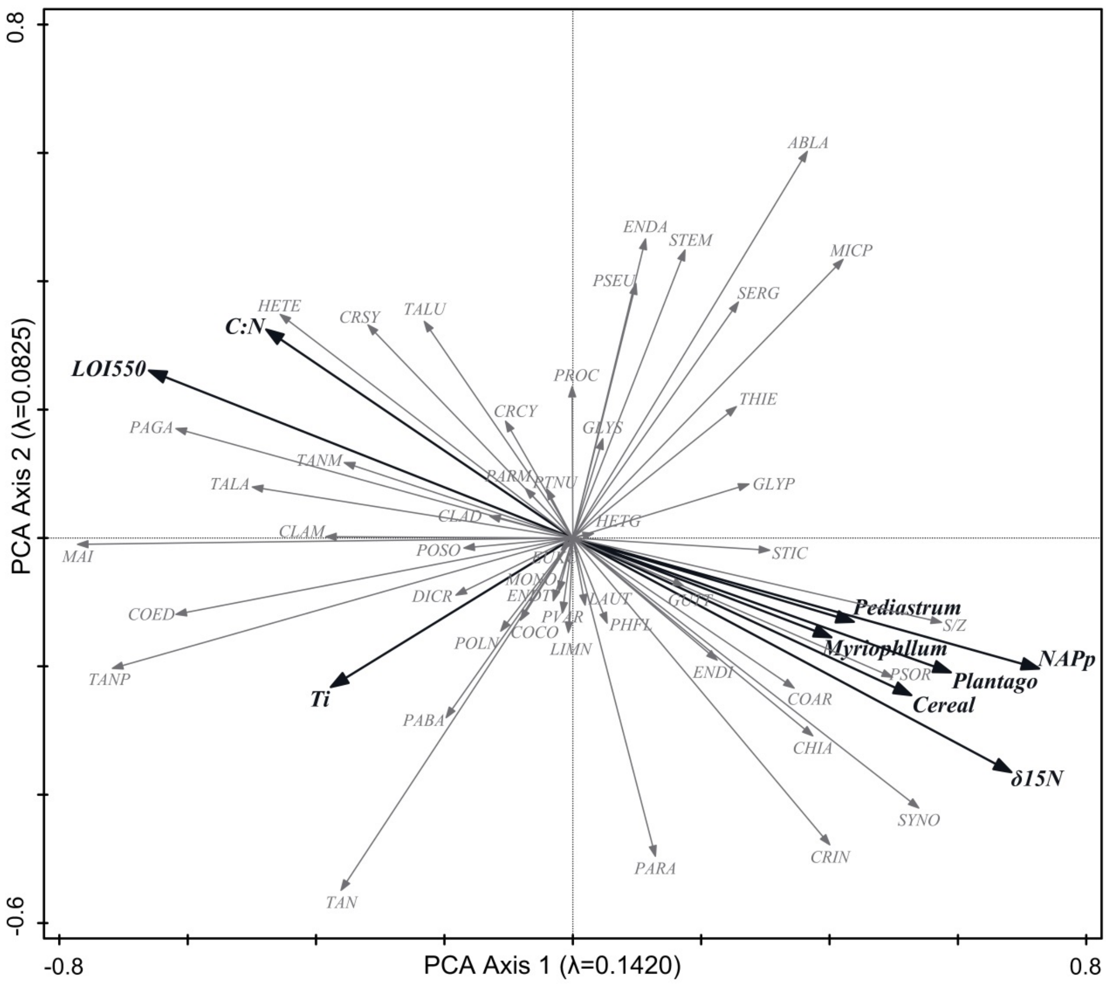

Figure 7.4A: PCA of passive associations of the chironomid taxa with nine statistically significant environmental variables (LOI_{550}, C:N, $\delta^{15}N$, Ti, NAPp, Cereal, *Myriophyllum*, *Pediastrum* and *Plantago lanceolata*).

Chironomid taxa are abbreviated as follows: ABLA = *Ablabesmyia*; CHIA = *Chironomus anthracinus*-type; CLAD = *Cladopelma*; CLAM = *Cladotanytarsus mancus*-type; COAR = *Corynoneura arctica*-type; COCO = *Corynoneura coronata*-type; COED = *Corynoneura edwardsi*-type; CRCY = *Cricotopus cylindraceus*-type; CRIN = *Cricotopus intersectus*-type; CRSY = *Cricotopus sylvestris*-type; DICR = *Dicrotendipes nervosus*-type; ENDA = *Endochironomus albipennis*-type; ENDI = *Endochironomus impar*-type; ENDT = *Endochironomus tendens*-type; EUKC = *Eukieferiella claripennis*-type; GLYP = *Glyptotendipes pallens*-type; GLYS = *Glyptotendipes severini*-type; GUTT = *Guttipelopia*; HETE = *Heterotanytarsus*; HETG = *Heterotrissocladius grimshawi*-type; LAUT = *Lauterborniella*; LIMN = *Limnophyes*; MAI = *Micropsectra insignilobus*-type; MICP = *Microtendipes pedellus*-type; MONO = *Monopelopia*; PAGA = *Pagastiella*; PVAR = *Parachironomus varus*-type; PARM = *Paramerina*; PARA = *Paratanytarsus*; PTNU = *Paratendipes nudisquama*-type; PABA = *Parakiefferiella bathophila*-type; PHFL = *Phaenopsectra flavipes*-type; POLN = *Polypedilum nubesculosum*-type; POSO = *Polypedilum sordens*-type; PROC = *Procladius*; PSEU = *Pseudochironomus*; SERG = *Sergentia coracina*-type; STEM = *Stempellina*; S/Z = *Stempellinella*; STIC = *Stictochironomus*; SYNO = *Synorthocladius*; TAN = *Tanytarsus* undifferentiated; TALA = *Tanytarsus lacetescens*-type; TALU = *Tanytarsus lugens*-type; TANM = *Tanytarsus mendax*-type; TANP = *Tanytarsus pallidicornis*-type; THIE = *Thienemannimyia.*

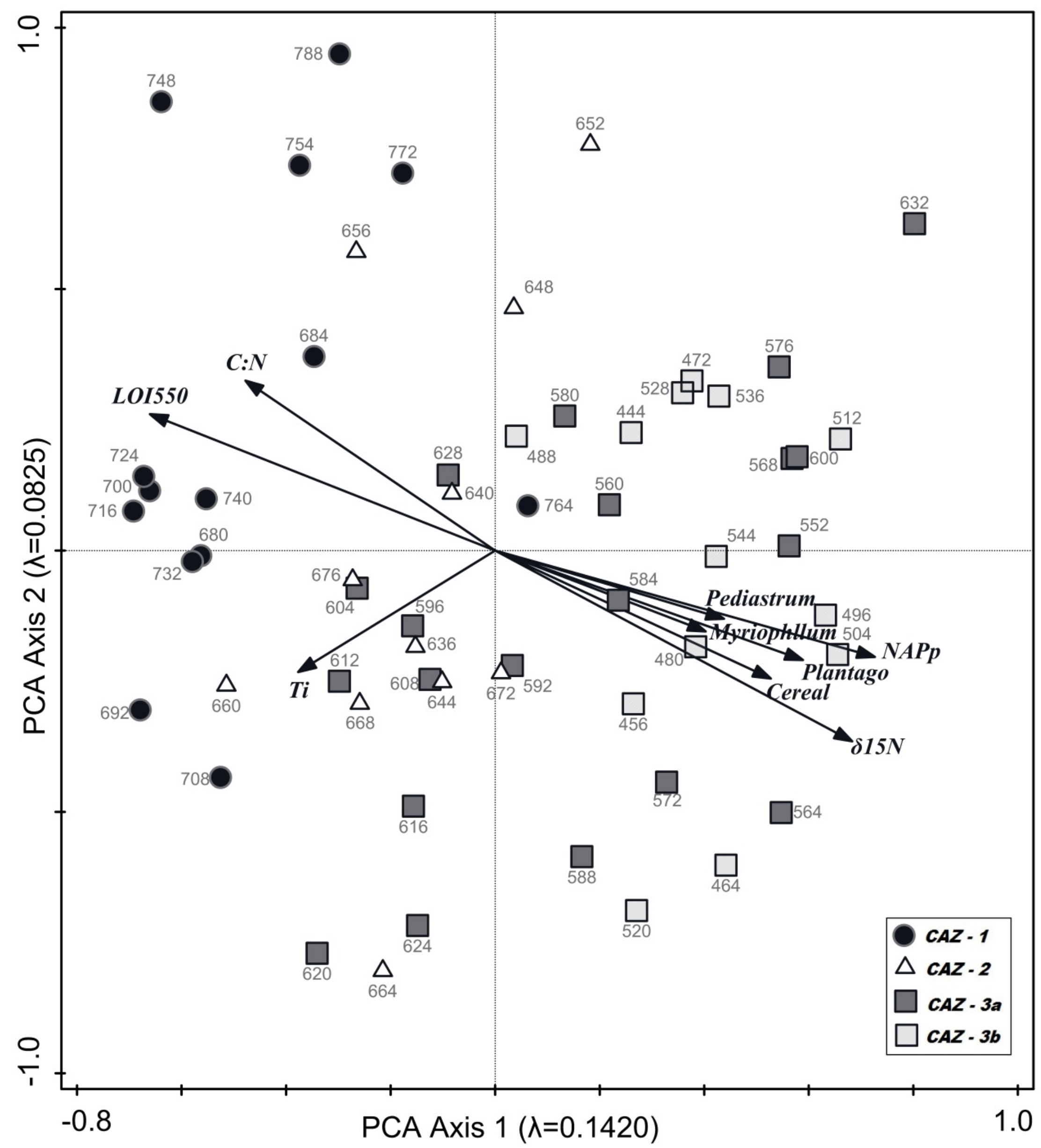

Figure 7.4B: PCA sample bi-plot of passive associations of the chironomid data with nine statistically significant environmental variables (LOI_{550}, C:N, $\delta^{15}N$, Ti, NAPp, Cereal, *Myriophyllum*, *Pediastrum* and *Plantago lanceolata*). Samples are divided into CAZ as indicated in the key.

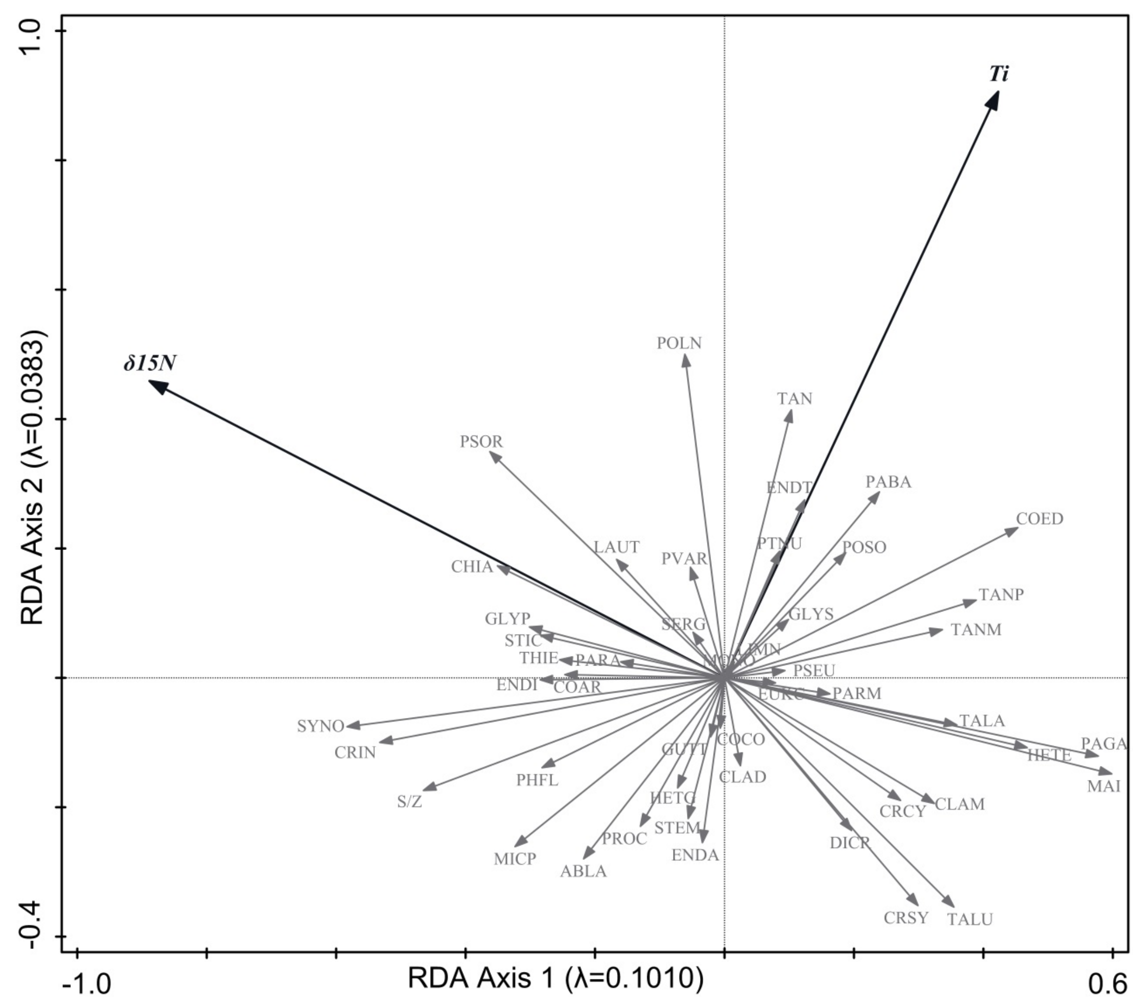

Figure 7.5A: RDA demonstrating the association of chironomid data with two statistically significant forward-selected variables ($\delta^{15}N$ and Ti).

Chironomid taxa are abbreviated as follows: ABLA = *Ablabesmyia*; CHIA = *Chironomus anthracinus*-type; CLAD = *Cladopelma*; CLAM = *Cladotanytarsus mancus*-type; COAR = *Corynoneura arctica*-type; COCO = *Corynoneura coronata*-type; COED = *Corynoneura edwardsi*-type; CRCY = *Cricotopus cylindraceus*-type; CRIN = *Cricotopus intersectus*-type; CRSY = *Cricotopus sylvestris*-type; DICR = *Dicrotendipes nervosus*-type; ENDA = *Endochironomus albipennis*-type; ENDI = *Endochironomus impar*-type; ENDT = *Endochironomus tendens*-type; EUKC = *Eukieferiella claripennis*-type; GLYP = *Glyptotendipes pallens*-type; GLYS = *Glyptotendipes severini*-type; GUTT = *Guttipelopia*; HETE = *Heterotanytarsus*; HETG = *Heterotrissocladius grimshawi*-type; LAUT = *Lauterborniella*; LIMN = *Limnophyes*; MAI = *Micropsectra insignilobus*-type; MICP = *Microtendipes pedellus*-type; MONO = *Monopelopia*; PAGA = *Pagastiella*; PVAR = *Parachironomus varus*-type; PARM = *Paramerina*; PARA = *Paratanytarsus*; PTNU = *Paratendipes nudisquama*-type; PABA = *Parakiefferiella bathophila*-type; PHFL = *Phaenopsectra flavipes*-type; POLN = *Polypedilum nubesculosum*-type; POSO = *Polypedilum sordens*-type; PROC = *Procladius*; PSEU = *Pseudochironomus*; SERG = *Sergentia coracina*-type; STEM = *Stempellina*; S/Z = *Stempellinella*; STIC = *Stictochironomus*; SYNO = *Synorthocladius*; TAN = *Tanytarsus* undifferentiated; TALA = *Tanytarsus lacetescens*-type; TALU = *Tanytarsus lugens*-type; TANM = *Tanytarsus mendax*-type; TANP = *Tanytarsus pallidicornis*-type; THIE = *Thienemannimyia.*

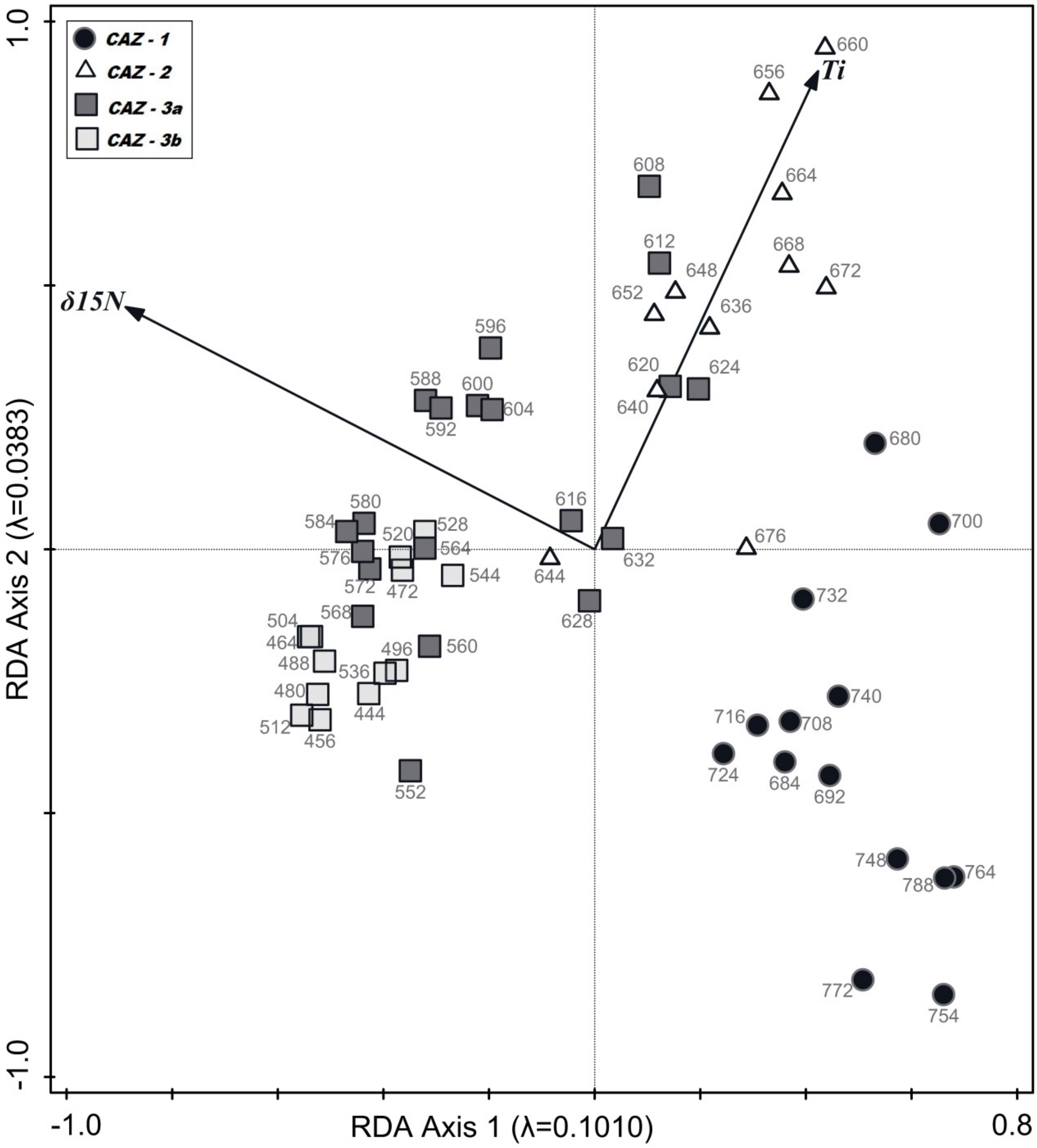

Figure 7.5B: RDA sample bi-plot of the association of chironomid data with two statistically significant forward-selected variables ($\delta^{15}N$ and Ti). Samples are divided into CAZ as indicated in the key.

Table 7.3: Partial RDAs for forward selected variables by themselves and with the effects of other forward-selected variables partialled out.

Variable	Covariable	λ_1	λ_1/λ_2	P	% variance
$\delta^{15}N$	None	0.088	0.848	0.002	9.4
	Ti	0.090	1.035	0.002	7.8
Ti	None	0.050	0.386	0.002	5.6
	$\delta^{15}N$	0.052	0.593	0.002	3.9

Table 7.4: Results of ordination analysis showing the chironomid taxa associated with high levels of various environmental variables.

Ordination Analysis	Taxa associated with high levels of:
Unconstrained PCA (8 environmental variables)	**Land-use variables ($\delta^{15}N$, NAPp, plantago, cereal, Pediastrum, Myriophyllum)** *Synorthocladius* *Psectrocladius sordidellus*-type *Crictopus intersectus*-type *Chironomus anthracinus*-type *Stempellinella*
	Ti *Tanytarsus pallidicornis*-type *Corynoneura edwardsi*-type *Tanytarsus undifferentiated* *Polypedilum nubesculosum*-type *Parakieferiella bathophila*-type
	LOI_{550} *Pagastiella* *Heterotanytarsus* *Tanytarsus lugens*-type
Interactive forward selection RDA	**Ti** *Polypedilum nubsesculosum*-type *Tanytarsus undifferentiated* *Parakieferiella bathophila*-type *Corynoneura edwardsi*-type *Tanytarsus pallidicornis*-type *Tanytarsus mendax*-type
	$\delta^{15}N$ *Synorthocladius* *Crictotopus intersectus*-type *Stempellinella* *Chironomus anthracinus*-type *Psectrocladius sordidellus*-type

7.4 Discussion of Palaeolimnological Results

7.4.1 Mesolithic to Middle Neolithic (c. 4590 – 3110 BC)

Mesolithic

Pollen evidence from the start of this period suggests a predominantly wooded landscape dominated by oak and hazel with NAPp at a minimum. This landscape is typical of the Mesolithic in Ireland where human impact upon the landscape was limited (Woodman, 2015). The low level of $\delta^{15}N$ prior to c. 4060 BC (with an average of 3.1‰) at Lough Inchiquin suggests, as the pollen data would support, that this period represents the pre-impacted state of Lough Inchiquin prior to the initiation of farming activity (Figure 7.6). The trophic status of the lake at this time would be deemed oligotrophic. The lack of nutrient enrichment under oligotrophic conditions limits algal growth, with relatively low levels of *Pediastrum* seen at this time, and facilitates high oxygen levels (Brodersen and Quinlan, 2006).

The chironomid community from the Mesolithic right through to Middle Neolithic in Lough Inchiquin is characteristic of an oligotrophic lake system. Predominant taxa associated with such conditions include *Micropsectra insignilobus*-type*, Heterotanytarsus*, *Pagastiella* and *Tanytarsus lugens*-type (Moller Pillot, 2009; Moller Pillot, 2013; Brooks et al., 2007). Particularly high levels of *Micropsectra insignilobus*-type and *Heterotanytarsus* at the start of this period demonstrate that lake nutrients at this time were limited. *Tanytarsus lugens*-type, a taxon associated with the profundal zone of oligotrophic lakes, is only present prior to c. 3980 BC (Brooks et al., 2007). The lack of this taxon after the adoption of farming is perhaps significant in terms of the initiation of anthropogenic nutrient input to the lake system. The taxon *Sergentia coracina-type* is well represented in this period and has been used as an indicator of oligotrophic to mesotrophic conditions in Ireland (Chique et al., 2018; Taylor et al., 2017a). It is better adapted to the onset of more eutrophic conditions than other, more ecologically limited, oligotrophic indicators (Moller Pillot, 2009; Brooks et al., 2007), however, and does remain well represented throughout the entire stratigraphy.

In the taxa bi-plot (Figure 7.4A) oligotrophic taxa such as *Heterotanytarsus*, *Pagastiella*, and *Micropsectra insignilobus*-type appear on the left of Axis 1 with more eutrophic taxa such

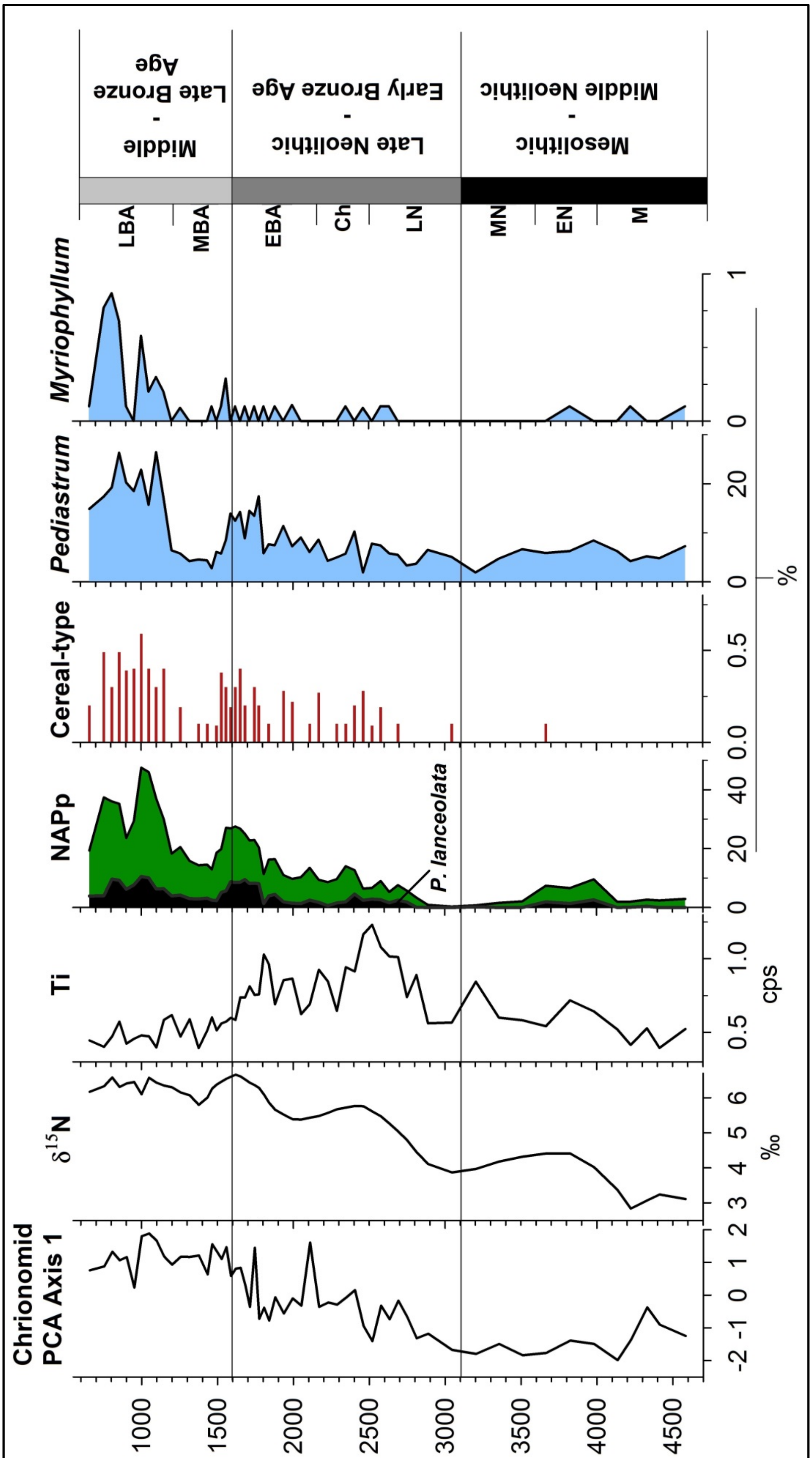

Figure 7.6: Composite diagram presenting a chironomid PCA Axis 1 representing trophic status, organic geochemistry ($\delta^{15}N$), inorganic geochemistry (Ti) and selected pollen data (NAPp, cereal-type, *Pediastrum* and *Myriophyllum*) plotted by calibrated years BC and divided into chronological periods as discussed in the text. Abbreviations are as follows: M = Mesolithic, EN = Early Neolithic, MN = Middle Neolithic, LN = Late Neolithic, Ch = Chalcolithic, EBA = Early Bronze Age, MBA = Middle Bronze Age, LBA = Late Bronze Age.

as *Cricotopus intersectus*-type, *Chironomus anthracinus*-type and *Synorthocladius* on the right. PCA Axis 1, which explains 14.2% of the variation in chironomid assemblages, can therefore be used as a proxy for trophic conditions. The $\delta^{15}N$ vector on the forward-selected RDA (Figures 7.5A and B) demonstrates increasing human impact with samples from this period concentrated away from this vector.

Early Neolithic

NAPp reached a maximum of 13.5% during the Neolithic *Landnam,* dated to c. 4060 – 3590 BC at Lough Inchiquin. This represents the beginnings of farming activity within the catchment of the lake but the pollen data does demonstrate that the intensity of farming activity increased substantially in later periods. A rise in $\delta^{15}N$ values started during the *Landnam* period rising from 2.8‰ to a maximum of 4.4‰ between c. 3880 – 3670 BC at the height of Early Neolithic farming activity (Figure 7.6). A study of modern surface sediment samples from lakes across western Ireland determined the mean $\delta^{15}N$ value for lakes with a moderately impacted catchment (20 – 80% agricultural cover) to be 3.7‰ (Woodward et al., 2012). Lough Inchiquin, then, could be deemed to fall within this category during the Early Neolithic, although it is a much larger and deeper lake than those examined. Nutrient enrichment is known to cause the development of macrophytes and the pollen evidence does suggest an increase in *Myriophyllum*, and less so of *Nymphaea*, during the *Landnam* period (Chase and Knight, 2006). Furthermore, *Myriophyllum* was shown to correlate positively with all of the land use variables (Table 6.1).

The forward-selected RDA (Figures 7.5B) demonstrates that samples dating to the Neolithic *Landnam* have moved along the $\delta^{15}N$ vector, compared with Mesolithic samples, suggesting that nutrient input did have a small effect on the lake system. Concurrent with this is a decrease in the C:N ratio which is suggestive of increased autochthonous productivity (Taylor et al., 2013). There is a slight decrease in $\delta^{13}C$ during the *Landnam* but the data on the whole suggests that $\delta^{13}C$ is not showing a uniform response to land-use within the catchment, similarly to Taylor et al. (2017b).

Despite no significant overall change to the chironomid composition with the onset of farming in the catchment, some slight changes may hint at a small response to the increase in nutrients. *Tanytarsus pallidicornis*-type and *Tanytarsus mendax*-type, both indicative of productive littoral environments are well-represented during the Neolithic (see Figure 7.1) (Brooks et al., 2007). Slight increases during the *Landnam* period likely relate to the rise in

$\delta^{15}N$ values at this time. *Dicrotendipes nervosus*-type and *Glyptotendipes pallens*- type both increase, and are known to be associated with macrophytes, specifically *Nymphaea* (Moller Pillot, 2009; Brooks et al., 2007). Low levels of eutrophic taxa were observed such as *Chironomus anthracinus*-type and particularly *Cricotopus intersectus*-type, which increases from the Early to Middle Neolithic, possibly associated with increased $\delta^{15}N$ (Moller Pillot, 2009; 2013).

Therefore there are slight, albeit limited, indications of the first impact upon the lake system at this time. The chironomid community does not respond to early farming activity in the catchment to the same extent seen in previous studies (Taylor et al., 2013; 2017a; 2017b). For example, at Lough Dargan, Co. Sligo, eutrophic taxa such as *Tanytarsus mendax*-type and *Chironomus anthracinus*-type dominated the period between c. 3730 – 3690 BC associated with a *Landnam* inferred from both pollen and geochemical data (Taylor et al., 2013). $\delta^{15}N$ values reached 3.6‰ during the Neolithic *Landnam* and were seen as the mechanism for chironomid change (Taylor et al., 2013). Similarly, Early Neolithic farming activity in the catchments of Templevanny Lough and Cooney Lough, Co. Sligo, was reflected in the concurrent increase in mesotrophic – eutrophic taxa driven by $\delta^{15}N$ influxes (Taylor et al., 2017a; 2017b). $\delta^{15}N$ increased to 4.1 – 4.6‰ at Templevanny Lough and to 3.6‰ at Cooney Lough during the *Landnam* phases (Taylor et al., 2017a; 2017b). The lakes investigated in Co. Sligo, however, are much smaller than Lough Inchiquin (<10ha) and are relatively closed systems. In contrast, Lough Inchiquin covers an area of 110ha with a much greater water depth (max of 30m compared to <11.2m). Brodersen and Quinlan (2006) note that lesser amounts of organic material, even at the same nutrient level, are found in the profundal zone of deep lakes compared to shallow lakes. Additionally, Lough Inchiquin is an open system with significant inflow and outflow from the River Fergus, and an estimated water residence time of approximately one month (Diefendorf et al., 2008). These factors may have allowed the Co. Sligo lake systems to be more readily impacted by small-scale farming activity than Lough Inchiquin.

Middle Neolithic

Woodland regeneration in the catchment of Lough Inchiquin occurred from c. 3510 BC and continued for the remainder of this period, demonstrated in Figure 7.6 by the significant decrease in NAPp. This coincides with a decline in $\delta^{15}N$ values and an increase in C:N, suggesting a less impacted lake system (Woodward et al., 2012). Periods of reduced NAPp associated with Middle Neolithic woodland regeneration in previous studies also coincide with a decline in mesotrophic – eutrophic taxa (Taylor et al., 2017a; Taylor et al., 2013; Taylor et al., 2017b). Increased C:N was interpreted as a decline in lake productivity at Templevanny Lough during the Middle Neolithic, similarly to the current study (Taylor et al., 2017b).

Inorganic geochemistry results are relatively stable throughout the entire period. A slight increase in values for Ti, Fe and Mn occurred during the *Landnam* which could be linked to the small scale in-wash of soil due to initial deforestation (AP falls from an average of 94.2 to 84%) (Cohen, 2003). This would be supported by a decrease in LOI_{550} (representative of % organic matter) at this time which has a strong negative correlation with the land use variables. LOI_{550} can elucidate changes in a lake ecosystem but interpretation can be complicated by both autochthonous and allochthonous processes (Birks and Birks, 2006; Shuman, 2003). Increased farming activity and potentially erosion relating to this, can be a controlling factor on the amount of organic matter within a sediment (Shuman, 2003). In addition to influxes of inorganic material, lake productivity and decomposition can be determining factors relating to LOI_{550} (Shuman, 2003).

7.4.2 Late Neolithic – Early Bronze Age (c. 3110 – 1600 BC)

Pollen evidence demonstrates that NAPp started to increase from c. 2890 BC and continued to rise for the remainder of this period to levels above that of the Neolithic *Landnam*. $\delta^{15}N$ values increased at the start of this period to a peak of 5.8‰ by c.2450 BC (Figure 7.6). This is an increase of >1‰ compared with the *Landnam* period, suggesting that the increasing intensity of farming activity was having a greater impact on the lake system at this time. Although there was a decline in $\delta^{15}N$ for the remainder of the Chalcolithic, values remained higher than during the Neolithic. Increasing lake productivity during the Late Neolithic is supported by declining C:N ratios which subsequently increase as $\delta^{15}N$ declines towards the end of the Chalcolithic. An intensification of farming occurred in the Early Bronze Age when NAPp reached 26.8% by c. 1600 BC. Increases in *Nymphaea* and *Myriophyllum* also occurred in the Early Bronze Age. With the transition to the Early Bronze Age $\delta^{15}N$ values increased to 6.7‰ by c. 1630 BC. The maximum in $\delta^{15}N$ occurred contemporaneously with the peak in NAPp when Early Bronze Age farming activity in the catchment was particularly intense. Concurrent with this was a decrease in C:N with both proxies indicating increased lake productivity due to farming intensity. LOI_{550} declined at

Lough Inchiquin during both periods of $\delta^{15}N$ enrichment demonstrating the negative correlation with land-use variables.

The chironomid community composition in the Late Neolithic to Early Bronze Age is suggestive of an increasingly nutrient-enriched environment (Figures 7.1 and 7.6). This is indicated by increases in mesotrophic – eutrophic taxa such as *Glyptotendipes pallens*-type and *Microtendipes pedellus*-type from c. 2890 BC (Moller Pillot, 2009; Brooks et al., 2007). The latter, in particular, increases during the Early Bronze Age. *Chironomus anthracinus*-type, a common taxa in the profundal zone of deep productive lakes, increases in abundance from c. 2750 BC when NAPp had already reached 5.7% (Moller Pillot, 2009; Brooks et al., 2007; Chique et al., 2018). This taxon reached a maximum of 10% by c. 1880 BC suggesting an increase in lake productivity in the Early Bronze Age compared to the Chalcolithic. Similarly, increases in *Psectrocladius sordidellus*-type, *Synorthocladius* and *Cricotopus intersectus*-type can be seen from the Chalcolithic to Early Bronze Age, indicative of increasing lake productivity in the latter period (Moller Pillot, 2013; Brooks et al., 2007; Ruiz et al., 2006). *Dicrotendipes nervosus*-type and *Paratanytarsus* are well-represented, especially in the Early Bronze Age, likely due to increased levels of macrophytes, especially of *Myriophyllum* at this time (Brooks et al., 2007). Pastoral farming was increasing within the catchment of Lough Inchiquin and this likely had an increasing impact upon the lake system.

Increasing NAPp during the Late Neolithic and Chalcolithic at Lough Dargan caused an increase in $\delta^{15}N$ affecting the chironomid community (Taylor et al., 2013). In the Early Bronze Age increasing $\delta^{15}N$ occurred at the same time as decreasing C:N during heightened levels of NAPp (Taylor et al., 2013). Similarly, more eutrophic taxa were observed during this period at Templevanny and Cooney Loughs associated with geochemical data suggestive of a more productive lake system (Taylor et al., 2017b; 2017a). On the forward-selected RDA (Figure 7.5B) the samples from this period at Lough Inchiquin have moved slightly along the $\delta^{15}N$ gradient. Chironomid PCA Axis 1 values increase slightly through the Late Neolithic and again in the Early Bronze Age due to increasing levels of mesotrophic – eutrophic taxa. Most notably on the RDA the samples from the Late Neolithic and Chalcolithic period have moved in the direction of the Ti vector.

Soil Erosion (c. 2870 – 1700 BC)

It is clear from the geochemical data that there were elevated levels of trace elements within the lake sediment during the period c. 2870 – 1700 BC (Figure 7.3). A significant increase in the relative intensity of Ti is observed from c. 2870 BC reaching a maximum level by c. 2480 BC. Similarly, the relative intensities of Fe and Mn increase during this period peaking by c. 2420 BC. Mackereth (1966) noted that high levels of trace elements were indicative of erosion, with changes in lake catchments reflected in lake sediment geochemistry. The values of Ti, Fe and Mn then decreased from these maxima but, despite fluctuations, remained elevated for the remainder of the Chalcolithic and into the Early Bronze Age. A decline in values for Ti, Fe and Mn occurred from c.1700 BC continuing for the remainder of the Early Bronze Age. The relative intensities of Ti, Fe and Mn follow the same general pattern but only Ti was selected in the PCA and interactive forward-selected RDA, and thus determined to have a significant influence on the chironomid community composition. Ti levels account for 5.6% of the variation in chironomid community composition. In addition, only Ti is strictly of terrigenous origin and largely unaffected by post-depositional processes (Arnaud et al., 2012). Therefore, it is commonly used as an erosion indicator in palaeolimnological studies.

In contrast, despite having been used as indicators of erosion (e.g. O'Connell et al., 2014; Boyle et al., 2004), the levels of Fe and Mn within lake sediment can be heavily affected by a number of independent environmental processes such as lake conditions and within-lake diagenesis (Mackereth, 1966; Engstrom and Wright Jr, 1984). Fe and Mn can be transported to lake systems as constituents of mineral particles which by itself would represent erosional activity, but the preservation of these elements within the sediment is ultimately determined by factors such as the ionic composition of the water, redox conditions and pH (Engstrom and Wright Jr, 1984). Reducing conditions within lakes leads to the release of Fe and Mn which, through mixing of the water column, are then re-oxidised and can precipitate, leading to preservation within lake sediment – the oxidised forms of these trace metals being of very low solubility (Naeher et al., 2013; Schaller and Wehrli, 1996; Granina et al., 2004; Engstrom and Wright Jr, 1984). Peaks in these elements can thus indicate reducing conditions within the lake and periods of anoxia. As the geochemical profiles of Ti, Fe and Mn follow the same general pattern, but taking into account the considerations above, Ti is viewed as the best representation of erosion into Lough Inchiquin.

The palaeoenvironmental interpretation of S concentrations is similarly complicated by diagenetic processes (Cohen, 2003). The concentration of sulphate in lakes is low but erosion within a lake catchment can cause additional sulphates to enter a lake system (Luther et al., 2003). Its preservation within lake sediment relies on sulphate reduction (Holmer and Storkholm, 2001). It is clear from the geochemical data that sulphur is reacting differently than the other trace elements (Figure 7.3). For the majority of the period S levels are consistently low but a period of high values occurs between c. 2330 – 1840 BC. There are three peaks in the levels of S; one in the Chalcolithic period at c. 2290 BC, and two during the Early Bronze Age at c. 1950 BC and c. 1870 BC. These all occur after the maxima in Ti, Fe and Mn. The reduction of sulphate to hydrogen sulphide occurs under anoxic conditions and subsequently binds with iron forming iron pyrite which is deposited and preserved within the sediment (Holmer and Storkholm, 2001). It is proposed that at Lough Inchiquin anoxic benthic conditions allowed for the reduction of S which, with high levels of Fe available, was able to form iron pyrite and be preserved within the sediment.

Within an Irish context titanium was used by O'Connell et al. (2014) to assess environmental change at Cooney Lough, Co. Sligo. Increases in trace elements, including titanium occurred contemporaneously with increases in NAPp associated with Early Neolithic farming activity, suggesting this had caused erosion within the catchment (O'Connell et al., 2014). As titanium is proposed to be indicative of erosion at Lough Inchiquin, the chironomid taxa associated with high levels of this element (see Table 6.4) would appear to be responding to changes within the lake system caused by this influx of terrigenous material during the Late Neolithic to Early Bronze Age. Sedimentation caused by erosion is known to impact chironomid community composition and particle grain size within the lake sediment will generally increase (Zhang et al., 2013). Sedimentation in the littoral zone will increase with the deposition of erosional material, changing the benthic substrate conditions which may influence the chironomid community composition. $\delta^{15}N$ data demonstrates that nutrient input increased which would have caused the littoral environment to be more productive, increasing food availability in this area and decreasing oxygen conditions.

An increase is seen in the levels of *Polypedilum nubesculosum*-type from the Late Neolithic which, while associated with eutrophic conditions and macrophytes, also has a preference for sandy sediments and organic silts (Moller Pillot, 2009; Brooks et al., 2007). Similarly, there is an increased abundance of *Parakieferiella bathophila*-type which is known to live in sandy sediments and as an entire genus are psammobiotes (thriving in sand-rich environments) (Moller Pillot, 2013). Two taxa, *Endochironomus impar*-type and *Stictochironomus*, are rare in the stratigraphy but increase at this time (Figure 7.1). Both of these, in addition to being mesotrophic taxa, are more common on sandy sediments (Brooks et al., 2007; Moller Pillot, 2009). Perhaps the influx of material from the catchment changed the sediment substrate creating more favourable conditions for these taxa. Additional taxa that increase substantially in this period are *Tanytarsus mendax*-type, *Tanytarsus pallidicornis*-type and *Corynoneura edwardsi*-type which are characteristic of a productive littoral environment (Brooks et al., 2007). All of these taxa are associated with high levels of Ti and have moved towards the Ti vector on the forward-selected RDA (Figure 7.5B). Increases in *Tanytarsus mendax*-type and *Tanytarsus pallidicornis*-type in Chique et al. (2018) were attributed to a nutrient-rich littoral environment.

The geochemical data suggests increased erosion into Lough Inchiquin occurred between c. 2870 – 1700 BC, with an erosion peak c. 2870 – 2270 BC. The beginnings of increased erosion occurred contemporaneously with the re-initiation of farming activity in the Late Neolithic. Farming intensity steadily increased with a substantial level of farming in the catchment of Lough Inchiquin by c. 1700 BC which continued for a further two centuries. The Burren soils are known to be highly fragile and susceptible to erosional activity (Moles and Moles, 2002) which may explain why such significant erosion began early in the farming regime. Arable activity in the catchment increased at this time and in fact peaks during the main period of titanium enrichment. It is proposed that the increased impact on the soil through possible ard cultivation, known from this period (Verrill and Tipping, 2010), in addition to pastoral activity, led to the erosion of soils from the catchment area. Although the slopes of Roughan Hill do not reach the edge of Lough Inchiquin, eroded soils may have been carried by the River Fergus into Lough Inchiquin.

Archaeological evidence for distinct farming activity between c. 2300 – 1550 BC is prominent over c. 370 acres on Roughan Hill, consisting of systems of field walls and four habitation sites (Jones, 2016; Jones, forthcoming-a). It is clear from the palaeoenvironmental evidence that human activity in the lake catchment was increasing before the proposed occupation of the settlements on Roughan Hill, with communities perhaps utilising other areas within the catchment. Earlier activity on Roughan Hill is evidenced through the continued deposition of human remains into Parknabinnia court tomb and the proliferation of wedge tombs in the Chalcolithic (Jones, 2016; Ó Maoldúin, 2017 pers. comm.). The most significant erosion into Lough Inchiquin ended by c.2270 BC, only a few decades after the proposed establishment of settlement activity on Roughan Hill. Perhaps this marked the beginning of a new land-use regime which had a lesser impact on the soils. Activity on Roughan Hill continued for a further two centuries with Ti having returned to levels seen in the Neolithic. This is similar to the situation seen at Cooney Lough where continued farming into the Early Bronze Age was contemporary with a reduction in erosion (O'Connell et al., 2014). Erosion initially causes the removal of the A-horizon, leaving the B-horizon of the soil exposed, which may be able to resist weathering processes more effectively because of its cohesiveness and lower infiltration capacity. (Toy et al., 2002).

It is clear that an intensification of land-use occurred towards the end of the Early Bronze Age but decreasing erosion suggests agriculture was becoming more sustainable or that the soils in the catchment were becoming more stable. Heavy erosion may have initially occurred if substantial rainfall coincided with the intensification of farming in the catchment. A shift to wetter and cooler conditions has been proposed at c. 2200 BC (i.e. the 4.2 ka event) but this has been contested within the Irish record (Baillie and McAneney, 2015; Roland et al., 2014; Fitzpatrick, 2015). This downturn is not contemporaneous with the most intensive erosion in the catchment and indeed a further downturn proposed for the Late Bronze Age (Plunkett, 2009; Baillie, 1989; Baillie and Munro, 1988) appears to have had no negative effect on the Burren soils. A major episode of soil erosion was identified in Molly's Lough between c. 2542 – 793 BC (Thompson, 1997), slightly later than at Lough Inchiquin but still within the Late Neolithic – Chalcolithic. This suggests an intensification of agriculture in the catchment of Molly's Lough which may be providing a more local signal of what could have been a regional occurrence. Geochemical data was not produced for Molly's Lough and instead sedimentation accumulation rates were used as evidence of erosion (Thompson, 1997). Significant erosion at Molly's Lough was also identified in the Late Bronze Age (c. 1218 – 639 BC) which does not compare with Lough Inchiquin (Thompson, 1997). This may be due to differing catchment characteristics, with the Molly's Lough profile reflecting only a very local signal (Lamb and Thompson, 2005). The pollen evidence suggests increasing farming activity in the catchment of this small lake from the Early Bronze Age with steep slopes to the north-west which may have enhanced erosion processes (Thompson, 1997).

Further evidence for erosion in the Burren area has previously been identified. At Knockanes mountain, c. 10km from Lough Inchiquin, a date of c. 1390 BC from charcoal buried beneath diamicton provided a *terminus-post-quem* for the movement of material associated with anthropogenic activity (Moles et al., 1999; Moles and Moles, 2002). This date falls close to the initiation of most severe erosion in the catchment of Molly's Lough but after the erosion into Lough Inchiquin (Moles et al., 1999). It is also speculated that further erosion occurred on the slopes of Slieve Rua and Mullaghmore in addition to evidence from speleothem analysis in caves across the Burren (Moles and Moles, 2002; Moles et al., 1999). A number of studies have postulated the erosion of soil from the Burren in prehistory which ultimately led to the limestone karst of today (Moles and Moles, 2002; Moles et al., 1999; Jeličić and O'Connell, 1992; Drew, 1983). The geochemical data from Lough Inchiquin provides unambiguous evidence for significant erosion of Burren soils from as early as the Late Neolithic.

Furthermore, the geochemical investigation into lake sediments from Lough Inchiquin has allowed for the separation of the two mechanisms that can affect $\delta^{15}N$ values – lake productivity and soil erosion. Previous palaeolimnological studies (Taylor et al., 2013; 2017b; 2017a) had to qualify proposed arguments of farming intensity determining $\delta^{15}N$ with the possibility that this could be due either to the direct in-wash of animal waste or increased erosion within the catchment. The differences observed between the $\delta^{15}N$ and inorganic geochemical data from Lough Inchiquin suggests that lake productivity caused by agricultural nutrient input is driving the increase in $\delta^{15}N$ values. No significant erosion is suggested from the Ti values during the Late Bronze Age but $\delta^{15}N$ values increase to maximum levels at this time, when farming intensity in the catchment is at its highest. In addition, the separation of the two variables ($\delta^{15}N$ and Ti) in the RDA and associations of all land-use variables with $\delta^{15}N$ in the PCA, demonstrates that, in this case, it is the increasing intensity of agricultural land-use and not erosion that is primarily driving the rise in $\delta^{15}N$ values in the lake system.

7.4.3 Middle to Late Bronze Age (c. 1600 – 660 BC)

The start of this period saw a decline in NAPp seen from c. 1560 BC and low levels continued until c. 1320 BC. Concurrent with this, $\delta^{15}N$ values decreased and C:N increased for the first half of the Middle Bronze Age suggesting a decrease in lake productivity (Figures 7.3 and 7.6). A significant decrease in *Pediastrum* also occurred at this time suggesting a decrease in anthropogenic nutrient influx. $\delta^{15}N$ levels still remained relatively high, however, and the chironomid composition did not seem to respond to this initial decline. The continued presence of cereal-type pollen at this time suggests both pastoral and arable farming continued within the catchment but that intensity had lessened. Similar decreases in both NAPp and $\delta^{15}N$ occurred during the Middle Bronze Age at Lough Dargan but the chironomid stratigraphy was unaffected leading Taylor et al. (2013) to propose that the lake had become more permanently altered by intensified farming activity in the catchment. Farming activity within the catchment of Lough Inchiquin subsequently increased from c. 1320 BC with substantially higher levels of NAPp in the Late Bronze Age between c. 1230 – 750 BC. NAPp reached its highest representation by c. 1000 BC (47.5%) with very high *Poaceae* (31.8%) and *Plantago lanceolata* (10.5%). Combined with the diversity of herb taxa, pollen evidence suggests the Late Bronze Age saw the most intensive period of pastoral farming in the catchment of Lough Inchiquin. The levels of cereal-type pollen attain the highest levels at this time, which may also be contributing to the increased $\delta^{15}N$ levels, as it was deemed to be a significant variable in the PCA.

A significant increase in algae and macrophytes occurred from c. 1230 BC. The increase in algae is likely due to nutrient enrichment of the lake system, with a high correlation seen between the two variables and *Pediastrum* is known to respond to anthropogenic nutrient influx (Chase and Knight, 2006; Chique et al., 2018). $\delta^{15}N$ increased from c. 1400 BC to a maximum of 6.6‰ by c. 1060 BC. This value was previously attained in the Early Bronze Age but was not maintained. For the remainder of the Late Bronze Age, however, consistently high $\delta^{15}N$ levels were observed ranging from 5 – 7‰ with an average of 6.3‰. $\delta^{15}N$ levels seem to have reached a plateau in the Late Bronze Age and do not exceed this level even in modern times. As animal manure is enriched in $\delta^{15}N$ (ranging from 10 – 20‰), the mechanism driving this increase in $\delta^{15}N$ is likely the input of nutrients from pastoral agriculture (Woodward et al., 2012; Botrel et al., 2014; Vander Zanden et al., 2005). C:N fluctuates but remains relatively low compared to the rest of the profile. The intensity of Late Bronze Age farming has increased substantially with both a pastoral and arable component potentially having an impact on the productivity of the lake system. NAPp decreased after c. 750 BC for the remainder of the period but was still sufficient to indicate a continuation of pastoral farming, albeit with some woodland recovery. The lake system does not respond to this reduction in farming intensity, with $\delta^{15}N$ remaining high throughout this period. This suggests that the lake has perhaps been more permanently altered, or may reflect the proximity of farming.

The samples from this period are clustered to the left of RDA Axis 1 in association with the $\delta^{15}N$ vector. In addition they have moved down RDA Axis 2 (associated with Ti) demonstrating that erosion is having less of an influence on the chironomid community. Similarly, on the PCA, samples from this period are concentrated to the right of PCA Axis 1 associated with high levels all of the land-use variables which share a positive correlation with $\delta^{15}N$. LOI_{550} decreases and maintains low levels throughout the Middle and Late Bronze Age. This may be due to a decrease in organic matter within the lake sediment as the intensity of farming activity in the catchment increases. The LOI_{550} curve, however, does not follow that of titanium suggesting a factor other than erosion is causing the decrease in percentage organic matter at this time, possibly relating to within-lake processes (Figure 7.3) (Birks and Birks, 2006). Conversely LOI_{950} increases during this period possibly due to increased biogenic carbonate within the lake sediment. As this is derived from the skeletal components of organisms, increases can reflect an increase in lake productivity (Einsele, 2013). Examination of the Inchiquin sediment core does suggest the increased presence of shell fragments in the period when LOI_{950} is at its highest (Figure 6.4). It follows that if the percentage of carbonate/mineral matter in the sediment is increasing, that the percentage of organic matter, as evidenced through LOI_{550}, will decrease. This is thought to be the reason for the separation of trends between Ti and LOI_{550}, the latter of which, in this case is not representing erosion in the upper half of the profile. $\delta^{13}C$ sees a large increase from the end of the Middle Bronze Age onwards correlating with the significant increase in *Pediastrum* (>20%) from c. 1230 BC. The $\delta^{13}C$ of algae (-25‰ to -30‰) (Anderson et al., 2008), with a high abundance in the lake, may have caused the $\delta^{13}C$ of the lake sediment to move towards this range.

The chironomid community composition during the Middle to Late Bronze Age is suggestive of a productive lake system with the highest abundance of eutrophic taxa in the record (Figure 7.1). On the PCA taxa bi-plot those that dominate in this period are seen on the far right of Axis 1, associated with eutrophic conditions. Prevalent taxa characteristic of eutrophic conditions at Lough Inchiquin include *Cricotopus intersectus*-type, *Microtendipes pedellus*-type and *Chironomus anthracinus*-type (Brooks et al., 2007; Moller Pillot, 2009; 2013). Slight increases are seen in these taxa during the Middle Bronze Age but the most significant increases are seen in the Late Bronze Age where they reach maximum representations in the stratigraphy. *Synorthocladius* increases slightly in the Middle Bronze Age and maintains a high representation throughout the Late Bronze Age. Although generally being rheophilic (associated with river water) (Brooks et al., 2007; Moller Pillot, 2013), the increased presence of *Synorthocladius* in this period is proposed to be representing increasingly productive littoral conditions as described in Ruiz et al. (2006), Raunio et al. (2007) and Chique (2017). Supporting this interpretation is the lack of other river taxa in the sediment record, except for a low representation of *Eukieferiella claripennis*-type (Brooks et al., 2007; Moller Pillot, 2013).

The mesotrophic – eutrophic taxon *Stempellinella/Zavrelia* becomes more common from the Middle Bronze Age onwards and combined with a significant increase in *Tanytarsus* undifferentiated suggests a nutrient-rich littoral environment at this time (Brooks et al., 2007; Chique et al., 2018). This environment would support the development of macrophytes, and high levels of *Myriophyllum* are observed in the pollen record during the Late Bronze Age. Taxa associated with macrophytes, *Dicrotendipes nervosus*-type, *Psectrocladius sordidellus*-type and, particularly, *Paratanytarsus* and *Ablabesmyia* are well represented in this period (Brooks et al., 2007; Vallenduuk and Pillot, 2007). There are only low occurrences of oligotrophic taxa such as *Pagastiella* and *Micropsectra insignilobus*-type (Brooks et al., 2007; Moller Pillot, 2009; 2013). Preferring well-oxygenated systems, the low representation of these taxa suggests that oxygen levels within the lake were lower than in the preceding periods (Brooks et al., 2007; Chique et al., 2018). The oligotrophic – mesotrophic taxon *Sergentia coracina-type* remains well represented throughout the Middle and Late Bronze Age (Brooks et al., 2007; Moller Pillot, 2009). Contrary to this, Taylor et al. (2017a) showed that this taxon decreased significantly with farming activity, being negatively associated with all land-use variables in small Irish lakes. Lough Inchiquin, although becoming more productive in the Late Bronze Age, seemingly never became a severely polluted lake system. This may be due, again, to the large size, depth and open system of Lough Inchiquin when compared with the small, closed-basin lakes investigated by Taylor et al. (2017a).

At Lough Inchiquin, $\delta^{15}N$ levels appear to be the driving force on the lake system and chironomid community composition in this period, particularly during the Late Bronze Age. $\delta^{15}N$ was shown to be the dominant factor influencing the chironomid taxa in the interactive forward-selected RDA accounting for 9.4% of the variation in chironomid data. The chironomid taxa associated with $\delta^{15}N$ in the RDA include *Synorthocladius*, *Cricotopus intersectus*-type, *Chironomus anthracinus*-type and *Psectrocladius sordidellus*-type (Table 6.4). Predominant taxa during the Late Bronze Age at Lough Inchiquin, *Microtendipes pedellus*-type, *Cricotopus intersectus*-type and *Chironomus anthracinus*-type, have all been associated with more recent pastoral farming in Ireland (Potito et al., 2014; Chique et al., 2018). Late Bronze Age farming activity had a much greater impact on the lake system than in any preceding period including the Neolithic *Landnam*. This situation was also demonstrated by Taylor et al. (2017a) at multiple sites across north-west Ireland. Increased farming in the catchment of Lough Dargan during the Late Bronze Age led to a rise in $\delta^{15}N$ values to 5.1‰ and a dominance of eutrophic taxa (Taylor et al., 2013). Similarly at Cooney Lough a shift to eutrophic taxa was evident in the Late Bronze Age associated with increased lake productivity with $\delta^{15}N$ at 4.4‰ (Taylor et al., 2017a).

The increased lake productivity in the Late Bronze Age suggested by the geochemical and chironomid data suggests pastoral farming in the catchment of Lough Inchiquin had intensified significantly. A recent study has demonstrated the increased ecological impact of human populations from the Middle – Late Bronze Age across Ireland, with an intensification of woodland clearance and agricultural practices being sufficient to alter the nitrogen cycle, evidenced through increased $\delta^{15}N$ values in animal bone from this period (Guiry et al., 2018). This suggests that the intensification of agriculture in the catchment of Inchiquin, which locally was having an impact on the lake system, was also occurring on a much broader scale with long-term effects on the environment and highlights the impact that ancient populations may have had on their environment (Guiry et al., 2018).

The activity at Inchiquin may also have occurred in closer proximity to the lake itself which would allow manure to be more readily in-washed. Surplus nitrogen within the soil, produced if livestock densities are high, can leach into rivers and lake systems from the surrounding catchment (Bunting et al., 2007). Woodward et al. (2012) demonstrated that the density of cattle in the catchment was positively correlated with lake sediment $\delta^{15}N$ from lakes across western Ireland and so perhaps herd size also increased in the Late Bronze Age. Woodward et al. (2012) determined that the mean value for lakes with >80% agricultural cover in the catchment was 5.1‰. This would place Lough Inchiquin firmly within this category during the Late Bronze Age, with perhaps the majority of the land in the catchment used for pastoral agriculture with a minor arable component. Cattle are thought to be the most important domesticate throughout prehistory but sheep, goat and pig may have contributed to the pastoral economy (Cooney, 2000). Animal bones have been recovered from many of the excavated sites on the Burren with cattle, sheep/goat and pig represented at Parknabinnia court tomb and at the excavated wedge tombs and habitation sites on Roughan Hill (Jones, 2004; Jones and Gilmer, 1999; Ó Maoldúin, 2015).

The Burren uplands are particularly well suited to pastoralism with mild winter and spring temperatures meaning that the winterage of cattle, and previously of sheep, is still important today (Feeser and O'Connell, 2010; Jones, forthcoming-a).

Although the stronger relationship is between $\delta^{15}N$ and NAPp, cereal-type also shares a positive correlation with $\delta^{15}N$. This relationship could be due to the practice of manuring. Manuring with domestic waste and animal dung has been practiced in western Europe since the Late Neolithic and particularly so in the Bronze Age (Bakels, 1997). There is extensive evidence for the manuring of arable soils within this period in Britain (Bakels, 1997; Guttmann et al., 2006; Macphail et al., 1990; Spencer, 2012), but evidence is more limited within an Irish context. Verrill and Tipping (2010), however, identified the addition of midden material and animal manure to soils at Belderg Beg, Co. Mayo, during the Bronze Age (Verrill and Tipping, 2010). It is certainly plausible that areas within the catchment of Lough Inchiquin were manured to aid arable agriculture, especially if earlier soil erosion had caused a loss of soil fertility.

Archaeological evidence for Late Bronze Age activity is scarce in the catchment area except for a habitation site at Teeskagh and an enclosure on the Carran Plateau at some remove from the lake (c. 6km and c. 8km, respectively) (Jones et al., 2010; Gibson, 2016). Outside of the catchment but still in the Burren, Late Bronze Age settlement activity has been recently identified at Turlough Hill, c. 16km north of Lough Inchiquin (Ó Maoldúin, 2018 pers. comm.; Ó Maoldúin and McCarthy, 2016). Further evidence is more limited in the form of artefacts and the possibility of, as yet undated, burnt mounds and enclosures dating to this period (Grogan, 2005a; Grogan, 2005b). Grogan (2005a) previously proposed that the lowland areas south of Roughan Hill, and so nearer to the lake, may have become more important in later periods due to soil erosion from the Burren uplands. Archaeological data suggests that settlement on Roughan Hill continued for some time after erosion occurred. It is plausible, however, that lowland areas closer to the lake itself became more important after c. 1550 BC, when the Roughan Hill settlement ended, which may explain why the Late Bronze Age saw no further erosion. The lack of Late Bronze Age settlement evidence and the regional nature of the pollen data from Lough Inchiquin may have suggested that human activity was concentrated at some distance from the lake at this time. Results of palaeolimnology, however, show localised and within-lake change which, when combined with anthropogenic pollen indicators with a limited dispersal capacity, certainly demonstrates a continued presence of human population and farming activity in the landscape in the immediate vicinity of the lake during the Late Bronze Age.

7.6 Conclusion

This study has allowed the intensity of farming activity from the Early Neolithic to the Late Bronze Age to be elucidated and its effects on the ecology of the lake to be demonstrated. Results demonstrate the changing farming intensity, proximity to the lakeside and the effects such activity has on the lake system itself throughout prehistory. This study has demonstrated the advantages of taking a multi-proxy approach to palaeoenvironmental investigations through combining new pollen evidence with chironomid, organic and inorganic geochemical data. The results highlight the sensitivity of chironomid taxa to prehistoric farming even in a large lake such as Lough Inchiquin, with Late Bronze Age farming, in particular, having a significant impact upon the chironomid community composition. The nutrient enrichment of the lake through time has been identified via palaeolimnology which can be linked to land-use in the surrounding catchment. The correlation of increasing NAPp with increasing $\delta^{15}N$ is particularly evident and shows the influence of agricultural activity on the productivity of the lake. Inorganic geochemistry has demonstrated that increased $\delta^{15}N$ values are indeed due largely to an increase in lake productivity from anthropogenic nutrient input, and less so from soil erosion. Additionally, the geochemical data from Lough Inchiquin has provided some of the best dated evidence for Holocene soil erosion from the Burren from as early as the Late Neolithic.

Chapter 8 – Palaeoenvironmental Investigations of Prehistoric Land-use at Rosroe Lough

8.1 Introduction

This chapter will discuss the results of pollen analysis undertaken on a sediment profile from Rosroe Lough, located within south-east Co. Clare, specifically within the Mooghaun Landblock (Figure 2.6). To summarise the archaeological discussion in Chapter 3, the Mooghaun Landblock is host to a dense concentration of later prehistoric sites but evidence of earlier activity is severely limited. Substantial human activity only began in the Chalcolithic – Early Bronze Age with the construction of wedge tombs and burnt mounds across the landscape (Grogan, 2005b). The densest concentration of archaeological remains is dated to the Late Bronze Age when the large hillfort of Mooghaun was constructed in addition to the lake settlement site of Knocknalappa and the deposition of the Mooghaun gold hoard, all within or just on the outskirts of the catchment area of Rosroe Lough (Grogan, 2005b; Grogan et al., 1999; Raftery, 1942; Eogan, 1983).

To date pollen analysis has been previously carried out on two sites within the Mooghaun Landblock at Mooghaun Lough and Caherkine Lough (Molloy, 2005; O'Connell et al., 2001). In comparison with other areas of Co. Clare, e.g. the Burren, this landscape has seen limited palaeoenvironmental research. Rosroe Lough will be the largest lake to have been investigated in this landscape providing a more regional pollen record with the catchment estimated as 19.3km^2 by the current study. The focus of this study will be to provide a detailed assessment of prehistoric human activity and landscape change over a relatively large area located in the centre of the Mooghaun landblock. The current archaeological narrative suggests that this area was of limited importance in early prehistory and previous palaeoenvironmental data corroborates this with a lack of an Early Neolithic *Landnam* in the pollen records (Molloy, 2005; O'Connell et al., 2001). It is an objective of this study to determine if the lack of early prehistoric activity was a more widespread phenomenon across this landscape or confined to the local catchments of the small lakes previously investigated. The main methodologies employed in this study were pollen analysis, loss-on-ignition and plant macrofossils.

8.2 Study Site

Rosroe Lough (N52°45’51” W8°49’33”) is a large lake encompassing 108ha located roughly centrally within the Mooghaun Landblock. The lake has an average depth of 6.3m (Shannon, 2008) and a maximum depth of 16.6m as identified in the current study. The lake consists of two large basins linked by a narrow channel of water. Grogan (2005b) has suggested that the extent of the lake may have been larger in prehistory with the two basins linked together. A number of small lakes are connected to Rosroe Lough by streams which flow into the northern-most part of the lake, while the southern basin has two small outflows (Figure 8.2). The southern basin (c. 850 x 910m) was chosen for coring as the bathymetry (Figure 8.1) indicated the presence of a large, deep basin. The topography surrounding the site is relatively flat but with a low ridge directly to the east. The larger hill on which Mooghaun hillfort is located shelters part of the western edge of the catchment with a series of more upland areas in the landscape to the north-west. This lake was chosen due to its proximity to archaeological remains particularly of the Late Bronze Age. Specifically the lake settlement site of Knocknalappa is situated on the eastern shore of Rosroe Lough while just outside of the western edge of the catchment is Mooghaun hillfort. The large size of Rosroe Lough will provide a more regional signal than has previously been obtained from the small lake of Mooghaun Lough (175 x 75m) (Molloy, 2005) and other investigations in the area, as discussed below. The delineation of the catchment of Rosroe Lough can be seen in Figure 8.2 which includes archaeological sites within it, and demonstrates the smaller catchment of Caherkine Lough. Archaeological sites within the wider landscape of the Mooghaun Landblock can be seen in Figure 2.6 in Chapter 2.

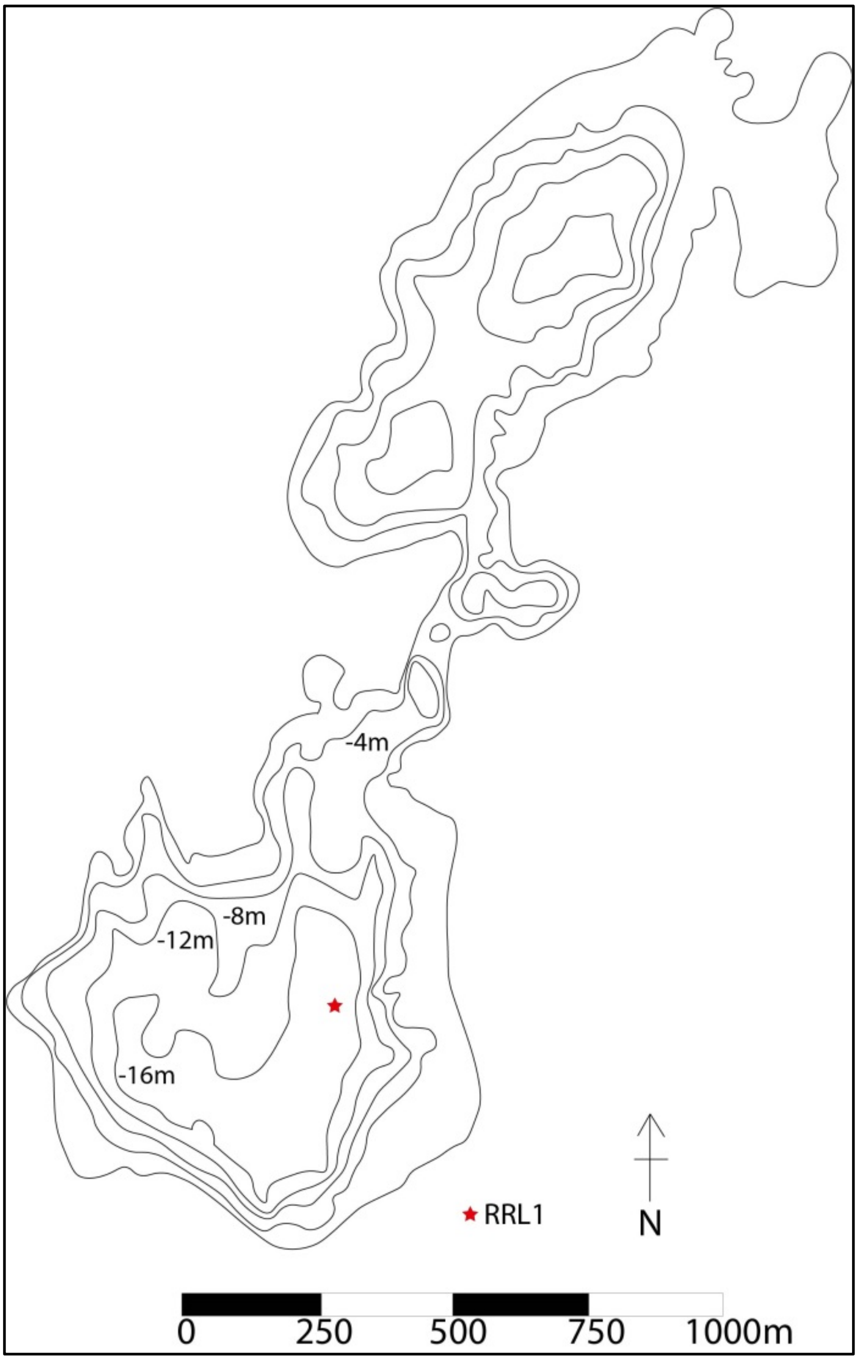

Figure 8.1: Bathymetry map of Rosroe Lough with water depth contours of -4, --8, -12 and -16m. The red star indicates the coring location for extraction of sediment core RRL1. Adapted from Thompson (2008).

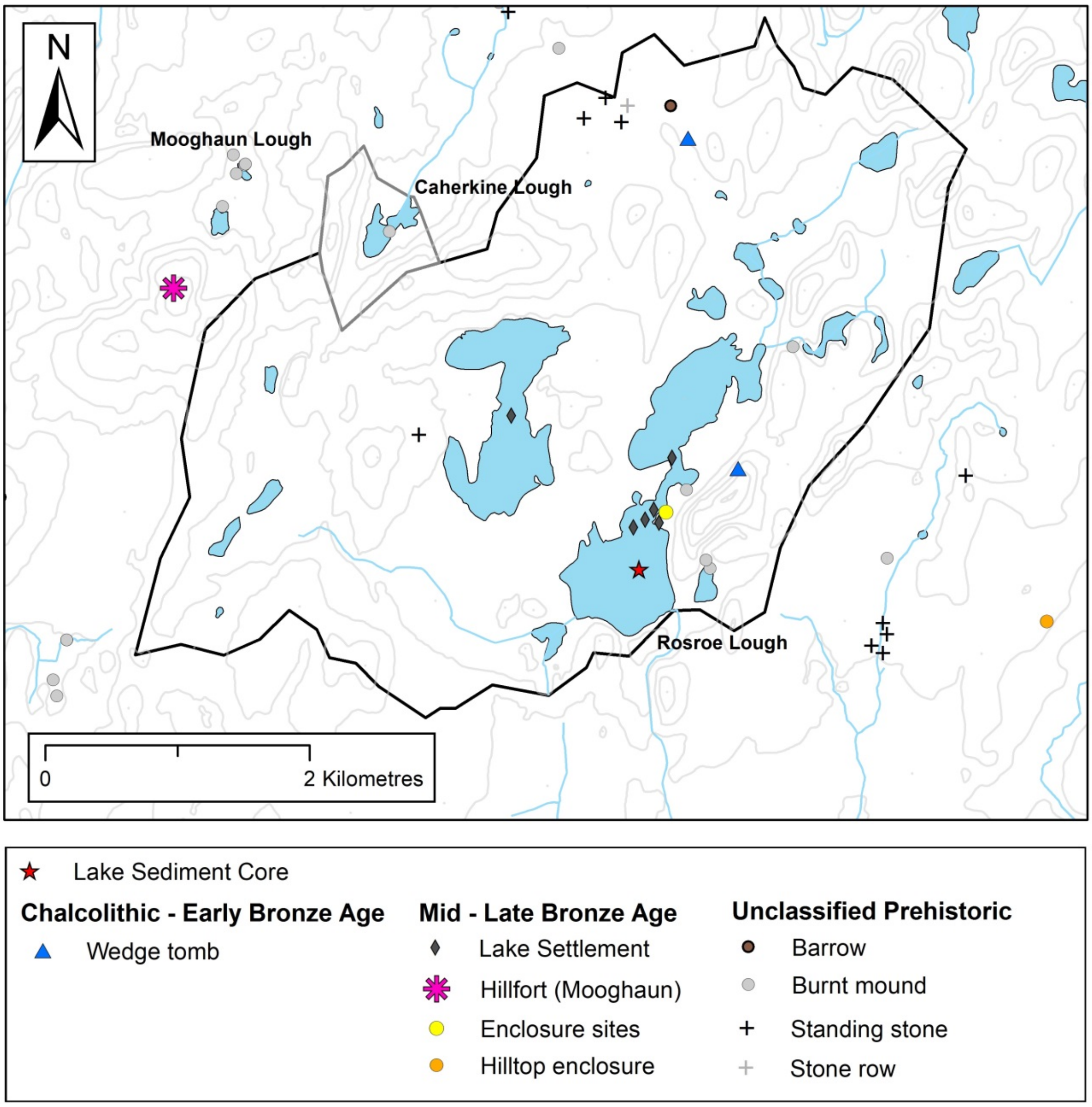

Figure 8.2: The distribution of relevant archaeological sites in the catchment of Rosroe Lough as denoted by the black line. Rosroe Lough is labelled and the red star indicates the coring location for sediment core RRL1. Two additional lakes have been labelled and are discussed in the text. The small catchment of Caherkine Lough is indicated by the dark grey line. Contours are shown in light grey to indicate the topography of the landscape. Source: author.

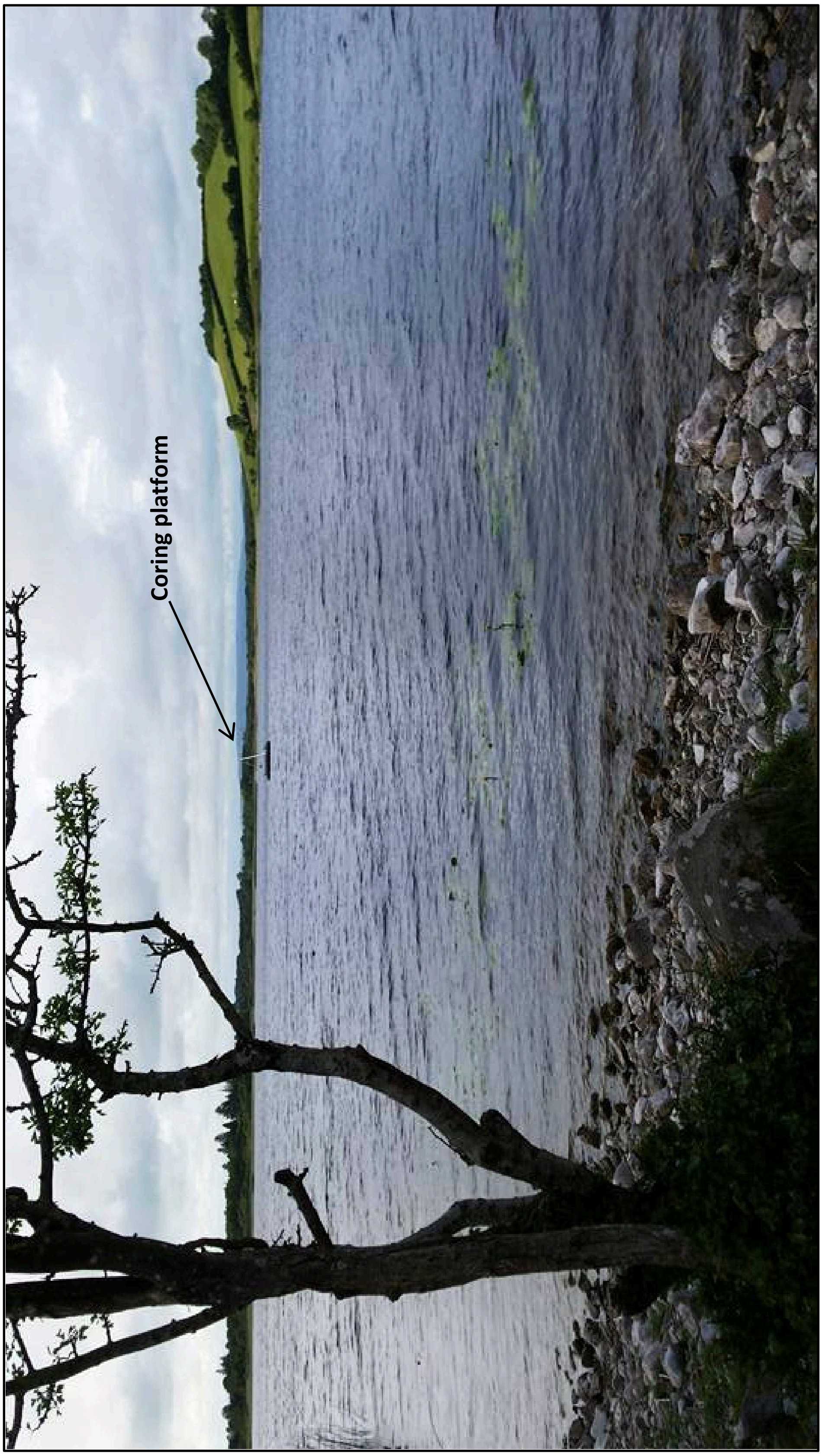

Figure 8.3: The coring platform in position in Rosroe Lough during fieldwork. Source: author.

8.3 Methods

A detailed description of all methods is given in Chapter 5 but the key points relating to this study are summarised below.

8.3.1 Core Extraction

A Usinger piston corer (Mingram et al., 2007) was used to extract two parallel sediment cores (RRL1 and RRL2) from Rosroe Lough in June 2016. Cores were extracted from the broad, deep basin in the southern portion of the lake (N52°45’51”W8°49’33”) at a water depth of 16.6m. Core RRL1 was 6m long consisting of c. 4m of Holocene sediment and c. 2m of glacial clay and RRL2 was 4m in length. The data presented pertains to core RRL1. Figure 8.3 shows the coring platform in position in Rosroe Lough.

8.3.2 Chronology

Age control for Rosroe Lough is based on ten ^{14}C-AMS determinations of which seven were accepted. Samples of 2cm-thick sediment were wet-sieved in order to retrieve suitable plant material for ^{14}C analysis. Radiocarbon dating was carried out at the 14Chrono Centre, Queen’s University Belfast, UK. An age-depth model was established using Bacon v. 2.2 Bayesian age-depth modelling software (Blaauw and Christen, 2011) utilising IntCal 13 (Reimer et al., 2013). All ages produced by Bacon are expressed as calibrated years BC /AD and rounded to the nearest ten years.

8.3.3 Loss-on-Ignition

Loss-on-ignition (LOI) was carried out on samples of 2cm^3 along the full length of RRL1 at 2cm intervals. This was carried out to provide an estimate of the organic matter and inorganic carbonate content of the sample which can be used to assess sedimentation rates. Guidelines for the determination of organic (LOI_{550}) and inorganic (LOI_{950}) carbon contents proposed by Heiri et al. (2001) were followed. Results for the interval 292 – 120cm are presented.

8.3.4 Pollen and Macrofossil Analysis

Pollen analysis was carried out on a total of seventy eight samples between 292 – 120cm. Samples were taken at 2cm intervals between 292 – 140cm with the two uppermost samples taken at 132cm and 120cm. Preparation of samples for pollen analysis followed Faegri and Iversen (1989). In all cases sample size was $1cm^3$. Pollen taxa were divided into arboreal pollen (AP) and non-arboreal pollen (NAP) with the latter divided into shrubs, ferns, pastoral indicators (NAPp), arable indicators, bog and aquatic. The minimum size for cereal-type pollen was 40µm and determined by characteristics presented by Beug (1961). Macrofossil analysis was carried out as described in Chapter 5.

8.4 Results

8.4.1 Sediment Core Description

In general the core consisted of dark grey-brown gyttja sediment with occasional shells, plant material and banding in colour. Glacial clay was present from c. 410cm. Further details are given in table 8.1 and the full sediment core is presented in Figure 8.4.

Table 8.1: Detailed description of the lithology of sediment core RRL1 extracted from Rosroe Lough.

Depth (m)	Lithology
0.50 – 1.50	Dark grey-brown gyttja with slight banding/mottling Occasional shells throughout
1.50 – 2.55	Dark grey-brown gyttja with lighter yellowish-brown banding Turning very dark from 2.36m Shells frequent throughout Plant material in B-half only
2.55 – 3.51	Dark brown-black gyttja that is more uniform/consolidated No shells Plant material in A and B-halves
3.51 – 4.51	Lighter brown Clay content increasing with depth until clay only from 4.10m Iron precipitate (orange) mottling within clay 4.11 – 4.38
4.52 – 5.52	Yellow-grey glacial clay with pink banding Dark grey sand/gravel layers
5.52 – 6.57	As above From 5.79 pink banding becomes diagonal

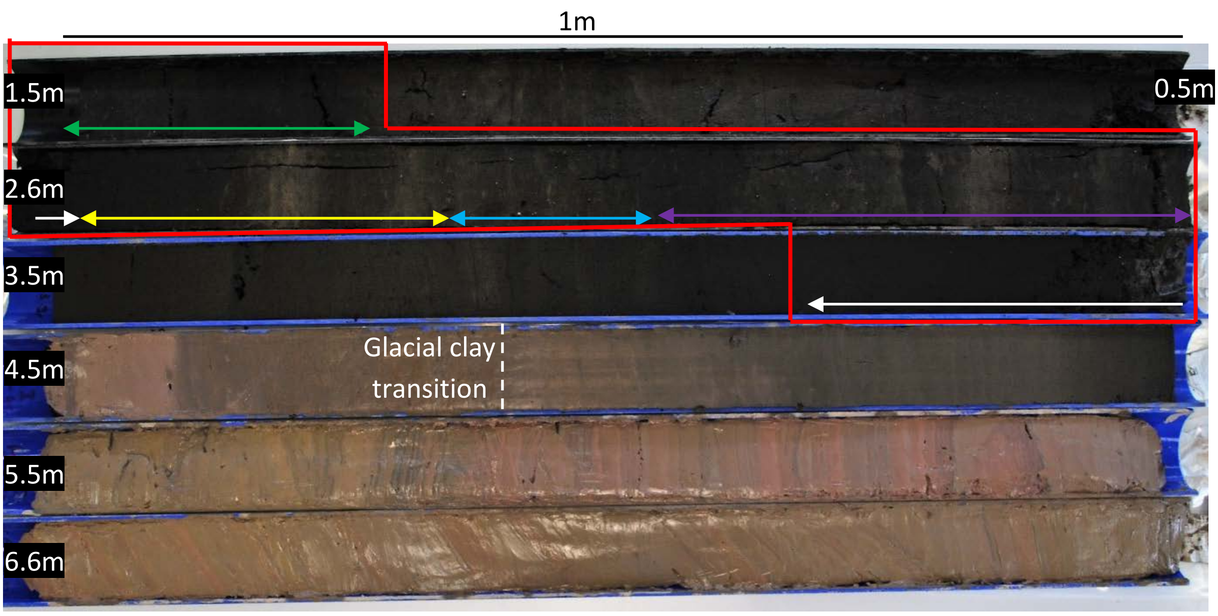

Figure 8.4: The full profile of lake sediment core RRL1 extracted from Rosroe Lough. The red outline indicates the section of the core investigated during this study. The arrows indicate time periods as follows: white = Neolithic; yellow = Bronze Age; blue = Iron Age; purple = Early Christian; green = Early Medieval. The white dashed line indicates the transition from Holocene sediment to glacial clay.

8.4.2 Chronology

Available ^{14}C dates are presented in Table 8.2. From initial pollen analysis carried out at low resolution it was thought that the full portion of the core studied (from 292 – 120cm) was prehistoric in date. As further ^{14}C dates became available, however, this view changed and it became apparent that both the prehistoric and early medieval had been investigated through the pollen analysis. Despite uncertainties in the dating evidence, the upper portion of the resultant chronology, extending into the medieval period, has been tentatively corroborated by the examination of similar pollen features for the medieval of the Caherkine Lough record (O'Connell et al., 2001). The aim of the dating programme was to develop a chronology for major changes in the pollen record which may infer human activity. Three samples were initially taken for ^{14}C-AMS dating. The first (RRL1-1) was taken close to the lower limit of the pollen diagram, the second (RRL1-2) was taken at the start of an increase in anthropogenic indicators, and the third (RRL1-3) was taken towards the top of the core segment analysed. After further pollen analysis had been carried out, four more samples were taken based on significant changes in the vegetation. The first of these (RRL1-4) was taken at what was believed to be the Elm Decline while RRL1-5 and RRL1-6 were both taken prior to a significant increase in anthropogenic indicators. An attempt was also made to bracket a period of intense activity (RRL1-7). Due to uncertainties over the accuracy of a number of ^{14}C determinations, particularly RRL1-3 and RRL-7, a further three samples were taken in an attempt to understand the chronology more clearly. As such, samples RRL1-8 and RRL1-10 were taken at similar depths to previous dates. A final sample (RRL1-9) was taken at the start of a period of woodland recovery.

The initial model (Figure 8.5) was examined and the determined age in relation to sediment depth, sedimentation rates and pollen data was considered. Three dates (RRL1-3, RRL1-8 and RRL1-7) were rejected on the basis of ^{14}C reversals, i.e. the ^{14}C determination provided was deemed too old for that particular sediment depth in relation to accepted dates in the sequence. The date provided by RRL1-7 was older than five previous dates within the sequence while RRL1-8 was older than three previous dates. Similarly, while the uppermost date (RRL1-3) provided an AD date as expected this was older than two previous AD dates obtained in the sequence (RRL1-6 and RRL1-2). Although RRL1-10 was at first rejected from the model due to its closeness in age with RRL1-5, both dates were subsequently included in the Bacon model which would produce an interpolated mid-point between the two dates. With these three dates rejected, the model produced a continuous sequence of dates and examination of the sedimentation rates and pollen data led to the acceptance of this chronology, although it must be treated with some level of uncertainty.

Table 8.2: Radiocarbon dates derived from material within sediment core RRL1 from Rosroe Lough. ^{14}C-AMS dates were obtained on plant material from wet-sieved, 2cm-thick sediment samples.

^{14}C lab code	Sample ID	Depth (cm)	^{14}C (BP)	Age range 1σ 68.3%	Age range 2σ 95.4%	Material dated	Comments
UBA - 34755	RRL1-3	132	1842±34	AD 130 – 219	AD 81 – 244	Wood	Reversal; Rejected
UBA – 36028	RRL1-8	152	2561±30	800 – 757 BC	805 – 747 BC	Charred seed/nutshell	Reversal; Rejected
UBA – 35616	RRL1-7	158	3404±30	1702 – 1663 BC	1770 – 1624 BC	Wood	Reversal; Rejected
UBA – 35615	RRL1-6	188	1545±38	AD 430 – 493	AD 422 – 594	Wood	Accepted
UBA – 34754	RRL1-2	190	1665±35	AD 344 – 415	AD 320 – 430	Wood	Accepted
UBA – 36029	RRL1-9	206	2215±28	260 – 208 BC	369 – 202 BC	Charred seed/nutshell	Accepted
UBA - 36030	RRL1-10	230	2972±31	1231 – 1155 BC	1283 – 1107 BC	Charred seed/nutshell	Accepted
UBA – 35614	RRL1-5	234	2840±33	1043 – 971 BC	1093 – 915 BC	Wood	Accepted
UBA - 35613	RRL1-4	260	4628±35	3498 – 3449 BC	3516 – 3397 BC	Wood	Accepted
UBA – 34753	RRL1-1	288	6003±43	4947 – 4836 BC	5001 – 4789 BC	Wood	Accepted

The model suggests that sedimentation started slowly which is to be expected given the lack of human activity seen from the pollen data in the basal section. Sedimentation then increased from c. 234cm concurrent with an increase in human activity suggested from the pollen record. From c. 206cm sedimentation slowed corresponding with a period of woodland recovery identified in the pollen data. Sedimentation then increased substantially from c. 190cm when intensive activity is again suggested from the pollen data. The accepted ^{14}C determinations, then, appear to corroborate the relative rate of sedimentation change inferred from the land-use indicators and are thus deemed to be of sufficient reliability for the current study. The three rejected dates (RRL1-3, RRL1-7 and RRL1-8) are likely the result of re-worked material within the sediment (Törnqvist et al., 1992).

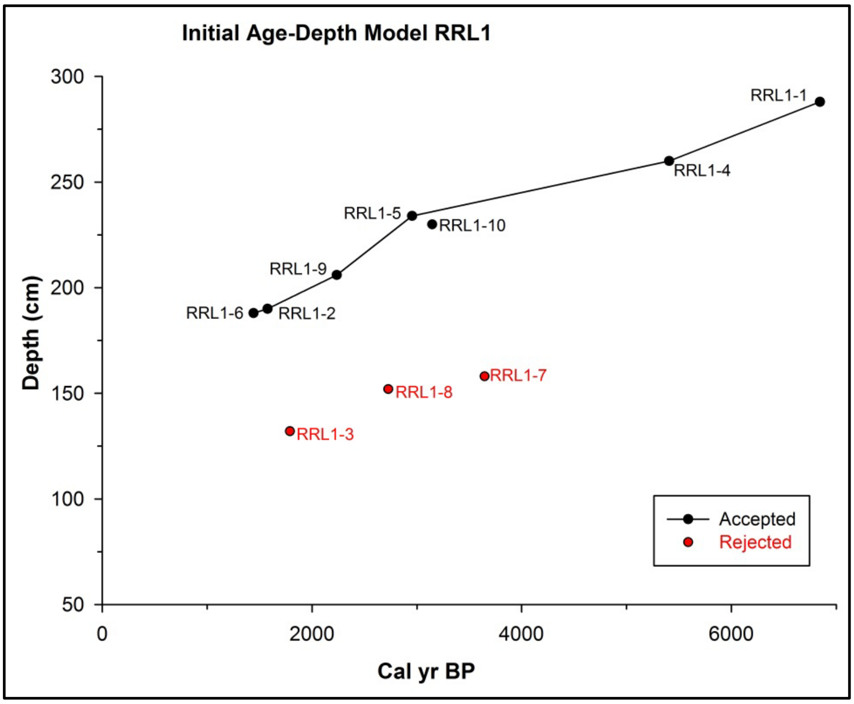

Figure 8.5: Initial age-depth model produced for sediment core RRL1 from Rosroe Lough showing accepted and rejected ^{14}C dates.

An age-depth model was produced using Bacon v. 2.2 Bayesian age-depth modelling software with the IntCal13 calibration curve (Figure 8.6) (Blaauw and Christen, 2011; Reimer et al., 2013). Dates were input to Bacon as ^{14}C BP which produced dates of calibrated years BP using a default calibration curve of IntCal13. The potential error within this age-depth model, however, is large in places. Throughout the core this potential error ranges from 179 years to 1435 years. The section of the core with the largest potential error (>1000 years) relates to the Late Neolithic to Early Bronze Age. The Middle – Late Bronze Age, in contrast, is relatively well dated with the 95% confidence interval ranging from 340 – 593 years. Due to the errors in ^{14}C determination towards the top of the profile a chronology could only be established between 288 – 188cm which runs from 4900 – 480 BC. The uppermost pollen sample was taken at 120cm and assuming a constant rate of accumulation from the uppermost accepted date (AD 480 at 188cm) the estimated age for the top of the pollen profile (120cm) has been determined as AD 1240. Thus, all dates above 188cm have been interpolated but because the Bronze Age section of the core has been bracketed by the uppermost accepted date, interpolation is only undertaken on the part of the core beyond the specific scope of this study.

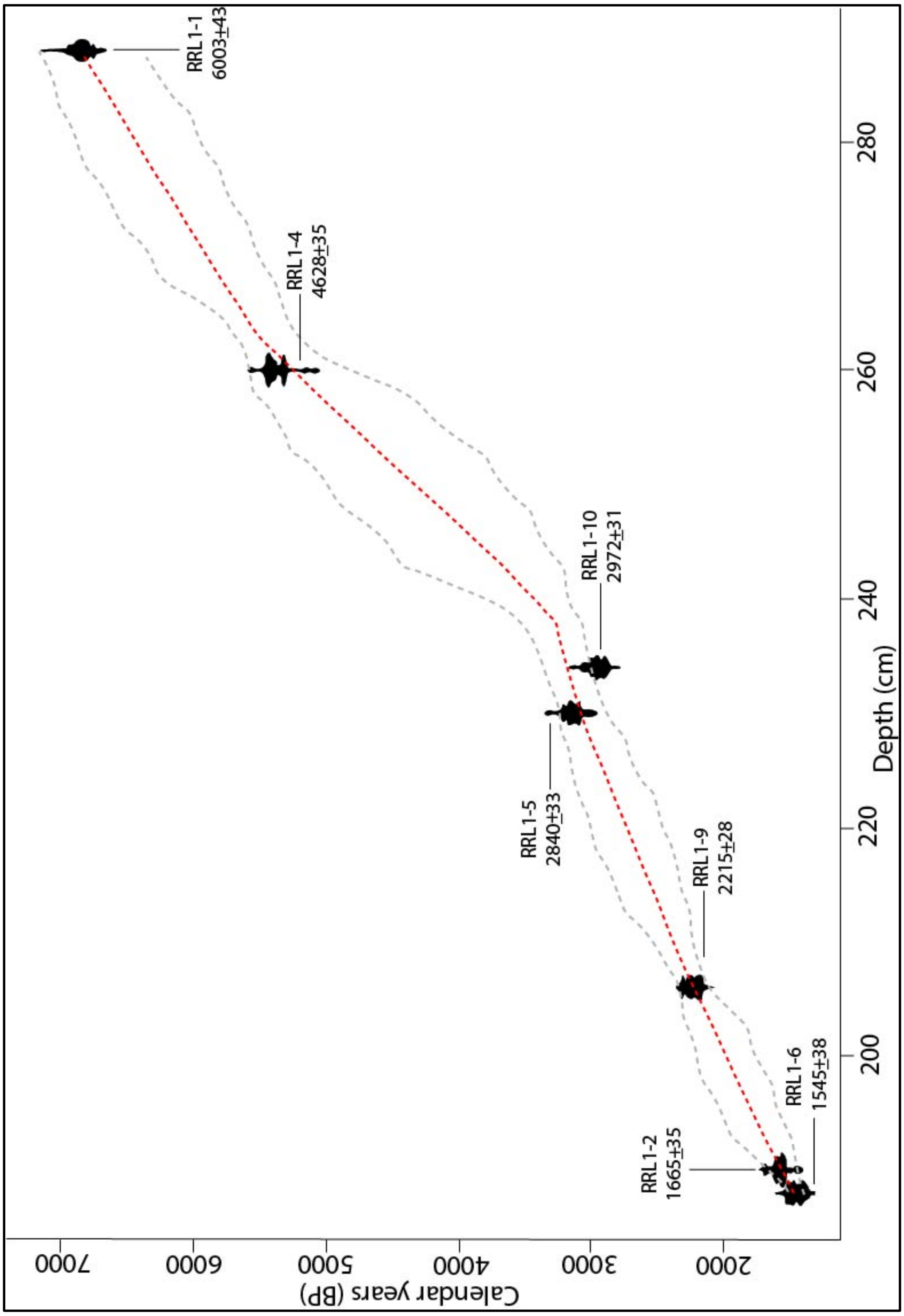

Figure 8.6: Age-depth model for sediment core RRL1 from Rosroe Lough produced by Bacon v. 2.2 Bayesian software on ^{14}C dates from RRL1. Black symbols indicate the probability distribution for calibrated ^{14}C dates. The red dashed line follows the weighted mean age for each depth and parallel grey dashed lines indicate the 95% confidence interval.

8.4.3 Results of Pollen Analysis

Pollen assemblage zones (PAZs) and subzones were established on the basis of significant changes in percentage and concentration pollen data across a range of pollen taxa, with emphasis on land-use indicators grouped together under the NAPp category. A time period was assigned to each PAZ based on the Bacon age-depth model produced. Dates marked with an asterisk have been interpolated using a constant sedimentation rate. The pollen data is presented in Figures 8.7 and 8.8. The main trends in LOI_{550} will be discussed for each PAZ (Figure 8.9).

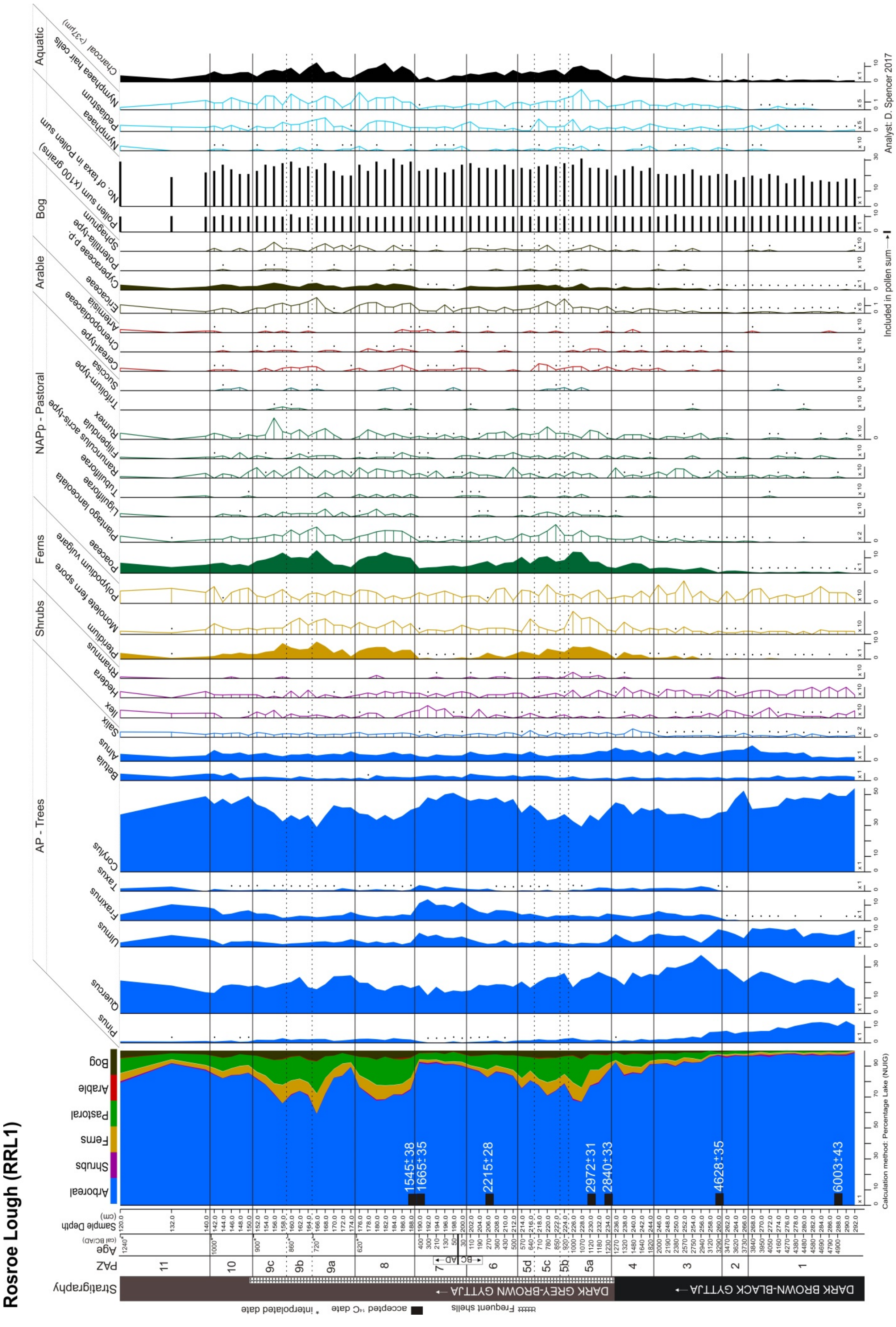

Figure 8.7: Percentage pollen diagram plotted to depth with age-scale provided in calibrated years BC/AD. The diagram is divided into eleven PAZs based on changes in the abundance of certain taxa. A simplified core stratigraphy is provided to the left. A composite diagram demonstrates the abundance of different ecological groupings - categorised and colour coded as indicated. Selected pollen percentage curves and pollen sum (x1000 grains) are then presented. Scales indicated at base of individual curves (scale of x1 = solid fill; exaggerated curve = hatched fill). Very low values are indicated by dots. Black bars indicate accepted radiocarbon dates which are displayed on the composite diagram.

Rosroe Lough (RRL1) Concentration

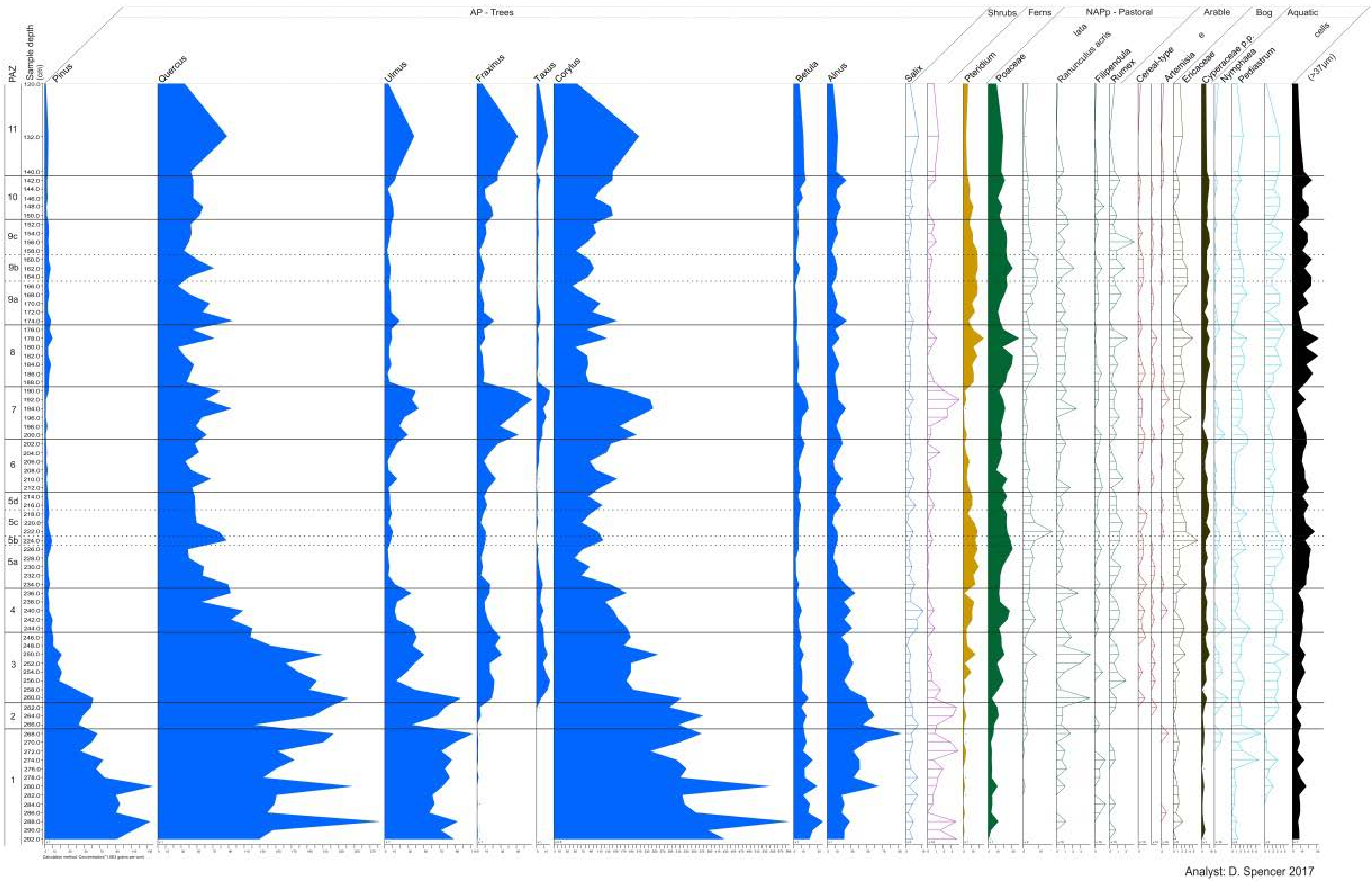

Figure 8.8: Concentration pollen diagram plotted by depth for main pollen taxa presented in Figure 8.7. The diagram is divided into the same eleven PAZs as percentage diagram to aid comparison. The same ecological groups and colour coding is used as in Figure 8.7. Selected concentration curves are presented and scale indicated at base of curves (scale of x1 = solid fill; exaggerated scale = hatched fill).

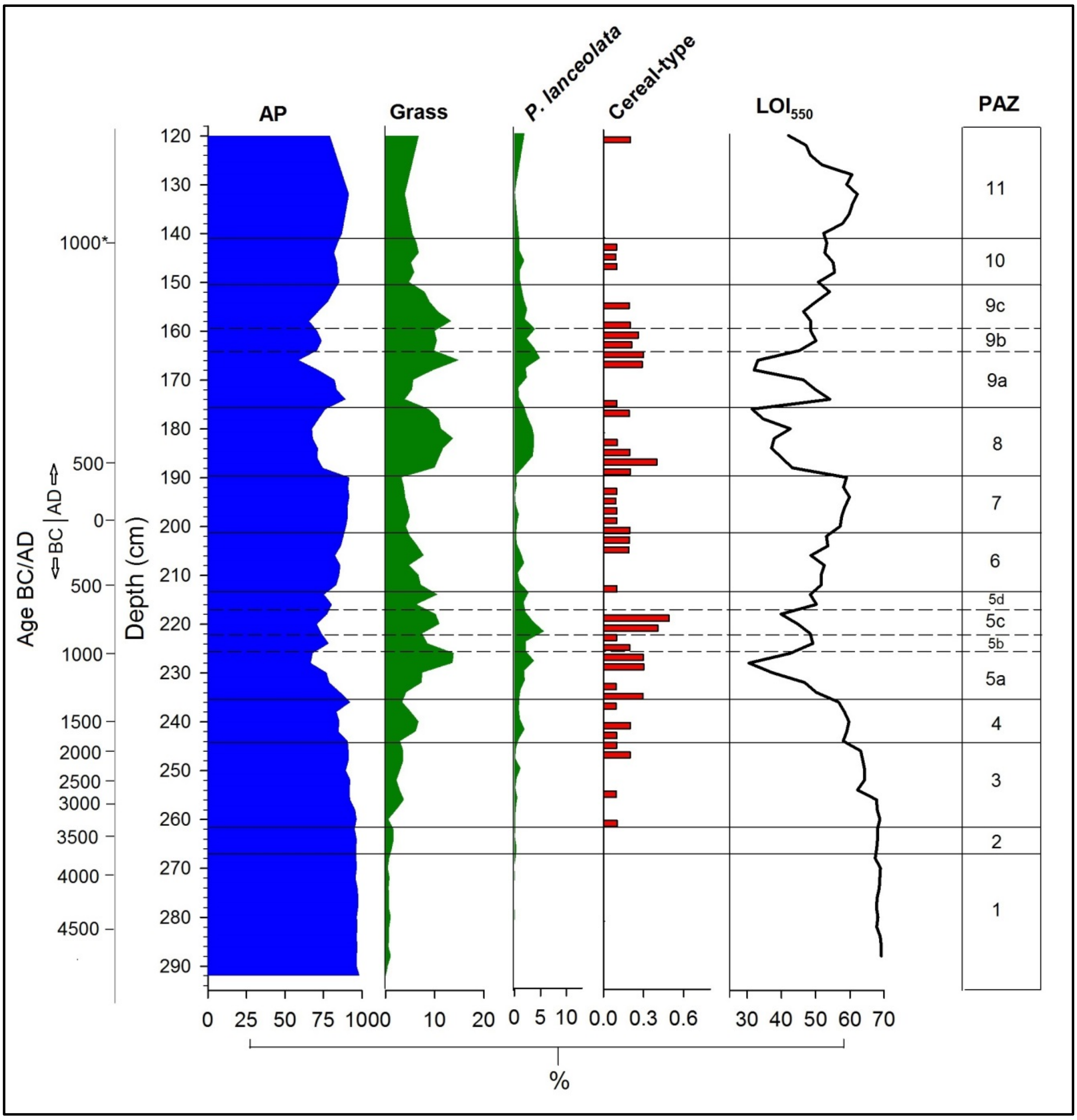

Figure 8.9: Selected percentage pollen curves representative of arboreal taxa and land-use indicators from the Rosroe Lough record plotted by depth alongside LOI_{550} data divided into PAZ.

PAZ-1 (292 – 268 cm; c. 4900 – 3790 BC)

AP is very high throughout accounting for 97% of TTP. The main contributors are *Corylus* (54.1 – 40.6%), *Quercus* (16.1 – 24.2%) and *Pinus* (11.4 – 7.2%) with lesser amounts of *Alnus* (2.7 – 10.3%). *Ulmus* increases mid-zone from 6.4 – 12.1% (280 – 268cm). *Hedera* has a constant presence ranging from 0.2 – 0.7% and *Ilex* ranges from 0.1 – 0.7%. NAPp values are very low <1.4%. An increase in *Pediastrum* occurs from 276cm from 0.1 – 0.9%. Pollen concentrations are high overall through the zone with the expansion of *Alnus* and *Ulmus* more pronounced than in the percentage data. LOI_{550} is high with an average of 68.4%. Plant remains were low in the macrofossil data for this zone (Figure 8.10).

PAZ-2 (266 – 262 cm; c. 3790 – 3380 BC)

AP remains high but decreases slightly from 96.4 – 95.4% by the close of the zone. *Corylus* increases from 40.6 – 52.5% across the zone boundary before declining to 39.1%. *Ulmus* decreases from 12.1 – 5.7% across the zone boundary before increasing to 10.2%. *Quercus* increases from 20.3 – 28.8%. *Hedera* and *Ilex* increase from 0.2 – 0.4% and 0.2 – 0.5%, respectively. NAPp increases slightly from 1.9 – 2.0% accounted for mainly by *Poaceae*. *Chenopodiaceae* is detected in one sample at 0.1%. Overall, the trends in percentage data are mirrored in the concentration data with pronounced falls in representation of *Quercus* and *Ulmus* at 266cm. LOI_{550} remains high with an average of 68.0%.

PAZ-3 (260 – 246 cm; c. 3380 – 1910 BC)

AP declines from 96.6 – 91.4%. This is accounted for by decreases in *Quercus* from a profile maximum of 28.5 – 24.8% and *Pinus* from 7.2 – 2.3%. *Ulmus* declines from 11.5 – 2.8% (260 – 256cm) before increasing to 8.6% by the end of the zone. *Corylus* initially decreases from 38.2 – 34.5% before increasing to 41.2% by the close of the zone. Continuous curves for *Fraxinus* and *Taxus* are established, expanding from 2.2 – 6.2% and 0.7 – 2.0%, respectively. NAPp expands from 1.4 – 4.3% with a peak of 5.0% at 250cm when AP is at a minimum of 89.6%. This is accounted for by an increase in *Poaceae* from 0.6 – 3.6% and *Plantago lanceolata* from 0.2 – 1.2% by 250cm. *Pteridium* also peaks (2.3%) in this spectrum. The diversity of NAPp has increased with *Ranunculus* registering significantly for the first time peaking at 0.6% by 250cm and *Rumex acetosa* at 0.4% by 256cm. Cereal-type is detected for the first time with one grain identified at 260cm and 254cm and two grains at 246cm.

Chenopodiaceae are also recorded in this zone. Slight increases are registered for *Pediastrum* and micro-charcoal (0.2 – 0.7% and 0.6 – 2.3%, respectively). Decreases in *Quercus*, *Ulmus* and *Corylus* are more pronounced in the concentration data compared with the percentage data. LOI_{550} starts to decrease from 256cm.

PAZ-4 (244 – 236 cm; c. 1910 – 1250 BC)

AP representation is at 90.8% at the start of the zone falling to 83.6% by 238cm and rising to 92.6% by the close of the zone. This is accounted for by fluctuations in *Quercus*, *Ulmus* and *Fraxinus*. Apart from a decrease of 4.3% at 240cm *Corylus* remains relatively stable. *Alnus* increases from 6.9 – 8.8%. *Ilex* and *Hedera* show increased representation. Of the ferns *Pteridium* increases from 1.0 – 4.7% by 238cm. NAPp increases from 4.4 – 8.7% by 242cm before decreasing to 5.1% by the end of the zone. This is accounted for by an increase in *Poaceae* from 3.0 – 6.8% by 240cm and in *Plantago lanceolata* from 0.9 – 2.0% by 242cm. *Rumex acetosa* (maximum of 0.3%), *Ranunculus* (maximum of 0.7%) and *Filipendula* (maximum of 0.2%) are recorded. A more continuous curve is established for cereal-type, absent in only one sample (Figure 8.11). Both *Chenopodiaceae* and *Artemisia* are represented at ≤ 0.2%. *Nymphaea* peaks at 0.3% at the start of this zone. Micro-charcoal sees an increase from 2.8 – 3.4% between 244 – 238cm before declining to 1.8%. Reductions in *Quercus*, *Ulmus*, *Fraxinus* and *Corylus* are expressed strongly in the concentration data in contrast to the percentage data.LOI_{550} decreases further from 240cm (59.7%) to 228cm (30.5%).

PAZ-5 (234 – 214 cm; c. 1250 – 530 BC)

This zone has the highest NAPp representation for the prehistoric part of the profile and because of changes in AP/NAPp it has been divided into four subzones to simplify the description. Concentration data is low overall for this zone.

Subzone 5a (234 – 226cm; c. 1250 – 960 BC)

AP representation decreases from 86.0 – 68.1%. This is accounted for by decreases in *Corylus* from 39.4 – 32.8%, *Quercus* from 24.5 – 17.0%, Ulmus from 8.3 – 1.8% across the zone boundary, *Alnus* from 6.4 – 4.5% and *Fraxinus* from 4.6 – 3.7%. *Pinus* and *Betula* increase slightly to 3.2% and 2.8%, respectively. *Rhamnus* peaks at 0.4% and *Pteridium* at 8.2%. NAPp representation reaches 18.4% before declining slightly to 17.5% by the close of the subzone. Contributing to this is an increase in *Poaceae* from 4.2 – 13.9%, *Plantago lanceolata* from 1.2 – 2.2% and *Rumex acetosa* from 0.1 – 0.6% (at 230cm). Increased levels of *Liguliflorae* (maximum of 0.3%), *Ranunculus* (maximum of 0.4%), *Filipendula* (maximum of 0.4%) and *Tubuliflorae* (likely *Anthemis* and *Bellis perennis* – maximum of 0.2%) are recorded. Cereal-type forms a near-continuous record reaching 0.3%. *Pediastrum* increases from 0. 5 – 1.6% and micro-charcoal increases from 4.6 – 10.6% at 228cm. LOI_{550} decreases from 50.1 – 42.6%.

Subzone 5b (224cm; c. 960 – 890 BC)

AP representation increases from 68.1 – 78.5% across the subzone boundary. Contributing to this is an increase in *Corylus* (32.8 – 37.4%), *Quercus* (17 – 26.1%) and *Ulmus* (1.8 – 2.4%). *Pinus* decreases from 3.2 – 2.8% and *Alnus* from 4.5 – 4.0%. *Rhamnus* decreases from 0.4 – 0.1% across the subzone boundary while *Ilex* representation increases. *Pteridium* decreases from 8.2 – 4.6% across the subzone boundary. NAPp representation decreases from 17.5 -11.5%. This is accounted for by a decrease in *Poaceae* from 13.9 – 8.5% and a decrease in all of the lesser herb taxa (e.g. *Liguliflorae*, *Ranunculus* and *Filipendula*). *Plantago lanceolata* increases from 2.2 – 2.3%. Cereal-type decreases to 0.2% with no further arable indicators present. *Pediastrum* decreases from 1.6 – 0.7% and micro-charcoal from 9.5 – 4.6%. The short resurgence in AP is reflected strongly in the concentration data with peaks in *Corylus*, *Quercus*, *Pinus* and *Ilex*. LOI_{550} increases slightly to 49.2%.

Subzone 5c (222 – 218cm; c. 890 – 670 BC)

AP representation decreases from 73.9 – 70.8% by 220cm before increasing to 77.5%. Fluctuation is accounted for by overall rises in *Quercus*, *Corylus* and *Ulmus* which all show a decreased representation at 220cm. *Pteridium* increases from 5.6 – 6.7% mid-subzone before decreasing to 2.6%. Overall NAPp representation increases from 11.5 – 15.9% with a slight reversal in the uppermost sample. The main contributors are *Poaceae* and *Plantago lanceolata* with lesser amounts of *Rumex acetosa* (maximum of 0.8%) and *Liguliflorae* (maximum of 0.3%). Cereal-type increases from 0.1 – 0.5% throughout the subzone. *Pediastrum* increases from 0.6 – 1.6% and micro-charcoal increases from 4.6 – 8.0% across the subzone boundary before decreasing to 5.9%.LOI_{550} decreases from 48.4 – 39.9%.

Subzone 5d (216 – 214cm; c. 670 – 530 BC)

AP representation peaks at 80.6% before falling to 75.4% by 214cm. The main contributors are *Corylus* (maximum of 43.3%) and *Quercus* (maximum of 20.7%). A corresponding decrease in NAPp to 8.9% is recorded with *Poaceae* falling to 6.3% and *Plantago lanceolata* to 1.8%. *Liguliflorae* is at very low levels and cereal-type is not recorded. By 214cm NAPp have again expanded to 14%. *Pediastrum* values are <1%. LOI_{550} decreases from 50.2 – 48.4%.

PAZ-6 (212 – 202 cm; c. 530 – 70 BC)

Overall AP is at a high representation of between 83.5 – 88.1% with a minimum of 82.6% at 206cm. *Corylus* values average 46.6%. *Quercus* representation is at c. 18% with a decline to 14.9% at 202cm. There is an increasing trend in *Fraxinus* (maximum of 8.4%), *Taxus* (maximum of 1.4%) and *Ulmus* (maximum of 4.9%). *Pinus* falls to c. <1%. Apart from an increase to 9.8% at 206cm, NAPp values decrease from 9.6 – 6.2%. Fewer of the lesser herbs e.g. *Liguliflorae* and *Rumex acetosa* are recorded. One cereal-type grain was recorded at 212cm and two grains at both 204cm and 202cm. Micro-charcoal decreases from 7.8 – 5.4%. The minimum representation of AP is expressed more strongly in the concentration data. LOI_{550} is relatively stable at an average of 51.8%.

PAZ-7 (200 – 190 cm; c. 70 BC – AD 440)

AP representation attains 92% accounted for by an increase in *Quercus* (maximum of 18.3%), *Ulmus* (maximum of 9.1%), *Fraxinus* (maximum of 13.8%) and *Taxus* (maximum of 4.0%). *Corylus* attains 51.0% (198cm) before decreasing to 42.0% by the close of the zone. NAPp decreases from 6.1% (at 198cm) – 4.2%. Accounting for this is a decrease in *Poaceae* from 5.0 – 3.3% and in *Plantago lanceolata* from 0.9 – 0.3%. Curves for *Liguliflorae*, *Tubuliflorae* and *Filipendula* are interrupted. Cereal-type is at a low representation ≤0.2% but is present in all but one sample. *Pediastrum* is at levels <1% and micro-charcoal decreases from 3.9 – 1.6%. Overall concentration levels are high in this zone. LOI_{550} is relatively stable at 58.4%.

PAZ-8 (188 – 176 cm; c. AD 440 – 620*)

AP decreases to 67.7% accounted for by decreases in *Corylus* (minimum of 33.6%), *Ulmus* (minimum of 1.7%), *Fraxinus* (minimum of 2.3%) and *Taxus* (minimum of 0.4%). *Quercus* is relatively stable while the representation of *Pinus* has increased. The *Ilex* curve is interrupted. *Pteridium* increases to 7.9% with overall fern representation increasing. NAPp increases to 18.6% by 182cm accounted for by increased levels of *Poaceae*, *Plantago lanceolata* and other herbs. Cereal-type is recorded at 0.4% together with *Chenopodiaceae*. *Pediastrum* expands and micro-charcoal reaches a maximum of 12.4%. In the upper sample AP representation has increased to 76.3% and NAPp has decreased to 12.0% Micro-charcoal is much lower by the end of the zone. Concentration values have decreased from the preceding zone and the decline in *Ulmus*, *Fraxinus* and *Corylus* is particularly well-expressed in this data. LOI_{550} decreases rapidly from 59.0% (190cm) to 31.4% (176cm).

PAZ-9 (174 – 152 cm; c. AD 620 – 900*)

Based on fluctuations in AP and NAPp this zone has been divided into three subzones. Concentration values are relatively low throughout the zone.

Subzone 9a (174 – 168 cm; c. AD 620 – 720*)

This subzone is one of high AP representation which declines throughout the zone from 89.5 – 71.8%. This is accounted for by increased representation of *Quercus* (24.7%) and *Corylus* (43.0%) which then decline in the uppermost sample. NAPp is low compared with PAZ-8 and increases from 4.9 – 14.1%. Contributing to this are low levels of *Poaceae* (minimum of 3.9%) and *Plantago lanceolata* (minimum of 0.8%). The cereal-type curve is interrupted with only one grain identified at 174cm. *Pediastrum* has fallen below 1% in all but the uppermost sample. LOI_{550} decreases from 54.1 – 32.0%.

Subzone 9b (166 – 156 cm; c. AD 720 – 860*)

Overall AP is lower in this subzone ranging from 59.0 – 71.7%. Contributing to this is a decrease in overall representation of *Corylus* (minimum of 32.6%) and *Quercus* (minimum of 15.7%) despite an increase in representation at 162cm. NAPp has increased overall to a maximum of 20.7% at 166cm. This is accounted for by increased levels of *Poaceae* and *Plantago lanceolata.* There is a slight decrease in NAPp mid-subzone before increasing to

15.2% by the close of the subzone. The lesser herbs e.g. *Liguliflorae*, *Rumex acetosa* and *Ranunculus* are well represented. A continuous cereal-type curve is re-initiated with a maximum of 0.3% at 164cm. *Pediastrum* decreases from 1.5 – 0.5% and charcoal decreases from 12.6 – 4.9% by 162cm. The increase in *Quercus* and *Corylus* is well represented in the concentration data. LOI_{550} increases from 33.1 – 46.5%.

Subzone 9c (154 – 152 cm; c. AD 860 – 900*)

AP increases from 78.0 – 81.5% accounted for by increased *Corylus* to 43.5%, *Quercus* to 18.2% and *Ulmus* to 3.5%. NAPp has decreased to 10.5% caused by a decline in *Poaceae* to 8.0% and *Plantago lanceolata* to 1.5%. Lower levels of herb taxa are observed but cereal-type is still present at 0.2% in one sample. *Pediastrum* and micro-charcoal have decreased. LOI_{550} increases from 50.1 – 54.1%.

PAZ-10 (150 – 142 cm; c. AD 900 – 1000*)

AP representation is high throughout ranging from 82.0 – 85.4%. The main contributors are *Corylus*, *Quercus*, *Fraxinus* and *Ulmus.* NAPp representation is lower in this zone ranging from 6.7 – 8.8%. An increase in *Poaceae* does occur, however, from 4.8 – 6.4%, with lesser amounts of additional herb taxa. Cereal-type is still recorded between 146 - 142cm. The main trends in percentage pollen data are mirrored in the concentration data. LOI_{550} increases from 50.7 – 53.2%.

PAZ-11 (140 – 120 cm; c. AD 1000 – 1240*)

A further increase in AP is seen in this zone reaching a maximum of 91.7% at 132cm. This is accounted for by increases in *Quercus* (maximum of 21.3%), *Fraxinus* (maximum of 10.6%) and *Ulmus* (maximum of 7.7%). *Corylus* decreases from 48.9 – 37.1%. NAPp is low decreasing to a minimum of 4.1% at 130cm. This is accounted for by *Poaceae* (minimum of 4.0%) and *Plantago lanceolata* (minimum of 0.1%). All herb taxa have decreased in representation and while the cereal-type curve is interrupted, two large grains were identified at 120cm (Figure 8.12). Concentration values are high in this zone. LOI_{550} increases from 52.4 – 62.2% by 132cm before declining to 42.1% by the close of the zone.

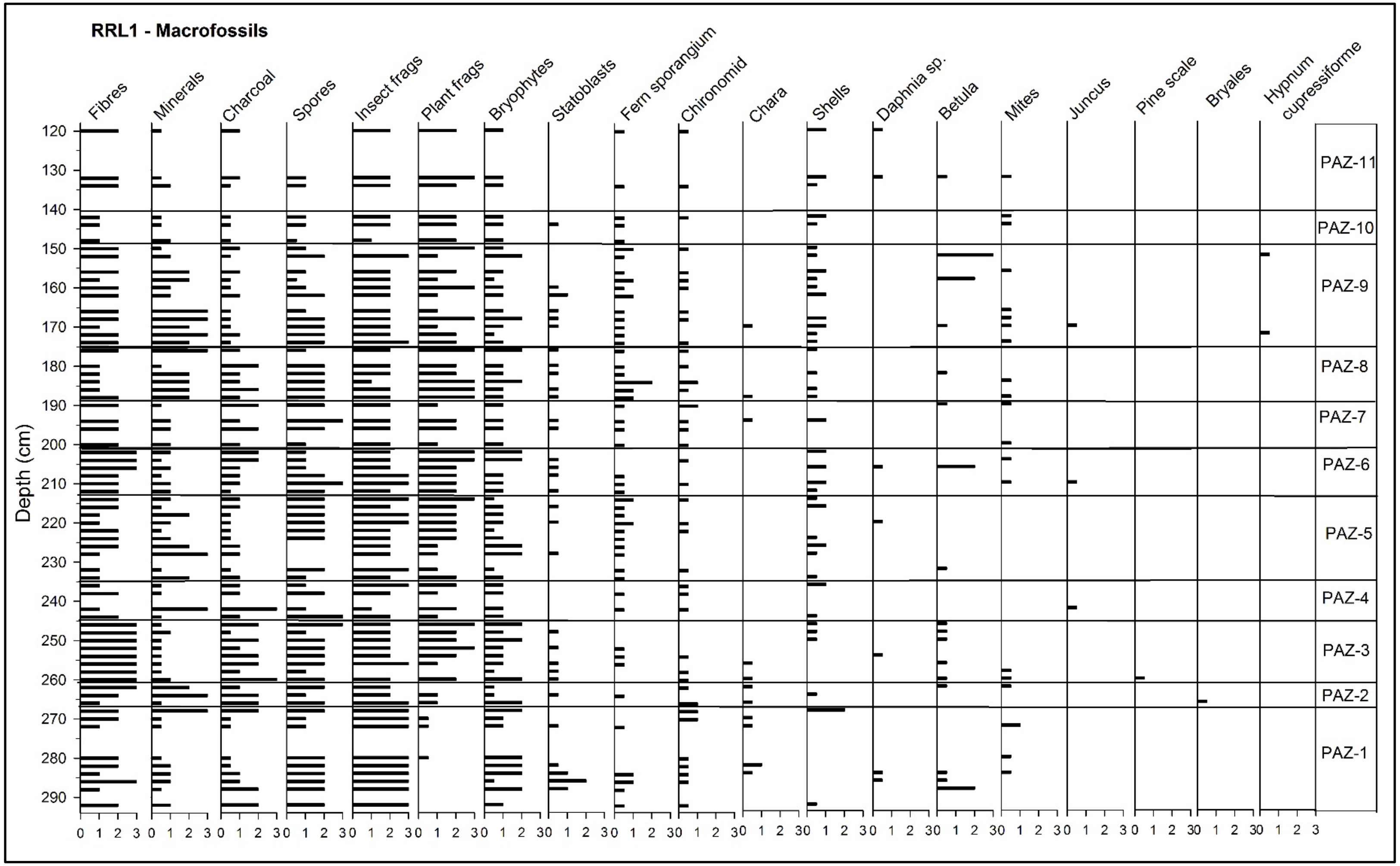

Figure 8.10: Macrofossil data from sediment core RRL1 extracted from Rosroe Lough, carried out on reatiend material from the pollen processing. The macrofossil types identified are labelled at the top of the diagram and the frequency is indicated by the length of the black bar. The frequency is as follows: 0.5 = rare, 1 = occasional, 2 = frequent and 3 = abundant.

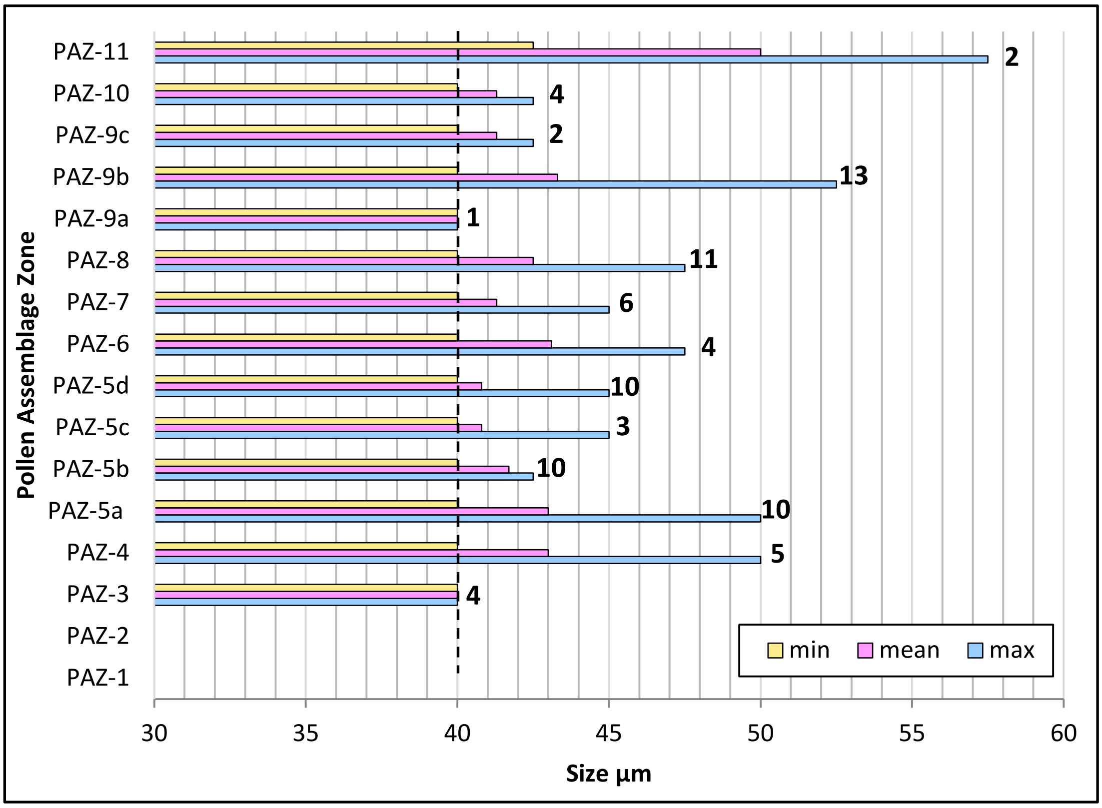

Figure 8.11: Cereal-type size statistics for the Rosroe pollen record. The minimum, mean and maximum grain size is indicated for each PAZ. The minimum size criterion of 40µm is represented by the black dashed line. The numbers to the right of the bar indicate the number of cereal-type grains identified. Results are presented for each PAZ.

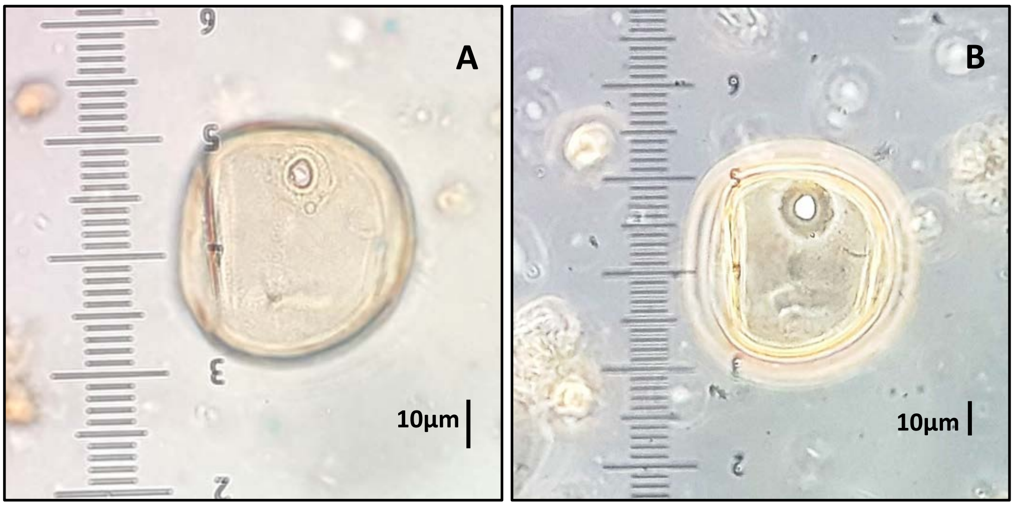

Figure 8.12: Example of a cereal-type pollen grain from the Rosroe pollen record. Grain identified at 240cm = c. 1480 BC (A) view under bright-field microscopy (B) view under phase-contrast microscopy.

Table 8.3: A summary of the main features in each PAZ for the Rosroe record. Chronology follows: Mesolithic (8000 – 4000 BC), Early Neolithic (4000 – 3600 BC), Middle Neolithic (3600 – 3100 BC), Late Neolithic (3100 – 2500 BC), Chalcolithic (2500 – 2150 BC), Early Bronze Age (2150 – 1600 BC), Middle Bronze Age (1600 – 2100 BC), Late Bronze Age (1200 – 600 BC) (Waddell, 2010; Roberts et al., 2013). * = interpolated dates

PAZ	**Spectra (cm)**	**Chronology cal yr BC**	**Period/age range**	**Main features and subzones**
11	142-120	AD1000 – 1240*	Early Medieval	AP increases, then decreases; NAPp trend is the reverse; *Quercus* increases; *Corylus* declines; cereal-type; low *Pediastrum* and micro-charcoal
10	150-142	AD900 -1000*	Early Medieval	High AP; low NAPp; cereal-type
9	174-152	AD620 – 900*	Early Christian	Low AP and high NAPp Subzone 9c: AP increases; NAPp decreases; cereal-type present but interrupted Subzone 9b: AP increases – *Corylus* and *Quercus*; reduced NAPp; cereal-type Subzone 9a: AP decreases; NAPp expands; low cereal-type; increased *Pediastrum*.
8	188-176	AD440 – 620*	Early Christian	AP decreases; significant expansion of NAPp – *Poaceae*, *Plantago lanceolata*, *Liguliflorae* and *Rumex acetosa*; increased cereal-type; expansion of *Pediastrum* and micro-charcoal.
7	200-190	70 – AD440	Early – Late Iron Age	AP increases – *Corylus*, *Ulmus* and *Fraxinus*; NAPp decreases; low cereal-type; micro-charcoal decreases.
6	212-202	530 – 70	Early Iron Age	AP increases – *Corylus*, *Taxus* recovery; NAPp declines – *Poaceae* and *Plantago lanceolata*; cereal-type curve interrupted; micro-charcoal decreases.
5	234-214	1250 – 530	Middle Bronze Age– Early Iron Age	Low AP and high NAPp Subzone 5d: AP increases; NAPp decreases; no cereal-type Subzone 5c: AP decreases; NAPp increases; cereal-type increases Subzone 5b: Peak in *Corylus* and *Quercus*; NAPp decreases; cereal-type decreases Subzone 5a: AP decreases – Corylus and *Ulmus*; NAPp expands – *Poaceae*, *Plantago lanceolata* and *Rumex acetosa;* cereal-type increases
4	244-236	1910 – 1250	Early – Middle Bronze Age	AP decreases – *Ulmus*; NAPp expands – *Poaceae*, *Plantago lanceolata* and *Rumex acetosa*; increased cereal-type
3	260-246	3380 – 1910	Middle Neolithic – Early Bronze Age	High AP; 2nd Elm Decline and recovery; *Fraxinus* and *Taxus* expand; NAPp increases – *Poaceae*; 1st cereal-type
2	266-262	3790 – 3380	Early – Middle Neolithic	High AP - *Corylus*; Elm Decline and recovery, low NAPp
1	292-268	4900 – 3790	Mesolithic– Early Neolithic	Very high AP – *Corylus* and *Quercus*; *Pinus* declines; *Alnus* increases; very low NAPp.

8.5 Discussion of Palaeoenvironmental Data

This discussion will focus primarily on data from the prehistoric period (Figure 8.13 and 8.14) although a summary of the main features of the landscape in the medieval period is provided. An assessment of human-environment interactions in the catchment of Rosroe Lough will be made relating the palaeoenvironmental data to the archaeological record of the area. A summary of the main palynological features of each PAZ is provided in Table 8.3. The discussion will also incorporate relevant detail from additional pollen records in this region of Co. Clare (Table 8.4). Further details on previous pollen records have been provided in Chapter 2.

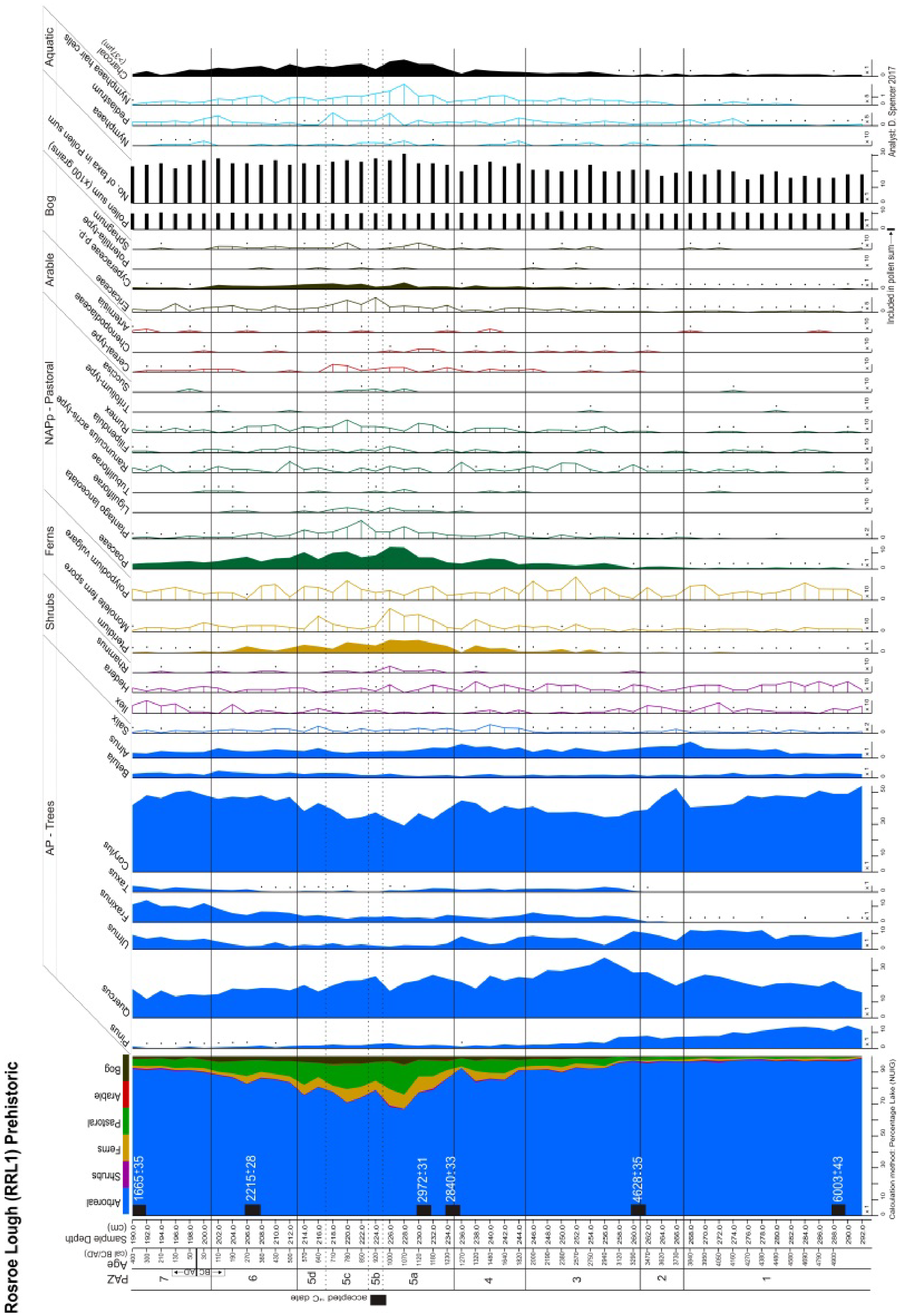

Figure 8.13: Percentage pollen diagram of the prehistoric section of sediment core RRL1 from Rosroe Lough plotted to depth with age-scale provided in calibrated years BC/AD. The diagram is divided into seven PAZs based on changes in the abundance of certain taxa. A composite diagram demonstrates the abundance of different ecological groupings - categorised and colour coded as indicated. Selected pollen percentage curves and pollen sum (x1000 grains) are then presented. Scales indicated at base of individual curves (scale of x1 = solid fill; exaggerated curve = hatched fill). Very low values are indicated by dots. Black bars indicate accepted radiocarbon dates which are displayed on the composite diagram.

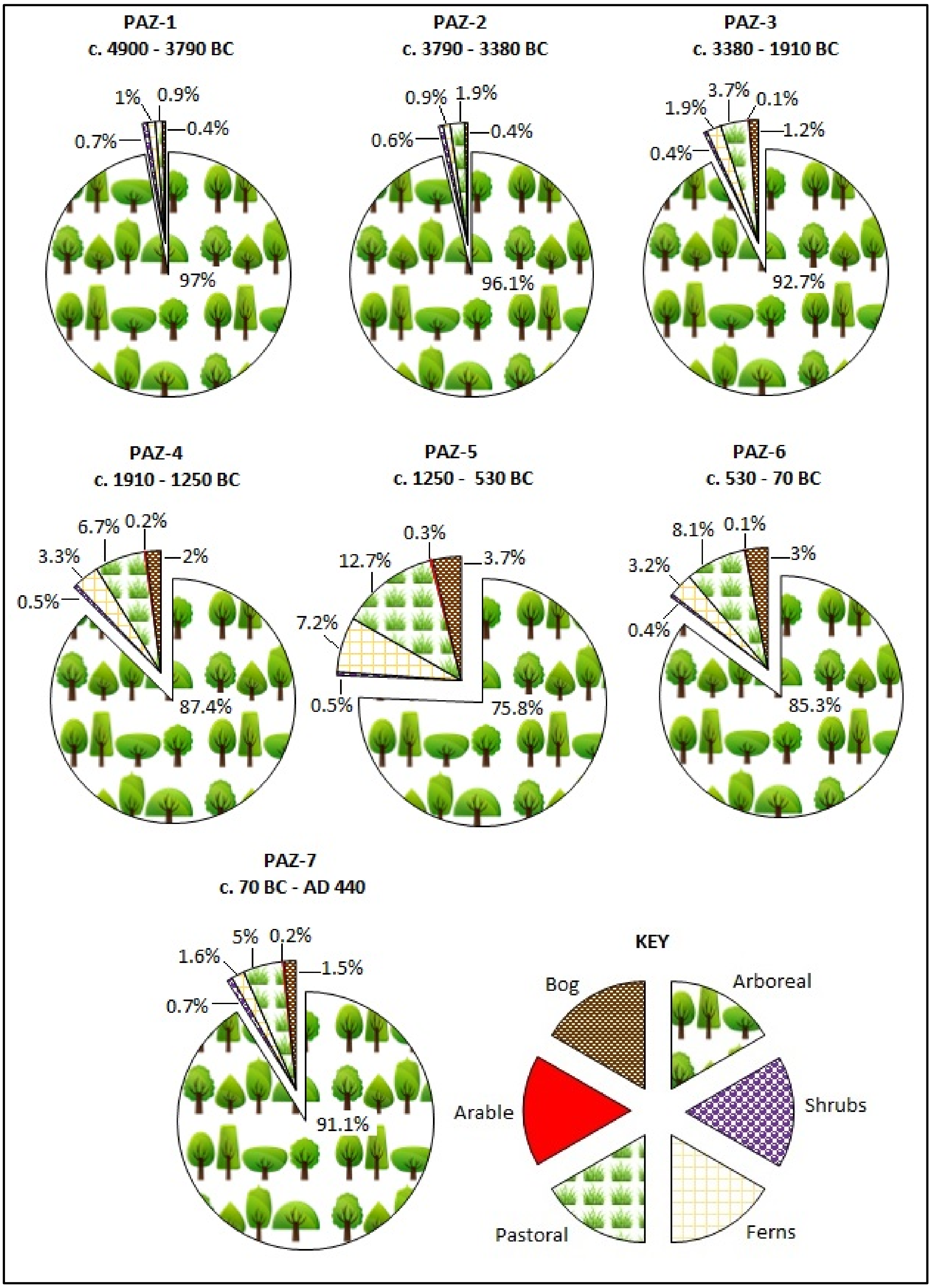

Figure 8.14: The percentage contribution of terrestrial pollen groups (as indicated in the key) from the Rosroe Lough prehistoric pollen data for each PAZ with associated chronology given.

Table 8.4: A summary of land-use dynamics from previously published pollen data from across the Mooghaun Landblock and further north at Caheraphuca Lough. A chronology for comparison with the Rosroe pollen record is provided in the first column. Archaeological time periods follows that of Waddell (2010) and Roberts et al. (2013).

↑ increase in human activity ↓decrease in human activity

Time period and chronology RRL1	**Mooghaun Lough (Molloy 2005; O'Connell et al., 2001)**	**Caheraphuca Lough (Molloy & O'Connell 2012)**	**Caherkine Lough (O'Connell et al., 2001)**
Pollen signal	Local	Local	Local
Mesolithic (4900 – 4000 BC)	Atlantic woodland: *Ulmus, Quercus*, *Pinus* and *Corylus*; initiation of *Ilex* and *Plantago lanceolata*	Atlantic woodland: *Quercus*, *Ulmus* and *Corylus;* lesser amount of *Pinus*	Woodland: *Quercus*, *Ulmus* and *Corylus*
Early Neolithic (4000 – 3670 BC)	Elm Decline c. 3900 BC NAPp remain low; no *Landnam*	Elm Decline c. 3850 – 3550 BC; NAPp remain low (*Plantago lanceolata* <2%); no *Landnam*	Elm Decline; NAPp remain low; no *Landnam*
Middle – Late Neolithic (3670 – 2560 BC)	*Ulmus* recovers; *Quercus* and *Pinus* expand; *Taxus* and *Fraxinus* expand by c. 2850 BC; *Corylus* declines	*Ulmus* recovers; *Fraxinus* c. 3100 BC, *Taxus* expansion – yew dominated woodland by c. 2800 BC	*Fraxinus* and *Taxus* expansion
Chalcolithic – Early Bronze Age (2560 – 1640 BC)	↑c.2250 BC; increased NAPp; increased *Pediastrum*; sharp decline in *Taxus* and *Quercus*; *Ulmus increases*; cereal-type recorded	↑ c. 2400 – 2300 BC NAPp expands; ↓woodland regeneration (*Ulmus*) ↑ c. 1800 – 1600 BC pastoral farming with arable component	*Pinus* declines; ↑ NAPp expands; cereal-type recorded
Middle Bronze Age (1640 – 1210 BC)	↑ woodland clearance; *Corylus* increases; ↓ some woodland regeneration; increased cereal-type	↓c. 1600 – 1200 BC woodland regeneration (*Ulmus*)	↓ *Ulmus* and *Fraxinus* recover; NAPp reduced
Late Bronze Age (1210 – 600 BC)	↑ Decline in *Ulmus* & *Corylus*; increased NAPp; increased micro-charcoal; *Landnam* c. 1000 – 750 BC; ↓ *Corylus* regeneration c. 750 – 650 BC	↑ Woodland clearance; increased micro-charcoal; NAPp and *Pteridium* expand; *Pediastrum* expands; *Landnam* c. 1200 – 950 BC pastoral and arable; ↓woodland regeneration but with continued farming	↑ NAPp expands; cereal-type recorded; not a *Landnam* event
Iron Age (600 BC – AD 1)	↑ Less intensive pastoral and arable farming; *Quercus* and *Fraxinus* increase; ↓ c. 300 BC – AD 1; continued arable farming;	↓ c. 650 reduced farming; *Ulmus* recovers; low NAPp	↑ stronger expansion of NAPp; strong pastoral and arable farming
Late Iron Age (AD 1 – 390)	↓ Late Iron Age Lull c. AD 1-300; *Ulmus* and *Fraxinus* recover	N/A	↓ Late Iron Age Lull; *Fraxinus*, *Taxus* and *Ulmus* recover

8.5.1 Vegetation and Land-use Dynamics through Prehistory

Mesolithic Woodland Dynamics (c. 4900 – 4000 BC)

As the profile opens, the landscape in the catchment of Rosroe Lough was dominated by mixed deciduous Atlantic woodland with AP at its highest for the profile (97% of TTP) (PAZ-1). Oak would have been the main tall-canopy tree with lesser amounts of elm and pine. This corresponds closely with the pollen records from Mooghaun Lough, Caherkine Lough and Caheraphuca Lough, c. 3.7km, 2.6km and c. 19km to the north-west, respectively (Molloy, 2005; O'Connell et al., 2001). Molloy (2005) remarks upon the importance of pine in the landscape surrounding Mooghaun Lough and similar levels can be seen at Rosroe, possibly due to the ability of pine to grow on the thinner soils that characterise this landscape. At Rosroe, hazel formed the primary understory component, decreasing slightly throughout the period as upper canopy trees (oak and elm) expanded. This is comparable with the Mooghaun record which may signify the formation of a denser woodland structure in the landscape of the Mooghaun Landblock (Molloy, 2005). From c. 4480 BC alder became more prominent in the Rosroe catchment possibly related to climatic factors (cf. Bennett, 1984) that allowed this species to out-compete pine, which itself became less prominent in the landscape. Corresponding with the alder expansion in the Rosroe record is evidence for increased precipitation and increased lake-levels both in Ireland and continental Europe (Holmes et al., 2007; Magny, 2004) As oak and elm were no longer in competition with alder, which had expanded onto wetter soils, these species expanded from c. 4380 BC.

In the Rosroe Lough record there was a small expansion of holly towards the end of this period which may relate to pre-elm decline woodland instability as suggested by O'Connell and Molloy (2001) and reviewed in Chapter 6. Some disturbance of the woodland canopy may have allowed this expansion, though this may have been caused by natural factors (Molloy, 2005). The presence of holly and ivy in the Rosroe pollen record for this period may reflect its growth at the edge of woodland areas and can also be seen in the Mooghaun and Caherkine records (Molloy, 2005; O'Connell et al., 2001). The levels of NAPp are very low in the Rosroe data which suggest that open habitats were not a prominent part of the landscape which can be envisaged as densely wooded. *Poaceae* was consistently present but did not exceed 2%, likely due to less dense areas of woodland where grass could become established within the woodland floor.

The lack of anthropogenic indicators within the pollen record for this period suggests very little, if any, human activity in the catchment of Rosroe Lough. This is supported by the archaeological record with no known Mesolithic sites in the study area. During an intertidal archaeological survey of the River Shannon estuary a wooden plank was discovered at Carrigdirty Rock 8 dated to c. 4779 – 4551 BC (O'Sullivan, 2001). While this is outside the margins of the Mooghaun Landblock, it is only c. 10.7km from Rosroe Lough and may attest to some activity in these estuarine environments to the south during the Mesolithic, although it may alternatively have been formed through the natural splitting of the trunk (O'Sullivan, 2001).

Elm Decline and Early Neolithic Woodland (c. 4000 – 3670 BC)

In the Rosroe pollen record a decline in *Ulmus* occurred from 12.1 – 5.7% over a period of c. 110 years between c. 3840 – 3730 BC according to age-depth modelling (PAZ-2). The timing corresponds well with the generally accepted date for the Elm Decline in mid-western Ireland of c. 3850 BC (O'Connell and Molloy, 2001). The decline in *Ulmus* is better expressed in the concentration data (Figure 8.8) as opposed to the pollen percentage data. Considering the lack of anthropogenic indicators at the onset of the decline it is likely that other proposed factors such as disease or climate exacerbated the decrease in this species (Edwards, 2004; Parker et al., 2002). As discussed in Chapter 6, elm-specific disease associated with the elm bark beetles *S. scolytus* is a widely accepted contributor to the decline (Parker et al., 2002; Clark and Edwards, 2004). This may have been influencial at Rosroe Lough where a factor other than human activity must have been the principal cause. Impacts of climate and disease have been proposed in addition to human activity for the Elm Decline elsewhere in Ireland (Stolze et al., 2013).

The timing of this feature in the Rosroe record corresponds well with the identification of the Elm Decline at Mooghaun Lough (c. 3900 BC) and Caheraphuca Lough (c. 3850 BC), while that of Caherkine Lough is thought to be broadly comparable but undated (Molloy, 2005; Molloy and O'Connell, 2012; O'Connell et al., 2001). *Ulmus* representation in the local landscape surrounding Mooghaun Lough fell from 14 – 4% (Molloy, 2005), which is of a similar magnitude to at Rosroe Lough suggesting that this was perhaps uniform across the wider expanse of the landscape in the Mooghaun Landblock. Representation fell even further in the catchment of Caheraphuca Lough to c. 1% (Molloy and O'Connell, 2012). Concurrent with the Elm Decline at Rosroe was an increase in *Corylus* which peaked at c.

3730 BC, likely due to a more open woodland canopy allowing hazel to flower more readily, as has been suggested by Molloy (2005) and Molloy and O'Connell (2012). This occurred in all of the pollen records from this area including the most northerly (Caheraphuca Lough) (Molloy, 2005; Molloy and O'Connell, 2012; O'Connell et al., 2001), with the lack of human activity in all cases indicating this was a natural feature of changing woodland dynamics.

There is no evidence for Early Neolithic land clearance at Rosroe Lough, contrary to the majority of Irish pollen diagrams where *Landnam* are seen in the Early Neolithic (O'Connell and Molloy, 2001). The landscape of the Early Neolithic in the Rosroe catchment remained wooded with AP maintaining very high levels (96.5% of TTP). No *Landnam* events were identified in any of the south-east Co. Clare pollen records (Mooghaun, Caherkine and Caheraphuca) with *Plantago lanceolata* at <2% and little change in *Poaceae* levels (Molloy, 2005; Molloy and O'Connell, 2012; O'Connell et al., 2001). In addition, other sites across Ireland have been identified where evidence for Early Neolithic *Landnam* is either weak or lacking (O'Connell and Molloy, 2001), especially at Derryinver, Co. Galway (Molloy and O’Connell, 1993), Lough Mullaghlahan and Lough Nabraddan, Co. Donegal (Fossitt, 1994), Lough Catherine, Co. Tyrone (Edwards, 1985) and Essexford Lough, Co. Louth (Weir, 1995).

In the catchment of Rosroe Lough elm subsequently began to recover from c. 3730 BC and increased for the remainder of this period which is also seen in the records from Mooghaun, Caherkine and Caheraphuca (Molloy, 2005; Molloy and O'Connell, 2012; O'Connell et al., 2001). The lack of evidence for Early Neolithic activity in the pollen record is supported by the archaeological record with Grogan (2005a) having previously proposed that Early Neolithic activity in this region of Co. Clare was minimal. No Early Neolithic sites are located within the catchment of Rosroe Lough but a single portal tomb, located c. 14km to the north-east of Rosroe Lough, attests to limited activity in the wider Mooghaun Landblock. Further evidence is artefactual in nature including stone axes and arrowheads within a c. 10km radius of the lake (Grogan, 2005b; Grogan and Condit, 2000). This attests to limited human activity within the landscape but is not indicative of sedentary settlement.

Middle – Late Neolithic Woodland Dynamics and Initiation of Farming Activity (c. 3670 – 2560 BC)

Tall-canopy oak and elm woodland continued to dominate the Rosroe catchment in the Middle – Late Neolithic which caused a reduction in the presence of hazel under this dense canopy. The main change in woodland composition was the expansion of both ash and yew from c. 3290 BC (PAZ-3). The establishment of these species in Ireland seems to be a common feature of pollen records from this period (discussed in Chapter 6) with the synchronicity of the yew expansion, especially in the west of Ireland, suggesting a climatic factor (O'Connell and Molloy, 2001; 2017; Watts, 1984; Molloy and O’Connell, 2016). The pollen records of Rosroe, Mooghaun and Caherkine are comparable in this regard, with yew in particular expanding rapidly from c. 2850 BC in the landscape surrounding Mooghaun Lough (Molloy, 2005). Similarly, these expansions occurred in the catchment of Caheraphuca Lough which led to a yew-dominated woodland by c. 2800 BC (Molloy and O'Connell, 2012). The subsequent reduction of yew was likely due to natural factors, for example, poor regeneration under its own canopy (Perrin et al., 2006), as human activity in the Mooghaun Landblock remained limited (Molloy and O'Connell, 2012; Molloy, 2005; O'Connell et al., 2001). The presence of a pine scale macrofossil (Figure 8.10) from this period indicates that pine was growing in the local environs of the lake. Ivy and holly probably formed part of the woodland edge community at this time.

In the Rosroe Lough record NAPp representation remained low suggesting that open areas were not a prominent feature of this landscape. One cereal-type grain, however, was identified towards the end of this period at c. 3290 BC, possibly indicative of low-level arable agriculture somewhere within the catchment. Cereal-type pollen was not recorded at this time in the Mooghaun, Caherkine or Caheraphuca records (Molloy, 2005; Molloy and O'Connell, 2012; O'Connell et al., 2001). The Rosroe pollen record is comparable with pollen records from across Ireland during the Middle Neolithic, including those that had previously seen considerable levels of Early Neolithic activity, which indicate a period of woodland regeneration from c. 3350 BC (O'Connell and Molloy, 2001; Molloy and O’Connell, 2004; Chique et al., 2017; Whitehouse et al., 2014).

A second Elm Decline can be identified in the Rosroe Lough record from c. 3290 BC and in this case was concurrent with a rise in anthropogenic indicators, mainly *Poaceae*, *Plantago lanceolata*, *Ranunculus* and *Rumex acetosa* (PAZ-3). A second decline in *Ulmus* was identified at Mooghaun Lough c. 2850 BC but indicators of human activity remained low during this period in the local catchment (Molloy, 2005). The first opening up of the woodlands at Rosroe Lough dates to the start of the Late Neolithic c. 3120 BC which is slightly earlier than most Irish pollen records which register a re-initiation of farming activity later in this period (O'Connell and Molloy, 2001; Whitehouse et al., 2014). The uncertainty of the age-depth model means that activity at Rosroe Lough may be more contemporary with general Irish trends than this date would suggest. Human activity is clearly expressed in the concentration data which indicates that hazel, oak, elm and pine were all affected. The decrease in *Corylus* was perhaps the combined result of increased oak levels and low-level clearance within the catchment. The increasing representation of NAPp suggests that farming activity had been initiated in the catchment for the first time albeit at a very small scale (NAPp <5%). The scale of human activity at this stage was not akin to a *Landnam* event but the simultaneous decrease in LOI_{550} suggests the beginnings of erosion potentially linked to deforestation. The increase in micro-charcoal towards the end of this period may be associated with clearance or settlement activities, but this may have been concentrated in the catchment of Rosroe Lough as there is no evidence of activity in the other pollen diagrams from the Mooghaun Landblock. A cereal-type grain was identified at the end of this period c. 2750 BC again suggesting that small scale cereal-cultivation may have been occurring somewhere within the catchment, potentially close to the lake itself due to the low dispersal capacity of cereal grains (Vuorela, 1973).

The lack of substantial evidence for human activity within the Rosroe pollen record is reflected in the archaeological record with no specific evidence dated to the Middle Neolithic within the catchment, although the aforementioned stone axes may date to this period. Late Neolithic activity is limited but an embanked enclosure at Coogaun, recently identified through geophysics as a henge, is located c. 6km north of Rosroe Lough (Condit and Grogan, 1998; Jones, 2018). Although burnt mounds are for the most part a Bronze Age phenomena, they first became widespread c. 2800 – 2500 BC giving the potential for some of the burnt mounds within the landblock to be of Late Neolithic date and constructed in a landscape that was starting to be altered by human activity (Hawkes, 2014; Grogan, 2005b).

Chalcolithic – Early Bronze Age Activity (c. 2560 – 1640 BC)

The level of human activity within the Rosroe landscape seems to have remained relatively stable from the Late Neolithic into the Chalcolithic. During the Chalcolithic the amount of oak, pine and yew in the landscape lessened, suggesting these species were preferentially cleared in advance of any small-scale farming activity occurring in the catchment. Similarly, the sharp decline in *Taxus* in the catchment of Mooghaun Lough at c. 2250 BC is thought to represent deliberate clearance linked to increased pastoral farming at the end of the

Chalcolithic when *Plantago lanceolata* reached c. 5% of TTP (Molloy, 2005). *Plantago lanceolata* reached a higher representation in the Mooghaun Lough record which perhaps suggests that open areas were more prominent around that lake. Conversely, at Rosroe, both elm and ash recovered during this period and hazel remained a stable understory component. Bracken, a coloniser of newly opened land (Marrs et al., 2000) expanded slightly in both catchments, suggesting that the anthropogenic indicators recorded relate to the establishment of small areas of pastureland. The diversity of any grassland areas in the catchment of Rosroe Lough at this time was low, however, with only small amounts of ribwort plantain, dock and buttercup present in the Rosroe catchment. NAPp representation at Caherkine Lough suggests the beginnings of pastoral farming activity with a reduction in *Taxus* observed, while at Caheraphuca Lough pastoral farming became more intensive between c. 2400 – 2300 BC and c. 1800 – 1600 BC (O'Connell et al., 2001). A period of woodland regeneration, however, occurred between these phases which was not suggested from the more southerly pollen records (Molloy and O'Connell, 2012).

From c. 1820 BC pastoral indicators increased and attained 8.7% by the end of the Early Bronze Age (c. 1640 BC), at the start of PAZ-4. All main tree species decreased, suggesting widespread clearance in the catchment at this time. This is also suggested by the decline in LOI_{550} presumably reflecting soil erosion as a result of disturbance. In the concentration data, a greater decrease in *Quercus* and *Corylus* registers, indicative of more intensive clearance (Figure 8.8 – PAZ 4). In contrast, alder and willow expanded, likely growing on damper ground close to Rosroe Lough itself or other lakes within the catchment. Grass expanded with ribwort plantain and bracken suggesting the establishment of more open areas presumably for pastoral farming. Cereal-type was found continuously from c. 2000 BC but did not exceed 0.2%. This suggests that small-scale arable cultivation was occurring somewhere within the catchment during the Early Bronze Age. It was in this period that cereal-type was recorded for the first time at Mooghaun, Caherkine and Caheraphuca Lough (Molloy, 2005; O'Connell et al., 2001; Molloy and O'Connell, 2012), suggesting a more widespread occurrence of arable agriculture in the Mooghaun Landblock.

At Rosroe Lough there was a small increase in *Pediastrum* possibly hinting at some farming activity close to the lake itself causing nutrient enrichment (Jankovská and Komárek, 2000). The levels of micro-charcoal increased, which may indicate burning associated with localised woodland clearance. A general increase in farming activities registers in pollen records from across Ireland in the Chalcolithic and especially Early Bronze Age, including the pollen records from the Burren (inclusive of new Inchiquin data) (Feeser, 2009; Watts, 1984; Molloy and O'Connell, 2004; 2016; Thompson, 1997; Ghilardi and O'Connell, 2013b), although generally to a much greater extent than is evident at Rosroe.

The pollen data suggests that while the landscape was still predominantly wooded, open areas were becoming more common. People were becoming more active within the landscape surrounding Rosroe Lough and this is supported by the archaeological record which becomes more substantial from this period onwards. This is supported by the date of c. 1887 – 1701 BC from one of the palisade stakes at Knocknalappa lake settlement on the eastern shore of Rosroe Lough (Grogan et al., 1999). The evidence of occupation on the peat and timber platform suggests a limited phase of occupation during the Early – Middle Bronze Age (Grogan et al., 1999) which might suggest some of the anthropogenic activity from c. 1820 BC occurred at the lake itself associated with this settlement activity.

Seventeen wedge tombs were constructed in the Mooghaun Landblock with two located within the Rosroe catchment, Knocknalappa and Knopoge (De Valéra and O' Nuallain, 1961). The remainder are mostly concentrated c. 11km to the north with outliers to the south and east suggesting widespread human activity across the landscape. The number of monuments suggests a substantial increase in human activity at this time, with the monuments likely constructed in a landscape that was starting to become more open. The archaeological record of the Early Bronze Age is more limited with finds of flat axes and halberds within the wider Mooghaun Landblock and Beaker pottery sherds in the area of Mooghaun hillfort (Grogan, 2005b; Ó Maoldúin, 2014; Carlin, 2011). The burial evidence used to suggest the importance of the North Munster landscape in the Early Bronze Age is actually concentrated further south in Co. Limerick (Grogan, 2005a), although it is perhaps likely that deposition continued into the wedge tombs in this area. Burnt mounds could again potentially date to this period which would increase the evidence for human activity within the catchment.

Middle Bronze Age Activity (c. 1640 – 1210 BC)

The Middle Bronze Age was characterised by a consistent low level of activity in the catchment of Rosroe Lough. At the start of this period NAPp increased to 8.7% of TTP (the highest value obtained so far in the record) and remained more-or-less at this level until c. 1320 BC. This is indicative of a small-scale pastoral farming economy representing the first substantial period of human activity within the catchment. This appears to have been concentrated in the first few centuries of the Middle Bronze Age with pastoral indicators decreasing from c. 1320 BC. Reductions in elm and oak from the start of this period would have created a more open canopy, allowing for the flowering of increased levels of herb taxa. The expansion of bracken in this period reflects the opening up of new land for pasture with species-rich grasslands inclusive of grass, ribwort plantain, dock, buttercup and meadowsweet present within the catchment. A minor arable component is suggested by the presence of cereal-type (Figure 8.12), goosefoot and mugwort. Willow and ivy, species more prevalent in open woodland (Preston et al., 2002), expanded while alder likely colonised moister ground.

NAPp representation in the Rosroe record started to decrease from c. 1320 BC which is comparable to Mooghaun Lough where some woodland regeneration occurred from that point (Molloy, 2005). The final few decades of the Middle Bronze Age in the Rosroe Lough record were characterised by increased pastoral activity, and with cereal-type now reaching 0.3%, an increase in arable cultivation. At the same time LOI_{550} decreased rapidly suggesting that farming activity or clearance in the final part of this period caused some soil destabilisation in the catchment. Arable indicators were also identified in the catchment of Mooghaun Lough and, interestingly, this occurred during the period of reduced pastoral farming (Molloy, 2005). The Middle Bronze Age in the catchment of Caherkine Lough was characterised by woodland regeneration with the establishment of a dense upper canopy of oak, elm and ash (O'Connell et al., 2001). This was also the case further to the north at Caheraphuca Lough where elm and hazel, in particular, recovered concurrent with a sharp decline in *Plantago lanceolata*. The combined evidence suggests that pastoral activity, for the most part, was concentrated in the first few centuries of the Middle Bronze Age followed by woodland regeneration which occurred earlier in the more northerly part of the region. Across Ireland the evidence for Middle Bronze Age farming activity is variable with some records registering prolonged periods of woodland regeneration (Molloy and O’Connell, 2004; Plunkett, 2009; Feeser and O’Connell, 2009; Ghilardi and O'Connell, 2013b) while others reflect continued activity (Thompson, 1997; Feeser, 2009; Watts, 1984). The low sampling resolution of this period in the Rosroe pollen record and tentative chronology may not fully reflect the land-use dynamics of this period.

In the Mooghaun Landblock increased evidence of human activity comes in the form of ritually deposited Middle Bronze Age artefacts in the River Shannon which suggests that this area was becoming important from a ritual perspective (Bourke, 2001). Artefacts dating to the Middle-Late Bronze Age have also been found within the catchment (Grogan et al., 1995). A burnt mound at Mooghaun Lough has been dated to c. 1250 BC (Molloy, 2005), constructed as the landscape was starting to become more open at the end of the Middle Bronze Age, and if others were contemporary this would increase the archaeological evidence for human activity at this time. Further evidence for possible activity in this period includes a number of standing stones and barrows which have a widespread distribution across the landblock area (Grogan, 2005b; Grogan et al., 1995; Grogan and Condit, 2000).

Intensive Late Bronze Age Activity (c. 1210 – 600 BC)

In the Rosroe pollen record a *Landnam* event involving the removal of woodland and the expansion of a suite of anthropogenic indicators, (e.g. grass, ribwort plantain, dock and buttercup), is recorded in this period during PAZ-5. This activity can be divided into two substantial predominantly pastoral farming phases (c. 1120 – 1000 BC and c. 850 – 710 BC) with an arable component, separated by a short phase of reduced human activity when woodland regenerated briefly. Overall, woodland species, including hazel scrub, decreased substantially with AP falling to 66.8% of TTP. Elm, oak and yew were reduced through clearance, with the latter virtually absent for the remainder of the Late Bronze Age. Buckthorn, a shrub of more open woodland (Preston et al., 2002), expanded in this period for the first time likely due to the reduction in dense woodland allowing shrubs to expand at the woodland edges. This species is also known to regenerate after grazing which may reflect its occurrence during this intensive farming phase (Preston et al., 2002).

During the first intensive phase of farming activity NAPp representation increased to peaks of 18.4% at c. 1070 BC (the highest value attained during the prehistoric period), and to 15.9% at c. 780 BC during the second phase. Particularly high values of *Poaceae* and *Plantago lanceolata* were recorded contemporaneously with the expansion of other herb taxa. There was an expansion of open pastureland in the catchment with species-rich grasslands inclusive of grass, ribwort plantain, dock and lesser amounts of meadowsweet, buttercup and daisies, with bracken also expanding. Arable cultivation is indicated by peaks in the cereal-type curve of 0.3% and 0.4 – 0.5% between c. 1070 – 1000 BC and c. 780 – 710 BC, respectively.

From c. 1000 BC there was a period of slightly reduced farming activity where oak and hazel, in particular, regenerated within the landscape. That farming activity continued between the two more intensive phases is indicated by the continued presence of NAPp but at a lower representation. The cereal-type curve was interrupted from c. 640 BC indicating a possible cessation of arable cultivation for the remaining decades of the Late Bronze Age while pastoral farming continued. The combined evidence suggests that within the Rosroe catchment in the Late Bronze Age there was a strong pastoral farming economy with a smaller arable component. Increased *Pediastrum* in this period may indicate that some farming activity was concentrated near the lakeside. LOI_{550} decreased during the first two centuries of the Late Bronze Age, likely associated with deforestation and the erosion of catchment soils. Concentration values for this period are low for all taxa indicating that sedimentation had increased, inhibiting the accumulation of pollen within the sediment and corroborating the interpretation of soil erosion.

The Rosroe pollen record is comparable with that of Mooghaun Lough where an expansion of NAPp occurred c. 1100 – 1000 BC with a significant *Landnam* recorded between c. 1000 – 750 BC (Molloy, 2005). The *Landnam* was much more substantial in the catchment of Mooghaun Lough where AP representation fell to 17% (Molloy, 2005) as opposed to 66.8% at Rosroe Lough. The pollen record from Mooghaun is expected to be 'local' whereas that of Rosroe will provide a more regional picture which, with a potential under-representation of NAPp due to the large size of Rosroe Lough, may account for differences in scale. Given the location of Mooghaun Lough, c. 750m from Mooghaun hillfort, Molloy (2005) suggests that the scale of woodland clearance was intrinsically related to the hillfort construction and as such spatially limited. Increased micro-charcoal was likely attributable to clearance activities in both the Mooghaun and Rosroe records, with especially pronounced charcoal at the start of the *Landnam* likely associated with the construction of the hillfort or burnt mounds on the shores of Mooghaun Lough (Molloy, 2005).

Although overall clearance in the wider landscape provided by the Rosroe Lough record was more limited, this period still saw the most intensive pastoral farming activity in the prehistoric section of the profile suggesting that human activity was not concentrated solely in the area of Mooghaun hillfort but extended across the wider region towards Rosroe Lough, c. 3km to the east. Further north at Caheraphuca this *Landnam* occurred slightly earlier at c. 1200 – 950 BC with AP falling to 52% of TTP combined with a substantial expansion of NAPp (Molloy and O'Connell, 2012). In all three pollen records cereal-type increased during this period, again more substantially at Mooghaun (Molloy, 2005; Molloy and O'Connell, 2012). *Pediastrum* also increased, suggesting localised activity was occurring in the vicinity of the lakesides causing the lakes to become enriched in this period (Molloy, 2005; Molloy and O'Connell, 2012; Jankovská and Komárek, 2000). At Caherkine Lough, however (1.3km from Mooghaun hillfort and 2.7km from Rosroe Lough), this *Landnam* was not recorded in the pollen record although low-level indications of farming activity (both pastoral and arable) were identified (Molloy, 2005; O'Connell et al., 2001). Caherkine Lough is a small lake (560 x 240m) and as such provides a fairly local pollen signal with the catchment area estimated at c. 0.7km^2 by the current study, suggesting that intensive farming was not occurring in the immediate vicinity of Caherkine Lough (Figure 8.2) (O'Connell et al., 2001). As such it is likely that the stronger pastoral farming signal recorded by the Rosroe pollen record is reflecting human activity that occurred outside the catchment of Caherkine Lough. Grogan (2005b) describes the area to the west of Rosroe Lough as the most densely occupied part of Mooghaun Landblock at this time. For the most part Caherkine Lough is surrounded, at present, by lower potential soils, with those of a higher potential more extensive in the catchments of Mooghaun and Rosroe (Finch et al., 1971; Grogan, 2005b). Perhaps this was also a limiting factor on prehistoric farming in this area.

Intensive human activity at Mooghaun Lough lasted for five centuries, while a slightly shorter period of c. 410 years is suggested by the Rosroe record and shorter still at Caheraphuca for c. 250 years (Molloy, 2005; Molloy and O'Connell, 2012). Although the Late Bronze Age was the period of most intensive human activity in south-east Co. Clare, the timing and duration of such activity varied across the region. The landscape of the wider region can be envisaged as fertile pasturelands supporting a substantial pastoral farming economy with small-scale arable cultivation. Plunkett (2009) has noted the correlation between the start of the Dowris phase (a prolific bronze- and gold-working phase c. 1000 BC) and the extensive intensification of pastoral farming activity across Ireland (e.g. Overland and O'Connell, 2008; Molloy et al., 2014; Ghilardi and O'Connell, 2013b; Molloy and O’Connell, 2004). The new pollen record from Rosroe provides a regional pollen signal from the Mooghaun Landblock (covering c. 19.4km^2) which combined with the local signals of Mooghaun and Caherkine, supports the assertion that this area of Co. Clare developed into a prestigious, hierarchical society based on a well-founded, primarily pastoral, farming economy (Plunkett, 2009; Grogan, 2005b; Jones, 2009).

That the pollen record suggests a high level of human activity during the Late Bronze Age corresponds with the archaeological record. In close proximity to the coring location is the lake settlement site of Knocknalappa dated of c. 1033 – 848 BC (Grogan et al., 1994; Grogan et al., 1999; Raftery, 1942). Intensive Late Bronze Age activity was identified over 400m^2 with further evidence of working platforms and a possible large bi-vallate enclosure adjacent to the lake which Grogan et al. (1999) proposed may indicate a larger settlement nearby. Considered together with the evidence for nutrient enrichment of the lake, and the low dispersal capacity of pastoral and arable indicators (Behre, 1981; Vuorela, 1973), this suggests a high level of human settlement and farming activity occurring in the vicinity of the lake itself. Mooghaun trivallate hillfort (c. 915 – 905 BC) is situated c. 3.6km from Rosroe Lough and less than 1km from Mooghaun Lough where previous palaeoenvironmental investigations took place (Grogan, 2005b; Molloy, 2005). Current dating evidence places the main construction of the ramparts within a period of pastoral farming activity when open areas would have been well established in the landscape. Mooghaun hillfort has been proposed as the centre of a 450km^2 chiefdom with a population of up to c. 9000 people (Grogan, 2005b). This would have required a substantial pastoral and arable economy which, while it is reflected in the wider regional pollen record from Rosroe, is perhaps not as strong as may have been envisaged. The data suggests that woodland was still quite prominent within the catchment with activity potentially more focused around the hillfort itself as represented by the Mooghaun Lough pollen record (Molloy, 2005). Further Late Bronze Age settlement activity is suggested by the hilltop enclosures, but all except one (which only produced a post-abandonment Iron Age date) are undated (Grogan, 2005b).

The importance of the region is reflected in the artefactual evidence from this area which includes prestigious goldwork, such as the gold pennanular bracelet retrieved from the earlier Knocknalappa wedge tomb (Grogan et al., 1995). Four hoards were retrieved from the Mooghaun Landblock including the Mooghaun hoard, thought to have been deposited in a burnt mound at Mooghaun Lough, which contained 146 pieces of goldwork (Eogan, 1983; Condit, 1996). The combined archaeological evidence suggests that this area was becoming increasingly more important throughout the Bronze Age with artefactual and settlement evidence suggesting wealth and prestige in the Late Bronze Age. The pollen evidence shows the Late Bronze Age to be the period of most intensive activity in prehistory reflecting the increased importance of this landscape as a place of settlement and subsistence.

Iron Age Reduced Activity (c. 600 BC – AD 390)

The Iron Age in the catchment of Rosroe Lough is characterised by increasing woodland cover with arboreal representation increasing from 83.5 – 92.0% throughout the period (PAZ-6). Regeneration of hazel was most evident from the start of this period with increased ash from c. 600 BC and yew recovering from c. 270 BC. *Ulmus* and *Fraxinus* declined from c. 270 BC concurrent with a small peak in *Poaceae* suggesting the decline was linked to human activity. Pine became a less prominent part of the woodland landscape, which is the widespread trend across Ireland leading to later extirpation (Huntley and Birks, 1983). Recent research at Rockforest, Co. Clare, however, has proposed that pine may have persisted in the Burren further north in Co. Clare (McGeever and Mitchell, 2016). There was substantial regeneration of hazel, elm, and ash from c. 110 BC likely associated with reduced human pressure on the landscape. The representation of micro-charcoal decreased particularly from c. AD 50 potentially indicating a reduction in settlement activities. *Pteridium* remained well represented until c. 190 BC suggesting that newly opened areas were still common in the landscape up to this point.

The Rosroe record is comparable to the Mooghaun Lough record which demonstrates decreasing pastoral activity from c. 650 BC (Molloy, 2005). From c. 300 BC hazel became more prominent in the landscape as human pressure lessened but pastoral and arable farming continued, albeit at lower intensity, throughout this period (Molloy, 2005). Similarly, at Caheraphuca Lough there was a reduction in farming from c. 650 BC which lasted throughout the Iron Age (Molloy and O'Connell, 2012). The elm population that had become established c. 650 – 450 BC was then dramatically reduced either as a result of clearance, or more likely, given the scarcity of NAPp, as a result of elm-specific disease (Molloy and O'Connell, 2012). In the small catchment of Caherkine, however, it was the Iron Age that was the period of most intensive farming activity, both pastoral and arable (O'Connell et al., 2001). This suggests, perhaps, that any activity in this period was more concentrated in the vicinity of this lake as all other pollen records in the area, including the wider regional signal provided by Rosroe, indicate a reduction of human activity. A contraction of NAPp occurred after c. 190 BC at Rosroe with *Plantago lanceolata* and the lesser herb taxa especially poorly represented. This suggests reduced pastoral activity and it is likely that no new areas were cleared. There would have been a continuation of some open areas but within an otherwise more heavily wooded environment.

LOI_{550} increased throughout the Iron Age, which combined with a high representation of all taxa in the concentration data suggests that sedimentation rates had decreased. One cereal-type grain was identified at c. 500 BC but the curve was then interrupted until arable agriculture was re-established from c. 190 BC (at 0.2% representation). This cultivation continued until c. AD 300 albeit at a low intensity (at 0.1% representation). *Pediastrum* decreased throughout the period suggesting activity at the lakeside had lessened. The re-establishment of woodland was particularly evident from c. 110 BC and continued until c. AD 400. This is thought to reflect the Late Iron Age Lull, a period of widespread woodland regeneration across Ireland generally occurring at variable points between c. 200 BC – AD 200 (Coyle McClung, 2013; Molloy, 2005; Jeličić and O'Connell, 1992; Thompson, 1997). This feature was identified in the Mooghaun pollen record c. AD 1 – 300 seen as a substantial expansion of AP, in particular *Ulmus, Fraxinus* and *Taxus*, a reduction in NAPp (Molloy, 2005). Similarly, at Caherkine Lough the regeneration of the same woodland species occurred at this time with NAPp and *Plantago lanceolata*, in particular, being substantially reduced (O'Connell et al., 2001). Overall, the pollen data from Rosroe suggests the continued presence of some small, open areas for pastoral agriculture during the Iron Age with cereal cultivation occurring on a small scale somewhere within the catchment but with an increased woodland component. Later, there was a substantial reduction in human pressure upon the landscape in south-east Co. Clare which is comparable with evidence elsewhere in Ireland for a distinct Late Iron Age Lull. An Iron Age artefact was found on the eastern shore of Rosroe Lough (Grogan, 2005b), but further evidence of occupation has not been identified.

Early Christian Activity (c. AD 400 – 900*)*

The Early Christian period saw two substantial phases of farming activity. The first was during the 5th to 7th centuries AD when a significant expansion of NAPp (to 18.6%) suggests an increase in open, grassland areas at this time likely for pastoral farming, seen as a distinct peaks in PAZ-8 and PAZ-9. Of the tree species, hazel, elm, ash and yew were all severely affected presumably due to the clearance of woodland areas. A high number of birch seeds were identified from this period (Figure 8.10) indicating that this species may have been growing close to the lake. Grass and ribwort plantain expanded while all herb taxa associated with pastureland increased significantly including dandelion, buttercup, meadowsweet and clover. An arable component is suggested by the identification of cereal-type pollen and an increased representation of arable weeds. An increase in

Pediastrum suggests that some of this farming activity occurred in close proximity to the lakeside. Some woodland regeneration then occurred, especially evident in the concentration data, before the second substantial phase of farming activity during the late 8th to late 9th centuries AD. This was of a similar magnitude (NAPp at 20.7%) to the first phase but with some fluctuation in landscape composition during the middle of the period when particularly hazel and oak saw a short phase of recovery. The Mooghaun pollen record extends to c. AD 600 and also registered an increase in open areas established for pastoral agriculture during this period with an arable component (Molloy, 2005). Intensification of agriculture, often with a much higher arable component has been identified across Ireland in the early historic period (Chique et al., 2017; Molloy and O'Connell, 2004; 2016; Ghilardi and O'Connell, 2013b).

This activity is likely associated with archaeological sites such as ringforts (cashels), although very few have been excavated to provide dating evidence (Comber, 2012). A 6th – 7th Century AD date was obtained from the site of Carrowdotia located c. 16km north-west of Rosroe Lough and further pits, metalworking sites and hearths of this period have been located in the wider landscape to the north-west (Bermingham et al., 2012a). It is likely that some of the ringforts located in closer proximity to the lake (seventeen within the catchment area) may date to this period. The site of Cahircalla More, c. 14km north-west of Rosroe, encompassed a settlement enclosure, smithy and fieldsystem established in the late 6th century AD and possibly continuing until the 12th century practising a mixed farming economy (Bermingham et al., 2012a). Such an economy is represented in the Rosroe pollen record and sites such as this may have been common in the landscape surrounding Rosroe Lough.

Early Medieval Activity (c. AD 900 – 1240*)*

The landscape in the catchment of Rosroe Lough was substantially more wooded during the 10th to early 13th centuries AD. There was a significant recovery of hazel and ash, within the oak-elm woodland, at the start of this period probably due to reduced human pressure on the landscape that is indicated by the decline in NAPp, especially of the lesser herbs (e.g. *Trifolium)* which is no longer present in PAZ-10. Limited arable farming may have occurred at the beginning of this period. The data suggests a declining openness of the landscape during the 10th century AD with a potential lull in activity during the 11th century AD when *Poaceae* and *Plantago lanceolata* diminished to 4.0% and 0.1%, respectively, while AP representation increased to 91.7%. Higher concentration values indicate that sedimentation rate has slowed which would be expected with a decline in farming pressure. This data is in contrast to the intensification of agricultural activity identified at Lough Muckno, Co. Monaghan, and at several sites across Ireland collated by Chique et al. (2017).

Known archaeological evidence from this period in the catchment of Rosroe, however, is limited, although pits representing medieval occupation of the landscape to the north-west have been identified through developer-led archaeology (Bermingham et al., 2012a). Settlement at some of the ringforts may also extend into this period. An 11th/12th Century AD charcoal production pit at Barefield, c. 15.3km north-west of Rosroe, produced a large amount of oak charcoal, with lesser amounts of elm (Bermingham et al., 2012a) both of which are represented in the Rosroe pollen record. In the wider landscape, Quin castle, c. 6km north-west, was established in AD 1280 and Clareabbey Augustinian abbey, c. 11.2km north-west, in the 11th – 12th Centuries AD (Ua Cróinín and Breen, 2014; Bermingham et al., 2012a). The majority of the castles in the Rosroe landscape date from the 15th Century AD but Rosroe castle or 'Peel Tower', located by the eastern shore of the northern basin of the lake was built c. AD 1380 – 1400 (Ua Cróinín and Breen, 2014). Given the uncertainty of the chronology for the medieval period this is worth mentioning, although the lack of human activity in the record may indicate that it does not extend far enough to relate to this medieval occupation of the lakeshore.

8.6 Conclusion

A palynological reconstruction at Rosroe Lough has been presented which, through the establishment of a sufficient chronology for the later prehistoric period, at least, has allowed for a detailed account of landscape change. Although the prehistoric period is contained within just over 1m of sediment, the data has allowed for changes within the landscape to be assessed within the context of human activity and the archaeological record of south-east Co. Clare. Substantial human interaction with the landscape in the form of pastoral farming did not occur until the Chalcolithic – Early Bronze Age, although the first signs of human activity in this region occurred in the Late Neolithic. The most intensive period of farming activity occurred in the Late Bronze Age with a primarily pastoral economy but with some small-scale arable cultivation. The palaeoecological and archaeological records correspond particularly well during the prehistoric period with little evidence of a human presence during the Neolithic. This is in contrast to the majority of Irish pollen records, which demonstrate strong *Landnam* in the Early Neolithic (O'Connell and Molloy, 2001), but saw correspondence with the three additional pollen records from this area of south-eastern Co. Clare. The profile from Mooghaun Lough was generally very similar to that of Rosroe throughout the prehistoric period but the Late Bronze Age *Landnam* registered much more strongly in the former record. The record from Rosroe, however, demonstrates that there was more widespread farming activity occurring across the landscape in the Late Bronze Age which may have supported the economy linked to the hillfort itself. This new palaeoecological data has confirmed previous palaeoenvironmental assertions for this area but has done so across a larger portion of the Mooghaun Landblock allowing the archaeological narrative of the growing importance of this landscape area throughout prehistory to be more readily supported by palaeoenvironmental data.

Chapter 9 – People, Land-use and Time: The View from the Lakes

This chapter seeks to bring together all new data produced by this research and frame it within a regional Irish archaeological and palaeoenvironmental context. The two new palaeoenvironmental datasets from Lough Inchiquin and Rosroe Lough are discussed in terms of their relationship with the archaeological record, and their relationship with each other, representing the landscapes of the Burren and the Mooghaun Landblock, respectively. Finally, the major findings of this research project are highlighted and used to interrogate the existing archaeological narratives of the research areas. Figure 9.1 provides an overview of the study region of Co. Clare, presenting the distribution of relevant archaeological sites and highlighting the catchment areas of the two study lakes.

9.1 Palaeoenvironmental Correspondence with the Archaeological Record of Lough Inchiquin

9.1.1 Early Neolithic (c. 4000 – 3600 BC)

The Early Neolithic *Landnam* that registers in the Inchiquin profile appears to correspond with the intensity of human activity inferred from the archaeological record. The close proximity of Ballycasheen portal tomb (c. 2.4km upstream) is important given the representation of anthropogenic indicators at this time which indicate human activity close-by, and a further probable portal tomb has also been recently discovered in this area (Mercer, 2014). Further from the lake, just outside of the catchment area, is Poulnabrone portal tomb where initial use has been dated through Bayesian modelling of a high number of ^{14}C dates to between c. 3885 – 3720 BC (model 3 at 95.4%) or c. 3825 – 3710 BC (model 4 at 95.4%) (Schulting, 2014). Taphonomic analysis by Beckett (2011) suggests that the dating of skeletal remains does accurately date the use of the monument and lends support to the proposition that Poulnabrone is the earliest megalithic monument in Ireland, on current dating evidence (Schulting, 2014).

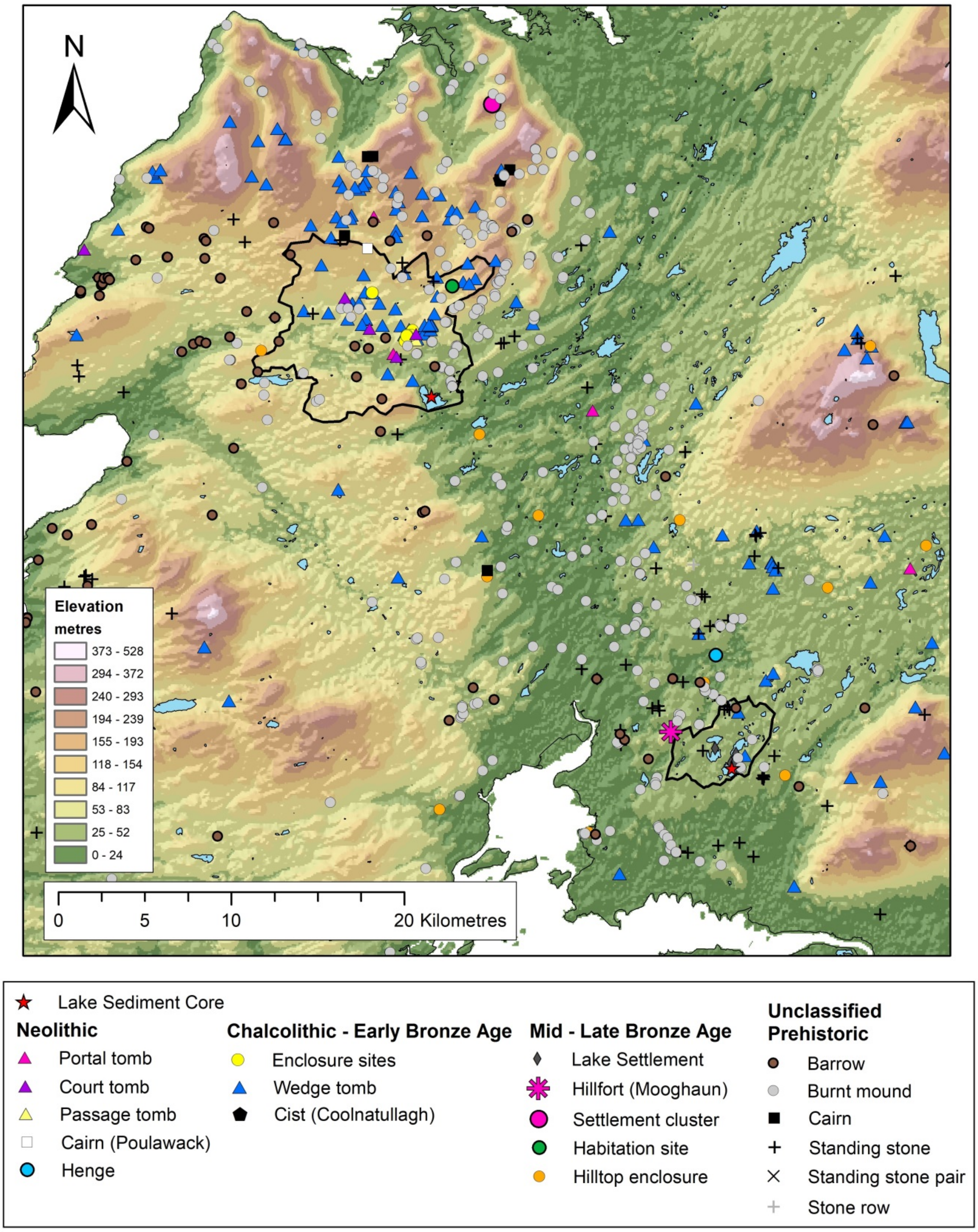

Figure 9.1: The distribution of relevant archaeological sites in Co. Clare and the delineation of the catchment areas of both study lakes (shown as solid black lines). The upper area delineated is the Lough Inchiquin catchment and the lower area delineated is the Rosroe Lough catchment. The map clearly shows the concentration of prehistoric sites in these two regions of Co. Clare. Late Bronze Age sites discussed in the text relate to the habitation site, enclosure to the west of this and settlement cluster to the north. Source: author.

This is relevant to the suggestion of early human activity from the Inchiquin pollen record which attests to an active human population in the Burren landscape by c. 3885 BC. Through the use of Bayesian age-depth modelling, the most intensive *Landnam* phase in the Inchiquin record is dated to c. 4060 – 3740 BC although it does extend to c. 3590 BC. While the chronology of the Inchiquin core is relatively robust there is a potential error range of c. 570 – 650 years for this period which creates a full range of c. 4290 – 3720 BC for the start of the *Landnam* period. It is unlikely, however, that human activity in the catchment of Inchiquin began prior to the weighted mean of c. 4060 BC due to the generally accepted start date for the Neolithic in Ireland (cf. Cooney et al., 2011). The initial use of Poulnabrone portal tomb corresponds with the beginnings of farming activity at Inchiquin, even if the minimum date of c. 3720 BC were taken as the start of the Neolithic *Landnam*. Current dating evidence thus suggests that the rise in NAPp and human activity indicated by the pollen record of Inchiquin, and the initial use of Poulnabrone, were contemporary. The dispersal of pollen from NAPp taxa is known to be limited (Behre, 1981), and as such it is likely that the activity registering in the pollen record was occurring in closer proximity to the lake than the Poulnabrone depression. The location of Ballycasheen portal tomb certainly indicates human activity close-by. The decrease in AP (which has a higher dispersal capacity) may suggest that Neolithic communities were having an impact upon the natural woodland across a wider region of the Burren, although it could also be representing the local situation. No dating evidence is currently available from Ballycasheen, and although all other ^{14}C dates from Irish portal tombs are later in date than Poulnabrone, it has been suggested by Schulting (2014) that a dating programme of Burren portal tombs may produce additional early dates.

A number of models have been developed for the start of the Irish Neolithic, one of the most recent of which (based on the Bayesian analysis of a large number of relevant ^{14}C dates) places the onset at c. 3850 – 3740 BC (Cooney et al., 2011). The Irish Early Neolithic house-horizon which has been used to propose a rapid shift to a sedentary lifestyle has been confirmed between c. 3720 – 3620 BC (Whitehouse et al., 2014; Smyth, 2014a). The current model for the beginnings of the Irish Neolithic both pre-dates the house-horizon and accommodates the initial use of Poulnabrone, suggesting that elements of the Neolithic did not all appear simultaneously (Cooney et al., 2011; Schulting, 2014). Sheridan (2010) envisages a Breton 'Atlantic' strand arriving to Ireland c. 4200 – 4000 BC followed by a Carinated Bowl Neolithic, both of which may have been preceded by a 'false-start' represented by the single domestic cattle bone from Ferriter's Cove, Dingle Peninsula. The provenance of this cattle bone, however, is uncertain and similarly uncertain early dates from the Magheraboy causewayed enclosure were excluded from the Neolithic model (Cooney et al., 2011; Danaher, 2008). The onset of the Neolithic is thought to have been rapid suggested by the proposed dietary shift to terrestrial domesticates and Bayesian chronologies of early plant macro-remains (Richards and Schulting, 2006; Whitehouse et al., 2014). The Early Neolithic *Landnam* at Inchiquin is accommodated within the time frame for the start of the Irish Neolithic indicating that this pollen record is pertinent to discussions on the earliest Neolithic in Ireland, especially given the association with the earliest dated megalith in Ireland.

By the time the first monuments were constructed, the domestic animals and crops of the Neolithic are thought to have been present within Ireland (Schulting, 2014). While the rise in NAPp at Lough Inchiquin may be related to pastoralism, two cereal-type grains were identified between c. 3740 – 3670 BC, in the second less intensive phase of the *Landnam*. It is thought that arable agriculture across Ireland, although a relatively minor part of the subsistence economy, was concentrated within the earlier part of the Neolithic when small, fixed-plots of emmer wheat and barley were likely established (O'Connell and Molloy, 2001; Whitehouse et al., 2014). Although only two cereal-type grains were detected at Lough Inchiquin, the pollen records examined by O'Connell and Molloy (2001), most of which were from western and northern Ireland, also only presented weak evidence of cereal growing. It is unclear whether this indicates that cereal was a minor component of the local economy as low representation may also be a result of the low production and dispersal of cereal pollen which can hinder its detection if carried on a small scale (Behre, 1981; Vuorela, 1973).

McClatchie et al. (2014), in the most comprehensive analysis of plant macro-remains for the Irish Neolithic to date, recorded cereal remains at 77% of Neolithic sites across Ireland (sample size = 52; distributed in the east and south of Ireland) with wheat and barley predominant. The data suggests a concentration of cereal cultivation in the earlier Neolithic with cereal identified at 86% of sites from c. 3750 – 3600 BC, 90% of sites from c. 3600 – 3400 BC and only 36% of sites between c. 3400 – 2500 BC (McClatchie et al., 2014). This is in close agreement with Irish pollen data which suggests arable agriculture took place during the first two centuries after the Elm Decline and the onset of Neolithic life (McClatchie et al., 2014; O'Connell and Molloy, 2001; Cooney et al., 2011). The first evidence for arable agriculture in the Lough Inchiquin pollen record (c. 3740 – 3670 BC) is consistent with this.

Somewhat later evidence for human activity in the Early Neolithic, from the archaeological record, comes from the Parknabinnia court tomb. Five ^{14}C dates, out of a suite of twelve dates, obtained on human remains from this court tomb have date ranges which extend into the Early Neolithic, which includes one of the earliest dates for court tomb use in Ireland at c. 3693 – 3376 BC (Schulting et al., 2012). The initial use of court tombs has been modelled to between c. 3700 – 3570 BC (Schulting et al., 2012). Both the use of court tombs across Ireland, and the activity specifically at Parknabinnia occurred during the second phase of the *Landnam* period (c. 3740 – 3590 BC) in the catchment of Lough Inchiquin. The 95% confidence interval for the end of the Inchiquin *Landnam* ranges from c. 3920 – 3240 BC but likely did not extend too far into the Middle Neolithic given the wider Irish trend for woodland regeneration at that time. The results of the Lough Inchiquin palaeolimnological analysis suggest that the scale of agriculture in the Early Neolithic was not sufficient to significantly affect the lake system at this point. Although there was a small flux in chironomid taxa and $\delta^{15}N$ levels, consistent with nutrient input relating to the *Landnam*, this was on a very small scale.

9.1.2 Middle – Late Neolithic (c. 3600 – 2500 BC)

The palaeoenvironmental data from the Middle Neolithic is more complex in terms of its correspondence with the archaeological record. The catchment of Lough Inchiquin at this time was characterised by woodland recovery and within the lake itself, $\delta^{15}N$ levels declined during this period. The combined evidence suggests a lack of agricultural activity at this time which is in agreement with the wider palaeoenvironmental trend across Ireland (O'Connell and Molloy, 2001; Whitehouse et al., 2014). The '*Plantago* Gap' as defined by Whitehouse et al. (2014) occurred and a reduction in human activity from c. 3500 BC and from c. 3350 BC is seen across Ireland and Britain (Whitehouse and Smith, 2010). The suggestion of a decreased population leading to this reduction in human pressure has been made in both instances (Woodbridge et al., 2014; Whitehouse et al., 2014). The recovery of woodland species occurred from c. 3550 BC at Lough Inchiquin, and as such, this data can be incorporated into the wealth of evidence for Middle – Late Neolithic afforestation within Ireland.

From the evidence of dated settlement sites, archaeobotanical assemblages and palaeoenvironmental data, Whitehouse et al. (2014) identified declining levels of activity from c. 3500 BC possibly related to a declining population. Settlement evidence from this period lacks clear dating or understanding but is represented by scatters of stake-holes at a small number of sites such as Knocknarea, Co. Sligo, Knowth, Co. Meath and post-built structures at Lough Gur, Co. Limerick (Smyth, 2014). Clearly, settlement at this time is less visible in the archaeological record but to what extent this is a true reflection of occupation levels, or an issue of preservation or recognition is hard to determine. As Smyth (2014) notes the Early Neolithic house-horizon covers only a small portion of the Neolithic and as such may not be a clear indicator of population size, but rather, the representation of a concern for social investment in domestic architecture which may not have continued into the Middle – Late Neolithic. Although the pollen data suggests a reduction in activity at this time in the catchment of Lough Inchiquin, the archaeological record suggests a continuation of occupation, which may have been reduced or more dispersed. This continuation is not reflected in the pollen data, but is evidenced through the deposition of remains into Parknabinnia court tomb, Poulanabrone portal tomb and Poulawack Linkardstown cist (Beckett, 2011). It is interesting that Smyth (2014) suggests the social function of Early Neolithic houses may have been replaced by monumental structures when one considers that significant activity occurred at three monuments in the Burren during this period. This represents mortuary activity over a c. 7km stretch of the Burren located c. 3km slightly to the north-west of Lough Inchiquin, even though the subsistence economy that supported the population does not register in the pollen record. Despite a significant reduction in farming activity in this area of the Burren, it was clearly not abandoned.

Activity at Parknabinnia court tomb also continued into the Late Neolithic and only two other court tombs in Ireland register similar late activity, Ballyglass 2 and Rathlackan in Co. Mayo (Schulting et al., 2012). This is unusual in the context of the twelve sites (forty-seven ^{14}C determinations on bone) used by Schulting et al., 2012 to form a Bayesian model for the chronology of Irish court tombs. There are, however, c. 394 court tombs across Ireland and as such the results are only a limited sample of excavated and well-dated examples (Schulting et al., 2012).The three Parknabinnia ^{14}C dates from this period were all obtained on human bone and represented at 2σ are as follows: c. 3097 – 2764 BC, c. 3006 – 2628 BC and c. 2905 – 2621 BC (Schulting et al., 2012). The re-initiation of farming activity in the Inchiquin record occurred at c. 2890 BC with a full date range of c. 3090 – 2710 BC. This suggests that the late activity at Parknabinnia court tomb and re-initiation of farming activity in this landscape were contemporary. There was a general re-establishment of pastoral farming across Ireland towards the end of the Late Neolithic c. 2700 BC (O'Connell and Molloy, 2001; Whitehouse et al., 2014). The age-depth model for Inchiquin thus suggests that farming activity was resumed relatively early in the Late Neolithic when compared with the wider Irish picture, which may be linked to the unusual continued use of the court tomb in this landscape.

McClatchie et al. (2014) noted that in contrast to the Early Neolithic, cereal remains were only found at 36% of sites dating from c. 3400 – 2500 BC, i.e. throughout much of the Middle and Late Neolithic. The cereal-type curve in the Inchiquin pollen record was interrupted after the Early Neolithic but one grain was identified at c. 3050 BC. Similarly, the beginnings of small-scale arable agriculture occurred from c. 2690 BC, evidenced by the establishment of a continuous cereal-type curve, which even if the 95% confidence interval is considered (c. 2840 – 2500 BC) still suggests cereal growing in the catchment of Lough Inchiquin in the Late Neolithic, which may not have been widespread across Ireland. Stevens and Fuller (2012) have proposed that the decline in cereal cultivation c. 3350 BC, in fact, continued until the Bronze Age in Britain although this has been refuted by Bishop (2015) on the basis of Scottish evidence. Whitehouse et al. (2014) demonstrated the continued presence of cereal cultivation in Ireland during the Late Neolithic, albeit at a lower intensity. The pollen data from Inchiquin attests to the re-establishment of an arable component at this time on the Burren, which would go on to become more prominent in later prehistory.

9.1.3 Chalcolithic – Early Bronze Age (c. 2500 – 1600 BC)

The archaeological record of the Burren, the Inchiquin pollen record and the palaeolimnological data all indicate an intensification of human activity during the Chalcolithic – Early Bronze Age. A mixed farming economy increased in intensity from c. 2520 BC, broadly contemporary with the proliferation of wedge-tomb construction across the Burren and the establishment of settlement sites on Roughan Hill (Jones, 1998; 2016; Jones et al., 2015; Jones and Walsh, 1996). This intensification was also identified in palaeolimnological data which highlighted the lake system response to increased agricultural activity at this time. The lake in this period had become more nutrient-enriched with increased levels of eutrophic chironomid taxa and an increase of >1‰ in the $\delta^{15}N$

levels compared with the Neolithic *Landnam*, indicating that by the Chalcolithic period agricultural intensity in the local vicinity of the lake had increased. The earliest date for human activity in the Chalcolithic from the archaeological record of the Inchiquin area has been obtained on cremated bone within the chamber of wedge tomb CL017 – 180002, located on Roughan Hill (Ó Maoldúin, 2017 pers. comm.). Recent dates confirm the use (and probably construction) of at least some of the Roughan Hill wedge tombs in the early centuries of the Chalcolithic (Ó Maoldúin, 2017 pers. comm.) and as such activity may have been contemporary with the evidence for increased pastoral farming from c. 2520 BC (c. 2730 – 2280 BC 95% confidence interval) and increased lake productivity by c. 2450 BC. It is likely that these tombs were constructed as the landscape was becoming increasingly more open which would have facilitated the construction of such a dense concentration of monuments across a small area.

Further activity from this point in the archaeological record is the establishment of the settlement sites on Roughan Hill. Bayesian modelling of twelve ^{14}C dates from these sites has proposed occupation of these enclosures between c. 2300 – 1550 BC, occupation starting between c. 2515 – 2208 BC and ending c. 1617 – 1480 BC (Jones, forthcoming-a). With the signal of pastoral and arable farming increasing in the Inchiquin pollen record from c. 2520 BC, the Roughan Hill enclosures are broadly contemporary, especially if the full date ranges for the Inchiquin record, and start of occupation are considered. Associated mound walls on Roughan Hill define contemporary field-systems (Jones, 2016). A later date, from the sequence of human remains within the chamber of Roughan Hill wedge tomb CL 017 – 180002, suggests that deposition continued throughout the Chalcolithic (Ó Maoldúin, 2017 pers. comm.). This is the only Roughan Hill wedge tomb to be dated so far but the remainder are likely contemporary as wedge tombs across Ireland have been confined to this period (Brindley and Lanting, 1991b). Given the close proximity, it is possible that the increase in NAPp representation at this time relates to activity on Roughan Hill, which given the density of wedge tombs across the Burren was potentially quite widespread. Archaeological evidence of human activity in the wider area has been discussed in Chapter 3, including habitation sites at Teeskagh and Rathwilladoon and fieldsystems and enclosures in the Coolnatullagh Valley (Gibson, 2016; Jones et al., 2010).

The Inchiquin pollen record suggests a further intensification of farming from c. 1810 BC which has an even tighter 95% confidence interval spanning just 270 years at 2σ. This is comparable to the palaeolimnological data which suggests an increase in, particularly, *Microtendipes pedellus*-type and *Chironomus anthracinus*-type in the Early Bronze Age proper. Thus, farming intensity in the Early Bronze Age had a greater impact upon the lake system than previous activity. The occupation of Roughan Hill continued until c. 1550 BC and so perhaps the increased farming is indicative of intensified occupation of this area in the Early Bronze Age, which may not be evident from the archaeological record alone. This is the closest known settlement and subsistence site to Lough Inchiquin and the increased eutrophication of the lake system does indicate that activity would have been close-by. While Jones et al. (2015) cannot be certain that occupation on Roughan Hill was continuous, the pollen record and consistent anthropogenic impact upon the lake system in this period, certainly suggests a continuation of farming activity in the local area of Lough Inchiquin, which may be related to the occupation of Roughan Hill. With land-use dynamics potentially linked to demographics (Woodbridge et al., 2014) the intensification of farming activity in the Early Bronze Age may demonstrate an increased population in this area of the Burren. Additional burial evidence from this period includes the cists inserted into Poulawack cairn c. 2000 BC, the secondary burial at Coolnatullagh (c. 1880 – 1610 BC), and the Chalcolithic – Early Bronze Age cremation inserted into Parknabinnia court tomb (Brindley and Lanting, 1991a; Eogan, 2002; Snoeck et al., Forthcoming). The burial evidence from this period is consistent with a high level of human activity.

The geochemical data generated during this study allowed substantial erosion into Lough Inchiquin to be identified between c. 2870 – 1700 BC. The most significant erosion occurred from c. 2870 (c. 3040 – 2700 BC 95% confidence interval) until c. 2270 BC (c. 2500 – 2060 BC 95% confidence interval). Although starting in the Late Neolithic this is broadly contemporary with the intensification of activity on Roughan Hill especially if the full date range for the start of Roughan Hill occupation is considered (c. 2515 – 2208 BC) (Jones, forthcoming-a). Potential reasons for such significant erosion early on in the farming regime have been discussed in Chapter 7 and the data adds to the distinct evidence for an intensification of human activity, both settlement and subsistence, from the Late Neolithic onwards in close proximity to Lough Inchiquin and potentially in the wider region. Substantial erosion came to an end at c. 1700 BC (c. 1830 – 1580 BC 95% confidence interval) and as such a substantial period of the Roughan Hill occupation (potentially six centuries) may have contributed to this erosional activity. Despite decreased erosion, the pollen record, palaeolimnology and archaeological evidence suggest a continuation of high levels of activity until c. 1550 BC in this area. This may have been the result of soil stabilisation within the catchment, however, which would account for this discrepancy in datasets. The palaeolimnological data suggests that the chironomid community composition at this time was, in part, determined by conditions in the lake as a result of soil erosion. In statistical analysis it was determined that the levels of titanium accounted for 5.6% of the variation in chironomid community composition and increases were seen in certain taxa which were shown to be associated with high levels of titanium. Thus, both the archaeological and combined palaeoenvironmental evidence suggests that this period was one of intensive human activity and occupation which had an effect not only on the landscape but also on the soil cover and freshwater ecosystems of the Burren.

9.1.4 Middle Bronze Age (c. 1600 – 1200 BC)

The Lough Inchiquin pollen record reflects decreasing farming activity from c. 1560 BC contemporary with the end of settlement occupation on Roughan Hill, on current dating evidence (Jones, forthcoming-a). Comparison of the full date ranges for decreased farming in the pollen record (c. 1670 – 1470 BC) and the end of Roughan Hill occupation (c. 1617 – 1480 BC) (Jones, forthcoming-a) indicates a striking contemporaneity. This potentially adds credibility to the suggestion that the intensive farming of the Early Bronze Age in the Inchiquin record may relate to the occupation of Roughan Hill. It is certainly the closest site of significant Early Bronze Age settlement so far discovered in this area. Significant woodland regeneration occurred from c. 1500 BC with a potential error range of just 160 years (c. 1590 – 1430 BC 95% confidence interval). No further settlement evidence has been found for this period but burial evidence suggests a continuation of occupation across the Burren. Specifically, on Roughan Hill a recent date from a secondary inhumation at wedge tomb CL 017 – 180002 suggests that the cairns of some, or all of the wedge tombs in this area, may have been later additions (Ó Maoldúin, 2017 pers. comm.). Additional burial activity also occurred at Poulawack cairn and Poulnabrone portal tomb (Brindley and Lanting, 1991a; Lynch, 2014). The palaeolimnological data did indicate some lake recovery at the start of the Middle Bronze Age with a slight decrease in productivity suggestive of a slackening of human pressure on the lake system. Although in decline, $\delta^{15}N$ values remained relatively high and no response was seen in chironomid community composition, with the lake likely having become more permanently altered by previous activity (as in Taylor et al., 2013). This period was one of varying intensity in farming activity across Ireland while more widespread woodland regeneration occurred in the latter stages (Plunkett, 2009). The evidence for a climatic downturn potentially related to the Thera eruption (1613 ± 13 BC) was presented in Chapter 3, with narrow growth-rings having been identified in Irish palaeoclimatic data (Risch and Meller, 2015; Baillie and Munro, 1988; Baillie, 1989). This may have been a contributing factor to the woodland regeneration that occurred towards the end of the Middle Bronze Age, or earlier in the case of the Inchiquin record.

The potential degree of correspondence between the different datasets may depend on the interpretation of the dates of burnt mounds in this landscape. The distribution of these sites can be seen in Figure 9.1. While the burnt mound tradition is now thought to extend back into the Neolithic (Hawkes, 2013; Hawkes, 2014) the majority date from the Bronze Age. Significantly, analysis of an increasing number of ^{14}C dates from excavated burnt mounds in Ireland has shown a clear concentration in the Middle Bronze Age with a further grouping in the Late Bronze Age (Ó Néill, 2003; Hawkes, 2011; Brindley et al., 1989). During the M18 Gort – Crusheen road scheme, to the east of the study area, nine burnt mounds produced only Early Bronze Age dates, four produced both Early and Middle Bronze Age dates, six produced only Middle Bronze Age dates, and seven had Middle – Late Bronze Age dates (Delaney et al., 2012). Additionally, the one excavated burnt mound on the Burren, Fahee South, produced a Middle Bronze Age date of c. 1408 – 1219 BC (Ó'Drisceoil, 1988; Brindley et al., 1989). Taken together, the evidence collated so far on the Irish burnt mound tradition, including those in proximity to the Burren and the single dated example from the Burren itself, suggests that it is likely that a number of those on the Burren date to the Middle Bronze Age. This would significantly increase the amount of human activity proposed from the archaeological record and would suggest some level of settlement activity in the area, with the distribution of burnt mounds potentially highlighting the distribution of contemporary settlement (see Ó'Drisceoil, 1988; Grogan and Condit, 2000), particularly in the eastern Burren. If this were the case the human activity inferred from the pollen record may not be as high as expected, but with the representation of NAPp still above 14% for much of the period, it does still reflect some occupation of the landscape which may be characterised by the burnt mounds within the catchment.

9.1.5 Late Bronze Age (c. 1200 – 600 BC)

It is during the Late Bronze Age that the greatest divergence between the archaeological and palaeoenvironmental records can be seen. The Inchiquin pollen record and palaeolimnological data both suggest that this was a period of substantial farming activity, both pastoral and arable, occurring at the highest intensity seen in the profile, and having the greatest impact upon the lake system. Two particularly intensive farming phases were identified between c. 1230 – 1000 BC and c. 900 – 750 BC. This Late Bronze Age expansion of farming activity appears to have been widespread across Ireland at this time especially from c. 1000 BC with the onset of the Dowris phase (Plunkett, 2009). In most areas of Ireland the increased intensity of Late Bronze Age farming is related to a general increase in archaeological visibility, potentially linked to an increased population (Plunkett, 2009; Armit et al., 2014). Evidence for a Late Bronze Age occupation of the Burren, however, is severely limited and as such does not correspond with the interpretation provided by the palaeoenvironmental data. Previous pollen investigations on the Burren hinted at continued activity at this time, particularly in the northern Burren (in the local catchments of Cappanawalla and Lios Lairthín Mór) but other Burren pollen records suggest a decrease in activity at this time in their local catchments (Thompson, 1997; Feeser, 2009; Feeser and O'Connell, 2009). Plunkett (2009) has suggested that the contrasting levels of activity suggested by pollen records across Ireland at this time represent the contraction of populations to prominent settlement areas. With the onset of intensive farming in the Inchiquin record occurring from c. 1230 BC and with a relatively tight 95% confidence interval of c. 200 years (c. 1320 – 1120 BC) the catchment of Lough Inchiquin would be deemed an important focal area for settlement activity under this interpretation. Where then is the archaeological evidence for this intensive activity?

Some of the burnt mounds on the Burren may well prove to date to the Late Bronze Age if investigated, which would increase the archaeological record for this period, with thirty such sites located within the Inchiquin catchment. Recent investigations have also led to the discovery of three areas of Late Bronze Age activity in the Burren, indicated on Figure 9.1. The first is an enclosure at Teeskagh, c. 6 x 4m that has been interpreted as a habitation site, also occupied earlier in the Neolithic and Chalcolithic with diagnostic artefacts such as barbed and tanged arrowheads (Gibson, 2016 476). Two ^{14}C dates obtained on charcoal from within a layer of midden soil and fire-affected sandstone thought to be representative of an occupation layer dated to c. 1208 – 976 BC and c. 1043 – 835 BC (Gibson, 2016). Although animal bone was not used for dating, it was recovered, and the assemblage of animal teeth was dominated by cattle and pig during the Late Bronze Age (Gibson, 2016) presumably part of the pastoral economy of the Burren. The Teeskagh site is located on a strategic high plateau adjacent to the much later 9th Century AD cliff fort of Cahercommaun and during excavations at this fort, stone axes attesting to much earlier occupation of the plateau were recovered (Hencken, 1938). The plateau appears to have been a focus of occupation throughout prehistory that continued into the Late Bronze Age and early historic period (Gibson, 2016; Hencken, 1938).

The second relevant site is a large enclosure (c. 140m in diameter) on the Carran plateau, c. 8km north of Lough Inchiquin, and just c. 3km west of Teeskagh, which produced two Late Bronze Age dates, c. 1210 – 931 BC and c. 1022 – 836 BC as well as probably Chalcolithic activity (Jones et al., 2010; Gibson, 2007). While the context of the Late Bronze Age material (charcoal related to the foundation level of the enclosure wall) may not be entirely secure, it does suggest the likely construction of the enclosure during the Late Bronze Age, despite only limited excavation (Jones et al., 2010). The close proximity of the site to four further large, undated, enclosures suggests that the potential for Late Bronze Age archaeology is there, and that a Chalcolithic or Early Bronze Age date should perhaps not be presumed for such features across the Burren. The recent Late Bronze Age dates obtained from excavations on Turlough Hill, relating to mountain-top house sites, provides the third indicator of previously unrecognised Late Bronze Age archaeology in the Burren, c. 17km north of Lough Inchiquin (Ó Maoldúin and McCarthy, 2016; Ó Maoldúin, 2018 pers. comm.). The dates from these three sites correspond with the phase of intensive Late Bronze Age farming that registers in the pollen record of Inchiquin. The distance of these sites from the lake, however, suggests that the strong NAPp representation is perhaps not specifically related to activity in those areas, although the River Fergus could carry anthropogenic pollen indicators from a greater distance within the catchment (Behre, 1981; Edwards and Hirons, 1984).

The addition of the palaeolimnological data, discussed in detail in Chapter 7, can elucidate the Late Bronze Age situation further. The collective data (chironomid and organic geochemistry) suggested a substantial increase in lake productivity at this time. Specifically, the highest abundance of eutrophic chironomid taxa, including those associated with modern pastoral agriculture (*Chironomus anthracinus*-type and *Microtendipes pedellus*-type (Potito et al., 2014)), occurred in this period with the chironomid community composition being indicative of a productive lake system. Similarly, the highest levels of *Pediastrum* are seen at this time which suggests a lake response to anthropogenic nutrient input (Jankovská and Komárek, 2000). Statistical analysis demonstrated that increased $\delta^{15}N$ levels were the driving force on the chironomid community composition at this time, accounting for 9.4% of the variation, and that these $\delta^{15}N$ levels were particularly high by c. 1060 BC.

As such, the combined pollen and palaeolimnological data indicates that pastoral farming activity had significantly increased in intensity and was occurring in close proximity to the lake in the Late Bronze Age, despite there being little archaeological evidence for this activity surrounding Lough Inchiquin. The only evidence in close proximity to the lake was the discovery of two swords in the immediate surrounds (Clare County Library, 2017; Lynch, 2014). The palaeoenvironmental evidence calls for a reappraisal of the significance of this area in the Late Bronze Age which would benefit greatly from investigation and excavation of undated features within the landscape immediately surrounding Lough Inchiquin and across the wider Burren. A site that could potentially date to the Late Bronze Age is the barrow on Knockloon Hill, c. 3.4km from the lake, which will be the target of excavation in June 2018 along with a large undated enclosure c. 20m to the east (Dowling, 2017).

9.2 A New Archaeological Narrative for the Burren based on New Data

9.2.1 Early Neolithic

The data suggests that as the Irish Neolithic began, the Burren was soon home to farmers engaged in both pastoral and arable agriculture, resulting in the contemporary dating of a *Landnam* in the catchment of Lough Inchiquin, and the construction and use of Early Neolithic tombs. The contemporary nature of Poulnabrone portal tomb and the Inchiquin *Landnam* would suggest that Ballycasheen portal tomb may also have been in use at this time. The results also highlight that while the archaeological visibility of this period is particularly high, this is mostly of a monumental or ritual nature, and that agriculture would have been carried out on a small scale in this period. No archaeological evidence of Early Neolithic agricultural practices or habitation sites have been identified but this is likely an issue of preservation and identification rather than reflective of a real absence. The lack of Early Neolithic field systems (bar Céide Fields, Co. Mayo where a recent re-evaluation has been discussed in Chapter 3), across Ireland, and within the Burren region, may be a true reflection of Early Neolithic farming practices.

9.2.2 Middle – Late Neolithic

Farming across the Burren decreased in the Middle Neolithic but human activity did not diminish entirely. Continued deposition in three important Burren monuments (Parknabinnia court tomb, Poulnabrone portal tomb and Poulawack Linkardstown cist) attests to a continued use of this landscape. The afforestation of the landscape in this period, however, suggests that it was no longer used for agricultural purposes. Whether this was a social choice, or a result of a sparser population is unclear. It does, however, correspond with a decrease in farming across Ireland and so may have been related to widespread subsistence and land-use change. The lack of settlement or agricultural evidence in the archaeological record may well relate to a distinct lack in the study area at this time, as the representativeness of the palaeoenvironmental record is such that if farming were present in the catchment at this time, it would be reflected in the data. In the Late Neolithic, both pastoral and arable agriculture re-commenced in the Burren and while deposition in Parknabinnia court tomb continued into this period, the increase in farming is not concurrent with a significant increase in the visibility of archaeological remains. Therefore, from the archaeological data alone, it could not be inferred that there was a potential increase in occupation or use of this landscape in the Late Neolithic, and the palaeoenvironmental data is, thus, key to this interpretation.

9.2.3 Chalcolithic – Early Bronze Age

An intensification of farming occurred in the Burren during this period which is reflected both in the archaeological and palaeoenvironmental records. As such there is a high degree of correspondence between the datasets with a mixed farming economy intensifying at a time when archaeological visibility in the area of Roughan Hill, especially, increases. There is evidence of both a burial/ritual and settlement nature in this period in the Burren. The degree of correspondence may result partially from the intensive investigations that have been carried out in the area of Roughan Hill, with both systematic survey and excavation leading to the identification of settlements and field-systems dating to this period, in addition to the dense concentration of wedge tombs which remain upstanding. Although aided by the nature of previous archaeological investigations, the combined archaeological, palaeoenvironmental and palaeolimnological data does reflect a distinct phase of farming activity. Additionally, an increase in anthropogenic indicators in the pollen record during the Early Bronze Age proper, highlights an intensification of use that would not be identified from the archaeological record alone.

9.2.4 Middle Bronze Age

In this period, a lack of dating evidence for the archaeological record complicates the degree of correspondence between the datasets. Predominantly of a burial nature, the only settlement evidence at this time comes from one dated burnt mound, although the likelihood is that more would date to this period if investigated. Similarly, it is proposed that wedge tombs continued to be used but, again, there is limited dating evidence for this. The palaeoenvironmental evidence reflects a decrease in farming activity contemporary with the end of occupation of the Roughan Hill settlements. The evidence may indicate that settlement became more dispersed or less permanent during this period and is reflected in the distribution of burnt mounds. The low archaeological visibility of this period may well relate to a change in subsistence strategy that allowed for some woodland regeneration in the Burren landscape. Certainly, if farming had continued to the same extent it would be reflected in the palaeoenvironmental data, even with a lack of associated archaeological remains.

9.2.5 Late Bronze Age

This period sees the greatest divergence between the records, due primarily to the nature of the archaeological record. It is not that Late Bronze Age archaeology is absent entirely, rather that poorly dated contexts and some artefactual find-spots only hinted at a very limited presence at this time. The palaeoenvironmental evidence has confirmed this presence and has demonstrated that Late Bronze Age farming was particularly intensive at this time in the Burren, as in the majority of Ireland, with a *Landnam* identified. Intensified farming at this time in Ireland is normally complemented by increased archaeological visibility (Plunkett, 2009) but in this case the low visibility of archaeological remains is clearly not an accurate reflection of past settlement. This lack of preserved or upstanding archaeological remains from the Late Bronze age led to very little research focus on this time period in the Burren. High status Late Bronze Age artefacts such as swords and the Gleninsheen gorget had previously attested to connections with important regions of Ireland during the Late Bronze Age (e.g. the Mooghaun Landblock) but now the palaeoenvironmental evidence has shifted focus to the importance of the Burren region itself. With the intensification of farming activity now established in the Burren, the archaeological narrative of this period would benefit greatly from systematic investigations close to Lough Inchiquin akin to those carried out on Roughan Hill. Recent work carried out on Turlough Hill is starting to reveal important archaeological remains of this period in the north Burren, and it is likely that this is a more widespread feature of the Burren landscape.

9.3 Palaeoenvironmental Correspondence with the Archaeological Record of Rosroe Lough

9.3.1 Neolithic (c. 4000 – 2500 BC)

The palaeoenvironmental data from the Rosroe record and the archaeological record of the Mooghaun landblock correspond well, in that both datasets indicate very little activity in this period. The lack of a Neolithic *Landnam* in this record contrasts strongly with the majority of Irish pollen records which demonstrate the start of pastoral and often arable farming during this period. In their examination of thirty-four pollen records from across Ireland, O'Connell and Molloy (2001), however, demonstrated that thirteen of these showed either weak or no evidence of Early Neolithic clearance or farming, indicating that *Landnam*-type events did not occur in all Irish landscapes. Despite evidence on the west coast of Ireland for Early Neolithic contacts at Ferriter's Cove, Co. Kerry and for an Early Neolithic presence at places like Lough Sheeauns, Co. Galway, three of the pollen cores with no evidence for Early Neolithic tree clearances are located on the extreme west coast of the counties of Kerry, Donegal and Galway (Lynch, 1981; Molloy and O'Connell, 1993; Fossitt, 1994). The evidence would seem to suggest that the Early Neolithic Irish landscape was not uniformly cleared and farmed. All previous pollen investigations in the Mooghaun Landblock, (Mooghaun Lough and Caherkine Lough) along with Caheraphuca Lough slightly further north, showed a similar lack of activity in the Early Neolithic from both palaeoenvironmental and archaeological data (Molloy, 2005; Molloy and O'Connell, 2012; O'Connell et al., 2001). The larger size of Rosroe Lough, with a catchment of 19.3km^2, in comparison with the above three lake sites (the current study estimated the catchment of Caherkine Lough to be just 0.7km^2) better corroborates this lack of Early Neolithic activity, suggested by the archaeological record, across a wider area of the Mooghaun Landblock.

As discussed previously, the local archaeological record is severely limited for the Early Neolithic with only find-spots of Early Neolithic material present within the catchment. Clogher portal tomb is located within the Mooghaun landblock, c. 15km north-east of Rosroe Lough, suggesting some activity in the area but as it lies well outside of the catchment area for this lake any potential anthropogenic indicators associated with this activity would likely not register in the Rosroe pollen record. Only limited pollen investigations have been carried out in the Mooghaun Landblock and with numerous lakes in closer proximity to Clogher portal tomb, future investigation of these may be able to elucidate if there was a higher level of Neolithic activity in that particular locale. With no Neolithic *Landnam* registering in the Rosroe pollen record, the first opening up of woodland appears to have begun c. 3120 BC (around the start of the Late Neolithic) but the chronology for this sediment core is not particularly robust; a problematic feature of all of the pollen investigations carried out in this area. The 95% confidence interval spans c. 1190 years (c. 3600 – 2410 BC) for the commencement of human interaction with the landscape (i.e. from the start of the Middle Neolithic to the start of the Chalcolithic). The wider Irish trend for Middle Neolithic woodland regeneration suggests it is perhaps unlikely that the start of human activity would lie prior to the weighted mean of c. 3120 BC and with human activity in the Mooghaun Landblock increasing towards the Chalcolithic it may potentially relate to activity at that point.

One archaeological feature is the henge at Coogaun, c. 6km north of Rosroe Lough (Jones, 2018 pers. comm.). Previously three potential henges had been identified in the Mooghaun Landblock but field inspection led to the re-assignment of two of these enclosures as ringforts (Condit and Grogan, 1998; Jones, 2018 pers. comm.). Henges are generally thought to date from the Late Neolithic (Waddell, 2010) and so the occurrence of a henge in this area of south-east Co. Clare is significant as it may be contemporary with the first indicators of human activity seen in the Rosroe pollen record.

9.3.2 Chalcolithic – Early Bronze Age (c. 2500 – 1600 BC)

In the Rosroe catchment, potentially more open areas were established during the Chalcolithic but it was not until the Early Bronze Age, c. 1820 BC, that there was a significant expansion. The potential error range for this date is still high, however, meaning that the date of c. 1820 BC has a 95% confidence interval ranging from c. 2540 – 1340 BC. As such it could feasibly relate to human activity occurring from the Chalcolithic to the

Middle Bronze Age. The archaeological record is strongest for the Chalcolithic with two wedge tombs located within the catchment of Rosroe Lough and seventeen distributed throughout the Mooghaun landblock, while two copper axes were also discovered in the northern region of the landblock (Grogan et al., 1994). A series of ^{14}C dated wedge tomb sites across Ireland has confirmed them to be a Chalcolithic phenomenon (Brindley and Lanting, 1991b) and so the construction of these monuments may be related to increased activity seen in the Rosroe pollen record, especially if tree clearances occurred in the earlier part of the c. 2540 – 1340 BC date range. More-or-less contemporary with the expansion of NAPp at c. 1820 BC, however, is the initial activity that occurred at the Knocknalappa lake settlement site, on the western shore of Rosroe Lough. Here, a date of c. 1887 – 1701 BC was obtained from a stake that was part of a palisade surrounding the brushwood and plank floor layer at the site (Grogan et al., 1999). Although the brushwood layer has not been identified to species, tree-roots of alder and ash were identified lying beneath this layer (Grogan et al., 1999) with both species present in the Rosroe pollen record for this period. It seems likely that the short period of increased pastoral and arable indicators from c. 1820 BC in the Rosroe pollen record may well relate to the initial stage of occupation on the shore of Rosroe Lough as evidenced by Knocknalappa. Pollen signals simultaneously provide both a regional and local signal of vegetation, which can be interpreted dependent upon the dispersal capacity of individual taxa (Behre, 1981; Bennett and Willis, 2001) (as discussed in Chapter 4). As such, while the regional signal from Rosroe Lough is reflecting a more widespread reduction in arboreal pollen across the catchment, the increased pastoral indicators (with a low dispersal capacity) are likely reflecting vegetation in closer proximity to the lake. As Knocknalappa is actually situated on the shores of Rosroe Lough, it is proposed that a large proportion of the NAPp in the pollen record will be reflecting activity at this lakeside site.

Despite an apparent increase in human activity registering in the pollen record during the Early Bronze Age, the archaeological evidence for this period is otherwise limited, compared with the Chalcolithic. Five burnt mounds are located within the catchment which have the potential to be of Early Bronze Age date, especially with excavated examples in mid-Co. Clare being from this period (Delaney et al., 2012; Hawkes, 2011; 2013; 2014). There are additional burnt mounds within the wider area but these could equally date to the Middle – Late Bronze Age (Hawkes, 2011) and their exact chronology will remain ambiguous unless excavated. In the north of the Mooghaun Landblock a bronze flat axe-head and a bronze halberd have been discovered which date to the Early Bronze

Age, but the distinctive Early Bronze Age burials (a single burial or cremation accompanied or contained within a pot), have a distribution mainly in the east and north of Ireland (Waddell, 2010). One does lie outside of this distribution, however, identified at O'Brien's Bridge c. 22km to the east of the study area (Waddell, 1970) but any associated activity would not register in the pollen record of Rosroe Lough.

While again lying outside of the catchment of Rosroe Lough, further Chalcolithic – Early Bronze Age activity has been identified in mid-Co. Clare during investigations for the M18 and N85 road systems. As discussed in detail in Chapter 3, this includes burnt mounds such as those at Cahircalla Beg (c. 13km north-west of Rosroe Lough) and burials such as the Manusmore Early Bronze Age cremation cemetery located c. 8km north-west of Rosroe Lough (Bermingham et al., 2012b). The results of this infrastructure project presented in Bermingham et al. (2012b) attest to increased human activity in this more southerly region of Co. Clare in the wider environs of the Mooghaun Landblock. It is likely, however, that the increased land-use represented in the Rosroe pollen record at this time relates directly to activity at the lakeside given the current dating evidence from the Knocknalappa lake settlement.

9.3.3 Middle Bronze Age (c. 1600 – 1200 BC)

The Middle Bronze Age saw a continuation of small-scale farming activity indicated by the Rosroe Lough pollen record and the archaeological evidence potentially suggests an increase in human activity. The continuation of farming activity in the pollen record and low dispersal of anthropogenic indicators may suggest that activity at the Knocknalappa lake settlement site continued for a time during this period, although no ^{14}C dates from the site indicate Middle Bronze Age activity. Some Irish pollen records demonstrate a period of woodland regeneration at this time (e.g. Ghilardi and O'Connell, 2013a; O'Connell et al., 2014; Plunkett, 2009). At Rosroe Lough there was a slight increase in arboreal representation towards the end of this period, c. 1320 BC, which has a 95% confidence interval of c. 480 years (c. 1590 – 1110 BC). As such this slight decrease could correspond to this wider Irish trend but with the Middle Bronze Age sampled at a low resolution (this entire period is contained within c. 8cm of sediment) it is hard to clarify this. The increase in archaeological visibility at this time, discussed in Chapters 3 and 8, includes artefacts (e.g. palstaves, spearheads and axe-heads), burnt mounds, barrows and standing stones (Grogan et al., 1995). Evidence for much of this proposed activity, however, is derived from undated sites within the landscape which are attributed to this period based on the generally accepted chronology of such features.

One of the burnt mounds located next to Mooghaun Lough has been ^{14}C dated and is thought to have been initially used at c. 1250 BC towards the end of this period (Molloy, 2005). Similarly, Middle Bronze Age dates have been obtained from burnt mounds in the wider landscape of the Mooghaun landblock, towards mid Co. Clare, for example at Cahircalla Beg c. 13km from Rosroe (Bermingham et al., 2012b). The same argument, as discussed for the Inchiquin catchment area, applies to the burnt mounds in the Mooghaun Landblock in that a number of them likely date to the Middle Bronze Age but will remain ambiguous until excavated (Hawkes, 2014; Hawkes, 2013; Hawkes, 2011; Brindley et al., 1989). If the eleven barrows and numerous standing stones within the Mooghaun Landblock are deemed to be Middle Bronze Age in date this suggests a substantial increase in human activity, although not specifically related to settlement or subsistence activities. Only one barrow, five standing stones and four burnt mounds are located within the catchment, however, which may or may not date to this period and so the scale of activity registering in the pollen record potentially corresponds well with the archaeological record. There may also be an overrepresentation of arboreal pollen due to the large size of the lake, and relative openness of the terrain in the surrounding landscape, which may mean that the scale of land-use at this time is not fully represented in the Rosroe pollen record.

9.3.4 Late Bronze Age (c. 1200 – 600 BC)

This phase is characterised by a substantial level of human activity indicated by both the palaeoenvironmental and archaeological data. Significantly, it is not until the Late Bronze Age that a *Landnam* occurred in the Rosroe catchment spanning the period c. 1120 – 710 BC. The chronology is much more robust in this section of the Rosroe sediment core with a 95% confidence interval of c. 360 years spanning c. 1290 – 930 BC, firmly placing the start of the *Landnam* in the Late Bronze Age. This corresponds not only with the previous palaeoenvironmental records for this area of Co. Clare (Molloy, 2005; Molloy and O'Connell, 2012; O'Connell et al., 2001) but with the majority of Irish pollen records which indicate substantial farming during this period (e.g. Plunkett, 2009). Although the first phase of activity at the Knocknalappa lake settlement site dated to the Early Bronze Age (see above), the main period of occupation is thought to be Late Bronze Age and while activity at the site may have continued into the Middle Bronze Age, a decrease in anthropogenic indicators towards the end of the Middle Bronze Age in the Rosroe record, and a peat layer between the two activity phases at Knocknalappa, indicate that occupation was not continuous throughout the Bronze Age.

A date of c. 1033 – 848 BC was obtained from accretion on a pottery sherd found within the Late Bronze Age occupation layer (Grogan et al., 1999). The pottery assemblage from Knocknalappa consisted of relatively fine ware, with the closest comparison being that found at Mooghaun hillfort, suggesting that Knocknalappa was a relatively high status site (Grogan, 2005b). The dating evidence suggests that activity on the shores of Rosroe Lough was contemporary with the significant increase in farming activity seen in the Rosroe pollen record. Given the location of Knocknalappa it seems likely that a significant portion of the NAPp representation in the pollen record relates to activity at this site. Only one ^{14}C date has been obtained from this occupation layer but the extensive deposits and successive layers of stone and timber upon the artificial platform led Grogan et al. (1999) to suggest occupation occurred over some time at this site. With the Rosroe pollen record suggesting substantial farming activity during the period c. 1120 – 710 BC it is possible that occupation at the Knocknalappa site continued for four centuries of the Late Bronze Age, which is potentially reflected in the pollen record. This may also give credence to the proposition by Grogan et al. (1999) that a large enclosure (80m in diameter), visible as a crop-mark and defined by two ditches, located c. 200m to the north-east of the lake settlement site, may represent further settlement activity at this time. In addition, the associated settlement platforms elsewhere in the lake discussed in Chapter 3, suggest that the excavated site was part of a larger complex of platforms with the pollen record potentially reflecting activity at all of these sites around the lakeside in this period. It was during this time that *Pediastrum* was at its highest level for the prehistoric record likely due to anthropogenic nutrient enrichment (Jankovská and Komárek, 2000). A further lake settlement site is situated in Finn Lough, directly to the west, and although undated, it may prove to be contemporary given its proximity to the Knocknalappa site and the fact that the Late Bronze Age saw the most intensive human activity indicated by the prehistoric pollen record.

The faunal assemblage from Knocknalappa produced cattle, sheep and pig bones (with some cut marks identified) (Raftery, 1942) which were likely part of the pastoral economy represented by the substantial increase in NAPp representation in the pollen record. Identified charcoal specimens included hawthorn, hazel, ash, holly, alder, oak and willow, believed to have come from structural layers within the site (Grogan et al., 1999), and all but hawthorn are well represented in the Rosroe pollen record at this time. Similarly, O'Sullivan (1994) identified immature ash posts within the palisade, with the wood technology suggesting that these were Late Bronze Age, and oak planks within the wooden jetty. Oak and ash timbers were also identified in the associated lake-platform sites on Rosroe Lough (O'Sullivan, 1996). Both species are represented in the Rosroe pollen record and decreases c. 1180 BC may indicate the clearance of these species, potentially for the construction of elements of the site, although the amount required may not have been sufficient to be detected in the pollen record. Additionally, the log-boats identified in the northern basin of Rosroe Lough were made of oak (Grogan, 2005b) which the pollen record indicates was available for exploitation in this period. Grogan et al. (1999) suggests that burnt mounds close to Rosroe Lough were likely contemporary with the Knocknalappa lake settlement site. It is suggested that this settlement site was a focal point in the landscape during the Late Bronze Age, which formed a component of the wider landscape dominated by Mooghaun hillfort (Grogan et al., 1999).

The dating of Mooghaun hillfort suggests construction c. 915 – 905 BC (Grogan, 2005b) which falls within the main *Landnam* period recorded in the Rosroe pollen record. All of the settlement evidence discovered and dated so far in the hillfort pre-dates the final completion but presumably occupation continued throughout the Late Bronze Age during which time this area rose in importance (Grogan, 2005b). As discussed previously, the *Landnam* signal in the Rosroe pollen record is not at the same magnitude as in the Mooghaun Lough record, which is likely due to the close proximity of the latter to the hillfort itself, and potentially the size of the lakes investigated. If the hillfort was seen as the symbolic capital of the region encompassing a territory of potentially c. 9000 people over 450km^2 (cf. Grogan, 2005b) it is likely that much of the Mooghaun Landblock was used for pastoral or arable agriculture. The Rosroe catchment is much larger (c. 19.3km^2) than those of the previously investigated lakes in the area and the pollen data may thus be more representative of the situation across a larger area of the Mooghaun landblock. The hilltop enclosures located in the Mooghaun landblock are thought to represent further Late Bronze Age activity although only one, Clenagh, has so far been investigated. The hilltop enclosure site of Clenagh, located c. 8.5km to the south-west of Rosroe Lough, produced only an Iron Age date within a post-abandonment context upon excavation (Grogan and Daly, 2005; Grogan and Daly, 1996). Thus, although the distinctiveness of the area in terms of metalwork finds, especially the Mooghaun gold hoard, has been used to argue for the development and establishment of this area in the Late Bronze Age (Grogan, 2005b;

Grogan et al., 1995; Eogan, 1993; Jones, 2009) only two settlement sites, the hillfort at Mooghaun and the lakeside site of Knocknalappa, have been definitively dated to this period within the Mooghaun Landblock.

Nevertheless, the correspondence between Mooghaun hillfort, Knocknalappa settlement site, prestigious metalwork depositions and the intensification of farming activity indicated by the Rosroe pollen record does suggest that this period was the most important over the course of prehistory. In addition, the Rosroe pollen record, which demonstrates that the activity seen in the Mooghaun Lough record was not strictly limited to the area immediately surrounding Mooghaun hillfort, lends support to the suggestion that further enclosures, barrows and burnt mounds in the region may well be of Late Bronze Age date. It would be beneficial for future investigations to target such sites to elucidate the Late Bronze Age of the wider Mooghaun landscape further.

9.4. A New Archaeological Narrative for the Mooghaun Landblock based on New Data

9.4.1 Neolithic

In this period both datasets, archaeological and palaeoenvironmental, suggest a distinct lack of human activity in the Mooghaun Landblock. The low visibility of the archaeological record at this time, (limited to find-spots and two monuments located outside of the catchment area), appears to be a true reflection of the occupation of this region and not a result of bias within the archaeological record from issues such as preservation or the nature of investigations. Given the lack of a Neolithic *Landnam* in the pollen record, interpretations that have been based on the scarcity of Neolithic remains are supported by the new palaeoenvironmental data. The data also confirms the interpretations of the two previously published pollen records from this area, which providing only very local signals of land-use, may have not been accurately reflecting activity across the landscape. The first human interaction with the landscape is suggested to have occurred in the Late Neolithic and so may be related to the construction or use of Coogaun henge, although this feature remains undated.

9.4.2 Chalcolithic – Early Bronze Age

Overall, the visibility of the archaeological record increased in this period which is concurrent with a suggested increase in human activity from the palaeoenvironmental record. The archaeological record of the Mooghaun Landblock is strongest during the Chalcolithic, however, while the palaeoenvironmental data for farming activity is strongest during the Early Bronze Age. This discrepancy may be caused by the nature of the archaeological record in the two time periods, with the upstanding remains of Chalcolithic wedge tombs preserved across the landscape. Much of the farming activity dating to the Early Bronze Age may relate to the Knocknalappa lake settlement site and so the increased representation of farming activity may be caused primarily by the location of archaeological sites rather than the inherent number of sites. Further Early Bronze Age archaeological sites (burnt mounds and burials) in south-east Co. Clare have, however, been identified through intensive investigations as a result of road schemes. As such the archaeological visibility of the Early Bronze Age Mooghaun Landblock may increase if thoroughly investigated.

9.4.3 Middle Bronze Age

There is some discrepancy between the archaeological and palaeoenvironmental records in this period. While the archaeological record is one of increased visibility when compared with the preceding period, the palaeoenvironmental data suggests a continuation of farming levels. The archaeological record is diverse including burnt mounds, barrows, standing stones and artefacts, but a lack of specific dating evidence from the majority does limit the robustness of interpretations regarding the scale of Middle Bronze Age occupation. Excluding the burnt mounds, there is limited settlement or agricultural evidence from this period and so the farming activity represented in the pollen record does give an indication of land-use at this time that is not seen from the archaeological remains. Middle Bronze Age woodland regeneration is perhaps not fully reflected in the pollen record, because of the low resolution of the data from this period, but could again be linked to a more dispersed occupation evidenced through burnt mounds, as may be the case in the Burren.

9.4.4 Late Bronze Age

The combined datasets suggest that the high visibility of the Late Bronze Age archaeological record is a true reflection of a significant phase of settlement and agricultural activity across the Mooghaun Landblock at this time. The development of this region to one of elite and prestigious metalworking, and high status settlement, is accompanied by new evidence for significant agricultural activity which has been identified as the first evidence for a *Landnam* in the pollen record. Although the archaeology alone has previously been used to suggest the importance of this area at this time, the majority of the sites are undated and only two settlement sites have definitively been identified (Knocknalappa and Mooghaun Hillfort). Thus, the palaeoenvironmental data supports the assertion of a significant increase in human activity and would suggest that if investigation was made into the dating of further archaeological features, (enclosures, barrows and burnt mounds), there would be Late Bronze Age discoveries. Mooghaun Hillfort itself lies outside of the catchment area but it is likely that associated agriculture occurred across the landscape to sustain the hillfort, an interpretation that the palaeoenvironmental data would support, despite the current lack of dated agricultural evidence such as field-systems or enclosures.

9.5 Comparison of Lough Inchiquin and Rosroe Lough Pollen Records

This section compares the pollen records of Lough Inchiquin and Rosroe Lough which are both the largest lakes within their respective landscape areas to have been investigated (Table 9.1). In the case of Lough Inchiquin the pollen data is reflective of a very large, regional catchment area covering c. 93.2km^2. As discussed in Chapter 6 this is in part due to the influx of the River Fergus which drains a substantial portion of the Burren and thus can carry anthropogenic pollen indicators from a further distance. While the catchment of Rosroe is much smaller than Inchiquin, it is still of a considerable size (c. 19.3km^2) when compared with the small catchments of the lakes previously investigated. The sediment core extracted from Lough Inchiquin is of much higher quality than Rosroe with a prehistoric period covering over 4m while it is restricted to only 1m of sediment in the Rosroe core. Examination of the 95% confidence interval for the Inchiquin age-depth model demonstrates a more robust chronology than for Rosroe. The overall resolution of analysis is thus much higher for the Inchiquin record.

Table 9.1: A summary of the main palynological features relating to human activity in the Inchiquin and Rosroe pollen records compared by time period.

Time Period	Inchiquin	Rosroe
Early Neolithic	Elm Decline c. 4060 BC; *Landnam* c. 4060 – 3590 BC; cereal-type detected	Elm Decline c. 3840 BC; no *Landnam*
Middle – Late Neolithic	Woodland regeneration – ash and yew; Re-initiation of farming c. 2890 BC; a continuous cereal-type curve initiated	Woodland continued – ash and yew; 2nd Elm Decline c. 3290 BC; very low level activity initiated c. 3120 BC; occasional cereal
Chalcolithic – Early Bronze Age	2nd Elm Decline c. 2460 BC; intensification of farming especially from c. 1810 BC	Increased farming c. 1820 BC – small peak by end of Early Bronze Age; cereal-type curve initiated
Middle Bronze Age	Woodland regeneration c. 1560 – 1320 BC AP = low of 86.6%; decreased cereal	Continued small scale farming; decreasing from c. 1320 BC
Late Bronze Age	Intensive farming (*Landnam*) NAPp = 47.5% by c. 1000 BC; pastoral and arable; decreased activity c. 750 BC	Intensive farming (*Landnam*) NAPp = 18.4% by c. 1070 BC; pastoral and arable; decreased activity c. 780 BC

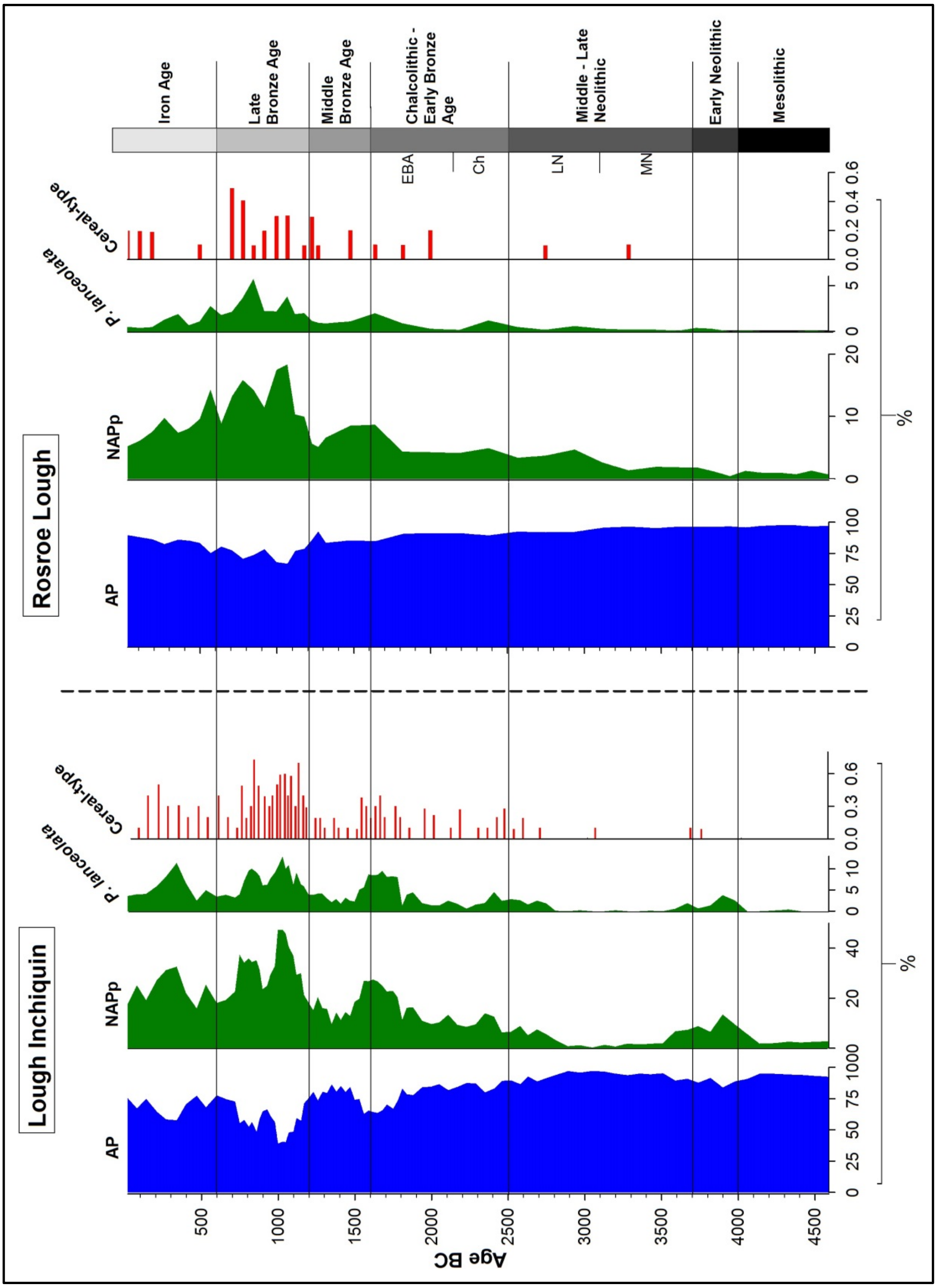

Figure 9.2: Comparison of selected percentage pollen curves representative of human activity from the Lough Inchiquin and Rosroe Lough pollen records plotted by calibrated age BC. This allows for a comparison of landscape representation and land-use dynamics by chronological period. Abbreviations are as follows: MN = Middle Neolithic, LN = Late Neolithic, Ch = Chalcolithic, EBA = Early Bronze Age.

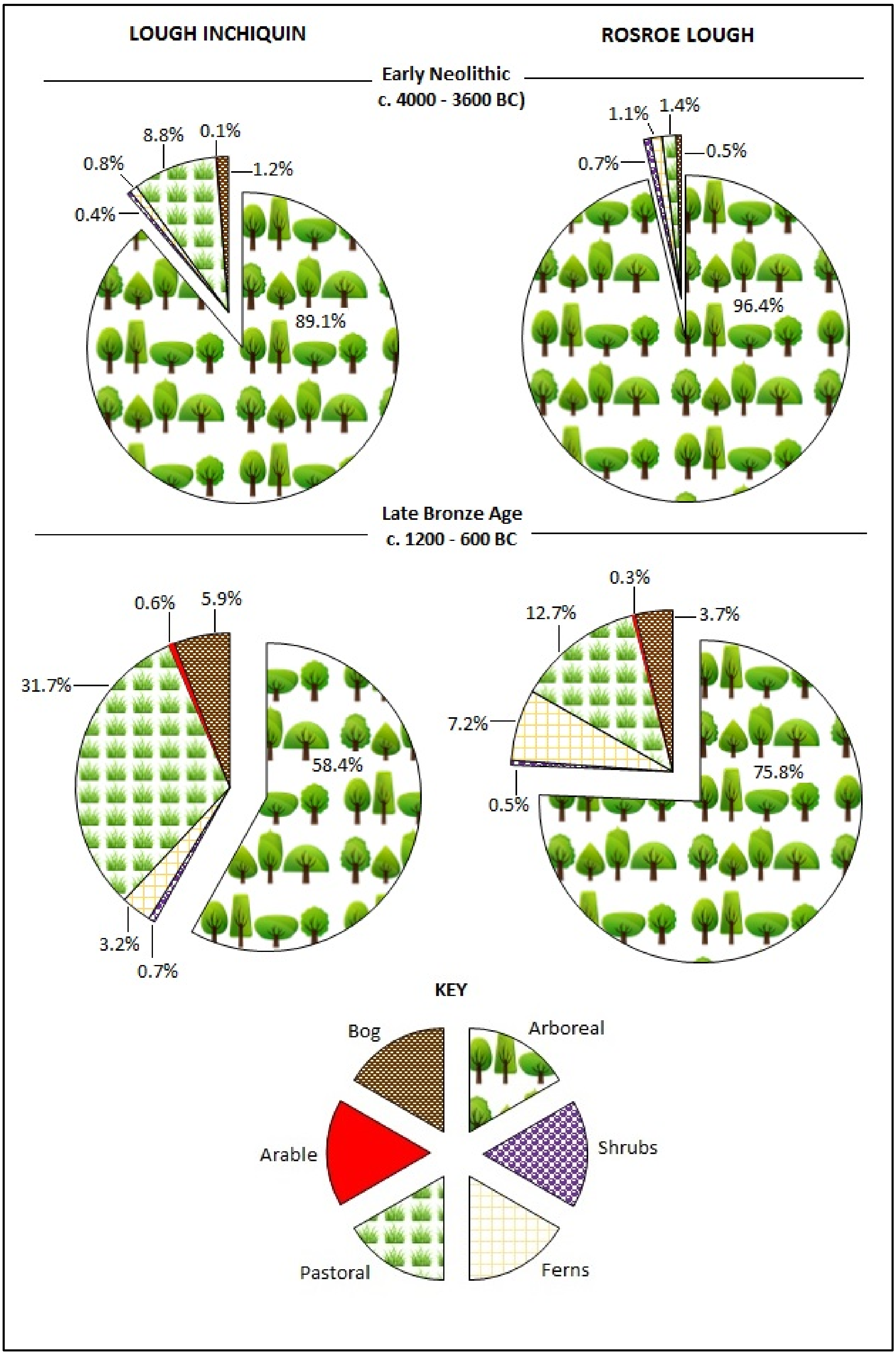

Figure 9.3: The percentage contribution of terrestrial pollen groups (as indicated in the key) for the Early Neolithic and Late Bronze Age from Lough Inchiquin and Rosroe Lough. Comparison of the Early Neolithic demonstrates the difference in human-environment interactions at this stage with a *Landnam* only in the Inchiquin record. Comparison of the two records in the Late Bronze Age highlights the similarities in landscape composition and land-use dynamics with both records registering *Landnam* activity.

9.5.1 Earlier Prehistory (Mesolithic – Late Neolithic)

The pollen record of both sites begins in the Mesolithic with high arboreal representation, characteristic of this period in Ireland and representative of the majority of Irish pollen records (Figure 9.2). The Elm Decline registered in both profiles, possibly slightly earlier at Inchiquin than Rosroe, but conforming to the generally accepted time frame for the Irish Elm Decline (Whitehouse et al., 2014; O'Connell and Molloy, 2001). Following the Elm Decline the two pollen records start to contrast which continues throughout this period (Figure 9.3). The pollen record from Inchiquin follows the general trends seen in most Irish pollen records for the Neolithic; Elm Decline → Neolithic *Landnam* → woodland regeneration → re-initiation of farming activity. The Rosroe pollen record, in contrast, does not register farming activity in this period which suggests much less human activity in the landscape of south-east Co. Clare in contrast to the Burren during the Neolithic.

The *Landnam* at Inchiquin resulted in AP representation falling to 84% and NAPp representation increasing to 8%, while at Rosroe Lough AP representation remained at 96% with negligible NAPp. This suggests that while the landscape of the northern part of Co. Clare, namely the Burren, began to change due to human action, the landscape of south-east Co. Clare and the Mooghaun Landblock remained largely unaffected by a human presence and saw the continuation of natural woodland. This area of Ireland, then, in the Early Neolithic did not see a uniform human presence but rather differing land-use dynamics across the region with a concentration of activity in the north, which for whatever reason, was preferable to Early Neolithic communities. This is also reflected in the archaeological record of the two areas, as discussed above.

Both catchments were characterised by a woodland environment during the Middle Neolithic with AP representation at 95% in the Inchiquin record and 96% in the Rosroe record. The dynamics behind these are different, however, with the high arboreal representation in the Inchiquin catchment demonstrating a dramatic change from the preceding period. Despite a continuation of human activity in the archaeological record, as discussed above, the farming communities that established themselves in the Inchiquin catchment in the earlier Neolithic were now having a more limited impact on the environment with woodland regenerating across the landscape. This suggests a potential shift in subsistence strategy, settlement placement or population size. The Rosroe record, in contrast, demonstrates continuity from the Early Neolithic with communities still not populating this region to any great extent. Woodland dynamics of the Late Neolithic in the two areas were similar with ash and yew becoming prominent contemporaneously in both records. With the chronology of the Rosroe record having been problematic and with a large potential error, the similarity of the two records at this stage lends support to the proposed chronology of the Rosroe record.

It is in the Late Neolithic that both records register human activity, and in the case of Rosroe, for the first time. The first opening up of the woodland environment began in the Rosroe catchment c. 3120 BC while a re-initiation of farming activity began in the Inchiquin catchment c. 2890 BC. The 95% confidence interval for this increase in activity in the two records overlaps, suggesting it was broadly contemporary in the two regions of Co. Clare. The intensity of this activity is much stronger in the Inchiquin record during this period with a rapid increase in NAPp representation to 9% and a fall in AP representation to 87%. The AP representation in the Rosroe record decreased to 92% and NAPp representation increased to 5%. The very wide catchment of Inchiquin may cause an overrepresentation of AP, due to its high dispersal properties, and so farming activity may have been even more intensive during this period than is reflected in the record. An almost continuous cereal-type record was established at this time in the Inchiquin record while only occasional cereal-type registered in the Rosroe record. The higher intensity of farming in the Inchiquin catchment may relate to a higher population density in this part of the Co. Clare landscape.

9.5.2 Later Prehistory (Chalcolithic – Late Bronze Age)

The later prehistoric period was broadly more similar in terms of land-use dynamics between the two areas of Co. Clare (Figure 9.3) with the archaeological records of both areas suggesting continued occupation from the Chalcolithic to the Late Bronze Age, although the Late Bronze Age evidence is more visible in the Mooghaun Landblock than in the Burren. The Inchiquin record demonstrates steadily increasing intensity of farming throughout the Chalcolithic with NAPp representation reaching a high of 14%. The representation of NAPp in the Rosroe record, which does not exceed 5%, suggests a relatively stable level of small-scale farming activities at this time. Differences in scale are reflected in the archaeological record which suggests a high level of activity in the vicinity of Lough Inchiquin at this time, with the dense concentration of wedge tombs and settlement sites on Roughan Hill being in close proximity. Although there are wedge tombs located within the Mooghaun landblock, most of these are in the wider region, with only two located in the catchment area.

In both cases there was an intensification of farming with the onset of the Early Bronze Age. Interestingly, this intensification occurred contemporaneously in the records, between c. 1820 – 1810 BC, suggesting that increased farming may have been related to wider social dynamics across Co. Clare. For example, Plunkett (2009) has suggested that mixed farming in the Early – Middle Bronze age in Ireland may have been related to an expansion of human activity across the landscape. Although contemporary, the intensity of farming in the catchment of Lough Inchiquin was greater than in the Rosroe Lough catchment with NAPp representation reaching 28% and AP representation falling to 64%. In the Rosroe record this was lower with AP representation decreasing to 85% and NAPp representation increasing to 9%. Again, this is likely due to the proposed levels of human activity occurring in close proximity to the lakes; with much greater evidence for Early Bronze Age occupation in the landscape surrounding Lough Inchiquin than Rosroe Lough.

The similarity of the records during the Middle Bronze Age is harder to recognise due to the poor resolution of this period in the Rosroe pollen record. A strong period of woodland regeneration occurred in the catchment of Lough Inchiquin which saw AP representation increase to 87% while NAPp representation decreased to 10%. Chironomid taxa did not respond to decreased farming at this time but there was a slight decrease in $\delta^{15}N$ levels and a significant decline in the level of *Pediastrum* suggestive of a less impacted system and the likelihood that any continued farming occurred at a greater distance from the lake. The low-level farming activity established in the Early Bronze Age in the catchment of Rosroe Lough appears to have continued in this period. There was, however, an increase in AP representation by almost 10% between c. 1320 – 1270 BC which potentially represents a period of woodland regeneration. With the potential error range of the above date range being inclusive of a larger portion of the Middle Bronze Age the records of land-use dynamics in these two areas could be more similar than they first appear.

The most intensive period of farming activity in both pollen records occurred in the Late Bronze Age. In the Inchiquin record AP representation decreased to a low of 39% by 1000 BC when NAPp representation reached a high of 48%. This suggests a significant level of activity especially given the possibility of over-representation of tree pollen in large, deep lakes (Chique, 2017). In the Rosroe record AP representation decreased to 67% with NAPp representation increasing to 18%. The highest levels of pastoral farming in both records (as indicated by NAPp and cereal-type representation) occurred c. 1000 BC, as the Dowris phase emerged. This suggests the interpretations of Plunkett (2009), regarding widespread farming in both established and newly cleared areas of the Irish landscape with extensive settlement, may also apply to Co. Clare during the Late Bronze Age. This is in contrast to the established view of Late Bronze Age activity in the Burren area which, with limited archaeological evidence and previous pollen investigations e.g. Thompson (1997) suggesting a '*Late Bronze Age lull'* in activity, led to interpretations based on a decline in the human occupation of this northern region of Co. Clare, e.g. Grogan (2005b). In contrast, the Mooghaun Landblock has generally been viewed as a landscape of great importance during the Late Bronze Age due to the greater visibility of the archaeology of this period. Comparison of the pollen records, however, suggests that the intensity of farming activity in the catchment of Lough Inchiquin was greater than at Rosroe Lough. Furthermore, the palaeolimnological evidence demonstrated an increased abundance of eutrophic chironomid taxa including those associated with pastoral agriculture in the Late Bronze Age of Lough Inchiquin which suggests that farming was particularly intensive in this period and that the high NAPp recorded was not a result of overrepresentation due to the influx of the River Fergus. Similarly, the high $\delta^{15}N$ levels that register in the Inchiquin record at this time are a result of intensive farming in close proximity to the lake during the Late Bronze Age.

In both areas the Late Bronze Age economy appears to have been based on mixed farming with the evidence for arable cultivation being the strongest in this period. The representation of cereal-type pollen is more similar than that of NAPp between the two records, reaching a high of 0.7% in the Inchiquin record and 0.5% in the Rosroe record. With issues of low production and dispersal of cereal-type pollen it is hard to determine the relative proportion of arable to pastoral farming (Vuorela, 1973) but in both cases the pollen record is suggestive of a small-scale arable component during the Late Bronze Age. In both catchments the Late Bronze Age was characterised by two particularly intensive farming phases with a short period of woodland recovery in-between, which is more clearly expressed in the Inchiquin record. This started c. 980 BC and lasted a little less than a century and, although the increased representation of woodland species only covers one sample in the Rosroe record, it is well-expressed in the concentration data and appears to be contemporary. Similarly, the end of the Late Bronze Age was one of decreasing levels of farming which occurred contemporaneously in the catchments of Lough Inchiquin and Rosroe Lough, from c. 750 BC and c. 780 BC, respectively. This suggests that Co. Clare was part of a more widespread reduction in agricultural pressure on the landscape that occurred across Ireland at this time (Plunkett, 2009). This can be seen as a disruption to the economic base of the Late Bronze Age which was not expressed in the archaeological record of the two regions, unless as suggested by Ó Néill (2003) there were fewer burnt mounds constructed and used after this point (see also Plunkett, 2009). Despite the differing archaeological visibility of this period in the two regions of Co. Clare, the land-use dynamics and subsistence base is especially comparable in this period.

Chapter 10 – Conclusion: New Data – New Perspectives

This study implemented an approach using lake sediments as a means to investigate human activity within the catchment areas of two large lakes in Co. Clare. As discussed previously (Chapter 4) lake sediments are especially suited to such studies that relate environmental change to human activity (Bennett and Willis, 2001). The sensitivity of the environmental proxies within lake sediment allows for a record of activity to be obtained across, in the case of large and deep lakes, a large catchment area (Edwards and Whittington, 2001). Particularly, it is the *continuous* accumulation of sediment that has allowed the results of this study to test and develop the existing models of the human occupation of Co. Clare through prehistory. Such models have previously relied to a large extent (but not exclusively) on archaeological evidence, which by its nature can be of varied visibility through time, (with the unknown date of some archaeological features being a particular problem in the study area). This study has demonstrated the complementary nature of the records provided by both archaeological and palaeoenvironmental data. The inherent nature of the archaeological record is that it is *episodic*, with a high dependency on the visibility of evidence, site preservation, adequately dated sites and the past nature of research. Each of these factors can produce a bias in the archaeological record, upon which interpretations on the human occupation and use of a landscape are based. Thus interpretations based solely on archaeological evidence are limited by the known archaeological record which is certainly not complete in terms of the use of a landscape. For example, archaeology relating to monumentality and burial is often more highly visible than that of settlement and subsistence without large-scale open area excavation.

This argument is especially relevant to the upland Burren landscape which is largely devoid of modern agriculture or development that may lead to the discovery and dating of buried sites but is a landscape known for its impressive megalithic monuments, with Poulnabrone portal tomb being a prime example. The record of settlement, therefore, is more limited than the monumental record with the main exception being the Roughan Hill habitation sites. These were identified through targeted intensive survey specifically looking for evidence of prehistoric habitation which, however, has not been carried out on a wider landscape scale. Similarly, although the investigations of the North Munster Project identified a landscape of later prehistoric settlement in the Mooghaun Landblock, only Mooghaun hillfort and Knocknalappa lake settlement site have been ^{14}C dated to the Late

Bronze Age. In both cases this means that the complete occupation record of the landscape is not necessarily evident in the archaeological remains. In contrast, the record of human activity and landscape change retained within Holocene lake sediments is continuous and with a good chronological resolution can provide detailed information on such change throughout prehistory (cf. Edwards and Whittington, 2001).

The lake sediments examined from Lough Inchiquin and Rosroe Lough have provided continuous records of landscape change and human activity which has, in the preceding chapters, been integrated with the archaeological record to provide a more complete interpretation. In terms of the Mooghaun Landblock this interpretation has not changed the existing narrative but rather has corroborated it over a greater extent of the landscape area within the Mooghaun Landblock than previously investigated. The palaeoenvironmental record demonstrated that the lack of Neolithic visibility in the archaeological record was due to the scarcity of human activity within the landscape in early prehistory and was not a result of archaeological bias, or the small catchment areas of previous palaeoenvironmental studies. The new data has also corroborated interpretations that highlight the increasing importance of this landscape in later prehistory, and particularly in the Late Bronze Age (e.g. Grogan, 2005a; 2005b).

In contrast, the new data provided by palaeoenvironmental analysis of lake sediment from Lough Inchiquin has allowed the existing narrative for this area to be further developed. The new pollen data has provided a record of land-use at a higher spatial resolution than previous pollen studies, allowing for an interpretation of human activity and landscape change over a wider area of the Burren. A major finding of this research has been the large-scale Late Bronze Age activity suggested by the palaeoenvironmental data that is not indicated by the archaeological record. Although there may have been a decrease in activity in certain areas of the Burren in the Late Bronze Age (Thompson, 1997; Feeser, 2009) this new data suggests that the intensity of farming activity in this period increased significantly over much of the region. The low dispersal capacity of anthropogenic pollen indicators and the combined palaeolimnological data, that demonstrates localised farming activity in the Late Bronze Age which had a significant impact on the lake system, suggests that the activity detected was likely intensive and concentrated in the landscape surrounding Lough Inchiquin at this time.

The archaeological invisibility of this period in the Burren led to interpretations that suggested the reduced importance of this significant early prehistoric landscape into the Late Bronze Age (Grogan, 1996; 2005b; Grogan and Condit, 2000). Together with the increased archaeological visibility of the Late Bronze Age in the Mooghaun Landblock this led to the suggestion that the later prehistoric period saw a potential shift in settlement from the northern uplands of Co. Clare, namely the Burren, to the more low-lying landscape of south-east Co. Clare potentially due to the over-exploitation of land (Grogan, 1996). The new data, while it does highlight an episode of soil erosion from the Burren, does not support this interpretation, with the most intensive agricultural activity taking place in the Late Bronze Age. This is counter to the widely accepted archaeological narrative of the Burren in which, even when potential Bronze Age sites were considered, as in Grogan and Condit (2000), the most intensive activity from the archaeological record was still proposed to be during the Chalcolithic. The suggestions made by Jones et al. (2010) of a changed use of the Burren landscape in the Late Bronze Age, focused on producer pastoralism for a power-base in the Lower Shannon region (inclusive of the Mooghaun Landblock), would better correspond with the new palaeoenvironmental data.

While artefactual evidence, e.g. the Gleninsheen gorget, suggests that the Burren was incorporated into a wider network of political alliances with south-east Co. Clare, the palaeoenvironmental data alone cannot elucidate this further. Similarly, issues of seasonality or the political intention behind this increased agricultural productivity cannot be determined from the new data. What is clear from the data, however, is that both regions of Co. Clare became increasingly more agriculturally important throughout prehistory, culminating in a large-scale intensive human occupation of both regions in the Late Bronze Age. As such this new research suggests that the Late Bronze Age of the Burren should, in fact, be a priority for future archaeological research and three potential areas of Late Bronze Age focus have already been discussed – the Carran Plateau, Teeskagh and Turlough Hill.

This study has also highlighted the advantages of palaeoenvironmental investigations that employ multiple proxies, with chironomid sub-fossil analysis, and organic and inorganic geochemistry analyses having been undertaken on the sediment from Lough Inchiquin in addition to palynology. The incorporation of this palaeolimnological data has added another dimension to the interpretation of Late Bronze Age activity. The impact upon the lake system itself was shown to be significant in this period with the chironomid data responding to an increase in nutrients, causing the lake to become more eutrophic and an increase in the abundance of eutrophic chironomid taxa, with $\delta^{15}N$ levels consistent with agriculturally impacted lake systems (Woodward et al., 2012; Potito et al., 2014). Despite the large size of Lough Inchiquin, and the hydrologically open system meaning that the pollen signal may be regional, the results of the palaeolimnology have demonstrated localised and within-lake change linked to human activity at the lakeside. This suggests that despite the paucity of archaeological remains dated to the Late Bronze Age in the immediate vicinity of the lake, Late Bronze Age communities utilised this landscape and there is the potential for remains to be found.

This multi-proxy approach has also allowed for another major finding of this research project – that of substantial soil erosion from the Burren uplands from the Late Neolithic to Early Bronze Age. This was discovered through the incorporation of inorganic geochemistry which highlighted a period of increased titanium in the sedimentary record – with titanium commonly used as an indicator of erosion, as previously discussed (e.g. Koinig et al., 2003; Arnaud et al., 2012). The Burren is one of the best examples of a karst landscape in the world and its development has been the focus of past research (Drew, 1983; Moles and Moles, 2002; Moles et al., 1999). While there is evidence for soil movement in the glacial period there is little known about this process in the Holocene despite a consensus that it was during this period that erosion led to the current landscape, largely devoid of deep soil cover (Moles and Moles, 2002; Moles et al., 1999; Drew, 1983; Jeličić and O'Connell, 1992). Research in the 1990s by Thompson (1997) and Moles et al. (1999) highlighted periods of prehistoric soil erosion that have already been discussed in the context of this research. In both cases, at Molly's Lough and at Knockanes Mountain, erosion was most significant in the later Bronze Age (Thompson, 1997; Moles et al., 1999). The Inchiquin data represents the most recent investigation into soil erosion from the Burren uplands which is suggested to have occurred from the Late Neolithic – Early Bronze Age. As such, the new data from Lough Inchiquin represents some of the earliest, well dated evidence for soil erosion from the Burren uplands. The data suggests that the process began early in the farming regime and corresponds well with the intensive farming phase on Roughan Hill indicated both by the habitation sites and palaeoenvironmental data (Figure 10.1).

To conclude, the new data has allowed for a re-assessment of the existing archaeological narrative of the prehistory of Co. Clare by examining lake sediment material providing a continuous record of human activity in the landscape. It has allowed for the development of new perspectives on the intensity, timing and dynamics of settlement and subsistence between the two research areas. Specifically, the suggestion of a shift in human occupation from north to south-east Co. Clare has been rejected and the importance of both areas in the Late Bronze Age has been highlighted bringing into focus the need for further archaeological research in this area. Significantly, major soil erosion from the Burren uplands has been identified at an early stage in the long history of human-environment interactions in this area, highlighting the sensitivity of Burren soils to farming activity, and the impact that prehistoric communities had on this landscape.

Figure 10.1: The view from Roughan Hill, an area of intensive prehistoric occupation, to Lough Inchiquin, where significant evidence of soil erosion from the Burren uplands has been identified. Source: author.

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