Environmental Change and Human Impact during the Mesolithic-Neolithic Transition in North-West Europe

A thesis submitted to the University of Manchester for the degree of Doctor of Philosophy in the Faculty of Humanities

2014

Sarah Elizabeth Kneen

School of Environment, Education and Development
Contents

Chapter 1. Introduction 12

Chapter 2. Literature Review 14
2.1 The Mesolithic-Neolithic Transition 14
2.1.1 Motivating or forcing factors of change 17
2.2 Late Mesolithic human impact 19
2.2.1 Distinguishing between anthropogenic and natural disturbances 19
2.2.2 Avoiding preconceptions in interpretation 21
2.2.3 Models of late Mesolithic land use 22
2.2.4 A new methodological approach 25
2.3 The role of climatic and environmental conditions on the Mesolithic-Neolithic transition 26
2.3.1 Mid-Holocene climate change 26
2.3.2 A potential link between climate and the cultural landscape? 27
2.3.3 Difficulties encountered in the study of climate and the cultural landscape 30
2.4 Summary and Research Gaps 32

Chapter 3. Research Aims 34
3.1 Aim 34
3.2 Objectives 34

Chapter 4. Site Selection 36
4.1 Regional site selection 36
4.2 Local site selection 36
4.2.1 Britain 36
4.2.1.1 Regional context 36
4.2.1.2 Local context 37
4.2.2 Southern Sweden 40
4.2.2.1 Regional context 40
4.2.2.2 Local context 41

Chapter 5. Methodology 45
5.1 Field coring strategy 45
5.2 Stratigraphic description 45
5.3 Loss-on-ignition 46
5.3.1 Theory 46
5.3.2 Laboratory method 46
5.4 Peat humification 46
5.4.1 Theory 46
5.4.2 Laboratory method 47
5.5 Inorganic Geochemistry 48
5.5.1 Theory 48
5.5.2 Laboratory method 49
5.5.2.1 Sample preparation 49
5.5.2.2 Testing the level of accuracy of the FP-XRF
5.5.2.3 Time series analysis to identify optimum count-time
5.5.2.4 Testing precision down-core
5.5.2.5 Data presentation
5.6 Pollen
5.6.1 Theory
5.6.2 Laboratory method
5.7 Non-pollen palynomorphs
5.7.1 Theory
5.7.2 Laboratory method
5.8 Charcoal analysis
5.8.1 Theory
5.8.2 Laboratory method
5.8.2.1 Micro-charcoal analysis
5.8.2.2 Macro-charcoal analysis
5.9 Chronology
5.9.1 AMS radiocarbon dating
5.9.1.1 Theory
5.9.1.2 Laboratory Method
5.9.2 Age-depth modelling

Chapter 6. March Hill Results
6.1 Preliminary fieldwork
6.2 Dan Clough Moss
6.2.1 Stratigraphy
6.2.2 Sampling strategy
6.2.3 Chronology
6.2.3.1 Radiocarbon dating
6.2.3.2 Age-depth modelling
6.2.4 Palaeoecological results
6.2.4.1 Description of pollen stratigraphic zones
6.2.4.2 Environmental interpretation of the Dan Clough Moss data
6.2.4.3 Episodes of woodland disturbance

Chapter 7. Bökeberg Results
7.1 Preliminary fieldwork
7.2 Bökeberg core
7.2.1 Stratigraphy
7.2.2 Chronology
7.2.2.1 Radiocarbon dating
7.2.2.2 Age-depth modelling
7.2.3 Palaeoecological analysis of Bökeberg
7.2.3.1 Lower-resolution palaeoeological results
7.2.3.1.1 Description of the lower-resolution pollen stratigraphic zones
7.2.3.1.2 Environmental interpretation of the lower-resolution Bökeberg data
7.2.3.1.3 Disturbances identified in the lower-resolution palynological record
7.2.3.2 Mesolithic high resolution analyses
7.2.3.2.1 Description of pollen stratigraphic zones
7.2.3.2.2 Environmental Interpretation of the high resolution Mesolithic data
7.2.3.3 Neolithic high resolution analyses
7.2.3.3.1 Description of pollen stratigraphic zones
7.2.3.3.2 Environmental Interpretation of high resolution Neolithic data

Chapter 8. Dan Clough Moss Discussion
8.1 Human impact on the environment across the Mesolithic-Neolithic transition
8.2 How the nature of human impact changed across the Mesolithic-Neolithic transition
8.3 The influence of changing environmental conditions upon the nature of human impact
8.4 Summary

Chapter 9. Bökeberg Discussion
9.1 Human impact on the environment across the Mesolithic-Neolithic transition
9.2 How the nature of human impact changed across the Mesolithic-Neolithic transition
9.3 The influence of changing environmental conditions upon the nature of human impact
9.4 Summary

Chapter 10. Conclusions
10.1 Review of Methodology
10.2 Research Aims and Objectives
10.2.1 Objectives
10.3 Future research into the Mesolithic-Neolithic transition

Chapter 11. Bibliography

WORD COUNT: 47,281
List of figures

4. Site Selection
   4.1 – Typical typology of Mesolithic archaeological sites in the vicinity of March Hill. 38
   4.2 – Location of Mesolithic and Neolithic finds in the Lake Yddingesjön area, with Bökeberg III excavations highlighted. 42

5. Methods
   5.1 – Silicon concentration measurements at a range of count times from Dan Clough Moss, with corresponding percentage error. 50
   5.2 – Titanium concentration measurements at a range of count times from Dan Clough Moss, with corresponding percentage error. 51
   5.3 – Silicon concentration measurements at a range of count times from Bökeberg, with corresponding percentage error. 51
   5.4 – Titanium concentration measurements at a range of count times from Bökeberg, with corresponding percentage error. 52
   5.5 – Down-core variability in FP-XRF derived silicon and titanium concentrations at Dan Clough Moss, including max and min values for each sampling point. 53
   5.6 – Down-core variability in FP-XRF derived silicon and titanium concentrations at Bökeberg, including max and min values for each sampling point. 53
   5.7 – Plant fraction of sample Beta-336993 used for AMS radiocarbon dating at Dan Clough Moss. 63

6. March Hill Results
   6.1 – Location of preliminary boreholes around March Hill. 67
   6.2 – Results of preliminary pollen analyses on basal peat samples, expressed as %TLP (total land pollen). 69
   6.3 – Age-depth model for Dan Clough Moss. Position is depth of the centre of the sample in mm below the peat surface. Modelled date (BP) is the calibrated, modelled age range at each depth, dark blue representing 68.2% uncertainty (1σ), and lighter blue 95.2% (2σ). 72
   6.4 – Dan Clough Moss pollen diagram with frequencies calculated as percentages of the pollen sum (TLP excluding Alnus). 74
   6.5 – Dan Clough Moss spore, charcoal, selected NPP and XRF diagram. Spores calculated as percentages of the pollen sum (TLP excluding Alnus), charcoal expressed as influx per unit volume per year, NPPs calculated as percentages of the total NPP sum, and Silicon and Titanium expressed as influx per unit volume per year. 75
   6.6 – Dan Clough Moss selected NPP and peat humification diagram. NPPs calculated as percentages of the total NPP sum, and peat humification expressed as percentage light transmission. 76

7. Bökeberg Results
   7.1 – Location of Bökeberg borehole in relation to known Mesolithic and Neolithic archaeology, and present peat deposit extent. Adapted from Regnell et al. (1995). 102
   7.2 – Selection of macro-fossils used for AMS radiocarbon dating for Bökeberg. 104
   7.3 – Age-depth model for Bökeberg. Position is depth of the centre of the sample in mm below the peat surface. Modelled date (BP) is the calibrated, modelled age range at each depth, dark blue representing 68.2% uncertainty (1σ), and lighter blue 95.2% (2σ). 105
   7.4 – Bökeberg lower-resolution (10mm) pollen diagram, with frequencies expressed as percentages of the pollen sum (TLP excluding Alnus). The depths on this diagram covered by 108
high-resolution pollen diagrams (Figs. 7.6 to 7.9) are shown by annotated boxes.
7.5 – Bökeberg lower-resolution (10mm) charcoal, NPP and XRF diagram. Charcoal is expressed as a concentration per unit volume, NPPs as a percentage of total NPPs, and silicon and titanium as a concentration per volume. The depths on this diagram covered by high-resolution pollen diagrams (Figs. 7.6 to 7.9) are shown by annotated boxes.
7.6 – Bökeberg Mesolithic high resolution pollen diagram, with frequencies expressed as percentages of the pollen sum (TLP excluding Alnus).
7.7 – Bökeberg Mesolithic high resolution charcoal, NPP and XRF diagram. Charcoal is expressed as a concentration per unit volume, NPPs as a percentage of total NPPs, and silicon and titanium as a concentration per volume.
7.8 – Bökeberg Neolithic high resolution pollen diagram, with frequencies expressed as percentages of the pollen sum (TLP excluding Alnus).
7.9 – Bökeberg Neolithic high resolution charcoal, NPP and XRF diagram. Charcoal is expressed as a concentration per unit volume, NPPs as a percentage of total NPPs, and silicon and titanium as a concentration per volume.

8. Dan Clough Moss Discussion
8.1 – Summary human impact diagram for Dan Clough Moss. Proxies expressed as in Figs. 6.4 to 6.6.
8.2 – Canonical Correspondence Analysis of major pollen types, with micro-charcoal, macro-charcoal and percentage light transmission as environmental variables.
8.3 – Summary human impact and bog surface wetness diagram. Proxies expressed as in Figs. 6.4 to 6.6.

9. Bökeberg Discussion
9.1 – Summary human impact diagram for Bökeberg. Proxies as expressed in Figs. 7.4 and 7.5.
9.2 – Summary human impact, bog surface wetness and lake level fluctuation diagram. Proxies expressed as in Figs. 7.4 and 7.5.
List of tables

5. Methods
5.1 – Simplified land cover classes and associated pollen taxa (modified from Brown et al. 2007). 57
5.1 – Range of depositional models with their OxCal keywords (adapted from Bronk Ramsey, 2008). 65

6. March Hill Results
6.1 – Stratigraphy of preliminary boreholes. 68
6.2 – Proportions of Ulmus in basal peat samples, expressed as %TLP (total land pollen) and %APC (AP=trees C=Corylus + Salix). 70
6.3 – Radiocarbon determinations for Dan Clough Moss. Calibrations were made using IntCal13 (Reimer et al. 2013) in OxCal 4.2 (Bronk Ramsey, 2009a). 71
6.4 – Modelled sample resolution for Dan Clough Moss. 71
6.5 – Key characteristics of three periods of woodland disturbance identified from the Dan Clough Moss palynological record. 100

7. Bökeberg Results
7.1 – Stratigraphy of sediment core from Bökeberg. 103
7.2 – Radiocarbon determinations for Bökeberg. Calibrations were made using IntCal13 (Reimer et al. 2013) in OxCal 4.2 (Bronk Ramsey, 2009). 104
7.3 – Modelled low-resolution (10mm) sample resolution. 106
7.4 – Modelled high-resolution (5mm) sample resolution. 106
7.5 – Key characteristics of five episodes of disturbance identified from the lower-resolution analyses at Bökeberg. 118
Abstract

The aim of this thesis is to investigate the environmental changes across the Mesolithic-Neolithic transition (c.7000-5000 cal BP) at two sites in north-west Europe. Specific research questions focus on the role of fire, the interaction of climate and environmental change and human impacts, and the degree of continuity across the transition. Previous work has led to hypotheses of human impacts in the late Mesolithic, usually through the use of fire, increasing the abundance of food. Detection of these practices and the change to farming in the Neolithic has long been the study of pollen analysts, but in this project additional techniques of NPPs, size-class differentiated charcoal, and silicon and titanium were added at high resolution in order to determine the relationships between the different forcing factors on mid-Holocene environments.

Sites were selected close to locations where known later Mesolithic artefacts have been found, with dated archaeological excavations. An upland UK bog site (Dan Clough Moss, near March Hill, West Yorkshire) and a lowland Swedish lake (Bökeberg, Skåne) provided contrasting environments, and enabled a range of proxies to be used from terrestrial peat and limnic sediments. ¹⁴C dates from selected macrofossils enabled an age-depth curve to be produced from each profile, with a Bayesian model applied to estimate the age of each sample.

Results show a detailed record of woodland change from both areas. At Dan Clough Moss, disturbance phases with evidence of local fires occur frequently (typically every 20-30 years) in the late Mesolithic, and have low magnitude but consistent records of coprophilous fungi. Some phases of disturbance are different however, without the fungal spore evidence, and with heath plants increasing in representation. Drier phases appear to correlate with more local fire, and increased hazel. The transition is marked by a change to longer duration but distant fires, and longer periods of woodland disturbance, increased ruderal species and more heathland. The dates of occupation phases show a late survival of Mesolithic practices, overlapping with the Neolithic by around 300 years.

At Bökeberg, a contrasting pattern is shown, with longer-duration phases of inferred human impact being replaced by shorter episodes of fire-associated disturbance after the date of the transition. Pollen and spore zones of disturbance concur with the dated occupation of late Mesolithic sites at the former lake edge. There is some evidence for markedly wetter, and then significantly drier, climate through the transition, and it could be inferred that this influenced the change in food production economies. However, the overall landscape changed only subtly, with more evidence of potential weeds of cultivation. At Bökeberg, there was no overlap- both radiocarbon and palynology suggest an abrupt transition from Mesolithic to Neolithic.

The landscape impact of the transition from Mesolithic to Neolithic at both sites was not a clear and consistent one. While Ulmus decline levels and thereafter had increases in weed species and other herbs the overall balance of trees and shrubs changed less than 20%. At both sites, climate may have been influential, although the evidence is inconclusive. Fires were important at both sites and in both periods, but at different scales and duration. Disturbance phases varied within the Mesolithic as well as between the Mesolithic and the Neolithic.
Declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or institute of learning.

Sarah Elizabeth Kneen
Copyright Statement

i) The author of this thesis (including any appendices and/or schedules to this thesis) owns certain copyright or related rights in it (the “Copyright”) and s/he has given The University of Manchester certain rights to use such Copyright, including for administrative purposes.

ii) Copies of this thesis, either in full or in extracts and whether in hard or electronic copy, may be made only in accordance with the Copyright, Designs and Patents Act 1988 (as amended) and regulations issued under it or, where appropriate, in accordance with licensing agreements which the University has from time to time. This page must form part of any such copies made.

iii) The ownership of certain Copyright, patents, designs, trademarks and other intellectual property (the “Intellectual Property”) and any reproductions of copyright works in the thesis, for example graphs and tables (“Reproductions”), which may be described in this thesis, may not be owned by the author and may be owned by third parties. Such Intellectual Property and Reproductions cannot and must not be made available for use without the prior written permission of the owner(s) of the relevant Intellectual Property and/or Reproductions.

iv) Further information on the conditions under which disclosure, publication and commercialisation of this thesis, the Copyright and any Intellectual Property and/or Reproductions described in it may take place is available in the University IP Policy (see http://documents.manchester.ac.uk/DoculInfo.aspx?DocID=487), in any relevant Thesis restriction declarations deposited in the University Library, The University Library’s regulations (see http://www.manchester.ac.uk/library/aboutus/regulations) and in The University’s policy on Presentation of Theses.
Acknowledgements

I would like to thank my supervisors Prof. Jeff Blackford, Dr. Peter Ryan and Dr. William Fletcher for four years of support, advice and help bringing this thesis together.

The School of Environment and Development, University of Manchester provided a scholarship for three years, and additional fieldwork and conference support was awarded by the Royal Geographical Society, Quaternary Research Association, Manchester Geographical Society, Manchester Doctoral College and Association for Environmental Archaeology, for which I am very grateful.

This work could not have been undertaken without the kind permission of the landowners for access to the sites, and thanks are due to Dr. Penny Spikins (University of York) and Dr. Mats Regnell (Stockholm University) for their advice and assistance with respect to March Hill and Bökeberg respectively. Fieldwork assistance from Prof. Jeff Blackford, Dr. Peter Ryan, Dr. William Fletcher, Dr. Mats Regnell and Dr. Catherine Jessen is gratefully acknowledged.

Dr. Christine Lane and Joanne Egan gave up valuable time to discuss the use of OxCal and interpretation of the age-depth model results, and Dr. Charlotte O’Brien (Durham University) and Dr. Barry Taylor (University of Chester) provided kind assistance in macrofossil identifications. Many thanks go to Emma Shuttleworth who helped in the development of the x-ray fluorescence methodology for this project.

Thanks also go to Dr. Jason Dortch for his never ending support, cheerfulness, high-fives, and bright hair; Dr. Chris Davies for the happy memories of two unforgettable trips to Iceland with a great bunch of undergraduate students in 2012 and 2013; and Dr. Beth Cole for her motivating words towards the culmination of this project. Ioanna Tantanasi, our coffee breaks together fuelled a lot of this work, as did Jennifer Ferreira’s magnificent cake creations and unexpected deliveries of posh chocolates just when you needed them (thank you!). A huge thank you must also go to Danielle Alderson for her selfless support over the last twelve months – I will pay you back in three years time I promise (it’s sooner than you think!).

A final thank you must go to my family, and to my partner Liam. All of your tireless and unconditional support and encouragement has been really appreciated over the last few years - I don’t think I would have been able to do this without you.
1. Introduction

The Mesolithic-Neolithic transition of north-west Europe is regarded as an important period of cultural and economic change. Traditionally associated with a move from hunter-fisher-gathering to mixed farming as the dominant mode of subsistence, changes in lifestyle, settlement pattern and demography were also proposed to have occurred. Groups would become gradually less mobile and more socially complex, developing social hierarchies and competition amongst groups, and initialising new ritual and burial practices (Armit and Finlayson, 1992).

Mesolithic groups have often been seen as ‘passive’ to their environment (Iversen, 1973), with little anthropogenic modification and impact upon their environment until large scale clearance and utilisation of the land from Neolithic times onwards (Iversen, 1941; Rackham, 1988). The role that Mesolithic and Neolithic cultures played as agents of environmental change however remain unconstrained, as increasingly the view of a ‘simple’ Mesolithic and ‘advanced’ Neolithic is criticised in the light of new archaeological, palaeoecological, chronological and anthropological evidence. Regionally distinctive transitions are identified in terms of the mechanisms, timing and rate of change, with evidence often revealing the full diversity of the hunter-gatherer culture and their successful adaptability to the local environment and available resources (Rowley-Conwy, 1986; Armit and Finlayson, 1992; Innes and Blackford, 2003; Blankholm, 2008).

Woodland disturbances are observed in the pollen records of a number of sites across north-western Europe, and evidence of pre-Neolithic cultivation and the purposive use of fire to benefit hunting and foraging resources seem to suggest that humans prior to the Neolithic ‘revolution’ became significant active agents in the environment (Tolan-Smith, 2008), manipulating and disturbing their environment much earlier than previously thought.

This apparent increase in Mesolithic complexity has important implications for the role that indigenous hunter-gatherers played in the transition to agriculture. The mechanisms behind the spread of farming and associated traits such as pottery making and sedentary lifestyles in the transition to Neolithic are still hotly debated (e.g. Sheridan, 2010; Thomas, 2008; Whittle et al 2011). Childe (1928) and Sheridan (2004; 2007; 2010) argue for the arrival of a ‘Neolithic package’, including domesticated plants, animals and new forms of architecture via a process of demic diffusion, where an influx of Neolithic farmers replaced
the indigenous population and their practices. An alternative viewpoint is that aspects of
the Neolithic culture were gradually adopted by indigenous hunter-gatherers, through a
cultural diffusion of ideas and practices over time, often depending on their societal and

The role of environmental conditions or climatic shifts upon the transition to Neolithic has
been highlighted by numerous authors (Bonsall et al. 2011; Tipping and Tisdall, 2004), with
a climatic amelioration, deterioration or increased instability suggested as motivations
behind the transition. At present the various palaeoenvironmental and palaeoclimatic
proxies available for this period appear not to be of sufficient chronological resolution to
address the question of synchronicity at this scale.

There is support for the existence of ‘persistent places’ in the late Mesolithic, where the
material culture and lifeways of the Mesolithic continued in an area which had been a key
focus for hunter-gatherer activity, for some time after the earliest appearance of Neolithic
material culture in other areas (Griffiths, 2014). This reinforces the idea that the transition
was not a sudden ‘event’, and that areas responded differently depending on the cultural
or economic importance of the existing Mesolithic lifeways, and the suitability of the
landscape for adoption of Neolithic practices.

Despite significant research effort, the processes of change during the Mesolithic-Neolithic
transition of north-west Europe remain poorly understood. There is still debate as to the
true extent of late Mesolithic human impact on the landscape, with the magnitude,
frequency and origin of inferred anthropogenic manipulation of the woodland often
contested (Simmons and Innes, 1987; Brown, 1997; Mason, 2000; Innes and Blackford,
2003; Soepboer and Lotter, 2009), and cereal-type pollen found in contexts prior to any
sign of Neolithic archaeology often argued to simply reflect large wild grass pollen (Behre,
2007; Brown, 2007). Difficulties correlating climate records of a different scale and
resolution to palaeoecological records are also limiting the investigation into a climatic or
environmental influence over the transition.

This thesis aims to address these issues by investigating both the changing nature of human
impact through the transition using high-resolution multi-proxy palaeoecology, and the
relative roles of climatic change, natural events and human impacts by utilising local
records of environmental change.
2. Literature Review

The aims of this chapter are to review the archaeological and palaeoecological context of the Mesolithic-Neolithic transition in north-west Europe, to explore models of late Mesolithic complexity and purposive manipulation of the environment, and to investigate the role environmental change may have played on the transition to fully Neolithic societies.

2.1 The Mesolithic-Neolithic Transition

Neolithic agricultural economies, with their domesticated animals and plants such as wheat, barley, pulses, flax, cattle, pigs, sheep and goat (Zohary and Hopf, 1993), spread from the Near East to Greece by c.9000 cal BP, reaching present-day Hungary by c.7450 cal BP (Price, 2000). Here the Linearbandkeramik (LBK) culture appeared, and spread rapidly across Europe in a westward direction, finally reaching and being adopted by most of continental by around 7000 cal BP (Price, 2000).

The first attempt to conceptualise the transition to agriculture came from Childe (1925), who suggested a process of demic diffusion whereby farmers would have moved into a region with an indigenous Mesolithic population, bringing not just domesticated plants and animals, but a ‘Neolithic package’ including increased sedentism, burial rituals, pottery, and new forms of architecture. Sheridan (2004; 2007; 2010a,b) stresses the continental context for many of the novel features of the Neolithic package, supporting a model of direct colonisation as the mechanism for change. As farming would have supported a much larger population density than hunter-gathering, farming populations would have increased at a much greater rate ‘squeezing out’ the indigenous population as increasing amounts of land would have been used for farming. Demic diffusion implies subsequent genetic homogeneity (Cohen, 1992; Gkiasta et al. 2003), and is supported by studies using DNA as a tracer of past populations and domesticates which have found a number of Neolithic humans and domesticated animals such as pigs to have Near East ancestry (Larson et al. 2007). Support also comes from attempts to quantitatively model the Mesolithic-Neolithic transition (Pinhasi et al. 2005) which estimated the rate of spread across Europe at 0.6-1.3 km/yr, consistent with that of demic diffusion (0.6-1.1km/y). Under this model, indigenous hunter-gatherers played no role in the transition to agriculture, powerless to resist its continuous advance (Zvelebil, 1986; Williams, 1989).
The demic diffusion model however has faced critique. Increasingly, the notion of the transition as an ‘instantaneous flip’ from Mesolithic to Neolithic lifeways is brought into question in the light of new high resolution palaeoecological evidence and improved chronological frameworks, which are revealing the true diversity and complexity of late Mesolithic societies in north-west Europe, and their successful adaptability to the local environment and available resources (Rowley-Conwy, 1986; Armit and Finlayson, 1992; Innes and Blackford, 2003; Blankholm, 2008). This increased complexity and potential population density may have meant that late Mesolithic hunter-gatherers were perhaps in a good position to resist colonisation by migrating farmers (Dennell, 1985), disproving the traditional view that Mesolithic societies were ‘passive’, mobile, opportunistic, incapable of transforming their way of life, and easily ousted by newcomers (Zvelebil, 1986).

Radiocarbon evidence suggests that whilst the spread of Linearbandkeramik (LBK) farming culture across Europe from Hungary c.7450 cal BP was rapid, it ended abruptly at the Atlantic and Baltic coast of north-west Europe (Bogucki, 1998) where established farming communities remained static for around a further 1000 years before expansion into Britain and Scandinavia (Price, 2000). This delay in the adoption of farming may have been due to the existence of complex late Mesolithic societies along the Atlantic and Baltic coasts, who may have had no desire or need to adopt a new way of life.

An example of such socially and economically complex hunter-gatherer culture is the Ertebølle of southern Scandinavia. Rowley-Conwy (1983; 1984; 1998) reported that the existence of several small, resource-specific exploitation camps visited on a temporary basis, and larger, more permanently occupied base camps, represented these Ertebølle sites. Pottery existed, suggesting an increasingly sedentary lifestyle, with an increased attachment to specific locations demonstrated by the presence of Ertebølle cemeteries (Rowley-Conwy, 1998). Hunter-gatherer technology was more complex, using intensive subsistence methods such as fish traps and the seasonal scheduling of the exploitation of resources (Rowley-Conwy, 1984). It has hence been suggested that such groups would have been able to cope with short-term resource shortages, making it likely that they would be able to resist colonisation by the first farmers (Rowley-Conwy, 1998; Zvelebil, 1998). At least in Britain and Ireland, this late Mesolithic complexity is suggested to manifest itself in purposive woodland manipulation in order to improve the supply of wild plant foods and hunting success (e.g. Simmons, 1975a+b; Jacobi et al, 1976; Zvelebil, 1994; Innes and Blackford, 2003). Due to the ecological effects of fire, observed charcoal records of
repeated burning throughout the later Mesolithic are presumed to have produced far more productive habitats, increasing the range and quantity of edible plant foods such as nuts and berries (Zvelebil, 1994), and increasing the grazing and browsing resources for game and wild animals, thereby improving hunting success (Mellars, 1975; 1976). The identification of a number of cereal-type pollen grains in pre-elm decline contexts (Hirons, 1983; Williams, 1985; Innes et al, 2003a) may also be interpreted as the possible adoption of agriculture before the arrival of fully Neolithic lifeways (Simmons and Innes, 1987).

There is also evidence of contact and exchange during this 1,000 year period of stasis in the spread of Neolithic lifeways across Europe. Artefacts that seem ‘exotic’ and associated with the Neolithic culture, such as pottery, shoe-last wedges, flat-pick axes and T-shaped antler axes have been found in Ertebølle contexts (Price and Gebauer, 1992; Regnell et al. 1995), suggesting contact between the Ertebølle hunter-gatherers of southern Scandinavia and Neolithic farmers further south. Domesticated animal bones have been found in Mesolithic contexts such as Ferriter’s Cove, Co. Kerry (Woodman et al. 1999), although the origin, date and actual species of this find have been questioned subsequently (Woodman 2009).

A potential trade network across the English Channel and Baltic Sea connecting Late Mesolithic societies with farming populations on the continent, and the evidence for gradual incorporation and adoption of Neolithic tendencies and practices by Mesolithic groups over a long period of time has led to the theory that the Mesolithic-Neolithic transition occurred due to a process of cultural diffusion or ‘indigenous adoption’, a model championed by Thomas (2003; 2004; 2007; 2008). Novel techniques such as animal husbandry and small-scale cereal growing are proposed to have been added to the traditional hunter-gatherer resources base over a lengthy phase of interaction, in places extending over 800 years (Zvelebil and Rowley-Conwy, 1986; Innes et al, 2003; Innes et al. 2009), and as a result nearly all aspects of the Neolithic subsistence economy were a continuation of advanced late Mesolithic practices (Andersen, 1991; Armit and Finlayson, 1996; Thomas, 2007). Zvelebil and Rowley-Conwy (1984) described this process in their ‘availability model’ which involved three stages for the adoption of agriculture - ‘availability’, ‘substitution’ and ‘consolidation’. The availability phase where Neolithic methods and techniques would have been known to Mesolithic groups is thought to be substantial in duration, followed by a substitution phase where aspects or techniques of the new culture were gradually adopted. The subsequent consolidation phase saw Neolithic culture and practices dominate (Zvelebil and Rowley-Conwy, 1984).
2.1.1 Motivating or forcing factors of change

The increased sedentism and socio-economic complexity of these highly adaptable late Mesolithic societies may have led them to become pre-adapted to the adoption of farming, allowing an easy transition to the Neolithic culture (Binford, 1983). With reference to Britain, Jacobi (1979) stated that the social organisation of societies that existed in the late Mesolithic would have allowed them to make a substantial contribution to the initiation of farming. The pioneering phase of farming would have contained a substantial Mesolithic component, with most initial farming settlements found in regions where most sedentary Mesolithic groups had already developed due to year-round abundant resources in the local vicinity, for example on the coast (Woodman, 2000).

Zvelebil and Rowley-Conwy (1984; 1986) suggested that in order for societies to progress through the three phases of their model, there must either have been a perceived advantage of the use of agriculture, or a crisis in the availability of the original resources they relied upon. If population growth accelerated significantly enough during the economically successful late Mesolithic period, this may have led to depleted resources and a population-resources imbalance forcing Mesolithic groups to seek more intensive means of food production such as agriculture (Binford, 1968; Cohen, 1981). Research has since highlighted that this was probably not the case, with Fischer (2002) arguing that, at least in southern Scandinavia, there is evidence for large base camps with inferred large populations since the middle Mesolithic (Larsson, 1980), yet no contemporaneous evidence of agriculture, and many transitions to farming around north-west Europe took place in resource-abundant societies (Cohen and Armelagos, 1984; Mithen, 1996; Fernandez-Armesto, 2001). Wirtz and Lemmen (2003) in their global model of the Mesolithic-Neolithic transition found that rather than population pressure it was continuous innovation and competition between subsistence strategies that was the prime mover for the development of agriculture. At least in some regions, expanding populations causing resource stress were therefore not the trigger of the transition to the Neolithic. Resource stress however may have arisen from increased specialisation of subsistence practices in the late Mesolithic, perhaps as a product of increasing competition for space and resources, and an over-reliance on a smaller range of resources may have left societies vulnerable to fluctuations in the resource base (Simmons and Innes, 1987; Zvelebil, 1990).

Considering the importance of demographic and social factors upon the transition to the Neolithic, a clear understanding of the influence and significance that environmental
conditions and the physical environment had upon the transition is lacking. Attempts to model the transition across Europe have identified a relationship between local environmental conditions and the timing of the Mesolithic-Neolithic transition, with a non-linear geographical spread potentially favouring areas along major river paths and coastlines due to easier human mobility or an increased carrying capacity of the land (Zvelebil, 1986; Davison et al. 2006). It has also been suggested through models that hunter-gatherers survived in regions where environmental conditions did not favour longer growing seasons and the adoption of farming (Patterson et al. 2010), supporting Lageras (1996) and Bonsall et al.’s (2001) model that it took a shift to drier, more continental type conditions to facilitate the transition to agriculture as this enabled soils to be more viable in maritime areas of Europe (Lageras, 1996; Bonsall et al. 2001). Earlier attempts at agriculture by Mesolithic groups were not ruled out, but it was suggested that it was not the dominant subsistence method until after the shift in climatic conditions. Other theories include ecological conditions deteriorating during the late Mesolithic, and the resulting resource stress, or even just perceived uncertainty or vulnerability, may have made Mesolithic groups more receptive to innovation and motivated them to adopt new lifeways (Tipping and Tisdall, 2004).

Given the potential of environmental conditions and their associated level of resources to influence not only the type of economy that prevailed but the location and spread of the ‘agricultural frontier’, the fact that north-west Europe is so ecologically diverse means it is perhaps not surprising that the Neolithic was adopted in different areas, at different times and in different ways (Zvelebil and Rowley-Conwy, 1986).

While debate remains over whether the eventual transition to the Neolithic was primarily due to ecological, economic or social factors, or a combination of the three, it appears that the transition was not a ‘sudden’ event and that people in different areas responded differently, depending on the cultural or economic importance of the existing Mesolithic practices, and the suitability of the landscape for adoption of Neolithic practices. Two distinct themes therefore emerge as factors which require further investigation to better understand the Mesolithic-Neolithic transition of north-west Europe: the increasing sophistication and complexity of Late Mesolithic groups, and climatic and environmental conditions across the transition.
2.2 Late Mesolithic human impact

Palaeoecological and archaeological studies are increasingly revealing the full diversity of the Mesolithic hunter-gatherer culture of north-west Europe, and their successful adaptability to their local environment and available resources (Rowley-Conwy, 1986; Armit and Finlayson, 1992; Innes and Blackford, 2003; Blankholm, 2008). The majority of records suggest that humans may have played a potentially significant role in structuring the late Mesolithic woodland and landscape, and had more of an impact on the environment than previously thought.

Woodland disturbance is a common feature identified in palynological studies of the late Mesolithic, often represented by a decline in arboreal pollen, and an increase in pioneer and secondary woodland taxa together with indicators of open or disturbed ground. These disturbances would have created landscape mosaics as a result, with a variety of successional plant communities increasing both the quantity and diversity of plant foods, and opening up space for grazing animals (Zvelebil, 1994).

Some of these woodland disturbances, predominantly in Britain, are associated with increased levels of charcoal, suggesting that fire was the cause of the disturbance. Most synchronous woodland disturbances and fire have been attributed to human activity and a deliberate manipulation of the environment by late Mesolithic cultures (Simmons and Innes, 1987; Innes and Blackford, 2003; Ryan and Blackford, 2009). However, differentiating between natural impacts and anthropogenic influence remains challenging (Behre, 1981; Tipping, 1996; Berglund, 2003).

2.2.1 Distinguishing between anthropogenic and natural disturbances

Charcoal in the palynological record simply reflects the presence of fire, not the type or scale of the fire, or its cause (Tipping, 1996). An increase in charcoal deposition could therefore represent a range of scenarios including a natural forest fire caused by lightning strike (Moore, 1996; 2000), deliberate anthropogenic woodland manipulation to attract game (Innes and Blackford, 2003; Ryan and Blackford, 2009), or even a domestic fire (Bennett et al, 1990a; Edwards, 1990). Whilst recognising the potential for natural fires, broad leaved deciduous woodlands in Britain are generally regarded as lacking susceptibility to fire (Edlin, 1970, Rackham 1986, Peterken, 1993), suggesting that the majority of late Mesolithic charcoal peaks are anthropogenic in origin. The frequent and
recurring nature of burning at several sites (e.g. Innes and Simmons, 1988; Jacobi et al. 1976; Simmons and Innes, 1981, 1988a, b, c) also supports an anthropogenic interpretation at certain locations, rather than a more random, natural sequence of burning (Innes and Simmons, 1988). Other authors however argue for a more natural cause of increased levels of fire during the late Mesolithic. Tipping (1996) argued that a shift to drier conditions and an increase in heath vegetation from 7000BP could have created better conditions for natural fire to take place.

Not all woodland disturbances are associated with fire and, like charcoal, it is difficult to distinguish palynologically between disturbances which were natural or anthropogenic in origin (Brown, 1997). Disturbance can and does occur naturally through processes of windthrow, disease, soil development and geomorphological change (Brown, 1997; Olsson et al. 2010). The ‘Vera hypothesis’ (Vera, 2000) argues that large herbivores were an essential driving force behind vegetation dynamics, and that the extent to which natural grazers played a part in early clearances is often underestimated (Vera, 2000). Unfortunately, the scarcity of large mammal remains limits detailed investigation of this hypothesis, but the similarity of pollen records from regions which supported large herbivores with records from Ireland where large herbivores were absent, suggests that they were not a controlling factor on woodland dynamics (Mitchell, 2004). Woodland disturbance without fire need not be solely natural. Coppicing would create a disturbance signature in the pollen record without an increase in charcoal (e.g. Christensen, 1997; Waller et al. 2005), and both Simmons and Innes (1996) and Brown (1997) suggested that woodland disturbance preceding an increase in charcoal by a number of years may indicate that fire was a factor in maintaining openings created previously, either by natural means, or by such techniques as ring-barking (Selby et al. 2010).

The opening of the woodland canopy could make fires more likely, as late summer grasses, mature heath and the previous year’s bracken are more combustible than the woodland species they replaced in the Mesolithic aged or early Neolithic woodland disturbance phases. Hence, a complex set of scenarios involving climate, human impacts and natural successional processes could result in similar signals. This project aims to investigate these possible pathways using a range of techniques and at high resolution.
2.2.2 Avoiding preconceptions in interpretation

Due to the difficulty of disentangling natural from human disturbances, the majority of interpretations of Mesolithic anthropogenic disturbance are often highly subjective. Tentative palynological evidence of late Mesolithic anthropogenic disturbance such as peaks in charcoal or cereal-type pollen grains, would strongly indicate human impact if found later in the Holocene (Brown, 1997). Interpretations of the late Mesolithic period can be shaped by the perceived unlikelihood of pre-Neolithic human impact or long-standing stereotypes of the period, a good example being the pre-Elm decline cereal pollen debate.

Within some of the Late Mesolithic woodland disturbances identified in the palaeoecological record, ‘early’ cereal-type pollen dated to almost 6,000BP have been recorded. Edwards and Hirons (1984) compiled a record of five sites across Ireland and three in England with pre-Ulmus decline cereal-type pollen, and Innes et al. (2003) found high resolution pollen evidence for cereal cultivation on the Isle of Man during the latter stages of a woodland disturbance episode at 5925BP ± 60. At present not many pre-Neolithic cereal-type pollen have been identified in southern Sweden, but Regnell et al. (1995) noted large cereal-type grains in phases prior to the elm decline associated with the later Mesolithic occupation of Bökeberg. Low numbers of finds may just be a product of sampling and search effort, as many of the cereal-type finds have been a result of scanning techniques and high pollen sum counts (Edwards et al. 2005).

These cereal-type pollen finds are dated to well before (typically 800 - 1000 years) the earliest dated Neolithic archaeology, and are suggestive of pre-Neolithic agriculture. However, without supporting archaeological evidence this is a point of much controversy (Behre, 2007; Brown, 2007; Tinner et al. 2007; 2008). There is concern over the ability of cereal pollen identification keys, for example Andersen (1979), to accurately distinguish between cereal-type pollen and other large grass pollen such as Glyceria (Behre, 2007). Contamination, long term transport, chronological uncertainties and the fact that large cereal-type pollen can originate from the swelling of wild grass pollen mounted in glycerol jelly are often used to explain the presence of single cereal-type pollen grains in pre-Neolithic contexts (Behre, 2007; Brown, 2007). It has been suggested that higher quantities, less sporadic in nature would be needed before results were statistically significant (Pilcher and Smith, 1979).
As archaeological evidence of agriculture from the Mesolithic is extremely rare, and pollen indicative of arable weeds, e.g. *Rumex acetosella*, Chenopodiaceae, *Polygonum* (Behre, 1981) perhaps just representative of pockets of open land, Edwards (1982) argued that cereal-type pollen grains are the only thing that can be taken with some confidence to indicate the presence of Mesolithic agriculture within the pollen source area. Earliest Neolithic archaeological finds include macro-fossils of cereal grains, processing equipment such as grinding stones, and storage vessels, all of which are absent in Mesolithic find sites, although Mesolithic groups may have practiced cultivation on a small scale, hence the lack of recognisable shift in the archaeological record apart from these few cereal-type pollen. Mesolithic dwelling sites are very rare, and later Mesolithic ones even more so (Waddington, 2007), which makes the probability of finding cultivation artefacts or macrofossils unlikely.

### 2.2.3 Models of late Mesolithic land use

Growing support from the palynological record for late Mesolithic human impact and complexity has led to the development of a number of models of sophisticated land use and environmental management by Mesolithic groups.

The application of fire to dense mid-Holocene woodland would have significantly increased ecosystem biodiversity, via a post-disturbance regeneration of woodland through ruderal and successional plant communities. The availability and productivity of wild plant foods such as berries and nuts for humans, together with forage for wild animals, would greatly improve as a consequence (Zvelebil, 1994). Coupled with an increased openness of the canopy, the improved forage would have been attractive to game populations. Not only the frequency but the density of animals within a known area would increase (Mellars, 1976), and the enhanced visibility of prey would improve hunting success. Regular burning would also remove the build-up of undergrowth and dead vegetation, reducing the chance of potentially highly destructive high-intensity fires (Mason, 2000). These known beneficial ecological effects of fire have led to the suggestion that records of fire in the late Mesolithic may represent purposive burning, in order to achieve economical benefits.

Mellars (1975, 1976) suggested that the increase in grazing and browsing resources as a result of fire was the most important and beneficial aspect to Mesolithic hunter-gatherers, the fire encouraging new herbaceous plants and fresh shoots to appear from stumps of trees and shrubs. Ethnographic observations in North America appear to support this (e.g.
Simmons (1969) suggested that Mesolithic people were strategic in their application of fire, exploiting existing openings and only firing the woodland edges surrounding them to enlarge them. Grazing animals would be attracted to the area by the improved grazing resources, yet with minimal effort expended on behalf of the hunter-gatherers. Mellars (1975, 1976) highlighted that this method would make animal movement in the landscape more predictable, thereby improving hunting success, and by burning on a rotational basis the movement of animals could to some extent be controlled.

This theory was later developed by Simmons (1975a, 1975b) who suggested that in the uplands of Britain the area above closed woodland would have been open or scrub woodland. This would have consisted of excellent browse for animals, and consequently attracted Mesolithic hunter-gatherers to the area. Simmons suggested that firing of this scrub vegetation was employed to improve browsing resources further, and therefore hunting success. Jacobi et al. (1976) had a similar theory, where Mesolithic hunter-gatherers deliberately burned the upper limit of the woodland to suppress the further migration of the woodland into the upland, thereby encouraging browse for animals.

In addition to improving browse resources for grazing animals, it is recognised that fire may also have been employed to encourage plant food resources for Mesolithic hunter-gatherers. Simmons (1975a, 1975b) and Jacobi (1978) suggest that burning of the upland scrub woodland may have been used for the purpose of encouraging or promoting the production of hazelnuts. Hazelnuts have been found in large quantities at many Mesolithic sites (Jessen, 1935; Smith, 1970; Larsson, 1983; Regnell et al. 1995; Mithen et al. 2001), and fresh Corylus shoots are often produced from their burnt stumps (Smith, 1970). Used as food, these hazelnuts could be roasted for longer storage, enabling a year-round, transportable food supply. In addition to hazelnuts, Regnell et al. (1995) also found evidence that acorns were purposefully gathered during the Ertebølle settlement of Bøkeberg. Quercus acorns can be used for food once they are soaked or roasted, as this removes any tannic acid which can make them bitter (Jacomet et al. 1989). They therefore represent an additional source of food that may have been encouraged as a result of fire. Other plant foods that may have benefited from burning or woodland disturbances may include Urtica fruits, Rubus fruits (raspberry), and Prunus spinosa (sloe berries).
The importance of wild plant foods is often underestimated in archaeobotanical studies. Clark (1976) and Ertuğ (2009) suggest this is due to the fragility of many food items such as leaves and flowers, and the practice of eating many foods in their fresh state, reducing the chance of them becoming charred and therefore preserving. Whilst Clark (1976) argued that plant foods made a substantial contribution to the Mesolithic diet, and Zvelebil (1994) suggested that the evidence amounts to the presence of intensive plant use strategies, there has often been a lack of sites in north-west Europe for which wild plant foods could confidently be interpreted as anything beyond opportunistic use. In 2001 however, Mithen et al. found an abundance of over 30,000 charred hazelnut shells at a Mesolithic site on the Isle of Colonsay, west coast of Scotland, which provided evidence of a degree of plant food exploitation in the Mesolithic that went beyond being merely opportunistic and incidental. Even studies looking at the modern day plant-human relationship in Turkey find that wild plant foods are highly valued by farmers and a seasonally important part of their routine diet (Ertuğ, 2009). It therefore appears that woodland manipulation through the use of fire may just as likely have been to increase this type of resource.

A further model of late Mesolithic land use is the ‘forest farming and utilisation’ model (Göransson, 1984, 1986, 1988). Göransson suggested that the late Mesolithic landscape would have included coppiced woodland. Trees would have been coppiced by the hunter-gatherers through methods such as ring-barking or girdling, below which they would sprout further browse for grazing animals, and increase the supply of twigs and leaves which may have been collected for winter fodder. This practice of coppicing would increase the level of light reaching the woodland floor and encourage further growth of grasses and plants containing berries or nuts. Low intensity fire may have been used to clear ground between coppiced trees, in preparation for the first cultivation of cereals. Whilst Göransson acknowledged that this type of coppiced woodland would be difficult to detect in the palynological record, the surrounding woodland filtering out any of the rarer pollen types, he suggested a number of stages that may be encountered. Firstly, arboreal pollen would peak as the trees are girdled, and then die back. A peak in charcoal would follow together with pyrophytic taxa such as Pteridium aquilinum. Next, an increase in Plantago lanceolata and other ruderals would be observed, with a continuation of charcoal as the openings are maintained by fire and grazing animals. This should then be followed by arable and disturbed ground indicators such as Cereal-type pollen, Artemisia and Chenopodiaceae, as cereals are beginning to be cultivated. Göransson suggests that cereal cultivation may have continued as the woodland regenerated back to a coppiced-wood, with increases in
Poaceae and Cyperaceae as the land between the trees begins to recover. Finally, arboreal pollen would begin to regenerate. The forest farming model suggests that grazing animals may have played a crucial role in early cultivation, useful for providing manure which would increase the soil fertility (Rowley-Conwy, 1981), and grazing would help to control some weeds. Detecting the presence of animals is therefore crucial to testing this model.

2.2.4 A new methodological approach

It is crucial that palynologists consider the evidence for late Mesolithic human impact objectively, and interpretations are sensitive to the complexity of early human impact on the environment. Woodland disturbances and fires are easily detectable through traditional pollen and charcoal analysis, and there is often a tendency to focus on these types of human impact alone. However it must be acknowledged that other types of human impact are very difficult to identify in the palynological record. For example, the encouragement of nuts and berries would be very difficult to identify as regionally abundant *Corylus* may swamp any local enhancements or variations in the species, and fruiting shrubs and herbs have relatively low pollen production rates making them poorly represented when woodland dominates a landscape (Warren et al. 2014).

Additional measures should be employed to enable the best detection of the nature of late Mesolithic human impact. High resolution sampling is essential if looking at early prehistoric short-term land use. For example, it can resolve major burning phases into discrete sub-phases that may reflect individual fires (Innes and Simmons, 2000; Innes et al 2013). This enables a more accurate interpretation of the duration and frequency of fires, which can help determine whether they were anthropogenic or natural in origin. High resolution analysis can also better reveal the sequence of events during a disturbance, for example whether woodland disturbance preceded burning, or if woodland was affected by some other means first. Again, this can help determine the likely forcing factors of disturbance.

Whilst the number of high-resolution studies covering the late Mesolithic or early Neolithic may be increasing in Britain, studies often lack multiple methods of reconstruction. A multi-proxy approach to investigating human impact can offset individual proxy deficiencies, and is especially important where low-scale disturbances may be invisible in the pollen record. A good example is non-pollen palynomorphs (NPPs) which have been used to identify the presence of grazed woodland, which is otherwise very difficult to detect palynologically.
While charcoal data are routinely used in palynology, the value of different size classes and of NPPs indicative of local fires have been under researched. Determining the local, regional or on-site nature of fires can help elucidate if the nature of fire use throughout the landscape changed, and may help identify their origins. Other alternative approaches include geochemical indicators such as Silicon and Titanium which have been identified as good indicators of soil erosion from woodland clearance or farming activities (Hölzer and Hölzer, 1998), and peat humification which can inform of shifts in bog surface wetness conditions, and again potentially aid distinction of the likelihood of natural or anthropogenic fires.

Although evidence remains circumstantial, latest palynological evidence for the Mesolithic-Neolithic transition appears to support the notion that late Mesolithic groups were agents of environmental change. If true, this may be responsible for the delayed uptake of agriculture in north-west Europe, and provides support for models of acculturation as the mechanism behind the transition.

2.3 The role of Climatic and Environmental conditions on the Mesolithic-Neolithic transition

2.3.1 Mid-Holocene climate change

Mid-Holocene climate change has been one of the most thoroughly debated topics since publication of the first results in Quaternary palaeoecology. Development of new and multi-proxy approaches, improved process-understanding, more secure and precise chronological control, better quantification, more widely used statistical techniques, and model-data integration and comparison (Walker and Lowe, 2007) have all led to advances in palaeoclimate science since the 1980s. An important development has been the combined analysis of different, independent proxy climate indicators which respond to different climate signals. Multi-proxy approaches have the potential to refine knowledge of the multivariate nature of climate change, and increase confidence in interpretations (Charman, 1997).

Tipping (2010) investigated several recently obtained palaeoclimatic records for the period spanning 7000 to 5000 cal BP, covering four aspects of climate change: atmospheric and ocean circulation; storminess; temperature; and precipitation. There appeared to be little overall agreement between the climate proxies, but this is likely to be due to the fact that
each method of reconstruction has a different level of imprecision, and dating uncertainties make confident correlations difficult. Temperature proxies were found to be rather inconsistent with speleothem $\delta^{18}O$ data from western Ireland (McDermott et al. 2001) and planktonic foraminiferal assemblages in the northern North Atlantic (Mayewski et al. 2004) suggesting that the climate became warmer after c.6000 cal BP, whereas pollen spectra in northern Finland expressed as July mean temperatures (Seppä and Birks, 2001) suggest that temperatures declined from c.6000 cal BP. Precipitation proxies were also inconsistent, with peat-stratigraphic analyses from a raised moss in south-east Scotland suggesting an increase in precipitation (Langdon et al. 2003) from c.6000 cal BP, whilst lake level fluctuations in the Alps suggest a decline (Magny, 2004) and lake level fluctuations in northern Scotland suggest it stayed the same (Tipping and Tisdall, 2004).

Most records did not show any distinctive step-change of climate coincident with the Mesolithic-Neolithic transition, and the general lack of agreement between proxies indicates that the climate across north-west Europe between 6500 and 5000 cal BP is still not fully understood. Many of the widely-used peat-based reconstructions of climate are younger than this (Langdon and Barber, 2005; Charman et al. 2006; Swindles et al. 2013), unfortunately limiting the number of palaeo-climate records currently available for this time period which are local to sites of interest.

### 2.3.2 A potential link between climate and the cultural landscape?

Interaction between cultural development and the natural environment is generally accepted. Holocene climate change and hence the ecological capacity of a region have been described as main factors behind the step-wise development of the cultural landscape in north-west Europe (Lamb, 1981, 1982; Jager, 1999; Berglund, 2003). Many contributions to the debate on the transition to agriculture have stressed the possible role of climate change (Bogucki, 1998; Bonsall et al. 2001; Tipping and Tisdall, 2004; Tipping, 2010; Finlayson and Warren, 2010).

A number of fields including geosciences, environmental biology, archaeology and anthropology are investigating the tight intersection of climatic, environmental, historical, and cultural conditions. A positive correlation between the cultural landscape and climate change is commonly found in the literature. Wendland and Bryson (1974) statistically compared radiocarbon dated Holocene environmental changes with cultural changes (worldwide) and found an approximate synchronicity, with a delay of 50-100 years for the
cultural changes. There was an observed correlation between particularly dry episodes and the adoption of agriculture in Sicily (Frisia et al. 2006), and Stöckli et al. (1995) demonstrated a growing importance of hunting during times of unfavourable climate. Patterson et al. (2010) in their model of the Neolithic transition noted the probable survival of hunter-gatherers in regions where environmental conditions did not favour farming. Agriculture requires a long growing season and sufficient summer warmth for seeds to ripen, and animal husbandry requires enough fodder to be produced through the summer to last through to the winter. Meeting these conditions is critical to a successful farming system, and so climatic conditions are potentially very relevant to their success or failure.

Scenarios where environmental deterioration may have reduced the carrying capacity sufficiently enough that settlements were abandoned, or cultures collapsed, reflect ‘catastrophist’ views where changes were so rapid, large or extreme that adaptation was impossible. These catastrophic theories are however often over-simplistic and deterministic in their approach. As the nature and precision of correlations between the cultural landscape and climate is wholly dependent on robust chronologies (Berglund, 2003), the extent to which climate is a factor over cultural development is often a matter of debate (Barker, 1985; Mannion, 1991; Bell and Walker, 1992; Roberts, 1998).

Even where correlations have been found to be robust, studies do not often consider the physical, ecological, economic or social mechanisms involved. For example, Stolze et al. (2012) studied the Neolithic of County Sligo, Ireland, and demonstrated that the nature and duration of farming practices correlated with climatic variability on the decadal to centennial scale. An increase in summer temperatures reconstructed by NPP and geochemical indicators, and a decrease in precipitation inferred from lower lake levels appeared to favour wheat cultivation, and subsequent exceptionally dry conditions correlated with a shift towards pastoral farming. The onset of cool and wet conditions during the middle Neolithic was linked with a decline in human activity, with periods of particularly high precipitation in the middle and late Neolithic thought responsible for the abandonment of the area. No mention of the physical or ecological effects upon the length of the growing season, impacts on economy or the social motivation behind the changes were made.

To fully understand the complex relationship between humans and their environment, an understanding of past climatic conditions and their local effects upon vegetation, fire frequency, environmental resources and human subsistence activities are required.
Common climate change recorded across north-west Europe at the Mesolithic-Neolithic transition may have had different impacts upon societies’ evolution towards agriculture, depending on the different social and environmental contexts. It is important to ask how climatic changes manifested themselves to local late Mesolithic and early Neolithic groups, and whether these changes would have been significant, influential or even observable, so as to have the potential to affect their lifestyle choices.

Anderson (1998) and Anderson et al. (1998) observed that charcoal concentrations within a sediment record increased during periods of relatively dry climate, and fires originating from lightning strikes have been found to be more common during periods of exceptional drought (Chandler et al. 1983). This suggests that climate plays a role as an external forcing upon fire frequency. Due to known effects of fire upon soil conditions and resultant vegetation, including soil erosion, acidification, expansion of blanket peat (Simmons and Innes, 1987; Tallis, 1991; Caseldine and Hatton, 1993; Giovannini, 1994; Atkins et al. 1998), ash fertilisation of the soil, and increased light penetration to the woodland floor increasing biodiversity, there is growing recognition that naturally caused fires played an important role in the ecology of woodlands, and hence climatic change could dramatically affect these parameters. It must be acknowledged however that a shift to drier conditions may not have led to an increase in solely natural fires. The likelihood of anthropogenic fires may have increased when conditions proved more favourable for burning.

Bonsall et al. (2001) noted a coincidence between the widespread adoption of agriculture throughout north-west Europe at c.6050 cal BP and a shift towards drier, more continental conditions, as reconstructed by a range of proxies such as lake-level, peat humification, pollen and beetles (Digerfeldt, 1988; Tipping, 1995; Anderson, 1998). They suggested that this shift in climatic conditions would have improved the viability of soils around Britain and southern Scandinavia, by reducing the level of waterlogging which can inhibit germination and retard growth. The length of the growing season would have been extended sufficiently that agriculture may have become a much more viable option or more successful if practiced previously, in areas where it had previously been unsuited. Schulting (2010) however highlighted that there was little agreement even at relatively small geographical scales concerning the direction and magnitude of the records of climate change used in the study, and that a link cannot currently be confidently made between a shift to drier, more continental conditions and the adoption of agriculture in north-west Europe.
An increasing variability of climate may have made the resources currently used by hunter-gatherers unreliable and unpredictable. Deteriorating sea-surface temperatures and salinity, increased seasonality and changing ocean currents identified by Tipping (2010) are thought to have been responsible for a widespread decline in the productivity of coastal resources at the Mesolithic-Neolithic transition, something which late Mesolithic people relied on heavily (Rowley-Conwy, 1984; Schulting and Richards, 2002; Schulting 2010). If climate change and its associated impacts were rapid and observed by single generations, they may have encouraged a more ready acceptance of new ideas and practices (Tipping and Tisdall, 2004). Even without a visible reduction in available resources, a degree of uncertainty may have been introduced, with seasons and conditions formerly predictable no longer able to be predicted with assurance (Tipping, 2010). As a result, Mesolithic hunter-gatherers may have become more receptive to innovation, increasingly seeing and choosing new ways of doing things. Climatic variations may have forced people to adjust by intensifying one or another type of economic production depending on prevailing climate conditions and landscape type. An example in the northern Pontic steppe near the Black Sea demonstrates that in climatically favourable wet periods, cattle herding and hunting were practiced in equal quantities, however in arid climate periods, when natural forest habitat decreased in the area, the role of animal husbandry increased as there were less hunting possibilities (Kotova and Makhortykh, 2010). Tipping (2010) argued that it was the preceding impacts of a deteriorating climate that prepared Mesolithic hunter-gatherers for an alternative way of life.

It is the view of several authors, therefore, that environmental variations had the potential to contribute to the progressive adaptive cultural development of many societies, with the introduction of new technologies facilitated by cultural links with other regions, but often encouraged by environmental fluctuation.

2.3.3 Difficulties encountered in the study of climate and the cultural landscape.

In addition to the enduring reaction against environmental determinism by both archaeologists (Jones et al. 1999) and environmental scientists (Kertész and Sümegi, 1999), conflicting palaeoclimate records at different scales and with different levels of precision, together with difficulties disentangling human impacts from local environmental impacts within pollen records (Behre, 1981; Berglund, 2003), have led many researchers to remain sceptical about invoking environmental factors to account for cultural and social change.
Across Europe, existing palaeoclimate data suggest important regional differences and even opposite trends in climate change for the mid-Holocene (Davis et al. 2003; Magny et al. 2003; Brewer et al. 2007; Schulting, 2010). Climate reconstructions obtained using different methods and proxies have been found not to be coherent, and sometimes even the same proxy record can be interpreted differently, such as the decline of bog oak from c.6000 cal BP being interpreted as being attributable to both drier and wetter conditions (Bridge et al. 1990; Baillie, 1992; Turney et al. 2006). There is therefore a need for a much better understanding of the physical and biological processes (Seppä et al. 2009; Huntley, 2012). To better refine the palaeoclimate record for the Mesolithic-Neolithic transition of north-west Europe, new well-dated, high-resolution, multi-proxy records for that particular region and time period must be obtained to enable improved data-model comparisons (Latalowa et al. 2013).

Challenges are encountered in integrating different data types such as palaeoclimatological and palaeoecological, from issues including different scales or resolution of analysis, to poor chronologies and interpolated dates. Patterns identified by large-scale palaeoclimate reconstructions including modelling based on pollen data (e.g. Cheddadi et al. 1997; Davis et al. 2003) are both temporally and spatially coarse. Combining such records with increasingly high-resolution palynological records is difficult, as they are most likely not responding to or recording changes on the same scale. Differences in the temporal resolution of records are often accompanied by differences in chronology resolution, which is crucial when attempting to temporally correlate different proxy records. Some proxies are inherently difficult to obtain a precise chronology for, such as dune mobilisation phases, making a precise correlation with the palaeoecological record almost impossible.

The timing of environmental and cultural events is crucial to understanding if there was a climatic or environmental effect upon human activity. Even with improvements in radiocarbon precision, quality of sample selection, and statistical modelling of series of dates (Bronk Ramsey, 2008), demonstrating cause and effect remains difficult. There may be considerable time-lags in proxies recording climate or environmental changes in the sediment record, lags between climate change and resulting local environmental changes, and lags between environmental changes and human response (Schulting, 2010). Multi-level intervening variables such as settlement structure, subsistence strategies, specific preferences for certain plant and animal species, the buffering potential of exchange networks at times of stress, and the options people may or may not have chosen from a
wide range of available options, may have affected how humans responded to climatic change, and add to the complexity of detecting any causality between such change and human activity (Magyari et al. 2012).

Whilst it remains possible that climate and environmental changes played a role in the Mesolithic-Neolithic transition of north-west Europe, at present the various palaeoenvironmental and palaeoclimatic proxies available for this period appear not to be of sufficient chronological resolution to address the question of synchronicity at this scale. Links with internal social and economic dynamics unfortunately also remain poorly understood.

2.4 Summary and Research Gaps

Despite significant research effort, the processes of change during the Mesolithic-Neolithic transition of north-west Europe are still poorly understood. A good chronology of both archaeological and palaeoenvironmental change is imperative to allow correlations, and a scarcity of robust late Mesolithic dates, at least in Britain, compared to those for the early Neolithic may be skewing archaeological interpretations of the timing, rate and nature of the transition (Griffiths, 2014). Interdisciplinary archaeo-palaeoenvironmental investigations are rare due to an unfortunately fragmentary record of latest Mesolithic archaeology with organic sediments of the same age, and those that do exist are often hampered by a lack of secure context for archaeological dates, and an overall low number of dates obtained from each site. More radiocarbon determinations, with more secure information about their sedimentary context, would allow better use of Bayesian statistical modelling as a tool to help refine the chronologies of sites.

There is still debate over the extent of late Mesolithic human impact on the environment, and how this impact changed across the Mesolithic-Neolithic transition. This has significance in terms of the proposed models of acculturation vs. demic diffusion for the process of transition, yet studies often lack the multiple methods of reconstruction, high-resolution analyses and sufficient chronology that are needed to fully elucidate the spatial and temporal scale of this human impact. Where such methods have been employed, there has been a tendency to study either the late Mesolithic period, or the early Neolithic, prohibiting investigation into how and exactly when the nature of land use changed across the Mesolithic-Neolithic transition.
High-resolution palaeoclimate records are limited and conflicting for the mid-Holocene, which is limiting investigations into the synchronicity of climatic and environmental changes with human impact and cultural change. Local climate records from either the same sediment core as the palynological record, or from well-dated records from the same site, may help achieve a better understanding of the effects of local environmental change upon the nature of human impact across the Mesolithic-Neolithic transition, both the internal ecological processes and the potential societal response.

This thesis aims to address these issues by investigating the changing nature of human impact across the Mesolithic-Neolithic transition, and the role environmental conditions and their fluctuation may have played in determining this activity.
3. Research Aims

3.1 Aim

The overall aim of this study is to investigate the environmental changes across the Mesolithic-Neolithic transition (c.7000-5000 cal BP) in north-west Europe. The focus will be on the dynamics of these changes, their timings and interactions, and the relative roles of climatic change, natural events and human action.

3.2 Objectives

1. Investigate the palaeoecological evidence for land management practices (including the duration of events, periods of intensification, possible methods employed), and through this, analyse the use of different resources. Changes in land use in the later Mesolithic and Neolithic will be recorded.

Specific questions that can be tested are:

- Was the period under investigation one of landscape change or continuity?
- Did Mesolithic practices persist into Neolithic timeframes, or did Mesolithic ages practices include elements of Neolithic traits?
- Do palaeoenvironmental changes correlate with archaeological records for presence or activity?

2. To investigate the potential forcing factors behind the nature of human impact.

Specific questions that can be tested are:

- Can data be extracted that infer climatic changes through the study period?
- Can non-climatic factors be inferred from the data, including natural fire and wild animals?
- To what extent were cultural activities influenced by climatic or natural environmental change?
Can anthropogenic and natural factors be disentangled from each other and from background variability?

The work for this PhD will involve reconstructing the cultural landscape across the Mesolithic-Neolithic transition at two contrasting north-west European archaeological sites dated to the transition period, interpreted in the wider context of previous work in each area.

The project aims to have the following impacts:

1. Findings will have relevance both for wider studies of the Mesolithic-Neolithic transition of north-west Europe, and the understanding of late Mesolithic and early Neolithic human impact set against environmental change.

2. Setting archaeological evidence within a dynamic ecological setting will provide an important complement to the complex story, and contribute to the international debates on the process of the transformation to Neolithic, and degree of Late Mesolithic impact on environment.

3. Testing models of purposive landscape modification through the use of fire, and an ‘initial Neolithic’ phase in the pollen record prior to supporting archaeological finds.
4. Site Selection

4.1 Regional site selection

Within north-west Europe, Britain and southern Sweden are particular regions of interest with regards to the dynamics of environmental change and human interaction across the Mesolithic-Neolithic transition. Both regions experience different transitions to the Neolithic in terms of settlement pattern, material culture, evidence of contact with continental farmers, and the nature of human impact. The two regions also represent different climate regimes with Britain on the more maritime edge of north-western Europe and southern Sweden representing a more continental type climate. Despite these differences, they both experienced a delay in the uptake of the Neolithic from continental Europe of at least a thousand years, whilst late Mesolithic cultures persisted to c.5900 cal BP. This research aims to investigate the differences and similarities in these two region’s transitions, with regards to the nature of human impact, how it changed over the transition, and the potential role environmental conditions played.

4.2 Local site selection

4.2.1 Britain

4.2.1.1 Regional context

The Central Pennine uplands have been chosen for study as it is a small area of moorland containing archaeological sites spanning from the beginning to the end of the Mesolithic, including the earliest known upland Mesolithic site of Lominot, and sites which date to the Mesolithic-Neolithic transition such as March Hill. It is a region noted to have the highest density of upland Mesolithic sites in England and Wales (Spikins, 1999), and potentially the world (Preston, forthcoming), with excavations as far back as the 1920s where Francis Buckley revealed not only a large volume of lithics, but also a number of ‘fire pits’ in the area (Buckley, 1924b, undated). The density and diverse chronology of finds ranging from c.10970 cal BP to c.5900 cal BP across the area suggests there may have been a focus of activity or repeated use of this area over a considerable period of time. This may have been for a particular purpose such as hunting, with high densities of microliths often interpreted as hunting camps (Mellars, 1976a). The area lacks any major local flint or chert resources, and so its status as the narrowest area on the Pennine watershed may be fundamentally
responsible for the concentration of find spots if it was utilised as an important crossing point to source raw materials.

The distribution of find sites suggest a genuine focus of activity in the Mesolithic, however as the area is rapidly eroding with footpaths and access routes nearby, it must be acknowledged that the location of find sites within the landscape must be treated with caution. Spikins (1999) found that peat erosion ‘maps onto’ known sites and suggests it is unwise to place much emphasis on the distribution of find sites. Preston (forthcoming) however suggests that the concentration of sites where erosion is most prevalent reflects a genuine focus of activity, with south-facing plateaux edges with a wide view proving popular, due to them being particularly attractive in terms of warmth and aiding hunting.

If there was a prolonged presence in the area, it may have helped create resource networks with tool caches, or develop landscape management techniques to attract game and exploit plant resources. Several records for mid-Holocene woodland disturbance in the area and other upland areas of Britain have led to the development of models describing sophisticated woodland management, particularly through the use of fire, by Mesolithic populations (Jacobi et al. 1976; Simmons and Innes, 1987; Innes and Blackford, 2003; Ryan and Blackford, 2009).

### 4.2.1.2 Local context

March Hill is one of the key sites at the Mesolithic-Neolithic transition in Britain. Located west of Marsden in West Yorkshire, it is a gently sloping east-facing hill overlooking March Haigh reservoir. Defined to the north and south by streams, the highest point is an area of steep scarp known as March Hill Top, reaching approximately 440m OD. Geologically underlain by Millstone Grit, blanket peat covers much of the upland from about 300m, which is incised by the headwaters of the river Colne and much shallower in depth on the hill top and slopes. The present day vegetation is predominantly *Eriophorum* and *Sphagnum*.

In the 1990s, the West Yorkshire Mesolithic Project carried out a number of excavations at March Hill in a direct response to the threat posed to an important Mesolithic site from the work of collectors and advancing peat erosion. Recent damage over the last decade or two has been severe, in the form of large numbers of pits with associated spoil heaps which still contain lithic material (Spikins, 1993). Two trenches on March Hill were excavated, March Hill Carr (trench A) and March Hill Top (trench B).
Figure 4.1 – Typical typology of Mesolithic archaeological sites in the vicinity of March Hill.
Excavations at March Hill Carr (Trench A) (Fig. 4.1) revealed 4 hearths, with a scalene triangle dominated assemblage (Spikins, 2002). 49 scalene triangle elements, 7 crescent microlith elements, 5 rod microlith elements and 2 isosceles triangle microliths were recovered from the trench alongside 1734 pieces larger than 5mm (Conneller, undated b). Archaeological interpretations of the purpose of the 4 hearths range include knapping activity and scalene triangle microlith production (Griffiths, 2012). 8 radiocarbon dates (2 from each hearth) date activity at March Hill Carr to the late Mesolithic between 6700-6450 cal BP, with a Bayesian modelled total duration of use of between 0 and 130 years (95.4% probable; or 0-60 years 68.2% probable) (Griffiths, 2012). All radiocarbon dates from the 4 hearths are statistically consistent. This suggests that they could represent a single archaeological ‘event’ with a group of people meeting or travelling together across the moors, or they could have equally been revisited a number of times over a relatively short period of time (Griffiths, 2012). The site is currently insufficiently precisely dated to determine if activity was contemporaneous or sequential, and further prior information such as stratigraphic relationships would be needed to refine the chronology further.

Trench B at March Hill Top (Fig. 4.1) revealed a hearth and an assemblage dominated by 14 rod microliths (Conneller, undated a; Spikins, 2002). The vast majority of material was recovered from one square metre (Spikins, 1996), and lithics were smaller on average than March Hill Carr with the average size of artefacts recovered being 1.25cm (Spikins, 2002). The site has been suggested to be one of rod microlith production, due to the recovery of a rod microlith and a core in the hearth, a partially burnt core, and knapping debris around the hearth itself (Griffiths, 2012). Field observations infer two distinct burning events in the hearth superimposed one on the other, as stratified between two burnt deposits was a flint core burnt more heavily on its uppermost side, suggesting an episode of burning after its deposition (Conneller, undated b). It is unfortunate that the phase of hearth use that the rod microlith and seven radiocarbon dates came from was not recorded, as although field descriptions and the statistical inconsistency of the radiocarbon dates suggest the hearth was fired at least twice, without evidence to substantiate this the use of the hearth can only be modelled to between 6180-5950 cal BP (95.4%; 6120-5990 cal BP 68.2%) and 6000-5910 cal BP (95.4%; 5990-5920 cal BP 68.2%), and the deposition of the rod core between these two phases at 6140-5920 cal BP (95.4%; 6060-5950 cal BP) (Griffiths, 2012).

The late date of this and other rod microlith dominated sites in England and Wales (Griffiths, 2014) may suggest that the change in flint assemblage may have been connected
to the appearance of a new set of practices at this time in Britain (Conneller, undated a). There is a probable (50% probability, Griffiths, 2014) chronological overlap between people using rod microliths and people using the first Neolithic material culture in the region, and it is possible that contemporaneous people were exploiting Mesolithic and Neolithic lifeways in the Yorkshire region, albeit in different parts of the landscape. Bayesian modelling of all available chronological data has revealed that the area around March Hill was a place of persistent activity in the Mesolithic, for at least 910-1250 years (95% probable, Griffiths, 2014), and such sites may contribute to key issues at the Mesolithic-Neolithic transition. Sites at and around March Hill are also noted to have the highest integrity of recorded Mesolithic artefact distributions in the world (Spikins, 1999), resulting in considerable potential for internationally significant sites to be recovered.

Despite a recent increase in archaeological research effort, the nature and timing of human impact across the Mesolithic-Neolithic transition at March Hill, and its relationship with environmental change, remain poorly understood.

4.2.2 Southern Sweden

4.2.2.1 Regional context

The processes of Neolithisation in southern Sweden have been widely discussed (e.g. Berglund, 1991; Larsson, 2013). The proximity of rich archaeological remains to a large number of lakes and bogs make the area an ideal place to study human-climate-environment interactions across the Mesolithic-Neolithic transition due to the excellent preservation conditions of many sites. Excavations of well preserved occupation layers, cemeteries and middens have allowed insight into society around the time of the Mesolithic-Neolithic transition.

There has been an increasing recognition that there may have been many similarities between the late Ertebølle culture and the early Funnel Beaker culture of southern Sweden, reflecting the last hunter-gatherer and first farmer cultures respectively. Larsson (2013) suggested that whilst a new economy arrived in terms of farming, the first monuments began to be built, and settlement patterns changed as large coastal settlements around Skåne were abandoned as permanent settlements in favour of occupying new inland areas; there was also a continuation of material culture, and that Ertebølle middens and coastal sites were often still used if only on a seasonal basis. He
argued this pointed to a common history, and that the early Neolithic in southern Sweden represented a cultural inheritance modified by innovation. How these innovations were motivated is another area for debate, with the influence of climate change, shoreline displacements and ecological changes, as discussed in Chapter 2.3, suggested as possible motives behind a change of lifeways, and a rather rapid transformation into the Funnel Beaker culture (Berglund et al. 199; Larsson, 1991). Marine resources such as fish and molluscs were highly valued and utilised in the late Mesolithic (Jarman et al. 1982; Tauber, 1982), and one of the biggest impacts of marine transgressions was that they brought about noticeable changes in the availability of these resources, which were relied upon for year-round hunter-fisher-gathering practices (Rowley-Conwy, 1984). Having been aware of farmers to the south for at least some centuries, the availability of an alternative subsistence strategy in the form of mixed farming may have presented people with a choice of whether to maintain the hunter-gathering way of life, or whether to adopt a novel economy focussed on domesticated plants and animals.

Some places or sites persisted through the Mesolithic into the Neolithic, and may have represented a sense of importance and belonging amongst its inhabitants (Cummings, 2002). Whilst originally it was believed that inland areas of southern Sweden were unknown and unused in the Mesolithic, sites such as Bökeberg by Lake Yddingesjön (Karsten, 2001; Regnell et al. 1995) highlight that lake environments were in use from the Mesolithic, simultaneous with the large coastal settlements, through to the Neolithic. Mesolithic groups were aware of ecological niches, with settlements in southern Sweden focussed in ecologically favourable areas such as lagoons, river mouths, and inland lake environments (Paludan-Müller, 1978; Larsson, 1984; Andersen, 1986). The lake edge environment at Bökeberg must have provided a good example of an ecologically diverse and favourable area for both Ertebølle and early Funnel beaker cultures.

4.2.2.2 Local context

Thirty Mesolithic and Neolithic settlements have been identified within the vicinity of inland Lake Yddingsjön, south-west Skåne, southern Sweden (Karsten, 1986). The majority of these settlements were noted to be situated close to the former lake shore, where ecological diversity would have been greatest. The density of sites at this location suggests it was economically productive and/or held special significance for both Mesolithic and Neolithic groups.
Figure 4.2 – Location of Mesolithic and Neolithic finds in the Lake Yddingesjön area, with Bökeberg III excavations highlighted (modified from Regnell et al. 1995).
Limestone geology is overlain by silty, clayey till. Until relatively recently, the area was rich in smaller lakes and wetlands. The lake has been subject to both a natural long-term infilling process, and artificial lowering by approximately 1.5m in the late 19th and early 20th Centuries (Regnell et al. 1995). As a result, today the lake has an area of approximately 2.1km², however the extent of peat deposits surrounding the lake more or less corresponds to the former much larger extent of the lake (Fig. 4.2). Today the landscape is much less diverse, consisting of grazed fields with occasional areas of peat cutting.

Karsten and Regnell (in preparation) excavated a late Mesolithic settlement at Bökeberg III, which was situated on a small peninsula in a former bay of Lake Yddingsjön (Fig. 4.2). 522m² of the settlement was excavated, in a direction perpendicular to the former lake shore from the settlement into the littoral zone of the palaeo-lake. A large quantity of flint tools and debris together with bones and antlers were found in the refuse layer within the littoral zone, and several pits and ditches were also discovered (Karsten and Regnell, in preparation). Bones and seeds found in the refuse layer have been dated to 7565 to 6720 cal BP, however the exact duration of the site’s occupation or use remains unknown. Even though graves, a common definition of a settlement’s permanence or status as a base camp (Larsson, 1988a), were not found at Bökeberg III, the quantity of artefacts, debris and constructions identified indicate the repeated or ‘semi-permanent’ use of the settlement, discounting it as a site used only for short periods during explorations from a main camp elsewhere (Regnell et al. 1995). Four axes were found of the Flachhacke-type, associated with contemporaneous farming economies in Central Europe, signifying contact with the continent at a time when agriculture had been introduced (Regnell et al. 1995).

Regnell et al. (1995) investigated the late Mesolithic vegetation and land use history through the use of pollen, charcoal and macro-fossils from the distal part of the refuse layer, where visible archaeological artefacts were rare so as to avoid disturbance from settlement activities. Pollen data suggested two phases of occupation and human impact at Bökeberg III, phase A dating from 7530 to 7340 cal BP and associated with the gathering of hazelnuts and acorns, soil erosion, and elm, oak, hazel and pine wood collected for fuel, construction or tools. Phase B dating from 7060 to 6600 cal BP was associated with the gathering of hazelnuts, and the collection of a large variety of wood from different types of woodland. Both phases of occupation correlated well with evidence for a period of locally reconstructed low lake-level from 7565 to 6600 cal BP, which was interrupted with a period of high lake-level, and low human impact, between 7405 to 7190 cal BP. Regnell et al.
(1995) interpreted this as reflecting late Mesolithic groups taking advantage of periods of lower lake-levels which gave them the chance to occupy slightly higher ground very close to the lake edge, where they benefitted from the boundary between different biotopes and vegetation types such as open water, the littoral zone, alder carr and deciduous woodland on elevated ground. Regnell et al. (1995) also found 3 large cereal-sized grass grains (>37µm) and an *Avena*-type grain prior to the elm decline, but dismissed Göransson’s (1988) suggestion that ‘garden cultivation’ may have occurred at this time in Skåne as macro-fossils of cereals were not found.

Being in close proximity to both late Mesolithic and early Neolithic archaeological sites, and where there is an organic sediment record extending back to at least 7500 years, higher resolution, multi-proxy analyses across the Mesolithic-Neolithic transition at Bökeberg will enable the timing and changing nature of human impact across the Mesolithic-Neolithic transition, and its relationship with environmental change, to be elucidated.
5. Methodology

The purpose of this chapter is to consider some of the theoretical issues raised by the methods employed in this study. It will also outline the field and laboratory procedures followed so as to enable comparison to other studies.

5.1 Field coring strategy

Being able to link the palaeoenvironmental record with the existing archaeological record for human presence allows a much greater insight into human-environment interactions and the cultural landscape (Berglund, 1991). To enable this link between the two archives, a strategy of palaeoecological sampling of organic anaerobic sediments as close to the known archaeology as possible has been employed, whilst avoiding any direct disturbance from the human activity. Details of how organic anaerobic sediments were located as close as preferable to the archaeology are provided at the beginning of the results chapter for each site.

Sediment cores were recovered using a 500mm Russian corer as described by Jowsey (1966), with a 50mm overlap on drives to ensure continuity of the stratigraphy (Faegri and Iversen, 1989). Due to the Russian corer’s 100mm nose, alternate drives from two adjacent cores avoided sampling peat disturbed by the previous drive (Faegri and Iversen, 1989). Each 500mm section of core was carefully placed in clean plastic guttering to provide support, and wrapped in cling film before being transported back to the laboratory and stored in the dark at 2°C to prevent oxidation and degradation.

5.2 Stratigraphic description

Sediments were initially described in the field with photographs taken of each core section. In the laboratory, the cores were cleaned by carefully scraping across the peat or gyttja to prevent contamination between stratigraphic layers, and the sediments described aided by notes and photographs taken in the field.
5.3 Loss-on-ignition

5.3.1 Theory:

The degree of organic content within a sediment can be determined through loss-on-ignition (LOI). The percentage of material lost following ignition gives a crude measure of the organic content of the sediment, with higher LOI values indicating a higher proportion of organic material. LOI can be used as an indicator of past landscape instability, with the level of minerogenic content potentially indicative of erosion increasing the levels of allochthonous input to the peat or lake either through surface runoff or deposition of atmospheric dust particles (Carcaill et al. 2006). Edwards and Whittington (2001) and Chiverrell (2006) identified that woodland clearance encouraged destabilisation of soils and increased sediment flux to lakes and basin peats, and silt inclusions associated with palynological evidence for woodland disturbance are known from the uplands of the British Isles, often during the mid-Holocene (Simmons and Innes, 1987; Innes et al. 2010).

5.3.2 Laboratory method:

The sediments were sampled at 20mm intervals and dried in a convection oven for 24 hours at 105°C to remove any water from the sample. This left approximately 0.1g of dry sediment which was then ignited at 550°C for 4 hours. At this temperature any organic matter is oxidised to CO₂. The following formula was used to calculate the percentage organic matter within the samples (after Heiri et al. 2001):

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

where \( \text{LOI}_{550} \) represents the percentage loss on ignition, \( \text{DW}_{105} \) represents the weight of the oven-dry sample prior to ignition, and \( \text{DW}_{550} \) represents its weight post-ignition at 550°C.

5.4 Peat humification

5.4.1 Theory:

Peat humification is a widely used technique to estimate the degree of peat decomposition. Well humified organic matter is assumed to indicate that relatively dry conditions prevailed at the bog surface at the time of peat formation, as it would have taken longer for plant material to reach the anoxic catotelm, resulting in greater
decomposition (Barber et al. 1994; Blackford, 2000). To this extent, poorly humified organic matter can indicate that wetter bog surface conditions prevailed at the time of peat formation. As an indicator of past surface wetness, the proxy can be used to infer shifts in the height of bog water-table. On ombrotrophic mires, humification of plant matter is known to correlate with changes in temperature and/or precipitation (Blackford and Chambers, 1993). The method has therefore been used as a palaeoclimate indicator (e.g. Langdon and Barber, 2004; Borgmark, 2005; Swindles et al. 2007), although it remains unclear whether it is precipitation or temperature that drives the variations. Humification analysis has been shown to be replicable, is applicable to all peat types, and has the advantage of being able to be applied over the whole profile, even where overly humified peat has resulted in the loss of identifiable plant macrofossils (Chambers and Blackford, 2001).

Issues of interpretation do exist, with the complex humification process whereby plant and microbial remains are transformed into humic substances through both biochemical and abiotic processes not fully understood at present or easily quantifiable (Caseldine et al. 2000; Zaccone et al. 2011). The role of peat-forming plant species is widely believed to have an effect upon peat humification (Blackford, 2000; Yeloff and Mauquoy, 2006), although the extent of which remains unknown. Yeloff and Mauquoy (2006) suggested that humification analysis should be carried out alongside plant macrofossil analysis to ascertain the influence of botanical composition, but acknowledged this is not always possible especially in blanket peat where plant macrofossils are often not preserved. Non-pollen palynomorphs indicative of certain bog forming vegetation may be able to assist interpretation in these cases. Payne and Blackford (2008) highlighted that a lack of correlation of humification data between cores, from their study sites in south east Alaska, suggests a lack of clear climate control, and that humification is indeed affected by other factors. Despite these issues, peat humification analysis does remain a useful and simple, although uncalibrated, technique of observing general trends in water-table dynamics in peatlands, and observing more variability than can be visibly seen in the stratigraphic record (Blackford, 2000).

5.4.2 Laboratory method:

The degree of peat humification was determined using an alkali extraction and colorimetry technique (Aaby, 1975; Blackford and Chambers, 1993). Samples were first dried in a convection oven at 40°C for 48 hours. They were then ground to a powder in a pestle and
mortar. A solution of 8% NaOH was added to the samples which were then brought to the boil and reduced to simmer on a hot plate for 2 hours. This extracted the humic acids produced in the decomposition process. The samples were filtered through a Whatman Number 1 filter paper and the colour of the resulting filtrate was measured for percentage light transmission using a CO7500 colorimeter (at 540nm), and expressed as a percentage of light transmittance (%LT) relative to deionised water. It is assumed that more highly decomposed peat produces a darker coloured alkali extract and therefore records lower light transmissions (Blackford and Chambers, 1993).

5.5 Inorganic Geochemistry

5.5.1 Theory:

The establishment and expansion of settlements and land use regimes can often create changes in the level of vegetation cover. Through processes such as woodland clearance and soil destabilisation, this activity may be reflected in varying intensities of erosion (Hölzer and Hölzer, 1998; Coombes et al. 2009). This erosional material from bare soils is transported onto bogs and into lakes through runoff or wind and rain deposition (Lomas-Clarke and Barber, 2004), where it is preserved. Soil derived silicon and titanium have been identified as good indicators of erosion from woodland clearance and farming activities (Hölzer and Schloss, 1981; Gorres and Frenzel, 1993; Kempter et al. 1997; Lomas-Clarke and Barber, 2004), with peaks in concentrations attributable to increased levels of human impact. Hölzer and Hölzer (1998) found a close correlation between pollen indicators of human impact such as Plantago lanceolata and Cerealia and silicon and titanium concentrations, although Plantago lanceolata occasionally lagged behind geochemical values, and Coombes et al. (2009) found that small increases in titanium above background levels coincided with reductions in Ulmus and Quercus, and an expansion of cereal cultivation.

Silicon may also be found in diatoms (Hölzer and Hölzer, 1994) and the opal phytoliths of Cyperaceae and Equisetum (Barber, 1981). Titanium comes from the same soil source as silicon, but is not also found in plants or algae. The significantly smaller concentrations of titanium in peat however make it slightly more difficult to measure, and so the two elements are often measured together. Concurrent peaks in both elements are suggested to reflect landscape instability rather than plant or diatom contributions (Hölzer and Hölzer, 1998). Coombes et al. (2009) suggested that peaks in silicon and titanium
contemporaneous with other human impact indicators were more convincing, and that peaks in concentration most likely reflected periods of landscape transition rather than established land use, as they found concentrations to decline whilst agriculture continued. Silicon and titanium analyses therefore have the potential to supplement the palynological record of human impact, especially where such early disturbances may be difficult to detect in the pollen record.

The following method outlines the testing of the field-portable X-ray fluorescence (FP-XRF) to ascertain the best methodology to obtain reliable silicon and titanium concentrations from both peat and gyttja sediment cores.

5.5.2 Laboratory method:

5.5.2.1 Sample preparation

Silicon and titanium concentrations were determined using a handheld Niton XL3t 900 XRF analyser. Analysis on wet sediment would be advantageous as it would leave the sediment core intact, and save significant sub-sampling, drying, homogenisation and potting-up time. However moisture content may be a major source of error when analysing samples that are saturated, as water absorbs and scatters x-rays, which lowers precision and accuracy and increases detection limits (Ge et al. 2005). This error can be minimized by drying the samples, and so samples were freeze-dried in preparation for analysis. Drying and prepping bulk samples also provides a more representative measurement of the sample, as scanning the top layer will only reflect the composition of the top 3mm of the sediment which can lead to high-amplitude variability.

10mm slices of bulk sediment were sampled from each sediment core. Samples were then freeze-dried to remove moisture content. To ensure a homogenous fine powder, samples were passed through a 250µm sieve before being potted up in sample pots using thin 4µm Mylar X-Ray Film (Ridings et al. 2000).

The FP-XRF chamber was purged with helium for a minimum of 50 minutes prior to measurement, to reduce the effect of the air gap between the sample and the sensor/receiver, so as to increase the ability of the machine to accurately detect the lightest elements - in this case silicon.
5.5.2.2 Testing the level of accuracy of the FP-XRF

To confirm there were no calibration issues and that the FP-XRF chamber was sufficiently purged, Certified Reference Material (CRM) 2709a was measured three times prior to the commencement of sample measurement. After a 50 minute helium purge, the FP-XRF consistently under-estimated silicon by c.13% and over-estimated titanium by c.6%. However, repeat analysis of the CRM produce coefficients of variation (CV) of only of 1% and 1.75% for silicon and titanium respectively, indicating that analyses of the CRM could be repeated at high precision.

5.5.2.3 Time series analysis to identify optimum count-time

A selection of samples across both sediment cores were analysed for silicon and titanium with count times of 60 seconds, 120 seconds and 180 seconds. As samples must be measured on two separate bands for the two elements, and re-measured three times to assess precision, 180 seconds was thought reasonable as a maximum count time in terms of overall time constraints. The percentage error of measurements was expected to decline with increasing count time, and so these results would allow an optimum count time to be identified for the remainder of samples, where the benefits of increasing precision would outweigh the extra time-cost.

Figure 5.1 – Silicon concentration measurements at a range of count times from Dan Clough Moss, with corresponding percentage error.
Figure 5.2 – Titanium concentration measurements at a range of count times from Dan Clough Moss, with corresponding percentage error.

Figure 5.3 – Silicon concentration measurements at a range of count times from Bökeberg, with corresponding percentage error.
Percentage error was observed to decrease with increasing count times on the FP-XRF, as expected. Results suggest that less than 10% error can be achieved for most sample concentrations, if analysed for 180 seconds. Samples with <400ppm silicon or <200ppm titanium however yielded larger percentage errors, at 12.5% and 14 to 40% respectively. Lower precision must therefore be acknowledged for extremely low concentrations.

### 5.5.2.4 Testing precision down-core

Samples were re-homogenised and measured three times at the identified optimal count time for each element. This increased the confidence and representivity of mean concentrations calculated for each sample, and facilitated an assessment of the heterogeneity of the sample matrix. Precision of the three repeat measurements was assessed using the CV statistic. For Dan Clough Moss, CV was found to be on average less than 20% for silicon and less than 30% for titanium. For Bökeberg, the CV of both silicon and titanium was less than 10%.

These statistics support results found in chapter 5.5.2.3, with the overall extremely low concentrations of silicon and especially titanium at Dan Clough Moss contributing to lower precision results. Whilst a CV value of less than 10% is preferred, it is notable that the higher CVs derived for Dan Clough Moss do not appear to mask significant peaks in
concentrations and relative trends within the sediment core, as reflected by the range of variability in Fig. 5.5 and Fig. 5.6. The lower CV for the Bökeberg core is largely reflective of the greater concentrations of the elements of interest within the core. Within-core variance at Dan Clough Moss may also reflect a lower level of homogenisation of the fibrous peat sediment.

Figure 5.5 – Down-core variability in FPXRF derived silicon and titanium concentrations at Dan Clough Moss, including max and min values for each sampling point.

Figure 5.6 – Down-core variability in FPXRF derived silicon and titanium concentrations at Bökeberg, including max and min values for each sampling point.
5.5.2.5 Data presentation

Silicon and titanium were expressed as influx of micrograms per volume of sediment per year (µm²/cm³/yr) at Dan Clough Moss due to a varying sedimentation rate and secure chronology throughout the analysed profile. As sedimentation is more linear at Bökeberg, and the chronology less secure, silicon and titanium were expressed as a concentration per volume of sediment (µm²/cm³).

Titanium originates from the same soil source as silicon, yet silicon can also be found in diatoms (Hölzer and Hölzer, 1994) and the opal phytoliths of Cyperaceae and Equisetum (Barber, 1981). The ratio of silicon/titanium (Si/Ti) was therefore calculated to indicate levels of biogenic silica deposition in Bökeberg’s lake sediment (Peinerud et al. 2001).

5.6 Pollen

5.6.1 Theory:

Pollen analysis is one of the most widely used techniques within palaeoecology, due to the abundance of the microfossils themselves and the range of sediment types in which they are preserved. A principle assumption of the method is that changes in the pollen assemblage identified within a stratigraphic layer of a sediment reflects changes in the flora that grew at or near the site when the deposit was formed (Moore et al. 1991). If the ecological requirements of the individual species are known, it is then possible to draw inferences about the past environment including woodland dynamics, landscape openness, human impact upon vegetation, and climate change (Birks and Birks, 1980; Gaillard, 2007). The modern-analogue indicator-species approach developed by Behre (1981, 1986) and Hjelle (1997, 1999) is a simple and frequently used method of identifying human interference with the vegetation. Pollen within surface samples collected from sites exhibiting certain land-uses are inspected to pinpoint those species which are uniquely associated with each type of land use. These then become markers of that land-use type in the fossil pollen record (Behre, 1981, 1986; Hjelle, 1997, 1999). Potential issues with this approach include modern analogues not existing for all past land-uses, and the assumption that the ecological tolerances of the species have not changed over time.

Inferences about woodland cover and human impact from the fossil pollen record are therefore not straightforward, with constructed pollen diagrams representing those parts of the pollen rain that have been recovered after fossilisation, sampling and preparation.
Many factors contribute to the over- and under-representation of pollen taxa, and must be borne in mind when interpreting pollen diagrams. The quantity of pollen deposited at any one time is dependent on a number of factors besides the frequency of the species in the area (Sugita and Takahara, 2001). Pollen productivity can vary due to a variety of factors. It can greatly depend upon the frequency of flowering, with Betula and Alnus flowering every year thereby producing a lot of pollen, but with Fraxinus, Fagus and Quercus having intervals between flowering years, producing less pollen and can therefore be under-represented in the pollen assemblage (Andersen, 1970; Hicks, 2007). Additional factors such as grazing pressure upon vegetation have also been shown to reduce pollen productivity rates (Groenman-van Waateringe, 1993). The conditions under which the plant grows is also a significant factor, with those plants growing in an open position producing and contributing more pollen to the record than those growing in a closed stand. The mechanism by which the plant is pollinated is significant. Wind-pollinated species have developed dispersal mechanisms to scatter their grains as effectively as possible, whereas insect-pollinated and self-pollinating plants are less efficient at doing so. For example, Tilia, Acer and Salix are known to produce significant quantities of pollen, but due to being insect-pollinated, have a less effective dispersal of their pollen and are often severely under-represented in the pollen rain as a result (Faegri and Iversen, 1989).

An appreciation of these factors is essential to accurately interpret a pollen diagram, yet useful inferences from pollen data have been shown to be possible without an exact representation of each species. Surface sample investigations have shown that despite potential pitfalls, pollen analysis is representative of the vegetation that prevailed at the time of deposition, and pollen taxa do reflect the major patterns of plant dynamics (Yu et al. 2004; Hicks, 2007).

5.6.2 Laboratory method:

Samples of 0.4ml were measured volumetrically, and a Lycopodium tablet with a predetermined quantity of spores was added prior to preparation to enable the concentration of pollen species to be determined (Benninghoff, 1962). Samples were prepared following standard procedures (Moore et al, 1991), including the removal of humic acids using potassium hydroxide, sieving through a 125µm mesh to remove coarse plant debris, and acetolysis to remove cellulose. Samples were then be dehydrated using ethanol and tert-butyl alcohol, and mounted onto glass slides using silicone oil of viscosity.
12,500 cS for examination under x400 magnification using a Zeiss light microscope. Critical identifications were made at x1000 using phase contrast microscopy and an oil immersion objective.

The choice of the number of grains counted in the pollen sum is a compromise between the need to achieve as large a sum as possible within a practical and feasible timescale (Moore et al. 1991). Birks and Birks (1980) suggested that a sum between 300 and 500 should produce a statistically significant result. A minimum sum of 300 terrestrial pollen grains (excluding spores and aquatics) were identified for each sample at March Hill. This was increased to 500 at Bökeberg due to an abundance of Alnus and Corylus, so as to ensure that rare indicator species were represented (Berglund and Ralska-Jasiewiczowa, 1986). Reference was made to the keys of Moore and Webb (1978), Faegri and Iversen (1989), Moore et al. (1991), and the University of Manchester Geography laboratory’s reference slide collection.

A pollen sum of total land pollen (TLP) (trees, shrubs, dwarf shrubs and herbs) has been used for the calculation of percentages and the plotting of pollen results at both sites, as it is most appropriate for showing changes in the balance between trees, shrubs, dwarf shrubs and herbs. Alnus in particular was excluded from the pollen sum, as due to its streamside and wetland preference it may have been locally superabundant and dominate the pollen assemblage to the point where other changes would be difficult to interpret (Janssen, 1959). Pollen and spores have been expressed as percentages of TLP using TILIA 1.4.10 software (Grimm, 2011). Summary curves for trees, shrubs, dwarf shrubs and herbs have also been presented.

Subdivision of a pollen diagram into zones allows sections of similar fossil content to be grouped, and patterns of change through time to be identified. Pollen records were zoned using a Constrained Incremental Sums of Squares cluster analysis (CONISS) as an option within TILIA, based on the pollen sum excluding rare taxa <1% TLP, with a square root transformation employed to increase the influence of the important but lower frequency herbs. CONISS clusters sample levels that are highly similar but is constrained to stratigraphically adjacent samples for division (Grimm, 1987). The results from CONISS were used as a guide, with zones subsequently delimited subjectively based on all multi-proxy data. Stratigraphic zones in the text are numbered and described in ascending order starting at the bottom of the profile.
Table 5.1 – Simplified land cover classes and associated pollen taxa (modified from Brown et al. 2007).

<table>
<thead>
<tr>
<th>Land cover class</th>
<th>Associated pollen taxa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disturbed ground</td>
<td><em>Plantago lanceolata</em>, <em>Chenopodiaceae</em>, <em>Urtica</em>, <em>Brassicaceae</em>, <em>Apiaceae</em>, <em>Mentha</em>, <em>Artemisia</em>.</td>
</tr>
<tr>
<td>Pasture</td>
<td><em>Poaceae</em>, <em>Ranunculus acris</em> -type, <em>Caryophyllaceae</em>, <em>Polygonum</em>, <em>Rumex acetosella</em>, <em>Rumex acetosa</em>, <em>Potentilla</em>, <em>Asteraceae lactucaeae</em>, <em>Asteraceae asteroidae</em>.</td>
</tr>
<tr>
<td>Marsh</td>
<td><em>Sphagnum</em>, <em>Caltha palustris</em>, <em>Filipendula</em>, <em>Succisa pretensis</em>, <em>Cyperaceae</em>.</td>
</tr>
<tr>
<td>Heath/Moorland</td>
<td><em>Juniperus</em>, <em>Betula</em>, <em>Vaccinium</em>, <em>Calluna vulgaris</em>, <em>Empetrum</em>, <em>Ulex</em>.</td>
</tr>
<tr>
<td>Bracken</td>
<td><em>Pteridium</em>.</td>
</tr>
<tr>
<td>Deciduous woodland</td>
<td><em>Pteropsida</em> (monolete indet.), <em>Polypodium</em>, <em>Ulmus</em>, <em>Fagus</em>, <em>Quercus</em>, <em>Alnus</em>, <em>Corylus</em>, <em>Tilia</em>, <em>Populus</em>, <em>Salix</em>, <em>Rubus</em>, <em>Sorbus</em>, <em>Ilex</em>, <em>Hedera</em>, <em>Fraxinus</em>, <em>Sambucus</em>.</td>
</tr>
<tr>
<td>Coniferous woodland</td>
<td><em>Abies</em>, <em>Picea</em>, <em>Pinus</em>.</td>
</tr>
<tr>
<td>Arable</td>
<td><em>Avena-type</em>, <em>Hordeum</em> –type, <em>Secale cereale</em>.</td>
</tr>
</tbody>
</table>

Pollen and spore taxa were placed into 8 simple land cover classes to aid interpretation (Table 5.1; modified from Brown et al. 2007). Problems of taxonomic precision inevitably lead to there being some species of a different ecology within a particular pollen type, however the ecology of the dominant pollen-producing species in each type was utilised when allocating the classes.

5.7 Non-pollen palynomorphs

5.7.1 Theory:

Non-pollen palynomorphs (NPPs) are commonly encountered during the routine counting of pollen grains on microscope slides. They include fungal, algal and faunal remains amongst others, and fungal spores are a particularly important part of the ‘non-pollen’ information stored in peat deposits (van Geel and Aptroot, 2006). Spores settle out under gravity (Deacon, 1984) in an approximate relative proportion to their abundance in the atmosphere (van Geel, 1972). Susceptible to preservation in anaerobic environments, NPPs are commonly found in slides prepared for pollen analysis following standard procedures.
Due to the preferential preservation of heavier spores, the fossil spore record is mostly reflective of local conditions (van Geel, 2001). Certain taxa have limited ecological amplitudes (Graham, 1967), and are sensitive indicators of specific ecological conditions or substrates such as animal dung, decaying wood, surface conditions and/or specific host plants (van Geel 2001; Blackford et al. 2006; Mighall et al. 2006; van Geel and Aptroot, 2006; Yeloff et al. 2007).

The value of NPPs in increasing our understanding of past ecosystem evolution has been increasingly recognised over the last few decades (Haas, 2010). An effective source of additional, complementary palaeoecological data (Van Geel, 2001; van Geel and Aptroot, 2006), NPPs can help disentangle vegetation and land use histories inferred from other more common proxies such as pollen analysis (e.g. Blackford et al. 2006; Mighall et al. 2008; Ryan and Blackford, 2010; Innes et al. 2013). NPPs therefore play an increasingly important role in interdisciplinary investigations including palaeoecological, archaeological and historical research.

Obligate dung genera such as Sporormiella (HdV-113) are known to grow on a wide variety of animal dung, especially herbivore dung (Davis, 1987; Baker et al. 2013). As pollen indicators of local grazing can also occur on un-grazed land and have ecological amplitudes too large to infer grazing with any confidence on their own (Hoaen and Coles, 2000), if present these taxa significantly contribute to the reconstruction of local grazing history (e.g. van Geel et al. 2003; Davis and Shafer, 2006; Court-Picon et al. 2006; Ryan and Blackford, 2010; Innes et al. 2013). They are particularly useful for identifying the presence of grazed woodland, which is otherwise difficult to detect palynologically (Vera, 2000; Mitchell, 2005). Most of the Sordariceae are also coprophilous (Lundqvist, 1972), and fungal types such as Cercophora (HdV-112) and Podospora (HdV-368) have also been used to suggest the presence of grazing animals (van Geel et al. 1986; 2001; Innes and Blackford, 2003; Ryan and Blackford, 2010). Whilst the species of these genera are predominantly associated with dung, they have also been found associated with a wide range of organic materials including dead wood and leaves. The obligate dung genus Sporormiella (HdV-113) therefore remains the most reliable indicator of dung at present, even though uncertainties with regards to taphonomy and preservation in certain environments, and the impact that local hydrology might have on its distribution, still exist (Baker et al. 2013).

Although the most direct indicator of fire is charcoal, it is often not possible to clearly distinguish whether the charcoal originated from a local or regional fire event (Blackford et
al. 2006). Fungal spores specifically associated with burnt plant matter such as *Neurospora* (HdV-55C) and *Gelasinospora* (HdV-1/2) (van Geel, 1978, 1986; Boyd, 1986) can therefore improve the palaeoecological information gained from traditional charcoal analysis, and have been used to indicate the local occurrence of fire (e.g. Blackford et al. 2006).

Fungal taxa found to be associated with specific host plants hold the potential to elucidate uncertainties within the pollen record, helping to distinguish between local and more regional vegetation changes (Blackford et al. 2006). For example, HdV-10 is associated with ericaceous rootlets (van Geel, 1978; Kuhry, 1985), whilst *Meliola ellisi* (HdV-14) is specifically associated with the leaves of *Vaccinium* (Dennis, 1978) although other ericaceous plants such as *Calluna vulgaris* must also have been a host plant (van Geel, 1978; van Geel and Aptroot, 2006). *Anthostomella* spores have been found in association with the local presence of *Eriophorum vaginatum* (van Geel, 1978; Long, 1994).

5.7.2 Laboratory method:

The most commonly used method of sample preparation for NPP analysis is the sequence of digestions and sieving standard for pollen preparations, with NPPs analysed alongside pollen in the same slides (e.g. Innes and Blackford, 2003). Recognising that standard pollen preparation procedures including acetolysation can affect or destroy parts of pollen grains, testate amoebae and Dinoflagellates, Clarke (1994) carried out a systematic study into preparation techniques for palaeomycological studies. Three different sediment types were prepared in three different ways, and results demonstrate that the standard palynological sample preparation is appropriate for the analysis of small fungal remains.

At present, the taxonomy of NPPs is such that it includes a mixture of taxa known to species level, family level, or solely to ‘Type’ number. NPPs encountered during the routine pollen count were identified on the basis of descriptions outlined in various published studies by van Geel and co-workers (e.g. van Geel, 1972; 1978; Pals et al. 1980; Kuhry, 1985; van Geel et al. 2003; van Geel and Aptroot, 2006). The author is grateful to Prof. J.J. Blackford who provided access to his unpublished fungal spore key which was a great aid to identification.

NPPs can be presented as a percentage of the main pollen sum (in this case TLP). Here however NPP taxa have been expressed as a percentage of an entirely NPP-derived sum (NPP), as this approach acknowledges their very different methods of production and
dispersal, and has the advantage of the NPPs being completely independent of the pollen data from the same levels, making statistical relationships between the two more valid (Innes et al, 2003). A minimum of 100 NPPs have been identified in each sample level. NPP data have been plotted alongside pollen data in the same format, to allow ease of analysis and comparison with other proxies.

5.8 Charcoal analysis

5.8.1 Theory:

Formed as a result of incomplete combustion of plant tissue (Patterson et al, 1987), charcoal offers the most direct evidence of the occurrence of fire in the past. Preserving well in lake, peat and soil deposits (e.g. Edwards and Whittington, 2000; Innes and Simmons, 2000; Whittington, 1983), stratigraphical analysis of charcoal can enable a reconstruction of past fire history, which can then be linked with vegetation change, climate change and human disturbances (Simmons and Innes, 1987; Edwards, 1990; Mason, 2000; Whitlock and Larsen, 2001; Innes et al. 2013).

As micro-charcoal is potentially wind-borne over large distances, perhaps even over sub-continental or global scales (Clark, 1988), a proportion of that found in sediment inevitably reflects regional not local fire events (Patterson et al. 1987). Larger macro-charcoal fragments (>500µm) however are assumed more representative of local fire events as fragments are often too large to be atmospherically transported distances more than a few metres, and so deposit either in situ, or via catchment erosion or discharge. These assumptions are supported by studies of charcoal from surface samples and sediment traps following modern fires. Blackford (2000) found that particles greater than 125µm were absent or less abundant on unburned ground, whilst they were most abundant in samples from the burned areas. Likewise, Ohlsen and Tryterud (1999) found the chances of finding charcoal >500µm within burned areas 90 times that within unburned areas, and virtually no charcoal >500µm was identified more than 1m from the edge of the burn. Analysing both microscopic and macroscopic charcoal therefore has the potential to distinguish between local and regional fire signals.

The resolution of samples analysed can have a significant impact on the interpretation of past fire histories. Coarse resolution sampling incorporating 15-20 years of accumulation may obscure the duration and return frequency of individual fire events. Fine-resolution
sampling can resolve major burning phases into discrete sub-phases that may reflect individual fires (Innes and Simmons 2000). Similarly, non-contiguous sampling may result in fire events remaining unobserved (Clark, 1988). Samples were therefore analysed contiguously and at fine resolution.

5.8.2 Laboratory method:

5.8.2.1 Micro-charcoal analysis

Micro-charcoal will be counted from standard pollen preparations. Whilst Rhodes (1998) suggested that pollen preparation procedures could have detrimental effects on the charcoal particles, Clark (1984) found no significant difference in the frequency of fragments or the area of charcoal encountered between control samples and those which had gone through the full pollen preparation procedure. The area of each micro-charcoal fragment encountered during the routine pollen count was recorded with the aid of a gridded-graticule eyepiece. This method gives greater weight to larger particles unlike the absolute abundance method where all charcoal particles are counted regardless of size (e.g. Iversen, 1941; Davis, 1967), which may be misleading if comparing samples with relatively few large fragments of charcoal with those with more frequent smaller fragments (Vescovi et al. 2010). It also removes any bias that may arise from mechanical fragmentation of the charcoal during the pollen preparation procedure (Rhodes, 1998). Fragments that were black, opaque and angular were identified as charcoal (Patterson et al. 1987).

Charcoal was expressed as influx of micro-charcoal per volume of sediment per year (µm²/cm³/yr) at Dan Clough Moss due to a varying sedimentation rate and secure chronology throughout the analysed profile. As sedimentation is more linear at Bökeberg, and the chronology less secure, charcoal was expressed as a concentration per volume of sediment (µm²/cm³).

5.8.2.2 Macro-charcoal analysis

Macro-charcoal fragments (>125µm) sieved out during the pollen preparations were retained and examined in a petri-dish with a low-power binocular microscope at x25 magnification. An eyepiece graticule was utilised to sum macro-charcoal fragments into 125-500µm and >500µm size classes, which were then expressed as influx per year.
(\mu m^2/cm^3/yr) for Dan Clough Moss, and as a concentration per unit volume of sediment for Bökeberg (\mu m^2/cm^3).

5.9 Chronology

5.9.1 AMS radiocarbon dating

5.9.1.1 Theory:

Radiocarbon dating is a radiometric technique which can be used to calculate the age of carbon bearing material up to a maximum of 50-60,000 years (e.g. Behre and van der Plicht, 1992; Bird et al. 2003). Dates can be obtained on a range of biogenic materials, including wood, peat, organic lake sediment, plant macro-fossils, charcoal, shell and coal (Walker, 2005).

Radiocarbon (\textsuperscript{14}C) is one of three isotopes of carbon. Both \textsuperscript{12}C and \textsuperscript{13}C are stable isotopes, however \textsuperscript{14}C decays to a stable form of nitrogen (\textsuperscript{14}N) through the emission of beta (\beta) particles, hence its radioactive nature. \textsuperscript{14}C is naturally formed by reactions in the upper atmosphere between cosmic ray neutrons and nitrogen. This \textsuperscript{14}C then oxidises to CO\textsubscript{2} and becomes part of the global carbon cycle being assimilated by plants through photosynthesis, and animals through the ingestion of plant tissue. Although the \textsuperscript{14}C within organisms is constantly decaying, it is also being continuously replenished from the atmosphere and so remains at a level equal to the atmosphere at that time. When an organism dies however, the uptake of \textsuperscript{14}C stops, and the \textsuperscript{14}C in the organism starts to decay at a known constant rate - its radiocarbon half-life. By measuring the amount of \textsuperscript{14}C that remains in a sample of fossil material, and comparing this to modern \textsuperscript{14}C, an age can be inferred for the death of the organism (Aitken, 1974; Bowman, 1990; Walker, 2005).

The production of \textsuperscript{14}C in the atmosphere however is not constant through time, and the causes of these variations remain unknown. Hypotheses include cosmic ray flux may vary due to changes in the strength of the earth’s geomagnetic field (Mazeaud et al. 1992), or by variations in the intensity of solar activity and solar winds (Stuiver et al. 1991). Such variations in the production of \textsuperscript{14}C means the \textsuperscript{14}C age of a sample does not reflect the true age, and it must be calibrated to convert to calendar age (Damon, 1970; Bowman, 1990; Walker, 2005). Calibration curves are produced by the international radiocarbon community, primarily through direct comparison between the ages of wood determined by dendrochronology and radiocarbon dates obtained from individual wood increments. The
latest of these is IntCal13 and allows $^{14}\text{C}$ dates to be calibrated to calendar years easily, extending back to about 50,000 years ago.

5.9.1.2 Laboratory Method:

Chronological control of the analysed sediment sequences has been provided by high precision Accelerator Mass Spectrometry (AMS) radiocarbon dating. Developed in the 1980s, AMS dating involves particle accelerators being employed as mass spectrometers to count the relative number of $^{14}\text{C}$ in a carbon bearing sample, as opposed to decay products measured during the alternative approach to radiocarbon dating, beta counting (Walker, 2005). Although more expensive, advantages of AMS over beta counting are the increased speed at which samples can be processed, and the smaller sample size required (Walker, 2005). Samples as small as a single seed or pollen grains can now be dated (e.g. Vandergroes and Prior, 2003) due to just 1mg of organic carbon being required for analysis. The potential temporal resolution of samples is therefore high (Chambers and Charman, 2004), with the smaller sample sizes producing dates that are both accurate and highly precise.

The reliability of the $^{14}\text{C}$ dating technique depends greatly on the material used for dating. At Dan Clough Moss, the plant fraction of each bulk peat sample, with any obvious contaminated rootlets removed, was used for analysis (Fig. 5.7) as in peat it is assumed to be in-situ and represent a short-lived specimen. The humic fraction, whilst also too small for a successful determination, may have been susceptible to downwash through the profile.

Figure 5.7 – Plant fraction of sample Beta-336993 used for AMS radiocarbon dating at Dan Clough Moss
The catchment of Lake Yddingesjön contains geologically old carbonate, which can be a source of infinitely old carbon for lake water. It dilutes the $^{14}$C concentration of the water, with any plants that photosynthesise sub-aqually, aquatic algae or animals which may feed on such plants and/or each other, also susceptible to this dilution in $^{14}$C levels. Due to this hard-water effect, lakes in southern Sweden are susceptible to radiocarbon errors of between ±200 and ±1000 years (Gaillard et al. 1991). Lake Yddingesjön is known to be affected by a hard-water effect of up to 400 years (Regnell, M. Pers. com.), and so macrofossils of terrestrial plants, which would have been in equilibrium with atmospheric $^{14}$C levels and hence not influenced by the hard-water effect, were therefore sought for AMS radiocarbon dating. In sections close to the horizons of interest, up to 4 cm$^3$ of material was sieved using 180µm and 90µm sieves, and then dispersed in deionised water to be examined under x20 magnification using a low-power binocular microscope. Identifications were made with reference to Birks (2007) and Maquoy and van Geel (2007), and the kind assistance of Dr. Charlotte O’Brien (Durham University) and Dr. Barry Taylor (University of Chester).

5.9.2 Age-depth modelling

The computer program OxCal v.4.2 (Bronk Ramsey, 2009a) and calibration curve IntCal13 (Reimer et al. 2013) was used to calibrate $^{14}$C dates and produce an age-depth model. OxCal and the use of Bayesian statistical modelling of radiocarbon dates has increased significantly within both Quaternary Science and Archaeology over the last 25 years. Bayes theorem tells researchers how to combine both prior information (what is known about the system before they start, e.g. the order of deposition) and likelihoods (the information that is obtained from a set of measurements. e.g. probability distribution functions (PDFs) for radiocarbon dated samples) (Bronk Ramsey, 2008). The aim of the model created is to find the best set of possible ages for each depth point in a sedimentary sequence. The algorithms within Bayes theorem “sample over all possible solutions with a probability which is a product of the prior and likelihood probabilities. The resulting distributions are referred to as the posterior probability densities and take account of both the deposition model and the actual age measurements made” (Bronk Ramsey, 2008, p.43).
Table 5.2 - Range of depositional models with their OxCal keywords (adapted from Bronk Ramsey, 2008).

<table>
<thead>
<tr>
<th>OxCal Keyword</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>D_Sequence</td>
<td>Age gaps between points known precisely (as in the case of tree rings, varved sediments or ice layers)</td>
</tr>
<tr>
<td>V_Sequence</td>
<td>Age gaps between points known approximately with normally distributed uncertainty</td>
</tr>
<tr>
<td>U_Sequence</td>
<td>Deposition assumed to be a function of another parameter z (usually defined as depth)</td>
</tr>
<tr>
<td>P_Sequence</td>
<td>Deposition assumed to be random giving approximate proportionality to z (usually defined as depth)</td>
</tr>
</tbody>
</table>

A Poisson Sequence (P_Sequence) was chosen as the most appropriate deposition model as it assumes deposition is random, and gives approximate proportionality to depth (Bronk Ramsey, 2008). The parameters of the model are

$$P_{\text{Sequence}}(k_0, p, D)$$

where $k_0$ is the base $k$ parameter, $p$ is the interpolation rate, and $D$ is the prior distribution. The rigidity of the model is defined by the $k$ parameter. Originally a fixed $k$ (Bronk Ramsey, 2008), Bronk Ramsey and Lee (2013) presented an extension to the model that allows for the specification of a variable $k$, to overcome the fact that $k$ values may vary by orders of magnitude depending on the sedimentary context.

Following Bronk Ramsey and Lee (2013), the age-depth models for both March Hill and Bökeberg have been defined as:

$$P_{\text{Sequence}}(0.1, 0.4, U(-2,2)).$$

The base $k$ parameter ($k_0$) was defined as 0.1 due to the fine nature of sedimentation, the interpolation rate ($p$) was defined as 0.4mm$^{-1}$ to allow the output of the model to be at 2.5mm resolution, and a default uniform prior distribution of $D$ ($U(-2, 2)$) was used which allows $k$ to vary between a factor of $10^{-2}$ and $10^2$.

A Boundary was included at $z=1380$ for March Hill to allow the model to extrapolate age-depth information to the top of the profile. Two boundaries were added to the Bökeberg model at the top ($z=2465$) and bottom ($z=3705$) of the sediment sequence for this same purpose.
6. March Hill Results

6.1 Preliminary fieldwork

Well-dated stratigraphic records did not previously exist at March Hill, therefore preliminary fieldwork was necessary to identify the optimal location for palaeoenvironmental investigation. Although the mineral soil underlying the blanket peat of the area could show some potential for pollen analysis (Dimbleby, 1957), potential difficulties such as poor preservation, removal of the pollen from the soil by downwash, and disturbance of the pollen stratigraphy through downwash or mixing of the soil could limit confidence in palaeoecological data gained from such material (Tallis, 1964). A location where peat initiation preceded the onset of the Neolithic (c.6000 cal BP) was sought to enable palaeoenvironmental reconstructions through the Mesolithic-Neolithic transition period.

In September 2010, a number of boreholes were recovered around March Hill and the archaeological sites identified during the 1990s excavations by West Yorkshire Archaeological Service (Fig. 6.1). The stratigraphies of six sediment cores were recorded in the field (Table 6.1). Pollen analyses were performed on basal peat samples of each core to estimate the approximate age of peat initiation. The well constrained record of the South Pennine Ulmus- decline c.4860 BP (c.5645-5585 cal BP 1σ) (Tallis and Switsur, 1990) provided the means of estimating whether peat initiation at a particular location was pre-c.6000 cal BP.
Figure 6.1 – Location of preliminary boreholes around March Hill
Table 6.1 – Stratigraphy of preliminary boreholes

<table>
<thead>
<tr>
<th>Borehole</th>
<th>Depth (mm)</th>
<th>Stratigraphy</th>
</tr>
</thead>
<tbody>
<tr>
<td>March Hill Top (a)</td>
<td>0-90</td>
<td>Unsampled</td>
</tr>
<tr>
<td>(borehole 1)</td>
<td>90-240</td>
<td>Dark brown humified silty peat</td>
</tr>
<tr>
<td></td>
<td>240-400</td>
<td>Black well humified silty peat</td>
</tr>
<tr>
<td></td>
<td>400-460</td>
<td>Brown silty sand</td>
</tr>
<tr>
<td></td>
<td>460-500</td>
<td>Light brown silty sand, increasing sand towards base</td>
</tr>
<tr>
<td>March Hill Top (b)</td>
<td>0-190</td>
<td>Black humified peat</td>
</tr>
<tr>
<td>(borehole 2)</td>
<td>190-330</td>
<td>Black sedge peat</td>
</tr>
<tr>
<td></td>
<td>330-410</td>
<td>Brown silty sand</td>
</tr>
<tr>
<td></td>
<td>410-430</td>
<td>Red-brown iron rich sand</td>
</tr>
<tr>
<td></td>
<td>430-500</td>
<td>Orange-brown sand</td>
</tr>
<tr>
<td>March Hill Hummocks</td>
<td>0-450</td>
<td>Unsampled</td>
</tr>
<tr>
<td>(borehole 3)</td>
<td>450-520</td>
<td>Orange-brown poorly humified sedge peat</td>
</tr>
<tr>
<td></td>
<td>520-540</td>
<td><em>Sphagnum</em> peat</td>
</tr>
<tr>
<td></td>
<td>540-560</td>
<td>Orange-brown poorly humified sedge peat</td>
</tr>
<tr>
<td></td>
<td>560-825</td>
<td>Orange-brown poorly humified sedge peat</td>
</tr>
<tr>
<td></td>
<td>825-860</td>
<td>Very dark grey-black silty peat</td>
</tr>
<tr>
<td></td>
<td>860-915</td>
<td>Light grey-brown silt</td>
</tr>
<tr>
<td></td>
<td>915-920</td>
<td>Charcoal</td>
</tr>
<tr>
<td></td>
<td>920-960</td>
<td>Light brown stratified silt</td>
</tr>
<tr>
<td></td>
<td>960-1055</td>
<td>Dark brown sedge peat with wood</td>
</tr>
<tr>
<td></td>
<td>1055-1150</td>
<td>Light brown stratified silt</td>
</tr>
<tr>
<td></td>
<td>1150-1400</td>
<td>Dark brown sedge peat with wood</td>
</tr>
<tr>
<td>March Hill Plateau</td>
<td>0-1560</td>
<td>Unsampled</td>
</tr>
<tr>
<td>(borehole 4)</td>
<td>1560-1745</td>
<td>Dark brown sedge peat</td>
</tr>
<tr>
<td></td>
<td>1745-1746</td>
<td>Charcoal</td>
</tr>
<tr>
<td></td>
<td>1746-1850</td>
<td>Dark brown sedge peat</td>
</tr>
<tr>
<td></td>
<td>1850-1851</td>
<td>Charcoal</td>
</tr>
<tr>
<td></td>
<td>1851-2070</td>
<td>Dark brown sedge peat with wood</td>
</tr>
<tr>
<td></td>
<td>2070-2500</td>
<td>Silty peat</td>
</tr>
<tr>
<td>March Hill Carr</td>
<td>0-205</td>
<td>Black sedge peat</td>
</tr>
<tr>
<td>(borehole 5)</td>
<td>205-270</td>
<td>Brown silty sand</td>
</tr>
<tr>
<td>Dan Clough Moss</td>
<td>0-400</td>
<td><em>Sphagnum</em> peat with sedge peat</td>
</tr>
<tr>
<td>(borehole 6)</td>
<td>400-900</td>
<td>Sedge peat with wood pieces and charcoal banding</td>
</tr>
<tr>
<td></td>
<td>900-1400</td>
<td>Sedge peat with <em>Sphagnum</em></td>
</tr>
<tr>
<td></td>
<td>1400-2315</td>
<td>Dark brown sedge peat</td>
</tr>
<tr>
<td></td>
<td>2315-2470</td>
<td>Silty peat</td>
</tr>
</tbody>
</table>
Fig 6.2 – Results of preliminary pollen analyses on basal peat samples, expressed as %TLP (total land pollen).
Table 6.2 – Proportions of *Ulmus* in basal peat samples, expressed as %TLP (total land pollen) and %APC (AP=trees C=Corylus + Salix).

<table>
<thead>
<tr>
<th>Borehole no.</th>
<th>Borehole name</th>
<th>Depth of basal pollen sample (mm)</th>
<th><em>Ulmus</em> (%TLP)</th>
<th><em>Ulmus</em> (%APC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>March Hill Top (a)</td>
<td>385-390</td>
<td>0.33</td>
<td>1.01</td>
</tr>
<tr>
<td>2</td>
<td>March Hill Top (b)</td>
<td>315-320</td>
<td>0.33</td>
<td>0.79</td>
</tr>
<tr>
<td>3</td>
<td>March Hill Hummocks</td>
<td>1385-1390</td>
<td>1.00</td>
<td>1.51</td>
</tr>
<tr>
<td>4</td>
<td>March Hill Plateau</td>
<td>2055-2060</td>
<td>0.33</td>
<td>0.52</td>
</tr>
<tr>
<td>5</td>
<td>March Hill Carr</td>
<td>190-195</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>Dan Clough Moss</td>
<td>2300-2305</td>
<td>4.67</td>
<td>6.31</td>
</tr>
</tbody>
</table>

Results of this initial pollen analysis (Fig. 6.2, Table 6.2) identified Dan Clough Moss as the only borehole location where peat initiation was clearly pre-*Ulmus* decline. Tallis and Switsur (1990) found average post *Alnus*-rise, pre-*Ulmus* decline samples to contain *Ulmus* c.5% APC, a pollen sum that included AP (all trees) and C (*Corylus* and *Salix*). The basal pollen sample at Dan Clough Moss yielded 6.31% APC *Ulmus*, whilst others had less than 2% APC. It also appeared to have the highest level of trees and shrubs at 74% TLP, with high levels of *Quercus*, *Alnus* and *Corylus* accompanying *Ulmus*, *Tilia*, *Betula* and *Pinus*. The core from Dan Clough Moss was therefore used for further analyses.

### 6.2 Dan Clough Moss

The stratigraphy, chronology and results of high-resolution multi-proxy analyses at Dan Clough Moss (SE00441, BNG12525) are outlined below.

#### 6.2.1 Stratigraphy

The stratigraphy of Dan Clough Moss can be seen in Table 6.1.

Total core depth was 2470mm, with organic sedimentation from 2315mm consisting of predominantly sedge peat with varying levels of *Sphagnum* and wood. Black bands of 2-5mm thickness were observed and are attributed to charcoal between 900-400mm.

#### 6.2.2 Sampling strategy

Low-resolution sampling for pollen analysis at 20mm intervals was used to locate the *Ulmus*-decline as a chronological marker, and covered 2305-1380mm to encompass both the late Mesolithic and early Neolithic time periods. High-resolution contiguous pollen samples at 5mm intervals focused on 2205-1580mm.
6.2.3 Chronology

6.2.3.1 Radiocarbon dating

The results of six AMS radiocarbon determinations are presented in Table 6.3.

Table 6.3 – Radiocarbon determinations for Dan Clough Moss. Analyses carried out by Beta Analytic, Florida, with calibrations made using IntCal13 (Reimer et al. 2013) in OxCal 4.2 (Bronk Ramsey, 2009a).

<table>
<thead>
<tr>
<th>Lab Code</th>
<th>Depth (mm)</th>
<th>14C date</th>
<th>δ13C/12C (‰)</th>
<th>cal BP (1σ)</th>
<th>cal BP (2σ)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta-318146</td>
<td>1520-1525</td>
<td>4510±30</td>
<td>-25.3</td>
<td>5290-5062</td>
<td>5301-5048</td>
<td>Peat - plant fraction</td>
</tr>
<tr>
<td>Beta-298436</td>
<td>1720-1725</td>
<td>4950±30</td>
<td>-26.1</td>
<td>5716-5644</td>
<td>5735-5606</td>
<td>Peat - plant fraction</td>
</tr>
<tr>
<td>Beta-318145</td>
<td>1840-1845</td>
<td>5030±30</td>
<td>-27.7</td>
<td>5886-5723</td>
<td>5894-5663</td>
<td>Peat - plant fraction</td>
</tr>
<tr>
<td>Beta-336993</td>
<td>2040-2045</td>
<td>5280±40</td>
<td>-24.0</td>
<td>6177-5991</td>
<td>6184-5940</td>
<td>Peat - plant fraction</td>
</tr>
<tr>
<td>Beta-318144</td>
<td>2200-2205</td>
<td>5430±30</td>
<td>-24.5</td>
<td>6284-6210</td>
<td>6291-6191</td>
<td>Peat - plant fraction</td>
</tr>
<tr>
<td>Beta-298437</td>
<td>2320-2325</td>
<td>5770±40</td>
<td>-27.5</td>
<td>6635-6510</td>
<td>6666-6475</td>
<td>Peat - plant fraction</td>
</tr>
</tbody>
</table>

6.2.3.2 Age-depth modelling

The results of Bayesian age-depth modelling, as described in chapter 5.9.2, upon the radiocarbon determinations outlined in Table 6.3 are presented in Fig. 6.3.

Table 6.4 – Modelled sample resolution for Dan Clough Moss

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Sample resolution (yrs per sample)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2322.5-2202.5</td>
<td>10.95</td>
</tr>
<tr>
<td>2202.5-2042.5</td>
<td>5.68</td>
</tr>
<tr>
<td>2042.5-1842.5</td>
<td>6.27</td>
</tr>
<tr>
<td>1842.5-1722.5</td>
<td>5.74</td>
</tr>
<tr>
<td>1722.5-1522.5</td>
<td>10.61</td>
</tr>
<tr>
<td>1522.5-1382.5</td>
<td>8.46</td>
</tr>
</tbody>
</table>

The age-depth model (Fig. 6.3) provides an estimated mean (μ) calibrated age BP at 2.5mm intervals throughout the analysed profile. Results suggest a relatively fast sediment accumulation of between 0.42 and 0.84 mm per year (11-22 calendar years per 10mm) during the dated interval, with the fastest accumulation rate found between 2202.5 and 1722.5mm. Each 5mm contiguous sample represents c.5.5-11 calendar years (Table 6.4), and confirms the high-resolution nature of the palaeoecological data.
Figure 6.3 – Age-depth model for Dan Clough Moss. Position is depth of the centre of the sample in mm below the peat surface. Modelled date (BP) is the calibrated, modelled age range at each depth, dark blue representing 68.2% uncertainty (1σ), and lighter blue 95.2% (2σ).
The level of uncertainty in the modelled calibrated age is greatest at the top of the profile between 1522.5mm and 1382.5mm. This is attributable to the fact that these dates were modelled using extrapolation from the last radiocarbon determination at 1522.5mm, and thus uncertainty increases the further the model extrapolates.

The mean modelled calibrated age determinations for each sample have been plotted alongside palynological data in Fig. 6.4, 6.5 and 6.6, allowing a chronological Y axis.

6.2.4 Palaeoecological results

Relative microfossil frequency diagrams obtained from Dan Clough Moss are presented. The diagrams have been divided into pollen assemblage zones based on a CONISS analysis of pollen data (see chapter 5.6.2), but with final zones determined subjectively based on the full multi-proxy data. This is then followed by a description of each zone and sub-zone, followed by an interpretation of environmental history.

6.2.4.1 Description of pollen stratigraphic zones

Zone DCM-1:

2305-2190mm (c.6490-6235 cal BP)

At the onset of peat accumulation, trees and shrubs represent 67% of the pollen sum (TLP) whilst herbs represent a relatively high 30% TLP. Alnus, Corylus and Quercus dominate, with lesser amounts of Betula (5%TLP), Ulmus (6% TLP), Tilia (2% TLP) and Pinus (2% TLP). Poaceae are high at 16% TLP, and high values of Rumex acetosa are found (7% TLP). Dwarf shrubs and charcoal is at a minimum. HdV-18 dominates the NPP assemblage accompanied small finds of Chateomium (HdV-7A), Cercophora (HdV-112), HdV-351, Anthostomella (HdV-4) and Copepoda (HdV-28). Percentage light transmission is relatively high at 22%, and Silicon and Titanium levels are low.

Through zone 1, tree and shrub taxa increase from 67 to 80% TLP. Trees increase from 29-45% TLP, while shrubs decline from 38 to 31% TLP. Corylus (decreasing from 38-30% TLP), Alnus (increasing from 25-40% TLP) and Quercus (increasing from 14 to 30% TLP) are the dominant tree and shrub taxa. Salix is present in low quantities (<1% TLP). Dwarf shrubs are low throughout the zone (c.3.5% TLP), and consist of Calluna vulgaris alone. Herbaceous taxa are relatively high, predominantly Poaceae (c.14% TLP) and Cyperaceae (c.6% TLP) with occasional finds of Rumex acetosa, Potentilla, Ranunculus acris –type, Filipendula and
Figure 6.4 – Dan Clough Moss pollen diagram with frequencies calculated as percentages of the pollen sum (TLP excluding *Alnus*)
Figure 6.5 – Dan Clough Moss spore, charcoal, selected NPP and XRF diagram. Spores calculated as percentages of the pollen sum (TLP excluding *Alnus*), charcoal expressed as influx per unit volume per year, NPPs calculated as percentages of the total NPP sum, and silicon and titanium expressed as influx per unit volume per year.
Figure 6.6 – Dan Clough Moss selected NPP and peat humification diagram, with NPPs calculated as percentages of the total NPP sum and peat humification as percentage light transmission.
Chenopodiaceae (<1% TLP). Herbs then decline from c.30 to 22% TLP by the end of the zone. Low quantities of *Pteridium* are present (fluctuating between 0-4% TLP), with lesser amounts of other Pteridophytes. *Sphagnum* increases within the zone from 12% initially to 104% TLP.

Both micro- and macro-charcoal influx estimates increase through the zone, with periods of higher influx (from 2242.5 to 2192.5mm) accompanied by *Gelasinospora* (HdV-1/2). The NPP assemblage is dominated by *Anthostomella* (HdV-4) fluctuating between 4 and 80% of the total NPP sum (NPP), and HdV-18 which declines from a peak at the base of the profile (c.68% NPP) to zero at 2222.5mm. *Copepoda* (HdV-28) are present (c.4% NPP), and HdV-12 appears and peaks at c.49% NPP by 2222.5mm. Of the dead wood and dung fungi, *Coniochaeta xylariispora* (HdV-6), *Sordaria* (HdV-55a), *Chaetomium* (HdV-7a) and *Kretzschmaria deusta* (HdV-44) are present in low quantities, with a peak (14% NPP) of *Cercophora* (HdV-112) at 2262.5mm. *Sporormiella* (HdV-113), an obligate coprophilous fungal spore, is present at 2202.5mm and 2192.5mm. *Puccinia* (HdV-357) is present near the base of the profile. Percentage light transmission is relatively high at c.20%, and Silicon and Titanium influx estimates are low throughout, averaging c.35µg/g/yr and c.3µg/g/yr respectively.

**Zone DCM-2:**

**2190-2075mm (c.6235-6105 cal BP)**

Zone 2 is characterised first by declining tree percentages with an expansion of dwarf shrubs, followed by a peak in herbaceous taxa and a recovery of trees and dwarf shrubs. This zone lasts approximately 130 years in total.

**Sub-zone DCM-2a:**

**2190-2145mm (c.6235-6185 cal BP)**

This sub-zone lasts approximately 50 years, and is defined by a decline in tree pollen as *Calluna vulgaris* expands for the first time. Trees decline from c.38 to 30% TLP through the zone, owing primarily to a decrease in *Quercus* from 30 to 15% TLP. *Alnus* also declines, yet *Quercus* and *Alnus* remain the most frequently encountered woodland taxa together with *Corylus*, which fluctuates between c.25 and 38% TLP. *Betula* and *Ulmus* also experience a decline, while *Pinus* remains c.4% TLP and *Tilia* c.3% TLP. *Hedera* is present (<1% TLP), and
Fraxinus and Salix are recorded after 2167.5mm. Calluna vulgaris expands through the zone to from c.3 to 14% TLP, and Empetrum and Vaccinium appear for the first time. Poaceae percentages remain relatively high at 12% TLP, and Cyperaceae remains c.5% TLP. Sporadic finds of Potentilla and Ranunculus acris–type are recorded, and Pteridium and other Pteridophytes remain c.1% TLP whilst Sphagnum falls from 104% to 9% TLP across the zone.

Micro-charcoal influx peaks at c.2182.5mm and c.2162.5mm, with macro-charcoal influx and Gelasinospora sp. (HdV-1/2) frequency following similar patterns. Sporormiella (HdV-113) also correlates with these fire indicators. Coniochaeta xylariispora (HdV-6) is consistent through the zone, with Cercophora (HdV-112), Sordaria (HdV-55a) and also present in low quantities. HdV-10 is significantly higher, fluctuating in frequency from 14 to 65% NPP. Anthostomella (HdV-4) is lower at c.22% NPP, and Copepoda (HdV-28) and HdV-18 have declined to c.1% NPP in this zone. Meliola ellisii (HdV-14) peaks at 38% NPPs at 2175mm, and HdV-12 reaches c.18% after 2157.5mm. Percentage light transmission remains around 20%, and Silicon and Titanium influx estimates are slightly higher at 59µg/g/yr and 4.5µg/g/yr respectively.

Sub-zone DCM-2b:

2145-2120mm (c.6185-6155 cal BP)

Subzone 2b is defined by lower tree pollen percentages and increases in dwarf shrubs in a phase that lasted approximately 30 years. Tree percentages are low (c.25% TLP), reflecting decreases in Quercus, Tilia, Ulmus, Pinus as well as Alnus. Fraxinus is mostly absent, and Corylus remains steady at c.30% TLP. Dwarf shrubs increase significantly, reflecting a peak in Empetrum (26% TLP at 2137.5mm), accompanying steady and consistent values for Calluna vulgaris and Vaccinium. Poaceae begin lower, but increase through the zone from around 8 to 15% TLP. Potentilla is still present, and Plantago lanceolata appears at 2142.5mm (<1% TLP). Pteridium is absent until 2127.5mm, and Sphagnum has increased to c.30% TLP by the end of the zone.

Micro- and macro-charcoal influx estimates begin low and increase through the zone. Sporormiella (HdV-113) is present throughout most of the zone, reaching 3.5% NPP. 2137.5mm is characterised by sporadic finds of Coniochaeta xylariispora (HdV-6), Cercophora (HdV-112), Sordaria (HdV-55a) and Kretzschmaria deusta (HdV-44). Anthostomella (HdV-4) is low (c.9% NPP), but Copepoda (HdV-28) increase to a peak (14%
NPP) at 2132.5mm. HdV-10 values are very high (ranging between 26 and 75% NPPs), with *Meliola ellisi* (HdV-14) low except for a peak at 2137.5mm. Percentage light transmission remains relatively high, and Silicon and Titanium influx estimates decline slightly.

**Sub-zone DCM-2c:**

**2120-2100mm (c.6155-6135 cal BP)**

Zone 2c is characterised by a significant increase in Poaceae with a decrease in *Corylus* in a phase that lasted approximately 20 years. *Quercus, Alnus* and *Corylus* dominate the tree and shrub taxa. *Alnus* and *Betula* have increased from Zone 2b, whilst *Corylus* has decreased to 19% TLP. *Fraxinus* is present throughout (<1% TLP). There is a large increase in Poaceae in this zone, reaching c.30% TLP. *Empetrum* and *Vaccinium* decline to <1% TLP reducing overall dwarf shrub proportions, *Calluna vulgaris* however remains at c.14% TLP. Herbs such as *Potentilla, Ranunculus acris* –type, *Filipendula*, and *Artemisia* are present in low quantities (0-2% TLP), and *Pteridium* is present throughout (<1% TLP).

High micro-charcoal and macro-charcoal influx estimates are accompanied by *Gelasinospora* sp. (HdV-1/2), with *Coniochaeta xylariispora* (HdV-6), *Sordaria* (HdV-55a) and *Sporormiella* (HdV-113) correlating with peak charcoal. HdV-10 is lower as HdV-12 increases. *Anthostomella* (HdV-4) begins to expand, whilst *Copepoda* (HdV-28) shows a decline. A small decline in percentage light transmission is observed, and both Silicon and Titanium influx estimates increase significantly through the zone, from c.50 to 170µg/g/yr and c.4 to 14µg/g/yr respectively.

**Sub-zone DCM-2d:**

**2100-2075mm (c.6135-6105 cal BP)**

Zone 2d opens with a decrease in Poaceae back to previous levels, and an increase in arboreal types and dwarf shrubs. Trees and shrubs recover to c.70% TLP, with increases in *Quercus, Ulmus, Betula, Pinus, Fraxinus* and *Corylus*. *Alnus* declines to c.16% TLP, yet *Quercus, Alnus* and *Corylus* remain the dominant taxa, with lesser amounts of *Betula* and *Ulmus*. *Calluna vulgaris* expands to a peak of 34% TLP at 2087.5mm, before declining to 10% TLP at the end of the zone. Poaceae levels are lower (c.11% TLP), but remain the dominant herb together with Cyperaceae (c.6% TLP). A range of other herbs are present at times, including *Rumex acetosa, Potentilla, Ranunculus acris* –type, *Artemisia, Urtica,*
Melampyrum, Caltha palustris, Drosera intermedia and Apiaceae. Pteridophytes are found in low quantities throughout, except Pteridium which only occurs at 2087.5mm correlating with a large Sphagnum peak of 460% TLP.

Both micro- and macro-charcoal influx estimates are low, yet dead wood or dung indicators Coniochaeta xylariispora (HdV-6), Cercophora (HdV-112) and Podospora (HdV-368) occur in high numbers between 2092.5 and 2087.5mm. Sporormiella (HdV-113) is only present at 2077.5mm. There is a large increase in Anthostomella (HdV-4) from c.20 to 70% NPPs, accompanied by an increase in Copepoda (HdV-28) (c.2 to 10% NPP) and a decline in both HdV-10 (c.30 to 2% NPP) and HdV-12 (c.40 to 8% NPP). Percentage light transmission is lower at c.16%, and Silicon and Titanium influx estimates remain high.

**Zone DCM-3:**

**2075-2040mm (c.6105-6055 cal BP)**

Zone 3 is dominated by arboreal taxa as dwarf shrub communities have declined, and covers a period which lasts approximately 50 years. Trees and shrubs make up 75% TLP, with Quercus, Alnus and Corylus dominating the pollen assemblage. Salix and Hedera are present at times (<1% TLP), and very low levels of dwarf shrubs are encountered (c.4.5% TLP). The first half of the zone is characterised by relatively high Poaceae (15% TLP) and low Cyperaceae values, while the latter half sees Poaceae falling to c.9% TLP and Cyperaceae increasing to c.9% TLP. Occasional Rumex acetosa, Filipendula, and Ranunculus acris –type are found, with higher values of Ranunculus acris –type identified at the beginning of the zone (c.2% TLP). Pteridophytes are present (c.2% TLP), and high frequencies of Sphagnum spores are found throughout (c.54% TLP).

Micro-charcoal influx estimates are high, peaking at 2062.5mm. Macro-charcoal influx and Gelasinospora sp. (HdV-1/2) are present throughout the zone, and Cercophora (HdV-112) and Sordaria (HdV-55a) are identified (c.2% NPP) from 2057.5mm with Sporormiella (HdV-113) appearing from 2042.5mm. Anthostomella (HdV-4) dominates the NPP assemblage, ranging from 20 to 60% NPP, and is joined by Copepoda (HdV-28) and an increase in HdV-18 and Tilletia sphagni (HdV-27) towards the end of the zone. High levels of HdV-12 are found in the first half of the zone. Percentage light transmission recovers to c.28%, and Silicon and Titanium influx estimates decline to original background values of c.32 and 3µg/g/yr respectively.
Zone DMC-4:

2040-1910mm (c.6055-5890 cal BP)

Zone 4 is characterised by a further large expansion and decline of dwarf shrubs, which lasts approximately 165 years.

Sub-zone DCM-4a:

2040-1945mm (c.6055-5935 cal BP)

The first half of zone 4a (2037.5-1987.5mm) are characterised by a decline in arboreal taxa and associated rise in heath species that lasted around 120 years. Trees and shrubs decline from c.38 to 31% TLP, as all arboreal species decrease except Betula. Dwarf shrubs expand from c.3 to 35% TLP as Calluna vulgaris increases from 13 to 31% TLP, Empetrum increases from 1 to 4% TLP, and low levels of Vaccinium and Erica also appear. Dwarf shrubs remain high through the second half of zone 4b (from 1987.5 to 1945mm).

Poaceae are relatively low in abundance, fluctuating between 4 and 16% TLP. Cyperaceae is higher during the first half of the zone (11% TLP), and herbs such as Artemisia, Apiaceae and Caltha palustris are present. Low levels of weed types including Ranunculus acris – type, Rumex acetosa, Plantago lanceolata and Caryophyllaceae are found during the latter half of the zone.

Micro-charcoal influx estimates peak at 2027.5, 2007.5, 1982.5 and 1962.5mm, and macro-charcoal influx is present throughout the zone. Cercophora (HdV-112), Kretzschmaria deusta (HdV-44), Sordaria (HdV-55a) and Sporormiella (HdV-113) are present sporadically through the zone although at low values. Sample 2027.5mm experiences high levels of both micro- and macro-charcoal, Kretzschmaria deusta (HdV-44) and Sporormiella (HdV-113). Sample 1992.5mm has macro-charcoal and Sporormiella (HdV-113), and sample 1972.5mm has macro-charcoal, Sporormiella (HdV-113) and Kretzschmaria deusta (HdV-44). A large peak in Coniochaeta xylariispora (HdV-6) of 55% NPP is seen at 2002.5mm. There is a small decline in Anthostomella (HdV-4) compared to the previous zone, fluctuating greating between 9 and 70% NPP. Copepoda (HdV-28) values are low. HdV-10 increases to c.35% NPP through the zone, and Meliola ellisii (HdV-14) increases to around 10% NPP. There is a slight decline in percentage light transmission to 16%, and Silicon and Titanium influx estimates have increased slightly to c.70 and 6µg/g/yr respectively.
Sub-zone DCM-4b:

1945-1910mm (c.5935-5890 cal BP)

Zone 4b is defined by an increase in arboreal species, particularly *Alnus* which becomes the dominant species by the end of the zone, and *Quercus*. Total tree and shrub taxa increase from 55 to 75% TLP, while dwarf shrubs decline and herbs remain low at c.11% TLP. *Quercus* increases from 15 to 20% TLP, with *Alnus* increasing to c.44% TLP when dwarf shrubs are at a minimum. Poaceae (c.5% TLP) and Cyperaceae (c.5% TLP) levels are low, but herbs such as *Potentilla, Filipendula, Ranunculus acris* –type, *Artemisia, Caltha palustris* and *Urtica* are also present (<1% TLP). *Pteridium* levels are low, but *Sphagnum* reaches c.33% TLP.

There is very low micro- and macro-charcoal influx throughout, yet *Gelasinospora* sp. (HdV 1/2) is present c.1.5% NPP throughout the zone, accompanied by a small increase of Xylariaceae undiff. (HdV-93) and *Coniochaeta xylariispora* (HdV-6). *Anthostomella* (HdV-4) is high at the start of the zone but later replaced by HdV-18 and *Copepoda* (HdV-28). HdV-10 is lower (c.10% NPP), and *Meliola ellisii* (HdV-14) declines to 1% NPP by the end of the zone. Percentage light transmission begins to increase, and Silicon and Titanium influx estimates are lower at c.45 and c.4µg/g/yr respectively.

Zone DCM-5:

1910-1855mm (c.5890-5825 cal BP)

Zone 5 is characterised by high arboreal percentages and increased herbaceous taxa, over a period lasting approximately 65 years. Trees and shrubs account for c.67% TLP. Total tree taxa are high, fluctuating between 30 and 44% TLP, consisting predominantly of *Quercus* and *Alnus*. *Corylus* remains high at c.30% TLP, *Fraxinus* increases reaches c.1.5% TLP, and *Salix* is present throughout the zone (<1% TLP). Dwarf shrubs are low, however a peak in *Empetrum, Vaccinium* and *Erica* is observed at 1882.5mm. Poaceae (c.9% TLP) and Cyperaceae (c.10% TLP) levels are enhanced, and there are sporadic finds of *Potentilla, Ranunculus acris*-type, *Caltha palustris* and *Urtica*. Occasional *Pteridium* are found, and both micro- and macro-charcoal influx is low.

*Coniochaeta xylariispora* (HdV-6) levels are higher reaching 9% NPP, and dead wood and dung fungal indicators such as *Cercophora* (HdV-112), *Sordaria* (HdV-55a), *Sporormiella*
(HdV-113), Xylariaceae undiff. (HdV-93) and Podospora (HdV-368) are found throughout the zone. Anthostomella (HdV-4) begins high (c.50% NPPs) before declining to zero, whilst there are low levels of Copepoda (HdV-28) and HdV-18. HdV-10 and Meliola ellisii (HdV-14) are very low or absent, yet HdV-12 fluctuates between 2 and 41% NPP, and HdV-64 is present (c.2% NPP) sporadically. Puccinia (HdV-357) is present near the end of this zone. Percentage light transmission is high throughout the zone at c.29%, and Silicon and Titanium influx estimates increase slightly to c.65 and c.4.5μg/g/yr respectively.

Zone DCM-6:

1855-1820mm (c.5825-5770 cal BP)

Zone 6 is characterised by an expansion of dwarf shrubs and corresponding decline in arboreal pollen lasting approximately 55 years. Trees and shrubs decline from c.67% to c.53% TLP as dwarf shrubs expand once more. Lower Quercus, Alnus, Betula, Fraxinus, Corylus and Salix are observed, as Calluna vulgaris expands to c.17% TLP along with Empetrum (c.15% TLP) and lower levels of Vaccinium and Erica. Poaceae are slightly lower at c.5% TLP, while Cyperaceae and Potentilla remain unchanged. Micro-charcoal influx estimate increases to a peak at 1837.5-1832.5mm and 1822.5mm. These peaks are accompanied by smaller peaks in macro-charcoal influx and Gelasinospora sp. (HdV-1/2). Coniochaeta xylariispora (HdV-6) is still present c.7% NPP, as are low levels of the dead wood and dung fungal indicators Cercophora (HdV-112), Sordaria (HdV-55a), Sporormiella (HdV-113) and Xylariaceae undiff. (HdV-93). Anthostomella (HdV-4) experiences a decline from c.30 to 10% NPPs, and small levels of Copepoda (HdV-28) remain present. HdV-18 has two peaks at 1847.5mm and 1827.5mm, whilst Meliola ellisii (HdV-14) has a large peak at 1837.5mm. There is a large increase in HdV-10 through the zone to 1 to 62% NPP, whilst HdV-12 declines slightly to c.14% NPP. Percentage light transmission declines from 1842.5mm, and Silicon and Titanium influx estimates remain similar to zone 5.

Zone DCM-7:

1820-1650mm (c.5770-5495 cal BP)

Zone 7 is characterised by high tree percentages being replaced by increasing herbaceous taxa, whilst dwarf shrubs remain high. This period lasts approximately 275 years.
Sub-zone DCM-7a:

1820-1745mm (c.5770-5685 cal BP)

Sub-zone 7a is dominated by arboreal taxa and dwarf shrubs. *Alnus* and *Corylus* dominate arboreal taxa in this zone, with *Alnus* peaking at the start of the zone (c.45% TLP) and *Corylus* reaching c.33% TLP. *Quercus* is lower at c.13% TLP, while *Betula* has increased to c.7% TLP. *Ulmus* remains present at 3-4% TLP. *Salix* is present in low quantities (<1% TLP) only from 1787.5mm to 1772.5mm. *Calluna vulgaris* continues to increase to a peak of 40% TLP at c.1775mm, while *Empetrum* has decreased from the previous zone to c.2% TLP and *Vaccinium* is no longer present by 1777.5mm. Total herbs including Poaceae (c.3% TLP) and Cyperaceae (c.6% TLP) remain consistently low (c.24% TLP total), and low levels of *Ranunculus acris* –type, *Potentilla* and *Filipendula* are found on occasion throughout the zone. There are finds of Chenopodiaceae, *Caltha palustris* and *Thalictrum* at the beginning of the zone, and *Plantago lanceolata* near the end. *Pteridium* peaks c.5% TLP at c.1782.5mm together with *Sphagnum* c.183% TLP.

Micro-charcoal influx estimates are relatively high throughout most of the zone, and experience two peaks at 1792.5mm and 1757.5mm. Macro-charcoal influx is present throughout, experiencing a large peak at 1792.5mm and a more moderate peak c.1762.5mm. Fungal indicators of dead wood and herbivore dung such as *Coniochaeta xylariispora* (HdV-6), *Kretzschmaria deusta* (HdV-44), *Sordaria* (HdV-55a), *Cercophora* (HdV-112), Xylariaceae undiff. (HdV-93) and *Sporormiella* (HdV-113) are found between 1817.5-1787.5mm and 1777.5-1747.5mm. *Chaetomium* (HdV-7a) peaks (c.1.5% NPP) between 1782.5 and 1772.5mm. HdV-10 dominates the NPP assemblage and reaches around 70% NPP throughout, while HdV-12 (c.12% NPP) and HdV-303 (c.6% NPP) are only present until 1787.5mm. Both *Meliola ellisii* (HdV-14) and HdV-5 appear in low quantities. *Anthostomella* (HdV-4) and HdV-18 are low yet experience a peak between 1777.5 and 1767.5mm, together with *Tilletia sphagni* (HdV-27) and *Phaeangellina empetri* (HdV-64). The decline in percentage light transmission continues for the first half of the zone, before increasing once more to c.17.5%. Silicon and Titanium influx estimates peak at 1782.5mm (122 and 11µg/g/yr respectively). 1772.5 1777.5 1782.5
Sub-zone DCM-7b:

1745-1650mm (c.5685-5495 cal BP)

Sub-zone 7b is characterised by a slight decline in tree pollen and expansion of Cyperaceae. Total tree taxa declines from c.25 to 15% TLP. Heath types remain prominent, *Ulmus* and *Tilia* values decline, *Fraxinus* is all but absent, and there is an introduction of some weed species. *Alnus* levels decline from 1687.5mm, and *Quercus* experiences a peak between 1682.5 and 1672.5mm. *Calluna vulgaris* remains high at c.26% TLP, and *Empetrum* and *Vaccinium* expand until 1697.5mm. Total herbs increase as Poaceae expands to c.5% TLP, and Cyperaceae experiences large peaks of up to 25% TLP at 1722.5mm, 1687.5mm and 1657.5mm. *Ranunculus acris* –type is present throughout (c.0.5% TLP), and Chenopodiaceae are identified at the base of the zone at c.1730mm. *Potentilla, Filipendula* and *Drosera intermedia* are found from 1722.5-1692.5mm, and *Plantago lanceolata* appears increasing to 1.5% TLP from 1697.5 to 1652.5mm. *Artemisia* is found near the top of the zone at 1657.5mm. Pteridophytes including *Polypodium* and *Pteridium* are present throughout in low values, and *Sphagnum* peaks at 1702.5mm and 1677.5mm.

Micro-charcoal influx estimates experience a large peak at the start of the zone at 1742.5mm, subsequently declining with a smaller peak observed at 1702.5mm. A second large peak in micro-charcoal influx is experienced at 1662.5mm. The first of the two large peaks appears prolonged in nature, with enhanced influx lasting approximately 28 years to at least 1727.5mm. Macro-charcoal influx also peaks at 1742.5mm, with enhanced deposition continuing to 1727.5mm. The second macro-charcoal peak however at 1687.5mm does not correspond with a peak in micro-charcoal. Macro-charcoal then begins to increase toward the end of the zone from 1667.5-1652.5mm. *Gelasinospora* sp. (HdV-1/2), and decaying wood or herbivore dung fungal indicators such as *Coniochaeta xylariispora* (HdV-6), *Cercophora* (HdV-112), *Sordaria* (HdV-55a), *Kretzschmaria deusta* (HdV-44) and *Sporormiella* (HdV-113) correlate well with macro-charcoal. HdV-12 begins to replace HdV-10, reaching c.35% NPP on average. HdV-303 reaches c.17% NPP from 1717.5 to 1707.5mm, and is followed by a large peak in *Tilletia sphagni* (HdV-27) between 1707.5 and 1672.5mm corresponding with the lowest levels of HdV-10, an absence of HdV-5, and a peak in *Sphagnum* spores. *Meliola ellisi* (HdV-14) is present throughout but in low quantities (c.3%). Percentage light transmission remains c.16.5%, and estimated influx of Silicon and Titanium peak at 1742.5mm and 1662.5mm, correlating with largest peaks in micro-charcoal influx.
Zone DCM-8:

1650-1605mm (c.5495-5395 cal BP)

Zone 8 is characterised by the continued expansion of Cyperaceae and decline of tree taxa. Trees are at a minimum declining from around 20% to only 10% TLP. Quercus has declined to c.5% TLP and lower levels of Betula, Ulmus and Pinus are encountered. Corylus however experiences a small increase through the zone to c.34% TLP. Calluna vulgaris remains the dominant dwarf shrub at c.22% TLP, as Empetrum declines to c.0.5% TLP. Poaceae decline slightly to c.3% TLP, while Cyperaceae continue to expand to a large peak of 50% TLP at 1627.5mm. Other herbs include low levels of Plantago lanceolata and Artemisia throughout, with Ranunculus acris-type, Apiaceae and Chenopodiaceae identified at the start of the zone. Pteridium is present (c.1% TLP), accompanied by lower levels of other Pteridophytes. Sphagnum levels are relatively low at c.7% TLP.

Micro-charcoal influx estimates are low in Zone 8 until a small peak at 1607.5mm. Macro-charcoal influx is low throughout. Kretzschmaria deusta (HdV-44) appears at 1607.5mm correlating with micro-charcoal influx, and finds of Sordaria (HdV-55a), Coniochaeta xylariispora (HdV-6) and Chaetomium (HdV-7a) are sporadic. The NPP assemblage is dominated by HdV-303 reaching 57% NPP on average. HdV-10 declines from 30 to only 6% NPP throughout the zone, replaced by HdV-12 which increases to 30% NPP. Low levels of Meliola ellisi (HdV-14) and HdV-5 are present, as are Anthostomella (HdV-4) and Copepoda (HdV-28). Percentage light transmission declines slightly through the zone from 15 to 12%, and Silicon and Titanium influx estimates decrease to 30µg/g/yr and 2µg/g/yr respectively.

Zone DCM-9:

1605-1380mm (c.5395-4955 cal BP)

Zone 9 is dominated by high percentages of Alnus and Corylus pollen, whilst dwarf shrubs also remain high. This zone covers approximately 440 years.

Sub-zone DCM-9a:

1605-1572.5mm (c.5395-5325 cal BP)

Zone 9 is marked by significant increases in the representation of Alnus and Corylus, replacing Cyperaceae in particular. Tree taxa remain low, with low levels of Quercus, Tilia,
Ulmus, Pinus and Betula. Alnus and Corylus however see great increases, Alnus increasing from c.20 to 40% TLP and Corylus c.40 to 50% TLP. Dwarf shrubs decline slightly to c.16% TLP, consisting mainly of Calluna vulgaris, and herbs continue to decline from c.30 to 21% TLP predominantly due to a continued decline in Cyperaceae. Occasional finds of Ranunculus acris –type, Filipendula, Plantago lanceolata, Artemisia and Chenopodiaceae are identified, and Sphagnum spores increase to a peak of c.55% TLP at 1582.5mm.

Both micro- and macro-charcoal influx estimates are very low. Decaying wood or plant indicators Pleospora (HdV-3b), Coniochaeta xylariispora (HdV-6) and Sordaria (HdV-55a) are present in low quantities at the start of the zone. The fungal assemblage is however dominated by HdV-10 increasing from 13 to 70% NPP during the zone, with HdV-12 declining from 37 to 18% NPP, and HdV-303 declining from 60 to 6% NPP. Meliola ellisi (HdV-14) is present in low quantities, as is Anthostomella (HdV-4). Percentage light transmission continues to decline to a minimum of 7%, and Silicon and Titanium influx estimates also remain very low.

Sub-zone DCM-9b:

1572.5-1432.5mm (c.5325-5050 cal BP)

Tree taxa recover slightly in Zone 9b, as Quercus and Betula reach c.11% TLP and c.5% TLP respectively. Pinus, Tilia and Ulmus remain very low (<1% TLP). Corylus dominates the assemblage at 44% TLP on average, together with Alnus at c.28% TLP. Dwarf shrubs persist, with Calluna vulgaris (c.26% TLP) accompanied by Empetrum (c.1.5% TLP) and Vaccinium (<1% TLP). Herbaceous taxa are low, until a peak in Poaceae and Cyperaceae at 1482.5mm. Sporadic finds of Potentilla, Ranunculus acris –type, Filipendula, Drosera intermedia, Plantago lanceolata, Chenopodiaceae and Caryophyllaceae are present throughout the zone, and Sphagnum spores peak (322% TLP) at 1562.5mm.

Micro-charcoal influx estimates increase from 1522.5 to 1462.5mm, representing a period lasting approximately 111 years. This micro-charcoal peaks at a depth of 1482.5mm which correlates with peak Poaceae and Cyperaceae values, whereas macro-charcoal influx peaks slightly later at 1462.5mm. Gelasinosporea sp. (HdV-1/2) is present c.2% NPP from 1562.5-1462.5mm, coinciding predominantly with the period of increased micro-charcoal. Fungal indicators of dead plant or wood remains such as Pleospora (HdV-3b) and Coniochaeta xylariispora (HdV-6) are also present during peak charcoal (1522.5 to 1462.5mm), but no obligate coprophilous fungi are present. The NPP assemblage is dominated by HdV-10
declining from 68 to 28% NPP through the zone, and HdV-12 increases from 6 to 50% NPP as a result. *Anthostomella* (HdV-4) (c.8% NPP) and *Meliola ellisi* (HdV-14) (c.5% NPP) are also present throughout, and *Isthmospora spinosa* (HdV-580) (van Geel et al. 2006) appears from 1522.5mm. Percentage light transmission remains low, increasing slightly from 8 to 13%, and both Silicon and Titanium influx estimates increase from 1502.5mm to 1442.5mm (c.20 to 101µg/g/yr and c.1 to 8µg/g/yr respectively).

Sub-zone DCM-9c:

**1432.5-1380mm (c.5050-4955 cal BP)**

Zone 9c is marked by an increase in tree pollen in relation to dwarf shrubs and herbs. Trees and shrubs increase to c.77% TLP, as dwarf shrubs decline to c.15% TLP. The main taxa that increase are *Quercus* (7 to 14% TLP), *Betula* (3 to 10% TLP), *Alnus* (25 to 29% TLP) and *Fraxinus* (0 to 1% TLP). *Calluna vulgaris* is still present, but lower at c.14% TLP on average. Poaceae and Cyperaceae levels are low, but make up the herbaceous taxa component together with rare finds of *Plantago lanceolata*. *Sphagnum* experiences a large peak at 1402.5mm.

There is a significant peak in micro-charcoal influx at 1422.5mm, and macro-charcoal is present throughout most of the zone. *Coniochaeta xylariispora* (HdV-6) also peaks at 1422.5mm. Peaks of HdV-12, HdV-18 and *Tilletia sphagni* (HdV-27) are found at 1402.5mm, and correlate with the peak in *Sphagnum* spores. HdV-10 peaks at 68% NPP at 1382.5mm. Percentage light transmission remains c.11%, and Silicon and Titanium influx estimates decline through the zone, from 101 to 49µg/g/yr and 8 to 3µg/g/yr respectively.

**6.2.4.2 Environmental interpretation of the Dan Clough Moss data**

Zone DCM-1:

**2305-2190mm (c.6490-6235 cal BP)**

The pollen, NPP and sedimentological evidence reflect woodland but with some openings and a wet soil surface at the time of peat initiation. Arboreal taxa dominated, and the woodland was likely to have been mixed deciduous *Quercus-Corylus* in composition, with *Alnus* perhaps benefitting from wet conditions around the site. High Poaceae, *Rumex acetosa* and *Potentilla* suggest areas of open grassland in the landscape, however fire was almost absent, and *Cercophora* indicates the presence of herbivore dung or dead and
rotting wood at the sampling location. Local indicators of sedges, and low peat humification support the interpretation that the locality was particularly wet at the time of peat initiation.

Through zone DCM-1 most tree species expanded, particularly Quercus. Corylus declined slightly, but Poaceae and other indicators of wet grassland or pasture such as Rumex acetosa, Filipendula and Potentilla remained relatively high, together with Puccinia reflecting a potential local presence of Poaceae (Ellis and Ellis, 1985, 1997). Evidence in support of wetter local bog surface conditions at this time included high levels of Cypereaceae pollen together with a dominance of fungal spores Anthostomella and HdV-18 near the base of the profile – both of which are found in association with Eriophorum vaginatum (van Geel, 1972; 1978; Yeloff et al. 2007) and periods of increased moisture (Mighall et al. 2006; Blackford, 2000). Copepoda indicative of small pools (van Geel, 1978), and low levels of peat humification were likely to be due to a higher water table inhibiting oxidisation of the peat (Barber et al. 1994; Blackford, 2000).

Very low frequencies of Calluna vulgaris indicate that heathland was not a significant component of the surrounding landscape during this period. Increasing micro- and macro-charcoal influx estimates from 2242.5 to 2192.5mm (c.6350-6240 cal BP), accompanied by Gelasinospora spp., suggests an increasing occurrence of fire in the local vicinity at this time. Coniochaeta xylariispora, Sordaria and Chaetomium indicate either the local presence of decaying wood or herbivore dung at times throughout zone DCM-1 (Lundqvist, 1972; van Geel, 1986), and Kretzschmaria deusta appearing with Cercophora before any evidence of burning at 2262.5mm (c.6400 cal BP) supports an interpretation of damaged or decomposing wood or herbaceous material at the sampling location, as it is a fungal spore known to infect and can be lethal to the trunks, stumps or roots of already wounded trees (Dennis, 1978; Rogers and Ju, 1988; Innes et al. 2006). Sporormiella at the top of the zone, an obligate coprophilous fungi common on the dung of both domestic and wild herbivores, suggests a possible increase in grazing animal numbers (Innes et al. 2013). Low silicon and titanium influx estimates indicate low levels of soil erosion or disturbance in the region at this time (Hölzer and Hölzer, 1998).
Zone DCM-2

Sub-zone DCM-2a:

2190-2145mm (c.6235-6185 cal BP)

*Calluna vulgaris* heathland expanded as woodland cover was reduced. This heathland was at least partly local to the sampling location as *Meliola ellisi*, assumed to be a *Calluna vulgaris* parasite (van Geel, 1978), and HdV-10, associated with the roots of *Calluna vulgaris* (Kuhry, 1985), have been found. The pollen of *Calluna* itself is also mostly derived from local sources within a 4 metre radius of a sampling location (Bunting, 2003). Fungal indicators of a local abundance of Cyperaceae and wetter bog surface conditions have reduced, and an abundance of HdV-10 indicates local dry conditions (van Geel, 1972; 1978; Yeloff et al. 2007). Heathland expansion and the shift from wet to drier bog surface conditions occurred contemporaneously at 6190mm (c.6235 cal BP), together with the first increase in charcoal. Charcoal peaks at regular c.20 year intervals within zone 2a. It is difficult to determine a causal relationship, but it is reasonable to suggest that a shift away from wetter conditions would have enabled increased use of fire, or the increased frequency of natural fires from lightening strike, although such short return periods in local indicators of fire suggest it is unlikely that such fires were caused by natural means. *Calluna vulgaris* may have benefitted as a result of burning or the resulting open ground and expanded as a result (Grime et al. 1988). Heathland however remained prevalent when burning was later absent at 2177.5mm (c.6220 cal BP), suggesting that fire was not the only factor controlling heathland development. A reduction of woodland cover during this phase could have contributed to its expansion, if reduced levels of interception and evapotranspiration led to increased leaching of the soils, making them increasingly acidic. *Sporormiella* appeared during episodes of burning, suggesting increased grazing herbivore numbers were attracted to fresher more palatable forage in newly created clearings in the landscape at this time, reflected by reduced *Quercus* and increased light-demanding Poaceae and *Pteridium*.

Sub-zone DCM-2b:

2145-2120mm (c.6185-6155 cal BP)

Whilst *Calluna vulgaris* heath was joined by an expansion of other heath species, there was further decline in woodland cover. High values of Ericaceous-indicating spores confirm the
local presence of *Calluna vulgaris* (Kuhry, 1985) and hence infer a drier substrate, with perhaps small pools of open water reflected by finds of *Copepoda* (van Geel, 1978). High proportions of dead wood fungal indicators at 2137.5mm (c.6175 cal BP) must reflect damaged or dying trees at the site, potentially caused by people, grazing animals or more natural processes such as wind-throw. Indicators of local grazing such as *Sporormiella* were present at this time, but evidence of fire was generally low. Evidence for burning increased towards the end of the zone, and once again local grazing indicators increased suggested that animals were potentially attracted to the clearings caused by the fire. There was no obvious increase in herbaceous taxa that would indicate improved forage for animals, however Poaceae pollen production may have been suppressed by the grazing pressure (Groenman-van Waateringe, 1993). The occurrence of fire does not correlate with particular periods of drier conditions, and suggests it may have been anthropogenically forced.

**Sub-zone DCM-2c:**

**2120-2100mm (c.6155-6135 cal BP)**

There was a large expansion in wet pasture with Poaceae and other light demanding and/or grassland taxa such as *Pteridium, Potentilla* and *Ranunculus acris* –type, indicating the continued presence of areas of open ground through this zone. The diversity of dwarf shrubs was reduced as *Empetrum* and *Vaccinium* declined, and *Betula* and *Alnus* began to recover. A high local and regional fire signature indicates fire at least at the sampling location throughout this zone lasting approximately 20 years, with occasional finds of *Artemisia* suggesting the presence of disturbed ground. A significant increase in the influx of silicon and titanium to the sampling location throughout this zone also suggests a potential increase in the level of soil disturbance in the catchment at this time. Local indicators of herbivore dung and fungi that may indicate dung or dead and decaying wood correlate only with those periods with highest charcoal deposition, suggesting once again that grazing animals may have been attracted to these fire clearings, and that there may have been a lot of damaged or decaying wood or plant matter as a result of either the fire disturbance or increased grazing pressure. HdV-12 and *Anthostomella* began to replace the abundant HdV-10, suggesting a slight increase in bog surface wetness towards intermediate conditions.
Sub-zone DCM-2d:

2100-2075mm (c.6135-6105 cal BP)

Most tree and shrub taxa recovered in this zone, as Poaceae frequencies fell. *Calluna vulgaris* increased, yet declining fungal indicators of its local presence suggest that it was not necessarily growing at the sampling location. Increasing *Salix*, *Sphagnum*, *Anthostomella* and *Copepoda* suggest an increase in locally wet bog surface conditions consisting of sedges and pools of open water, perhaps with *Salix* on the margins of the bog. There was no evidence for burning in the catchment, yet herbaceous indictors of disturbed ground such as *Urtica*, *Artemisia* and Apiaceae were still present and high silicon and titanium influx estimates suggest a relatively high level of soil disturbance in the area. These disturbance indicators were joined by occasional finds of fungi indicative of grazing herbivores and dead or decaying wood such as *Sporormiella*, *Cercophora* and *Coniochaeta xylariispora*. Zone DCM-2d appeared to reflect increasingly wet surface conditions, reduced occurrence of burning, and a recovery of arboreal pollen whilst areas of disturbed ground were still prevalent.

Zone DCM-3:

2075-2040mm (c.6105-6055 cal BP)

Regeneration of woodland led to heaths being increasingly shaded out. Poaceae, *Ranunculus acris* –type and *Rumex acetosa* suggest that areas of grassland or pasture still existed, and the presence of charcoal in different size classes and *Gelasinospora* spp. suggest burning at least at the sampling location throughout this zone, which lasted approximately 40 years. Peak charcoal influx was at 2062.5mm (c.6090 cal BP). Silicon and titanium influx began high but declined significantly through the zone, most likely reflecting the commonly observed negative relationship between percentage tree pollen and concentration of lithogenic elements (Hölzer and Hölzer, 1998; Martinez-Cortizas et al. 2005). Dung indicators and those indicative of dung or decaying wood however became present from 2057.5mm (c.6085 cal BP). Increasing Cyperaceae, *Sphagnum* and *Caltha palustris*, together with declining peat humification and fungal indicators of the local dominance of sedges, *Sphagnum* and open pools including *Anthostomella*, HdV-18, *Copepoda* and *Tilletia sphagni* suggest the existence of wetter bog surface conditions and a possible marsh-type environment. As there is no evidence of woodland clearance which may have had the potential to increase water table levels, it is possible that this shift to
wetter conditions was due to natural climatic change at the time. Although wetter, burning continued throughout this zone increasing the likelihood that they were not the result of natural wildfires from lightening strikes. Intense or severe fire can kill rather than encourage *Calluna vulgaris* (Grime et al. 1988), and so may have been responsible for the decline in heathland in this zone. Waterlogged conditions may also have contributed.

**Zone DMC-4**

**Sub-zone DCM-4a:**

2040-1945mm (c.6055-5935 cal BP)

Zone DCM-4a represents a slight woodland reduction allowing heathland taxa to expand. Herbs began relatively high then declined through the zone as Cyperaceae declined and other rare herbs appeared. Cyperaceae and *Caltha palustris* in the first half of the zone suggest a wetland or marsh environment was present with Apiaceae perhaps growing on the woodland edge. *Ranunculus acris* -type and *Rumex acetosa* suggest the presence of pasture throughout, with *Plantago lanceolata, Artemisia* and Caryophyllaceae indicating areas patches of disturbed, drier ground.

There is charcoal evidence of repeated fire events both on- and off-site, with a return period of between 25 to 30 calendar years. This is slightly longer than the repeated episodes of burning of zone DCM-2a. Evidence for herbivore dung and damaged wood was found throughout most of the zone, sometimes correlating with charcoal influx peaks. The landscape appears to have had some fairly open spaces as reflected by herbaceous indicators of pasture and declining woodland cover, which may have encouraged increased grazing numbers to the site. Increases in HdV-10 and *Meliola ellisii* indicate increasing levels of *Calluna vulgaris* and other heaths locally, at the expense of local indicators of Cyperaceae. This change in local bog vegetation and a slight increase in the level of peat humification infer drier bog surface conditions, and may be responsible together with encouragement from regular burning for the expansion of heathland in this zone. Although drier conditions suggest that these fires may have been natural in origin, the response of various NPP and pollen taxa would have been beneficial to hunter gathers in terms of attracting grazing animals to the area, and may have been part of a purposive management of the woodland.
Sub-zone DCM-4b:

1945-1910mm (c.5935-5890 cal BP)

Woodland recovered in zone DCM-4b, possibly as a result of the lack of evidence for burning at this time. *Calluna vulgaris* declined, either in area or in pollen productivity due to either a lack of regeneration through fire, or due to increased waterlogging. Although an increase in tree and shrub taxa suggest an increase in woodland cover, there appears to have been patches of open land such as pasture and marsh where *Potentilla, Ranunculus acris*- type, *Filipendula* and *Caltha palustris* could grow. *Artemisia* and *Urtica* indicate the presence of some disturbed ground, however they were only present in low numbers and there was no notable increase in atmospherically deposited silicon or titanium linked to soil erosion. As the woodland recovered however, this may have suppressed the signal of both non-arboreal taxa and the atmospheric deposition of lithogenic elements from the regional landscape.

Bog surface conditions appeared increasingly wet with a decline in peat humification, and an increase in fungi indicative of sedges and pools of open water. This increase in wetness may be attributable to a natural climatic change, as no clearance of woodland was observed which may have contributed to the site’s water table levels. It is likely that wetter conditions would have made burning either through natural or anthropogenic means more difficult, and may hence be responsible for the low fire frequency is zone DCM-4b. Dead or decaying wood indicators were present and may also be attributed to rising water tables.

Zone DCM-5:

1910-1855mm (c.5890-5825 cal BP)

Arboreal pollen remained high consisting of mixed deciduous woodland with wetter areas probably characterised by *Salix* and *Alnus carr*. Heathland types remained low, but higher levels of light demanding *Fraxinus* and *Pteridium* together with increased Poaceae and Cyperaceae and the presence of *Potentilla, Ranunculus acris* –type, *Puccinia, Caltha palustris* and *Filipendula* indicate that there were some areas of open pasture and marsh. NPPs which reflect the local occurrence of sedges such as *Anthostomella* were abundant, together with HdV-12. Peat humification was the lowest it reached throughout the whole profile suggesting a potentially higher water table. This increased wetness would potentially be climatic in origin, as there is no evidence that woodland clearance would
have contributed to bog water tables at this time. These wetter conditions may have been responsible for the lower incidence of burning, making natural and even anthropogenic fires less likely. *Urtica* suggests the presence of some disturbed ground, and fungal indicators of herbivore dung and the availability of dead wood or decaying plant matter throughout the zone support the interpretation that grazing animals and areas of pasture were present. There was however very weak evidence for fire either in the vicinity of the sampling location or the surrounding region, and soil disturbance indicators remained low.

**Zone DCM-6:**

1855-1820mm (c.5825-5770 cal BP)

A further reduction in woodland cover allowed heathland to develop and expand once more. There was a reduction in *Alnus* and *Salix*, corresponding with the onset of a shift to drier conditions. Peat humification increased, and spores indicative of heathland types such as HdV-10 and *Meliola ellisii* increased, replacing local sedge and open pool indicators *Anthostomella* and *Copepoda*. This decrease in relative bog surface wetness and inferred fall in water table may have been climatic in origin as woodland declines often have the potential to reduce interception and increase runoff in a catchment, thereby heightening water tables, not the reverse. Woodland reduction appears to have had little effect on the water table at Dan Clough Moss at this time. Two peaks of micro-charcoal were found at 1832.5mm (c.5785 cal BP) and 1822.5mm (c.5775 cal BP), just ten years apart, however micro-charcoal was relatively high throughout, and macro-charcoal indicates at least part of this was of local origin. Drier conditions indicate that natural fires may not be ruled out in zone DCM-6, however their consistency through the zone in the local vicinity suggests it is perhaps unlikely that they were due to lightening strikes alone. These drier conditions may have made deliberate burning of the landscape more attractive or successful. A small increase in geochemical indicators of soil disturbance was found at 1822.5mm (c.5775 cal BP), corresponding with the latter micro-charcoal peak and fungal indicators of herbivore dung. Dung indicators were not present with the first micro-charcoal peak. NPPs which have an affinity for either decaying wood or herbivore dung appeared towards the beginning and end of the zone. Overall the data suggests a period of woodland disturbance by fire and potentially animals, with drier surface conditions and an expansion of heathland.
Zone DCM-7

Sub-zone DCM-7a:

1820-1745mm (c.5770-5685 cal BP)

*Quercus* within a mixed woodland remained low as earlier successional trees and shrubs such as *Betula, Alnus* and *Corylus* expanded. The diversity of heathland species was reduced as *Empetrum* declined, yet *Calluna vulgaris* continued to expand. Total herbaceous taxa were low, however occasional presence of herbs such as *Caltha palustris, Filipendula, Ranunculus acris* –type, *Potentilla, Plantago lanceolata, Chenopodiaceae* and *Artemisia*, together with damaged wood indicator *Kretzschmaria deusta*, indicate patches of open pasture, marshland and disturbed ground in the overall wooded landscape. High levels of the fungal spore HdV-10 suggest that there were high levels of *Calluna vulgaris* or other heath species near the sampling location, reflecting the local nature of the heathland at the time. Repeated episodes of burning on-site are indicated by micro- and macro-charcoal influx peaks at c.5740 cal BP and 5700 cal BP, suggesting a 40 year return to peak burning episodes at the site. The substantial amount of macro-charcoal deposited at 5740 cal BP may reflect a large scale fire at the site itself. Peat humification experienced a small increase across the zone, and the overall NPP assemblage suggests a shift towards drier bog surface conditions, with a dominance of HdV-10 and low levels of *Anthostomella, HdV-18* and *Copepoda*. There is clear evidence at this time of a substantial and effective fire disturbance. Drier conditions however cannot rule out natural origins for the fires.

Sub-zone DCM-7b:

1745-1650mm (c.5685-5495 cal BP)

Tree taxa continued to decline in zone DCM-7b - not withstanding the occasional reversal - indicating a progressive opening of woodland cover. Declines included *Ulmus*, percentages of which fell from 2.0 to 0.8% at 1720mm at a level dated to c.5645 cal BP, typical of the regional *Ulmus* decline (Tallis and Switsur, 1990). Heathland was still prevalent, but herbaceous taxa, particularly Cyperaceae, began to increase. *Ranunculus acris* –type and *Potentilla* suggest areas of pasture, and *Plantago lanceolata* appeared almost consistently from 1697.5mm (c.5590 cal BP), indicating a continued presence of disturbed land.
Two large peaks in micro-charcoal influx were observed at c.5685 cal BP and c.5520 cal BP, with a smaller peak at c.5600 cal BP. The lower peak appears longer in duration, with enhanced micro-charcoal influx continuing at least 28 years subsequent to peak influx. The upper two peaks were not mirrored by a peak in macro-charcoal influx, suggesting they were not local to the sampling location and that the microscopic charcoal had been atmospherically transported from a more regional source (Patterson et al. 1987; Clark, 1988). Assuming that the concentration of charcoal deposition decreases with distance from source, the large micro-charcoal peak of 5520 cal BP paired with low levels of macro-charcoal suggests that there may have been a very large or persistent fire in the extra-local or regional area. Another possibility is that macro-charcoal produced from a more local fire was broken into smaller pieces during mechanical pollen preparation procedures, amounting to the large amount of micro-charcoal in the sample. This is unlikely as all samples were subjected to the same pollen preparation method, and Gelasinospora sp., linked to charred plant remains (Simmons and Innes, 1996), were also absent at this time. The data therefore supports an interpretation that these later fire events were not in the local vicinity of the sampling site, and may have represented fires of differing sizes or distance from the sampling location.

During the fire events, there were a number of disturbance indicators evident in the palaeoecological record. Herbaceous taxa such as Chenopodiaceae and Plantago lanceolata indicate the presence of disturbed land, and silicon and titanium influx peaked during the larger micro-charcoal peaks suggesting increased levels of soil disturbance at these times. Kretzschmaria deusta indicates the presence of decaying wood or plant matter on-site, whilst Sporormiella suggests grazing herbivores. These local grazing and disturbance indicators correlate mainly with evidence of local fire.

When micro-charcoal influx was at a minimum, Sphagnum spores and Tilletia sphagni, a fungal species which uses Sphagnum as a host plant (Kuhry, 1985), indicate the local expansion of Sphagnum at the sampling site. Together with an increase in fungal indicators of drier bog surface conditions during times of peak charcoal influx, this suggests that fire and hydrological conditions correlated well in this zone with more fires when drier conditions prevailed, and less fires when wetter conditions prevailed. Woodland continued to decline which may have had the potential to increase water tables through reduced interception and evapotranspiration. Drier conditions prevailing therefore appear to be of climatic origin, suggesting that increased burning at this time could either be natural or due
to anthropogenic exploitation of more favourable conditions. The benefits to the economy of these burning episodes however are clear.

Zone DCM-8:

**1650-1605mm (c.5495-5395 cal BP)**

A further woodland reduction particularly affecting *Quercus* allowed Cyperaceae to expand. A lack of corresponding NPPs such as *Anthostomella* and Hdv-18 suggests that this increase in sedge may not have been local to the sampling site, and a peak in the fungal spore Hdv-303 and increasing peat humification points to drier bog surface conditions at the sampling site. There was a small peak in micro-charcoal influx at the end of the zone suggesting the occurrence of fire in the extra-local to regional landscape, and this correlated with *Kretzschmaria deusta* indicating damaged or decaying wood. Fungi indicative of either damaged wood and/or herbivore dung such as *Sordaria* and *Coniochaeta xylariispora* were present at times, and *Plantago lanceolata*, Chenopodiaceae, *Artemisia* and Apiaceae indicate disturbed ground. Herbaceous indicators of pasture such as Poaceae or *Ranunculus acris*-type however remained at a minimum. It appears this zone represented a continued transition from woodland to blanket bog, with evidence of some disturbance.

Zone DCM-9

Sub-zone DCM-9a:

**1605-1572.5mm (c.5395-5325 cal BP)**

There was a large expansion of *Corylus* and *Alnus* as Cyperaceae and tree taxa such as *Quercus*, *Tilia* and *Ulmus* declined. *Alnus* carr likely increased, and there were no large fire events or increase in soil derived silicon and titanium. *Plantago lanceolata* and *Artemisia* suggest some areas of disturbed ground, and low levels of *Coniochaeta xylariispora*, *Sporidesmium* and *Sordaria* indicate the presence of decaying wood at the start of this zone, potentially reflecting a short-term local disturbance such as windthrow. Increased levels of peat humification, and fungal indicators such as Hdv-10 and Hdv-12, suggest drier bog surface conditions with *Calluna vulgaris* at the locality. This zone has apparently contradictory indicators- wet loving tree expansion alongside increases in dry indicators, and limited local disturbance. At this time, the blanket bog area on the Dan Clough plateau
may have been expanding and changing, with fringing alder and hazel on higher, drier
ground to the east and west.

Sub-zone DCM-9b:

**1572.5-1432.5mm (c.5325-5050 cal BP)**

Woodland was still dominated by *Alnus* and *Corylus*, with a lesser amount of *Betula* and
*Quercus*. Heathland was present at least at the sampling location, and together with high
levels of HdV-12 and increased peat humification, indicates that dry-intermediate bog
surface conditions persisted during this period. Both Poaceae and Cyperaceae, and micro-
charcoal influx estimates, increased between 1522.5mm and 1462.5mm (c.5215-5100 cal
BP) and peaked at 1482.5mm (c.5140 cal BP). This suggests that fire may have created
areas of open space where more light demanding taxa and those indicative of disturbance
could colonise and flourish, such as *Ranunculus acris* -type, *Filipendula*, *Potentilla* and
*Plantago lanceolata*, and *Coniochaeta xylariispora* which is indicative of the presence of
dead or decaying wood or plant matter. Increasing silicon and titanium influx from
1502.5mm to 1442.5mm suggest that levels of soil disturbance in the catchment may have
increased, perhaps as a result of this fire disturbance and the removal of vegetation cover,
or as a result of more open conditions on-site allowing more windblown dust to be
deposited from neighbouring areas. In the early Neolithic, more lowland areas to the east
may have been the source of this dust.

Sub-zone DCM-9c:

**1432.5-1380mm (c.5050-4955 cal BP)**

Woodland expanded in zone DCM-9c, as heathland and herbaceous taxa declined. The
beginning of the zone (c.5035 cal BP) experienced a peak in micro-charcoal influx, which
was accompanied by *Plantago lanceolata* and *Coniochaeta xylariispora*. The evidence
suggests an episode characterised by fire, disturbed land and the presence of dead and
decaying wood at the sampling location at this time. This fire disturbance was succeeded by
a local expansion of *Sphagnum*, as indicated by *Sphagnum* spores and *Tilletia sphagni*. High
levels of HdV-10, HdV-12 and peat humification however indicate dry-intermediate bog
surface conditions, and suggest that the *Sphagnum* was small and temporary in scale on
the bog. Silicon and titanium influx declined through the zone, reflecting the recovery in
woodland cover and a decline in disturbance indicators.
6.2.4.3 Episodes of woodland disturbance

Three major periods of woodland disturbance were indentified from the palynological data. Two are dated to the late Mesolithic: (i: c.6235-6120 cal BP and ii: c.6050-5930 cal BP), and one dated to the early Neolithic (iii: c.5820-5395 cal BP). The characteristics of each disturbance are outlined below (Table 6.5).

Table 6.5 – Key characteristics of three periods of woodland disturbance identified from the Dan Clough Moss palynological record.

<table>
<thead>
<tr>
<th>Woodland disturbance</th>
<th>Depth (mm)</th>
<th>Age (cal BP)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>iii</td>
<td>1850-1605</td>
<td>5820-5395</td>
<td>Arboreal decline; expansion of heath; pasture and disturbed ground. Local fires (60-110 year return). Regional fires (15-80 year return). Some herbivore dung and decaying wood indicators. Consistently drier bog surface conditions.</td>
</tr>
<tr>
<td>ii</td>
<td>2035-1940</td>
<td>6050-5930</td>
<td>Arboreal decline; expansion of heath; pasture. Local fires (25-30 year return). Herbivore dung and decaying wood indicators. Drier bog surface conditions.</td>
</tr>
<tr>
<td>i</td>
<td>2190-2090</td>
<td>6235-6120</td>
<td>Arboreal decline; expansion of heath and herbs; pasture. Local fires (c.20 year return). Herbivore dung; some decaying wood indicators. Drier bog surface conditions.</td>
</tr>
</tbody>
</table>
7. Bökeberg Results

7.1 Preliminary fieldwork

Previous work in the area included a study of pollen and plant macro-fossils associated with a late Mesolithic settlement on the former lake shore (Regnell et al. 1995). Analyses at Bökeberg III covered the period from 7650 to 5750 cal BP, details of which can be found in Chapter 4.2.2.

The exact coring location was not ideal for the current study, as radiocarbon dating revealed potential disturbance and mixing near the base of the profile as a result of lake-level lowering (Regnell et al. 1995). Furthermore, the sediment stratigraphy identified a change from gyttja to peat just after the time period analysed, which would have included the early Neolithic required for this project. A longer profile was therefore required, with continuous sedimentation of the same type preferred, so that observed dynamics within the data were not influenced by the terrestrialisation of the lake and related changes to the pollen catchment area.

A core was obtained 100m further into the former lake, west of the small peninsula where the late Mesolithic settlement was excavated (Fig. 7.1). A previous low-resolution pollen diagram existed from this approximate location (Regnell, unpublished), and common pollen assemblage zones confirmed the suitable age of the sediments at this location. Unfortunately the core no longer exists, and so with the help of Dr Regnell a new core was taken from this location.
Figure 7.1 – Location of Bökeberg borehole in relation to known Mesolithic and Neolithic archaeology, and present peat deposit extent. Adapted from Regnell et al. (1995).
7.2 Bökeberg core

The stratigraphy, chronology and results of the lower and high-resolution multi-proxy analyses at Bökeberg (N 55° 31’ 55.4” E 13° 15’ 31.3” ) are outlined below.

7.2.1 Stratigraphy

Table 7.1 – Stratigraphy of sediment core from Bökeberg

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Stratigraphy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1450-2285</td>
<td>Red-brown silty peat + wood</td>
</tr>
<tr>
<td>2285-2615</td>
<td>Laminated light gyttja</td>
</tr>
<tr>
<td>2615-3250</td>
<td>Coarse dark brown gyttja</td>
</tr>
<tr>
<td>3250-4480</td>
<td>Fine dark brown gyttja</td>
</tr>
<tr>
<td>4480-4590</td>
<td>More minerogenic dark brown gyttja</td>
</tr>
<tr>
<td>4590-4950</td>
<td>Laminated blue-grey clays/silts</td>
</tr>
</tbody>
</table>

The stratigraphy of the sediment core recovered from Bökeberg began with laminated blue-grey clays and silts, indicative of a minerogenic lake environment. Lake sediment deposition then became increasingly organic in nature, with dark brown gyttja deposited between 4590 to 2615mm suggesting a relatively shallow productive lake environment. Laminated light gyttja is then found before a transition to silty peat with wood, reflecting the gradual infilling of the lake.

7.2.2 Chronology

7.2.2.1 Radiocarbon dating

In parts of the core, no terrestrial macro-fossils for radiocarbon dating were preserved. Five horizons yielded suitable material, including clearly terrestrial plant parts such as Betula fruits (Fig. 7.2). The results of the AMS radiocarbon determinations are presented in Table 7.2.
Figure 7.2 – Selection of macro-fossils used for AMS radiocarbon dating for Bökeberg.

Table 7.2 – Radiocarbon determinations for Bökeberg core. Analyses carried out by Beta Analytic, Florida, with calibrations made using IntCal13 (Reimer et al. 2013) in OxCal 4.2 (Bronk Ramsey, 2009a).

<table>
<thead>
<tr>
<th>Lab Code</th>
<th>Depth (mm)</th>
<th>14C date</th>
<th>δ13C/12C (o/oo)</th>
<th>cal BP (1σ)</th>
<th>cal BP (2σ)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta-355859</td>
<td>2670-2710</td>
<td>4840 ± 30</td>
<td>n/a</td>
<td>5606-5488</td>
<td>5645-5481</td>
<td>Budscales; Betula fruits</td>
</tr>
<tr>
<td>Beta-359790</td>
<td>2820-2830</td>
<td>5000 ± 30</td>
<td>-27.5</td>
<td>5841-5661</td>
<td>5888-5651</td>
<td>Tilia fruit; Betula fruits</td>
</tr>
<tr>
<td>Beta-361272</td>
<td>2940-2950</td>
<td>5240 ± 30</td>
<td>-25.5</td>
<td>6093-5931</td>
<td>6176-5920</td>
<td>Budscales; Betula fruits; Betula catkin</td>
</tr>
<tr>
<td>Beta-359792</td>
<td>3090-3100</td>
<td>5540 ± 30</td>
<td>-22.8</td>
<td>6393-6295</td>
<td>6399-6290</td>
<td>Vegetative matter</td>
</tr>
<tr>
<td>Beta-359158</td>
<td>3240-3250</td>
<td>5740 ± 30</td>
<td>-28.2</td>
<td>6602-6487</td>
<td>6635-6453</td>
<td>Alnus cone</td>
</tr>
</tbody>
</table>
7.2.2.2 Age-depth modelling

The results of Bayesian age-depth modelling, as described in chapter 5.9.2, upon the radiocarbon determinations outlined in Table 7.2 are presented in Fig. 7.3.

Figure 7.3 - Age-depth model for Bökeberg. Position is depth of the centre of the sample in mm below the peat surface. Modelled date (BP) is the calibrated, modelled age range at each depth, dark blue representing 68.2% uncertainty (1σ), and lighter blue 95.2% (2σ).
The age-depth model (Fig. 7.4) provides an estimated mean ($\mu$) calibrated radiocarbon date BP at 2.5mm intervals throughout the analysed profile. Results suggest a relatively rapid sediment accumulation at Bökeberg, with average accumulation rates spanning 1.5-2.3 years per mm (c.15-20 years per 10mm). Each 5mm sample represents c.9 calendar years, and confirms the high-resolution nature of the palaeoecological data.

The scarce and sporadic distribution of terrestrial macrofossils throughout the core has led to a necessary extrapolation of the modelled age-depth curve within OxCal to predetermined boundaries at the top and bottom of the palynologically analysed sequence. This was obtained by adding boundaries at depths 2460mm and 3710mm. The level of uncertainty in calendar age estimation increases with distance from the preceding radiocarbon determination, reaching a maximum uncertainty of c.1000 years (95.4% confidence) at 3710mm.

Results of the age-depth model have been plotted alongside palynological data in Figs. 7.4-7.9.

### 7.2.3 Palaeoecological analysis of Bökeberg

The period 7400 to 5140 cal BP was initially investigated at 40mm resolution. This identified two periods of particular interest, representing a late Mesolithic and early Neolithic disturbance. These periods were identified on the characteristics of a decline in total tree cover, increased concentrations of charcoal, and finds of *Plantago lanceolata* and other disturbed ground indicators. Higher resolution analyses (contiguous 5mm samples)
were focussed on these levels (Figs. 7.6 to 7.9), to interpret the type and nature of these disturbances with regards to evidence for human impact and natural environmental change.

7.2.3.1 Lower-resolution palaeoecological results

The lower-resolution results cover 3710-2460mm and have been dated to c.7405-5140 cal BP. Results are displayed in Fig. 7.4 and 7.5.

7.2.3.1.1 Description of the pollen stratigraphic zones

Zone BK-1:

3710-3285mm (c.7405-6640 cal BP)

Zone 1 is characterised by high levels of *Alnus* and *Corylus*, with dryland trees increasing in importance. High concentrations of charcoal are found, together with fungal indicators of dead or decaying wood and declining concentrations of silicon and titanium. The lithology is fine dark brown gyttja.

Sub-zone BK-1a:

3710-3525mm (c.7405-7070 cal BP)

Trees and shrubs dominate the assemblage at approximately 94% TLP. *Corylus* and *Alnus* are the most frequent types, with lower levels of *Quercus, Ulmus, Tilia, Betula, Pinus* and *Fraxinus*. Total tree pollen increases slightly from 40 to 49% TLP whilst shrubs decline from 54 to 47% TLP, mostly reflecting small increases in *Betula, Ulmus, Quercus* and *Tilia*, and a decline of *Corylus* from 54 to 47% TLP. Low quantities of *Salix* and *Calluna vulgaris* are present from 3625mm. The first half of the sub-zone (3710-3625mm) sees higher levels of herbs such as *Poaceae* (c.2% TLP), *Cyperaceae* (c.1.5% TLP), *Calthta palustris* (c.2% TLP), and *Pteropsida* (monolete indet.) (c.6% TLP), accompanied by rare finds of *Ranunculus acris* – type, *Artemisia* and *Apiaceae*. Later in the zone, *Poaceae* decline to c.1% TLP, *Cyperaceae* to 0.5% TLP, *Calthta palustris* to c.1.5% TLP and *Pteropsida* (monolete indet.) to c.4.5% TLP. *Typha latifolia* and *Pteridium* appear in low quantities from 3625mm, and the aquatic pollen *Nymphaea* is present throughout.
Figure 7.4 – Bökeberg lower-resolution (10mm) pollen diagram with frequencies expressed as percentages of the pollen sum (TLP excluding Alnus). The depths on this diagram covered by high-resolution pollen diagrams (Figs. 7.6 to 7.9) are shown by annotated boxes.
Figure 7.5 – Bökeberg low-resolution (10mm) charcoal, NPP and XRF diagram. Charcoal is expressed as a concentration per unit volume, NPPs as a percentage of total NPPs, and silicon and titanium as a concentration per volume. The depths on this diagram covered by high-resolution pollen diagrams (Figs. 7.6 to 7.9) are shown by annotated boxes.
Micro-charcoal concentrations are relatively high throughout, its peaks at 3705, 3625 and 3545mm correlating with the presence of macro-charcoal. High levels of *Pediastrum* and algal type HdV-128b are encountered (c.36% and c.60% NPP respectively), with low levels of cyanobacteria *Anabaena* present (c.2.5% NPP). *Triposporium elegans*, *Filinia* –type, *Gelasinospora* spp. (HdV-1/2), *Coniochaeta xylariispora* (HdV-6), HdV-18, *Tilletia sphagni* (HdV-27) and *Diporotheca* sp. (HdV-143) are present on occasion (<1% NPP), *Gelasinospora* spp. correlating with peak macro-charcoal concentrations. Silicon and titanium concentrations begin high and decline from c.18,700 to 12,750ppm and c.700 to 500ppm respectively, with a small peak at 3625mm. Increasing percentages of organic matter through this sub-zone however is likely responsible for this trend, with titanium concentrations normalised against organic matter content suggesting more stable, if relatively high, concentrations through the sub-zone.

**Sub-zone BK-1b:**

**3525-3285mm (c.7070-6640 cal BP)**

Zone 1b is differentiated by a small shift in the balance of tree species, with higher representation of dryland deciduous types, a trace of wetland shrubs, and changes in aquatic NPPs.

Both total trees and total shrubs remain c.47% TLP, whilst total herbs also remain c.6% TLP. *Alnus* and *Corylus* still dominate the assemblage. Lower *Betula* (c.7% TLP) and *Pinus* (c.6.5% TLP) are recorded as *Quercus*, *Ulmus*, *Tilia* and *Fraxinus* experience small increases. *Salix*, *Myrica* and *Calluna vulgaris* are present, and Poaceae reaches c.2% TLP as do Cyperaceae and *Caltha palustris*. *Ranunculus acris* –type, *Asteraceae asteroidae*, *Plantago lanceolata*, *Urtica*, Apiaceae and *Filipendula* are recorded sporadically (<1% TLP). *Pteropsida* (monolete indet.) remains c.4% TLP, with *Pteridium* recorded at 3505 and 3385mm. *Nymphaea* is joined by the aquatic *Nuphar*.

Micro-charcoal concentration is again relatively high, with concentrations peaking from 3465 to 3385mm. Macro-charcoal concentrations increase through the sub-zone. The phase 3525 to 3465mm is characterised by high *Pediastrum* (c.58% NPP), relatively low HdV-128b (c.40% NPP) and *Anabaena* (<1% NPP), and rare finds of *Coniochaeta xylariispora* (HdV-6), HdV-18 and *Meliola ellisi* (HdV-14) (<1% NPP). The phase 3425 to 3385mm sees lower *Pediastrum* and higher HdV-128b, and *Anabaena* corresponds with peak concentrations of micro-charcoal. *Kretzschmaria deusta* (HdV-44) and *Diporotheca* sp.
(HdV-143) are also present at this time. The phase 3345 to 3305mm experiences once again higher levels of *Pediastrum*, lower levels of HdV-128b and *Anabaena*, and other NPPs such as *Filinia* –type, *Coniochaeta xylariispora* (HdV-6), HdV-18, *Tilletia sphagni* (HdV-27) and *Diporotheca* sp. (HdV-143). Silicon and titanium concentrations continue to decline to c.9,700ppm and c.470ppm respectively, yet titanium experiences a peak (c.560ppm) between 3385 and 3345mm. There is still a small increase in organic matter through this zone, and titanium concentrations normalised against organic matter content reveal a continuation of higher levels of lithogenic material, with a peak still occurring between 3385 and 3345mm.

**Zone BK-2:**

**3285-2805mm (c.6640-5755 cal BP)**

Zone 2 is characterised by an increase in dryland trees, and a decline in both *Alnus* and *Corylus*. The lithology changes from a fine dark brown gyttja in zone 1 to a coarser dark brown gyttja in zone 2.

**Sub-zone BK-2a:**

**3285-2885mm (c.6640-5900 cal BP)**

Sub-zone 2a is marked by an increase in dryland trees, predominantly *Quercus* (c.16% TLP), *Tilia* (c.8% TLP) and *Fraxinus* (c.4% TLP). Total trees and shrubs remain high at approximately 95% TLP, with trees increasing to 55% TLP. *Alnus* and *Corylus* levels decline, with herbs including Poaceae, *Ranunculus acris* –type, *Filipendula*, Chenopodiaceae, *Melampyrum*, Cyperaceae and *Caltha palustris* present in low quantities.

Micro-charcoal declines from 3265 to 3185mm, before a peak at 3145mm. Macro-charcoal is present from 3225 to 3105mm and from 3025 to 2945mm. *Pediastrum* remains relatively high, fluctuating between 37 and 66% NPP, whilst HdV-128b fluctuates between 30 and 60% NPP. The cyanobacteria *Anabaena* is present throughout, with enhanced values 3265 to 3185mm and 3065 to 2905mm. *Filinia* –type is present from 3285 to 3025mm and replaced by *Diporotheca* sp. (HdV-143) appears from 3025mm. *Tilletia sphagni* (HdV-27) is present sporadically throughout the sub-zone. Titanium concentrations continue to decline from c.420 to 320ppm, whilst silicon, and therefore the Si/Ti ratio, begins to increase from 3105mm.
Sub-zone BK-2b:

2885-2805mm (c.5900-5755 cal BP)

Total tree taxa begin to decline slightly in sub-zone 2b, from 56 to 51% TLP, mainly reflecting lower levels of *Ulmus* (c.10% TLP), *Fraxinus* (c.3.5% TLP) and *Pinus* (c.4% TLP). *Corylus* begins to increase from 41 to 44% TLP, and *Calluna vulgaris* remains present in low quantities. Poaceae are lower (c.1% TLP), and wetland herbs are present including Cyperaceae, *Caltha palustris*, *Typha latifolia*, and joined by *Ranunculus acris* –type, *Artemisia* and *Apicaeae. Pteropsida* (monolete indet.) levels are lower at 3% TLP).

Micro-charcoal concentrations are low, and no macro-charcoal is recorded. Both *Pediastrum* and *Anabaena* decline to 34% and 2% NPP respectively, whilst HdV-128b peaks at 64% NPP. *Diporotheca* sp. (HdV-143) appears at 2825mm, reflecting a peak in silicon and Si/Ti. Titanium concentrations continue to decline to 277ppm.

Zone BK-3:

2805-2460mm (c.5955-5140 cal BP)

Zone 3 is characterised by declining dryland trees, an expansion of *Alnus* and *Corylus*, and an increase in herbaceous indicators of disturbance. The lithology changes to laminated light gyttja from 2615mm.

Sub-zone BK-3a:

2805-2685mm (c.5955-5550 cal BP)

A small decline in total tree taxa is observed to c.50% TLP. The greatest declines are seen in *Ulmus* (10 to 4% TLP), *Tilia* (9.5 to 6% TLP) and *Fraxinus* (4 to 2.5% TLP), while *Quercus* and *Betula* increase from 16 to 19% TLP and 9 to 15% TLP respectively. *Alnus* expands to 59% TLP, and there is a small increase in *Corylus* to c.45% TLP. Poaceae, *Ranunculus acris* –type, *Artemisia* and Chenopodiaceae make up the herbaceous component together with wetland species Cyperaceae, *Caltha palustris* and *Typha latifolia*. Higher levels of *Pteropsida* (monolete indet.) are found (8% TLP) in this sub-zone, and aquatics begin to decline.

There is a small peak in micro-charcoal concentrations at 2785mm, accompanied by macro-charcoal. *Pediastrum* is lower at c.27% NPP, HdV-128b increases from 23 to 53% NPP and there is a large peak (25% NPP) of *Anabaena* at 2745mm. *Triposporium elegans* peaks at
c.50% NPP at 2785mm, and 26% NPP at 2705mm. Titanium concentrations remain low at c.250ppm, and the Si/Ti ratio declines slightly from c.80-53.

Sub-zone BK-3b:

2685-2460mm (c.5550-5140 cal BP)

Sub-zone 3b is characterised by a large expansion in Corylus and a further decline in dryland tree taxa. Total trees continue to decline to c.37% TLP, but this time it is Quercus which declines to c.14% TLP, Tilia to c.3.5% TLP, Fraxinus to c.2% TLP and Pinus to c.3% TLP. Betula remains high at c.15% TLP, as does Alnus at c.55% TLP. Corylus expands to c.56% TLP, and low levels of Salix are present from 2625 to 2585mm. Poaceae declines to <1% TLP, and Plantago lanceolata and Artemisia are present together with rare finds of Chenopodiaceae and Apiaceae. Cyperaceae and Caltha palustris decline and are absent by the end of the zone, similarly aquatic pollen types are absent from 2545mm.

Micro-charcoal concentrations are enhanced slightly throughout this sub-zone, accompanied by macro-charcoal predominantly from 2585 to 2465mm. There is a large expansion in Pediastrum from 23 to 92% NPP, as HdV-128b declines from 56 to 8% NPP and Triposporium elegans decline from 16 to 0% NPP. Anabaena is now only present at 2665mm and 2545mm, and low levels of Diporotheca sp. (HdV-143), Sordaria (HdV-55a) and HdV-18 are found only at 2545mm. Titanium concentrations remain low (c.220ppm) while Si/Ti increases c.80 to 150, before declining from 2545 to 2505mm and increasing to a peak again at the end of the zone.

7.2.3.1.2 Environmental interpretation of the lower-resolution Bökeberg data

Zone BK-1:

3710-3285mm (c.7405-6640 cal BP)

Sub-zone BK-1a:

3710-3525mm (c.7405-7070 cal BP)

The diagram opens at a time of almost completely closed woodland, with trees and shrubs dominating the pollen diagram. The woodland was most likely to have been deciduous Quercus-Ulms-Corylus in composition, with low levels of Pinus potentially in the drier more sandy areas. Alnus was abundant benefitting from wet conditions around the lake.
edge and surrounding wetlands, forming a possible belt of *Alnus* carr between areas of higher ground and the lake shore. Poaceae were present in low quantities together with Cyperaceae and *Caltha palustris*, and probably reflected wetland or marsh environments close to the littoral zone, which later included *Salix, Typha latifolia*, and potentially the heath taxon *Calluna vulgaris*. Fungal indicators of the local presence of sedges and *Sphagnum* infer that wetland areas were close to the sampling location.

Micro-charcoal concentrations were high throughout, with peak concentrations at 7395, 7250 and 7105 cal BP accompanied by macro-charcoal. Due to the location of Bökeberg in its catchment and its low lying topography, it is unlikely that charcoal would have been washed in through river or stream flow. Charcoal must either have been wind deposited, or washed in from the slightly elevated areas surrounding the lake from local human disturbance or natural wildfire. Due to its size, the charcoal particles were not likely to have been wind transported far (Patterson et al. 1987), and so must represent fires close to the sampling location, at least at approximately 150 year intervals. *Coniochaeta xylariispora* was present, together with *Triposporium elegans*, a parasitic fungal spore on woody substrates either living, dead or decaying (Ellis and Ellis, 1985, 1997). This suggests the presence of dead or decaying wood close to the sampling location. Such indicators can increase when anthropogenic woodland disturbance occurs, but may also be present in natural situations, as fallen trees and branches are part of a normal forested landscape, especially close to the edge of a lake. High concentrations of silicon and titanium and *Diporotheca* sp. suggest a presence of disturbed ground near the lake edge (Hillbrand et al. 2012).

*Pediastrum* and HdV-128b were abundant suggesting shallow eutrophic conditions (Pals et al. 1980). Enhanced *Anabaena* percentages found at times of peak macro-charcoal concentrations suggest a link between local disturbance and an increased input of nutrients to the lake (Hillbrand et al. 2014).

**Sub-zone BK-1b:**

**3525-3285mm (c.7070-6640 cal BP)**

*Quercus-Ulmus-Corylus* woodland still dominated, with a small decline in *Alnus* and *Betula* surrounding the lake. *Myrica* joined *Calluna vulgaris* reflecting the presence of some areas of wet heath or bog, potentially more minerotrophic in nature at this time. Cyperaceae and *Caltha palustris* reflect marsh or wetland areas most likely situated around the edge of the
lake. Aquatic pollen *Nymphaea* and *Nuphar* were present signifying the presence of open water of mesotrophic or eutrophic status.

There is evidence of fire throughout this sub-zone, with high concentrations of both micro- and macro-charcoal indicating fires at least in the local area throughout this period. Fungal indicators of dead or damaged wood such as *Coniochaeta xylariispora* and *Kretzschmaria deusta* were also present throughout, and whilst this may again reflect the natural littoral environment, evidence for a prolonged episode of local fire coupled with *Plantago lanceolata* and *Urtica* at the time of peak micro-charcoal concentrations at 6820 cal BP indicate contemporaneous areas of disturbed ground and potential human impact on the local environment. The input of silicon and titanium to the lake remained relatively high, peaking between 6820 and 6745 cal BP. *Diporotheca* sp. was also found suggesting soil erosion or possible trampling by livestock (Cugny, 2011; Hillbrand et al. 2012).

There was a shift in the dominance of lake water NPPs with increasing percentages of the green algae *Pediastrum* and declining HdV128b, likely reflecting a change in the trophic status of the lake. A slight enrichment in the cyanobacteria *Anabaena* with increased macro-charcoal suggests a link between local fire disturbance and increases in the level of eutrophication of the lake water (van Geel et al. 1994; Hillbrand et al. 2014). Human activity on the lake shore may therefore have temporarily increased the supply of nutrients to the lake.

**Zone BK-2:**

**3285-2805mm (c.6640-5755 cal BP)**

**Sub-zone BK-2a:**

**3285-2885mm (c.6640-5900 cal BP)**

The *Alnus* carr around the lake had declined by zone 2a, whilst *Quercus-Ulms-Corylus* woodland remained prevalent. *Quercus* increased on higher ground, and *Hedera* was likely a common climber on deciduous trees in more shaded woods. An expansion in light-demanding *Fraxinus* suggests areas of open land - potentially pasture in nature due to the presence of Poaceae, *Ranunculus acris* -type and Caryophyllaceae, or due to disturbed ground indicated by finds of Chenopodicaeae. Areas of marsh or wetland are reflected by Cyperaceae, *Caltha palustris* and *Tilletia sphagni*; with *Calluna vulgaris* surviving on
hummocks or areas of drier land. Regional evidence for fire was present from 6600 to 6400 cal BP, and local fires may have been present from 6530 to 6340 cal BP and 6180 to 6010 cal BP. The cyanobacteria *Anabaena* increased from 6010 to 5940 cal BP, correlating with an increase in both silicon and the Si/Ti ratio, which can reflect increasing levels of biogenic silica deposition (Peinerud et al. 2001). The trophic status of the lake may therefore have increased at this time.

**Sub-zone BK-2b:**

**2885-2805mm (c.5900-5755 cal BP)**

Even though total tree taxa began to decline in this zone, *Quercus-Corylus* woodland still dominated. *Ulmus* concentrations began to decline, most likely to be an effect of the *Ulmus* decline which Regnell et al. (1995) dated at Bökeberg III to 5900 cal BP. Areas of marsh, heath and pasture were still present. Fire, on the other hand, was scarce reflected by low micro-charcoal concentrations and an absence of macro-charcoal. Titanium concentrations continued to decline, indicating no increased input of lithogenic material to the lake at this time as a result of soil disturbance, or falling lake levels.

Aquatic pollen such as *Nymphaea* and *Nuphar* were still present but in low quantities, indicating relatively shallow meso- to eutrophic water conditions. *Pediastrum* levels had declined, and a decline in *Anabaena* suggests a potential reduction in the level of nutrient input to the lake (Hillbrand et al. 2014). This coincides with an increase in the Si/Ti ratio which indicates an increased deposition of biogenic silica (Peinerud et al. 2001), suggesting that the diatoms and NPPs may be responding to different factors.

**Zone BK-3:**

**2805-2460mm (c.5755-5140 cal BP)**

**Sub-zone BK-3a:**

**2805-2685mm (c.5755-5550 cal BP)**

*Alnus* and *Betula* expanded, perhaps benefitting from increasingly wet conditions at the lake edge as reflected by *Salix* and *Typha latifolia*. *Quercus* expanded on higher ground, however total tree cover declined with the reduction in *Ulmus* values corresponding to the *Ulmus*-decline which appears to have occurred between c.5790-5720 cal BP. Areas of
pasture, marsh and heath persisted, suggesting that the woodland was not fully closed. Species indicative of disturbed ground such as *Artemisia* and Chenopodiaceae were present, yet titanium concentrations remained low suggesting there may have been no significant soil disturbance increasing the deposition of lithogenic material into the lake. Micro-charcoal concentrations also remained low throughout the zone except for a small peak at 5720 cal BP. *Trisporium elegans* also peaked at 5720 cal BP, suggesting the presence of woody substrates - whether living, dead or decaying - at the time there was fire in the area (Ellis and Ellis, 1985, 1997). *Pediastrum* levels were low, and a peak in *Anabaena* at 5660 cal BP indicates a potential increase in phosphorous concentrations and nitrogen-limited conditions (Hillbrand et al. 2014). *Anabaena* has a competitive advantage over green algae due to it being capable of nitrogen fixation (Hillbrand et al. 2014). Si/Ti declined slightly through this phase, indicating a slight reduction in the production and deposition of biogenic silica (Peinerud et al. 2001).

**Sub-zone BK-3b:**

2685-2460mm (c.5550-5140 cal BP)

*Corylus* expanded whilst dryland tree taxa such as *Quercus* and *Tilia* declined on higher ground. These changes coincided with an increase in the evidence of fire in the local area, and herbaceous indicators of disturbed ground such as *Plantago lanceolata*, *Artemisia* and Chenopodiaceae were present. Titanium concentrations however remained low, suggesting stable soil conditions. *Alnus* was still common, and *Salix* was present suggesting an *Alder-Salix* carr surrounding the lake with high quantities of *Betula*. Aquatic pollen declined and was absent from 5300 cal BP, suggesting either a lack of nutrients (oligotrophy), hyper-eutrophic conditions, or a terrestrialisation of the sampling location. The sediment stratigraphy changed to a laminated light gyttja at 5425 cal BP, probably reflecting infilling processes as the lake terrestrialised soon after. *Pediastrum* replaced algal type HdV-128b as the dominant NPP from c.5370 cal BP. *Trisporium elegans*, an indicator of woody substrates (Ellis and Ellis, 1985, 1997), was present but declined in abundance through the zone. The Si/Ti ratio indicates a peak of biogenic silica deposition at 5730 cal BP and 5155 cal BP (Peinerud et al. 2001). Low levels of *Diporotheca* sp. and *Anabaena* suggest some soil disturbance potentially through trampling (Cugny, 2011; Hillbrand et al. 2012) and an influx of nutrients to the lake (Hillbrand et al. 2014) respectively at 5370 cal BP.
### 7.2.3.1.3 Disturbances identified in the lower-resolution palynological record

Five episodes of disturbance were identified from the low resolution palynological data. Four are dated to the late Mesolithic (i: up to 7360 cal BP; ii: c.7285-7145 cal BP; iii: 7070-6640 cal BP; iv: 6565-6300), and one to the early Neolithic (v: 5555-5153 cal BP). The characteristics of each disturbance are outlined in table 7.5.

Table 7.5 – Key characteristics of five episodes of disturbance identified from the lower-resolution analyses at Bökeberg.

<table>
<thead>
<tr>
<th>Disturbance</th>
<th>Depth (mm)</th>
<th>Age (cal BP)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>v</td>
<td>2685 - 2465</td>
<td>5555 - 5153</td>
<td>Fire – smaller scale / further away? Decline in arboreal pollen; Expansion of <em>Betula</em> and <em>Corylus</em>; disturbed ground indicators. Woody substrate.</td>
</tr>
<tr>
<td>iv</td>
<td>3245 - 3085</td>
<td>6565 - 6300</td>
<td>Local fire. Arboreal expansion; some heath; high <em>Corylus</em>; pasture and disturbed ground indicators.</td>
</tr>
<tr>
<td>iii</td>
<td>3525 - 3285</td>
<td>7070 - 6640</td>
<td>Local fire. Decline in <em>Alnus</em> and <em>Betula</em>; high <em>Corylus</em>; disturbed ground indicators. Decaying wood indicators.</td>
</tr>
<tr>
<td>ii</td>
<td>3645 - 3565</td>
<td>7285 - 7145</td>
<td>Local fire. Small heath expansion; high <em>Corylus</em>; pasture and disturbed ground indicators. Decaying wood indicators.</td>
</tr>
<tr>
<td>i</td>
<td>? - 3685</td>
<td>? - 7360</td>
<td>Local fire. Dead or decaying wood indicators. High <em>Corylus</em>.</td>
</tr>
</tbody>
</table>
7.2.3.2 Mesolithic high resolution analyses

High-resolution analyses cover a period of late Mesolithic disturbance identified from the low-resolution analyses (Fig. 7.4 and 7.5), characterised by high concentrations of both micro- and macro-charcoal, a small decline in arboreal pollen, disturbed ground indicators such as *Plantago lanceolata*, *Artemisia* and *Urtica*, and fungal indicators of damaged wood such as *Kretzschmaria deusta*. The profile has been dated to c.6990-6775 cal BP. Results are displayed in Figs. 7.6 and 7.7.

7.2.3.2.1 Description of pollen stratigraphic zones

Zone BK-M1

3480-3455mm (c.6990-6945 cal BP)

Trees and shrubs account for c.95% of the pollen sum (TLP), and include predominantly *Corylus* (c.46% TLP), *Quercus* (c.17% TLP) and *Alnus* (c.47% TLP). Other tree taxa include *Ulmus* (c.11% TLP), *Tilia* (c.5% TLP), *Fraxinus* (c.2% TLP), *Pinus* (c.6% TLP) and *Betula* (c.7% TLP). *Salix* is present from 3467.5mm to 3457.5mm. The herbaceous component of the vegetation consists of low levels of Poaceae, Cyperaceae, *Caltha palustris*, and rare finds of *Filipendula*, *Urtica*, Chenopodiaceae and *Ranunculus acris* –type. Aquatic pollen is infrequent. Micro-charcoal concentrations are high throughout, however macro-charcoal is only present in significant quantities towards the end of the zone. The NPP assemblage is dominated by *Pediastrum* (c.40% NPP) and the algal type Hdv-128b (c.57% NPP), and low levels of *Anabaena* are present throughout (c.2% NPP). Both silicon and titanium concentrations are relatively high at c. 13,200ppm and c.500ppm respectively.

Zone BK-M2

3455-3425mm (c.6945-6890 cal BP)

Whilst total tree and shrub taxa remain steady at c.93% TLP with high levels of *Alnus* and *Corylus*, zone BK-M2 is characterised by a small increase in the herbaceous component of the vegetation. Poaceae, Cyperaceae and *Caltha palustris* increase from c.1% TLP in zone BK-M1 to c.2% TLP, again joined by sporadic finds of *Rumex acetosa*, *Artemisia*, *Urtica*, Apiaceae and *Filipendula*. *Pteridium* is also found at times in this zone. Micro-charcoal concentrations are slightly lower from 3452.5 to 3442.5mm, but increase once more from 3437.5 to 3427.5mm. Macro-charcoal is also now present throughout most of the zone.
Figure 7.6 – Bökeberg Mesolithic high resolution pollen diagram with frequencies expressed as percentages of the pollen sum (TLP excluding *Alnus*).
Figure 7.7 – Bökeberg Mesolithic high resolution charcoal, NPP and XRF diagram. Charcoal concentration and non-pollen palynomorphs (NPP) and geochemistry diagram. Charcoal is expressed as a concentration per unit volume, NPPs as a percentage of total NPPs, and silicon and titanium as a concentration per volume.
The algal spore HdV-128b dominates the NPP assemblage (c.69% NPP), as Pediastrum declines to c.26% NPP. Anabaena is still present (c.2% NPP), and HdV-303 reaches c.1.5% NPP. HdV-18 is also present throughout this zone in low quantities, and Kretzschmaria deusta (HdV-44) is found from 3452.5 to 3442.5mm, and at 3427.5mm. Titanium concentrations fluctuate between c.430 and 510ppm, and the Si/Ti ratio declines from c.24 to 21.

Zone BK-M3

3425-3375mm (c.6890-6800 cal BP)

There is a small decline in total arboreal pollen to around 90% TLP in zone BK-M3, Alnus and Corylus are still the dominant taxa. The dwarf shrub Calluna vulgaris appears more consistently in this zone, and herbaceous taxa increase to c.10% TLP. Cyperaceae and Caltha palustris increase from the previous zone to c.3% and c.4% TLP respectively, whilst Poaceae remains c.2% TLP. Rare finds of Ranunculus acris –type, Chenopodiaceae and Artemisia are also present, and low levels of Pteridium are consistently found from 3392.5mm to 3377.5mm. Micro-charcoal concentrations remain relatively high throughout, greatest from 3422.5 to 3407.5mm, and between 3392.5mm and 3377.5mm. Macro-charcoal is present throughout most of the zone, correlating predominantly with periods of peak micro-charcoal. HdV-128b still dominates the NPP assemblage at c.62% NPP, but Pediastrum increases to c.25% NPP. Pediastrum peaks at the time of minimum micro-charcoal concentrations between 3412 and 3397.5mm. Anabaena increases through the zone, from 0 to 4.5% NPP. Coniochaeta xylarispora (HdV-6) and Kretzschmaria deusta (HdV-44) are found from 3422.5 to 3392.5mm, and Cercophora (HdV-112) is found at 3402.5mm and 3387.5mm. HdV-18 is present from 3402.5 to 3377.5mm, and HdV-303 remains present throughout in low quantities. Silicon and titanium concentrations remain relatively stable, with small peaks at 3397.5mm and 3387.5mm.

Zone BK-M4

3375-3360mm (c.6800-6775 cal BP)

Zone BK-M4 is characterised by an increase in Corylus (to c.45% TLP) and wetland shrubs such as Salix and Frangula, lower percentages of Alnus, and lower Cyperaceae and Caltha palustris. Total arboreal pollen has increased slightly to c.93% TLP, although slightly lower Quercus, Ulmus and Fraxinus levels are recorded. Micro-charcoal is again present
throughout, but concentrations peak at 3367.5mm. *Artemisia* and *Coniochaeta xylariispora* (HdV-6) also appear during this micro-charcoal peak, and there is a slight enrichment in silicon and titanium concentrations. Macro-charcoal however is absent during peak micro-charcoal concentrations. *Pediastrum* expands through the zone from c.43 to 58% NPP as the algal type HdV-128b declines from c.53 to 38% NPP. *Anabaena* is still present throughout at c.3.5% NPP, and low levels of HdV-18 and *Tilletia sphagni* (HdV-27) are found from 3372.5mm to 3367.5mm.

**7.2.3.2.2 Environmental Interpretation of the high resolution Mesolithic data**

**Zone BK-M1**

**3480-3455mm (c.6990-6945 cal BP)**

Tree and shrub taxa accounted for c.95% of the pollen sum, indicating a relatively closed landscape. *Quercus-Ulmus-Corylus* woodland would have dominated on higher ground, with *Alnus* the major tree at the lake edge. *Urtica* may have grown in this *Alnus* carr (Regnell et al. 1995), or could represent patches of disturbed ground together with Chenopodiaceae. Cyperaceae, *Caltha palustris* and *Filipendula* indicate that areas of marsh or wetland were present. Micro-charcoal concentrations were high throughout, suggesting a continued occurrence of fire over a period lasting at least 35 years. Little macro-charcoal was observed however, indicating that these fires may not have been local to the sampling location. High levels of both *Pediastrum* and HdV-128b probably indicate shallow, eutrophic water (Pals et al. 1980), which supports the interpretation for lower lake-levels at this time by Regnell et al. (1995). *Anabaena* suggests a level of nutrient input to the lake from the catchment (Hillbrand et al. 2014), and relatively high titanium concentrations suggest an input of lithogenic material to the lake as a result of soil disturbance, either by human activities, or as a result of the lower lake levels exposing land susceptible to erosion. The Si/Ti ratio was enhanced, suggesting an increase in the level of biogenic silica deposited in the sediment (Peinerud et al. 2001), supporting the suggestion of a higher trophic status of the lake at this time.
Zone BK-M2

3455-3425mm (c.6945-6890 cal BP)

Total tree and shrub taxa remained high, with Quercus-Ulmus-Corylus woodland still present on higher ground and Alnus having expanded slightly at the lake edge. Wetland species such as Cyperaceae and Caltha palustris had also increased, suggesting an expansion of marsh surrounding the lake, and the fungal spore HdV-18 suggests that this was local to the sampling location. Whilst total woodland cover remained steady, a small increase in Poaceae and occasional Artemisia and Urtica suggest that areas of open and potentially disturbed land began to increase in the landscape. The appearance of Pteridium, a shade intolerant plant, supports this inference of a small increase in woodland openness. Charcoal provides evidence of fires throughout the zone, which covers approximately 55 years. Macro-charcoal was also present from 6930 cal BP, indicating that at least some of these fires were local in origin and persistent over a prolonged period of time. An expansion of algal type HdV-128b also from 6930 cal BP suggests shallow, eutrophic water conditions (Pals et al. 1980). Anabaena remained present, and the Si/Ti ratio declined through this zone indicating a reduction in the level of diatom production and biogenic silica deposition (Peinerud et al. 2001). Evidence of lake water status is therefore conflicting, and further research into the various indicators’ ecological amplitudes is needed in the future. There does however appear to be a correlation between the prolonged evidence of fire in the local environment, and a change in lake status indicators.

Kretzschmaria deusta from 6940 to 6920 cal BP and at 6895 cal BP indicated the presence of dead or decaying wood close to the sampling location (Innes et al. 2006). Whilst this can be natural in a woodland edge environment, its correlation with other anthropogenic indicators and archaeological evidence for occupation suggests that it may have been the result of anthropogenic disturbance of the local environment. Titanium concentrations remained relatively high, suggesting a continued deposition of lithogenic elements to the lake due to soil disturbance, either as a result of the presence of bare ground or due to the lower lake level of this period.
Zone BK-M3

3425-3375mm (c.6890-6800 cal BP)

Woodland composition remained largely unchanged. Marsh or wetland taxa increased, suggesting an expansion of this habitat around the lake, with Hdv-18 indicating the local nature of these wetlands to the sampling site from at least 6850 cal BP. Heath expanded slightly, and evidence for fire was found throughout the zone. Local fire was evident at least from 6885 to 6815 cal BP, indicating the repeated nature of local fire in this area at this time. *Pteridium*, which is a pyrophytic species, is found at 6885 cal BP and from 6830 to 6805 cal BP, corresponding with higher levels of micro-charcoal. Chenopodiaceae and *Artemisia* were present, suggestive of areas of disturbed ground, and fungal indicators of dead or decaying wood were found from 6885 to 6820 cal BP. These dead wood indicators were not constrained to periods of highest charcoal concentrations, suggesting that either there were causes of local disturbance other than fire such as ring-barking or natural wind-throw, or that trees killed or weakened by the fire subsequently became infected, causing damaged or dead wood fungal indicators to continue long after the charcoal signal of fire. Continued high silicon and titanium concentrations suggest continued levels of soil disturbance, and *Cercophora* at 6850 and 6820 cal BP indicates the presence of herbivore dung and/or decaying wood.

Hdv-128b dominated the NPP assemblage, suggesting a continuation of shallow, eutrophic water conditions (Pals et al. 1980), and an increase in *Anabaena* through the zone suggests an increased input of phosphorous or other nutrients to the lake (Hillbrand et al. 2014).

Zone BK-M4

3375-3360mm (c.6800-6775 cal BP)

This is a short phase characterised by a decline in wetland areas including the extent of *Alnus* carr. Early successional taxa such as *Betula* and *Corylus* began to expand through zone BK-M4, creating a predominantly closed landscape. *Salix*, *Frangula* and *Filipendula* suggest the presence of damp woods close to the lake edge, and declining levels of *Cyperaceae*, *Caltha palustris* and Hdv-18 suggest a reduction in areas of marsh land. Evidence for burning peaks at 6785 cal BP, yet the lack of macro-charcoal indicates that this burning was outside the lake catchment, suggesting a large magnitude fire or series of fires at distance. Contemporaneous finds of *Artemisia* at this time suggest areas of disturbed
ground, and potential fungal indicators of damaged wood such as *Coniochaeta xylariispora* were also found (van Geel, 1978). The lake water NPP assemblage shifts when *Pediastrum* increases and HdV-128b declines, and continuously higher *Anabaena* suggest a possible increase in lake water nutrients during this zone (Hillbrand et al. 2014).

7.2.3.3 Neolithic high resolution analyses

High-resolution analyses cover a period of early Neolithic disturbance identified from the low-resolution analyses (Fig. 7.4 and 7.5), characterised by the presence of micro- and macro-charcoal, disturbed ground indicators such as *Artemisia* and Chenopodiaceae, and a decline in arboreal pollen. The profile has been dated to c. 5535-5315 cal BP. Results are displayed in Figs. 7.8 and 7.9.

7.2.3.3.1 Description of pollen stratigraphic zones

**Zone BK-N1**

**2675-2625mm (c.5535-5445 cal BP)**

Trees and shrubs dominate the assemblage, representing c.89% of the pollen sum (TLP). Total trees represent c.42% TLP, while total shrubs represent c.47% TLP. Woodland taxa are predominantly *Betula, Quercus* and *Corylus*, with high values of *Alnus* likely to be local in nature. Lower levels of *Tilia, Ulmus, Fraxinus, Fagus* and *Pinus* constitute the remainder of the tree taxa. *Corylus* is the dominant shrub taxa (c.47% TLP), with occasional finds of *Salix* at 2652.5mm and 2637.5mm. *Calluna vulgaris* pollen are scarce. Herbaceous taxa represents c.11% of the pollen sum. Poaceae is variable and ranges between 1 and 4% TLP throughout the zone, higher values often correlating with *Plantago lanceolata*. Herbs such as *Ranunculus acris* –type, *Asteraceae asteroidae, Rumex acetosa*, Chenopodiaceae, *Urtica*, *Apiaceae* and *Filipendula* are found sporadically through the zone (<1% TLP), whereas *Artemisia* is found throughout (c.1% TLP), as are *Cyperaceae* (c.2% TLP) and *Caltha palustris* (c.3% TLP). *Pteropsida* (monolete indet.) fluctuates between 3 and 12% TLP within the zone, and *Pteridium* is present until 2652.5mm. Aquatic pollen is infrequent.

Micro-charcoal concentrations peak between 2655 and 2645mm, and low levels of macro-charcoal are found throughout. HdV-128b dominates the NPP assemblage (c.64% NPP), whilst *Pediastrum* (c.23% NPP) peaks at 2652.5mm, and from 2637.5 to 2627.5mm. *Anabaena* is present in low quantities between 2662.5 and 2647.5mm, and *Diporotheca* sp.
Figure 7.8 – Bökeberg Neolithic high resolution pollen diagram, with frequencies expressed as percentages of the pollen sum (TLP excluding *Alnus*).
Figure 7.9 – Bökeberg Neolithic high resolution charcoal, NPP and XRF diagram. Charcoal concentration and non-pollen palynomorphs (NPP) and geochemistry diagram. Charcoal is expressed as a concentration per unit volume, NPPs as a percentage of total NPPs, and silicon and titanium as a concentration per volume.
(HdV-143), Coniochaeta xylariispora (HdV-6), HdV-18 and Tilletia sphagni (HdV-27) are also present at this time. Triposporium elegans is present throughout, peaking from 2672.5 to 2662.5mm and at 2627.5mm. Silicon concentrations are relatively high, peaking at c.30,000ppm from 2657.5 to 2642.5mm, whilst titanium concentrations are low throughout (c.220ppm). The Si/Ti ratio follows silicon concentrations and peaks from 2657.5 to 2642.5mm.

Zone BK-N2

2625-2570mm (c.5445-5345 cal BP)

The proportion of trees and shrubs remains steady at c.89% TLP in Zone BK-N2 with few changes in composition. The herbaceous component is similarly quite steady, but with Plantago lanceolata now present throughout (c.1% TLP), and other herbs such as Potentilla, Caryophyllaceae, Rumex acutosella and Mentha appearing for the first time. Caltha palustris expands slightly in this zone to c.4% TLP.

Micro-charcoal concentration peaks at 2622.5mm, 2612.5mm, 2602.5mm and 2592.5mm, each peak lasting approximately 9 to 10 years in duration. Low levels of macro-charcoal are present until 2582.5mm. Pediastrum takes over from HdV-128b as the dominant NPP taxa by 2607.5mm, reaching c.70% NPP. Triposporium elegans is low throughout, yet peaks at c.27% NPP between 2612.5 and 2607.5mm, correlating with the largest peak in micro-charcoal. Tilletia sphagni (HdV-27) is present from 2622.5 to 2607.5mm, Anabaena appears from 2607.5 to 2592.5mm and Kretzschmaria deusta (HdV-44) appears from 2612.5 to 2607.5 and 2592.5mm, correlating well with the two largest charcoal peaks. Titanium concentrations remain low, whilst silicon and therefore Si/Ti peak from 2617.5 to 2612.5mm and from 2592.5 to 2582.5mm.

Zone BK-N3

2570-2555mm (c.5345-5315 cal BP)

The herbaceous component declines in zone BK-N3, leaving only low levels of Poaceae, Artemisia, Cyperaceae and Caltha palustris. Tree and shrub taxa increase to c.96% TLP, with woodland still dominated by Betula, Quercus and Corylus. Alnus is still prominent, but declines through the zone, with Salix present throughout. There is a large peak in micro-charcoal concentrations at 2567.5mm accompanied by Anabaena and Coniochaeta
xylariispora (HdV-6). Pediastrum remains the dominant NPP at c.78% NPP, and Kretzschmaria deusta (HdV-44) is found throughout the zone. Titanium concentrations and the Si/Ti ratio remain low.

7.2.3.3.2 Environmental Interpretation of high resolution Neolithic data

Zone BK-N1

2675-2625mm (c.5535-5445 cal BP)

Zone BK-N1 indicates a relatively closed woodland landscape. Betula-Quercus-Corylus woodland dominated, while Tilia and Ulmus were less frequent. Alnus was likely to have been locally abundant benefitting from wet conditions surrounding the lake. Areas of pasture are represented by Poaceae accompanied by Ranunculus acris -type, Rumex acetosa and Asteraceae asteroidae. Herbaceous indicators of disturbed ground such as Plantago lanceolata, Chenopodiaceae and Artemisia were present, and Cyperaceae and Caltha palustris indicate marsh areas most likely surrounded the lake.

There is increased evidence of fire between 5500 and 5480 cal BP, which began to increase once more towards the end of the zone. Macro-charcoal was present but low throughout, which suggests that there may have been continuous fires on a very small scale in the local environment, or larger fires at a greater distance from the sampling site. There was a phase of increased burning in the wider landscape that lasted c.20 years, and the onset of a subsequent one, within this zone of approximately 90 years duration. Titanium concentrations overall were low, but slightly enhanced during this peak episode of fire from 5485 to 5475 cal BP. Plantago lanceolata and Artemisia were also present in low quantities, suggesting areas of disturbed ground perhaps due to an exposure of bare ground. HdV-128B dominated the NPP assemblage, with Anabaena present during times of peak charcoal concentrations. The Si/Ti ratio also peaked at this time, indicating increased levels of biogenic silica deposition (Peinerud et al. 2001).

Fungal evidence of the presence of dead or decaying wood such as Kretzschmaria deusta and Coniochaeta xylariispora prior to this period of increased fire from 5520 to 5505 cal BP correlates with a temporary decline in Quercus and Alnus, and an increase in Plantago lanceolata.
Zone BK-N2

2625-2570mm (c.5445-5345 cal BP)

In zone BK-N2, a small increase in the diversity of the herbaceous component of the vegetation was observed. Species indicative of pasture, such as Poaceae, *Ranunculus acris* -type, *Asteraceae asteroidae*, *Rumex acetosa* and *Potentilla* were present, together with consistently present *Plantago lanceolata and Artemisia* and occasional Chenopodiaceae and Caryophyllaceae, indicating the persistence of areas of disturbed ground. Marsh or wetland areas remained present.

Micro-charcoal reflecting fire in the wider landscape was found throughout the zone, with peaks at 5440, 5420, 5405 and 5385 cal BP indicating an approximate 20 year return period to peak. The size of each charcoal peak was of a smaller magnitude to those found during the Mesolithic high-resolution analyses, except that at 5420 cal BP. This suggests potentially smaller scale fires in the Neolithic, or simply fires further from the Bökeberg sampling location, which matches the archaeological evidence that activity moved away from the Bökeberg site in the Neolithic.

*Kretzschmaria deusta*, a fungal indicator of wounded and decaying wood (Innes et al. 2006), was identified during some of the fire episodes but not all, and *Triposporium elegans* again peaked around the time of the largest micro-charcoal peak, suggesting the presence of decaying woody substrates connected to these fire events. As the fires appear to be further from the sampling location however, this local evidence for damaged or decaying wood may derive from other processes such as natural wind-throw, or anthropogenic coppicing. No evidence of a particular species encouraged by such coppicing, or a resulting increase in grazing intensity was identified.

*Anabaena*, which is thought to increase with nutrient input to a lake (Hillbrand et al. 2014), peaked from 5410 to 5385 cal BP and was found together with other herbaceous indicators of disturbed ground such as *Plantago lanceolata*, Chenopodiaceae, *Artemisia*, and micro-charcoal. Low titanium concentrations however indicate no significant influx of lithogenic material to the lake due to soil disturbance at this time. *Pediastrum* replacing HdV-128b as the dominant NPP, accompanied by a decline in *Triposporium elegans*, indicates a shift in lake trophic status in zone BK-N2. Peaks in the Si/Ti ratio from 5430 to 5420 cal BP and from 5385 to 5265 cal BP, lasting between 10 and 20 years, indicate short-term increases in
biogenic silica deposition (Peinerud et al. 2001), which may be linked to a higher lake trophic status.

Overall, this phase suggests a repeated fire disturbance of the wider landscape, with an increase in herbaceous indicators of disturbed ground and a change in trophic status. Disturbance was likely to not have been local to the Bökeberg site however, reflecting the archaeological record that activity moved away from Bökeberg in the Neolithic.

Zone BK-N3

2570-2555mm (c.5345-5315 cal BP)

The abundance and diversity of herbaceous taxa declines in zone BK-N3, as trees and shrubs recover to c.96% TLP. This suggests a reduction in areas of open or disturbed ground. *Alnus* declined together with *Cyperaceae* and *Caltha palustris* suggesting a reduction in the extent of marsh or carr environments, although *Salix* was still present. There is charcoal evidence for fire at 5340 cal BP, yet macro-charcoal was absent, suggesting that the fire was not local to the sampling location. Taxa indicative of disturbed ground such as *Artemisia* and *Plantago lanceolata* were less common, but accompanied by finds of *Kretzschmaria deusta* indicating the local occurrence of damaged or decaying wood at the site. Low concentrations of titanium suggest no increase in input of lithogenic material to the lake as a result of any soil disturbance, and there is no significant change in lake water NPP assemblage, although *Anabaena* does once again increase with fire disturbance. This phase suggests continued fire-related disturbance in the wider area, and a recovery of woodland close to the sampling site.
8. Dan Clough Moss Discussion

The overall aim of this chapter is to investigate both the changing nature of human impact across the Mesolithic-Neolithic transition at Dan Clough Moss, and the potential influence that changing environmental conditions may have had.

8.1 Human impact on the environment across the Mesolithic-Neolithic transition

Peat initiation at Dan Clough Moss (DCM) began at c.6510 cal BP, in the later, but not latest, Mesolithic regionally. At this time the environment was characterised by woodland but with some openings and a wet soil surface. Quercus-Corylus woodland dominated, with Alnus perhaps benefitting from wet conditions around the site. Although openings in this woodland cover are inferred from high levels of grasses and other herbs, there is no evidence for fire disturbance at this time. Four hearths with a scalene triangle dominated flint assemblage have been excavated at March Hill Carr, and found to be associated with a range of activities including knapping and scalene triangle production (Spikins, 2000). Artefacts were concentrated in a degraded former mineral soil directly beneath peat, and the use of these hearths has been dated using Bayesian methods to 6700-6450 cal BP (Griffiths, 2012). As the date for peat initiation at Dan Clough Moss falls within this range for late Mesolithic activity, it is possible that human impact was in part responsible for peat initiation at this site. Similar links between the onset and rate of soil deterioration and human presence have been seen regionally in the Pennine area (e.g. Williams, 1985; Simmons and Innes, 1987; Tallis and Switsur, 1990). A reduction in woodland cover in the surrounding landscape would have the potential to increase runoff into depressions or basins in the landscape, as levels of interception and evapo-transpiration by tree species decline. An increase in the water-table of these basins would lead to anaerobic conditions reducing the rate of organic decomposition, and peat could start to form as a result (Tallis, 1991). Repeated burning and grazing has also been found to accentuate irreversible soil deterioration (Tallis and Switsur, 1990; Tallis, 1991; Atkins et al. 1998). Mesolithic people had been in the region from at least 10500 cal BP, with very early dates on charcoal associated with Mesolithic microliths from Lominot III (10954 ± 120 cal BP) 400m to the east, Waystone Edge (10690 ± 120 cal BP) 2km to the north west and Warcock Hill South (10437 ± 495 cal BP) 4km to the south east (Switsur and Jacobi, 1975). Inferred Mesolithic impacts are observable in the palynological record from c.9000 cal BP at Robinson’s Moss,
13km to the south and Alport Moor, 22km to the south (Tallis and Switsur, 1990) and Soyland Moor, 7km to the north (Williams, 1985). These continue to be observed at least to 6500 cal BP at nearby Black Heath, c.2km to the north east (Ryan and Blackford, 2010). Whilst it seems therefore possible that human impact may have influenced peat initiation at Dan Clough Moss, it cannot at present be discounted that a natural shift to wetter conditions (Tallis, 1991), or natural woodland disturbances, were responsible. Peat could also have been initiated through the gradual acidification of soil conditions through the postglacial period (Smith and Taylor, 1989).

The first record of fire at DCM appears from 6350 to 6240 cal BP, after the dated occupation of March Hill Carr. Fire appears to have been within the vicinity of the sampling location, yet bog surface conditions locally were still wet, dominated by sedge and small open pools. This palynological signal appears to have similarities with disturbance phases in other areas of the UK, particularly Dartmoor (Caseldine and Hatton, 1993) and the North York Moors (e.g. Innes and Simmons, 2000). The occurrence of fire in a wet environment and without the presence of heath species or much Pteridium has been interpreted as having a high likelihood of human agency (Ryan and Blackford, 2010).

A further woodland opening and a number of episodes of fire were recorded in the 130-year period between 6235 and 6105 cal BP (zone DCM-2). Heath expansion in this zone may have been attributable to an opening of the woodland canopy, reducing levels of interception and evapo-transpiration, thereby increasing leaching of the soil and making it more acidic. It may also have originated due to fire encouragement, or natural edaphic factors (Hobbs and Gimingham, 1987; Tallis, 1991).

Fires local to the site only approximately 20 years apart were observed between 6235 and 6185 cal. BP (zone DCM-2a). The first expansion of heath and a shift from wet to drier bog surface conditions correspond with the first increase in charcoal at 6235 cal BP. Whilst difficult to determine a causal relationship, it is reasonable to suggest that a shift towards drier conditions would have been conducive to an increased use of fire. Whilst it would also have been more favourable for natural wildfires from lightening strike, such short return periods of fire local to the sampling location suggest that, in a predominately deciduous woodland, and on a bog that was still relatively wet, it would be highly unlikely that such fires would burn so frequently and regularly naturally. Chandler et al. (1983) highlight that in Europe, severe fires only occur during periods of exceptional drought, with the fire season belonging to spring and autumn, and consisting of a return period of over 6000
years for a particular location. Natural fire characteristics of deciduous woodland are however extremely difficult to elucidate, since most analogous woodlands are intensively managed or guarded against fire, or are in fact secondary woodland rather than mature communities (Simmons, 2003). In this case, their frequency in time and space is such that natural causes seem unlikely, and are interpreted as likely being anthropogenic in origin. Grazing intensity increased during times of peak charcoal, suggesting that animals may have been attracted to fire-cleared spaces and their rejuvenating vegetation. After approximately 20 years, *Calluna* can become woody and little grazed (Grime et al. 1998). Firing at regular intervals rejuvenates older *Calluna* making it more viable forage, with burnt discontinuous stands of *Calluna* often grazed more intensively than large patches (Anderson et al. 1998). The palynological evidence of zone DCM-2a therefore provides support for models of deliberate manipulation of the vegetation by the use of fire, so as to improve forage, attract animals and improve hunting success (Zvelebil, 1994; Innes and Blackford, 2003). This relationship between fire and *Calluna* however does not continue through the remainder of DCM-2, as *Calluna* remains persistent when micro-charcoal influx is at a minimum in zones DCM-2b and DCM-2d.

Woodland continued to decline from 6185 to 6155 cal BP (zone DCM-2b), yet this time not associated with fire. High levels of dead or decaying wood were present at the sampling location at 6175 cal BP, with lower levels of these indicators and evidence for grazing animals such as *Sporormiella* found throughout the rest of the zone. It is possible that woodland manipulation processes such as ring-barking or coppicing were responsible for the woodland opening and decaying wood indicators (Christensen, 1997), increasing grazing numbers to the improved levels of forage as a result. No obvious increase in forage was observed however, yet it is possible that Poaceae pollen production was suppressed by heavy grazing pressure (Groenman-van Waateringe, 1993). Coppicing is, however, acknowledged to be extremely difficult detect in the palynological record (Göransson, 1984, 1986, 1988), and it does also remain possible that natural processes such as wind-throw caused woodland disturbance which attracted grazing animals to the site, but that this opening was maintained through other anthropogenic methods. Activity at March Hill Top has been dated to between 6180 and 5910 cal BP, and so human manipulation of the woodland cover appears to have been possible during this period.

Also within this late Mesolithic occupation period of March Hill Top, a period of fire lasting approximately 20 years from 6155-6135 cal BP (zone DCM-2c), again local to the sampling
site, was associated with an expansion of pasture and local grazing indicators. Pollen and geochemical indicators of disturbance were present, together with potential indicators of dead or decaying wood. Occuring during a period of slightly wetter conditions, the prolonged nature or recurrence of fire close to the sampling site itself suggests that while it remains possible this signature was caused by natural wild fire, it is likely that the resulting woodland opening, or that created by heavy grazing pressure in zone DCM-2b, was maintained with the use of fire by Mesolithic people for a period of 20 years, for the economic benefits of attracting or maintaining grazing herbivores in the area. This in-part supports Simmons (1969) model that Mesolithic hunter-gatherers would have exploited foci of herbivore density and extended them by burning, together with Innes (1996) and Brown’s (1997) suggestion that fire was used to maintain openings created previously either by natural or anthropogenic means, such as ring-barking. If true, this practice may reflect the increase in geochemical indicators of soil disturbance if the same areas were kept open and grazed for a period of approximately 50 years. Increased woodland openness would also enable higher levels of atmospherically derived silicon and titanium to deposit at the sampling location. It appears unlikely that this enrichment in lithogenic material was due to a slower accumulation of peat at this time, as NPP indicators suggest an increase in bog surface wetness with increasing lithogenic elements, indicating a potential increase in sediment accumulation rate, if any. It remains possible however that burning may have destroyed some soil organic matter, resulting in enhanced silicon and titanium concentrations at this time.

Fire in the local area from 6105 to 6055 cal BP (zone DCM-3), peaking at 6090 cal BP, corresponded with a recovery in arboreal pollen but also an increase in herb types. Wetter bog surface conditions during this time correlated with a decline in heathland. Although fire can encourage *Calluna* heath, severe fires can kill it. Hot fires can burn into the organic layers destroying the underground *Calluna* parts, and hence have the potential to cause heath decline (Gimingham, 1970). The onset of *Calluna* decline was prior to any evidence of severe fire however, and it is more likely that continuous waterlogging caused heath species to be replaced by more herbaceous taxa such as Cyperaceae (Simmons, 2003). As there is no obvious evidence of woodland decline, which has the potential to increase water table levels, it is possible that the wetter conditions were due to natural climatic change. Despite this, burning in the locality continued, suggesting it was not likely to be the result of wildfire. There was no observable change in woodland composition, and grazing indicators were only found at 6065 cal BP with potential indicators of grazing or decaying
wood from 6085 cal BP. This suggests that if these were anthropogenic fires in the local area, there were no significant openings in canopy cover and no observable increases in herbivore numbers as a result. Lack of species normally encouraged by fire, such as *Calluna vulgaris*, may indicate that in fact the charcoal record could reflect the use of a domestic fire. A hearth at March Hill Top has been dated to between 6180 and 5910 cal BP, and domestic fire known to have been used.

A further phase of woodland reduction, lasting approximately 105 years from 6055 to 5950 cal BP (zone DCM-4a), was associated with repeated fires in at least the local area. Charcoal peaked at 25 to 30 year intervals, slightly longer in return period than zone DCM-2a but still fairly regular. Bog surface wetness indicators suggest a move towards drier conditions, and whilst it is possible that this would have led to increased likelihood of natural fires upon lightening strike, their frequency local to the sampling location make entirely natural origins unlikely. Drier conditions however would have facilitated the easier use of fire by Mesolithic groups, in an attempt to manipulate and manage their environment. Increased grazing intensity during this period, together with fire disturbance of woodland and indicators of damaged wood local to Dan Clough Moss provide support for models of fire-assisted woodland management (Simmons and Innes, 1987; Moore, 2000). The shift away from wetter conditions, a woodland reduction and regular firing of the vegetation could be responsible for the observed heath expansion (Tallis, 1991), which may have also provided additional forage for game animals. As this period overlaps with known human occupation at March Hill Top, these anthropogenic interpretations appear possible.

Woodland declined once more with heath expansion, over a period of approximately 55 years from 5825 to 5770 cal BP (zone DCM-6). This period could represent the earliest Neolithic influence in the wider region, dated to between 5870 and 5670 cal BP (Griffiths, 2011). Fire was present close to the sampling site throughout, peaking at 5785 cal BP and 5775 cal BP, and occurred at a time of transition from wetter bog surface conditions and low peat humification, to increasingly drier conditions. This shift in conditions may have been responsible for causing some increase to natural fires from lightening strikes, however charcoal peaks just ten years apart in the local vicinity highly suggest human agency was likely to have been responsible. Local evidence for grazing was only found in one sample at 5780 cal BP, and the non-arboreal component of the vegetation was low. Drier conditions and regular firing were likely to have been responsible for the large expansion and encouragement of heathland at this time, but it may also have been due to
the general spread of blanket bog across the upland landscape, with *Calluna* and other ericaceous pollen registering from a wider catchment.

Continued woodland decline was observed from 5770 to 5495 cal BP (zone DCM-7), a period lasting 275 years, and dating to the early Neolithic. Bog surface conditions were consistently drier, and heathland continued to expand close to the sampling location. Local fires were present at 5740 cal BP and 5700 cal BP, the prior likely to have been very local and/or substantially larger in size, due to large amounts of macro-charcoal found at this level. A more prolonged, again local, fire was observed later from 5685 cal BP, with enhanced charcoal influx continuing for around 30 years subsequent to peak influx. In 5600 cal BP and 5520 cal BP there were fires recorded in the extra-local to regional landscape, the latter peak in micro-charcoal being such a magnitude paired with low macro-charcoal that it suggests that this may have been a very large or persistent fire. Local evidence of grazing, decaying wood and disturbed ground correlate with the local fires, suggesting that fire clearings of the local woodland were successful in attracting increased grazing animals to the area. A woodland decline could have affected Dan Clough Moss’s hydrological conditions, increasing the water-table due to reduced interception and evapo-transpiration in the catchment. Drier conditions prevailing through a period of woodland decline suggests that the shift to drier conditions may have been climatic in origin, and that the fire events recorded may have been a consequence of an increased likelihood of natural fires originating from lightening strike. It is also possible however that anthropogenic exploitation of more favourable conditions for burning caused some or all of the fires. It is perhaps likely that the prolonged nature of burning close to the sampling site around 5685 cal BP required anthropogenic influence to persist, and the benefits to economy of these burning episodes are clear in that local fires attracted increased grazing numbers to the area, albeit in lower numbers than found in the late Mesolithic. The observed economic benefits however can not determine the original nature of the fire, but it appears more likely that the return period of 80 years within the extra-local to regional landscape could have been indicative of natural wildfire, over those local to Dan Clough Moss.

Woodland cover continued to decline for a period of 100 years from 5495 to 5395 cal BP (DCM-8), in the early Neolithic, as Cyperaceae expanded. A lack of corresponding NPPs suggests that this increase in sedge was not local to the sampling site. Indicators for disturbance were rare, with only occasional finds of *Plantago lanceolata*, low silicon and titanium influx, and evidence for fire and damaged wood only found at 5400 cal BP.
Corresponding with this fire, *Corylus* began to expand, at least to 5350 cal BP. Evidence that this expansion could be due to the anthropogenic encouragement of *Corylus* is lacking, such as fungal indicators of damaged or decaying wood which may occur if the coppiced trees were local to the sampling location. Coppicing practices however are notoriously difficult to detect in the palynological record, and so it cannot be ruled out on this basis. Alternatively, *Corylus’* expansion with *Alnus* and a decline in Cyperaceae could reflect natural succession and further development of the blanket bog with *Alnus* and *Corylus* potentially fringing the bog on higher or drier ground.

*Alnus* and *Corylus* remained prevalent until 4965 cal BP, declining only between 5170 and 5100 cal BP when Cyperaceae in the wider landscape expanded once more. Fire was present at this time, together with the disturbance indicator *Plantago lanceolata*. Macro-charcoal however was relatively low indicating the extra-local to regional nature of the fire, and as a result no local indicators for increased grazing pressure were observed at Dan Clough Moss. These fires could indicate a clearance of the fringing bog vegetation such as *Alnus* and *Corylus*, resulting in an expansion of Cyperaceae. Drier bog surface conditions were observed during this period suggesting the fires may have been natural in origin, however drier conditions were not exclusive to times of increased fire during this period.
Figure 8.1 – Summary human impact diagram for Dan Clough Moss. Proxies expressed as in Figs. 6.4-6.6.
8.2 How the nature of human impact changed across the Mesolithic-Neolithic transition

Woodland disturbances identified across the period 6500 to 5000 cal BP (Fig. 8.1) covering the period from latest Mesolithic to earliest Neolithic were similar in character in that they all experienced a reduction in arboreal pollen corresponding with an expansion of heath. There was no significant difference in the inferred level of woodland openness during each disturbance, as total arboreal levels declined to approximately 40% TLP (excluding *Alnus*) during both the late Mesolithic and early Neolithic disturbances. The composition of the arboreal component upon recovery however did change in the Neolithic, with *Quercus* levels remaining low and *Corylus* expanding in its place from 5395 cal BP. One of the biggest differences from the late Mesolithic to the earliest Neolithic is that episodes of woodland disturbance became longer in duration. As a whole, late Mesolithic disturbances lasted approximately 110 years before woodland recovered to previous levels, yet the long phase of woodland disturbance recorded in the Neolithic persisted for approximately 430 years. This may reflect a possible shift to a more continuous, rather than transient or episodic, use of the landscape in the Neolithic period.

Most of the episodes of woodland disturbance were associated with fire (Fig. 8.1), however the return frequency and scale of fire appeared to change at around c.5800 cal BP, representing the transition period between the late Mesolithic dates at March Hill (6180-5910 cal BP) and earliest Neolithic dates in the Yorkshire and Humberside region (5870-5670 cal BP) (Griffiths, 2011). Fires became less frequent with return periods of peak charcoal between 40 and 80 years, rather than the 20 to 30 year return interval observed prior to 5950 cal BP in the later Mesolithic. Neolithic fires from 5600 cal BP onwards appeared larger in scale, but increasingly extra-local or regional in nature from c.5520 cal BP. There is also less positive evidence that these fires were part of any purposive management of the woodland, as fewer indicators of grazing were found associated with fire disturbances than in the late Mesolithic period. This may suggest that fire had a different purpose or cause in the Neolithic. However, as most fungal indicators of grazing are local indicators, their absence from c.5500 cal BP may just reflect a shift of fire and any related increase in grazing intensity away from the Dan Clough Moss sampling location. If purposive use of fire to attract grazing herbivores was practiced in the early Neolithic, evidence suggests that it was less successful at Dan Clough Moss than in the late Mesolithic.
The data suggest that the nature, duration, scale and location of anthropogenic impacts on the environment did change at the onset of the Neolithic. Evidence from the late Mesolithic supports a model of fire-assisted woodland management, a pattern seen at other sites around the central Pennines (e.g. Ryan and Blackford, 2010) although not previously in such detail, or with the degree of precision in reconstruction. Fire may have been used either to create openings in woodland or scrub, or to extend original or pre-existing openings created by grazing animals or other anthropogenic methods. There is evidence to support woodland manipulation through coppicing methods such as ring-barking or girdling, which would benefit Mesolithic hunter-gatherers by increasing wood and plant resources, and improving forage for grazing herbivores thereby increasing chances of hunting success. The palynological evidence does not however provide as strong support for these models in the early Neolithic, and the signal could arguably be natural in origin due to the nature of the fire episodes, and the lack of archaeological evidence in the area extra-local area post-5910 cal BP.

The shift in the nature of woodland disturbance and fire at Dan Clough Moss occurred following an episode of low woodland disturbance, with high levels of arboreal pollen such as *Quercus* and low levels of heath species recorded from around 5935 to 5825 cal BP. The earliest Neolithic sites in the Yorkshire and Humberside region have been dated to between 5870 and 5670 cal BP (95.4% probability) (Griffiths, 2011), and coincide well with the subsequent shift in the nature of disturbance towards less frequent fires more regional in nature, and longer episodes of arboreal decline. This suggests that a change in material culture in the wider region coincided with a change in the nature of human impact, and a potential shift away from late Mesolithic sites. No characteristic aspects of Neolithic land use were observed during the late Mesolithic at Dan Clough Moss, with no evidence of more permanent or longer-lasting clearances, no cultivation indicators, and no record of cereal-type pollen. Typical late Mesolithic lifeways and manipulation of the environment around March Hill appear to have persisted much later than most other places in Britain (Griffiths, 2011). Indeed, dates from the rod site at March Hill Top are contemporaneous with the earliest known Neolithic sites in Britain (Griffiths, 2011). It appears that there was later a move away from such areas and land use manipulation practices, perhaps towards the lowlands which may have provided better conditions for new the practices of the Neolithic, such as cultivation or animal husbandry, or away from the area completely. However, there is limited radiocarbon evidence for early Neolithic sites in the region to test this hypothesis at present (Griffiths, 2014).
This research presents the first attempt to reconstruct human impact contiguously and at high resolution through the Mesolithic-Neolithic transition in northern Britain. Innes et al. (2013) compared high resolution analyses of Mesolithic and Neolithic disturbances approximately 1000 years apart at Bonfield Gill Head, North York Moors. Evidence revealed that the late Mesolithic phase was defined by repetitive application of fire to woodland to encourage a mosaic of vegetation which would aid hunting and promote Corylus. The early Neolithic data showed aspects of the ‘forest farming’ model, with an inferred succession of tree girdling, fire-prepared cultivation, and coppice-woodland management. While Mesolithic practices appear similar at Dan Clough Moss, no evidence for forest farming has been found as no crop plant pollen, or high frequencies of the regular weeds of cultivation have been identified. The low visibility of low-scale alterations of woodland however makes it a difficult model of early Neolithic impact to test using palynology. Other studies in the central Pennine region have recognised an increased use of fire for the potential benefits to the economy from c.6800 cal BP (Williams, 1985; Tallis and Switsur, 1990; Ryan, 2006; Ryan and Blackford, 2010), which this study does not disprove.

8.3 The influence of changing environmental conditions upon the nature of human impact

If late Mesolithic material culture and economies persisted at March Hill beyond the period where those of Neolithic character were already being found around Britain, it is important to consider why this may have been, and why the eventual shift took place. The potential that environmental conditions have to influence or shape cultural decisions has been discussed earlier (Chapter 2.3). An increase in environmental variability or a shift to less favourable conditions may have put stress on original hunter-gatherer practices, making Mesolithic groups more open to new ideas and cultures (Tipping and Tisall, 2004). It has also been suggested that a shift towards drier, more favourable conditions at the Mesolithic-Neolithic transition could allow practices previously unsuitable, such as cultivation, to be adopted (e.g. Bonsall et al. 2001) The following sections tests these ideas at Dan Clough Moss.

Canonical Correspondence Analysis (CCA) of the major pollen types with micro-charcoal area influx (conditional effect $\lambda=0.01$, $p=0.014$), macro-charcoal frequency influx (conditional effect $\lambda=0$, $p=0.326$) and percentage light transmission (conditional effect $\lambda=0.02$, $p=0.002$) used as environmental variables (Fig. 8.1) was carried out to examine the
influence that the degree of peat humification and inferred drier bog surface conditions, and both regional and local fires may have had upon the vegetation assemblage. Results illustrate that neither the degree of peat humification or fire had any significant control over the distribution of the whole pollen dataset. A small negative correlation can be identified between *Plantago lanceolata*, Caryophyllaceae, Chenopodiaceae, *Artemisia* and the percentage light transmission, and trees such as *Quercus* and *Ulmus* have a small positive correlation with percentage light transmission. This suggests that disturbance indicators may correlate with periods of increased peat humification and inferred drier bog surface conditions, whereas deciduous woodland species may correlate to some degree with periods of lower peat humification and inferred wetter bog surface conditions. Bog surface wetness conditions may therefore have had some effect upon the degree of human disturbance of the environment, which appears to have been greater during periods of drier conditions. Although statistically weak, this correlation is observable in figure 8.3. Weak statistical correlations may arise from lags existing in the high-resolution data, together with the fact that peat humification data is at present non-quantifiable.

![Figure 8.2](image)

**Figure 8.2** – Canonical Correspondence Analysis of major pollen types, with micro-charcoal, macro-charcoal and percentage light transmission as environmental variables.
The two identified late Mesolithic phases of woodland disturbance i and ii do coincide with NPP indicators of drier bog surface conditions, with woodland recovery and, at times, lower levels of fire when conditions appear wetter (Fig. 8.3). A shift towards more continuous drier bog surface conditions is observed from c.5800 cal BP. Peat humification increases steadily, and NPP indicators of local bog forming vegetation switch from a dominance of sedges with open pools to those associated with the roots of *Calluna* and drier, more decomposed peat.

It is around 5800 cal BP that the first Neolithic aged fire disturbances appear (phase iii), and the earliest known Neolithic sites in Yorkshire are dated (Griffiths, 2014). This suggests that there was a major shift in material culture, and land use practices, at the time of a shift to a more prolonged episode of drier conditions (Fig. 8.3). The correlation between fire and drier conditions could reflect natural processes, but evidence shows this was unlikely based on the location, frequency and nature of the fires (see chapter 8.1).

Bog surface wetness conditions appeared quite variable in the late Mesolithic, and the shift towards more stable drier conditions may have enabled practices previously deemed unsuitable or unsuccessful, such as cultivation, to be practiced. The evidence supports aspects of Bonsall et al.’s model (2001) that the beginning of the Neolithic was characterised by a shift to drier, more continental conditions across north-west Europe, making farming a viable practice - yet no evidence for agriculture was found in the March Hill area.

The prolonged 135-year period of wetter bog surface conditions between approximately 5935 and 5800 cal BP may also have led late Mesolithic hunter-gatherers to question or abandon their generally successful methods centred around fire, and perhaps encouraged either a more ready acceptance of new ideas and techniques of subsistence which may already have been practiced elsewhere at this time (Tipping and Tisdall, 2004; Tipping, 2010), or led to the abandonment of the area as a persistent and popular place.

Whatever its impact, it seems possible in terms of timing that environmental change may have had some level of influence upon the nature of land use around the March Hill area and the transition to the Neolithic.
Figure 8.3 – Summary human impact and bog surface wetness diagram for Dan Clough Moss. Proxies expressed as in Figs. 6.4-6.6.
8.4 Summary

The nature, duration and scale of human impact have been found to change at the Mesolithic-Neolithic transition at Dan Clough Moss. Woodland disturbances became significantly longer in duration, potentially reflecting a shift towards more continuous rather than episodic use of the landscape. Whilst most woodland disturbances were associated with fire, the scale and frequency changed from late Mesolithic to early Neolithic, with less positive evidence that it was used as part of a purposive management of the woodland. A shift in material culture coincident with a shift in the nature of human impact, together with a potential move away from the site, indicates that there was no evidence of economic overlap between the two cultures at March Hill. Instead, late Mesolithic groups and practices were found to have persisted at March Hill for longer than most of the rest of the UK, before an apparent abandonment of the site and/or its woodland manipulation practices from c.5950 cal BP.

A 135 year episode of wetter conditions found directly subsequent to the latest Mesolithic archaeological and palynological evidence of human impact in the March Hill area suggests that it may have influenced late Mesolithic groups to the extent that they questioned or abandoned their original practices centred around fire. Conditions were then seen to shift towards a more prolonged episode of drier bog surface conditions from c.5800 cal BP, coinciding well with the appearance of the earliest dated Neolithic archaeology in the wider region between 5870 and 5670 cal BP (Griffiths, 2011), suggesting that conditions may have perhaps become more favourable or viable for Neolithic practices such as cultivation. Such correlations suggest that climatic or environmental conditions may have had some influence upon the nature of human impact, and the timing of the Mesolithic-Neolithic transition in the March Hill area.
9. Bökeberg Discussion

The overall aim of this chapter is to investigate both the changing nature of human impact across the Mesolithic-Neolithic transition at Bökeberg, and the potential influence that changing environmental conditions may have had.

9.1 Human impact on the environment across the Mesolithic-Neolithic transition

The profile opens at approximately 7395 cal BP, when the environment around Bökeberg was almost completely closed woodland. Quercus, Ulmus and Tilia flourished on higher ground, and Alnus probably formed a belt between areas of higher ground and the lake shore. High levels of Corylus may have been found at the woodland edge or in more open areas of the woodland. There is archaeological evidence for occupation at Bökeberg III from 7530 to 7340 cal BP (Fig. 9.1), where late Mesolithic groups were found to have gathered hazelnuts and acorns, and elm, oak, hazel and pine wood for fuel, construction or tool purposes (Regnell et al. 1995). Evidence for the later part of this occupation phase is visible in the palynological record in zone BK-1a which begins c.7400 cal BP, with fires local to Bökeberg prior to 7320 cal BP, fungal indicators of decaying wood, and high Corylus percentages which, together, may reflect an anthropogenic encouragement of hazel either by fire or coppicing for their nut production.

Further evidence of fire local to Bökeberg is found from at least 7250 to 7180 cal BP (zone BK-1a). There is no corresponding archaeological evidence for occupation at Bökeberg III at this time (Fig. 9.1), but species normally encouraged by fire, such as Calluna vulgaris, expand together with shade intolerant Pteridium, herbaceous indicators of pasture such as Ranunculus acris –type and Caryophyllaceae, and those indicative of disturbed ground such as Artemisia and Apiaceae. There is also evidence of damaged wood local to the site. This impact on the vegetation may reflect a late Mesolithic purposive use of fire to manage their environment, with such a practice often identified in Britain by a woodland disturbance accompanied by an increase in charcoal and herbaceous and fungal indicators of grazing (Ryan and Blackford, 2010). No such fungal indicators of grazing were identified at this time at Bökeberg, however due to the nature of fungal spores depositing close to their source of production (Ingold, 1971; Lacey, 1996), their absence within a sediment core does not necessarily rule out grazing in the area. This phase of disturbance however
corresponds with the onset of a period of lower lake levels, as reconstructed through macrofossil analysis of the littoral sequence at Bökeberg III (Regnell et al. 1995). If interpreted as representing significantly drier or warmer conditions, this may suggest that an increase in aridity was responsible for an increase in the incidence of natural fire from lightning strike (Chandler et al. 1983), and any related vegetation disturbance. At present it is not possible to distinguish the origin of this fire disturbance.

A further episode of local burning from 7035 to 6675 cal BP (zone BK-1b), an episode lasting approximately 360 years, correlates well with the archaeological record of further occupation at Bökeberg III dated from 7060 to 6600 cal BP. Regnell et al. (1995) noted that during this occupation phase, hazelnuts were gathered, and a large variety of wood was collected from all types of woodland for fuel or construction purposes. Corylus remained prevalent through this period, possibly reflecting continued encouragement as a key resource. Indicators of damaged or decaying wood such as *Kretzschmaria deusta* and *Coniochaeta xylariispora* (van Geel, 1978; Innes et al. 2006) may reflect the coppicing of Corylus to benefit from an increased production of hazelnuts. They may also reflect damaged wood from the known collection of wood resources around the lake at this time. *Alnus* and *Betula* appear the most affected, and suggest a possible burning of the lake edge vegetation at this time. Occasional finds of *Plantago lanceolata*, *Urtica* and Apiaceae were found indicating disturbed ground, and *Diporotheca* sp. towards the end of the zone suggests soil disturbance either due to human activity or livestock trampling of the wetland and lake shore ecosystem (Cugny, 2011 cited in Hillbrand et al. 2012).

The apparent abandonment of this occupation period in the archaeological record at approximately 6600 cal BP corresponds with a synchronous change in lithology towards a coarser gyttja and a substantial increase in lake level at Bökeberg (Regnell et al. 1995). Evidence of local fire is still present however in the palynological record for approximately 260 years until 6340 cal BP, with species normally encouraged by fire such as *Calluna vulgaris*, and those indicative of areas of pasture such as Poaceae, *Ranunculus acris*-type, *Caryophyllaceae* and *Asteraceae asteroidae* reflecting its impact on the landscape. These fires, however, appear much smaller in scale than the earlier events due to lower concentrations of macro-charcoal. They may also perhaps represent fires at a slightly greater distance from the sampling location. As a result, total tree taxa begin to recover around Bökeberg, with notable increases in *Quercus* and *Fraxinus*. If higher lake levels are taken to indicate wetter climate conditions, whether it be an increase in precipitation or a
decline in temperature, this suggests that these fires were not likely to have been the result of an increase in natural fire from lightning strike, especially considering they covered a period lasting 260 years. Anthropogenic burning, but further from Bökeberg itself, is most likely in this period, potentially to clear new areas for settlement, and/or as a result of camp fires.

Evidence suggests a less disturbed landscape from 6340 cal BP, with continued recovery in woodland cover as Quercus, Ulmus and Tilia increase, and less evidence for fire or damaged or decaying wood. There is evidence that the lake level at Bökeberg was lower at this time (Regnell et al. 1995) yet there is no archaeological or obvious palynological evidence of human impact. Fewer fires through this potentially drier period, inferred from the fall in local lake levels, suggests that a connection between increased aridity and fire frequency (e.g. Chandler et al. 1983; Anderson, 1998; Anderson et al. 1998) is not demonstrated at this time.

In Regnell’s original work at this locality, large cereal type grains, noted as potentially 'early' cereal pollen, had been found in phases prior to the elm decline of c.5900 cal BP, and associated with the later Mesolithic occupation near the coring site. However in this study, no larger grass grains were recorded, and indicators of disturbed ground such as Plantago lanceolata, Artemisia and Chenopodiaceae were rare until c.5800 cal BP. Although samples are not contiguous, and pollen sums less than in studies where cereal pollen has been specifically targeted through rapid-scanning techniques (Edwards et al. 1986; Edwards and McIntosh, 1988), this lack of cultivation evidence suggests no overlap between later Mesolithic and initial Neolithic food production economies.

Woodland taxa began to decline from 5900 cal BP, mainly consisting of a reduction in Ulmus likely to be attributable to the classic elm decline of southern Sweden (Gaillard et al. 1991; Andersen and Rasmussen, 1993). This period represents the time of transition from Ertebølle to Funnel Beaker culture, which generally became established in southern Sweden between 5900 and 5815 cal BP (Larsson, 1991). There is no archaeological evidence for Neolithic occupation of Bökeberg III, and no obvious palynological evidence for their impact on the environment at this time.

Evidence of fire, likely to be extra-local to regional in nature, begins to increase from 5720 cal BP, as Betula, Alnus, and Quercus expand whilst Ulmus and Tilia decline through to 5550 cal BP. Corylus also expands further, together with herbaceous indicators of disturbed
ground such as *Artemisia* and Chenopodiaceae, and indicators of woody substrates. This may represent a manipulation of the woodland to, for example, increase the production of hazelnuts and potentially acorns, although evidence for acorn use in the early Neolithic is scarce. The woodland may also have been manipulated to clear ground ready for cultivation, although no positive evidence for cultivation such as cereal-type pollen was identified, even in samples dated to the Neolithic period. The palynological record therefore supports the archaeological record (Karsten, 1986; Karsten and Regnell, in preparation) at Bökeberg suggesting that human activity may not have been local to the site at this time, which would make any identification of small-scale cultivation activities from the record extremely difficult using traditional palynological techniques. Non-traditional palynological techniques such as rapid scanning of samples for cereals (Edwards et al. 1986; Edwards and McIntosh, 1988) may have better success in identifying such small-scale early cultivation.

Throughout the period from 5500 to 5155 cal BP, fire is present, probably local to Bökeberg due to the presence of macro-charcoal. The overall lower concentrations however, suggest fire on a smaller scale or at a greater distance than those in the late Mesolithic. Herbaceous indicators of disturbed ground such as *Plantago lanceolata*, *Artemisia*, Apiaceae and Chenopodiaceae are present during this long phase which lasts approximately 345 years, and total tree cover continues to decline with very minor fluctuations, consisting of a reduction in later successional trees such as *Quercus* and *Tilia*, and an expansion in *Betula* and *Corylus*. *Triposporium elegans* suggests that woody substrate was present throughout. Evidence therefore suggests a period of disturbance that had a moderate effect upon the woodland, with fire disturbance likely to have been small in scale. Other land use practices may have been practiced, such as coppicing of the woodland, although this remains very extremely difficult to detect in the palynological record (Göransson, 1984, 1986, 1988).
Figure 9.1 – Summary human impact diagram for Bökeberg. Proxies expressed as in Figs. 7.4 and 7.5.
9.2 How the nature of human impact changed across the Mesolithic-Neolithic transition

Overall from the lower resolution analyses, woodland cover appears to remain relatively closed and stable throughout the Mesolithic-Neolithic transition, with extensive carr-wetland areas surrounding the lake itself. Evidence for fire local to Bökeberg is greater in the late Mesolithic, but herbaceous indicators of disturbance such as *Plantago lanceolata* are more prevalent in the early Neolithic, perhaps reflecting a shift in focus away from fire-related activity to one of early forest cultivation or animal husbandry. No positive evidence for farming has been identified in this study, though this may be a function of settlement moving away from the Bökeberg locality to other areas around lake Ydningesjön after 6340 cal BP, together with the fact that the palynological signal of early farming would be inherently weak due to a superabundance of high pollen producing tree taxa in the immediate vicinity which would swamp the signal (Göransson, 1984, 1986, 1988; Warren et al. 2014).

Determining the exact character of human impact through low resolution analyses can be extremely difficult. Samples are often not contiguous and entire events or evidence of human activities may be missed due to the sampling strategy. Evidence previously identified as one event may actually be a composite of different events if investigated in higher resolution (Innes et al. 2013). Understanding the timing of different features of a disturbance can enable a much improved reconstruction of the nature of land use and the sequence of events leading up to and immediately following it.

High resolution contiguous sampling across a period of late Mesolithic disturbance (Figs. 7.6 and 7.7) has revealed evidence of fire throughout the analysed sequence, which dates from 6985 to 6775 cal BP. Three periods of enhanced levels of charcoal are identified, the first appearing to have started before the beginning of the sequence continuing to 6955 cal BP, the second from 6915 to 6855 cal BP, and the third from 6835 to 6780 cal BP. These are rather prolonged episodes of burning, lasting up to 60 years, most of which likely to be local in nature. The prolonged and repetitive nature of these fires in the local area suggests that they are not likely to have been completely attributable to wildfire. The low-resolution diagram highlighted a possible burning of lake edge *Alnus* and *Betula* over this phase, possibly to make easier access and increase the diversity of the lake edge environment, and the high-resolution analysis highlights that these trees did not appear to consistently
recover between episodes of fire through this zone. It is known there were people using the site of Bökeberg III between 7060 and 6600 cal BP (Regnell et al. 1995), and so it is possible that some of the charcoal record may instead be reflecting hearths or campfires in use during the period of occupation.

Investigating an early Neolithic episode of disturbance in high resolution (Figs. 7.8 and 7.9) again revealed multiple episodes of fire in a 210 year period from a 5530-5320 cal BP. Three major peaks in micro-charcoal are recorded at 5495, 5420 and 5340 cal BP, with a 75 to 80 year return period. Prior to the first of these peaks is a 15 year period (5520 to 5505 cal BP) characterised by a decline in Quercus, fungal indicators of damaged wood, herbaceous indicators of disturbed ground such as Plantago lanceolata and Artemisia, and indicators of more open pasture including Poaceae, Asteraceae asteroidae and Rumex acetosa. It is possible that this palynological signal represents the coppicing of trees which would lead to their die back, increased levels of light reaching the woodland floor, and encourage the growth of different herbs (Göransson, 1984, 1986, 1988). Subsequent fire may then have been used as a means clearing the regenerating ground flora between trees to allow the growing of early cereals. Macro-charcoal indicates that these fires were local to Bökeberg itself, however even though Plantago lanceolata is present throughout, no positive evidence for cultivation was found. Less evidence for this potential sequence of events is seen for the two subsequent fire events. The latter fire appears to have been extra-local to regional in nature, and as such has less associated recorded disturbance in the vegetation record.

What is evident from the data is that fire became much less of a significant feature of the landscape around Bökeberg in the early Neolithic than in the late Mesolithic, both in scale and duration of events. Fire events became shorter in duration, and overall concentrations of charcoal accompanied by macro-charcoal suggest that fires may have been significantly smaller in scale in the early Neolithic. Regardless of this, mature woodland species declined and pioneer or secondary successional trees plus herbaceous indicators of disturbance were more prevalent than in the late Mesolithic period. This suggests that fire may have had a different purpose or significance in the early Neolithic, and that other practices may have been carried out which impacted upon the vegetation, particularly clearance through ring-barking and/or the coppicing of trees. Although evidence for settlement at Bökeberg is only found up to c.6600cal BP, find-sites with mixed Mesolithic and Neolithic material, or
unspecified Stone Age material, have been found approximately 400m away (Fig. 7.1) and so may be reflected in the Neolithic timeframe of this palynological profile.

The end of the late Mesolithic Ertebølle culture has been dated to approximately 5950 cal BP (Larsson, 2013). No evidence that the nature of land use observed during the late Mesolithic disturbance phase continued into the Neolithic has been found at Bökeberg. The nature of fire use together with the overall impact on the environment changed noticeably between the two high resolution periods investigated. The scale of fire disturbance is observed to have declined at Bökeberg c.700 years earlier than the transition to Neolithic, from c.6660 cal BP. This may reflect an active reduction in the use of fire from this point, perhaps as a consequence of a contemporaneous increase in lake level (Regnell et al. 1995) and people moving away from the sampling location, or wetter conditions may have reduced either the frequency of natural fires from lightening strike, or the feasibility of using fire as a woodland management tool. Further research at high resolution would be required to investigate the exact nature of the subsequent fire disturbance 6600-6340 cal BP, and whether it had fundamentally Mesolithic or Neolithic traits. From the low resolution palynological data available, these disturbances appear to have been late Mesolithic in character due to a distinct absence of Plantago lanceolata and other indicators of disturbed ground such as Artemisia and Chenopodiaceae, whilst arboreal levels remained high.

9.3 The influence of changing environmental conditions upon the nature of human impact

This project aimed to consider how environmental change may have influenced the nature of human impact across the Mesolithic-Neolithic transition. This project aimed to consider how environmental and/or climatic change may have influenced the nature of human impact across the Mesolithic-Neolithic transition. There is unfortunately little agreement in existing palaeoclimate records for southern Sweden, with conflicting data at different scales and with different levels of precision. Combining these often temporally and spatially coarse data with increasingly high-resolution palynological data is also inherently difficult, with each responding to and recording changes on very different scales, and requiring robust chronologies to integrate the two. It is also important to consider how any climatic change may have manifested itself to local late Mesolithic and early Neolithic groups, and
whether the change would have been significant, influential or even observable, so as to have the potential to affect their lifestyle choices.

Being situated at a lake edge, climatic change which manifested as fluctuations in lake level may have had a significant influence upon settlement occupation and activities at Bökeberg. The area available for settlement, grazing or crops may have expanded or contracted as a result, as would the diversity and productivity of vegetation and resources around the lake edge (Gaillard and Digerfeldt, 1991). Chiverrell et al. (2004) highlight the importance of wetland resources, such as rushes, sedges and grasses for a variety of purposes including food, fibres, fuel or building material. Major fluctuations in lake level and the surrounding wetlands therefore have the potential to be responsible for changes in the level or nature of anthropogenic land use in an area, and may have been a contributing factor towards the transition to Funnel Beaker culture at the beginning of the Neolithic. A shift to less favourable conditions may have made late Mesolithic Ertebølle groups more open to trying new methods of subsistence, or alternatively a shift towards conditions more favourable for the viable practice of typical Neolithic activities may have influenced the timing of their adoption.

When investigating past lake level changes, most evidence can also be explained by other environmental changes, and so multiple lines of evidence must be combined to increase the possibility of reconstructing an accurate lake level record. The types of evidence often combined include sediment lithology, sediment structure, sediment hiatus’, the level of the sediment limit and the distribution of lake vegetation, but increasingly additional proxies such as stable isotopes, molluscs, diatoms, cladocera and plant macro-fossils are being added in an attempt to improve the number and quality of reconstructions (Magny, 2007). Several lake level records have been reconstructed for southern Sweden over recent decades, and overall suggest the onset of a general period of lower humidity and lake levels from c.7500 cal BP, culminating between c.5600 and 5200 cal BP, but continuing until c.3000-2600 cal BP (Digerfeldt, 1988; Gaillard and Digerfeldt, 1991) (Fig. 9.2). Fluctuations beyond this broad pattern are acknowledged as being likely, and are reflected by the variance seen in lake level records from across southern Sweden (Gaillard and Digerfeldt, 1991; Harrison and Digerfeldt, 1993; Almquist-Jacobson, 1995; Hammarlund et al. 2003).

Regnell et al. (1995) used plant macrofossils recovered from the littoral sequence at Bökeberg III to provide local information about lake level fluctuations at the site between
Figure 9.2 – Summary human impact, bog surface wetness and lake level fluctuation diagram for Bökeberg. Proxies expressed as in Figs. 7.4 and 7.5.
c.7565 and 5800 cal BP (Fig.9.2). They demonstrated a major period of lower lake level from 7565 to 6600 cal BP, interrupted by slightly higher lake levels 7410 to 7190 cal BP. Lake levels then became substantially higher 6600 to 6300 cal BP, before falling from 6300 to 5740 cal BP.

Archaeological evidence of occupation from 7530 to 7340 cal BP and from 7060 to 6600 cal BP has been found to correspond particularly well with a major period of lower lake level at Bökeberg between 7565 and 6600 cal BP (Regnell et al. 1995) (Fig. 9.2). Upon comparison of the lake level record with the newly obtained palynological data, evidence of human impact on the landscape through the period covering c.7400 to 5200 cal BP does not always correspond with periods of lower lake level. Whilst the most substantial phase of human impact in the palynological record from 7035 to 6675 cal BP does correspond with both archaeological evidence for occupation and a period of lower lake levels, local burning was also recorded at times of higher lake level from 6675 to 6340 cal BP, and there is very little evidence for human impact during a subsequent period of lake lowering from 6300 to 5740 cal BP, suggesting the correlation between human impact and lower lake level is not as strong towards the later Mesolithic (Fig. 9.2). Although charcoal evidence of human impact was present during a phase of higher lake level, fires were smaller in scale suggesting the landscape was either less suited or there were less people around. Lake level was recorded as being ‘particularly low’ where evidence for human impact was highest from 7565 to 6600 cal BP (Regnell et al. 1995), and perhaps suggests that subsequent phases of lake level lowering in the late Mesolithic were not of sufficient magnitude to attract settlement or use of the area, and hence no positive evidence of human impact in the locality being found. This correlation between settlement and substantially lower lake levels supports models proposed for the late Mesolithic that the use of resources and hence settlement in the late Mesolithic were often directed towards places where species diversity and density was high, often between as many ecological zones and vegetation types as possible (Paludan-Müller, 1978; Larsson, 1991). Lower lake levels may also have simply provided larger areas of drier ground, where people found it easier to settle.

Without a local lake level record at Bökeberg for the early Neolithic period, regional records for lakes within southern Sweden can be considered. Records across southern Sweden suggest a general decline in lake levels culminating at c.5200 cal BP (Digerfelt, 1988; Gaillard and Digerfeldt, 1991), and stratigraphic evidence at Bökeberg supports this
as the lake shows signs of terrestrialisation soon after (Fig. 9.2). If lake levels consistently declined from the macro-fossil inferred drop at 6300 cal BP, this may suggest that fewer fluctuations in the position of the lake edge may have enabled the uptake of new or different land practices from around 5700 cal BP. A significant water level lowering is identified around 5800 cal BP at lake Bysjön, one of the most complete and detailed records in southern Sweden located c.25km north-east of lake Yddingesjön (Digerfeldt, 1988). If an abrupt decline in lake level was observed at Bökeberg at 5800 cal BP, this would highlight a correlation between major changes in culture, nature of land use, and local environmental conditions.

9.4 Summary

The nature of land use at Bökeberg did appear to change from late Mesolithic to early Neolithic. Local evidence for human impact was more prevalent in the late Mesolithic, reflecting the archaeological record for occupation, and was characterised by repeated episodes of prolonged burning of the landscape, which may have been to produce or maintain access to the most diverse areas of resources. Fire became less of feature of the local landscape c.450 years earlier than the dated transition to the Neolithic, from c.6400 cal BP, and became both smaller in scale and of shorter duration in the early Neolithic, reflecting a potential move towards different land use practices where fire played a different or diminished purpose.

Previous work had highlighted a correlation between archaeological evidence for late Mesolithic occupation at Bökeberg and periods of lower lake level (Regnell et al. 1995). A linear relationship was not identified when comparing the new palynological record with this reconstructed lake level record, as human impact was identified during periods of higher lake level, and low levels of disturbance recorded during subsequent lake level declines (Fig. 9.2). Human impact was significantly smaller in scale during the period of increased lake level however, and the lake level lowering was of a smaller scale when human impact was not recorded at Bökeberg. This suggests that there may be a correlation between the extent of human impact at this site and the position of the lake edge, potentially linked to the level and diversity of resources available at the time.

There appears also to be a link between indicators of lake trophic status and human impact, often where an inferred increase in the supply of nutrients to the lake correlates with indicators of disturbance, perhaps as a result of human occupation or animal grazing
in the locality. At present however, not enough is known about the ecological requirements and preferences of many of the lake NPPs identified in this study, and further work is needed or additional proxies such as diatoms, chironomids, or lake chemistry utilised to gain a better understanding of this potential relationship. This is unfortunately beyond the scope of the present research.
10. Conclusions

The aim of this chapter is to review the key findings in the context of the initial project aims. First, methodologies are reviewed, including the relatively new techniques applied in this study. Second, evidence for the changing nature of human impact across the Mesolithic-Neolithic transition of both sites is assessed, and third, the influence of potential forcing factors behind this is discussed. Finally, the future direction of such research into the Mesolithic-Neolithic transition is discussed.

10.1 Review of Methodology

Combining traditional palaeoecological analyses such as pollen with additional proxies such as non-pollen palynomorphs, charcoal size analysis, x-ray fluorescence and high-resolution analyses, has been successful in providing additional palaeoecological information with which the interpretation of the pollen data could be refined.

Non-pollen palynomorphs have been particularly useful in disentangling vegetation and land use histories from pollen data. The identification of indicators of local herbivore grazing has enabled a more confident reconstruction of grazing history than based on pollen evidence alone, and has led to woodland disturbances being able to be investigated in relation to models of purposive landscape management. For example, if grazing intensity was seen to increase as a result of fire disturbance of woodland, as zone in DCM-2a, this may provide support for models of the manipulation of the woodland by fire so as to increase and improve forage resources for herbivores, and therefore hunting success (Simmons, 1975a,b; Jacobi et al. 1976; Mellars, 1976). The role that grazing herbivores may have played in maintaining woodland openings can also be investigated.

_Gelasinospora_ spp. (HdV-1/2) are found in their highest frequencies in layers containing high micro-charcoal counts, and in association with charred plant material (Simmons and Innes, 1996; Innes et al. 2004). They have therefore often been interpreted as indicating local burning (Innes and Blackford, 2003), and have the potential to help interpret the local or regional nature of fire identified in the charcoal record, which may then be used to evaluate the likelihood of a natural origin. At Dan Clough Moss, whilst _Gelasinospora_ spp. frequencies generally do correlate with macro-charcoal influx, there are times when _Gelasinospora_ spp. is present where there is little evidence for local or regional fire (DCM-4b), and frequencies in general decline from DCM-7a whereas macro-charcoal influx...
increases. This suggests that there may be other controls over the occurrence of *Gelasinospora* spp. such as preservation, or the dryness of the substrate (van Geel and Aptroot, 2006).

Fungal indicators of local vegetation have proven useful in determining the proximity of heath or sedge vegetation to the sampling location. A large increase in Cyperaceae pollen at Dan Clough Moss (DCM-8) not accompanied by spores commonly associated with sedges such as *Anthostomella* (HdV-4) or HdV-18, indicates that this expansion was not necessarily local to Dan Clough Moss. HdV-10 commonly associated with the roots of *Calluna vulgaris* (Kuhry, 1985) corresponds well with *Calluna vulgaris* pollen and indicates that the expansions and declines of this species seen throughout the profile were local in nature. An indication of the local bog vegetation can provide information as to the bog surface wetness conditions that persisted at the time, which when combined with peat humification analysis can provide an indication of changing local conditions at the site, which if undisturbed by woodland clearances, could be climate related.

Fungal spores are more prevalent in peat sediment due to origins on terrestrial substrates and low dispersal, and so less additional ecological information could be identified for Bökeberg. Aquatic NPPs were identified in abundance, such as *Pediastrum* and *Anabaena*, and have hinted towards a relationship between human impact and the supply of nutrients to the lake. However at present, a significant amount of further work is needed into their taxonomy and ecological requirements and preferences before any ecological inferences can be confidently made.

Clark (1988) suggested that smaller charcoal fragments would be transported greater distances from their source than larger charcoal fragments, and that larger fragments should therefore indicate the local presence of fire. This suggestion has been tested in modern surface sample studies such as Blackford (2000). Quantifying both micro-charcoal and macro-charcoal can help elucidate the local or regional nature of an identified fire event, which may have implications for its suggested origin, whether natural or anthropogenic. Repeated fires throughout zones DCM-2 and DCM-4a were likely to have been local to the sampling location due to the presence of macro-charcoal and *Gelasinospora* spp. Their return period of as little as 20 years suggests that these fires were not likely to have been due to lightening strike alone, which has implications as to the impact of late Mesolithic groups on the landscape at this time.
X-ray fluorescence has provided relatively quick and easy data as to enrichments in the concentrations of silicon and titanium within the peat or lake profiles, which have been shown in previous studies to have a close correlation with indicators of increased human impact, and may reflect soil destabilisation due to woodland clearances (Hölzer and Hölzer, 1998; Lomas-Clarke and Barber, 2004). Overall concentrations were very low at Dan Clough Moss, and peaks do not appear to consistently reflect evidence of woodland disturbance or the largest fire events. At Bökeberg overall concentrations of silicon and titanium are higher, and there is a small correlation between titanium and charcoal evidence for fire local to the site in the late Mesolithic. This increase in titanium may reflect higher densities of people or animals at Bökeberg during this time, destabilising the soil enough to increase concentrations in the lake, although the overall signal was low. As overall concentrations are so low and close to the limit of detection at Dan Clough Moss, perceived influxes of soil derived dust may have originated from the regional landscape, and hence not correlate with local evidence for disturbance.

Employing high resolution analyses at the two sites has provided additional detail with which to refine the interpretation of the pollen data. It enables an understanding of the timing of different features within a disturbance, which can enable a much improved reconstruction of the nature of land use, and the sequence of events leading up to and immediately following it. For example at Dan Clough Moss, a potential period of woodland disturbance through coppicing was able to be highlighted in zone DCM-2b, due to accompanying low levels of charcoal, high levels of dead or decaying wood at the start of the zone, which was then followed by suggested increased grazing densities. It is possible that a woodland manipulation such as coppicing improved levels of browse as a result, attracting increased herbivore numbers to the area. No obvious increase in forage was observed in the pollen record, yet it is possible that Poaceae pollen production was suppressed by heavy grazing pressure (Groenman-van Waateringe, 1993). At Bökeberg, what appeared at lower resolution to be a single episode of fire in zone BK-1b, was actually found to be a composite of at least three prolonged episodes of burning, lasting up to 60 years, and local in nature. Identifying the prolonged and repetitive nature of these local fires suggests that they were not all likely to have been attributable to wildfire. High resolution palaeoecological analyses therefore offers a far greater level of detail and ecological understanding than that can be offered by lower resolution analysis alone.
10.2 Research Aims and Objectives

Traditionally the study of the Mesolithic-Neolithic transition has been addressed by the research of either the late Mesolithic, or the early Neolithic. This is true in the case of both archaeological and palynological studies into the period. The danger of this approach is that differences in intellectual traditions about the corresponding periods can often highlight stereotypes, and perpetuate the idea of a binary flip between the two cultures, where the differences may be less evident if objectively studied together. Issues with using the dichotomous terminologies of ‘Mesolithic’ and ‘Neolithic’ suggest that any slight change within the two is revolutionary, whereas realistically the Holocene is a period of continuous change. This research therefore presents findings of a multi-proxy investigation into environmental changes across the Mesolithic-Neolithic transition period as a continuum, at two north-west European sites dated to the transition. Research aimed to highlight how, when and if the nature of human impact changed across the transition, and the role that environmental conditions and their fluctuation may have played in determining this activity.

10.2.1 Objectives

1. Investigate the palaeoecological evidence for land management practices across the Mesolithic-Neolithic transition (including the duration of events, periods of intensification, possible methods employed), and through this, analyse the use of different resources. Changes in the nature of land use in the later Mesolithic and Neolithic will be recorded.

Palynologically inferred land use did differ between the late Mesolithic and early Neolithic at both sites. Whilst woodland disturbance was present throughout both profiles, and often associated with fire, the nature, location and scale of these disturbances changed across the Mesolithic-Neolithic transition.

At Dan Clough Moss, evidence suggests that during the late Mesolithic from c.6235 to 5950 cal BP, the repeated use of fire local to the sampling location, often linked with increasing grazing intensities indicated through coprophilous fungi such as *Sporormiella*, represented a woodland manipulation practice to increase the quantity and quality of browse for herbivores (Simmons, 1975a,b; Jacobi et al. 1976; Mellars, 1976). Increasing herbivore numbers and improving the prediction of their location would have improved hunting
success for late Mesolithic hunter-gatherers, and may represent an example of increasing late Mesolithic complexity. In the early Neolithic however, from c.5825 cal BP, woodland disturbances became longer in duration, and fires were less frequent however larger in scale. Less evidence for increased grazing intensity suggests a shift away from purposive management of the woodland to improve forage resources, towards a more continuous rather than episodic use of the landscape or woodland at the Mesolithic-Neolithic transition. It may also reflect an increase in natural wildfires from lightening strike, due to a shift towards continuously drier bog surface conditions.

No evidence for Neolithic traits or practices such as farming were identified at Dan Clough Moss, but late Mesolithic people and their practices were seen to persist in the March Hill area for longer than most other areas in the UK, potentially overlapping with the age range of the regional earliest Neolithic by up to 290 years (Griffiths, 2014b). This has implications for the process and rate of transition throughout the country, suggesting that the timing of the transition varied spatially, possibly attributable to population, cultural or economic importance of the area, or prevailing local environmental conditions. This provides evidence against a rapid process of transition across the country due to processes of demic diffusion, although slower diffusion of an incoming population, or step-wise pattern of migration, is possible.

At Bökeberg, fire was a distinct feature of late Mesolithic activity, but less evidence was available that may suggest it was to improve forage for grazing animals, such as coprophilous fungi. *Alnus* and *Betula* were affected, possibly reflecting a fire clearance of lake edge vegetation to gain easier access and increase the resulting diversity of the lake edge environment. Fires were often prolonged and local, whereas in the Neolithic the evidence for fire suggests episodes were much shorter in duration and on a smaller scale, suggesting a shift in the use of fire as a method of manipulating the environment at the time of a cultural shift to the Neolithic. This is the opposite pattern to that shown in upland Britain, at Dan Clough Moss, nearby Black heath (Ryan et al. 2010) and elsewhere. Potential evidence for anthropogenic coppicing in the Neolithic around 5500 cal BP was revealed by high resolution analyses. No evidence for Neolithic practices were found during the late Mesolithic. Although Regnell et al. (1995) did find evidence of large cereal-type grains in phases prior to the elm decline during previous investigations, which he later discounted due to a lack of macrofossils of cereal, this has not been replicated here. The palynologically-inferred shift in land use was dated to the time of the widespread uptake of
the Funnel Beaker culture in southern Sweden (earliest Neolithic), hence no evidence for late Mesolithic persistence can be seen at Bökeberg.

The palynological record of human impact did match the archaeological record for human activity at Bökeberg particularly well, but also highlighted other potential periods of impact on the environment, adding to the occupation history for this site or other sites close to the coring location that are still buried beneath peat. Latest Mesolithic activity at March Hill Top corresponded with a period of woodland disturbance associated with fire, within the precision possible through radiocarbon dating. Again, the palynological record provides a more complete picture of human impact at the site, and adds considerably to the archaeological record in terms of phases of occupation and inferred impact on the surrounding landscape. A further phase of occupation is suggested, between 6235 and 6135 cal BP, as well as those known through the finds of datable artefacts suggesting that there were two phases of anthropogenic burning of the landscape in the late Mesolithic from 6235 cal BP, which lasted approximately 110 years each. By creating disturbance, which could have then been self-perpetuating by creating more combustible vegetation and attracting animals, later Mesolithic cultures may have initiated the rise to prominence of heathland and other open ground habitats, which continued into the recent past (Tallis, 1991).

2. Investigate the potential forcing factors behind the nature of human impact.

Dan Clough Moss has provided a high resolution bog surface wetness record from the same sediment core as the palynological data. This has allowed a correlation between indicators of bog surface wetness and evidence for human impact, and has highlighted a link between drier/warmer climate creating drier bog surface conditions, and increased human impact. A shift to wetter conditions followed by a prolonged drier episode corresponds well with the apparent abandonment of the March Hill area followed by the earliest evidence for Neolithic activity in the wider region. Evidence provides support in part for those models that suggest a shift towards drier, more continental conditions facilitated the uptake of the Neolithic in north-west Europe (e.g. Bonsall et al. 2001). However it remains possible that factors in society may have outweighed the possible effects of a climatic change. While there is evidence of changes in local environmental conditions, potentially linked to climate change, how that change applied pressure to existent cultures is not clear.
Palynological indicators of warmth- thermophilous types such as *Tilia*, *Ulmus* and *Corylus*, do not suggest large climatic shifts in terms of temperature at either site, which would suggest that the changes in lake level and peat decomposition are more driven by rainfall/precipitation changes. A change to wetter conditions may have reduced the ability of undergrowth or litter layer fires, and cooler climates would reduce hazel productivity, but the major food sources of forest animals, acorns and fish are perhaps unlikely to have been greatly perturbed by the relatively small changes in rainfall, or temperature, inferred for the time period (Tipping 2010).

Existing local lake level records from Bökeberg allowed a correlation with the palynological record for human impact across the Mesolithic-Neolithic transition. Evidence suggests that human activity, albeit limited in impact, was present during times of higher lake level, but that the evidence of impact on the environment was greater during periods of significantly lower lake levels, i.e. drier phases. These findings suggest that changing environmental conditions did have an effect upon the nature and extent of human impact, at least in the late Mesolithic, and suggests that drier periods enabled more forest manipulation. Alternatively, it could be that the recently dried lake edge, which typically might become reedswamp dominated by *Phragmites* or *Cladium*, rather than open water, provided a resource-rich and accessible human habitat. The subsequent resubmergence of the sites in a time of raised lake levels could have then preserved the archaeological material- hence the climatic shifts inferred resulted in the location and preservation of the archaeological record, although did not entirely force the changes seen. An earlier Mesolithic example of this process has been described from the Vale of Pickering (Taylor, 2012).

Whilst these records begin to help disentangle a local environmental change-land use relationship at the Mesolithic-Neolithic transition, relating changing land use practices to regional climate change is more difficult. There remains a lack of regional-local, precise and accurate palaeoclimatic data for the mid-Holocene, and where datasets do exist they are often conflicting (Tipping, 2010). These differences are possibly due to genuine regional variations, but may also be a result of different methods of reconstruction (lake levels, tree rings, and peat bog records for example), different temporal resolution, and imprecise chronologies. Further problems are caused by different scales or spatial resolution of analysis, whilst underlying interpretations of the same climate proxy may also differ. More well-dated, high-resolution, multi-proxy records from the local regions need to be obtained, to enable improved data-model comparisons and overall climate reconstructions.
10.3 Future research into the Mesolithic-Neolithic transition

Chronology is imperative to understanding the dynamics of land use and environmental change across the Mesolithic-Neolithic transition. It is not possible to debate the rate or extent of change, or assess whether environmental changes were perceptible to people, without it, and Whittle (2007) highlighted the need for far better chronologies than the ones archaeology has become accustomed to, or become complacent about. More radiocarbon determinations, both in palynology and archaeology, with more secure information about their sedimentary context, would allow better use of Bayesian statistical modelling as a tool to help refine the chronologies of sites. Too often interpretations are based on too few radiocarbon dates, or without robust contexts, and Warren (2009) highlighted that the use of Bayesian statistics is regionally variable throughout Europe. A more widespread adoption of the best chronological methodologies available is crucial to allow highly detailed local investigations like this thesis to be utilised in regional comparisons. Correlation of the palynological record with dates from archaeological sites is currently, however, limited to the precision of calibrated radiocarbon dates. Issues of lower precision are also encountered related to the radiocarbon plateaux around the time of the Mesolithic-Neolithic transition. Additional chronological approaches such as tephrochronology or dendrochronology would therefore have the potential to significantly improve radiocarbon chronologies, and consequently studies of synchronicities, for this time period.

An increased collaboration between palaeoenvironmentalists and archaeologists, both in choosing complimentary sampling sites for such interdisciplinary studies, and the methodological strategy are also needed. Further sites with a continuous organic sediment record through the Mesolithic-Neolithic transition are required in close proximity to latest Mesolithic and or earliest Neolithic archaeology, with site selection enhanced if the potential for an independent climate proxy is nearby, such as speleothems or tree rings.

A wider utilisation of higher resolution multi-proxy palynology, as employed in this study, to help disentangle anthropogenic from natural changes and to determine the processes of disturbance, together with the rapid scanning of pollen slides for cereal type pollen, have the potential to significantly improve palaeoenvironmental change and human impact research for this time period. However, on its own this approach (as followed in this study) is unlikely to ever resolve the causality issue- while people and disturbance can be shown
to coincide and be contemporaneous, whether people caused the changes remains a ‘likely inference’ – with the alternatives not disproved.
11. Bibliography

Aaby, B. and Tauber, H. (1975) Rates of peat formation in relation to degree of humification and local environment, as shown by studies of a raised bog in Denmark. Boreas, 4, 1-17.


Behre, K.E. and van der Plicht, J. (1992) Towards an absolute chronology for the last glacial period in Europe: radiocarbon dates from Oerel, northern Germany, Vegetation History and Archaeobotany, 1, 111–117.


Iversen, K. (1973) The development of Denmark’s nature since the last glacial. Danmarks Geologiske Undersøgels V, 7-126.


Ryan, P. and Blackford, J.J. (2010) Late Mesolithic environmental change at Black Heath, south Pennines, UK: a test of Mesolithic woodland management models using pollen,


