UNIVERSITY OF READING

Examining the relationship between environmental change and human activities at the dryland-wetland interface during the Late Upper Palaeolithic and Mesolithic in Southeast England

PhD

Department of Archaeology, School of Archaeology, Geography and Environmental Science

Michael Simmonds

September 2016

Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

Michael Simmonds

Abstract

This thesis investigates environmental change across the Late Glacial and Early Holocene boundary in southeast England, and places these results within their archaeological setting. This has developed our understanding of vegetation change during a period of climatic variability, and enhanced our knowledge of environmental change and the environmental context of human activities. The County of Surrey formed the research focus because of the diverse assemblages of Upper Palaeolithic and Mesolithic archaeology, and preliminary studies suggested a relationship with human activities at the ecotonal boundary between wetland and dryland.

The research focused on palaeoenvironmental investigations from four sites: Thursley Bog, Ockley Bog, Elstead Bog B and Langshot Bog, studied using sedimentological, pollen, stable isotope and microscopic charcoal analyses to generate high-resolution reconstructions of climate change, vegetation succession and fire histories. The results have provided important contributions to our understanding of climatic change and vegetation succession, with evidence for a downturn in climate during the Loch Lomond Stadial. Evidence also indicates the presence of *Corylus, Alnus* and *Pinus* at earlier dates than previously observed within southeast England.

Analyses of archaeological data suggest that sites at the wetland/dryland interface are likely to have been frequently visited by Late Upper Palaeolithic and Mesolithic groups. The archaeological and palaeoenvironmental records suggest that people exploited their environment for hunting and gathering during the Late Upper Palaeolithic and Early Mesolithic. During the Later Mesolithic there is some evidence for the anthropogenic use of fire to create or maintain woodland clearings to attract animals for hunting.

Overall, this research has resulted in a greater picture of human activities and environmental change during the Late Glacial and Early Holocene in Surrey. It is likely that people interacted with the environment during the Late Upper Palaeolithic and Mesolithic, but this was predominantly comprised of environmental exploitation rather than large-scale manipulation.

Acknowledgements

Firstly I would like to thank my supervisors, Dr Nick Branch, Dr Rob Hosfield and Dr Stuart Black for their encouragement, assistance and help over the past four years. The research presented in this thesis was funded by The Faculty of Science at the University of Reading, Historic England, Surrey County Council and Surrey Archaeology Society, and my thanks go out to all of them for allowing this project to come to fruition.

Access to the sites used in the study was facilitated with the help of James Giles (Natural England) and Doug Boyd at Thursley Common and Derrick and Roger Pride at Elstead Bog. A special thanks goes to the team at Chobham Common: Stephen Fry, Victoria Russell, David Boddy, Jill Titlestad and Darren Brito. Their assistance and discussion on all aspect of Chobham Common and the many cups of tea they provided on cold or wet fieldwork days was invaluable! Many other people were involved in discussions about alternative sites across Surrey and the South East, including but not limited to Steve Proud (Surrey Wildlife Trust) and Ian Rickards (Kent Wildlife Trust) and their help was much appreciated.

The dating in the project was funded by Historic England, and thanks go particularly to Peter Marshall, Jonathan Last and Jane Corcoran for their detailed assistance with the project. Various town, district and county councils were contacted for information and thanks are needed for all of the officers that assisted with finding information for the project: in particular, Tony Howe, Alex Egginton, Nigel Randall and Wayne Weller at Surrey County Council. Thanks also go to David Graham at Surrey Archaeological Society and Dr Lucy Farr at the University of Cambridge for support with the project.

Special thanks go to my other PhD students who provided ideas, discussion and support, often over a coffee, beer or large fried breakfast, including: Sarah Thoma, Sarah Jones, Matt Austin, Lionello Morandi, Tom Hoyle and Will Mills. Numerous members of staff at the University of Reading have also been of great assistance, including Prof. Dominik Fleitmann, Dr Steve Gurney, Kevin Williams, Dr Chris Speed, Dave Thornley and Richard Tegg.

Very special thanks go to Rachel who both put up with me dragging her around various bogs and heathlands in South East England, and then discussing the results at home! Finally I have to thank all of my family and friends who have always been up for a beer and a chat whilst I completed this thesis: Mum, Dad, Dave, Jo, Steve, Glen, Ayla, Jim, Adam and everyone else that I don’t have space to name.

Contents

List of Figures

List of Tables

1. Introduction

1.1. Introduction

This research project provides a new integrated model for the Late Upper Palaeolithic and Mesolithic (15,000-6000 cal. BP) helping to develop the palaeoenvironmental and cultural record in southeast England. It was established through examination of the relationships between environmental change, climate change and human activity at the dryland-wetland interface across the Late Glacial and Early Holocene, with a specific geographical focus on the County of Surrey.

The Late Upper Palaeolithic and the Mesolithic are two archaeological periods divided by the onset of warmer climatic conditions at the start of the present interglacial, 11,700 years ago. These two cultural periods would have witnessed modifications in the vegetation composition and structure against a background of climatic amelioration and short-term climatic variability. The interaction between Late Upper Palaeolithic and Mesolithic groups and the vegetation is inadequately understood in southeast England, and could have included woodland clearance, exploitation of specific species and soil modification. The exact nature of the vegetation during the Late Glacial and Early Holocene is also currently debated with two competing hypotheses: the established theory of ‘closed climax forest’, and the potential of a parkland scene, whereby woodland was interspersed with forest glades and grassland (Vera, 2000; Whitehouse and Smith, 2010). This parkland would have been an excellent environment for browsing and grazing animals, particularly around areas with a source of drinking water. In turn, these wetland/dryland interface areas would have been important to Late Upper Palaeolithic and Mesolithic hunters and gatherers due to their natural biodiversity. These hunter-gatherers may have interfered with the local vegetation cover (burning, deforestation etc.) in order to attract grazing animals, and this signature should be present within the palaeoenvironmental records. This is a topic of critical importance to the National Heritage Protection Plan (NHPP) set out by Heritage England (English Heritage, 2013), which details the importance of these wetland/dryland interface regions, and the value of the cultural resource that lowland wetlands can provide. Many of these lowland wetlands are also under threat from degradation or destruction, either due to a lack of appropriate designation or through poor or ill-informed management decisions. Developing a methodology to classify both the significance that these lowland wetlands provide in terms of their palaeoenvironmental and cultural resource, and the threat to these wetlands is paramount for meeting the aims of the NHPP.

Therefore the identification and analysis of high-quality palaeoenvironmental records from lowland wetlands in southern England is critical, as these sites have the potential to address the research issues of both palaeoecological and archaeological significance, specifically relating to the wetland/dryland interface. Southeast England also has a rich and diverse distribution of habitation sites and find-spots from both the Late Upper Palaeolithic and Mesolithic (Wymer and Bonsall, 1977; Wymer, 1982; Wymer, 1996; Cotton, 2004), and provides an excellent focal point for research into both periods. In particular, the County of Surrey was chosen as the primary focus for this study for a number of reasons:

- Late Upper Palaeolithic and Mesolithic records are abundant across the County, with 573 records spanning the period, providing one of the highest artefact densities in the southeast region. Details of these records (both the Historic Environment Record and grey literature) are documented at the Surrey County Council offices in Kingston-upon-Thames, and managed by the Heritage Conservation Team.
- Previous research has tentatively suggested a spatial correlation between archaeological records and environmental conditions (Rankine, 1949b; Farr, 2008; Jones, 2013b), especially between wetlands (rivers, lakes, bogs etc.) and human activities (Cotton, 2004; Jones, 2013b), however the temporal and spatial relationships between the artefacts and their palaeoenvironmental context are not fully understood.
- Prior to the rise in sea level during the Early Holocene, Surrey was well connected to the continental mainland (Shennan et al., 2000), and so the region is important for our understanding of human, animal and plant dispersals after the Last Glacial Maximum (Gaffney et al., 2007). With its landlocked location, archaeological records have not been lost due to sea level rise.
- The County has diverse geological deposits and widespread topographical variation leading to a variety of depositional environments, providing scope for exploring human behaviours and environmental change in a variety of contexts.
- There is a paucity of published high-resolution palaeoenvironmental records spanning the Late Glacial and Early Holocene in Surrey, which is surprising given the number of lowland wetlands that could facilitate the compilation of these records.

Examination of the palaeoenvironmental and cultural record from lowland wetlands in Surrey also enables comparisons with other Late Upper Palaeolithic and Early Holocene landscapes, allowing for an assessment of the findings in a wider geographical context.

1.2. The Geographical and Geological Context of the Study Area

1.2.1. The Geographical Context

The County of Surrey is in southeast England, bordered by six other counties: Kent, Greater London, Berkshire, Hampshire and West and East Sussex (Figure 1.1). It is important to realise that these boundaries are purely administrative, and Late Upper Palaeolithic and Mesolithic groups would not have been restricted to an area contained within county borders, exemplified by the long distance transport of materials during the Mesolithic (Barton, 2009). Therefore it is important to consider archaeological data from across the southeast region when examining habitation sites and location patterns.

Figure 1.1. The location of Surrey and other counties in southeast England.

1.2.2. The Geological Context

There are three main landscape units with unique characteristics in the southeast, dating from the Jurassic period onwards (Gallois, 1965): the chalk downs, the London basin and the

Weald. The geological bedrock of the region is sedimentary and weakly consolidated, with the exception of the Chalk and some Sandstone units (Jarvis et al., 1984) (Figure 1.2).

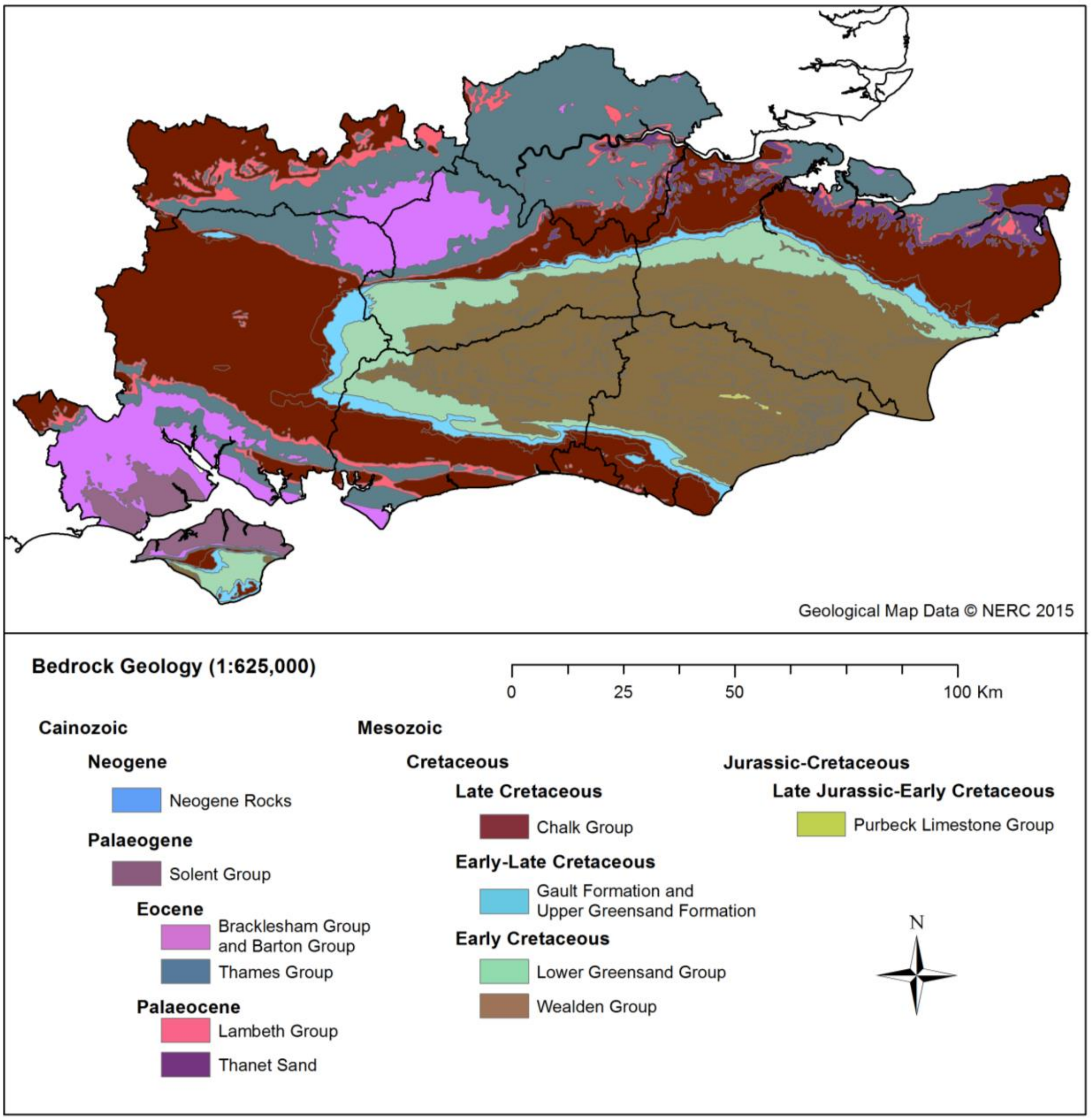


Figure 1.2. Bedrock geology of southeast England (The British Geological Survey ©NERC 2015).

The London Basin consists of Cretaceous Chalk overlain by tertiary marine and river deposits and superficial sediments (Kinniburgh et al., 1994) and is bounded by the chalk outcrops of the North Downs and the Chilterns (Kinniburgh et al., 1994). The tertiary sequence comprises of the Thames, Lambeth and Bracklesham Groups and the Thanet Sands (Dennis et al., 1997). The North and South Downs are two long Chalk Group escarpments, predominantly comprised of Upper Chalk (Gallois, 1965), skirting the north and south borders of the Weald respectively. The Weald is enclosed by the North and South Downs (Gallois, 1965) and is dominated by series of clays and sands (Radley, 2006). The Hastings Beds dominate the High

Weald, and the Weald Clay Group forms the Low Weald (Radley, 2006). In addition to bedrock geology, Quaternary superficial deposits are also important (Figure 1.3).

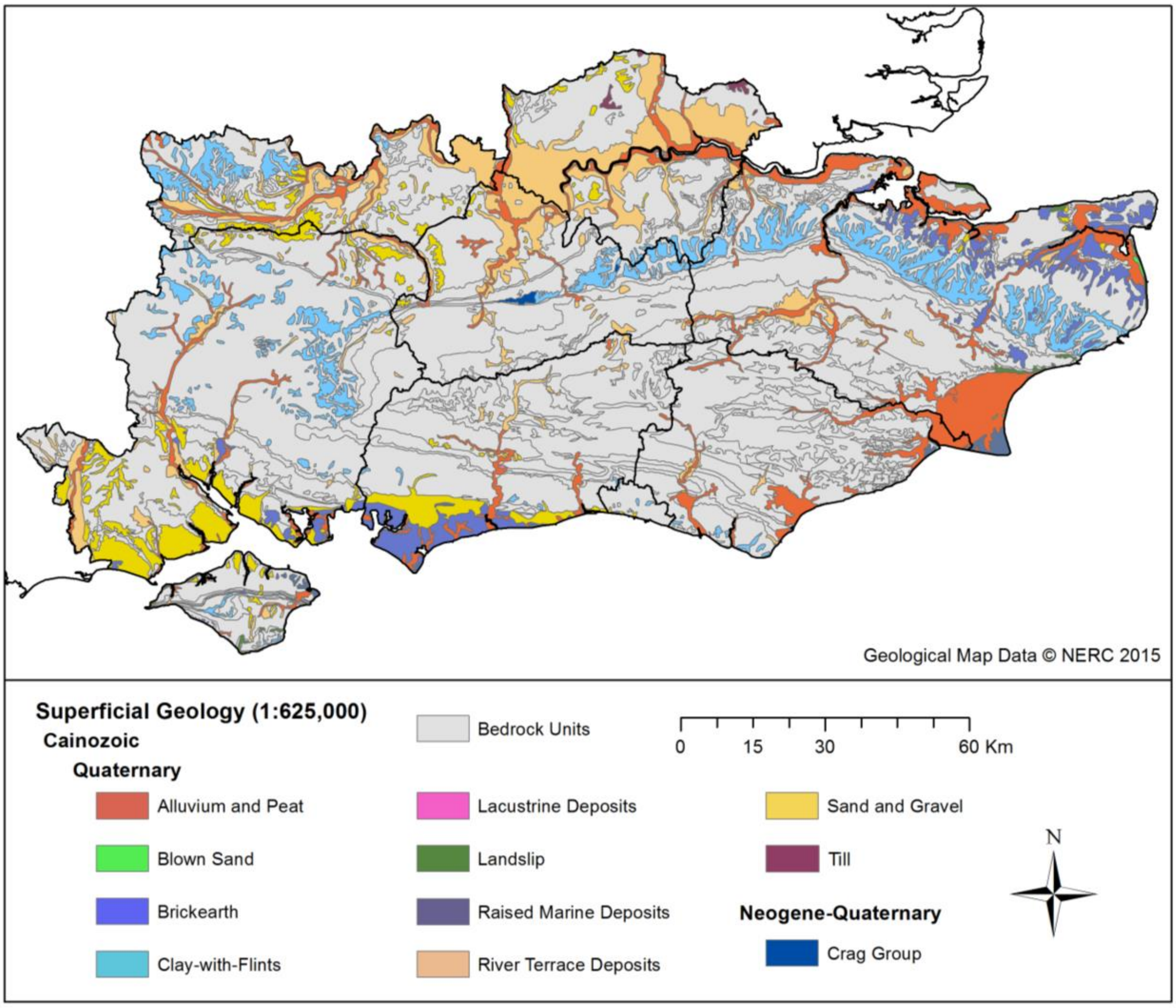


Figure 1.3. Superficial geology of southeast England (The British Geological Survey ©NERC 2015).

Superficial deposits in the London Basin are primarily comprised of river terrace deposits and alluvium surrounding the Thames and its tributaries eastwards to the North Kent Coast. The North Downs have large clay-with-flint outcrops that are not present along the South Downs, which are largely devoid of superficial deposits, apart from minor river terrace outcrops and alluvium. These clay-with-flint deposits are often cited as source material for archaeological flintwork (Scott-Jackson, 2000). Superficial deposits in the Weald are predominantly found in coastal regions (such as Romney Marsh) and river valleys.

These three main southeast landscape units are also identified within Surrey (Figure 1.4). The north is dominated by the London Basin, with the chalk escarpment of the North Downs bridging the gap to the greensands and clays of the Weald.

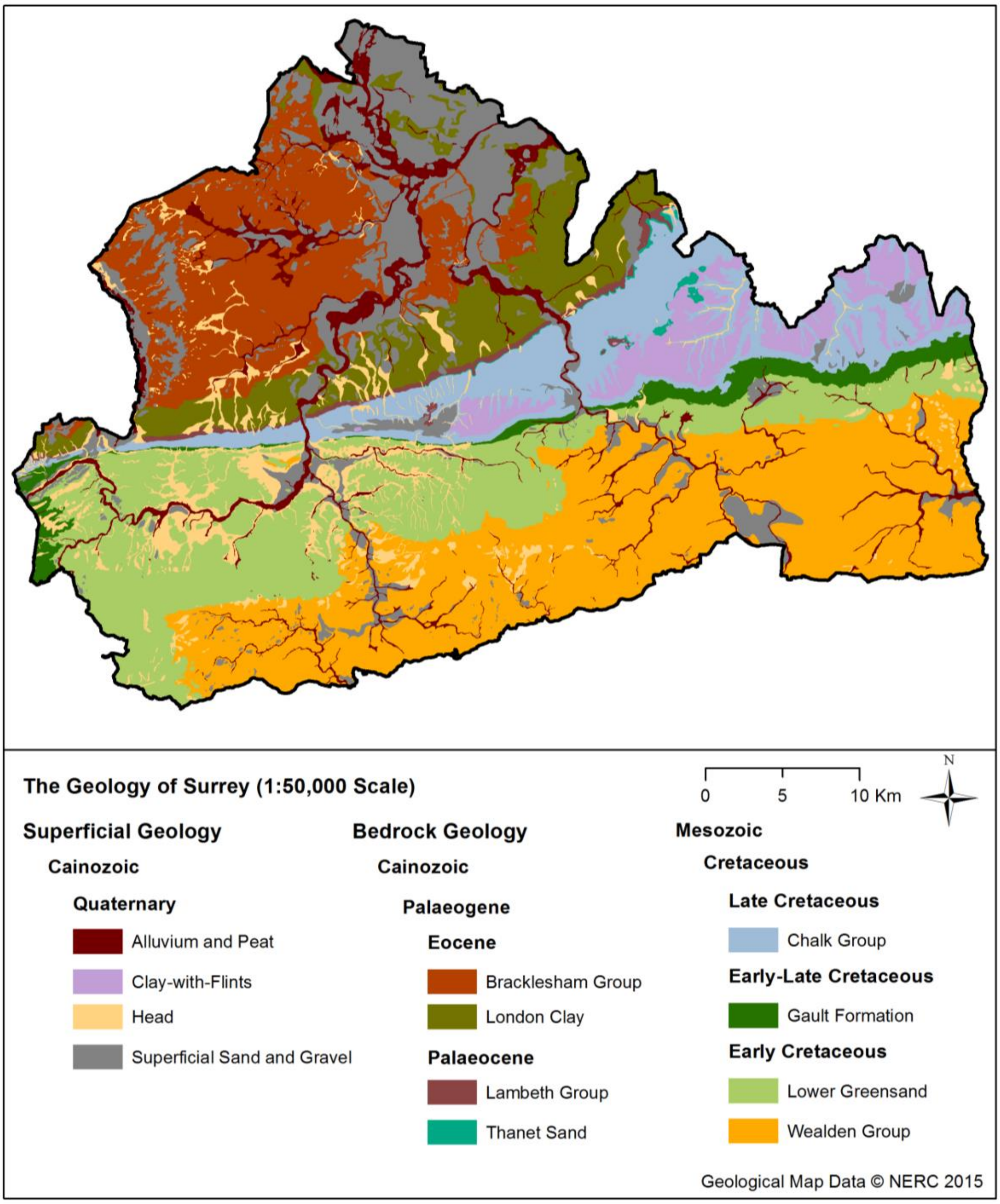


Figure 1.4. Bedrock and superficial geology of Surrey (The British Geological Survey ©NERC 2015).

The relatively low-lying London Basin occupies northwest Surrey, encompassing the predominantly sandy, silty and clay units of the Bracklesham and Lambeth Groups and London Clay. Extensive superficial alluvium and river terrace deposits across the London Basin (Figure 1.4) often provide Holocene palaeoenvironmental sequences (Needham, 1992; Needham, 2000; Branch and Green, 2001; Branch et al., 2003). The North Downs extends east to west, and is overlain by clay-with-flints in the east. The Downs occupy higher ground (>100m a.s.l), and create a distinct barrier between the Weald (predominantly >50-100m a.s.l and the London Basin (<50m a.s.l). The Weald is predominantly comprised of Lower Greensand and Wealden Clay, with superficial deposits of Head, alluvium and river terraces. Land cover diversity is relatively low, with ~92% of the land cover represented by four categories: built up areas, arable and horticultural, improved grassland and woodland.

1.3. Chronological Context

The primary focus of this study is the Late Glacial and Early Holocene, specifically ~15,000 to ~6000 cal. BP, a time of major climatic, environmental and cultural change. During the Late Glacial, Britain was in the final throes of the Pleistocene, a period of repeated glaciations and de-glaciations. The Late Glacial period includes the Dimlington Stadial, the Lateglacial Interstadial and the Loch Lomond Stadial (Lowe and Walker, 2015) and occurred during the Late Upper Palaeolithic archaeological period, dated from ~14,800 cal. BP (Jacobi and Higham, 2009) until the onset of the Holocene at 11,700 cal. BP (Scarre, 2005). The Late Upper Palaeolithic saw hunter-gatherers moving around the landscape, and the re-occupation of northern Europe during the Lateglacial Interstadial, with possible abandonment of Britain (or at least a sparse archaeological signal) during the Loch Lomond Stadial. On a local scale, hunter-gatherers would have migrated around the landscape in response to changing climatic conditions and through following, intercepting and hunting seasonal animal migrations, primarily utilising projectile points (Barton, 2009). Stone tools, including Cheddar Points, curved-backed and penknife points and long-blades characterise the lithic assemblages of the Late Upper Palaeolithic. The transition between the Late Glacial and the Holocene at 11,700 cal. BP is identified through a change from the colder, harsher conditions of the Late Glacial (particularly the Loch Lomond Stadial) to warmer and more hospitable conditions in the Early Holocene (Lowe and Walker, 2015). This period saw a cultural change from the Terminal Upper Palaeolithic to the Mesolithic period with the Mesolithic spanning between 11,500 cal. BP and 6000 cal. BP (Barton and Roberts, 2004; Woodbridge et al., 2014). The period is defined by Mesolithic hunter gatherers using diagnostic stone tools including microliths, axes, scrapers, burins, awls and flint blades, set against a background of general climatic amelioration (Mithen, 2003). There are various names and conventions for the terminology of these climatic and archaeological periods, those used within this study and alternative terms are highlighted in Figure 1.5.

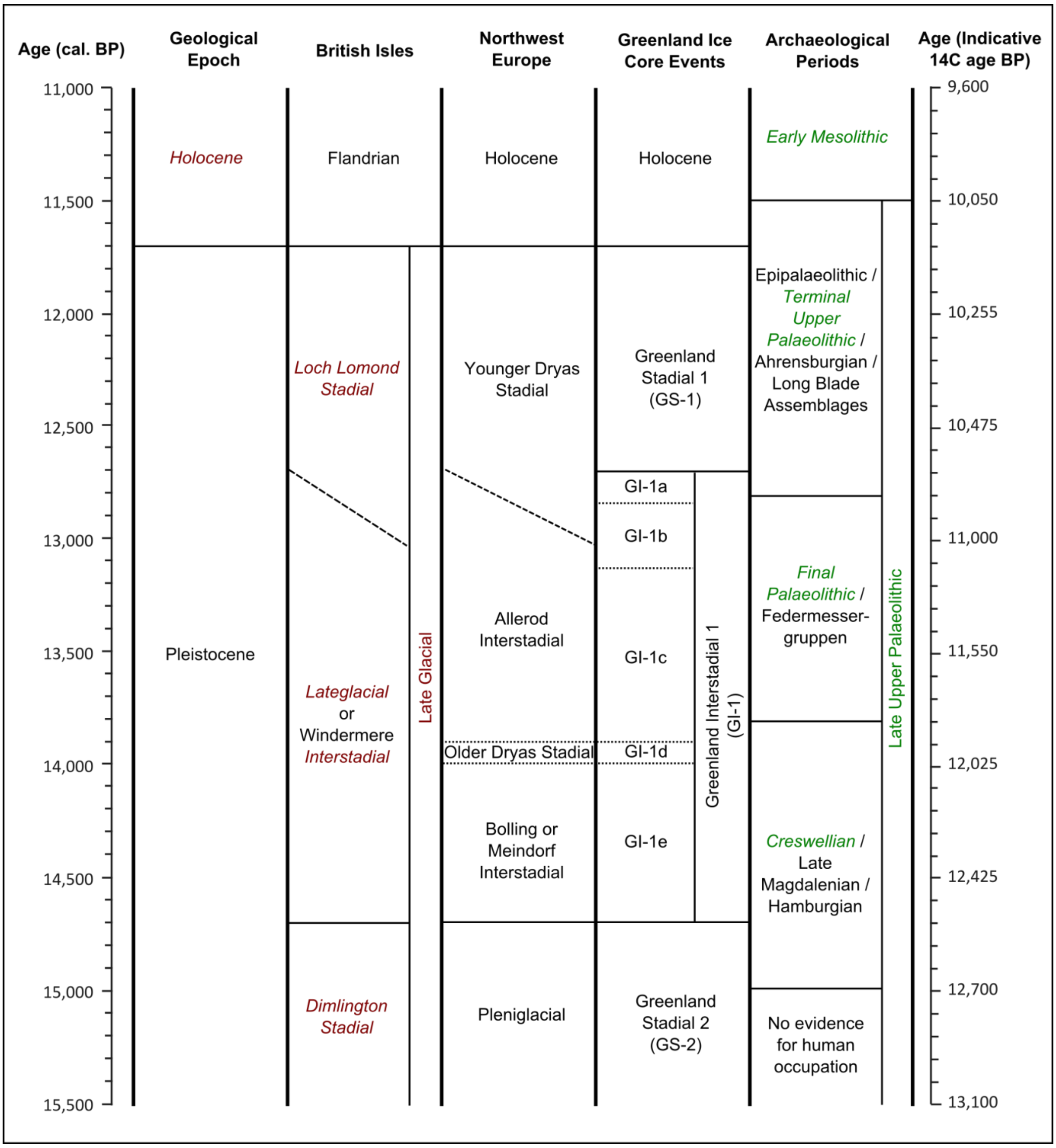


Figure 1.5. Terminology of climatic and archaeological periods used in Britain, northwest Europe and Greenland. Those terms highlighted in red indicate those used in this study relating to Quaternary history whilst those in green indicate the archaeological terminology used.

1.4. Climatic and Environmental Context

1.4.1. Climatic Context

In order to understand Late Upper Palaeolithic and Mesolithic human activity in Surrey and southeast England, it is important to understand the climate and environment. The climate across these periods was highly variable, with a number of fluctuating climatic events (Lowe and Walker, 2015). An understanding of the climate and environment can help to define causes of change within vegetation and human activities, and help to differentiate between these environmental and human signals. Within the southeast there is a paucity of high quality palaeoenvironmental data for this period, significant as the region is important for understanding Late Glacial and Early Holocene plant migration and succession, due to the migration of species from Europe, and the impact of human communities on the landscape (Branch and Green, 2004).

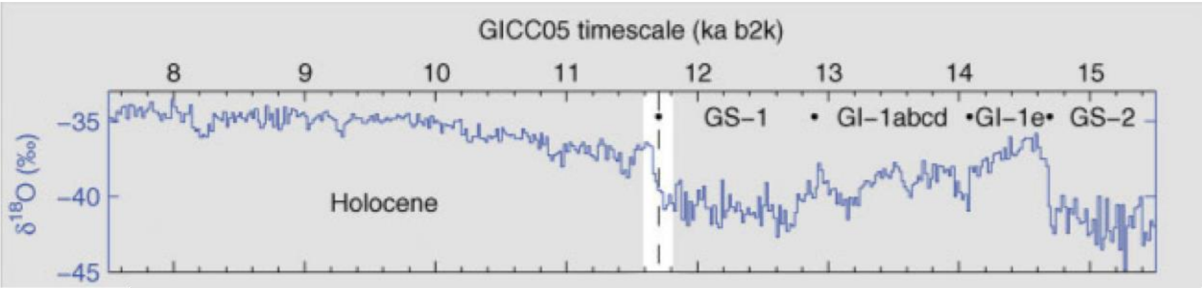


Figure 1.6. The δ18O record spanning the Glacial-Interglacial Transition. The dashed line indicates the position of the Pleistocene/Holocene boundary. From Walker et al. 2009: Figure 5, Page. 9.

The start of the Late Glacial is marked by the Lateglacial Interstadial in Britain, dating to 14,700-12,900 cal. BP (Lowe and Walker, 2015), characterised by warmer conditions than the preceding Late Devensian Stadial. At ~14,000 cal. BP, The Older Dryas led to a short downturn in climate over ~120 years. Following this, the retreat of sea ice led to warmer waters around European coastlines, resulting in higher year-round temperatures throughout the rest of the Lateglacial Interstadial (Atkinson et al., 1987; Bell and Walker, 2005). The Loch Lomond Stadial brought a return to glacial and periglacial conditions in the North Atlantic region from ~12,900 cal. BP (McDougall, 2001; Shuman et al., 2002; Barrows et al., 2007), leading to the regrowth of small ice sheets and glaciers in the British Isles (Manley, 1959; Sissons, 1980; Hubbard, 1999). Central and southern England would have had discontinuous permafrost cover (Isarin, 1997), mean annual air temperatures of -2°C to -5°C and a colder, drier and less hospitable habitat (Briffa and Atkinson, 1997). Rapid warming at the end of the Stadial is dated to ~11,700 cal. BP, with warming of 7°C over 50 years (Dansgaard et al., 1989; Severinghaus et al., 1998), marking the onset of the Holocene and the British Mesolithic (Golledge, 2010; Lowe and Walker, 2015).

The Holocene (~11,700 cal. BP to present) is the current interglacial within the Quaternary (Roberts, 2009; Lowe and Walker, 2015). The Greenland ice core records show no changes of a similar magnitude or abruptness of the prior cold stage or termination. The initial Early Holocene climate was relatively cool as it recovered from the Younger Dryas and the climate gradually warms (by ~0.6˚C) from the Early Holocene to ~6000-5500 cal. BP. This is a time known as the Holocene Thermal Maximum or Climatic Optimum (Davis et al., 2003; Lowe and Walker, 2015). However, when the Early Holocene has been examined in higher resolution, recent evidence has identified a number of Holocene climatic fluctuations (Briffa and Atkinson, 1997; Mayewski et al., 2004; Lowe and Walker, 2015). These Early Holocene climatic cooling events are smaller than the events of the last glacial period (Richerson et al., 2001) but still occur over short timescales, with durations of 100-200 years and an average temperature drop of 0.5-1°C (Renssen et al., 2007; Lowe and Walker, 2015). These Early Holocene events occurred alongside sea-level rise, due to both isostatic movement of the land and increasing meltwater influx into the oceans. During the Mesolithic, there may have been a possible total rise of 40m (Devoy, 1982; Devoy, 1987; Shennan and Andrews, 2000; Lowe and Walker, 2015), leading to opening and development of the English Channel (Figure 1.7) (Shennan et al., 2000; Edmunds et al., 2001; Streif, 2002; Barker, 2006; Catt et al., 2006).

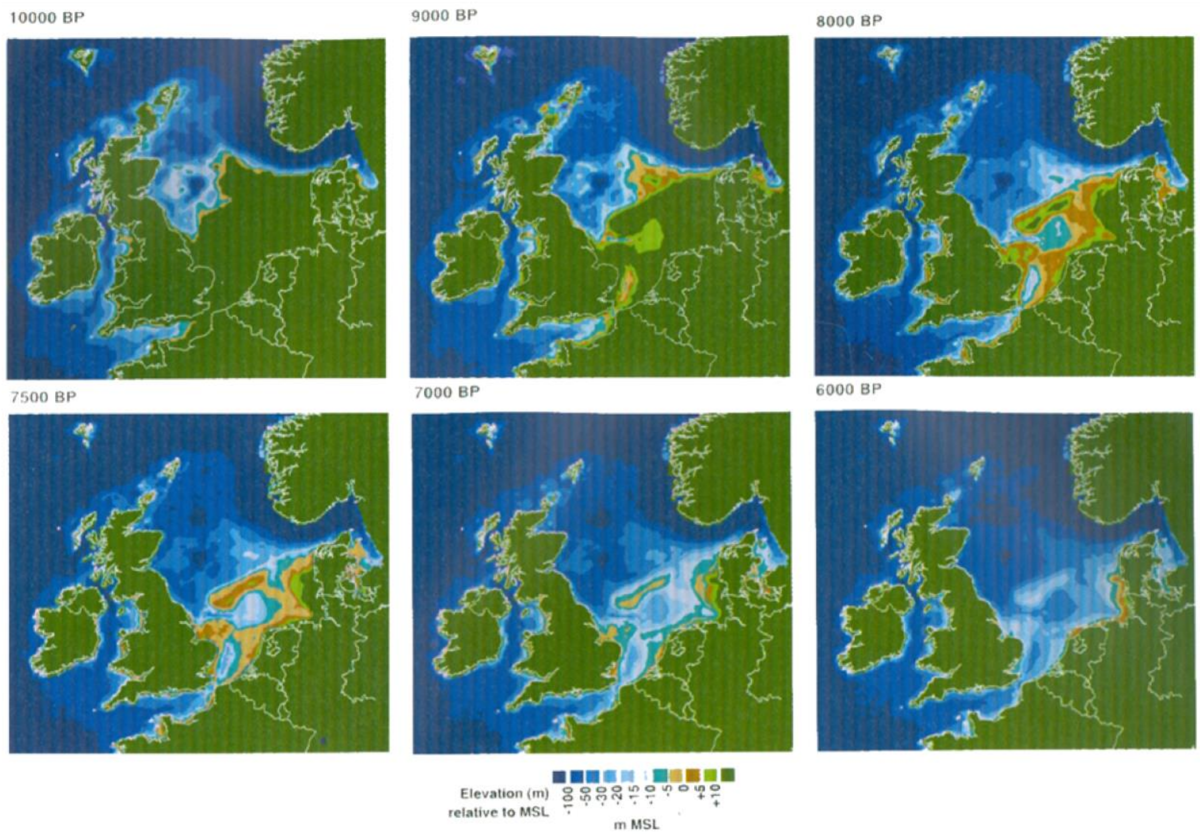


Figure 1.7. Palaeogeographic reconstructions of northwest Europe between 10,000-6000 cal. BP. From Shennan et al., 2000: Figure 5, Pages 310-311.

Two distinct Early Holocene periods of rapid climate change have been identified between 9000-8000 cal. BP and 6000-5000 cal. BP (Mayewski et al., 2004) where there is evidence for polar cooling and atmospheric circulation modification (Lowe and Walker, 2015). Clearly defined cold events are also identified at 11,100, 10,300, 9400, 8100 and 5900 cal. BP (Bond et al., 1997; Bond et al., 1999) in a variety of proxy records including lake sediments (Magny, 1993; Magny, 2004; Lücke et al., 2003; Morellón et al., 2008), bogs and mires (Turney et al., 2005; Charman, 2010), and ocean sediments (Bond et al., 1997; Chapman and Shackleton, 2000; Hall et al., 2004). Some of these events, such as the 9400 cal. BP Bond Event has been identified in the British Isles (Marshall et al., 2007; Lang et al., 2010), although due to the apparent short duration of the event (~50 years) many records do not provide the resolution to study the event in detail.

A period of climatic deterioration alongside lower annual temperatures occurs between 9000-8000 cal. BP (Prasad et al., 2006), also encompassing the 8200 cal. BP event, a defined cold relapse (Wanner et al., 2011), thought to be the largest magnitude climatic event during the Holocene (Alley et al., 1997; Bond et al., 1997; Mayewski et al., 2004) where average temperatures may have decreased by ~1.5°C in Europe (von Grafenstein et al., 1998; Marshall et al., 2007). This has been attributed to a large outburst flood and subsequent influx of water into the Atlantic (von Grafenstein et al., 1998; Barber et al., 1999; Alley and Ágústsdóttira, 2005). Within southeast England, evidence from palaeoenvironmental records is sparse for these climate change events. After 8000 cal. BP the trend of climatic amelioration continued to the thermal maximum at ~6000 cal. BP (Davis et al., 2003), although some evidence suggests another cold relapse at 6300 cal. BP (Wanner et al., 2011). At 6000 cal. BP, another period of rapid climate change deterioration is identified, lasting until 5000 cal. BP (Mayewski et al., 2004), encompassing the 5900 cal. BP Bond Event (Renssen et al., 2007). In Britain, this coincides with the cultural shift from Mesolithic hunter-gatherers to Neolithic farming communities (Whittle, 1990; Whittle, 1999; Whittle and Cummings, 2007).

1.4.2. Environmental Context

An understanding of the current environmental data is of critical importance in order to understand how new data fits with the current palaeoenvironmental framework. This review considers a range of site types across the southeast which all have good radiocarbon chronologies, and at least one high-resolution proxy record, which ensures that these records can answer temporal questions. Those sites in the southeast that have met these criteria have been divided into five research zones to critique the evidence for Late Glacial and Early Holocene climate and environmental change.

1.4.2.1. **The Upper and Middle Thames Valley**

Environmental records are especially prevalent along the Upper Thames Valley and the Kennet Valley (Figure 1.8), where a number of sites exist that are dated to the Late Glacial and Early Holocene. The broad vegetation trends derived from these sites are detailed, and some of these sites have produced evidence for archaeological activity (Needham, 1992; Needham, 2000; Parker and Robinson, 2003; Froom, 2012).

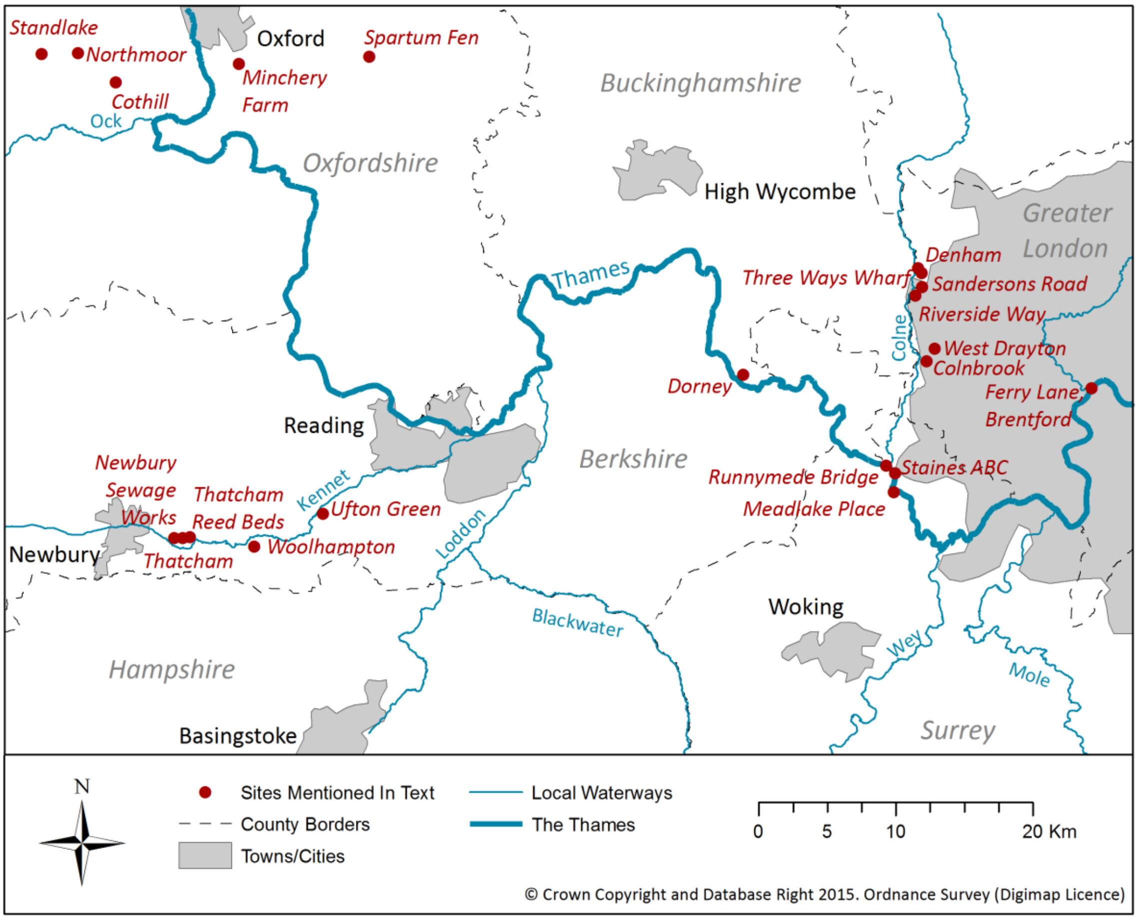


Figure 1.8. Sites along the Thames Valley and West London mentioned in the text.

Pollen evidence from Spartum Fen (Parker, 2000b) indicates that tundra style vegetation was present before the Lateglacial Interstadial. Spartum Fen (Parker, 2000b) records, dated to 15010-14670 cal. BP, indicate that the Lateglacial Interstadial was characterised by a *Betula*, *Juniperus* and *Pinus* woodland, with *Salix* found in wetter areas. Herbaceous plants including Poaceae and Cyperaceae were also present. Similar records of Lateglacial Interstadial vegetation are provided from Minchery Farm (Parker and Preston, 2014). At Colnbrook (16,680-15,640 cal. BP) and West Drayton (13,320-12,800 cal. BP) in the Lower Colne Valley, macrofossil records show open, cold climate vegetation and evidence for damp ground and marsh (Gibbard and Hall, 1982). As conditions deteriorated towards the Loch Lomond Stadial, there is an increase in Poaceae and Cyperaceae and a small increase in *Pinus*. *Betula* and *Salix* are still present but are sparse across the landscape and potentially dwarf variants. Evidence for these changes are recorded from Spartum Fen (Parker, 2000b), Standlake (Sandford, 1965), and a peat lens dated to 13,310-12,860 cal. BP at Northmoor (Shotton et al., 1970). These are significant as there is a general paucity of data indicating a change in the environment during the Loch Lomond Stadial within southeast England.

A greater number of records detail the transition into the Early Holocene, including Cothill (Day, 1991), Woolhampton site and Thatcham Reedbeds (Chisham, 2004), Eton Rowing Lake, Dorney (Parker and Robinson, 2003), Riverside Way (Wessex Archaeology, 2006), Denham (Scaife, 2004), Ferry Lane in Brentford (Scaife, 2015e), Sandersons Road, Uxbridge (Wessex Archaeology, 2006) and Three Ways Wharf (Lewis, 1991; Lewis et al., 1992; Lewis and Rackham, 2011). Evidence from these sites shows a mixed *Pinus* and *Betula* woodland, with *Salix* present on the margins of lakes and river channels. *Corylus* began to colonise soon after the *Betula* and *Pinus* woodland took hold. As climatic conditions continued to ameliorate, mixed deciduous woodland began to develop, primarily to the detriment of *Betula*, and then subsequently outcompeting *Pinus*. At Newbury Sewage Works, this dominance of *Pinus* and *Corylus* occurs by ~10,800 cal. BP (Healy et al., 1992). The mixed woodland consisted of *Corylus*, *Ulmus* and *Quercus* and dated within the Kennet Valley at Woolhampton, Newbury Sewage Works, Ufton Green and Thatcham Reedbeds (Healy et al., 1992; Chisham, 2004) where *Quercus* and *Corylus* expand at ~10,490-10,180 cal. BP, and *Ulmus* from 10,240-9910 cal. BP (Chisham, 2004). At Eton Rowing Lake, this woodland was present by ~10,200 cal. BP (Parker and Robinson, 2003), where a short expansion of *Alnus* occurred for ~500 years and subsequently does not return until the mid-Holocene. At Cothill, this deciduous matrix was present by 9900-9740 cal. BP. Cothill showed evidence for prolonged presence of *Pinus* until 8300-8180 cal. BP, attributed to the repetitive clearing of woodland by humans, and recolonized by *Pinus*. *Tilia* and *Alnus* then joined this mixed woodland later, dated to ~7600 cal. BP at Cothill (Day, 1991). The mixed woodland remains dominant throughout the Later Mesolithic, and was still present at Cothill at 7840-7470 cal. BP (Day, 1991). At Newbury Sewage Works, there is also evidence for burning, thought to be on the floodplain, and some small scale anthropogenic clearance has been identified (Healy et al., 1992). This clearance is thought to have allowed an increased number of animal species to browse within the area bordering the sites and is identified through increases in herb pollen into the dominant *Pinus*, *Quercus* and *Corylus* woodland (Healy et al., 1992). The increasing browsing potential within these *Quercus* and *Corylus* dominated open woodlands may have led to clearings being continually maintained through herbivore grazing (Vera, 2000).

1.4.2.2. London and the Lower Thames Valley

Palaeochannels and tributaries associated with the River Thames have provided a number of excellent radiocarbon dated palaeoenvironmental sequences (Figure 1.8 and Figure 1.9), often comprised of peat and alluvium, especially along the banks of the Thames (Devoy, 1979; Branch and Lowe, 1994; Batchelor et al., 2012; Branch et al., 2012; Batchelor et al., 2015; Batchelor and Young, 2015).

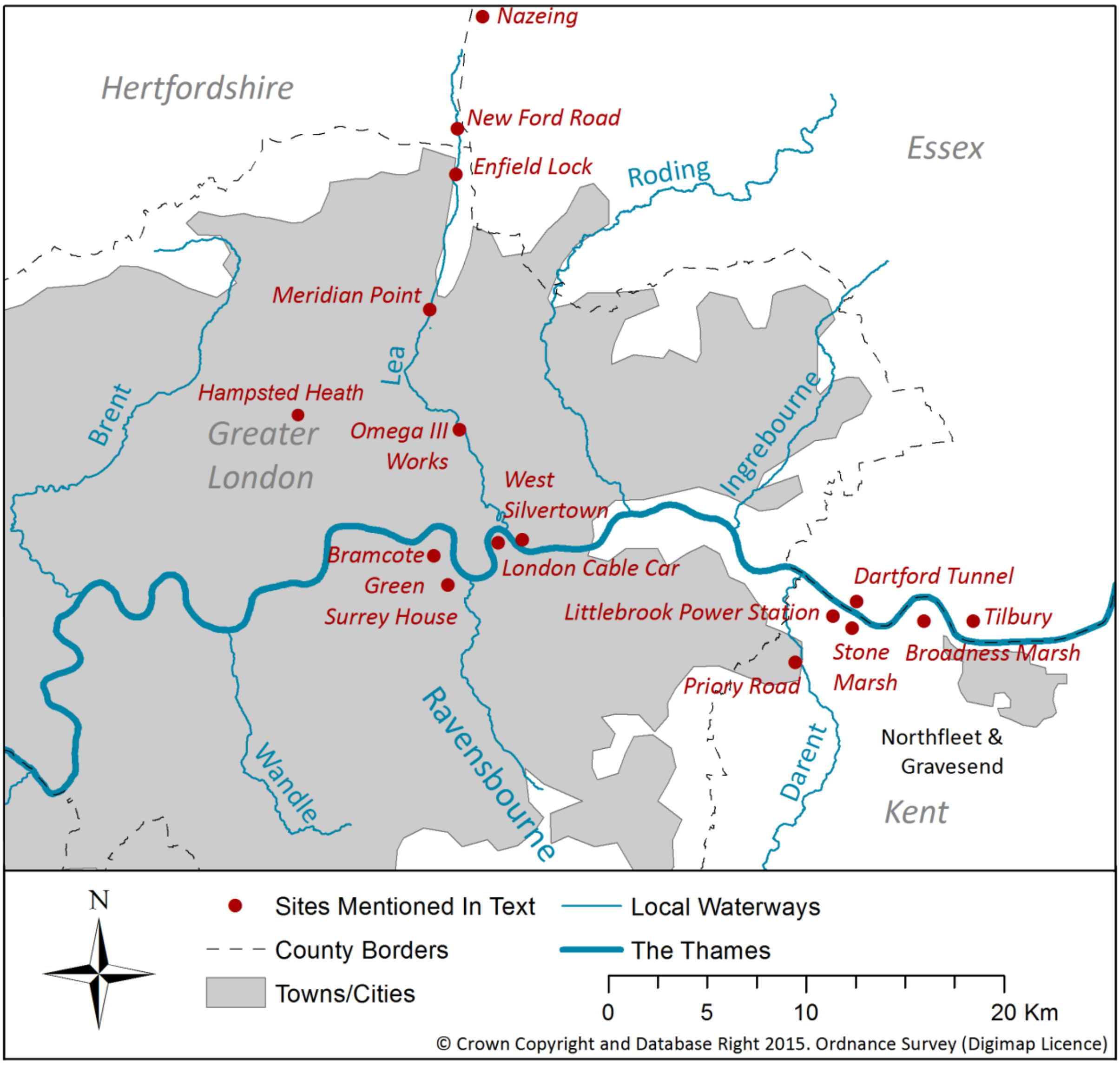


Figure 1.9. Sites in East London and the Lower Thames mentioned in the text.

During the Lateglacial Interstadial the sites of Bramcote Green (Branch and Lowe, 1994) and West Silvertown (Wilkinson et al., 2000) provide evidence for open, scrubby vegetation consisting of *Betula*, *Salix* and *Juniperus*. At Bramcote Green, Late Glacial *Pinus* does not reach the dominance seen at other sites in the southeast, possibly related to the presence of denser *Betula* woodland. As conditions deteriorated towards the Loch Lomond Stadial, *Juniperus* declined and *Betula* and *Salix* were joined by *Pinus*. Poaceae and other herbaceous taxa are also present. Five sites show evidence for this change in vegetation composition: Colnbrook and West Drayton (Gibbard and Hall, 1982), Silvertown (Branch and Lowe, 1994; Wilkinson et al., 2000), New Ford Road and Meridian Point (Corcoran et al., 2011). At West Silvertown and the North London sites, *Alnus* was present and is becoming more frequently observed as a wetland component of Late Glacial assemblages (The Museum of London, 2000). Enfield Lock (Chambers et al., 1996), Meridian Point (Corcoran et al., 2011) and Priory Road (Batchelor and Young, 2015) suggest a decline in herbaceous species and re-establishment of *Juniperus* alongside *Betula* and *Pinus* during the transition into the Early Holocene. The Early Holocene woodland is characterised by an expansion in broadleaved woodland alongside *Pinus*, including *Corylus*, *Ulmus* and *Quercus* with the *Tilia* expansion occurring slightly later. Herbaceous species included Poaceae and Cyperaceae, and *Alnus* was present in the wetter areas. A number of sites identify this expansion of broadleaved woodland and herbaceous taxa, including Nazeing (Allison et al., 1952), Hampstead Heath (Girling and Greig, 1977), Tilbury, Stone Marsh, the Dartford Tunnel, Littlebrook Power Station, Broadness Marsh (Devoy, 1979), Bramcote Green (Branch and Lowe, 1994) , Enfield Lock (Chambers et al., 1996), New Ford Road, Omega III Works site (Corcoran et al., 2011), West Silvertown (Wilkinson et al., 2000), Surrey House (Batchelor et al., 2012), London Cable Car (Batchelor et al., 2015) and Priory Road (Batchelor and Young, 2015).

1.4.2.3. **The Southeastern Counties**

Across Kent and East Sussex a number of sites have been investigated that provide radiocarbon dated Late Glacial and Early Holocene palaeoenvironmental records (Figure 1.10).

The sites of Sevenoaks (Skempton and Worssam, 1976), Brook (Kerney et al., 1964); (Preece, 1994) and Holywell Coombe (Kerney et al., 1980; Preece and Bridgland, 1998) identify a *Betula*, *Pinus* and *Juniperus* open woodland during the Lateglacial Interstadial. The wetter areas in the landscape were dominated by *Salix*. An increase in herbaceous species and slight decline in the arboreal cover suggested the presence of the Loch Lomond Stadial at Holywell Coombe (Kerney et al., 1980; Preece and Bridgland, 1998). A further decline in *Juniperus*, alongside an increase in the dominance of *Betula* and *Pinus* woodland has been attributed to the warming at the start of the Holocene and is identified at Panel Bridge (Waller, 1993), Holywell Coombe (Kerney et al., 1980; Preece and Bridgland, 1998) and Wateringbury (Kerney et al., 1980). An Early Holocene presence of *Alnus* at Panel Bridge is likely to be due to exploitation of the wetter local conditions (Waller, 1993).

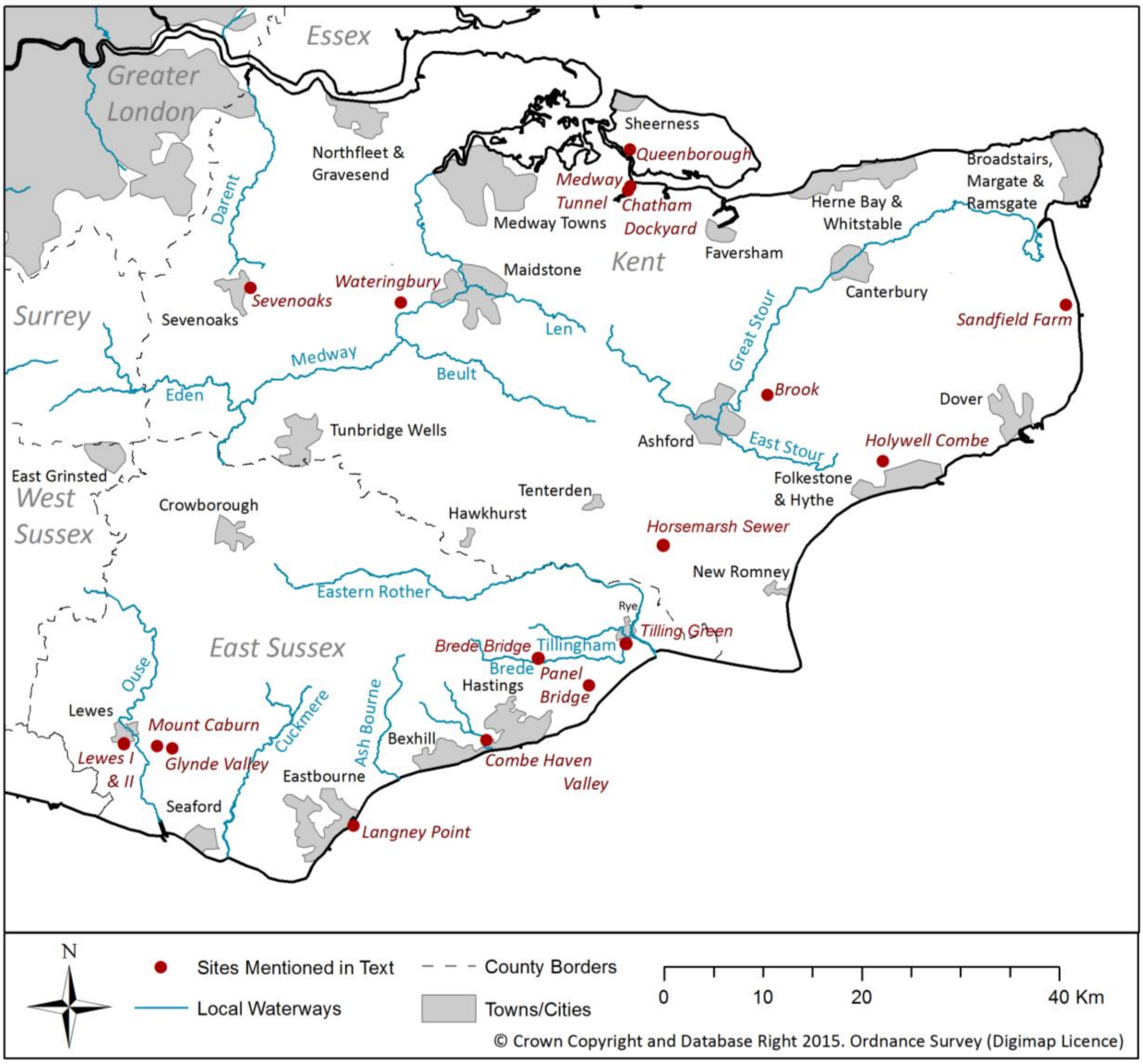


Figure 1.10. Sites within Kent and East Sussex that are described in the text.

A gradual expansion of broad-leaved deciduous woodland including *Corylus*, *Ulmus* and *Quercus* at Wateringbury (Kerney et al., 1980), Holywell Coombe (Kerney et al., 1980; Preece and Bridgland, 1998), Lewes I and II (Thorley, 1981), Panel Bridge (Waller, 1993), Brede Bridge (Waller and Marlow, 1994), Horsemarsh Sewer (Waller et al., 1999), Mount

Caburn (Waller and Hamilton, 2000; Waller and Long, 2010), Queenborough (Pratt et al., 2003; Scaife, 2015d), Tilling Green, Rye (Waller and Kirby, 2002), Sandfield Farm (Scaife, 2015d), Chatham Dockyard and the Medway Tunnel (Scaife, 2015d) is identified during the Early Holocene. At Panel Bridge, this transition occurred between ~10,200-8200 cal. BP. The deciduous woodland continued to expand during the Holocene with the arrival of *Alnus* and *Tilia* at the Lower Brede and Tillingham (Waller and Long, 2010), Horsemarsh Sewer on Walland Marsh (Waller et al., 1999) and at Holywell Coombe (Preece and Bridgland, 1998). At Brede Bridge (Waller and Marlow, 1994), *Tilia* was the dominant species within this mixed deciduous woodland. *Acer* was a component of the woodland at Mount Caburn, and *Pinus* continued to be present within the Late Mesolithic Holocene in the Glynde Valley (Waller and Hamilton, 2000); (Waller and Long, 2010). At Sandfield Farm, an opening of the woodland occurs at ~6350 cal. yr. BP with *Plantago*, herbaceous taxa, *Tilia* and *Quercus* pollen expanding against an *Alnus* decline (Waller and Long, 2010). This could be due to the exploitation of woodland possibly through coppicing. During the Later Mesolithic, the presence of *Fraxinus* and *Fagus* at Lewes I and II have been suggested as potential indicators of forest opening, potentially related to the hunting of game in this region (Thorley, 1981).

1.4.2.4. **The South Central Region**

The south central region includes West Sussex, Hampshire and the Isle of Wight, and encompasses numerous Late Glacial and Early Holocene records (Figure 1.11). Many of these sites are unpublished but detailed in the Southern Pollen Review (Scaife, 2015a; Scaife, 2015b; Scaife, 2015c). The region is dominated by the studies that have been undertaken in and around the Solent area, with sites throughout the Holocene and earlier (Scaife, 2015a).

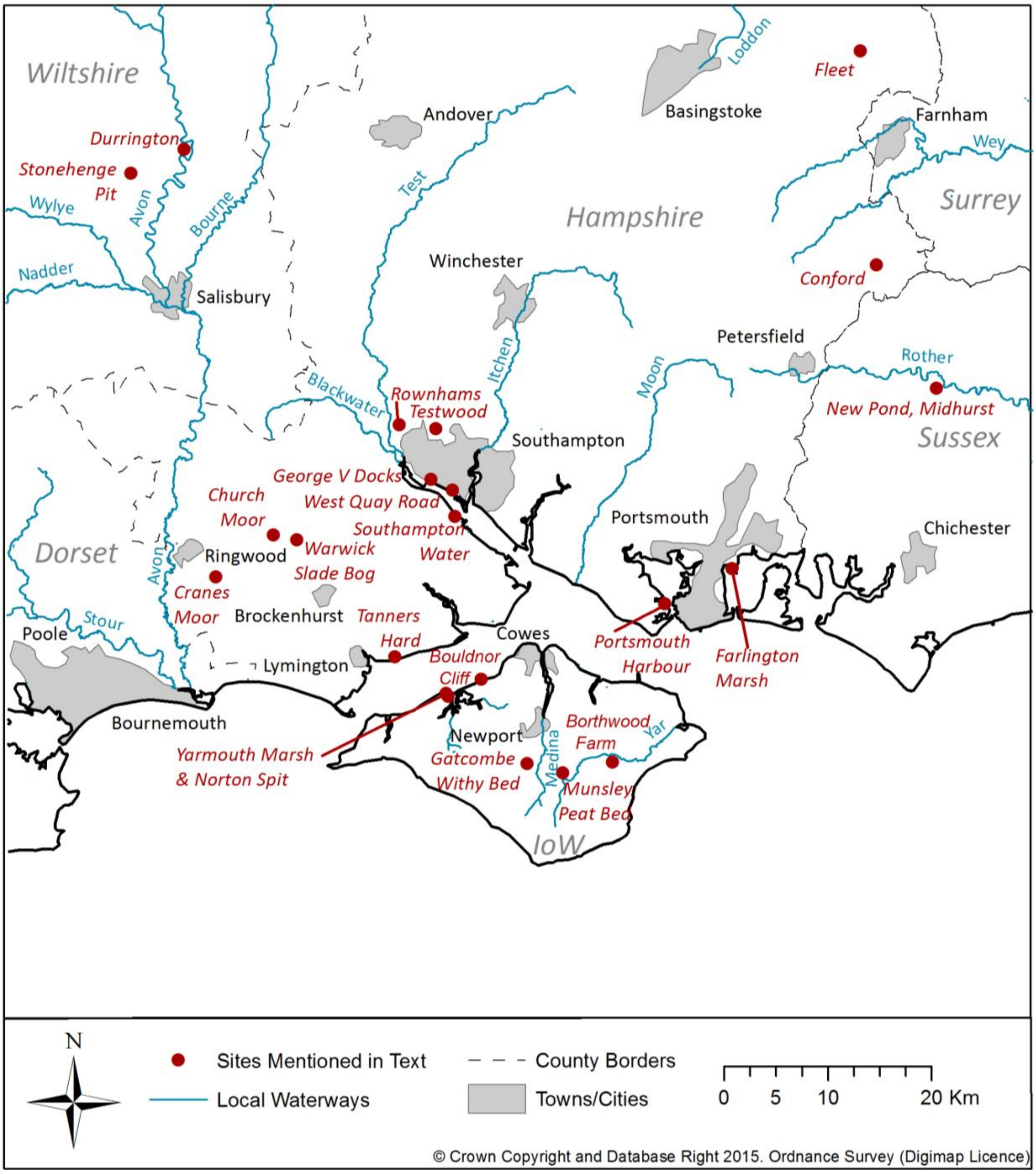


Figure 1.11. The Hampshire, West Sussex and Isle of Wight sites as mentioned within the text.

The sites of Gatcombe Withy Bed (Scaife, 1980a; Scaife, 1987), Fleet, Testwood and Rownhams in Hampshire (Scaife, 2015a), New Pond in Midhurst (Scaife, 2001), Cranes Moor, Church Moor and Warwick Slade Bog (Barber and Clark, 1987) all provide evidence for vegetation succession dating to the very end of the Late Glacial . The landscape at this time was dominated by cold tundra herbaceous species. At the base of Gatcombe Withy Bed, Ericaceae and *Juniperus* were also identified (Scaife, 1980a; Scaife, 1987). The transition into the Early Holocene is identified by an increase in arboreal species, particularly *Pinus* and *Betula*. *Juniperus* and Ericaceae are still present and *Salix* is identified and thought to be growing on the wetter areas of the landscape. A number of sites provide evidence for this period, including Gatcombe Withy Bed (Scaife, 1980a; Scaife, 1987), Cranes Moor, Church Moor, Warwick Slade Bog (Barber and Clark, 1987), West Quay Road (Nicholls and Scaife, 2008; Scaife, 2015a), George V Docks (Godwin, 1940), Portsmouth Harbour (Godwin, 1945), Munsley Peat bed (Scaife, 1980a; Scaife, 1982), New Pond in Midhurst (Scaife, 2001), Fleet, Testwood, and Rownhams (Scaife, 2015a).

Corylus woodland then begins to expand during the Early Holocene and is joined by *Quercus* and *Ulmus*, often to the detriment of *Pinus* and *Betula*. *Tilia* and *Fraxinus* then become a component of the woodland towards the Mid-Holocene thermal optimum, alongside an expansion in *Alnus* on wetter ground. This broad-leaved expansion is identified at multiple sites within the south central region, including Gatcombe Withy Bed (Scaife, 1980a; Scaife, 1987), West Quay Road (Nicholls and Scaife, 2008; Scaife, 2015a), Munsley Peat bed (Scaife, 1980a; Scaife, 1982), Tanners Hard (Maritime Archaeology Trust, 2012), Farlington Marsh (Scaife, 2000b), Bouldnor Cliff (Momber et al., 2011b; Momber et al., 2011a), Borthwood Farm (Scaife, 1987), Yarmouth Marsh and Norton Spit (Scaife, 2015b), Cranes Moor, Warwick Slade Bog (Barber and Clark, 1987), Stonehenge and Durrington (Barber and Clark, 1987; Scaife, 2015a). A small rise in herbaceous species is also noted in some sites at this time, potentially related to human activity (Barber and Clark, 1987). At the site of Conford, a very late survival of *Pinus* (up to ~6050 cal. BP) was observed, surviving later than at all of the other sites examined within the southeast. This has been attributed to the ability of *Pinus* to remain competitive against deciduous species in the free draining sands and saturated soils of the Lower Greensand Formation. Post 7050 cal. BP the continued presence of *Pinus* is also attributed to both the lack of available nutrients preventing competition and also regular burning (Groves et al., 2012).

1.4.2.5. **Surrey**

There are only a handful of sites studied within Surrey, with a large bias towards the Thames Valley margins and the north of the County (Figure 1.12). The County, in comparison to the surrounding regions, has a paucity of records with sequences dating to the Late Glacial and Early Holocene periods.

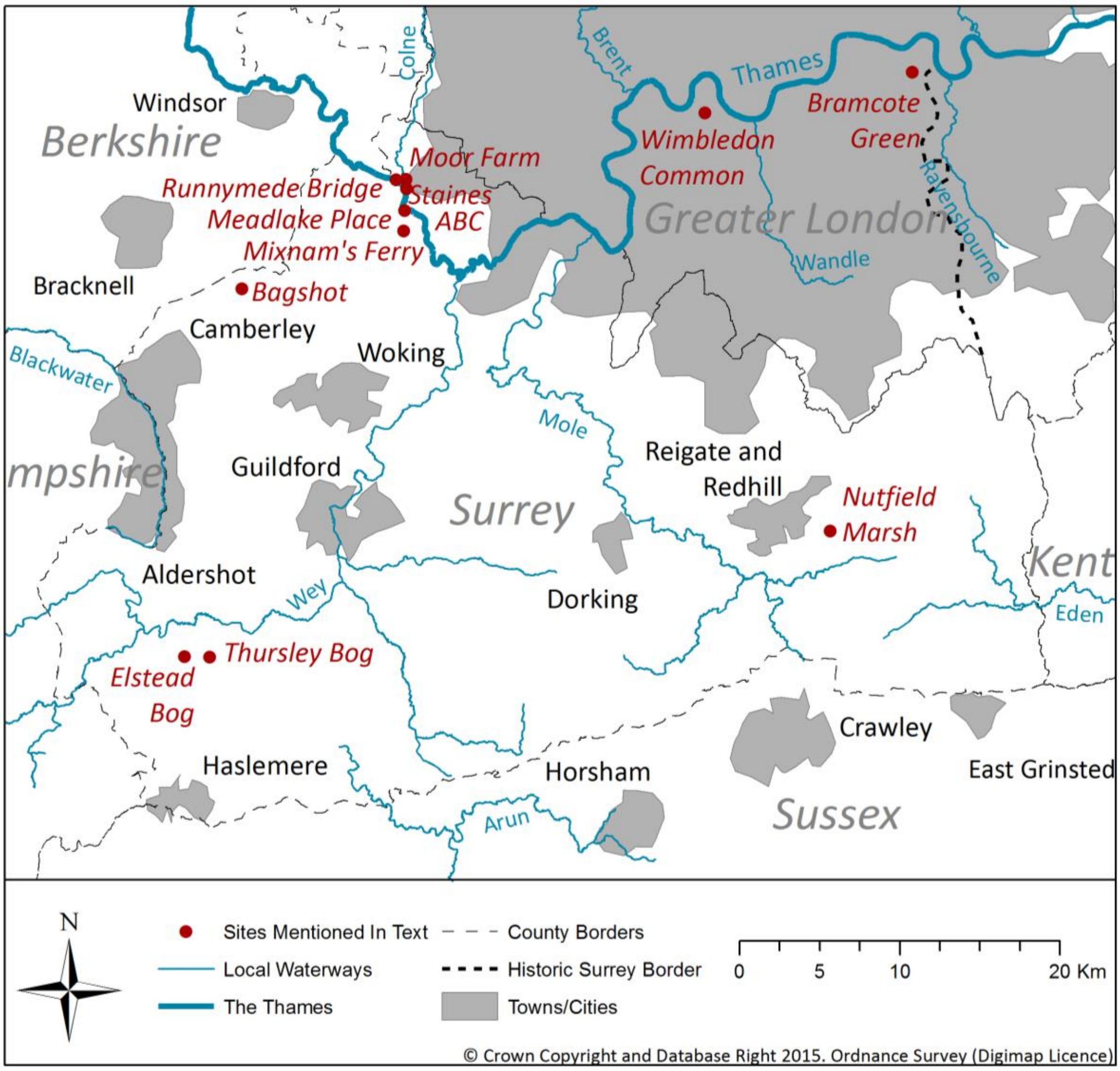


Figure 1.12. The location of the sites within Surrey that are mentioned within the text.

Evidence from the River Thames around Staines indicate large expanses of Holocene sediments overlying the Late Devensian Shepperton Gravel (Branch and Green, 2004). A number of sites from this region present a picture of vegetation development in north Surrey from the Early- to Mid-Holocene. Moor Farm offers the oldest sequence, dating from ~11,000 cal. BP (Keith-Lucas, 2000). Eight sequences at Runnymede span from ~10,200 cal. BP to the Late Bronze Age (Scaife, 2000a; Ambers, 2000) and a series of infilled river channels at Meadlake Place date from ~10,100-9200 cal. BP (Branch and Green, 2001; Branch and Green, 2004). At Staines ABC, alluvial deposits date from ~10,100 cal. BP (Branch et al., 2003). There is currently no evidence of Late Glacial environmental or climatic change from Surrey, and so the impact of the Loch Lomond Stadial is currently not known.

The record from Moor Farm shows that in the Early Holocene (~11,000 cal. BP) the vegetation comprised of *Juniperus* alongside *Artemisia*, Poaceae and Cyperaceae. This transitions into a *Pinus* and *Betula* dominated woodland with *Salix* woodland in wetter areas. At Runnymede Bridge, this woodland cover is gradually replaced by deciduous woodland with *Quercus, Ulmus* and *Corylus* at ~8860 cal. BP (Scaife, 2000a), where *Alnus* and *Salix* would have been dominant on the wetter floodplain. Some ruderal taxa such as *Plantago lanceolata, Scabiosa,* Chenopodiaceae and Poaceae were present, possibly suggesting Mesolithic hunter-gatherers' interaction with the vegetation (Scaife, 2000a). These taxa coincide with the increase in *Corylus*, potentially utilised as a food source (Simmons and Tooley, 1981; Tallantire, 2002). There does not appear to be any direct evidence for the 8.2 Kya event at these sites. Drier climax woodland of the Late Mesolithic was composed of *Tilia* and *Fraxinus,* with *Ulmus*, *Quercus* and *Corylus*. There was also a range of ruderal taxa, suggesting the woodland was not a dense and closed deciduous forest (Scaife, 2000a). Similar trends were also observed at other sites within the Staines area of the River Thames, including at Meadlake Place, a temporary decline in *Alnus* coincides with a mineral rich deposition, cited as evidence for local human activity during the Late Mesolithic (Branch and Green, 2001), and similar trends were observed at Staines ABC (Branch et al., 2003). These Middle Thames sites show a similar pattern of vegetation history to the sequence at Bramcote Green (Branch and Lowe, 1994) and at Farm Bog on Wimbledon Common (Jennings and Smythe, 2000).

In addition to the Middle Thames in Surrey, other important sites are found in other parts of the County. Elstead Bog A provides a vegetation record dating from the Late Glacial to the end of the Mesolithic, studied on multiple occasions (Godwin, 1940; Godwin, 1956; Seagrief and Godwin, 1960; Carpenter and Woodcock, 1981; Farr, 2008). The site occupies a small hollow in the Lower Greensand and has been identified as the only Relict Cryogenic Mound (RCM) in southeast England (Watson and Morgan, 1977; Hutchinson, 1980; Carpenter and Woodcock, 1981; Bryant and Carpenter, 1987; Ballantyne and Harris, 1994). Relict Cryogenic Mounds are landscape remnants of the last glacial period, when Surrey was a periglacial environment (Huggett, 2007). An abundance of aquatic species suggests a small lake or pond was present at Elstead during the Early Holocene. *Juniperus, Betula* and *Salix* woodland with some open ground meadow dominated the surrounding landscape. Domination of the woodland by a mix of *Pinus* and *Betula* leads to a reduction in herbaceous taxa from ~11,000 cal. BP. Deciduous woodland takes hold within the region from ~8700 cal. BP with *Quercus, Fraxinus* and *Tilia* becoming established alongside *Ulmus* and *Corylus.* As with the sites in northern Surrey, there is no evidence of significant vegetation change at the time of the 8.2 Kya event. *Alnus*-carr conditions develop towards the end of the Mesolithic period at ~6200 cal. BP (Farr, 2008). A prolonged presence of *Pinus* (until ~6,000 cal. BP) is similar to Conford, another Greensand site (Groves et al., 2012) and suggests *Pinus* persists for longer on sandy geologies. Thursley Common lies within 1km of Elstead Bog and investigations suggested development of heathland dated to the Bronze Age (Moore and Wilmott, 1976). However, the basal units showed high proportions of *Pinus, Betula, Salix, Rumex* and *Artemisia.* This is a signal identified at other Late Glacial/Early Holocene sites and further study is needed to fully understand the age and pattern of deposition across the entire Thursley Bog and Ockley Bog sites.

A Late Glacial and Early Holocene peat sequence was identified at Bagshot (Groves, 2008). The Late Glacial had widespread bare ground with patches of heathland, *Salix* and *Juniperus*. *Pinus*, *Betula* and open areas of *Plantago* and *Artemisia* signify the onset of the Holocene alongside an early presence of *Alnus*, prior to 11,200 cal. BP. Post ~11,200 cal. BP, *Pinus* dominated with sporadic occurrences of *Corylus*. This early presence of *Corylus* is significant, as it represents one of the earliest dates for the species in southeast England. A hiatus in sedimentation was identified between 9800-7550 cal. BP, attributed to drier conditions and a lowering of the water table. Post hiatus, wetter conditions were present with *Alnus*-carr alongside Cyperaceae, *Salix* and *Betula*. *Quercus* and *Corylus* woodland dominate drier ground (Groves, 2008). Nutfield Marsh was investigated through pollen and microcharcoal analysis, identifying a *Pinus*, *Quercus*, *Ulmus, Tilia* and *Corylus* woodland at ~10,000 cal. BP. Wetter areas were dominated by *Salix*, Cyperaceae and Poaceae until ~7000 cal. BP when *Alnus*-carr developed, alongside a reduction in *Pinus* and *Betula* (Farr, 2008).

The sites in Surrey and the southeast can be surmised in five main biostratigraphic zones (Branch and Green, 2004) providing a broad indication of vegetation development:

- Pre 11,500 cal. BP
    - Open scrubby tundra style vegetation comprising of *Juniperus*, *Betula* and *Salix* woodland. Often continues into the very Early Holocene.
- 11,500-10,200 cal. BP
    - *Pinus* becomes dominant on dryland zones. On the wetland edge *Salix* continues to be the dominant species, alongside Cyperaceae.
- 10,200-8900 cal. BP
    - Mixed deciduous woodland of *Quercus*, *Betula*, *Corylus* and *Ulmus* developed in previously *Pinus* dominated areas. *Salix* was dominant at the wetland edge.

- 8900-7000 cal. BP
    - Mixed deciduous woodland dominated drier areas, with the addition of *Tilia* and the loss of *Betula*. *Alnus*-carr woodland formed on the wetter areas.
- 7000-6300 cal. BP
    - Herbaceous plants increased, with a decline in arboreal taxa.

1.5. Cultural History during the Late Glacial and Early Holocene

The Upper Palaeolithic dates from ~45,000 to 11,500 cal. BP and is commonly split into the Early Upper Palaeolithic and the Late Upper Palaeolithic. The Late Upper Palaeolithic dates to the end of the Upper Palaeolithic period, from ~14,800 to 11,500 cal. BP (Pettitt and White, 2012a). The Mesolithic follows the Late Upper Palaeolithic and dates to ~11,500-6,000 cal. BP (Barton, 2009; Collard et al., 2010; Woodbridge et al., 2014).

1.5.1. The Late Upper Palaeolithic

The Upper Palaeolithic environment was harsh, with subsistence gained through traversing the landscape with a predominantly hunting economy (Richards et al., 2000). The Late Upper Palaeolithic dates from ~14,800 to 11,500 BP, when southeast England was attached to the European mainland, reflected in the flint artefact styles of the time (Barton et al., 2009; Gowlett et al., 1987). The landscape during the Late Upper Palaeolithic would have been relatively plant and animal species poor to begin with as temperatures ameliorated from the Last Glacial Maximum. Late Upper Palaeolithic sites contain butchered animal bones and lithics (e.g. Creswell/Cheddar points) that are thought to have been projectile points (Morrison, 1980), although with the flexibility to be used for other tasks, such as knives (Taller et al., 2012). It is possible that an increasing faunal diversity allowed recolonisation, with red deer, cattle and wild horses all present once colonisation had occurred (Jacobi and Higham, 2011). Three main archaeological periods recognised for the Late Upper Palaeolithic are: the Creswellian, the Final Upper Palaeolithic (Federmesser groups) and the Terminal Upper Palaeolithic (long blade assemblages) (Barton, 1999). The Terminal Upper Palaeolithic culture is thought to overlap with the earliest Mesolithic. Table 1.1 details the common subgroups within the Late Upper Palaeolithic.

Table 1.1. Overview of the three defined Late Upper Palaeolithic sub-periods.

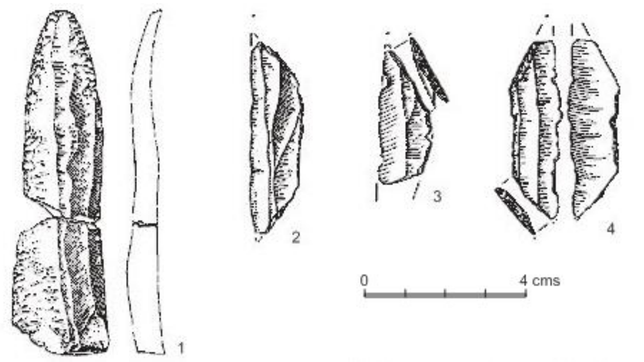
<table>
<tr><td colspan="2">Creswellian / Late Magdalenian / Hamburgian ~15,000-13,800 cal. BP
(Barton and Roberts, 1996; Barton, 1999; Barton, 2009; Pettitt et al., 2012)</td></tr>
<tr><td>Typical Archaeological Material</td><td>Characterised by the presence of Cheddar and Creswell points, piercers, end scrapers on long blades, burins, truncated blades, Magdalenian blades and organic artefacts such as reindeer antler batons (Barton, 2009). The Creswell point may show a connection between the Creswellian and Final Palaeolithic (Barton et al., 2003).


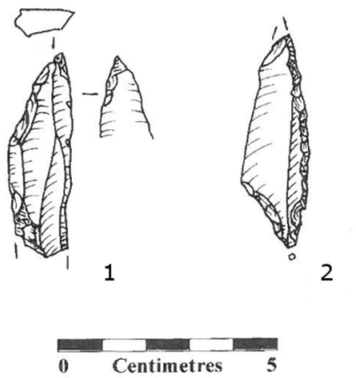
Figure 1.13. Creswellian artefacts from Three Holes Cave and Kent's Cavern, Devon. 1- End-scraper on a blade; 2, 3 & 4 - Trapezoidal-backed blades (Cheddar Points). From: Barton, 2009: Figure 2.2.</td></tr>
<tr><td>Sites, Mobility and Hunting</td><td>The majority of finds come from cave sites, with less extensive finds found in open areas. Locations favour upland areas and river catchments. There is evidence for extensive movement within the landscape, particularly in the hunt for raw materials (Barton, 2009).
A wide variety of animals would have been used both for resources and food, including wild horse, red deer, arctic hare, mammoth, reindeer, brown bear, wild cow and others (Barton, 2009) .</td></tr>
<tr><td colspan="2">Final Upper Palaeolithic / Federmessergruppen ~13,800-12,800 cal. BP
(Barton and Roberts, 1996; Barton, 1999; Conneller et al., 2007; Pettitt, 2008)</td></tr>
<tr><td>Typical Archaeological Material</td><td>Flintwork commonly consists of curved-backed points and blades and the penknife point in addition to organic hunting equipment such as an increasing use of projectiles (made of bone or antler). A broad variety of raw materials is used, from flint, pebble flint and chert (Butler, 2005; Barton, 2009). There is also evidence for the long distance movement of raw materials (potentially up to/over 80km) (Barton, 2009)


Figure 1.14. Final Palaeolithic flints. 1 – Curved-backed point, 2- penknife point. After Butler, 2005: figure 29.</td></tr>
<tr><td>Sites, Mobility and Hunting</td><td>More sites are observed than the Creswellian with less dominance towards caves. Mammoth may have disappeared. Food consisted of fruits, seeds, fungi and berries, marine and terrestrial mammals (Richards et al., 2005; Barton, 2009).</td></tr>
</table>

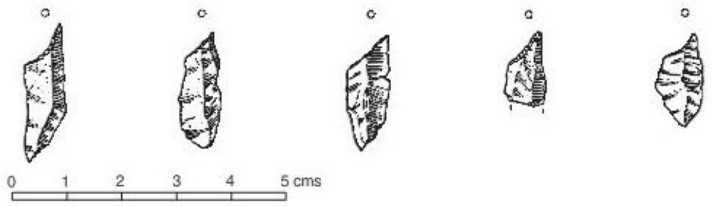
<table>
<tr><td colspan="2">Terminal Upper Pal./ Epipalaeolithic / Epi-Ahrensburgian / Long Blade Assemblages
~12,800-11,500 cal. BP (Pettitt, 2008; Barton, 2009; Grant et al., 2014)
It is important to note that there is little direct dating of this period.</td></tr>
<tr><td>Typical Archaeological Material</td><td>Dominant lithics are based on long-blade technology (>12cm) and opposed platform blade cores (Barton, 2009). End scrapers, microliths and burins are also found (Barton and Roberts, 2004).


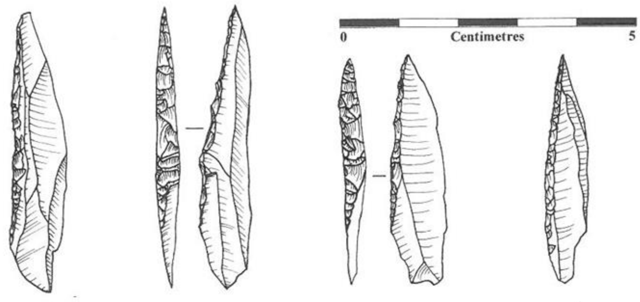
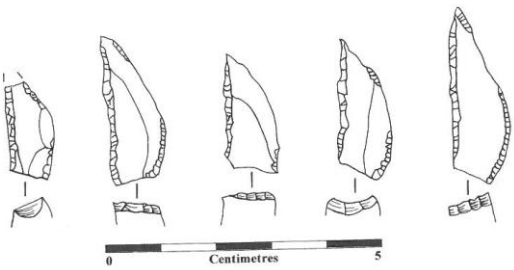
Figure 1.15. 'Long blade' artefacts. Microliths with concave truncation from Scatter 'A' at Three Ways Wharf. From Barton, 2009: figure 2.12.</td></tr>
<tr><td>Sites, Mobility and Hunting</td><td>Majority of sites identified in southeast England. Sites were likely short lived, with no evidence for hearths, and little burnt remains (Barton, 2009).
Hunting of animals over relatively large distances is thought to have occurred (Barton, 2009).</td></tr>
</table>

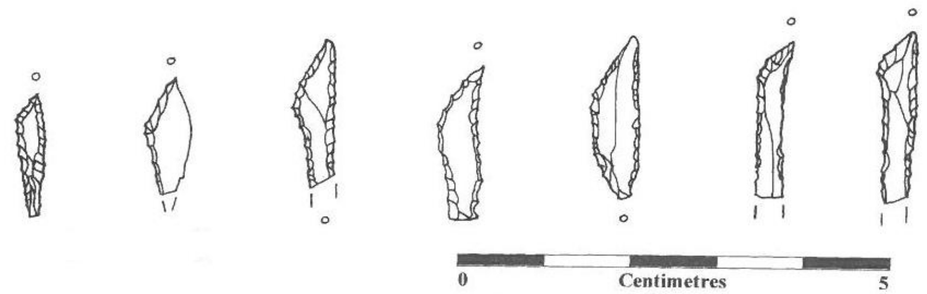
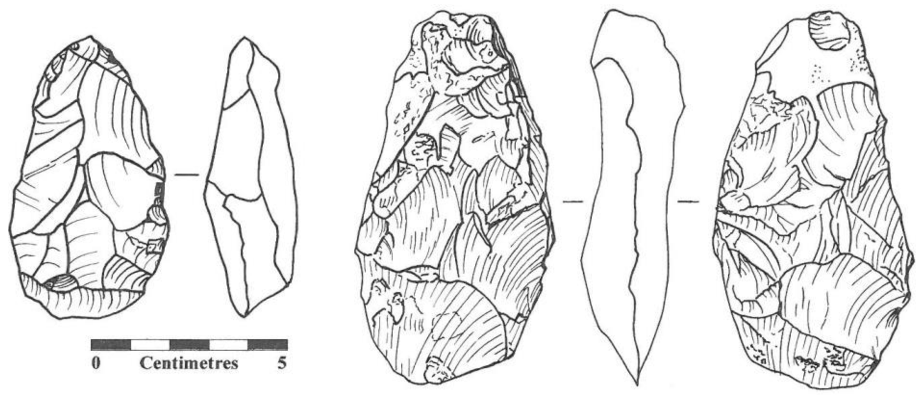
1.5.2. The Mesolithic

The Mesolithic period is thought to have initiated due to the sudden and intense climatic warming at the end of the last glaciation (Barton and Roberts, 2004). The period is defined by the dominance of flintwork, with tool kits frequently based on hunting equipment. Two types of flintwork symbolise the Mesolithic: the microlith and the tranchet axe (Butler, 2005). The Mesolithic is divided into two periods, the Early Mesolithic and the Late Mesolithic. Within the southeast, the Horsham Period is recognised as a regional subset of the Early Mesolithic (Table 1.2) (Butler, 2005). It is likely there is no clear distinction between these periods (Barton and Roberts, 2004). In contrast to the Late Upper Palaeolithic nomadic forager, the Mesolithic hunter-gatherer lifestyle was very variable, with some small and mobile groups, or groups present at base camps, thought to be semi-permanent due to the type and assemblage size of artefacts, with societies that provide evidence for significant differentiation in social hierarchy (Milner and Mithen, 2009). Sites ranged from small overnight occupations to activity areas to multiple occupation sites. The overall population of Britain is thought to range between 4,560 and 20,520 at any one time (Edwards, 2004; Milner and Mithen, 2009).

The Mesolithic diet was varied, including both marine and terrestrial food, and foodstuffs were exploited on a seasonal basis (Mithen, 2000). Unfortunately the poor preservation of plant remains means that they are likely to be highly under represented. Starr Carr indicates evidence for the hunting of large species including: red deer, roe deer, elk, aurochs and wild boar (Mellars and Dark, 1998). It is likely these animals were stalked in dense woodland with spears or bows and arrows, although there is a possibility that the animals were ambushed. The ambushing of animals may have been achieved through the creation of clearances within woodland (Vera, 2000). There is also evidence for the use of the domesticated dog, which would likely have been utilised during hunting (Milner and Mithen, 2009).

Table 1.2. Overview of the Mesolithic sub-periods.

Early Mesolithic *~11,500-9600 cal. BP* (Reynier, 1998; Barton and Roberts, 2004; Tolan-Smith, 2008)	
Typical Archaeological Material	Characterised by lithic assemblages made up of large and relatively simple microlith forms and bifacially flaked adzes (Barton and Roberts, 2004).  *Figure 1.16. Obliquely blunted microliths from Hengistbury Head. After Butler, 2005: Figure 37.*
Sites, Mobility and Hunting	Evidence for both material exchange between different Mesolithic groups and long-distance movement of people (Rankine, 1952). A variety of animals, including deer and wild pig were hunted, as identified at Star Carr (Milner and Mithen, 2009).
Horsham Period *~10,000 cal. BP* (Reynier, 1998)	
Typical Archaeological Material	A regional variant of the Early Mesolithic period, distinctive to Surrey, Sussex and other parts of the southeast (Reynier, 1998). Characterised by the specific Horsham point microlith alongside other flints typical of the Early Mesolithic.  *Figure 1.17. Horsham points from Kettlebury 103. After Butler, 2005: Figure 38.*
Sites, Mobility and Hunting	Similar to that of the Early Mesolithic. Implication that bows and arrows used more than spears for hunting (Ellaby, 1987).

Late Mesolithic *~9600-6000 cal. BP* (Switsur and Jacobi, 1979; Barton and Roberts, 2004; Pettitt, 2008; Tolan-Smith, 2008; Collard et al., 2010; Grant et al., 2014; Woodbridge et al., 2014)	
Typical Archaeological Material	The Late Mesolithic lithic technology is dominated by small geometric microlith forms (e.g. scalene triangles). A shift from broad to narrow blade assemblages is not paralleled on the continent (Farr, 2008). There is a suggested increase in the use of tranchet axes in the southeast during the Later Mesolithic (Butler, 2005).  *Figure 1.18. A range of scalene microliths from Hermitage Rocks. From Butler, 2005: figure 39.*  *Figure 1.19. Two examples of tranchet adzes. From Butler, 2005: figure 41.*
Sites, Mobility and Hunting	Appears to be a greater number of sites than the Early Mesolithic but the sites themselves cover a smaller spatial area. Rock shelters identified as seasonal hunting bases. 'Pit sites' are also present and potentially used as rudimentary shelter (Evans et al., 1999). Late Mesolithic sites are relatively sparse leading to issues understanding the continuity of occupation between the latest Mesolithic and earliest Neolithic (Barton and Roberts, 2004).

1.5.3. Late Upper Palaeolithic and Mesolithic Activity in the Southeast

The southeast has a rich history of Late Upper Palaeolithic and Mesolithic research, through the discovery of isolated find spots and large scale sites. Sites with ecofactual data are particularly significant in understanding settlement and subsistence patterns, although they are few in number (Farr, 2008). The need for such sites remains important, as there is a general paucity of this information. The sites identified here provide the best insight into Late Upper Palaeolithic and Mesolithic occupation, culture and technology in the southeast region. Late Upper Palaeolithic evidence is found across southeast England (Table 1.3 and Figure 1.20) with the earliest records for occupation found in Kent at Oare. Further detail on these sites and their relevance to the broader picture of human activity in the environment can be found within the discussion (Chapter 9).

Table 1.3. Sites dating to the Late Upper Palaeolithic in southeast England

Archaeological Period	**Site(s) and References**	**Typical finds**
Creswellian	• Oare, Kent (Jacobi, 1982; Barton, 2009; Pettitt and White, 2012) • Stonewall Park and Romsey (Huxtable and Jacobi, 1982) • Wandsworth and Wallington (The Museum of London, 2000) • Wey Manor Farm (Jones and Cooper, 2013)	Variety of shouldered points and other flint tools.
Creswellian - Final Upper Palaeolithic	• Brockhill (Cox, 1976; Bonsall, 1977b; Mills, 2012) • Guildford Fire Station (Attfield et al., 2014) • Hengistbury Head (Barton, 1992; Pettitt and White, 2012a) • Church Lammas (Jones, 2013c)	Variety of tools including scrapers, blades and burins.
Terminal Upper Palaeolithic	• Avington VI, Wawcott XII and Crown Acres (Froom, 2005) • Leatherhead, Brooklands, Runfold and Farnham (Jones, 2013c) • Gatehampton Farm, Goring (Barton, 1995) • Riverdale, Kent (Champion, 2007) • Rock Common in West Sussex (Harding, 2000) • Springhead (Jacobi, 1982) (Wessex Archaeology, 2008) • Three Ways Wharf (Lewis and Rackham, 2011)	Long Blade assemblages

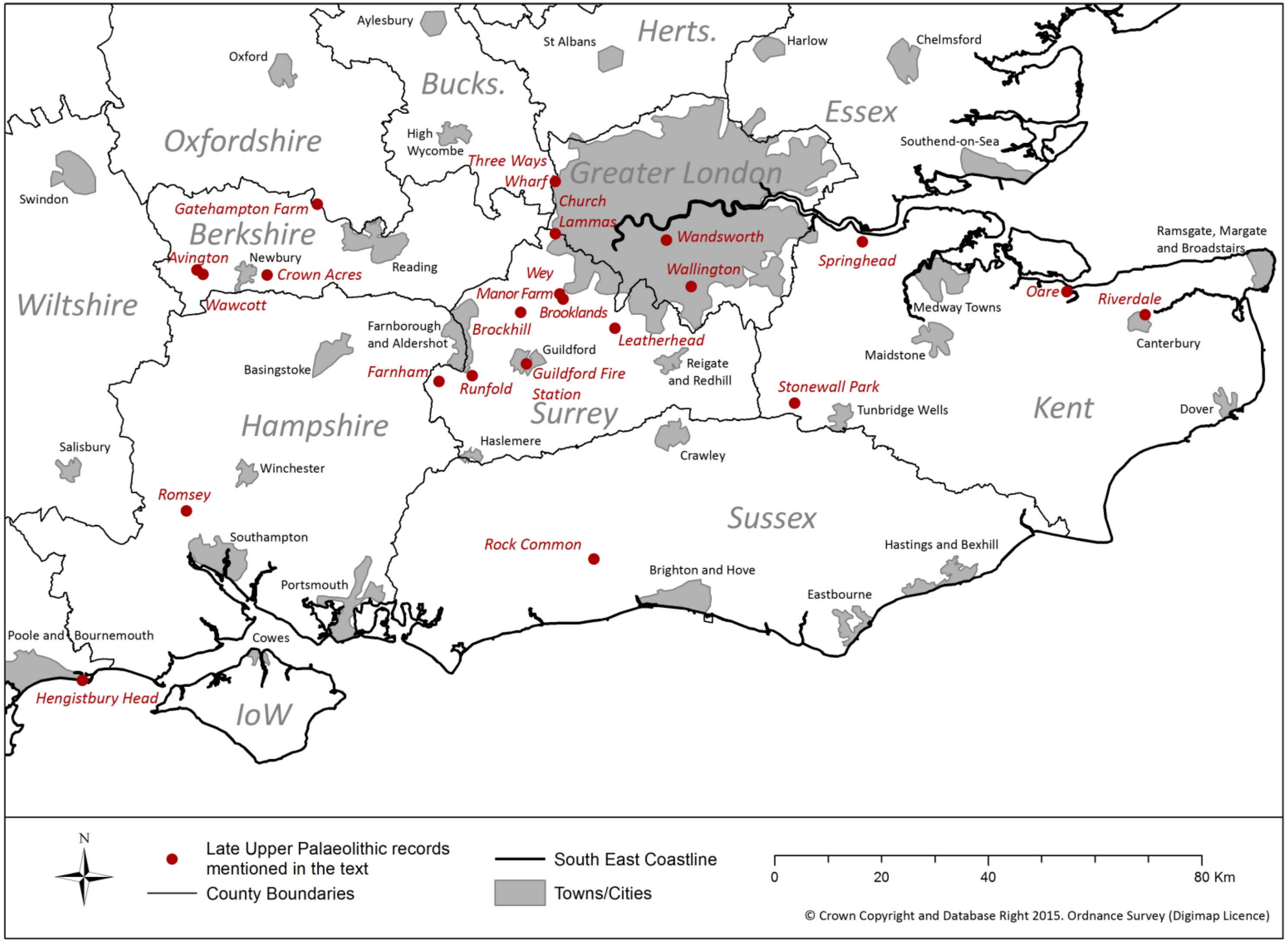


Figure 1.20. Important Late Upper Palaeolithic sites in Surrey and the southeast.

The size of these assemblages indicates that small groups of people were active across southeast England during the Late Upper Palaeolithic. In addition to this evidence, many records are likely to be lost beneath the English Channel and North Sea, due to the amount of land lost following sea level rise (Champion, 2007). Many more sites and records are known from the British Mesolithic and a number of important sites and archaeological records have been discovered in the southeast (Table 1.4 and Figure 1.21).

Table 1.4. Sites dating to the Mesolithic in southeast England

Archaeological Period	**Site(s) and References**	**Typical finds**
Early Mesolithic	• Buckland (Ellaby, 1987) • Ditton (Champion, 2007) • Frensham Great Pond North (Rankine, 1949a) and South (Rankine, 1949b) • Iping Common, Sussex (Keef et al., 1965) • Moor Farm, Bray (Ames, 1991-1393) • Oakhanger Site V & VII (Rankine, 1953; Rankine et al., 1960) • Redhill (Evans, 1861; Ellaby, 1987) • Sandown Park, Esher (Burchell and Frere, 1947) • Scatter C West, Three Ways Wharf (Lewis and Rackham, 2011) • Thatcham Reedbeds, Berkshire (Churchill, 1962; Wymer, 1962; Healy et al., 1992; Carter, 2001; Barton and Roberts, 2004) • Vauxhall (Symonds, 2014) • West Heath, Hampstead (Girling and Greig, 1977)	Microliths (obliquely blunted), scrapers, saws, adzes and awls.
Horsham Period	• Fairbourne Court, Harrietsham (Jacobi, 1982) • Kettlebury sites and the Lions Mouth (Ellaby, 1987; Reynier, 2002) • Longmoor Enclosure I, Hampshire (Huxtable and Jacobi, 1982) • Oakhanger Site V & VII (Rankine, 1953; Rankine et al., 1960) • Rock Common, West Sussex (Harding, 2000) • Saltwood Tunnel, Kent (Garwood, 2011)	Horsham Points (other flintwork similar to that of the Early Mesolithic).
Late Mesolithic	• Abinger Common (Leakey, 1951) • Addington (Dimbleby, 1963) • Beechbrook Wood (Cramp, 2006; Garwood, 2011) • Blick Mead (Jacques and Phillips, 2014) • Bourne Spring (Clark and Rankine, 1939) • Broom Hill, Lower Test Valley (Hey, 2010) • Confluence of Thames & Effra in Vauxhall (Cohen, 2011) • Eton, Windsor (Hey, 2010) • Farlington Marshes, Langstone (Allen and Gardiner, 2000) • Gravelly Guy, North Stoke & Goring (Hey, 2010) • Hunt’s House, Guys Hospital (Taylor-Wilson, 2002) • Hermitage Rocks, High Hurstwood (Jacobi and Tebbutt, 1981)	Scalene triangles, microburins, burins, gravers, awls, rods, adzes.

Archaeological Period	**Site(s) and References**	**Typical finds**
Late Mesolithic (continued)	• High Rocks (Money, 1960) • Jennings Yard site in Windsor (Roberts, 1993) • Lock Crescent, Kidlington (Booth, 1997) • Low Farm, Fulmer (Farley, 1978) • Lower Halstow and Perry Wood (Jacobi, 1982) • Oakhanger III, VIII & XX (Milner and Mithen, 2009) • Park Farm, Binfield (Roberts, 1993) • Rainbow Bar (Sommerville and Tetlow, 2011) • Sandway Road (Harding, 2006; Garwood, 2011) • Stonewall (Jacobi, 1982) • Streat Lane, Sussex (Butler, 2007) • Swanscombe (Jacobi, 1982) • Tilgate Wood (Clark, 1934; Rankine, 1960) • Wawcott III & Wawcott XXIII (Froom, 1976) • Woodbridge Road, Guildford and Charlwood (Bishop, 2008)	Scalene triangles, microburins, burins, gravers, awls, rods, adzes.
Potential 'persistent places' (Jones, 2013b)	• North Park Farm (Jones, 2013b) • Orchard Hill (Ellaby, 1987; Jones, 2013b) • Rookery Farm (Hooper, 1933) • Sandy Meadow (Winser, 1987)	Repeated visits across periods – variety of tools from all periods.

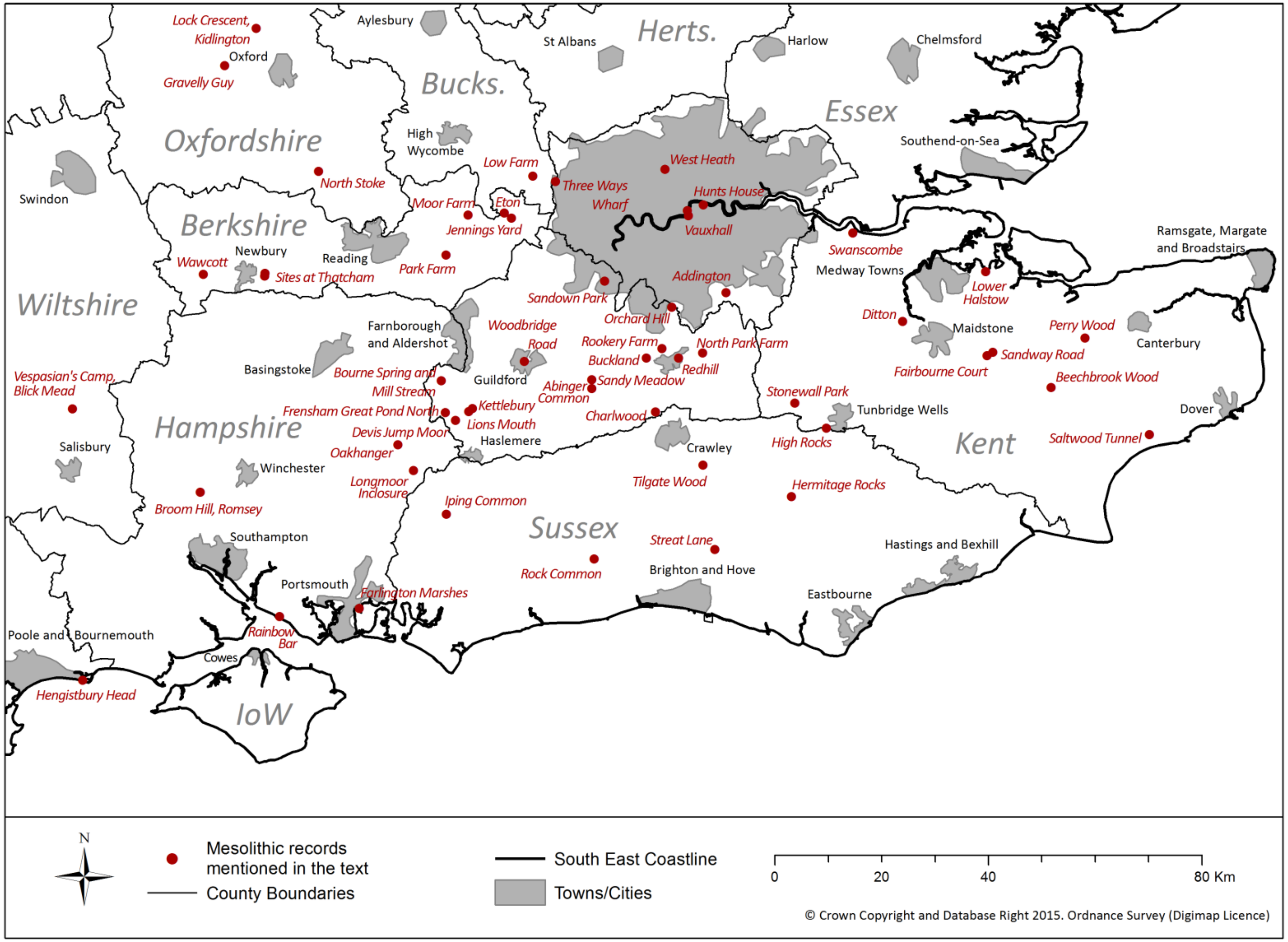


Figure 1.21. Mesolithic sites within Surrey and the southeast as discussed in the text.

The onset of the Neolithic (from ~6000 cal. BP) heralded a cultural change whereby hunting and gathering switched to a society broadly based on mobile pastoralism and sedentism. Evidence for this transition in southeast England is rare due to a lack of archaeological sites reliably dated to the end of the Mesolithic (Garwood, 2011). It appears there is no continuity across the transition, as at many Late Mesolithic sites, evidence for the Early Neolithic is very low and often absent. There are also no Late Mesolithic sites with associated pottery or evidence of animal domestication (Hey, 2010).

1.5.4. The Late Upper Palaeolithic and Mesolithic in Surrey

Surrey provides evidence of occupation from the Late Upper Palaeolithic through to the Late Mesolithic, and excellent summaries of archaeological work undertaken in the County have been published (Ellaby, 1987; Cotton, 2004). This review concerns only the most important sites that help inform on occupation patterns, activity evidence and the hunter-gather lifestyle. Surrey, in comparison to the surrounding counties and regions, has a high density of archaeological records, in addition to a number of well-excavated archaeological sites dating throughout both periods. Therefore the County is an excellent region to examine the potential interactions between humans and the environment during these periods.

Late Upper Palaeolithic evidence is observed at Wey Manor Farm in Addlestone (Jones and Cooper, 2013), Brockhill (Mills, 2012), Church Lammas (Jones et al., 2013) and the Guildford Fire Station site (Attfield et al., 2014). At Wey Manor Farm, a flint scatter of ~400 flints including Creswellian and Cheddar points, was typologically dated to ~14,000 cal. BP (Jones and Cooper, 2013). It is the earliest site found within the region and is thought to represent butchering and retooling by a hunting group (Jones, 2013c). The site of Brockhill is dated to ~13,800-12,800 cal. BP and had over 1500 lithics, including backed blades, burins and end-scrapers (Bonsall, 1977b; Bird et al., 1980). The site is one of only four open air sites with this type of assemblage in southern England (Jones, 2013a). It is thought to have been used as a short stay hunting camp with processing of large fauna and organic materials (Smith, 1924; Smith, 1925; Hooper, 1933; Cox, 1976; Bonsall, 1977a; Bonsall, 1977b; Mills, 2012). Excavations at Guildford Fire Station (Attfield et al., 2014) have identified over 5550 artefacts, including blades, scrapers and burins and Federmesser-type curved backed bi-points (Attfield et al., 2014). Church Lammas provides an excellent example of a temporary reindeer hunting camp with a long blade assemblage and reindeer and horse remains dating to the Final Upper Palaeolithic (~12,000 cal. BP). The site is chronologically and typologically similar to the site at Three Ways Wharf in Uxbridge (Lewis and Rackham, 2011; Jones et al., 2013). The discovery of long blades at Leatherhead, Brooklands, Runfold and Farnham may also indicate short butchery stays by Palaeolithic people (Jones, 2013c), and other Late Upper Palaeolithic records in Surrey are likely to represent misplaced tools during hunting forays (Jones, 2013c). With the relatively high level of Late Upper Palaeolithic activity within Surrey, it is possible that these people may have been interacting with the natural environment, potentially burning or manipulating their surroundings to assist with hunting and gathering. Unfortunately due to a lack of Late Glacial palaeoenvironmental records, an understanding of the vegetation at the time of these Late Upper Palaeolithic sites is hard to ascertain.

Mesolithic activity is well documented across the County, but there is a distinct lack of undisturbed single phase sites (Cotton, 2004). There also appears to be a lack of sites identified in the northwest of the country, and there is the potential that sites may have been chosen due to particular environmental or cultural factors. Early Mesolithic sites include Frensham Great Pond North (Rankine, 1949a) and South (Rankine, 1949b), where a number of obliquely backed points were discovered, in addition to a Portland Chert blade, interpreted as evidence of a widespread exchange network. Obliquely backed points and other period-diagnostic flints have also been discovered from Sandown Park in Esher (Burchell and Frere, 1947), Buckland (Ellaby, 1987) and in Redhill (Evans, 1861; Ellaby, 1987). There are also a large number of Early Mesolithic findspots across the County (Wessex Archaeology and Jacobi, 2014), possibly representing lost items during hunting forays or evidence of sites yet to be excavated. The flint assemblages suggest, in general, that spears would have been the primary hunting weapon amidst a *Pinus* and *Betula* woodland (Ellaby, 1987).

Horsham sites are defined by the presence of class 10 microliths which have distinctive basal retouching (Tolan-Smith, 2008), often represented within assemblages that have a distinctly Early Mesolithic appearance. Horsham-type evidence is observed at the Kettlebury sites and the Lions Mouth on Hankley Common and Devil's Jumps Moor (Ellaby, 1987). Kettlebury (Reynier, 2002) has one of the largest Horsham collections in the southeast, and was likely to have been a re-tooling station (Reynier, 2002) with activity radiocarbon dated to ~9500-8500 cal. BP (Gillespie et al., 1985; Reynier, 1998). The presence of Horsham points and the decreasing size of microliths relative to the Early Mesolithic may imply a higher reliance on using bows for hunting, as the forest became denser with the expansion of *Quercus* and *Ulmus* (Ellaby, 1987). This increasing density of forest and woodland appears to indicate that Mesolithic groups were not clearing areas of woodland but rather altering their tool technology to overcome developments in the natural environment. This could be further understood through the analysis of new palaeoenvironmental records.

Later Mesolithic sites are identified through developments in microlith shapes, the loss of scrapers and saws, and the occurrence of sites found in or near pits (Cotton, 2004). Woodbridge Road, Guildford (Bishop, 2008), OSL dated to ~7700 cal. BP, suggests flintworking around a number of hearths. The site may have been repeatedly visited by small groups engaging in specific tasks (Bishop, 2008). Pits at Bourne Spring (Clark and Rankine, 1939) and Abinger Common (Leakey, 1951) were identified alongside large flint assemblages. The Farnham pits may have resulted from flint quarrying and the pit at Abinger may be Neolithic, with Mesolithic flints washed into the pit at a later date (Ellaby, 1987). They may also be tree throw pits, which may have been incorporated into a rudimentary shelter if they were present during the period of Mesolithic activity (Evans et al., 1999). Charlwood, Surrey (Ellaby, 2004) is dated to ~7300-6700 cal. BP and over 21,000 pieces of débitage and tools were found in a pit enclosure setting. Pits at both Charlwood and Woodbridge Road appear to be contemporaneous to occupation, and were excavated around working and living areas (Bishop, 2008).

In addition to these Early or Late Mesolithic sites, the notion of ‘persistent places’ (Jones, 2013b) has been put forward for the North Park Farm site at Bletchingley, as evidence indicates repeated visits throughout the Early to Late Mesolithic. The North Park Farm site extends over more than 1 hectare, with 12 hearths, 1 million pieces of débitage, 17,000 microliths and 13 radiocarbon dates to place the site in its chronological context (Jones, 2013b). Early Mesolithic activity was likely to be short term to replenish hunting toolkits, although some evidence exists for butchery and hide processing. The Late Mesolithic witnessed an intensification in usage of the site, with evidence for microlith and adze production, maintenance and discard of tools (Jones, 2013b). Macrobotanical analysis suggests *Quercus* was important from ~9400 cal. BP, potentially being targeted as a slow burning fuel wood (Farr, 2013), with *Corylus* potentially indicative of food refuse, although amounts were low compared to other sites (Jones, 2013b). Persistent places have also been observed at Sandy Meadow (Winser, 1987), Rookery Farm (Hooper, 1933), Bourne Mill stream (Rankine, 1936) and Orchard Hill (Ellaby, 1987; Jones, 2013b). The potential long term occupation of these areas may have led to a greater interaction with the local environment rather than a passing through signal or brief hunting foray. To identify the possibility of this prolonged interaction, further palaeoenvironmental data spanning large periods of the Mesolithic are required.

In addition to these sites, numerous records have been discovered through organised groups and personal collectors. These records are often un-stratified, discovered as surface findspots and scatters, or through fieldwalking. These records are integrated into the countywide database, with their significance and distribution investigated through spatial analysis.

1.5.5. Human and Animal Interaction with the Environment

Environmental evidence has shown the nature of vegetation development set against climate change, but it is also important to consider the potential impact of humans on the environment. Some evidence exists to show that Mesolithic people were interacting with and modifying the woodland, but very little evidence exists from Late Upper Palaeolithic contexts, not assisted through a lack of palaeoenvironmental records dating to this period.

A considerable body of evidence for human activity on the environment during the Early Mesolithic is provided by sites within the wetland/dryland interface, which was clearly an important area for Mesolithic people. This is best shown at the site of Star Carr, where during the Mesolithic period, the site was situated at the edge of a lake (Conneller et al., 2012). Evidence for wooden platforms situated within the lake appear to have been used for assisting with movement across the wetland, and may have been landing places for boats (Conneller et al., 2012). There is also evidence for the modification of the vegetation around the lake edge through the use of burning, where burning is identified from 12,000 cal. BP and continued throughout the Mesolithic (Mellars and Dark, 1998). This was recorded at a time when the local woodland had developed into dense mixed deciduous woodland, and may have been less attractive to hunting. This burning therefore may have been in order to keep the reedswamp (and lake) open and stop the encroachment of trees, so that animals would continue to visit the site (Mellars and Dark, 1998). Other countries in northwest Europe also provide evidence for the importance of this wetland/dryland interface, with records indicating the use of wooden boats, skis and fish traps (Conneller et al., 2012). The Early Mesolithic sites at Thatcham and Woolhampton, both situated on the River Kennet, provide evidence for local fires within wetland interface contexts within the southeast. At these sites there is evidence for wetland herb, Poaceae and woodland burning across both the wetland and dryland zones. These fires led to a decrease in *Pinus*, and herbaceous taxa increase, attributed to Mesolithic groups expanding into natural clearings and manipulating their shape and size (Chisham, 2004), a similar behaviour to that thought to have potentially been practiced since the Neanderthals (Roebroeks and Bakels, 2014). The lack of observed impact of burning on *Corylus* and *Betula* has been attributed to targeting of specific species during burning, with *Corylus* potentially being utilised as a food source (Chisham, 2004). As occurred at Star Carr, clearings at the wetland/dryland edge may have been created in order to attract game for hunting. Further palaeomicrocharcoal records would be useful in further understanding the relationship between fire, the wetland/dryland zones and human activities during the Late Upper Palaeolithic and Mesolithic.

Evidence for Late Mesolithic anthropogenic activity is predominantly found in upland contexts, such as Dartmoor (Caseldine and Maguire, 1986), the North York Moors (Innes et al., 2010) and The Pennines (Innes and Blackford, 2003). Within the southeast, a Late Mesolithic *Alnus* rise such as at Cranes Moor (Barber and Clark, 1987), Runnymede Place (Scaife, 2000a) and Elstead Bog (Farr, 2008) may be linked to human activity (Smith, 1970), however, the distribution and nature of local archaeological evidence suggest that the rises are not associated with abundant Mesolithic activity (Simmons, 1994). There is therefore a need for new palaeoenvironmental evidence situated near archaeological important regions to examine this *Alnus* rise in greater detail.

In addition to humans, the Vera Hypothesis (Vera, 2000) proposes that large herbivores would have had a substantial ecological effect on the landscape, leading to fragmented forest and grassland. This is based on the presence of trees with light demanding seedlings, such as *Quercus* and *Corylus*, indicating large herbivores were causing and maintaining woodland openness (Groves et al., 2012). Previous studies have not shown much evidence to support the Vera Hypothesis during the Early Holocene, primarily due to the abundance and prolonged dominance of *Pinus*. *Pinus* is highly prone to browsing and would not be expected to have lasted so far into the Holocene if herds of large herbivores were active within the forests (Scott et al., 2000; Palmer and Truscott, 2003; Groves et al., 2012). Within Surrey, a greater spatial spread of sites is required in order to adequately understand the nature of clearings within the woodland cover. The establishment of *Tilia*, a shade tolerant taxa, would also be highly vulnerable to bark stripping and not expected to survive if large herbivores were present (Groves et al., 2012). The impact of both humans and animals will be examined and discussed in Chapter 9.

1.6. Current Issues with Existing Palaeoenvironmental and Archaeological Evidence

Through this review of the archaeological and palaeoenvironmental work undertaken to date within Surrey and the southeast, it is evident that a range of sites have been analysed, providing an understanding of Late Glacial and Early Holocene environmental history and human activities, primarily based upon pollen analysis. However, through the assessment of the records from the southeast, it is clear that there are several areas where our knowledge and understanding of environmental and climate history, and human activities, can be improved:

- Surrey has a large range of Mesolithic records, and a relatively high number of Late Upper Palaeolithic records. It is not currently understood whether there is any relationship between these records, and what the spatial patterning is like across the County. Are there areas where no records are found, or where more records than expected were found? This is important to define as it helps to identify both preferential sampling in the present day or actual settlement patterns and choices during the Late Upper Palaeolithic and Mesolithic.
- Many archaeological records are defined within broad chronological periods, explicitly the Late Upper Palaeolithic or Mesolithic. Through the use of chronologically restrictive periods, including the Creswellian, Final Palaeolithic, Terminal Upper Palaeolithic, Early Mesolithic, Horsham and Late Mesolithic, a greater understanding of when people were present in the landscape can be obtained. This is by no means an ideal chronology, however the nature of the material present at these archaeological sites rarely allows for higher chronological certainty.
- Many of the archaeological sites within Surrey have not been evaluated in respect to both their landscape and environmental characteristics. Work to address this had started in Surrey (Farr, 2008), and there is evidence to suggest that the environment may have influenced site location, however the discovery of many new archaeological sites means that this needs further development. Knowledge of where people were likely to be active within the landscape is important when looking for evidence of how and if people interacted with the vegetation.
- There is also a paucity of information on human interactions with the vegetation cover during both the Late Upper Palaeolithic and Mesolithic. Although a number of palaeoenvironmental records have been studied, they have often not been assessed in both their environmental and archaeological contexts in order to ascertain whether observed changes were due to anthropogenic or climatic factors. Evidence exists for

the use of wetland/dryland interface zones by humans during this time, and therefore these wetland palaeoenvironmental records offer an ideal opportunity to examine the potential interactions between humans and the environment.

- In addition to this, relatively few sites have analysed micro-charcoal. The analysis of micro-charcoal is important as it allows for the fire-history of a site to be examined, and should be assessed alongside palynological work for all sites as it can provide information on both the palaeoenvironment and potential anthropogenic activity. This is especially important in the southeast due to the potential use of fire for clearance of *Pinus* woodland as observed at Thatcham (Chisham, 2004).
- A lack of sites dating to the Late Glacial period, including both the Lateglacial Interstadial and the Loch Lomond Stadial has made understanding vegetation change difficult, often made harder as some of the records dating to this period are also poorly dated. This means it is hard to understand vegetation change on a regional scale, and difficult to tie the information into both the chronological and archaeological timescale. This also means that there is little information available on how vegetation changed as the climate deteriorated during the Loch Lomond Stadial.
- Although there are more palaeoenvironmental records dating to the Early Holocene than the preceding Late Glacial, there is still relatively sparse evidence for periods of Rapid Climate Change, including the 9000-8000 cal. BP period and the 8.2 Kya event. These events modified the climatic conditions, however it would appear that there was only a small reaction, if at all, to this climatic change within the vegetation record. The analysis of sites will help to examine this further, although it is important that these sites are robustly dated with a strong radiocarbon chronology. Those sites that are well dated are able to provide much higher levels of information on the timing of particular events and also enable further integration of the palaeoenvironmental record with dated archaeological remains.
- A number of species have shown trends that differ to earlier research across Britain. This includes both the early presence of *Alnus* in North London, and the prolonged occurrence of *Pinus* at Bagshot. However, due to the low number of palaeoenvironmental sites dating to this period, it is hard to understand whether these changes are indicative of wider regional development or very local occurrences. Surrey provides an ideal location for examining a number of identified vegetation changes due to both the location and the geology of the County.

1.7. Aims, Hypotheses and Objectives

The following aims were designed to increase the knowledge of: (1) the palaeoenvironmental history across the Late Glacial and Early Holocene in Surrey, and (2) understand how Late Upper Palaeolithic and Mesolithic groups interacted with the vegetation and environment:

1. Understand where Late Upper Palaeolithic and Mesolithic people may have been present in the landscape.
2. Reconstruct the palaeoenvironmental history of Surrey during the Late Glacial and Early Holocene.
3. Quantify the impact that Late Upper Palaeolithic and Mesolithic groups had on the vegetation cover during the Late Glacial and Early Holocene.
4. Assess the potential that lowland wetland sequences have for providing information on palaeoenvironmental history and cultural impacts

Based upon the modern day understanding of palaeoecological and archaeological data from Surrey and southern England, the following hypotheses were proposed for the palaeoecological history of Surrey and the potential interactions between humans and their environment. In each case a null hypothesis (H_0), the default position to be tested against the evidence, is provided alongside a competing, alternative hypothesis (H_1):

Hypothesis 1: H_0 – Late Upper Palaeolithic and Mesolithic archaeological finds are evenly distributed across the County.

H_1 – Late Upper Palaeolithic and Mesolithic archaeological finds are not distributed evenly across the County.

Hypothesis 2: H_0 – The environmental characteristics of Surrey had no relationship with findspot locations.

H_1 – There is a relationship between the environmental characteristics of Surrey and archaeological findspots.

Hypothesis 3: H_0 – No evidence for the Loch Lomond Stadial is provided from lowland wetland proxy records in Surrey.

H_1 – There is evidence for the Loch Lomond Stadial from lowland wetland proxy records in Surrey.

Hypothesis 4: H_0 – Records from lowland wetland sites in Surrey do not provide evidence for rapid climate changes during the Holocene.

H_1 – Holocene rapid climate changes are observed in the records from lowland wetland sites in Surrey.

Hypothesis 5: H_0 – Based on evidence from lowland wetlands and the archaeological record, there is no indication for human activity with their environment during the Late Upper Palaeolithic or Mesolithic periods.

H_1 – The evidence from lowland wetlands and the archaeological record does indicate human activity with the environment during the Late Upper Palaeolithic or Mesolithic.

Hypothesis 6: H_0 – Lowland wetland sites in Surrey do not provide sequences that are significant due to their cultural and palaeoenvironmental importance, or under threat of destruction or degradation.

H_1 – Lowland wetland sites in Surrey provide sequences that are of significant palaeoenvironmental and cultural importance, or are under potential threat of destruction or degradation.

To accomplish these aims and test the hypotheses, the following objectives were created:

1. Collate existing catalogues of Late Upper Palaeolithic and Mesolithic archaeology.
2. Quantitatively and qualitatively examine relationships between archaeological sites and their environmental settings.
3. Identify sites suitable for palaeoenvironmental reconstruction.
4. Classify intensity of Mesolithic activity around potential palaeoenvironmental sites.
5. Undertake field-based investigations to collect and analyse palaeoenvironmental samples from chosen sites and ascertain the age of the sediments.
6. Create a temporal framework through the use of radiocarbon dating.
7. Use laboratory investigations to reconstruct the palaeoenvironment and identify evidence for human impact on the landscape at the dryland-wetland interface.
8. Evaluate the potential for using isotope analysis to reconstruct climate change.
9. Create criteria, based on the lowland wetlands used in the research, to evaluate the significance and threat to the lowland wetland sites examined during this research.

1.8. Outline of the Thesis

This chapter has introduced the archaeological activity across southeast England and the climatic and environmental backdrop to this archaeological record, in addition to the aims, objectives and hypotheses. The following chapters examine the aims and objectives through analysis of archaeological and environmental archives. Chapters 2 & 3 look at the creation, implementation, and results of the archaeological data synthesis and predictive modelling. Field methods and a detailed County-wide site search are presented in chapter 4. Chapter 5 highlights the rationale and methodology behind the laboratory methods employed within the study. Results and the interpretation of field and laboratory investigations are presented in chapters 6 (Langshot Bog), 7 (Thursley and Ockley Bog) and 8 (Elstead Bog B). Chapter 9 discusses the results from both the archaeological and environmental work specific to Surrey, and in a wider context. Chapter 10 details the potential significance of, and threat to, wetland and waterlogged archaeological and environmental sites through the development of a significance and threat classification system. Chapter 11 presents the conclusions of the research and looks at how it can be developed and built upon through further study.

2. Methodology for Analysing the Late Upper Palaeolithic and Mesolithic Resource in Surrey

2.1. Introduction

This chapter outlines the methodology behind the creation of an archaeological database for Surrey and the southeast, how the database can be interrogated to improve our knowledge and understanding of the cultural history, and its use in conjunction with the palaeoenvironmental archive available in Surrey. Archaeological data are available in numerous formats and collated across a wide range of sources, and the methodology for their standardisation and cataloguing is presented. This includes the collation and tabulation of all the Late Upper Palaeolithic and Mesolithic records present within Surrey, and neighbouring counties of Hampshire, East and West Sussex, Kent, Berkshire and Greater London.

The methods for using geographical information systems (GIS) to graphically present and analyse both spatial and non-spatial data and for creating archaeological predictive models are also provided. The archaeological database allows for a quantification of the known archaeological resource and the development of a GIS model allows for both the spatial and non-spatial elements of this database to be queried. This allows for the examination of both modern day visibility of archaeology and identification of hotspots of archaeological activity (Lake et al., 1998; Wheatley and Gillings, 2000). The models are explicitly designed to examine relationships between archaeological remains and their environmental settings and predict areas where archaeological remains may be found. This is achieved through the combination of archaeological records, topographical variables and environmental settings with the aim of creating a predictive distribution map highlighting potential archaeological discovery areas. Both the spread of present day archaeological remains and the results of the predictive models will help to understand the distribution of prehistoric people in the landscape and recognize factors that have led to site visibility and preservation. The knowledge of where people were, or were likely to be, present in the landscape, alongside records of vegetation change, can help to determine whether observed shifts in vegetation cover may have been caused by natural vegetation succession or human modification of the environment. This is important when attempting to place the records derived from the lowland wetland sites into both their archaeological and palaeoenvironmental context.

2.2. Cataloguing Archaeological Information

Complete current catalogues of Late Upper Palaeolithic and Mesolithic archaeology were not available from a single resource; instead a number of potential sources that hold information on archaeological finds had to be consulted:

- Historic Environment Records (HER)
- Gazetteer of Mesolithic sites in England and Wales with a gazetteer of Upper Palaeolithic sites in England and Wales (Wymer and Bonsall, 1977)
- Grey Literature
- Palaeolithic and Mesolithic Lithic Artefact (PaMELA) database (Wessex Archaeology and Jacobi, 2014)

For the Surrey database, the primary focus of the research, the data were complete and up to date as of April 2013 based on the sources listed above. Museum accession records were not consulted, as much of these data were present in the HER (Tony Howe, Surrey County Council, pers. comm.) and based on his experience, it was considered that any absences would not have been detrimental to the overall study. For the surrounding counties, Hampshire, East and West Sussex, Kent, Berkshire and Greater London, the approach adopted in this research was less intensive, consulting only the HER. This was considered acceptable because these counties were not the primary focus of this investigation, and this method provided an accepted level of information based on the proportional dominance of HER data. The HER includes information on historic buildings, important landscapes and historic artefacts, including spatial information (often a OS grid reference), and non-spatial information such as artefact type, age estimate and a description. Separate HERs exist for most Unitary Authorities in England and a large amount of variation exists between each individual database. This is a result of both differing standards between HERs (such as the Kent HER supplying grid references in OS format, and the Surrey HER using northings and eastings) and also varying recording types across time.

The HER for Surrey in April 2013 did not include any records from 2011-2013. Reports for these years were contained within grey literature documents held at the Surrey History Centre in Woking. If any of those reports provided evidence for Late Upper Palaeolithic or Mesolithic archaeology they were subsequently included in the dataset. The Gazetteer (Wymer and Bonsall, 1977) is a record of all Late Upper Palaeolithic and Mesolithic finds in the country and associated information, essentially an early countrywide HER. The majority of the Gazetteer records matched HER records and provided additional or new information, therefore leaving a minority of unique records. These were excluded from the HER dataset and tabulated as new separate records. These HER and Gazetteer sources were subsequently collated and the resulting database included all of the Late Upper Palaeolithic and Mesolithic records from across the County of Surrey. An arbitrary cut-off date of April 2013 was applied, to ensure the dataset remained consistent throughout the study. A secondary dataset included all the surrounding counties' HER results. The PaMELA database (collated for Surrey only) was based on Roger Jacobi's personal examination of a wide array of Late Upper Palaeolithic and Mesolithic flints, often with a greater emphasis on specific tool types and potential tool dates (Wessex Archaeology and Jacobi, 2014). This was a separate dataset, due to the differing site information contained within the Jacobi archive.

2.2.1. Nomenclature and rationale for data standardisation

The dataset compiled from the HER, grey literature and the Gazetteer contained a variety of formats that did not correlate between records. A rationale for the process of data standardisation was employed to solve this issue. In order to begin standardisation, data from all counties was assimilated and consulted to examine the differences between the amounts of information supplied. This led to the creation of a number of standard categories with the majority of HER datasets providing information (Table 2.1). An example of the tabulated data can be found in Table 2.2.

Table 2.1. Categories included within the Surrey and southeast datasets.

Category	**Explanation**
HER Number	Number given to record by County HER
Site Name	Name of site or local settlement
Monument Type	Closed answer category: *Findspot/Small Lithic Scatter/Large Lithic Scatter/Undefined Lithic Scatter/Lithic Working Site/Occupation Site/Unspecified* Monument types primarily designated on the English Heritage Monument Type Thesaurus (Heritage, 1999) and the nature of the Surrey HER dataset: • Findspot – Points where only one artefact is present. Often records approximate location of stray finds. • Small Lithic Scatter – Scatters with less than 20 pieces of lithic material. A lithic scatter is a spatially discrete spread of surface artefacts. Often not recovered from archaeological contexts. • Large Lithic Scatter – Includes 20 or greater pieces of lithic material. • Undefined Lithic Scatter – The amount of material at the lithic scatter is not known but is greater than one. • Lithic Working Site – Locations where there is evidence for working

	of tools. Locations often have large quantities of débitage and associated material. o Includes terms: Chipping Floor, Flint Knapping Site, Flint Working Site and Knapping Site. • Occupation Site – Sites with evidence for occupation and may have evidence of burning. May be short or long lived sites. • Unspecified – no information is known about finds. These could be further classified and organised into a number of groups that have not been included here. However, it is felt that within the scope of this study, these groups helpfully categorise the nature of the Late Upper Palaeolithic and Mesolithic assemblages across the County. A number of records have been modified from their original HER Monument type and reclassified within the framework used in this study when there appeared to be no justification for their original classification.
Archaeological Period	Broad archaeological classification. Category required when disseminating between Mesolithic and Palaeolithic data.
Easting	The numerical easting (X) coordinate for a feature.
Northing	The numerical northing (Y) coordinate for a feature.
Details	Lists finds related to the record.
Quantity of Material	Closed answer category: *One Piece/ Single Figure / Tens / Hundreds / Thousands / Unspecified* These classes will allow for the spatial representation of how much archaeology is present within a landscape, not just the basic presence of archaeology.
Site Specific Details: *Evidence for:* Burning Cores and Manufacturing Debris Microliths and Points Axes, Maceheads and Sharpening Flakes Scrapers, Gravers and Other Pieces	Closed answer category: *Yes/No/Unspecified* The site specific categories are only looking for the presence/absence of each type of find at each site, and therefore they are a yes/no response, with unspecified used for those records that have no detailed information. These categories were chosen as they enable quick identification of a number of different types of record. Increasing categories would have led to unnecessary complication within the database when trying to look at trends. Shows if there was any evidence for burning at the record spot. Includes records with any mention of Hearths, Burning, Charcoal, Burnt Flint etc. Indicates presence of these tools at the record spot. Identifies locations of where tools may have been being produced (Butler, 2005). Indicates presence at the record spot. Microliths and points may indicate the potential occurrence of hunting at the findspot (Crombé et al., 2001). Indicates presence of these tools at the record spot. These are tools that may have been used for a variety of uses, including woodland clearance, woodworking, hammering and digging (Butler, 2005). Indicates presence of these tools at the record spot. Other pieces include flints such as burins. This group may represent site activities, such as the preparation and cleaning of animal hide and/or food preparation and the engraving of antler (Berridge and Roberts, 1986).
How were the finds	Closed answer category*: Chance Find/Fieldwalking/Archaeological*

found	*Investigation/Development Led Archaeology/Industrial Activity/Unspecified* • Chance Find – found by individuals and reported as an individual or small collection of finds. • Fieldwalking – organised activity with the aim of identifying surface lithics and frequently defined within the archaeological records. • Archaeological Investigation – investigation undertaken by archaeological groups in the absence of development or other external influences. • Development Led Archaeology – archaeological investigations undertaken as a result of the development process including watching briefs. • Industrial Activity – finds found during routine industrial activity e.g. quarrying. • Unspecified – no indication on how the finds were discovered. Method of discovery is important when considering the distribution of the sites. Helps to determine if the distribution is accurate, or if there areas have been under- or over-investigated.
Extra Information	Text field indicating any further information as supplied by the HER.
Source (If Cited)	Indication of the publication source if cited by the HER.

Table 2.2. Tabulated example of the HER data in the format used within this study.

HER Number	**Site Name**	**Monument Type**	**Archaeological Period**	**Easting**	**Northing**
2762	Old Jackmans Nursery, Woking	Findspot	Mesolithic	499620	156970

Details	**Quantity of Material**	***Evidence for Burning***	***Cores + Manufacturing Debris***	***Microliths and Points***	***Axes, Picks Maceheads, and Sharpening Flakes***
1 Tranchet Axe.	One piece	No	No	No	Yes

Scrapers, Gravers and Other Pieces	**How Were Finds Found?**	**Extra Information**	**Source (If Cited)**
No	Chance Find	The axe is of mottled grey unpatinated flint.	Surrey Archaeological Collections, Volume 64.

2.3. Other sources of Mesolithic Data

The PaMELA database differed in a number of ways to both the Gazetteer (Wymer and Bonsall, 1977) and local HERs, as there was often greater detail on specific tool types such as individual microlith typology. The primary reason this database differed to the HER database was the temporal data linked to many of the records, meaning the archive was an excellent resource for assessing both the spatial and temporal patterning of Late Upper Palaeolithic and Mesolithic archaeology across the County. The temporal framework was based on the use of diagnostic flints (typology) as a method for determining the age of records (Figure 2.1). In order to understand how these diagnostic flints fit within a chronological framework, it is invaluable that diagnostic flint types were cross referenced with independent dating methods from the same site, allowing them to be placed into an independent chronological context. This has occurred at a number of Late Upper Palaeolithic and Mesolithic sites (Mellars and Dark, 1998). Other occurrences of specific flint types can then be assigned their respective age. These typological definitions were subsequently placed into the Late Upper Palaeolithic and Mesolithic archaeological terminology framework used within this study. This included the PaMELA use of a 'Middle Mesolithic' phase being re-classified as the Horsham Period, as it was based primarily on the presence of type 10 microliths, including the Horsham Point (Butler, 2005). It is important to acknowledge that often a simple Early/Late Mesolithic distinction is used (Milner and Mithen, 2009), and the Horsham Period has been considered a southeastern regional variant of the Early Mesolithic (10,350-9700 cal. BP) (Reynier, 1998; Tolan-Smith, 2008).

Unfortunately, the PaMELA archive was not directly comparable to the HER database created for this project. The archive was primarily derived from the observation of museum collections by Roger Jacobi, and was not kept fully up to date after 1977 (Wessex Archaeology and Jacobi, 2014). The data from the PaMELA archive were not integrated with the HER data but used as a separate dataset. This facilitated its use for testing the predictive model derived from the HER data because it provided an independent record of Mesolithic activity across the County. The PaMELA archive was downloaded and a database detailing the relevant Surrey records created. This database had the primary function of identifying typologically dated artefacts and therefore excluded detailed information about all the identified lithics associated with specific records. The Surrey PaMELA database categories are detailed in Table 2.3 and an example of the collated data are displayed in Table 2.4.

Table 2.3. Categories included within the Surrey PaMELA dataset.

Category	Explanation
PaMELA Number	Number given to record by the PaMELA database
Site Name	Name of site or local settlement
Chronology	Closed answer category: *(see list below for closed answers)* The PaMELA archive has categorised a series of type fossils allowing for a broad dating scheme to be applied to different tool types. The type fossils as defined by Wessex Archaeology (Wessex Archaeology and Jacobi, 2014) are: • *Early Upper Palaeolithic** – leaf points, blade points • *Aurignacian** – nosed scrapers, busked burins • *Gravettian** – Font-Robert points • *Creswellian* – bi-truncated trapezoidal backed blades (Cheddar Points), obliquely-truncated backed blades (Creswell Points) • *Late Upper Palaeolithic* – shouldered points, Zinken • *Final Upper Palaeolithic* – penknife points, convex-backed blades • *Terminal Upper Palaeolithic* – long blades, bruised blades, Brancaster cores • *Early Mesolithic* – type 1, 2, 3, 4 microliths; tranchet axes and adzes • *Middle Mesolithic* – type 10 microliths • *Late Mesolithic* – type 5, 6, 7, 8, 9, 11, 12, 13 microliths * outside the remit of this study
Easting	The numerical easting (X) coordinate for a feature.
Northing	The numerical northing (Y) coordinate for a feature.
Accuracy	Closed answer category: *General/Accurate/Close/No Information* A text based measure of how accurate the given easting and northing coordinates are. No further definitions were provided for these categories.
Precision	Closed answer category: *1000/100/10/No Information* A numerical measure of the easting and northing coordinates precision. Therefore a coordinate with 100 precision was recorded as an 8 digit easting/northing.
General Typology	Closed answer category: *Débitage/Retouched Tool Débitage/Retouched Tools/Cores/Core Tools* Five major groupings of lithic finds. Highest and first level of PaMELA classification providing the ability to analyse the database broadly.
Typological Flints	Open answer category Taken from the second or third tier of the PaMELA classification system. Details flints found at the site that could be reliably identified. Many were standardised by PaMELA using published typologies. For examples see Figure 2.1.

Table 2.4. Example of the PaMELA dataset.

PaMELA Number	Site Name	Chronology	Easting	Northing
9423	Caesars Camp Site V	Early and Late Mesolithic	483500	150000

Accuracy	Precision	General Typology	Typological Flints
Close	100	Retouched Tool	Tranchet Axe and 12 x obliquely blunted points. Class 7a2PB with elongated tail Class 7a1, small Class G2a1 tanged point Class C2 with elongated tail.

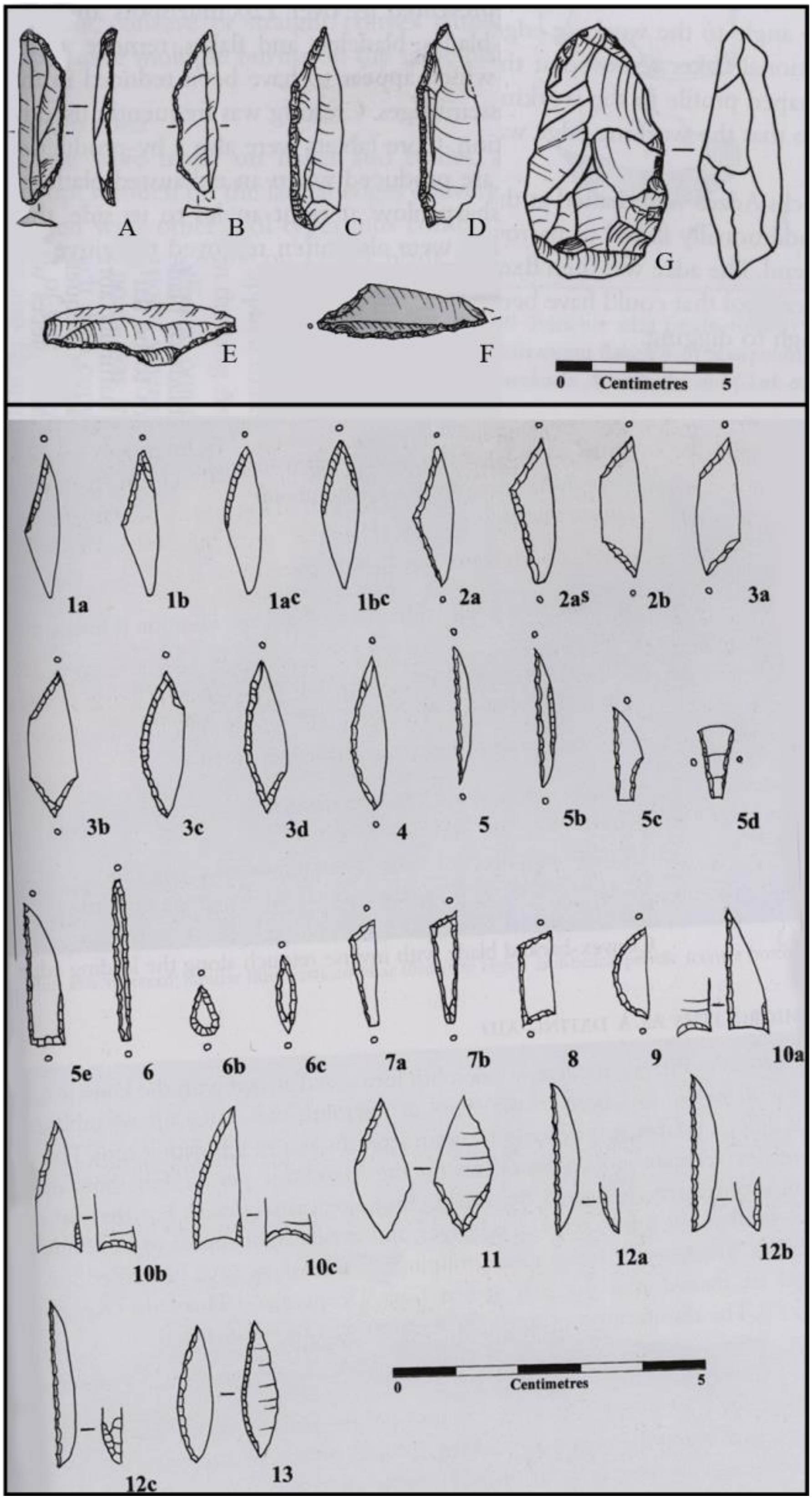


Figure 2.1. Selected typological flints. A & B: Cheddar Points, C & D: Creswellian Points, E: Shouldered Point, F: Penknife Point, G: Tranchet Adze. 1-13: Jacobi's classification of various microliths (After Butler, 2005: fig. 28: pg. 77; fig. 29: pg. 80, fig. 36: pg. 95 and fig. 41: pg. 104).

2.4. Late Upper Palaeolithic and Mesolithic Activity, and the Environment

It is important to recognise that the distribution of archaeology across Surrey reflects both past and present geological and archaeological taphonomic processes. A number of environmental variables were identified as being important in the decision making process of Mesolithic groups when interacting with the landscape. This is thought to be derived from the interaction of past populations with both social and environmental factors (Mithen, 1988), therefore it is important that both archaeological distribution patterns and the environmental variables are analysed (Warren and Asch, 2000; Lock and Harris, 2006). In Late Upper Palaeolithic and Mesolithic landscapes, a number of environmental factors can influence the distribution of human activities leaving a material trace (Kvamme and Jochim, 1990):

- Topography, in the form of elevation (Kvamme, 1985; Kvamme and Jochim, 1990; Brandt et al., 1992; Kvamme, 1992), has often been cited as a major determining factor in site location for hunter gatherer groups. It often governs viewpoints and access to local resources, with settlements located on higher elevation ridge tops, rather than within valley bottoms (Kvamme and Jochim, 1990), although this can be dependent on the nature and duration of the settlement.
- Hydrology is frequently identified as important in respect to the positioning of Mesolithic sites (Kvamme and Jochim, 1990; Brandt et al., 1992; Kvamme, 1992) and it is understandable that Mesolithic communities would have wanted to be in close locality to permanent or semi-permanent rivers and streams, lakes and springs. Subcategories include both the horizontal and vertical distance to streams and the distance to a stream of Strahler third order or greater (Kvamme and Jochim, 1990). The general hydrological conditions, effectively a location's ability to collect and hold water, are also important. Wettest areas may be unsuitable for site locations but wet/dry boundary zones may provide ideal conditions. This is measured through the TOPMODEL principle of water flow across a catchment (Beven and Kirkby, 1979).
- Slope angles are important, as sites are likely to have been situated upon relatively level ground (Kvamme, 1992). Activities would have occurred on relatively level surfaces where steep slopes do not inhibit tasks (Kvamme and Jochim, 1990). Slope can also affect soil type and surface vegetation (Farr, 2008) and the degree of exposure.

- Aspect has been shown to be important (Kvamme and Jochim, 1990; Brandt et al., 1992), with a major split between south and north facing sites. Higher amounts of solar radiation would be received by southern facing sites in the northern hemisphere, which may provide a preferable microclimate for settlement (Farr, 2008).
- Geology has often been used to form the basis of further maps, such as vegetation cover or varying landform proxies, frequently due to soil type being an overriding factor in site location (Farr, 2008). However, within Surrey, it has been shown that the geology itself may be a major determining factor of site location due to preferential conditions offered by particular geological substrates (Mellars and Reinhardt, 1978).
- Distance to specific natural resources, such as the clay with flint and Greensand would have been important (Barton, 2009). The North Downs have extensive clay-with-flint outcrops (Field, 1998), with nodules of flint of various sizes and amounts of weathering available on the surface (Gallois, 1965). The locations of these outcrops are significant as the time taken to travel to and from these locations of natural resources may have been important in determining settlement location (Barton and Roberts, 2004). The extensive Greensand geological units tract across southeast England, including Kent, Surrey, Hampshire and both East and West Sussex (Gallois, 1965). The Greensand is associated with some of the most substantial Mesolithic assemblages in the County (Rankine, 1956). Clasts of ferruginous sandstone can also be found within the Greensand, and were often utilised as hearths within the Mesolithic period (Jones, 2013b).

Soil maps were not used due to major disparities between modern soil data and their archaeological equivalents (Bell and Walker, 2005). This is an issue as it is not fully understood how climate, vegetation, hydrology and human activity affect soil development over time (Canti, 1992). At Holywell Coombe in Kent, Lateglacial soils supporting a woodland landscape were modified by the removal of this woodland during the Bronze Age, resulting in soil erosion and subsequent colluviation (Preece and Bridgland, 1999; Bell and Walker, 2005). This led to a heavily modified soil and the process is noted at many other sites across the country (Preece and Bridgland, 1999).

Through utilising the environmental variables above, an indication of where Mesolithic groups may have been active within the landscape was developed. Combining these variables led to a predictive map of potential distribution of Mesolithic activity across the landscape.

Through the addition of two modern variables, land cover type, and the distance to roads, paths and tracks modern day archaeological visibility could be examined within the model. These two variables meant that the present day location of artefacts were taken into consideration, and created a predictive model that examined the potential for finding archaeological material. Both models were created and analysed independently.

2.4.1. Analysing Relationships between Archaeology and the Environment

In order to examine links between the archaeological datasets and the environmental variables, statistical tests were used to determine whether a significant relationship exists between them, or whether the observed patterning within the archaeological dataset could be explained by chance. To achieve this, the Chi-Square goodness-of-fit test was used. This test is used when examining a sample set to see if its observed distribution differs from that of its expected distribution. The chi-square test has a number of assumptions (Sheskin, 2003):

- Nominal or categorical data with frequencies must be used for analysis and each observed record is only counted once.
- Data represents a random sample of independent observations.
- Expected frequencies in each category are greater than 5.
  - If the expected frequency is less than 5 the test may not fully explain the distribution of sampled points. However, it has been proven that the test is robust when there are more than 1 degree of freedom, the expected frequency value is greater than 1 and no more than 20% of the expected frequencies are less than 5 (Cochran, 1952; Sheskin, 2003; Mitchell, 1971).

The null hypothesis states that the observed frequency is the same as the expected frequency for each category. The Chi-Square test was used to examine the distribution of Mesolithic records against all of the environmental variables that have been classified into bins, as these variables are all nominal categorical data (some variables would have been continuous data pre-classification). The methodology for the chi-squared test can be found in Appendix 13.1.

2.5. GIS as a tool for spatial analysis

The two Surrey datasets (the HER dataset and the PaMELA dataset) and the southeast HER dataset are excellent resources, but it is difficult to thoroughly analyse a dataset that has an intrinsically spatial component, as standard statistical tests often do not take the spatial positioning of points into account. The use of a GIS has been commonly used in order to be able to spatially display and interrogate large archaeological and geographical datasets (Worboys and Duckham, 2004). The spatial positioning of the records can be analysed quantitatively through hotspot mapping using kernel density plots. Kernel density plots are used when analysing distributions of point events (Xie and Yan, 2008) and are present in many GIS programmes, including ArcGIS (Gibin et al., 2007). Kernel density estimates for this project were created using ArcGIS 10.2.2 and the Spatial Analyst extension. A kernel density estimate layer is created by transforming the intensity of individual events (discrete points) as an estimate of density (a continuous raster surface) (Porta et al., 2009). Density is estimated at a pre-set number of evenly spaced locations within a 2D homogenous Euclidean space (Xie and Yan, 2008), resulting in a magnitude per unit area output where nearby objects are weighted higher than distant objects (Porta et al., 2009).

A standard density plot examines spatial relationships between all of the records in the database, but does not consider different amounts of material found at each record, which could range from individual flint finds to sites with thousands of pieces. Within the database, these are all classified as a single record, and are therefore represented with the same weighting in a standard density plot. To examine whether the size of the assemblage paints a different picture of Mesolithic activity in the County, kernel density plots with a population weighting were utilised. Population weighting within kernel density plots provided a way to classify different record groups within the same database, which is ideal when comparing between different amounts of material found at a record location. The population weighting was defined from the amount of material found at each record.

The population field (weighting) has to be created carefully because very large or very small values can give incorrect or unintuitive results. If the mean of the population field is much larger than 1 then there will be numerous small rings generated around each point. If the mean is much smaller than 1 then the County is likely to be covered in a large swathe of homogeneous density. To examine this issue, two weighting classifications were devised (Table 2.5). Population weighting 1 was based on incremental addition where the larger records are allocated a higher number. Population weighting 2 was given a weighting value based on the actual amount of artefacts at each record spot. All unspecified values (199 cases) were given a value of 1, as this was the minimum number of flints that could be at each location. Population Weighting 1 had a mean much closer to one, and therefore should provide a good population field to use for density analysis. The disadvantage of this method is that there was the potential that very large (and subsequently important sites) may be underrepresented. In order to check this, kernel densities were run using both population weighting methods, and showed that both pick out major sites, but population weighting 1 also identified areas of broader archaeological activity, since the weighting was more evenly spread (Figure 2.2). This led to the use of population weighting 1 in this study.

Table 2.5. Two population weighting classifications tested in this study.

Amount of Material	Population Weighting 1	Population Weighting 2
One Piece	1	1
Single Figure	2	5
Tens	3	10
Hundreds	4	100
Thousands	5	1000
Unspecified	1	1
Mean	1.69	40.3

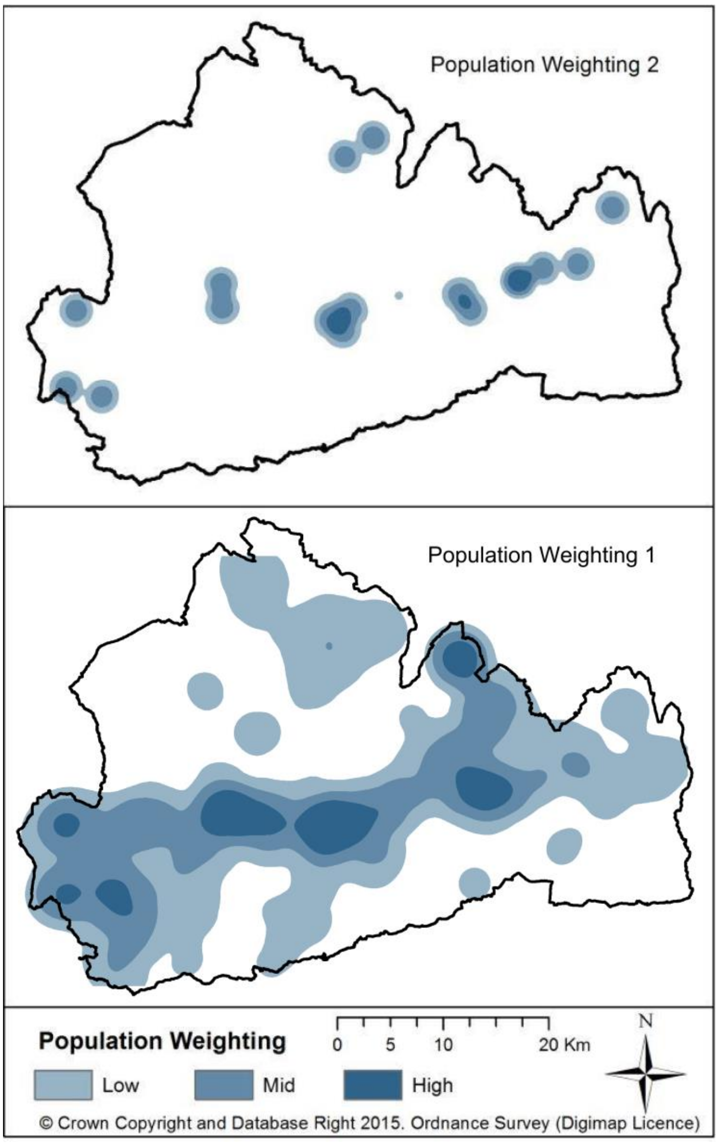


Figure 2.2. Differences between the two population weightings.

The timing of archaeological sites can also be examined using GIS, as palaeo-time-slice maps can be drawn showing the evolution of the archaeological record through both time and space. This ability to interlink both time and space means archaeological data are perfectly suited to GIS analysis (Farr, 2008).

2.5.1. Why use GIS for predictive mapping?

The use of GIS for predictive modelling of archaeological site locations has occurred in a number of studies within the literature that examine archaeological distribution in various parts of the world (Brandt et al., 1992; Lake et al., 1998; Espa et al., 2006). Predictive models are tools that enable the projection of known patterns into unknown times or places. This is particularly important in an archaeological context for modelling archaeological distributions in un-surveyed landscapes, and then relating these results to the context of cultural resource management (Verhagen, 2007). The idea of building models to predict the distribution of sites or landscape use has been around since the 1960's (Kvamme, 2006). These models were used to examine settlement archaeology and work out preferred archaeological locations and were developed through the recognition of sampling biases, the characterisation of background environments and the applications of sophisticated statistical tests and models. The underlying principle behind these predictive models within archaeology is that any settlement patterns are to some extent determined or influenced by the environment (Warren and Asch, 2000), although it is important to observe that natural and social/cultural factors would have played a part. These models will not include all possible settlement variables as, in addition to some environmental variables that are excluded, cultural variability is also often excluded (Warren and Asch, 2000; Gardner, 2009). It is often difficult to obtain reliable and accurate quantitative measurements for cultural variables, and therefore their insertion into predictive models is difficult (Kohler, 1988). However, they have been utilised in models where available, such as using line of sight analysis to examine the significance behind the placement of archaeological features, such as long barrows (Verhagen, 2007). The impact of these excluded variables can be examined from the model results through looking at the percentage of correctly and incorrectly predicted results, highlighting variance that was not explained by the environmental dataset.

2.5.2. Correlative and Deductive Models

Two distinct approaches are used within archaeological modelling, correlative modelling and deductive modelling. Correlative modelling (or inductive modelling) is based on deriving an archaeological model through statistical functions such as regression or discriminant functions (Kvamme, 2006). Correlative models are formed from empirical observations, for example the distribution of archaeological sites. This is based around inductive logic, where a hypothesis is created based on the evidence that has been observed. These models examine the study patterns of site location data and then create predictions of where there is the highest archaeological potential for finding new archaeological sites. These predictions are then used to help in the planning process and can be used to protect regions from development. These models therefore quantify the relationships between environmental locations and archaeological sites. One issue with inductive models is that any bias within the sampling process, such as a particularly active local archaeological group, may skew the resulting distribution (Ebert, 2000).

A deductive model is a theory driven model looking at the likelihood of site distribution based on accepted archaeological concepts, such as resource exploitation, using deductive logic whereby a hypothesis is created and then tested by using observable data. Deductive models are based on previous findings within the study region or anthropological theory, predicting how human patterns of land use are reflected in the archaeological record (Church et al., 2000). These models can also be vulnerable to sampling bias if based upon previous study results. Often, a categorical separation between the two types of model is unnecessary, as it would be almost impossible to implement a model based on only one approach (Wheatley and Gillings, 2000).

Commonly, archaeological models have been created through assigning a weighted value to all variables (environmental and cultural) within the study region (Wescott and Kuiper, 2000). The weighted value is assigned to each variable based on the amount of influence this variable has on the overall location of the record. Difficulties within this approach arise when attempting to designate how the weighted number is calculated for each variable, which is often undertaken by using the Kolmogorov-Smirnov test. A variable with a strong association to site locations are therefore connected and assigned higher weighting within the model (Gardner, 2009). This approach has been used within previous archaeological studies, although there are some issues with a model based on user determined weighted values. First, the subjective nature of designating weighted values leads to bias within the model and a lack of statistical validation. Secondly, through the alteration of weighted values, highly different predictions can be generated from the same dataset (Lock and Harris, 2006). An inductive model, followed by the application of weighting attributes, has been applied to the Mesolithic period within the County of Surrey (Farr, 2008). Weighted values were derived from the tested significance of these variables to site location, leading to a map of potential likelihood for Mesolithic settlement.

Another option that can be used for predicting site locations is logistic regression analysis (Kohler and Parker, 1986; Warren and Asch, 2000), which developed from correlative modelling, as it uses existing data in order to create predictions (Church et al., 2000). This method uses independent environmental variables to create a formula that can predict the probability of a site occurring on an area of land (Warren and Asch, 2000). Through predicting group membership on a probability curve, an interaction of environmental variables is identified that discriminates between site and non-site records (Warren and Asch, 2000). The selection of these variables uses a theoretical perspective derived from knowledge of the subject, therefore utilising parts of a deductive model. Logistic regression analysis was chosen to create and develop the models within this study, as it provides a robust method for identifying and entering variables, and variable significance is based on statistical testing. A logistic regression model also allows for accuracy to be tested through using a testing sample that is originally withheld from the input dataset (Warren and Asch, 2000).

2.6. Methodology for Building and Implementing the Spatial Model

Logistic regression analysis uses a wide range of predictor variables. It is important to identify the data sources, the type and classification of the data for use within the model.

2.6.1. Sources of environmental data

Environmental factors were derived from a variety of different sources and subsequently analysed, modified and reclassified in order to be used effectively (Table 2.6). Data were tied to the British National Grid projection system, which provided spatial continuity across the different layers of data. The reclassification of continuous data into categories enabled the binary regression model to provide a higher accuracy of correct results, as there were more data points per grouping than if these individual variables used a continuous classification.

Table 2.6. Type and source for datasets used in mapping and predictive modelling for the Mesolithic archaeology of Surrey.

Variable/Variable Source	**Scale**	**Original Units**	**Type of Data**
BGS 1:50000 Geological Maps			
Geology	Nominal	-	Vector
Distance to Greensand	Ratio (Scale) – Dichotomised into Ordinal	Millimetre	Raster
Distance to Clay-with-Flints	Ratio (Scale) – Dichotomised into Ordinal	Millimetre	Raster
Land Cover Map 2007			
Land Cover	Nominal	-	Vector
OS Landform Profile DTM			
Elevation	Ratio (Scale) – Dichotomised into Ordinal	1m	Raster
Aspect	Ratio (Scale) – Dichotomised into Nominal	1°	Raster
Slope	Ratio (Scale)	1%	Raster
Total Wetness Index	Ratio (Scale) – Dichotomised into Ordinal	-	Raster
OS MasterMap Data			
Distance to 3rd Order River	Ratio (Scale) – Dichotomised into Ordinal	Millimetre	Raster
Distance to Roads, Paths and Tracks	Ratio (Scale) – Dichotomised into Ordinal	Millimetre	Raster

Dichotomising (dividing into groups) continuous variables offered advantages and disadvantages. The initial disadvantage was the inherent loss of data in nominal groups, potentially leading to a loss of statistical power for subsequent tests and overly confident results (Babyak, 2004). For this model, the practice of dichotomising continuous variables meant the output could have become less robust at very small spatial scales. However based upon the spatial scale of the Mesolithic input data, where point locations could vary across 10-100m, the number of different predictor variables and the inherent complexity within land use patterns, this was not thought to be detrimental to the final output.

2.6.2. Elevation

Topography was based upon the Landform Profile Digital Terrain Model (DTM), a digital elevation model (DEM) from Ordnance Survey. Landform Profile DTM is a 10m set of gridded height values that were mathematically interpolated from OS contour data. Accuracy of the data was approximately ± 2.5m. The data were downloaded as georeferenced TIFF files, imported as individual layers into ArcMap 10.2.2 and transformed into a single DTM layer file (raster – raster dataset – mosaic). The DTM was then categorised into a number of height bands at 50m intervals (Table 2.7).

Table 2.7. Categories of elevation used within the predictive model.

Elevation ***Height (m a.s.l)***	***Category***
0-50	0
51-100	1
101-150	2
151-200	3
201-250	4
251-300	5

2.6.3. Geology

Superficial and bedrock geological maps were downloaded from Edina DIGIMAP at 1:50000 scale. These maps supplied by the BGS were classified at a number of scales. For simplification, these have been collated into groups (where applicable) or other categories (Table 2.8). One exception was the Langley Silt Member, a superficial unit included with the London Clay. This exception was based on consultation with previous geological maps of the County (Branch and Green, 2004; Farr, 2008) and the fact that the Langley Silt Member was exclusively clays and silts, and from a surface/landscape viewpoint would behave more like the bedrock of the London Clay than superficial sands and gravels.

Table 2.8. Categorisation of BGS 1:50000 Geological Categories.

Geological Classification	**Geological Epoch**	**Included BGS 1:50000 Geological Units**
Alluvium and Peat	Quaternary (Period)	Alluvium; Peat
Bracklesham Group	Eocene	Bagshot Formation; Camberley Sand Formation; St Ann's Hill Pebble Bed Member; Stanners Hill Pebble Bed Member; Swinley Clay Member; Windlesham Formation
Chalk Croup	Late Cretaceous	Glauconitic Marl Member; Holywell Nodular Chalk Formation and New Pit Chalk Formation (Undifferentiated); Lewes Nodular Chalk Formation; Lewes Nodular Chalk Formation, Seaford Chalk Formation and Newhaven Chalk Formation (Undifferentiated); Melbourn Rock Member; Newhaven Chalk Formation; Seaford Chalk Formation; West Melbury Marly Chalk Formation and Zig Zag Chalk Formation (Undifferentiated)
Clay-with-Flints	Quaternary (Period)	Clay with Flints Formation; Headley Heath Member
Head Deposits	Quaternary (Period)	Head Deposits
Lambeth Group	Palaeocene	Lambeth Group

London Clay	Eocene	Claygate Member; Langley Silt Member; London Clay Formation
Lower Greensand	Early Cretaceous	Atherfield Clay Formation; Bargate Sandstone Member; Folkestone Formation; Hythe Formation; Sandgate Formation
Superficial Sand and Gravel	Quaternary (Period)	Arun Terrace Deposits, 4 Member; Black Park Gravel Member; Boyn Hill Gravel Member; Caesars Camp Gravel Formation; Disturbed Blackheath Beds; Kempton Park Gravel Formation; Lynch Hill Gravel Member; Netley Heath Deposits; River Terrace Deposits (Undifferentiated); River Terrace Deposits, 1; River Terrace Deposits, 1 (Bramley Wey); River Terrace Deposits, 1 (Godalming Wey); River Terrace Deposits, 1 (Mole); River Terrace Deposits, 2 (Bramley Wey); River Terrace Deposits, 2 (Godalming Wey); River Terrace Deposits, 2 (Mole); River Terrace Deposits, 2 to 3; River Terrace Deposits, 3 (Blackwater); River Terrace Deposits, 3 (Godalming Wey); River Terrace Deposits, 4; River Terrace Deposits, 6; River Terrace Deposits, 7; River Terrace Deposits, 8; Superficial Sand and Gravel of Uncertain Age and Origin; Shepperton Gravel Member; Surrey Hill Gravel Member; Taplow Gravel Formation.
Selbourne Group	Early-Late Cretaceous	Gault Formation; Upper Greensand Formation
Thanet Sand	Palaeocene	Thanet Sand
Wealden Group	Early Cretaceous	Ardingly Sandstone Member; Ashdown Formation; Grinstead Clay Member; Lower Tunbridge Wells Sand; Upper Tunbridge Wells Sand; Wadhurst Clay Formation; Weald Clay Formation

2.6.4. Aspect

Aspect was calculated from the digital elevation model (Spatial Analyst – Surface – Aspect) and ordered into 9 categories relating to the direction each cell is facing (Table 2.9).

Table 2.9. Aspect categories used within the predictive model.

Aspect (°)	Category
-1	Flat
337.51-22.5	North
22.51-67.5	Northeast
67.51-112.5	East
112.51-157.5	Southeast
157.51-202.5	South
202.51-247.5	Southwest
247.51-292.5	West
292.51-337.5	Northwest

2.6.5. Slope

Slope angles were calculated in ArcMap 10.2.2 (Spatial Analyst - Surface – Slope). The slope raster layer was derived from the DEM. Slope was initially classified into categories based on the Natural Jenks method in ArcMap (Table 2.10).

Table 2.10. Categories of slope angles.

Slope Angle (°)	Category
0-1.432	0
1.433-4.169	1
4.170-6.763	2
6.763-9.520	3

Slope Angle (°)	Category
9.521-13.271	4
13.271-17.753	5
17.754-24.261	6
24.262-63.706	7

If this classification was utilised within the binary regression equation then multicollinearity could occur between slope and other variables that can be derived from or are related to slope, such as aspect and total wetness index. Multicollinearity occurs when variables are closely correlated and one may be linearly predicted from another. Slope was subsequently entered into the model as a continuous variable, allowing for a binary regression model to calculate a robust iterative model, which did not suffer from multicollinearity. The categories (Table 2.10) were used in conjunction with the chi-square test to ascertain whether any relationship existed between the Mesolithic records and the slope angle.

2.6.6. Total Wetness Index

The total wetness index (TWI) characterised the landscape in terms of cell-by-cell flow, and examined the landscape in terms of the local slope and contribution of an area, creating a scale based on the TOPMODEL system of catchment water flow (Beven and Kirkby, 1979). The TWI showed each parcel of land’s potential to hold or retain water, and therefore provided a scale from dry to wet. The TAUDEM method (Appendix 13.2) of processing the TWI was chosen as it allowed for more detailed spatial analysis of water flow through using D-infinity as opposed to 8-direction that ArcGIS functions utilise (Tarboton, 1997; Tarboton, 2004).

Areas with a slope angle of 0 led to unclassified cells (no data) within the output, as the model was unable to calculate a value as log0 tends to infinity. These flat areas had a high likelihood of ponding water subsequently leading to high moisture indices. The data resulted in a range of values from 1.39-20.30 (dry-wet) and a number of no data values, which were classified as very wet (Table 2.11).

Table 2.11. Values derived from the TWI to create the index categories.

TWI Category	Minimum TWI Value	Maximum TWI Value
Dry	1.39	4.27
Dry/Wet	4.27	5.82
Wet	5.82	20.30
Very Wet	No Data	No Data

The data was aggregated using a cell factor of 5, meaning aggregated cells had a size of 50 x 50m (as opposed to 10x10m), thus simplifying variation across the dataset. This aggregation allows general trends in wetness to be identified and subsequently provided a broader idea of wide ranging moisture conditions. This was important when using the data in the predictive model as moisture present across a surface is a highly continuous surface and very sharp changes (<10m) in moisture retention occur very infrequently. A general trend of moisture variation across the boundary zones of the four categories therefore provided a more realistic total wetness scenario. Data was classified into 4 categories; dry, dry/wet, wet and very wet.

2.6.7. Distance to Strahler Order 3 and Greater Rivers

The stream network was derived from OS mapping, and the DEM through using the TauDEM package available for ArcMap (Tarboton et al., 1991; Tarboton, 2004) (TauDEM Tools – Stream Network Analysis – Stream Definition by Threshold). Limitations of the TauDEM package mean that the start and end points of streams may not be sourced correctly and so the derived network was cross-compared to the OS mapping to ensure its accuracy (Steinke et al., 2013) with any errors or gaps in the dataset corrected. The use of the TauDEM method ensures only natural streams were selected, excluding man-made watercourses such as drainage ditches and canals. Other channels and waterways would have undoubtedly existed within the Late Glacial and Mesolithic landscapes, and the modern rivers will have been altered by both natural and anthropogenic channelization. Therefore the modern location of the rivers may not necessarily reflect their prehistoric setting (Vanacker et al., 2001).

Two methods were employed to combat this; first, the total wetness index was utilised within the predictive model to understand broad hydrological conditions based on natural landscape features. Secondly, classified Strahler stream ordering was employed. Strahler ordering dictates that streams flowing from the source are Strahler first order (order 1). When two steams of the same order join, the order is increased by 1. The order does not increase if a stream of lower order joins a higher order (Huggett, 2007). The stream network was reclassified to only include rivers with a Strahler order of 3 or greater (TauDEM Tools –

Stream Network Analysis – Stream Reach and Watershed), a method frequently used in archaeological modelling as these streams may have offered a more permanent source of water during the Late Upper Palaeolithic and Mesolithic (Kvamme and Jochim, 1990; Warren and Asch, 2000). The distance from the watercourses was then calculated (Spatial Analyst – Distance – Euclidean Distance) and the Strahler ordering were classified into distance bands (Table 2.12). This means the exact distance to the nearest river was not being used, and allowed for small lateral movement within these major rivers (during and since the Early Holocene) to be negated due to the increased spatial allowance the large 500m categories provided.

Table 2.12. Categories of distances to Strahler order 3+ rivers used in the predictive model.

Distance (m)	**Category**
0-500	0
500-1000	1
1000-1500	2
1500-2000	3
2000-2500	4
2500-3000	5

Distance (m)	**Category**
3000-3500	6
3500-4000	7
4000-4500	8
4500-5000	9
5000-5500	10
>5500	11

2.6.8. Distance to Lower and Upper Greensand and Clay-with Flints

Distance to clay-with-flints and distance to Greensand variables were calculated in the same way. The geological units were extended to 50km outside the County border, in order to ensure that the correct data were being gathered for sites (and non-sites) near to the border. Geological units were selected using a SQL expression to isolate each unit from the other 11 unrequired categories (Analysis Tools – Extract – Select). The shortest distance from the input geology to every pixel within the County was then calculated (Spatial Analyst – Distance – Euclidean Distance), and categorised into distance bands (Table 2.13) for both greensand and clay with flints.

Table 2.13. Categories of clay-with-flint distance and greensand distance.

Clay with Flint	
Distance (m)	***Category***
0-1000	0
1001-5000	1
5001-10000	2
10001-15000	3
15001-20000	4
20001-25000	5

Greensand	
Distance (m)	***Category***
0-1000	0
1001-5000	1
5001-10000	2
10001-15000	3
15001-20000	4
20001-25000	5

2.6.9. Land Cover

Land cover type was derived from the Land Cover Map (LCM 2007), which designates a land cover type for the UK based on satellite imagery and digital mapping. The categories of land cover were based on the broad habitats as defined in the UK Biodiversity Action Plan. The initial Great Britain land cover map had twenty different classes, of which twelve are present within Surrey. These can be further classified into sub-categories, however the main categories were used as those classes meaningfully relate to where objects may be found in the present day, and the model has a higher chance of finding relationships based on broad categories. Due to this, a number of classes have also been amalgamated when categories are based upon ecological factors unrelated to archaeological material. For example, grassland nutrient status is unlikely to be a pivotal factor in the chance of finding artefacts; instead open grassland cover is more likely to be the defining factor. Therefore the land cover classes have been grouped into:

- Grassland
    - Acid Grassland
    - Calcareous Grassland
    - Improved Grassland
    - Neutral Grassland
    - Rough Low Productivity Grassland
- Woodland
    - Coniferous Woodland
    - Broad Leaved, Mixed and Yew Woodland
- Heathland
    - Dwarf Shrub Heath
- Built Up
    - Built Up Areas and Gardens
- Freshwater
    - Freshwater
- Inland Rock
    - Inland Rock
- Arable and Horticulture
    - Arable and horticulture

2.6.10. Distance to Roads, Paths and Tracks

A road, path and track layout was derived through OS MasterMap data, downloaded from Edina Digimap. Data was extended across the county borders in order to ensure that sites on or near to the border were not returning incorrect data due to an edge effect. InterpOSe for

Digimap was used to undertake a conversion between .gml2 files and ESRI .shp files. Individual 100km squares were downloaded and converted into a single polygon layer, including only the road, path and track data. The distance to this layer was calculated for both the site and non-site data and every pixel within the county (Spatial Analyst – Distance – Euclidean Distance). These results were categorised (Table 2.14) into visible distance bands based on the likelihood of archaeological remains being visible from the path or being exposed or eroding from the local area. The category distances were based on personal experience and it is acknowledged that these distances may not be wholly appropriate for all land cover types, however it was felt these categories offered a suitable range of distance scales to begin to understand if the distance to roads, paths and track does affect the distribution of artefacts.

Table 2.14. Categorised distance to roads, paths and tracks used within the predictive model.

Distance to Road, Path or Track Network (m)	**Classification**
0	On Path
0.1-2.5	Verge
2.6-10	In Sight
>10	Unrelated to RPT Network

2.6.11. Implementing a Binary Logistic Regression Model

In order to begin to model the Mesolithic dataset, it is important to ascertain that the observed spread of data is unlikely to have occurred by chance, and compare distances between points to determine whether they were distributed randomly (Wheatley and Gillings, 2002). If the distribution is likely to have occurred by chance then there is no statistical reason for attempting to understand linkages between the dataset and the environment. High/Low Clustering (Getis Ord General G) was used to examine clustering within the data. To use the Getis Ord General G test, any points with the same coordinates were grouped (Spatial Statistics – Utilities – Collect Events) and a new data column was added indicating the number of sites at each integrated point. The Getis Ord General G test was then run using this dataset. The Nearest Neighbour Index was another clustering assessment tool, but is highly dependent on the perimeter of the shape involved (the County boundary), and only the mean distance and broad scale variation were taken into account, meaning there was no potential for local variation. These disadvantages mean that the Getis Ord General G test was likely to be more robust for this dataset.

Chi-squared analysis of the individual model variables identified variables that were not significantly related to the Mesolithic dataset. These variables were still included within the model as if they were omitted, this would be an attempt at automated selection (Babyak, 2004), a process that was avoided by using an 'enter method' for the binary logistic regression. The removal of these variables may also result in overfitting of the model. Model results may still identify no significance in these variables, however they may be significantly involved with others in two (or greater) way interactions, and the significance factors of other variables can alter depending on the inclusion of "non-significant" data (Babyak, 2004). This also explains why the output could include a high amount of non-significant p-values, as these may be variables where their variance was explained by higher order terms.

The data must meet the assumptions of a binary regression model (Vittinghoff and McCulloch, 2007; Burns and Burns, 2008):

- Dichotomous dependent variables must be used (Burns and Burns, 2008)
- A linear relationship occurs between continuous variables and the logit of the outcome variable (Field, 2013).
- There is no multicollinearity between groups (Burns and Burns, 2008; Field, 2013).
- Predictive groups must have dependent variable outcomes (Burns and Burns, 2008).
- Large sample sizes of each predictor variable are necessary (Burns and Burns, 2008) to ensure that variables do not over or under represent themselves within the model (Peduzzi et al., 1996; Bagley et al., 2001). It has been suggested that 10 samples per predictor is a robust amount to perform binary logistic regression, with a potential in some cases for this to be reduced to 5 (Vittinghoff and McCulloch, 2007)

If variables were entered where data does not occur in association with both of the two groups (site and non-site), quasi-data separation would occur. This means that the maximum likelihood estimate will not exist for the model, and therefore the results for the model are not correct (Giaimo et al., 2006; Allinson, 2008). In order to deal with any variable that exhibits quasi-complete separation it can be grouped into another category, or removed from the model entirely (Webb et al., 2004).

To examine the results of the model, a number of non-site locations (533) were created using a random point generator (ArcGIS 10 add on: Hawths Tools – Sampling Tools – Generate Random Points). In an idealised scenario, the County would have been systematically surveyed and non-site locations would be known. As the County has not been completely surveyed, these sites can be considered “pseudo non-sites” (Gardner, 2009) as they occur only where Mesolithic archaeology is currently not observed. These non-site points provided a database of random locations with derived environmental data as per the HER dataset. This method of “pseudo non-sites” has been used in other studies with high success rates (Duncan and Beckman, 2000; Warren and Asch, 2000; Gardner, 2009). Values of all variables were extracted from ArcGIS (Data Management – Extract Multi-Values to Points) for both site and non-site locations and exported into SPSS. A binary logistic regression model was then run in SPSS to calculate the model coefficients for the entered variables. The SPSS regression model used an enter method with a constant and maximum iterations set to 20. The enter model was used as this enabled all of the variables to be entered at the same time into the regression model. This is important because the predictors that are included within the model are based on sound theoretical reasoning (Field, 2013). There is also no weighting given to the order that the model variables are entered. Other regression models can be influenced by random variation related to the order of variable input (Field, 2013).

Continuous variables (e.g. slope) were entered as calculated. In the case of categorical variables (e.g. geology or distance to greensand), the data was treated differently. These categorical variables had no numerical significance, so would be incorrect to have treated them as interval scale variables (Hosmer and Lemeshow, 2004). These categorical variables were modified to use dummy coding (Peng et al., 2002) and represented as zeroes and ones (Field, 2013). If a categorical variable had x number of variables, then x-1 dummy variables were needed (Hosmer and Lemeshow, 2004; Field, 2013). One group was chosen as a base category and assigned 0 for all of its values. All other groups were then assigned a 1 for the occurrence of their variable, and a 0 for all other categories until all dummy variables had been filled (Field, 2013). In order to confirm that it did not make any difference which variable was used for the dummy variable, the model was run with both Thanet Sands and Weald Clay as a geological dummy reference category and final results were identical.

In order to create the model output in map form, the raster calculator within ArcGIS was used. This required those variables where the original data were not represented in raster form to be converted to raster (Conversion Tools – To Raster – Polygon to Raster – with a cell size of $1m^2$). Using the SPSS β coefficients, the raster calculator and Equation 2.1, the predictive model could be drawn:

Equation 2.1. Logistic regression equation to create the predictive model.

$$P(Predictive\ Model) = \frac{1}{1 + Exp\ (-(Logistic\ Regression\ Model)}$$

Where: $Logistic\ Regression\ Model\ =\ Constant\ + (\beta 1 * Variable\ 1) + (\beta 2 * Variable\ 2) + \cdots + (\beta n - 1 * Variable\ n - 1)$

SPSS is able to generate a regression model for any set of input variables, however this does not mean that the data fit the model particularly well, therefore limiting the real life usage of the model (Field, 2013). Therefore, in order to ascertain whether the model fits the dataset, both the Chi-squared values and the residuals can be consulted (Table 2.15). The most useful parameter estimate is β, the estimated regression coefficient, the value used in the predictive model equation to ascertain the probability of each category. The 2-log likelihood and chi-squared statistic are able to show the overall fit of the model. For the model to be a significant fit to the data, the chi-squared value has to be <0.05. A reliability analysis using the Kappa statistic can ascertain how well a logistic regression equation preforms above a chance probability (Gardner, 2009) and was calculated in SPSS (Analyse – Descriptive Statistics – Crosstabs). A withheld sample (58 sites from the Gazetteer that are not in the HER dataset) was used to test the model further through examining the predictive value of each record and using frequency distributions to examine their patterning.

Table 2.15. Residual statistics and their significance (Field, 2013).

Residual Statistic	**Good fit between model and data if:**	**Interpretation**
Cook's Distance	Less than 1	Helps identify points that are highly influential on the model
Leverage	Should be near to or equal to expected leverage. Expected leverage is (k+1)/N. k = no. of predictors and N = sample size.	As above
DFBeta	Less than 1	As above
Standardised residual and studentised residual	Only 5% outside ±1.96 and 1% outside ±2.58. Values above and around 3 need further analysis.	Helps isolate points for which the model does not fit well

Through implementing the spatial modelling process, and ensuring a robust and accurate model is created, an idea can be gained on the environmental processes that influence both Late Upper Palaeolithic and Mesolithic activity in the past (Model 1 – Chapter 3) and also the chances of identifying Late Upper Palaeolithic and Mesolithic records in the present (Model 2 – Chapter 3).

2.7. Summary

This chapter has highlighted how the archaeological databases have been created and provided information on the specific categories within the datasets. Examination of archaeological interaction with the environment led to the development of a theoretical basis for predictive modelling, utilising an array of environmental and modern day datasets in order to understand where people may have been present within the landscape, and where this archaeological information may be discovered today. Chapter 3 presents the results of the analysis of the archaeological datasets, examines relationships between the archaeological and environmental records, and discusses the findings of the predictive modelling.

3. Results and Interpretations: Surrey's Archaeological Resource and GIS Modelling

3.1. The HER Dataset

The Surrey HER provided 519 Mesolithic records and grey literature added another 14 sites to this total. Records were collated at Surrey County Council and the dataset was deemed complete as of April 2013. In addition, there were 12 Upper Palaeolithic records and 28 Palaeolithic records. No breakdown between Early Upper Palaeolithic and Late Upper Palaeolithic was available from the HER database. The 28 general Palaeolithic sites within the database were not deemed suitable as their precise time period was indefinable.

The third source of data was the Gazetteer of Mesolithic sites in England and Wales (Wymer and Bonsall, 1977). The results from the Gazetteer were amalgamated with those of the HER, based on names, locations and details of each individual site. This allowed for the creation of a single dataset instead of two separate datasets (the Gazetteer and the HER). Cross-referencing the HER with the Gazetteer showed that the correlation between datasets was very good. The Gazetteer was completed in 1977 and contained 322 Surrey Mesolithic sites (Table 3.1). The vast majority of the data had been entered into the HER; therefore it was not surprising that a good match was made between the two datasets. In total there were 58 sites that could not be matched from the gazetteer to the HER database. These sites were included in the dataset as a source of reference but they were not included within the initial predictive modelling dataset, due to the fact they appeared to be unique records and therefore not part of the HER database. The Gazetteer included only one Upper Palaeolithic record, from Pepper Harrow near Godalming, described as a possible Earlier Upper Palaeolithic open-air site with a solitary leaf point (Wymer and Bonsall, 1977). As this was outside the period of interest it was not included within the dataset. Details of every record can be found in Appendix 13.3.

Table 3.1. Sources and quantities of the archaeological data in the HER dataset.

Data Source	Upper Palaeolithic Records	Mesolithic Records
Historic Environment Record	12	519
Grey Literature	0	14
The Gazetteer (Wymer and Bonsall, 1977)	0	322 (264 correlate with HER)
Total	12	533 (+58 unique Gazetteer records)

These records were plotted within a GIS to examine distribution across the County (Figure 3.1). The spatial accuracy across the different sources of information was very variable, with accuracy levels ranging from 1m^2 to 1,000m^2. Archaeological investigations, developer led archaeology and industrial activity often produced high quality location data, whereas many fieldwalking findspots and older records provided less accurate information, with records often based on name places or vague descriptions of the location. This level of accuracy was compatible with that seen in other large-scale archaeological datasets generated through a combination of professional and non-professional activity, for example the Southern Rivers Palaeolithic Project (Wessex Archaeology, 1993; Wessex Archaeology, 1994) and the Lower Palaeolithic Occupation of Britain Dataset (Wymer, 1999). To ameliorate the effects of lower spatial resolution in the site location data, many of the modelling variables were re-classified into broad sub-divisions.

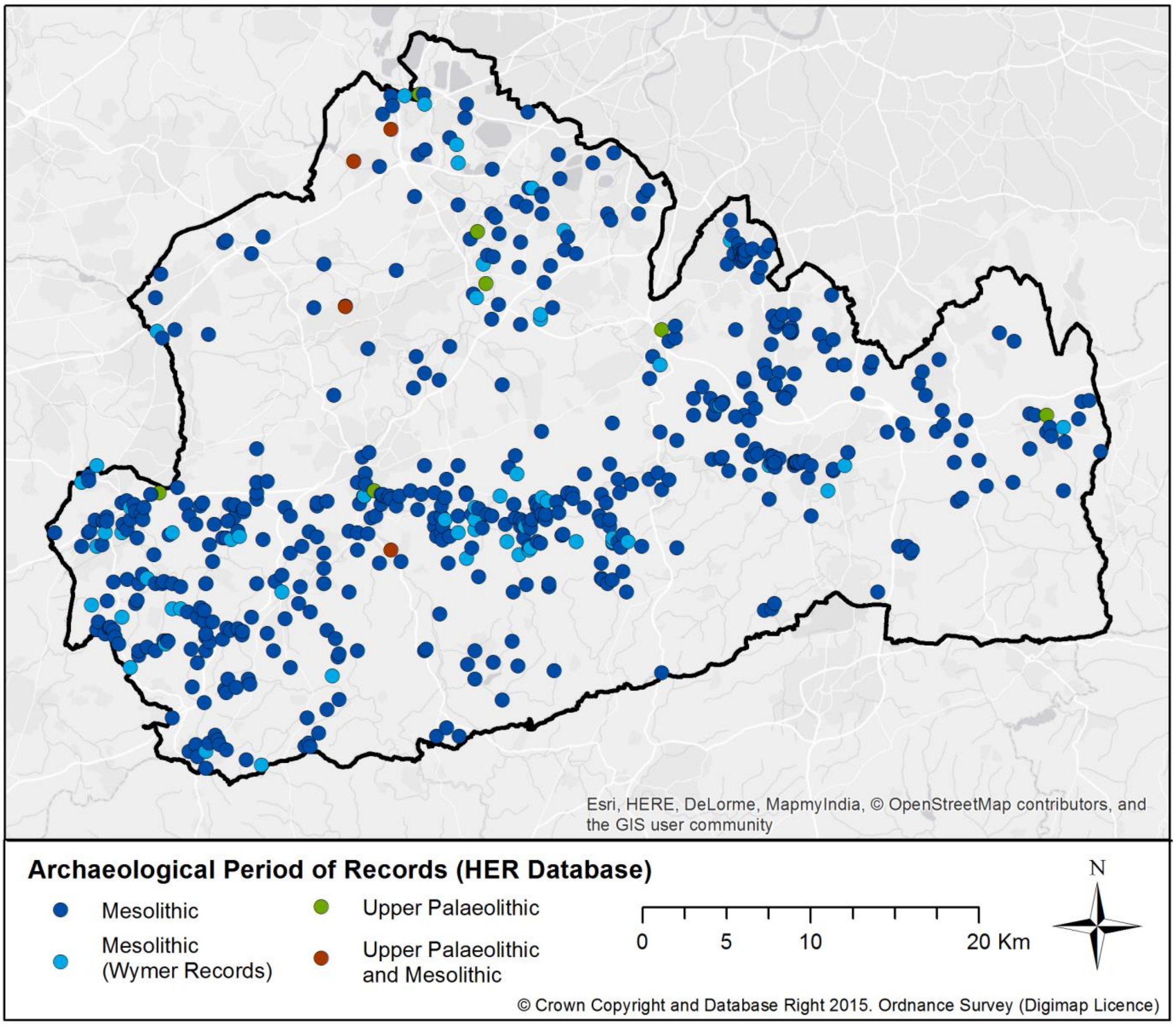


Figure 3.1. Distribution of Upper Palaeolithic and Mesolithic sites in the HER database.

Through visually examining the spatial distribution of the sites, there appeared to be a clustering of sites along a broadly east-west trajectory, with some clustering of sites towards the north. To examine this further, the number of finds at each record were plotted (Figure 3.2) to see if this identified any further areas of higher activity.

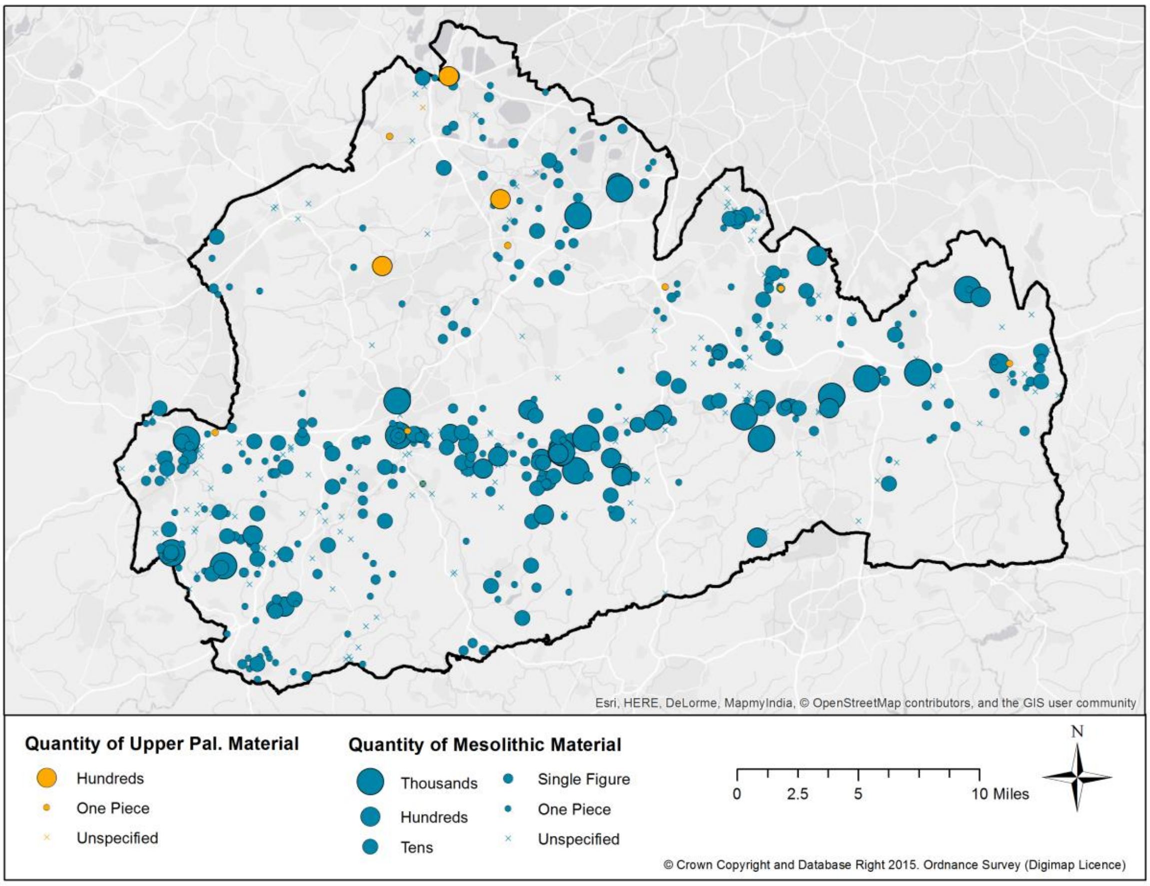


Figure 3.2. Quantity of material found at the Upper Palaeolithic and Mesolithic records.

There was clearly a diverse assemblage of record sizes across the County, ranging from individual pieces through to sites with over 1000 flints. These sites were scattered, with limited patterning being able to be picked out by eye (Figure 3.2) although the same east-west and northern clusters could be identified in this plot as in the initial spatial plot (Figure 3.1). In order to quantitatively examine countywide patterning, kernel density estimates were used to create 'hot-spot' maps. No density mapping was undertaken for the Palaeolithic points due to the paucity of sites. A standard and a weighted kernel density estimate (methods explained in Chapter 3) were run on the 533 Mesolithic records (Figure 3.3).

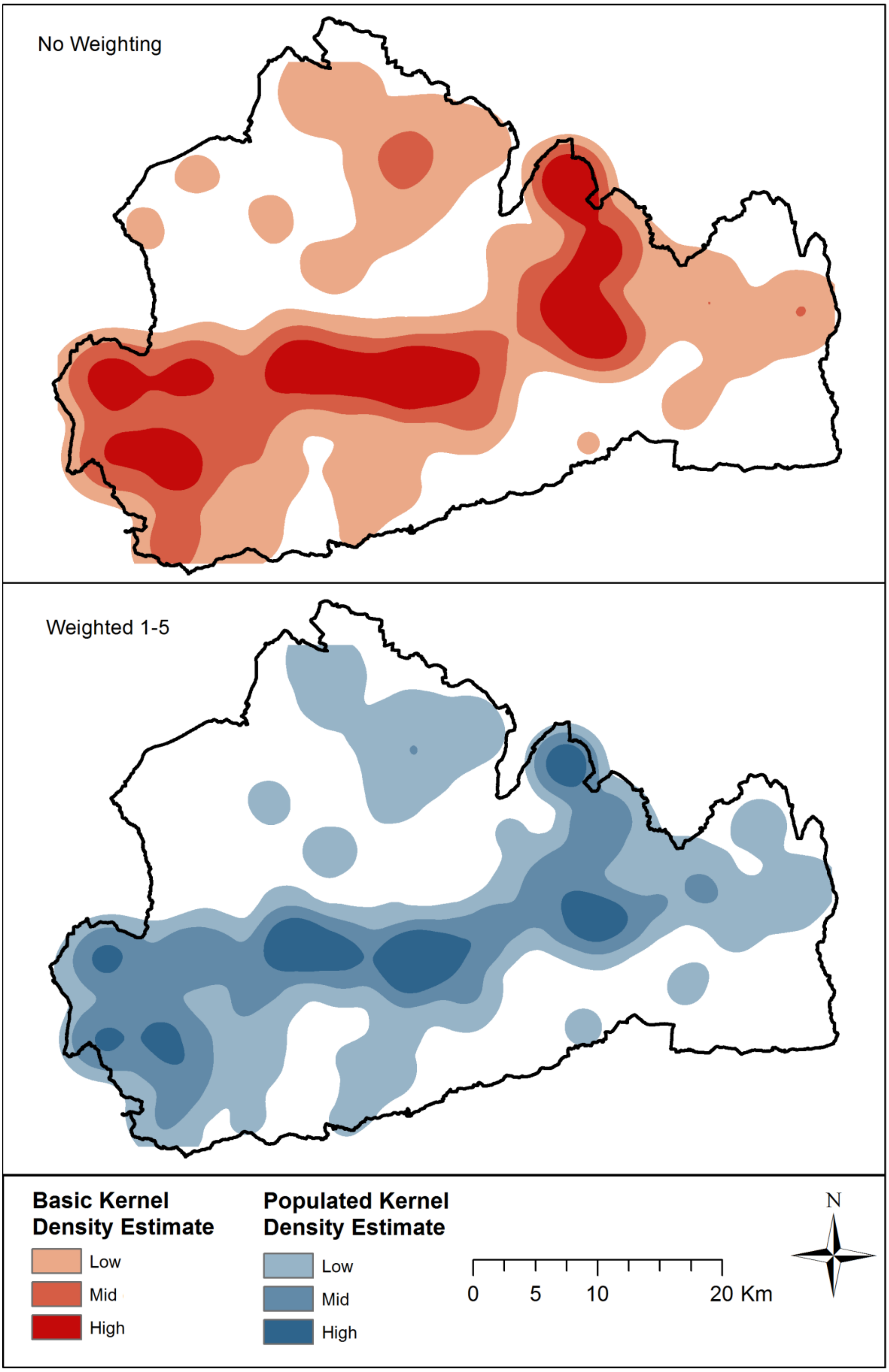


Figure 3.3. Basic and population weighted kernel density estimates for Mesolithic sites.

The results of the density analysis showed a large proportion of activity occupies a band spreading west to east across the centre of the County, with some further outcrops to the north. Visually, the methods did not highlight much variance between the population weighted model (based on a weighting of 1-5 depending on site size) and a standard non-weighted model, and therefore weighting was not used throughout the mapping work. The slightly smaller groupings within the populated density estimate appear to represent the larger sites present in the record. This overall lack of difference was likely due to the 200 unspecified points within the dataset that have to count as single points, which aligned more of the dataset towards the non-weighted example due to the high occurrences of records where the value was 1 (339 cases). If these single findspots and unspecified sites were removed from the dataset, the plots still showed a broadly similar pattern. This suggests that the distribution of these single pieces and unspecified records did not exert an over-influence on the dataset and the patterns observed in Figure 3.3 accounted for these individual records, but were not defined by them. Using a non-weighted dataset was beneficial as there was no ambiguity in the size of relative classes or weighting methods.

The hotspot maps highlighted difficulties with using the County border for the edge of the dataset. The patterning observed in the hotspot mapping appeared to show that activity stops at the border and does not continue across the boundary. This would clearly not have been the case and because the County is an arbitrary boundary, the surrounding HER databases were collated in order to examine Mesolithic distribution across the southeast of England. This was not undertaken for the Upper Palaeolithic due to the very small size of the dataset. In total there were 4,079 Mesolithic records across the southeast (Table 3.2 – Appendix 13.4).

Table 3.2. Mesolithic HER records broken down into counties.

County	Area (km^2)	No. Mesolithic Records	Records per km^2
Kent	3,736	565	0.15
Surrey	1,663	533	0.32
Sussex (West and East)	3,871	1,297	0.34
Hampshire	3,769	547	0.15
Berkshire	1,262	291	0.23
Greater London	1,569	846	0.54

Looking at the density of sites across the different counties, there were clearly some major differences. Both Kent and Hampshire have relatively large geographical extents but the amount of Mesolithic activity was relatively low. London has a very high density, potentially related to the large amount of developer-funded archaeology. These Mesolithic records were visually mapped (Figure 3.4), and plotted as a kernel density estimate (Figure 3.5) in order to examine the potential edge effects of boundaries.

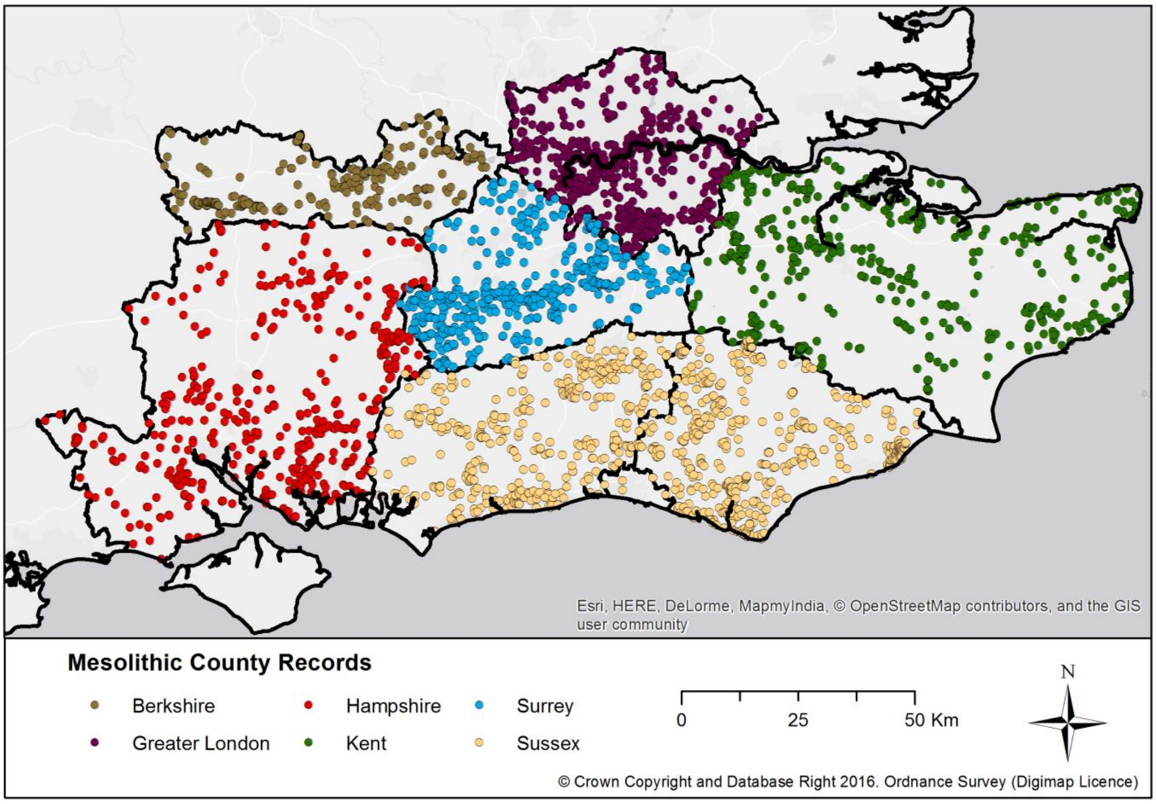


Figure 3.4. Distribution of Mesolithic HER records in the southeast.

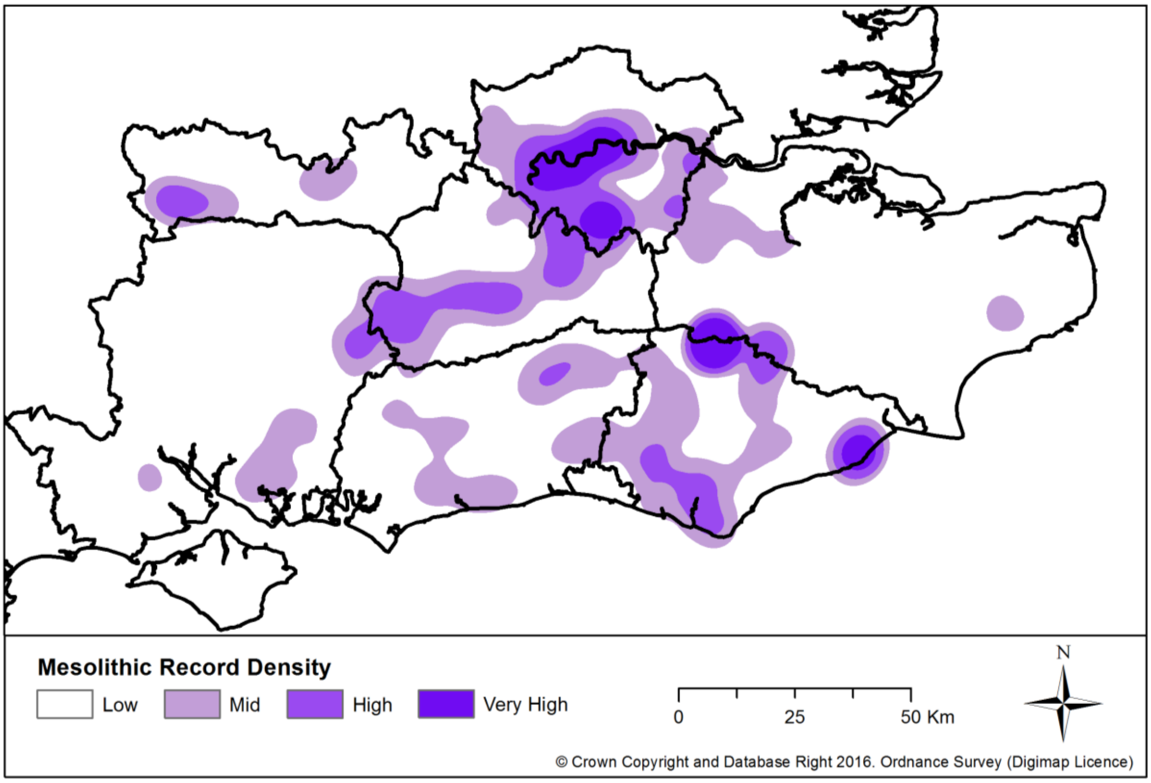


Figure 3.5. Density map of Mesolithic records across the southeast.

The maps showed no major edge effects skewing the Surrey data. The large west-east band of dense archaeology continued into Hampshire and northeast into London, with the lower densities observed in the southeast of the County also present in the adjoining areas of Kent and West Sussex. The Berkshire/Surrey boundary was also sparsely populated. These results indicated that by using the Surrey border as an arbitrary boundary, no important clusters of Mesolithic archaeology were being ignored.

In addition to the spatial location of all the records, a number of other categories were included within the dataset (see Chapter 2). The level of detail varied across the database; especially with the older archaeological records where very little data was originally recorded. The largest groups of site types (Table 3.3) were lithic scatters and findspots. Undefined lithic scatters provided no information on size of the lithic scatter, just that multiple artefacts were present.

Table 3.3. Breakdown of HER record type as defined by criteria in Chapter 2.

Record Type	**Number of Records**	
	Upper Palaeolithic	*Mesolithic*
Findspot	7	143
Small lithic scatter	0	93
Large lithic scatter	0	53
Undefined lithic scatter	2	202
Lithic working site	3	22
Occupation site	0	16
Unspecified	0	4
Total	12	533

The high numbers of findspots and lithic scatters were unsurprising as people would have been utilising landscape mobility strategies for a number of reasons, while the nature of hunter-gatherer archaeology (e.g. the range of material culture, the ephemeral nature of occupation sites) was also likely to result in a lithic scatter-focused record. It was also possible that these locations may have housed further evidence for large-scale lithic working or occupation sites that have not yet been discovered. The distribution of these record types was spatially mapped using ArcGIS to provide a visual analysis of the distribution of Upper Palaeolithic and Mesolithic archaeology (Figure 3.6).

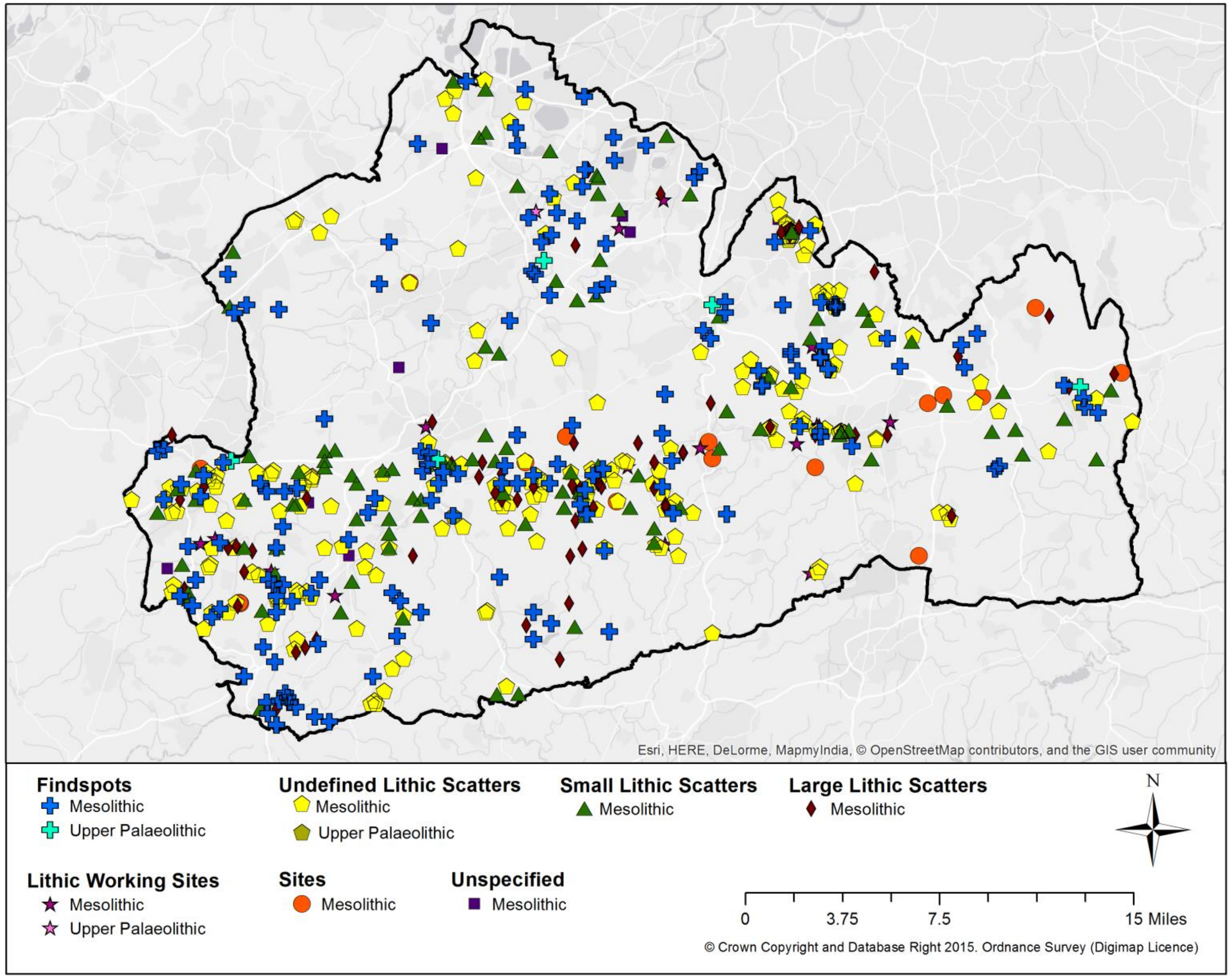


Figure 3.6. HER records with archaeological period and type of record. (Findspots = single artefacts, small lithic scatters <20 lithics, large lithic scatters >20 lithics. Undefined scatters=no information. Lithic working sites = large quantities of débitage and stratified remains, e.g. chipping floors. Occupation Sites = excavated and identified or offer evidence for domestic activities e.g. burning and lithic remains. Unspecified records=no information).

Initial observations appeared to show that the majority of occupation sites were situated in the southern half of the country, with the majority on or around the Lower Greensand. The London Clay, Wealden and Bracklesham Groups were particularly poorly represented in all categories. There also appears to be patterning of data, with all record types preferring the greensand belt, clay-with-flints, alluvium and superficial sands and gravels. This supported the patterning seen within the findspot density analysis. These observations were statistically examined using a variety of environmental factors to examine relationships between these factors and record distribution through the predictive modelling. It is important to note that material may not be present everywhere, and it is likely that people would have reused paths and routes through the landscape, for example a path running along the foot of the Downs from east-west along the Greensand, leading to an increase in material deposited in certain places within the landscape.

The database was also used as an opportunity to break the records down into further categories. Type of lithic material was especially important as this helped to examine and understand the type of activity occurring at each particular location and to ascertain if there was any patterning between different discarded tool types, quantities of discarded material and/or particular locations, and way a way to examine the potential lack of finds in some areas of the County. Again, this suffered from the same variability in the quality of input data as record type; however, some meaningful results were gathered (Table 3.4). In order to examine whether any differences existed between these lithic types, density plots were used (Figure 3.7).

Table 3.4. Breakdown of site-specific details as defined by criteria in Chapter 2. Some Mesolithic sites have material in more than one category and therefore the column total exceeds the total number of records. Many Upper Palaeolithic records provide no information and therefore the column total was less than the number of sites.

Site Specific Details	**Number of Records**	
	Upper Palaeolithic	***Mesolithic***
Evidence for Burning	1	15
Cores and Manufacturing Debris	3	263
Microliths and Points	1	144
Axes, Maceheads and Sharpening Flakes	0	184
Scrapers, Gravers and Other Pieces	3	124

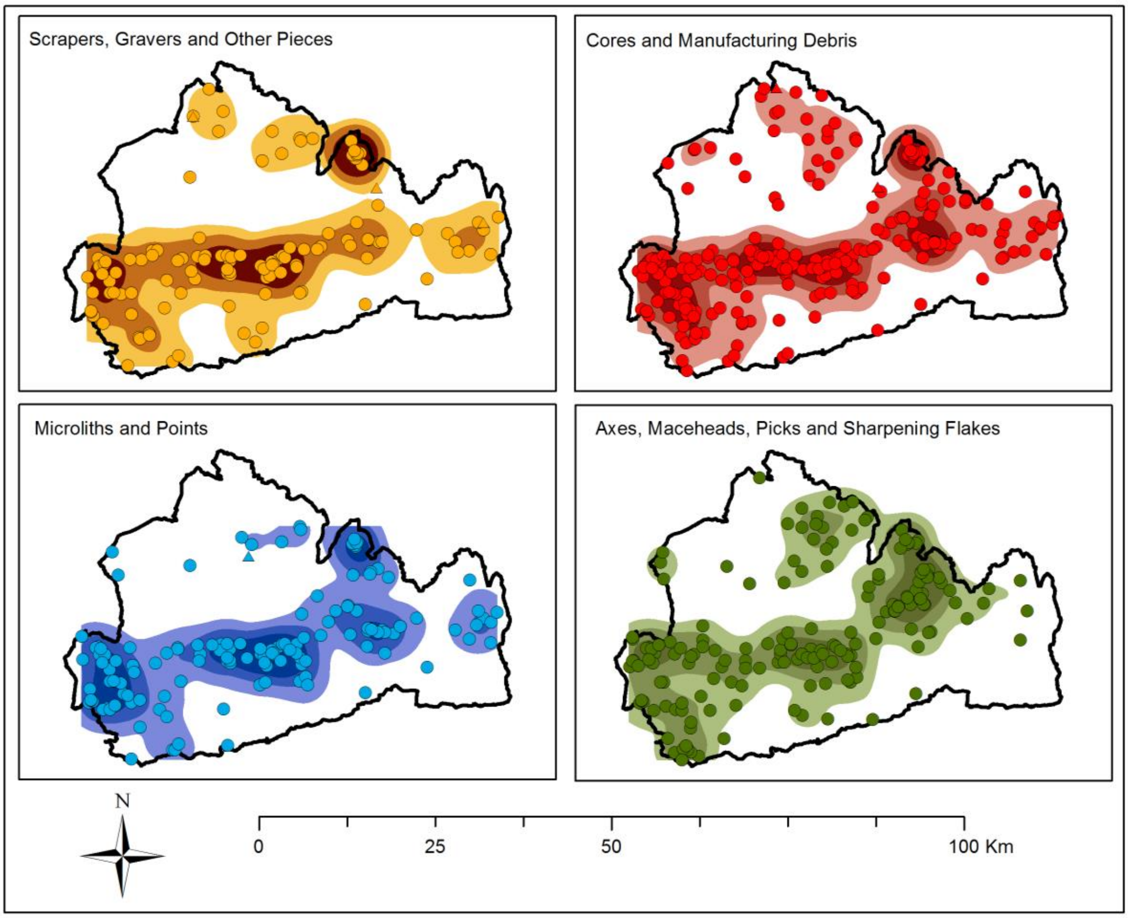


Figure 3.7. Density and distributions of the four different lithic categories.

The density plots did not show much of a difference between the four different lithic categories. The main west-east band of material ran across all four categories, with small outcrops of each category the only difference between the four. There was a possibility that sites in the north had a higher proportion of domestic-type assemblages, with more scrapers, gravers, cores and manufacturing debris, and fewer microliths and points. This correlation was statistically analysed using band correlation statistics in ArcGIS (Table 3.5).

Table 3.5. Band correlation statistics for the four lithic groups.

Type of Material	*Axes, Maceheads, Picks and Sharpening Flakes*	*Scrapers, Gravers and Other Pieces*	*Cores and Manufacturing Debris*	*Microliths and Points*
Axes, Maceheads, Picks and Sharpening Flakes	1	0.75	0.81	0.77
Scrapers, Gravers and Other Pieces	0.75	1	0.91	0.92
Cores and Manufacturing Debris	0.81	0.91	1	0.94
Microliths and Points	0.77	0.92	0.94	1

The correlation figures showed that all of the plots were highly correlated (values trending towards 1) and suggested little difference was observed between the types of lithic material. Therefore, this dataset was not particularly useful at a countywide scale, but was of greater benefit at a local scale for examining activity on a record-by-record basis.

3.2. The PaMELA Dataset

The PaMELA database provided 12 individual Late Upper Palaeolithic records, 408 unique Mesolithic records, and two records with both Late Upper Palaeolithic and Mesolithic archaeology (Figure 3.8 – Appendix 13.5). In addition to these 422 points, there were 111 sites where no location information was provided. These were excluded from the final PaMELA database.

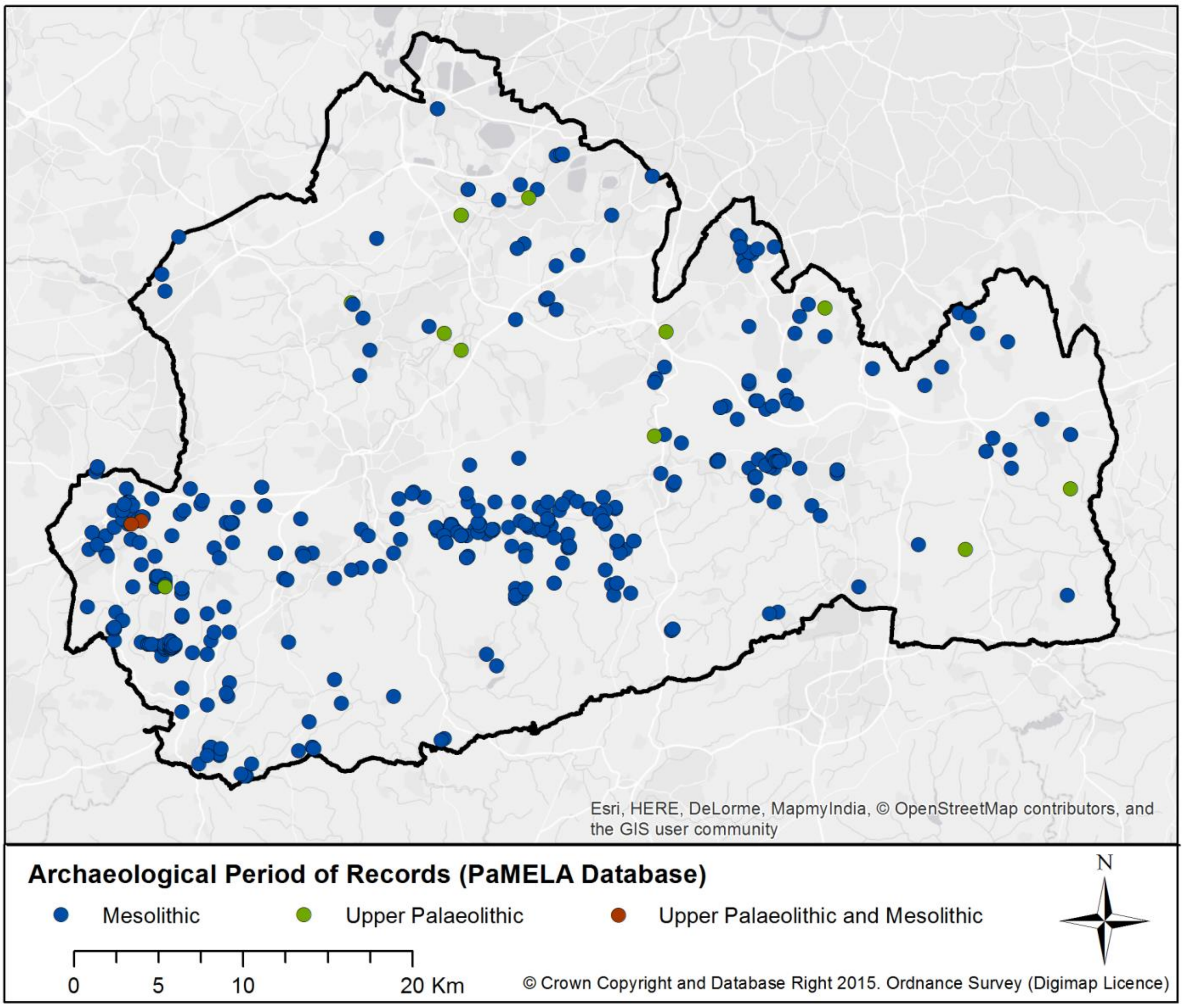


Figure 3.8. PaMELA distribution of Upper Palaeolithic and Mesolithic records.

The PaMELA archive showed that archaeological remains existed from the Late Upper Palaeolithic (the general post-glacial period) through to the Late Mesolithic. A number of records also spanned multiple time periods. The distribution of sites through time showed that the Early Mesolithic had the most records (Table 3.6). In addition to these points, there was one Late Upper Palaeolithic record that could not be assigned a time period, and 103 Mesolithic records that could not be classified in more detail. These records were excluded when looking at the distribution of sites over time across Surrey (Figure 3.9).

Table 3.6. PaMELA breakdown of archaeological records in Surrey. Sites that were multi-period will be represented more than once and therefore the total number of records was greater than in the PaMELA database.

Period	**Age Range (cal. BP)**	**Number of Records**
Creswellian/Late Upper Palaeolithic	~15,000-13,800	2
Final Upper Palaeolithic	~13,800-12,800	4
Terminal Upper Palaeolithic	~12,650-11,500	8
Early Mesolithic	~11,500-9,600	346
Horsham Period (or Early Mesolithic Stage 3)	~10,350-9,700	44
Late Mesolithic	~9,700-6,000	66
Mesolithic (no defined period)	~11,500-6,000	103

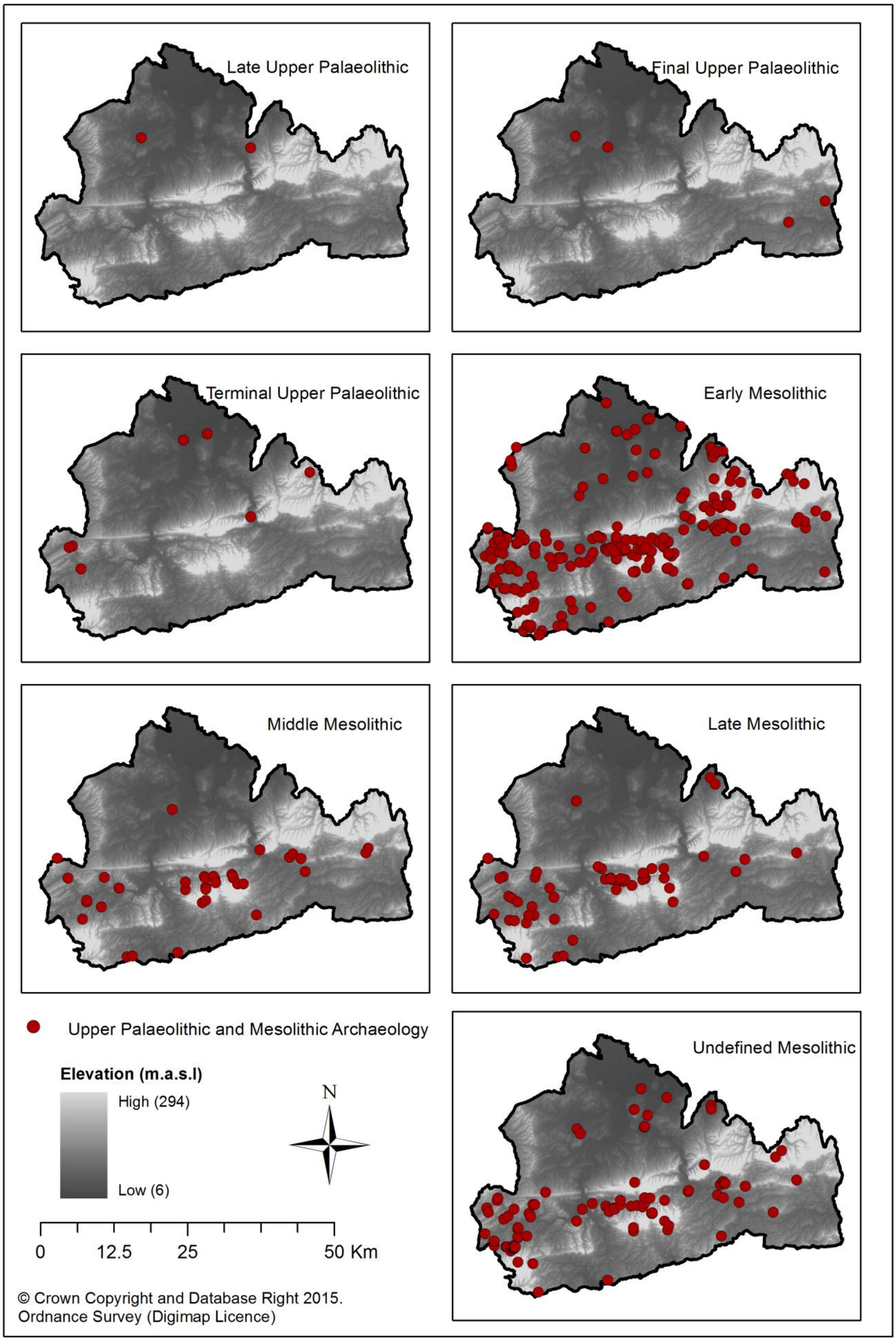


Figure 3.9. Distribution of sites (PaMELA archive) through specific time periods.

The Late Upper Palaeolithic had a scattering of sites, spread across the County, and at no time were there enough sites to begin examining the spatial distribution or patterning. An increase in sites was observed during the Early Mesolithic, where sites were spread with a strong bias to the west-east patterning observed in the HER data. The Horsham period had a majority of sites confined to the south of the County with only one site identified in the north. This was a pattern that continued into the Late Mesolithic, where no sites were identified on the Clay-with-Flints and only three sites were identified in the north. These are patterns that have also previously been observed (Ellaby, 1987; Cotton, 2004) and it may be due to different activities undertaken in these regions during the three Mesolithic periods. This may be a reflection of the type of diagnostic artefacts that are used to identify these periods, especially if the range of artefacts used during the Horsham Period and Late Mesolithic are not identified in the typological dating system. The HER records indicate a diverse range of tool types in the North of Surrey although there is a lack of microliths, and these periods are defined on their microlith assemblages. Therefore these areas may have been used during these periods, but for activities other than those using microliths. This may mean that this area was not suitable for hunting during the Late Mesolithic, further examined in conjunction with the palaeoenvironmental data in Chapter 9.

This means it is important to take into account the 103 broad Mesolithic records that were present in the PaMELA database as these, if not spread evenly in time and ascribed to one particular Mesolithic period, would have modified the distribution pattern, and may provide further evidence for activity across the County. These undefined Mesolithic records (Figure 3.9) were scattered broadly across the County, and do not appear to assist with broadening the range of Mesolithic activity. This identifies one issue with typological classification systems and can lead to difficulties interpreting the PaMELA record, particularly when looking at spatial patterning and trends through time. Where the PaMELA dataset was very useful, however, was for gathering further information on specific sites that could be linked to other information; for example a radiocarbon dated palaeoenvironmental record.

3.3. A Comparison of the two databases

Ideally, once the PaMELA dataset had been downloaded it would have been integrated with the HER database in order to have a single database providing the maximum information about Late Upper Palaeolithic and Mesolithic archaeology across the County. Unfortunately, the datasets did not correlate. Only 48 sites correlated on a basis of their grid references and only a further 64 could be tentatively correlated based on their site information. This left 310 records (73.5% of the dataset) that did not correlate at all, in addition to those which may have been incorrectly correlated. This mismatch between the two records was due to a number of factors; (1) the records may be new independent records, therefore a match would not be expected; (2) different names may have been applied to sites, and (3) grid references may have differed. Because of these discrepancies, the two datasets were not combined and they were considered to provide complementary but different information, at least for the majority of records. The HER database was primarily used for information about finds and artefacts at different sites, due to the greater detail on artefacts, and the greater number of sites. The PaMELA dataset was used to examine temporal patterns in the archaeology due to the typological distinctions given to diagnostic flints within this record. If information was required about a specific location then both databases could be examined, gathering as complete a picture as possible.

There were similarities in the data, however, which could be observed within the density plots (Figure 3.10). These were designated as hotspots, predominantly along the Lower Greensand that runs east-west across the centre of the County. Density maps were created using sites in the surrounding counties, in order to mitigate against any edge contamination effects from the arbitrary County border. Band collection statistics provided a correlation co-efficient of 0.78, and identified a moderate to strong positive correlation between the PaMELA and HER data within Surrey. Having two different datasets provided an excellent opportunity for robust spatial predictive modelling, as the model could be built upon the larger HER dataset, and tested with the PaMELA dataset.

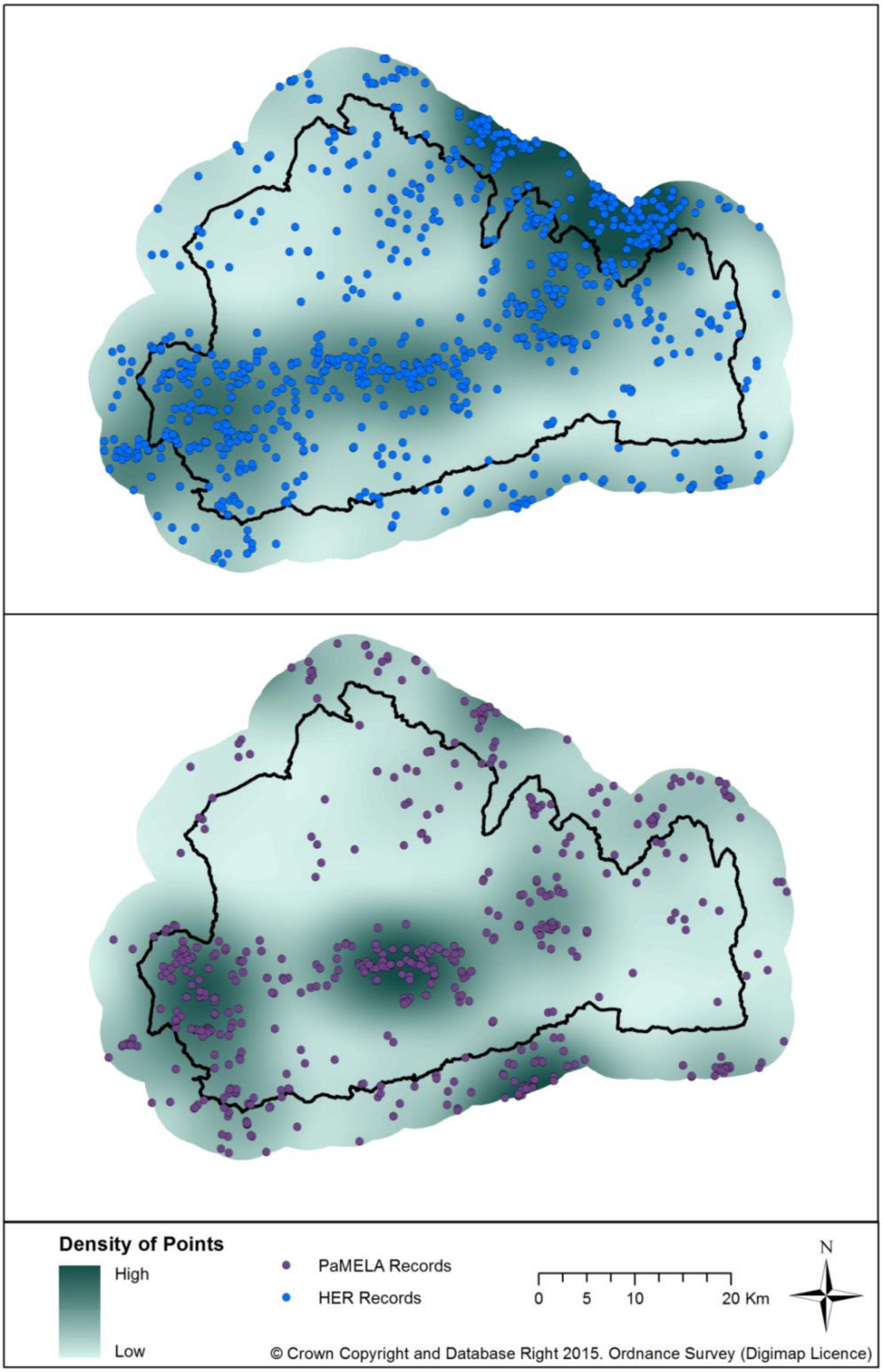


Figure 3.10. HER and PaMELA Mesolithic records and their relative density within Surrey.

3.4. Environmental variables and the archaeological record

Analysis of environmental variables and the archaeological record provided valuable information on where Mesolithic people may have been most active and some of the reasons why these may have been favoured locations. The Late Upper Palaeolithic records were not considered here as the results would not be statistically significant due to a lack of record points, although some anecdotal observations were examined if they followed or contrasted significantly with the patterns observed from the Mesolithic data.

3.4.1. Elevation

The topography of Surrey was dominated by the North Downs and Surrey Hills, running broadly west to east across the centre of the County. The maximum height was 294m a.s.l at Leith Hill. The minimum height was almost at sea level, where the River Mole joins the River Thames. This was in an area of the County where much of the elevation was below 50m a.s.l. due to the passage of rivers across the Thames valley floor (Figure 3.11).

All assumptions were met for the elevation dataset. One category had expected frequencies below 5, but this accounted for less than 1% of the expected frequencies, meaning that the test was still robust (Cochran, 1952; Mitchell, 1971). The critical value of X^2 was 12.59 with 5 degrees of freedom at $\alpha = 0.05$ (Table 3.7). As 73.742 > 12.59 there was a significant difference between the expected and observed distributions and a relationship existed between elevation and Mesolithic record distribution.

Table 3.7. Chi-squared statistical test for Mesolithic records and their elevation.

Height (m a.s.l)	**Number of Cells**	**Area (km^2)**	**Area (%)**	**Observed Number of Records**	**Expected Number of Records**	**Chi-Square Statistic**
0-50	4794608	479.460	28.708	114	153.018	9.949
51-100	7458544	745.854	44.659	213	238.037	2.633
101-150	2585924	258.592	15.483	114	82.528	12.001
151-200	1436236	143.624	8.599	75	45.836	18.555
201-250	380284	38.028	2.277	9	12.136	0.810
251-300	45216	4.522	0.270	8	1.443	29.794
Total	16700812	1670.081	100	533	533	***73.742***

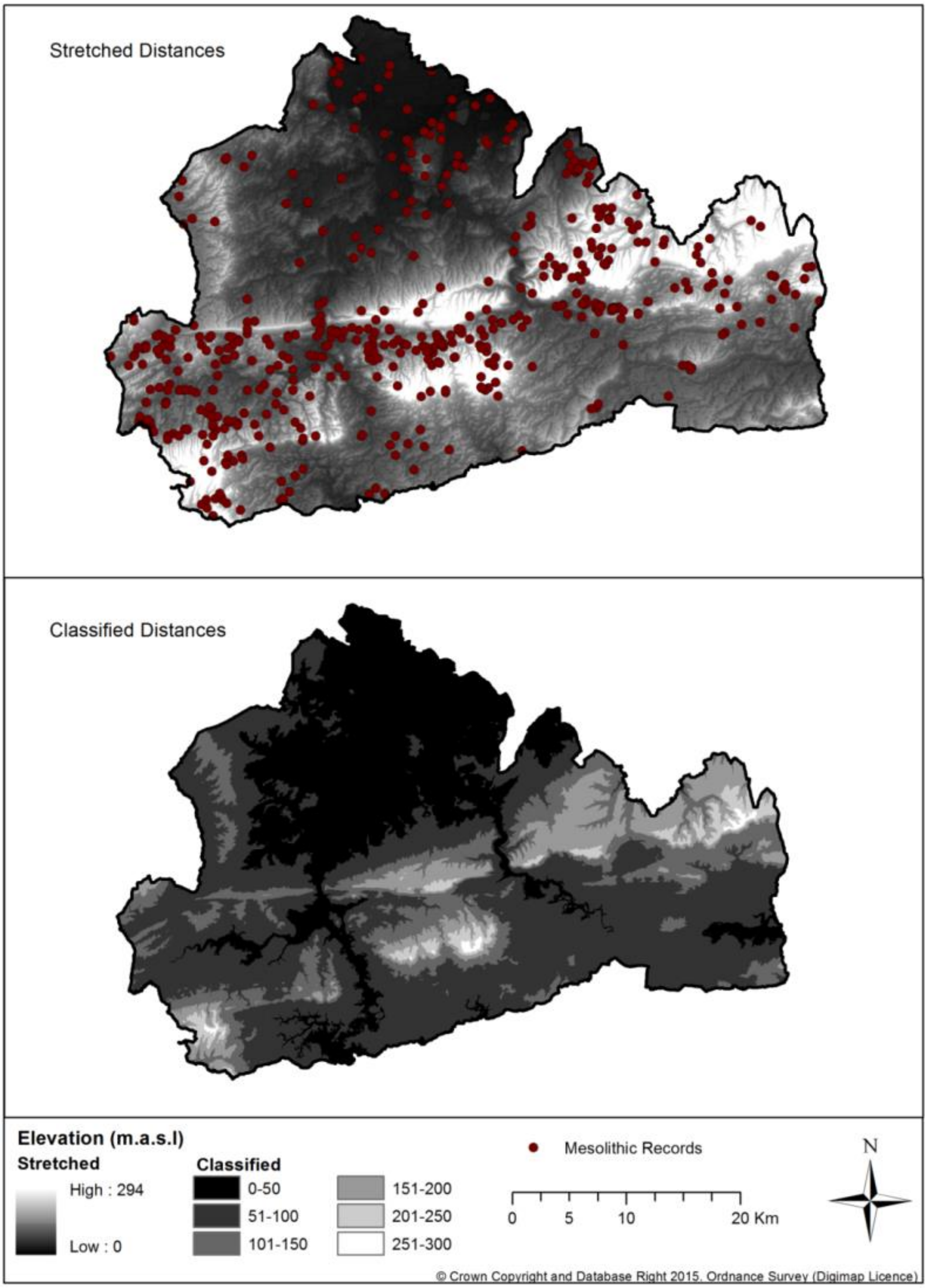


Figure 3.11. Elevation stretched and classified maps with the Mesolithic records.

The distribution of Mesolithic records was not spread equally across the County in relation to their elevation. The majority of sites (83%) were found below 150m, although there were fewer records than expected on lower topographies (0-100m) and more sites than expected on many of the higher topographies (100-200m, 251-300m). Although there was clearly a distinct focus on lower level locations, primarily due to the amount of area that these categories occupy, higher elevation locations were also being visited by Mesolithic people at a significantly higher frequency than may have been expected. The hypothesis that Mesolithic sites situate themselves on higher ridge tops (Kvamme and Jochim, 1990) appeared to be disproven in Surrey, as the majority of sites were found in lowland locations. These records identified in the highest elevations comprise primarily of lithic scatters and findspots, with a dominance of axes, microliths and associated debris. This may indicate that Mesolithic people were using the higher regions potentially for shorter periods of time as lookout or observation points whilst hunting, or, in the case of the higher land around the Clay-with-Flints, as part of raw material acquisition trips.

3.4.2. Geology

The geology of Surrey is diverse and included large areas of both bedrock and superficial deposits (Figure 3.12). The Chalk group split the County in the middle, with the major facies of the Lower Greensand and Wealden Groups to the south, and the Bracklesham and London Clay units to the north. The superficial deposits were found extensively within the north, with large areas of superficial sand and gravel and alluvium, which were found to a much lesser extent in the south. Large clay-with-flint outcrops were found on the chalk escarpments in the east of the study area.

All assumptions were met for the Geology dataset. Although two categories exhibited expected frequencies below 5, this equated to only 1% of the expected frequencies, so the Chi-squared test was still robust (Cochran, 1952; Mitchell, 1971). The critical value of X^2 was 19.68 with 11 degrees of freedom at $\alpha = 0.05$ (Table 3.8). As $496.00 > 19.68$ the null hypothesis (no difference between expected and observed Mesolithic record distribution related to their geology) could be rejected. This means there was a significant difference between the expected and observed distribution of Mesolithic records in relation to geology.

Examining the distribution map (Figure 3.12) shows that the Mesolithic records did not appear to be evenly distributed, and that locations were potentially related to geological type (Mellars and Reinhardt, 1978).

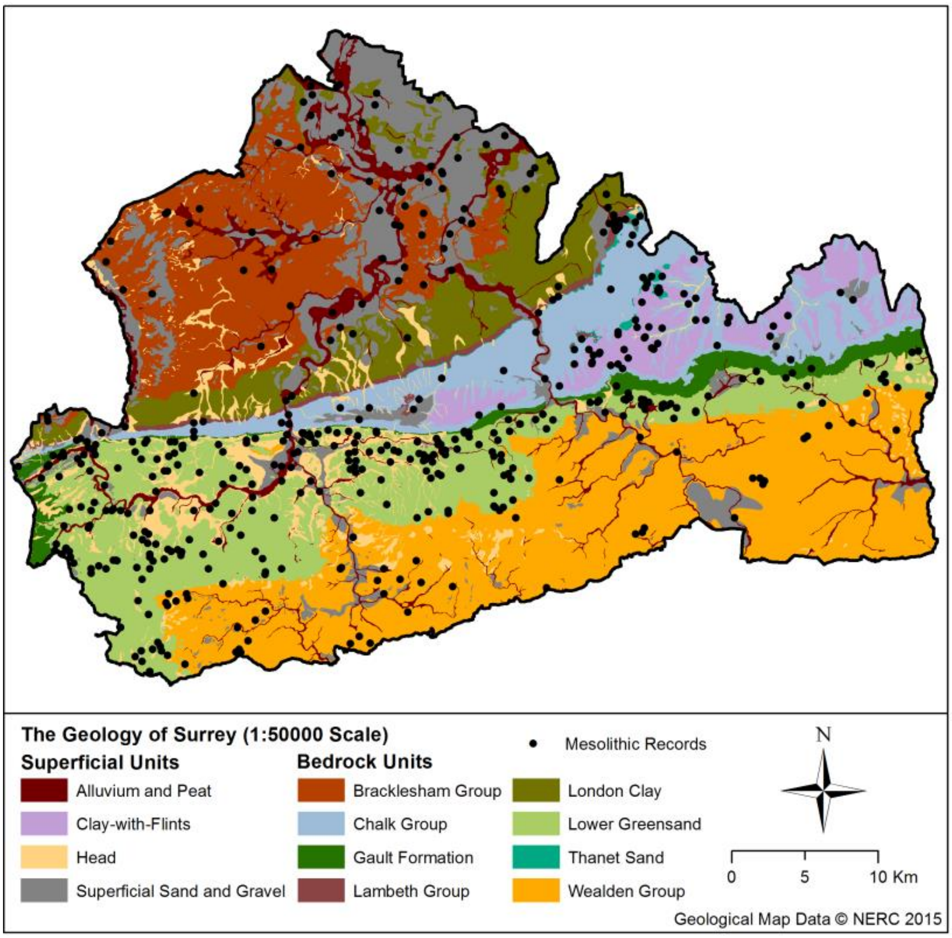


Figure 3.12. Geological units within Surrey.

Table 3.8. Chi-squared statistical test for Mesolithic records and their geological setting.

Geology	**Area (km²)**	**Area (%)**	**Observed No. of Records**	**Expected No. of Records**	**Chi-Square Statistic**
Alluvium and Peat	93.801	5.617	19	29.936	3.995
Bracklesham	197.911	11.850	23	63.163	25.538
Chalk Group	151.471	9.070	33	48.342	4.869
Clay-with-Flints	72.779	4.358	36	23.227	7.024
Head	95.694	5.730	44	30.541	5.932
Lambeth Group	13.269	0.795	12	4.235	14.238
London Clay	122.810	7.354	7	39.195	26.445
Lower Greensand	268.489	16.076	231	85.688	246.426
Selbourne Group	40.139	2.403	5	12.810	4.762
Sand and Gravel	221.813	13.282	69	70.791	0.045
Thanet Sand	4.849	0.290	14	1.547	100.212
Wealden Group	387.046	23.175	40	123.525	56.478
Total	1670.072	100	533	533	***495.964***

There appeared to be a concentration of records on and around the Lower Greensand, and this was confirmed to be a significant observation, with over 2.5 times more records on the Lower

Greensand than expected if the distribution was random. Significant differences also occurred on the Thanet Sands, Lambeth Group and the Clay-with-Flint outcrops, all areas where there were more records than expected, although the Thanet Sands and Lambeth Group had small numbers overall. These areas may have been significant raw material acquisition locations. The Wealden Group, London Clay and the Bracklesham Group, all had fewer records than would be expected by chance. The lower than expected finds on the alluvium and peat are important, as these are areas that people may have expected to visit due to potential hunting and gathering opportunities. The observed lack of records may be related to the potential that some of these deposits are younger than the Mesolithic, and therefore the records may be buried leading to underrepresentation on this substrate.

3.4.3. Aspect

The aspect map was based on the elevation and determined the direction each cell in the County was facing (Figure 3.13). The aspect map was coloured based on the MKS-ASPECT system which preserved perceptual relief (Moellering, 1993) and was able to show clear distinctions between the predominant valleys and ridges.

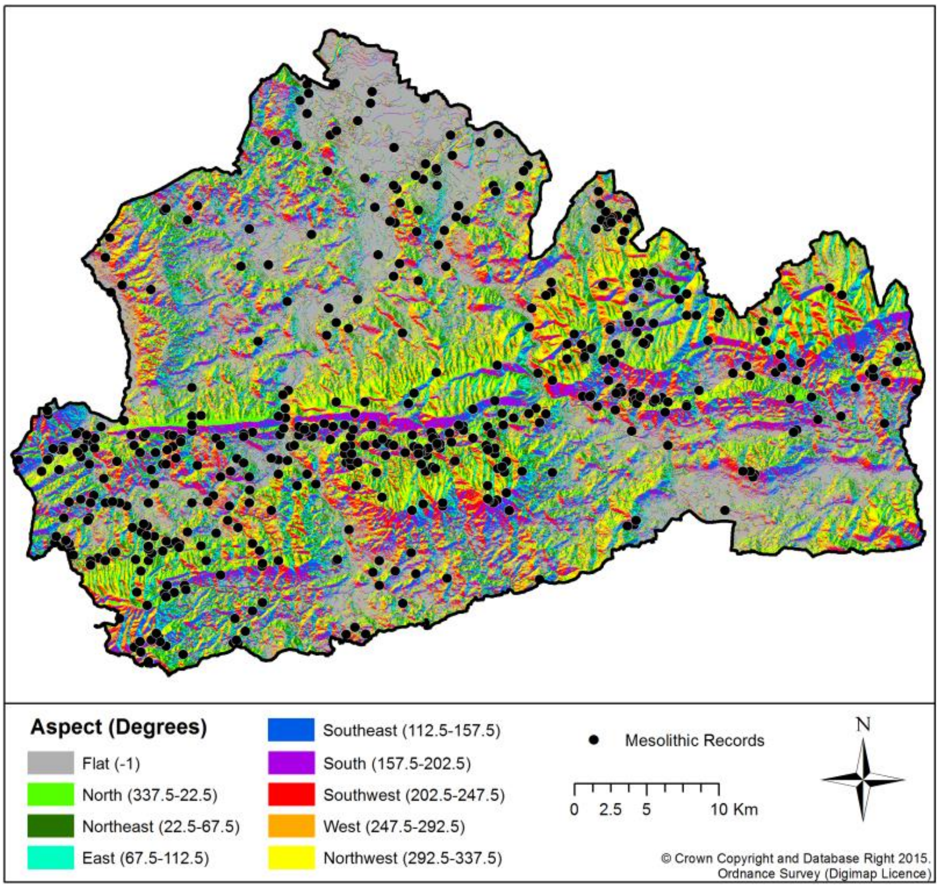


Figure 3.13. Aspect categories based on the digital elevation model.

The aspect dataset met all the assumptions for the chi-square test (Table 3.9). The critical value of X^2 was 15.51 with 8 degrees of freedom at $\alpha = 0.05$. The chi squared statistic 10.064 < 15.51 so there was not a significant difference between the expected and observed distribution of Mesolithic records and therefore the distribution may have been due to chance. Aspect did not seem to be a controlling factor in determining Mesolithic locations in Surrey. There was still some evidence to suggest that the hypothesis that Mesolithic locations would prefer the higher solar insolation received from south facing slopes was correct, as the southeast, south and southwest facing slopes all had more records than expected, however this was not statistically significant when the dataset was analysed as a whole, which may not be surprising if many of the findspots reflect casual losses during trips or short-term activities. This may be the case, as only 6 out of the 16 total site records within the dataset can be found across these three south facing aspects, a number which would be expected to be higher if people were actively choosing these south facing slopes.

Table 3.9. Chi-squared statistical test for Mesolithic records and their aspect category.

Aspect Category	**Number of Cells**	**Area (km^2)**	**Area (%)**	**Observed Number of Records**	**Expected Number of Records**	**Chi-Square Statistic**
Flat	5204905	520.491	31.166	153	166.113	1.035
North	1503234	150.323	9.001	48	47.975	0.000
North East	1562969	156.297	9.359	47	49.882	0.166
East	1211054	121.105	7.251	37	38.650	0.070
South East	1580005	158.001	9.461	51	50.425	0.007
South	1282913	128.291	7.682	52	40.944	2.986
South West	1308857	130.886	7.837	55	41.772	4.189
West	1184051	118.405	7.090	30	37.789	1.605
North West	1862799	186.280	11.154	60	59.451	0.005
Total	16700787	1670.079	100	533	533	***10.064***

3.4.4. Slope

Slope angles for Surrey were plotted in ArcGIS (Figure 3.14) and analysed using the chi-squared test (Table 3.10). One category had an expected frequency below 5, however this accounted for only 0.25% of the expected frequencies so the test was considered robust. All other chi-square assumptions were met. The critical value of X^2 was 14.07 with 7 degrees of freedom at $\alpha = 0.05$. The chi-square value (24.739) was greater than the critical value (14.07) and the null hypothesis was rejected. Therefore a significant difference existed between expected and observed distribution of Mesolithic records compared to their slope angle.

Table 3.10. Chi-squared statistical test between slope angles and Mesolithic records.

Slope Angle (°)	**Number of Cells**	**Area (km^2)**	**Area (%)**	**Observed No. of Records**	**Expected Number of Records**	**Chi-Square Statistic**
0-1.432	6500245	650.025	38.922	181	207.453	3.373
1.433-4.169	5764373	576.437	34.516	173	183.968	0.654
4.170-6.763	2320660	232.066	13.896	103	74.063	11.306
6.763-9.520	1029075	102.908	6.162	34	32.843	0.041
9.521-13.271	556894	55.689	3.335	15	17.773	0.433
13.271-17.753	328245	32.825	1.965	16	10.476	2.913
17.754-24.261	159385	15.939	0.954	7	5.087	0.720
24.262-63.706	41910	4.191	0.251	4	1.338	5.300
Total	16700787	1670.079	100	533	533	***24.739***

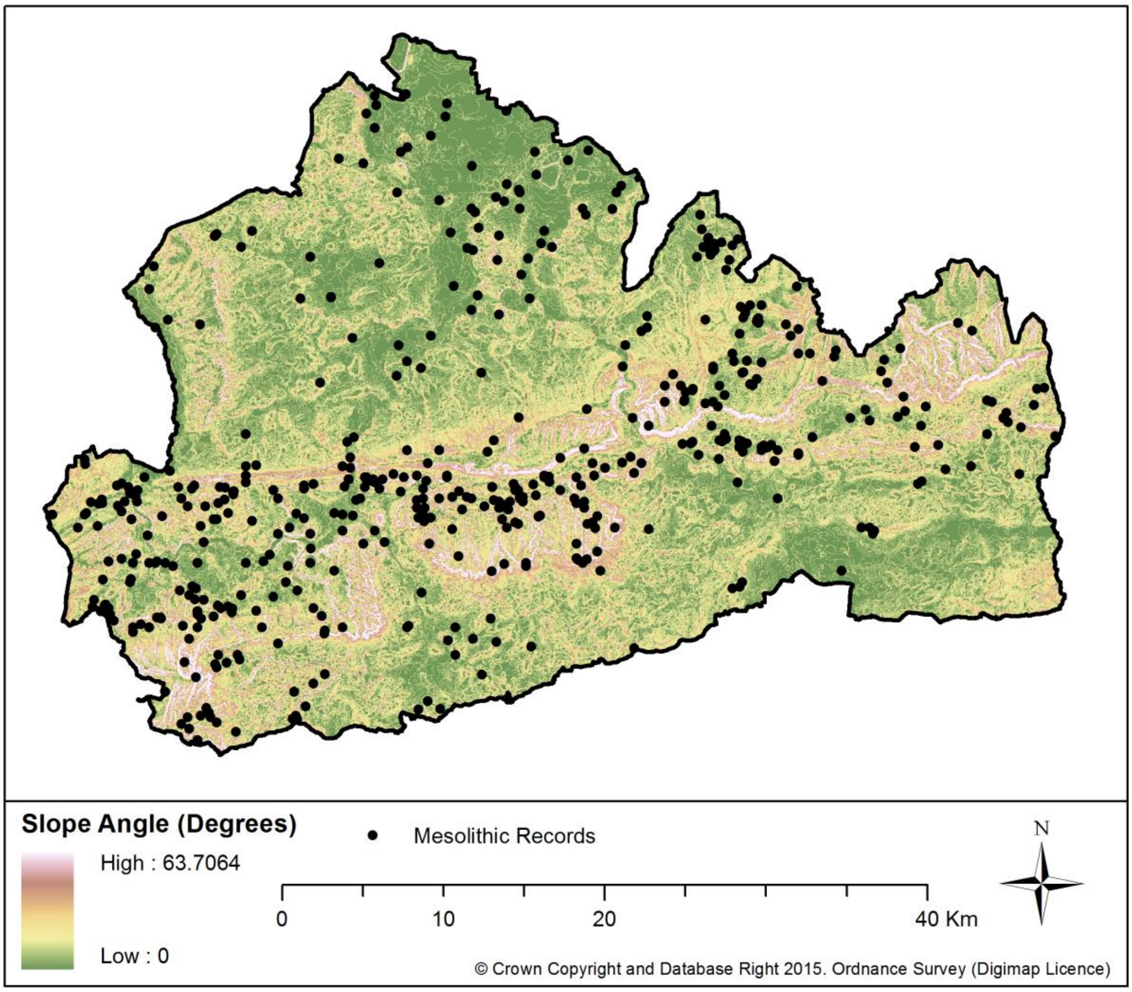


Figure 3.14. Slope angles across Surrey.

Hunter-gatherer sites have often been argues to be preferentially situated on low lying ground or the lower slopes where mobility was not overly impeded (Kvamme and Jochim, 1990; Kvamme, 1992). From the results of analysing the Surrey dataset, the vast majority of sites

(86%) were found on sites where the slope angle was less than 6.7 degrees. Although there were lower than expected numbers of records on the very low slopes (0-4.1˚), the higher than expected number of sites on the 4.1-6.7 degree ground and the sheer number of sites across this entire low-angle range suggest that Mesolithic locations were preferentially chosen due to a lower slope angle, although not necessarily completely flat, and this may also have indicated a bias towards easier identification locations (e.g. fieldwalking). There were also more sites than expected on the steeper ground. Records on steeper ground often correlated with a higher elevation and may have resulted from visits to these locations due to their potential observation benefits. As with the records at higher elevation, these are primarily comprised of findspots and lithic scatters, again with microliths, axes and debris potentially suggesting their use as lookouts during hunting trips.

3.4.5. Total Wetness Index

The total wetness index (TWI) examined the land's potential to hold and retain water (Figure 3.15). It is not thought that the landscape wetness has changed significantly due to the static geology present in the region likely being a governing factor, although this could be a possible aspect to consider as watercourses and soil types can change over time. This is ameliorated through the use of cell aggradation as discussed in Chapter 2. A chi-squared test was used to examine relationships between Mesolithic record locations and TWI category (Table 3.11). No assumptions were broken with the data and the critical value of X^2 was 7.81 with 3 degrees of freedom at $\alpha = 0.05$. A significant difference existed between the expected and observed distribution of Mesolithic records in relation to the total wetness index, and the null hypothesis could be rejected as the chi-square statistic 13.792 > 7.81.

Table 3.11. Chi-squared statistical test for Mesolithic records and the total wetness index.

TWI Category	**Number of Cells**	**Area (km^2)**	**Area (%)**	**Observed Number of Records**	**Expected Number of Records**	**Chi-Square Statistic**
Very Wet	107521	268.803	16.095	62	85.785	6.594
Wet	200702	501.755	30.043	144	160.128	1.624
Wet/Dry	320412	801.030	47.962	292	255.637	5.172
Dry	39419	98.548	5.901	35	31.450	0.401
Total	668054	1670.135	100	533	533	***13.792***

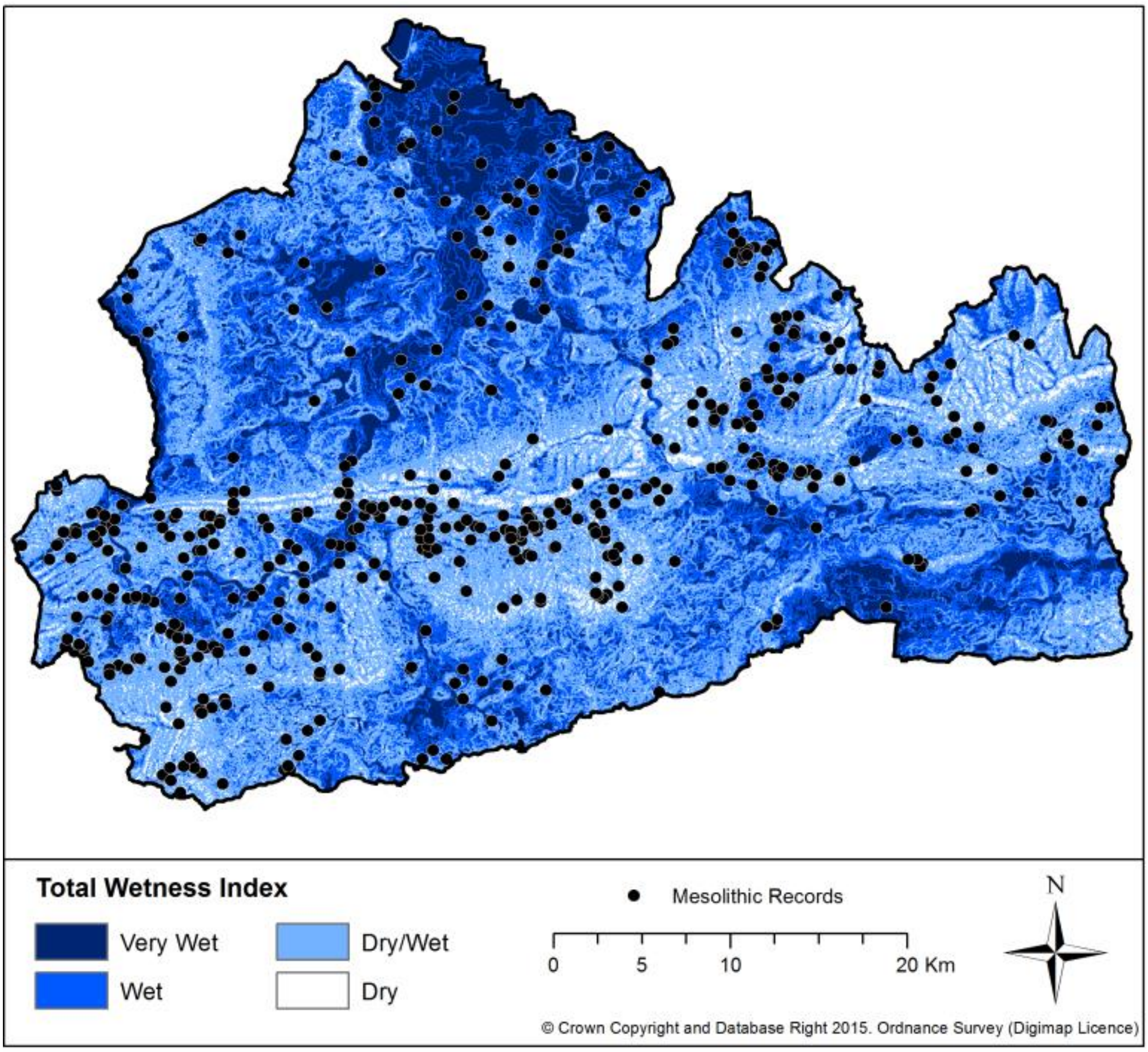


Figure 3.15. Total Wetness Index categorised values and Mesolithic archaeology.

Locations on and across the wet/dry boundary may have provided ideal conditions for Mesolithic activities, as the wettest areas may have been highly unsuitable due to either continual waterlogging or a sustained high risk of flooding (Farr, 2008). In Surrey, the majority of sites, more than would be expected, were situated upon the wet/dry regions (55%). This is a significant finding as it highlights the prominence that these areas would have had within the Mesolithic landscape. The importance of these areas was discussed in Chapter 1 and will be further debated in Chapter 9 alongside the palaeoenvironmental record from wetland sites near to the wet/dry edge. Both the wet and very wet categories produced fewer sites than were expected, suggesting that Mesolithic people may have visited these locations on fewer occasions or for less time. It may also be that these areas were less appealing to modern day archaeological investigations.

3.4.6. Distance to Strahler Order 3 and Greater Rivers

Rivers with a Strahler order of over 3 were likely to be relatively permanent in the landscape (Figure 3.16). Edge effects were taken into account in this dataset due to the potential for streams and rivers on or near the County border. A chi-squared test assessed the link between rivers and Mesolithic records (Table 3.12). The chi-squared assumptions were met, with only 0.7% of dataset with expected frequencies below 5 (Cochran, 1952; Mitchell, 1971). The critical value of X^2 was 19.68 with 11 degrees of freedom at $\alpha = 0.05$. Because $9.686 < 19.68$ the null hypothesis was accepted and there was no significant difference between expected and observed distribution of Mesolithic records in relation to their distance to >3 Strahler rivers.

Table 3.12. Chi-squared test: Mesolithic records and distance to Order >3 Strahler rivers.

Distance to >3 Order Strahler Rivers (m)	Number of Cells	Area (km^2)	Area (%)	Observed No. of Records	Expected No. of Records	Chi-Square Statistic
0-500	265175311	265.175	15.878	93	84.630	0.828
501-1000	238509002	238.509	14.281	89	76.120	2.180
1001-1500	217205554	217.206	13.006	62	69.321	0.773
1501-2000	200140580	200.141	11.984	62	63.874	0.055
2001-2500	176035442	176.035	10.541	55	56.181	0.025
2501-3000	147129367	147.129	8.810	52	46.956	0.542
3001-3500	130191162	130.191	7.796	32	41.550	2.195
3501-4000	112317051	112.317	6.725	31	35.846	0.655
4001-4500	89362546	89.363	5.351	24	28.520	0.716
4501-5000	55329179	55.329	3.313	17	17.658	0.025
5001-5500	27201954	27.202	1.629	10	8.681	0.200
>5501	11474683	11.475	0.687	6	3.662	1.492
Total	1670071831	1670.072	100	533	533	***9.686***

The hydrological location of Mesolithic sites has often been argued to be of high importance when determining site location (Kvamme and Jochim, 1990; Brandt et al., 1992; Kvamme, 1992). However, the chi-square test results showed that this relationship was not statistically significant for Surrey and there appeared to be no relationship between the two. There was some evidence for more sites than expected in regions within 1000m of >3 order streams, however this was not significant. Possible reasons for this included the fact that the dataset includes findspots and scatters in addition to the occupation site data. Therefore a relationship may have existed between the occupation sites and river network; however there were not enough sites within the database for the application of this test to be significant and visual examination of the data was inconclusive. It may also be that some of the streams or rivers may have changed course or dried out and infilled, skewing the modern day picture of where these Strahler >3 order rivers were within the landscape. LIDAR data was used in order to try and assess the potential presence of palaeoechannels proximal to modern day rivers, however this was unsuccessful due to the coarseness of LIDAR resolution (1m) and modern day land manipulation around many of the watercourses in Surrey. In order to further attempt to check if this observation was a result of the categorisation of the dataset into 12 distance bands, the test was run with broader categories (1000m distances between bands), which encompassed the potential scale of local channel shifting. The result remained to accept the null hypothesis and there was no significant difference between observed and expected record distributions in relation to Strahler streams ($X^2 = 7.930 < 11.07$ with 5df at $\alpha = 0.05$). This may have been due to the use of alternate water sources such as local springs or ephemeral channels, or the nature of modern collecting.

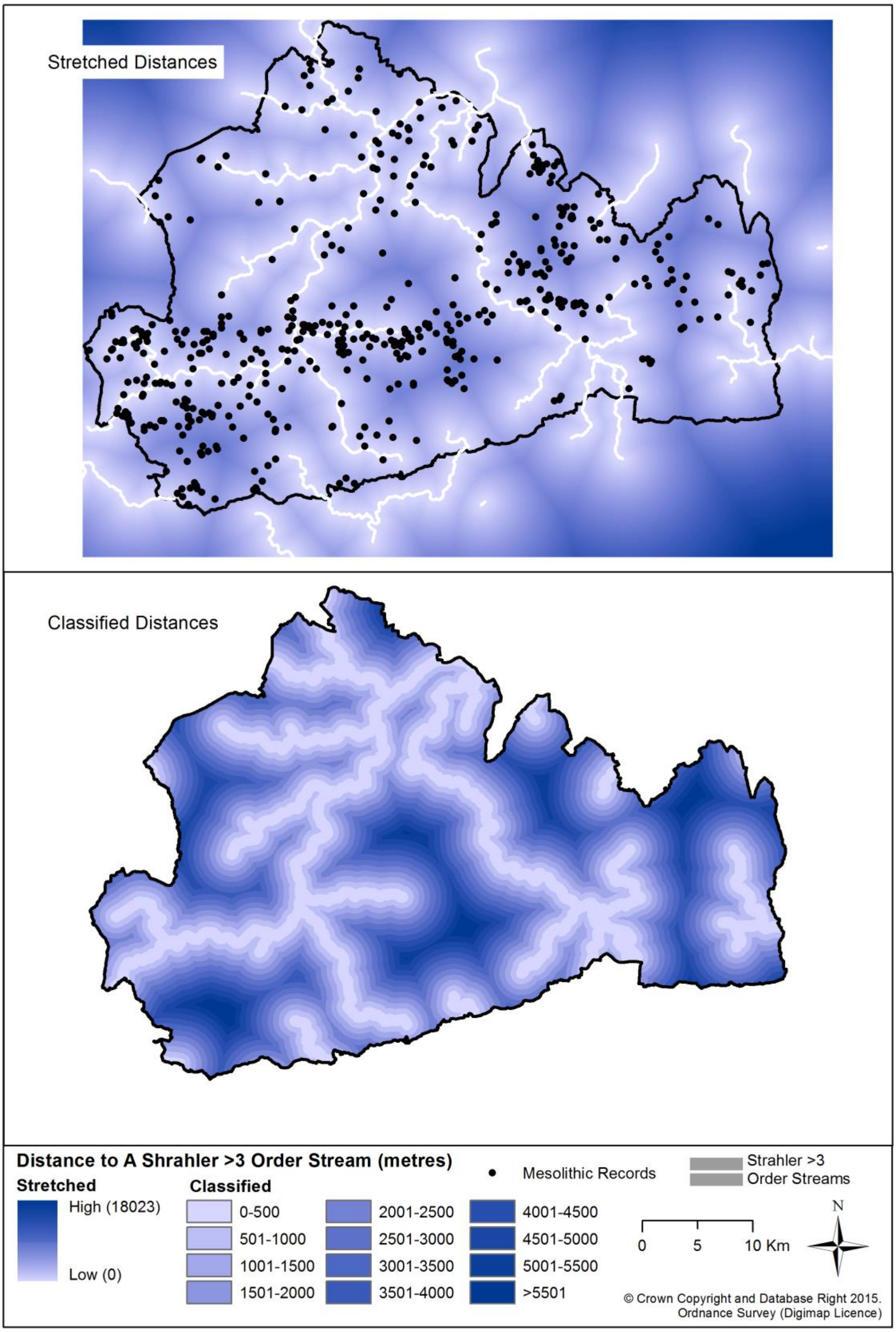


Figure 3.16. Distance to a Strahler >3 order stream, classified and stretched maps.

3.4.7. Distance to Lower and Upper Greensand

The Greensand units within Surrey run east-west across the County with much larger expanses in the west (Figure 3.17), and also extend across Kent, Hampshire and Sussex (Gallois, 1965). The Greensand is crossed by alluvial channels (potentially significant as regions local to water resources during the Mesolithic), superficial sand, gravel and head deposits that overlie the Greensand bedrock causing it to be highly fragmented. A chi-squared test examined relationships between the distance to the Greensand and Mesolithic records (Table 3.13).

Table 3.13. Chi-squared statistical test for Mesolithic records and the distance to Greensand.

Distance to Greensand (m)	**Number of Cells**	**Area (km^2)**	**Area (%)**	**Observed No. of Records**	**Expected No. of Records**	**Chi-squared Statistic**
0-1000	5395994	539.599	32.310	329	172.211	142.748
1001-5000	4477023	447.702	26.807	77	142.882	30.378
5001-10000	3355604	335.560	20.092	49	107.093	31.513
1001-15000	1743259	174.326	10.438	46	55.635	1.669
15001-20000	1120940	112.094	6.712	23	35.774	4.561
>21000	607990	60.799	3.640	9	19.404	5.578
Total	16700810	1670.081	100	533	533	***216.447***

The chi-squared assumptions were met for the distance to Greensand data. The critical value of X^2 was 11.07 with 3 degrees of freedom at $\alpha = 0.05$. As the chi-square statistic 216.447 > 11.07 there was a significant difference between the expected and observed distribution of Mesolithic records and the null hypothesis was rejected. This showed a significant correlation between the distance to the Greensand and record location.

The Greensand has long been identified as the source of many of the largest Mesolithic sites in the country (Rankine, 1956) and this was evidenced within Surrey with 62% of the dataset within 1000m of the Greensand. There were many more sites on the Greensand than would have been expected by chance and assemblage abundance within the distance categories decreased with increasing distance from the Greensand. Although this was to be expected with the declining area of greensand in each band further away, the observed distribution declined by more than would be expected from a random distribution, and suggested a strong relationship between the Mesolithic records and the Greensand geologies. Potentially, this was related to the ferruginous sandstone clasts that could have been present within the greensand which may have been used within hearths (Jones, 2013b).

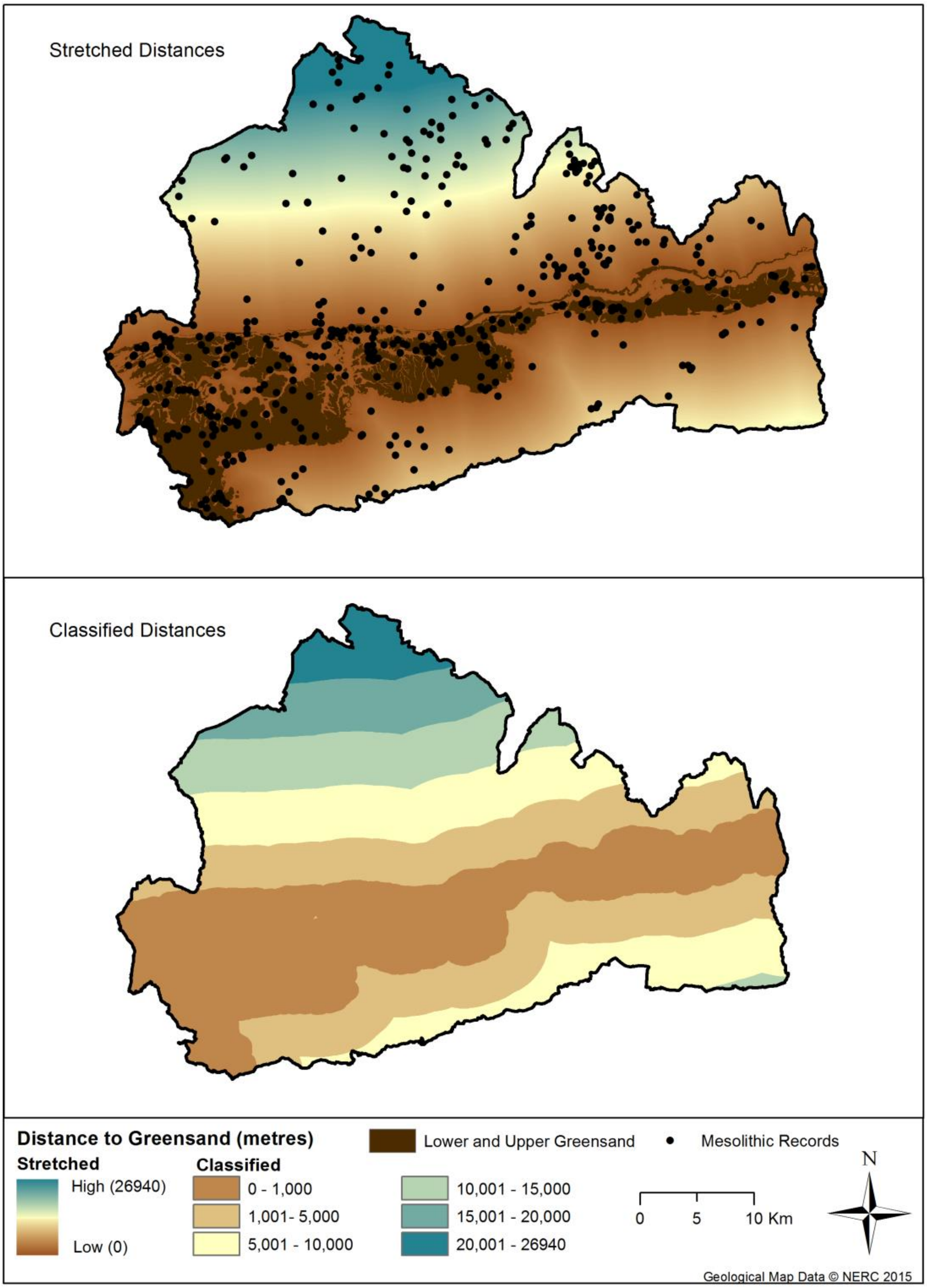


Figure 3.17. Distance to Lower and Upper Greensand.

3.4.8. Distance to Clay-with Flints

The distribution of the clay-with-flints geology in Surrey is predominantly to the east of the County and runs along the exposed face of the North Downs, often overlying the Chalk, the main unit within the Downs (Figure 3.18). This extensive formation continues to the east into Kent and further large expanses of clay-with-flints occur to the west in Hampshire and to the north in Berkshire. A chi-squared model examined links between the flint outcrops and Mesolithic records to see if significant relationships existed (Table 3.14).

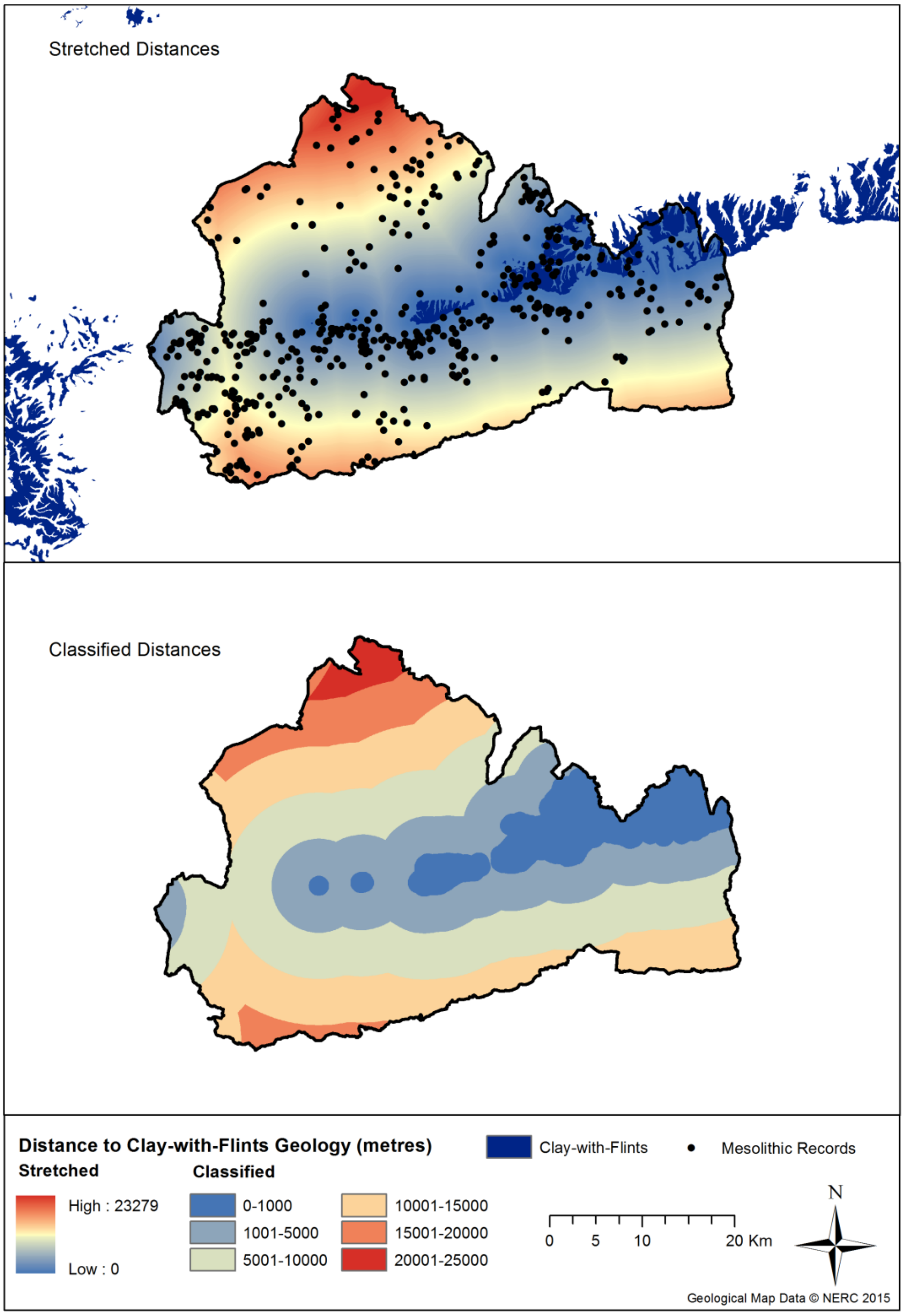


Figure 3.18. Distance to Clay-with-Flints geology.

Table 3.14. Chi-squared test for Mesolithic records and the distance to clay-with-flints.

Distance to Clay-with-Flints (m)	Number of Cells	Area (km^2)	Area (%)	Observed Number of Records	Expected Number of Records	Chi-Square Statistic
0-1000	195599694	195.600	11.712	72	62.425	1.469
1001-5000	383808402	383.808	22.982	203	122.492	52.915
5001-10000	517525826	517.526	30.988	128	165.167	8.364
10001-15000	403295671	403.296	24.148	96	128.711	8.313
15001-20000	134695995	134.696	8.065	28	42.988	5.226
20001-25000	35145915	35.146	2.104	6	11.217	2.426
Total	1670071503	1670.072	100	533	533	***78.712***

All assumptions of the test were met with the distance to clay-with-flints dataset. The critical value of X^2 was 11.07 with 3 degrees of freedom at $\alpha = 0.05$. The chi-square statistic of 78.712 > 11.07 meant that there was a significant difference between the expected and observed distribution of Mesolithic records in relation to their distance to clay-with-flint outcrops. The clay-with-flints on the North Downs (Field, 1998) would have been an important natural source of material due to the abundance of flint (Barton and Roberts, 2004; Barton, 2009). Flint would have been available at other locations in Surrey (Gallois, 1965), however the density of flint within the formation may have made this a particularly important source. The results of the chi-square test showed that there were significantly more records than would be expected in locations up to 5000m from the clay-with-flints geology, which accounted for over half of the entire dataset. There is the potential that this relationship could be explained by the locality of the Greensand, and these records are actually related to the Greensand distance, not the distance to Clay-with-Flints. However this is not thought to be the case due to the greater number of records within 1000m of the Clay-with-Flints than expected as well, indicating that this was an important source of raw material. Records that were further than 5000m from the clay-with-flint all show fewer records than was expected. This suggested that Mesolithic records were closely linked to their distance to the clay-with-flint outcrops, most likely due to the presence of a highly valuable natural resource.

The following two variables related to the chances of discovering Mesolithic archaeology. This was because they were both constructs of the modern day use of the land across the County and therefore had no bearing on when or where the artefacts and/or other materials were deposited in Surrey.

3.4.9. Land Cover

Due to the fragmented nature of land cover types in Surrey it was difficult to discern any pattern from the map of land cover type (Figure 3.19). The chi-square test was therefore useful to examine these relationships (Table 3.15), and from the results of the test it was clear that the chances of finding archaeology did vary depending on the current land surface type.

The land cover type dataset met the assumptions for the chi-squared test. The category 'inland rock' had expected frequencies below 5, but only accounted for 0.25% of the overall dataset, meaning that the test was still robust as it was less than 20% (Cochran, 1952; Mitchell, 1971). The critical value of X^2 was 12.59 with 11 degrees of freedom at $\alpha = 0.05$. As $27.01284 > 12.59$ the null hypothesis was rejected and so there was a significant difference between the expected and observed distribution of Mesolithic records. Therefore land cover was influential in determining record discovery location.

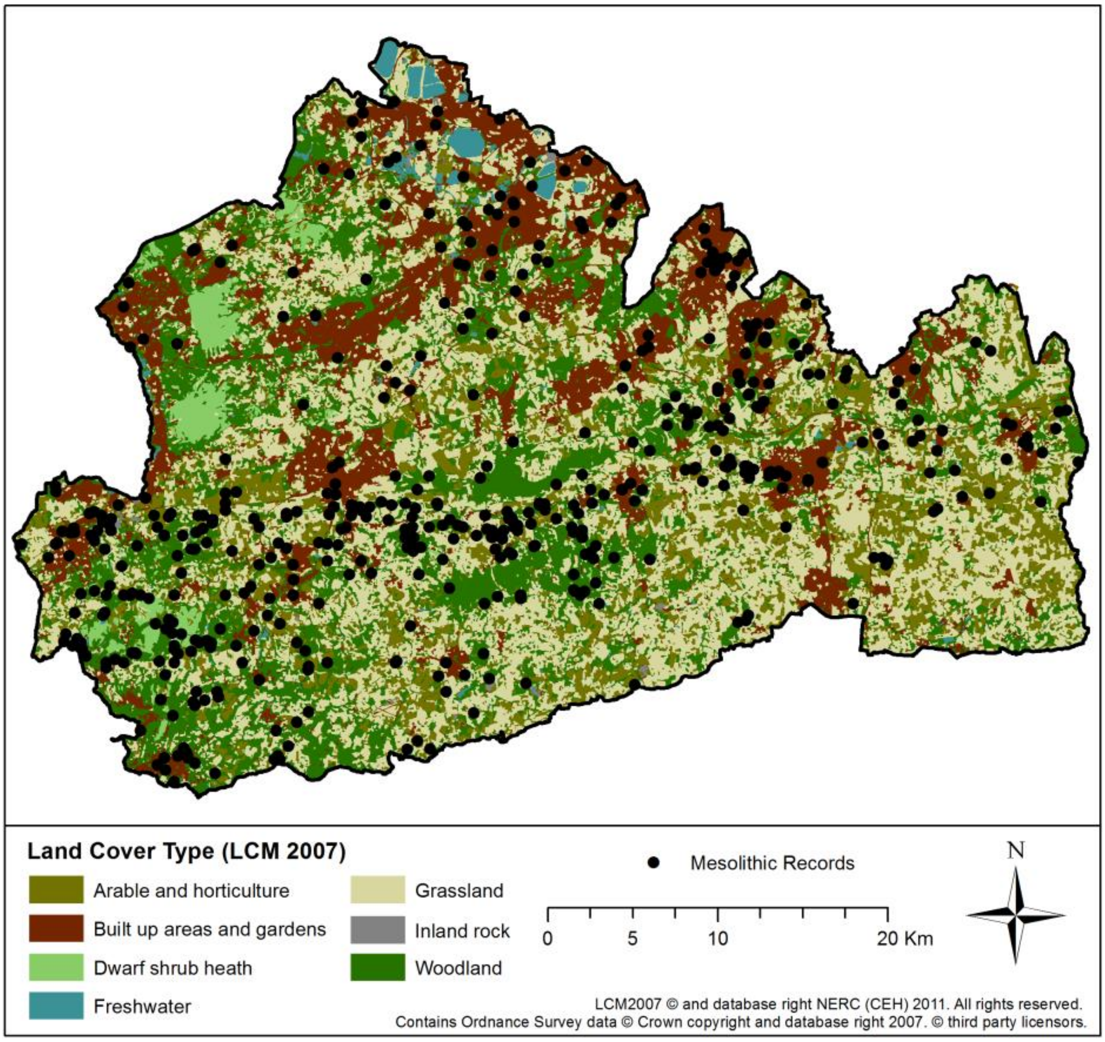


Figure 3.19. Land-cover types in Surrey.

Table 3.15. Chi-squared statistical test for Mesolithic records and their land cover type.

Land Cover Type	Area (km^2)	Area	Observed No. of Records	Expected No. of Records	Chi-Square Statistic
Grassland	610.142	36.533	146	194.723	12.191
Arable and Horticulture	264.193	15.819	95	84.316	1.354
Freshwater	22.561	1.351	5	7.200	0.672
Inland rock	4.047	0.242	4	1.291	5.681
Woodland	427.018	25.569	148	136.280	1.008
Built-Up	302.189	18.094	119	96.442	5.276
Dwarf Shrub Heath	39.942	2.392	16	12.747	0.830
Total	1670.092	100	533	533	***27.013***

The results showed that grassland and woodland accounted for 294 sites, approximately 55% of the dataset. This was not entirely unexpected as these two categories covered the greatest land area (62% of the County). However, there were fewer records than expected on grasslands, and more records than expected across woodland, built-up areas, dwarf shrub heath, and arable and horticultural land. Both inland rock and freshwater land cover types were fairly small so it was difficult to draw meaningful conclusions from these categories. It was likely that current land management practices and land uses accounted for much of this observed distribution, however it was also important to take into consideration the relationship of these land cover types and geology when the distribution patterns were assessed. Built up areas were likely to be overrepresented because of the amount of archaeological work that had been associated with new developments since 1990 and the development of PPG-16 and further legislation. This is not immediately evident in the HER however, as only 57 records provided clear evidence for developer led excavations. It may be that many of the archaeological excavations (56 records) and industrial activity (22 records) were undertaken through urban development work but not recorded as such. Arable and horticultural land was scattered across a diverse range of geologies, so it was perhaps ploughing and fieldwalking that unearthed large and diverse records in these contexts, thereby increasing its observed value in relation to the area. Woodland and dwarf-shrub heath within Surrey were characterised by tree throws, sparse ground flora and the exposure of soils and sediments at the surface, such as the sands of the Lower Greensand being occasionally exposed. These areas would have offered an increased potential for chance surface finds. These factors may have helped explain the higher than expected number of records on these land-cover types. The lower than expected relationship between grasslands and Mesolithic records may be that grasslands did not lend themselves well to finding archaeology as they were characterised by an infrequently disturbed sub-surface and covered with dense vegetation on the surface, making artefacts harder to uncover.

3.4.10. Distance to Roads, Paths and Tracks

The road, path and track network across Surrey is dense (Figure 3.20) and it is important to find out if any significant relationships existed between the network and Mesolithic records (Table 3.16). This helped to understand whether modern day access to, and visibility of, archaeology was determining where Mesolithic records were found.

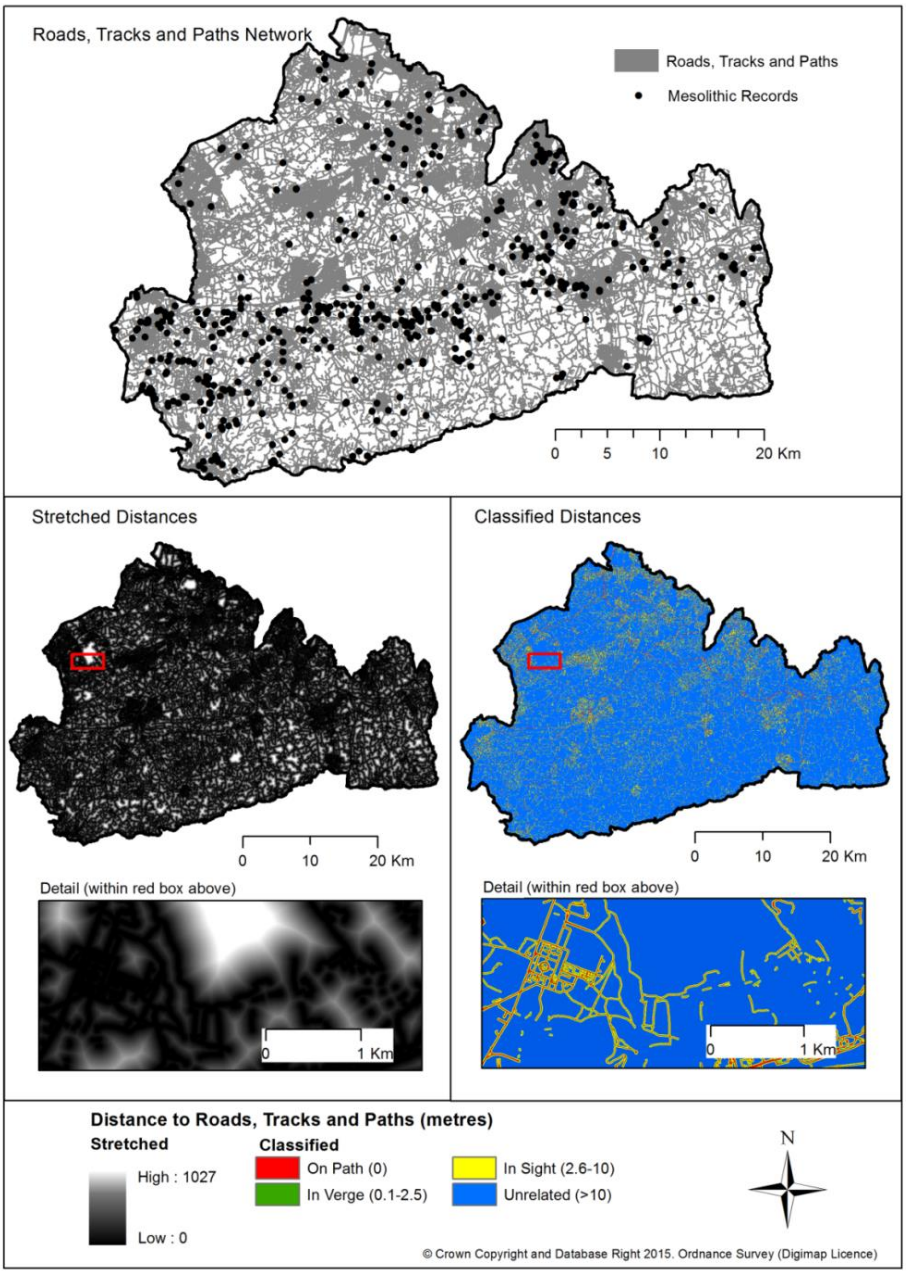


Figure 3.20. Distance to roads, paths and tracks. Top centre shows Surreys' road, track and path network. Bottom right shows the classification of distances and their grouping in detail. Bottom left highlights the raster data (across the same area) indicating distance to nearest road, path or track.

Table 3.16. Chi-squared test of record location and the distance to roads, paths and tracks.

Distance to Roads, Paths and Tracks (m)	Number of Cells	Area (km^2)	Area (%)	Observed No. of Records	Expected No. of Records	Chi-Square Stat.
On Path (0)	58151359	58.151	3.482	21	18.559	0.321
In Verge (0.1-2.5)	46166349	46.166	2.764	17	14.734	0.349
In Sight (2.6-10)	149644457	149.644	8.960	64	47.759	5.523
Unrelated (>10)	1416109409	1416.109	84.793	431	451.948	0.971
Total	1670071574	1670.072	100	533	533	***7.164***

The chi-square assumptions were met for the roads, paths and tracks dataset. The critical value of X2 was 7.81 with 3 degrees of freedom at $\alpha = 0.05$. $7.164 < 7.81$ so there was not a significant difference between the expected and observed distribution of Mesolithic records and the null hypothesis was accepted. Therefore there was no significant relationship between records and their relationship with the road, path and track (RPT). There also appeared to be no relationship between the type of record and the distance from the path, with a variety of records identified at all distance scales. The records unrelated to the network accounted for both the majority of the dataset and the majority of the area of the County. This disproved the hypothesis that higher numbers of records were likely to be found on or near to the RPT network due to a higher chance of being seen by a people on an ad-hoc basis, showing that the RPT network did not determine how and where records were found.

3.5. The Binary Logistic Regression Model

The spatial maps of the HER artefact distribution showed a pattern of Mesolithic activity, in relation to a number of environmental variables. The nearest Neighbour Index for HER Mesolithic sites in Surrey showed clustering (Z=-16.59; P=0.000) with a less than 1% possibility that the observed pattern occurred by chance. The Getis Ord General G test corroborated the results of the Nearest Neighbour Index and showed that there was clustering within the dataset (Z=1.996423; P=0.046) so there was less than 5% probability that these sites were distributed by chance. As neither statistic suggested that the distribution of Mesolithic sites occurred by chance, further modelling was used to attempt to understand the patterns observed within the archaeological data. Once it was confirmed none of the assumptions had been broken, a binary logistic regression model was run using the variables described in Chapter 2. Two maps were produced from the HER data analysis:

- Conditions for archaeological discovery (model 1)
- Potential Mesolithic activity areas (model 2)

3.5.1. Conditions for Archaeological Discovery (Model 1)

3.5.1.1. **Data Input and Model Development**

Dichotomy was met because the data consisted of two groups that were either site or non-site (Mesolithic or random). The relationship between slope and its log transformation was not significant (HER p=0.996; PaMELA p=0.901), and therefore linearity was not violated. Multicollinearity was not an issue for any of the variables within the HER or PaMELA datasets, as all tolerances >0.1 and all VIF values <10 (Field, 2013), therefore all groups were mutually exclusive. All of the predictor samples were large enough for logistic regression, with the exception of Land Cover Type 'inland rock'. This was excluded as this predictor variable had only five samples. All other groups had at least ten samples in each category. The SPSS classification showed that 71.9% of sites were correctly classified (Table 3.17). The model's overall success rate of 72% was very good (Table 3.17) and the prediction success range was within the expected range of 70-73% that other archaeological site prediction models often achieved (Warren and Asch, 2000). Using the β values (Table 3.18) a predictive model was produced to identify the probability of any location in the study area having conditions favourable for Mesolithic record discovery (Table 3.19). The most important value in the table was β, as it was the value of each variable that was entered into the regression equation in log-odds units. It provided information on the relationship between the independent and dependent variable, with the amount of increase (positive values) or decrease (negative values) in the predicted log odds of the outcome based on a 1 unit shift in the predictor. Exp(β) presented these β values in odds ratios for ease of interpretation. As already identified (Chapter 2), the variable significance (Wald and Sig.) was difficult to interpret as their variance may have been explained by higher order terms.

Table 3.17. Conditions for Archaeological Discovery – HER data classification table.

Observed	Predicted		
	Mesolithic	Non-Site	% Correct (%)
Mesolithic	383	150	71.9
Non-Site	149	384	72.0
Overall Percentage			72.0

Table 3.18. Variables in the Equation: Conditions for Archaeological Discovery - HER data.

Variables	β	S.E.	Wald	df	Sig.	Exp(β)	95% C.I.for EXP(β)	
							Lower	*Upper*
Str0_500	.623	.703	.786	1	.375	1.865	.470	7.390
Str500_1000	.779	.695	1.256	1	.262	2.179	.558	8.508
Str1000_1500	.447	.701	.407	1	.523	1.564	.396	6.176
Str1500_2000	.606	.702	.746	1	.388	1.833	.463	7.253
Str2000_2500	.404	.704	.330	1	.566	1.498	.377	5.953
Str2500_3000	.288	.695	.172	1	.678	1.334	.341	5.212
Str3000_3500	-.010	.719	.000	1	.989	.990	.242	4.052
Str3500_4000	.818	.729	1.259	1	.262	2.267	.543	9.469
Str4000_4500	.637	.737	.745	1	.388	1.890	.445	8.019
Str4500_5000	.122	.775	.025	1	.875	1.130	.247	5.158
Str5000_5500	-.184	.777	.056	1	.813	.832	.181	3.817
RPTOnPath	.989	.470	4.421	1	.035	2.687	1.069	6.753
RPTInVerge	-.440	.409	1.154	1	.283	.644	.289	1.437
RPTInSight	.062	.238	.068	1	.794	1.064	.667	1.697
Clay0_1000	-1.515	1.054	2.067	1	.151	.220	.028	1.734
Clay1001_5000	-1.339	1.004	1.779	1	.182	.262	.037	1.876
Clay5001_10000	-1.740	.997	3.046	1	.081	.175	.025	1.239
Clay10001_15000	-1.360	.990	1.887	1	.170	.257	.037	1.786
Clay15001_20000	-1.484	.917	2.621	1	.105	.227	.038	1.367
Grn0_1000	1.361	.826	2.716	1	.099	3.900	.773	19.681
Grn1001_5000	.704	.816	.743	1	.389	2.021	.408	10.008
Grn5001_10000	.431	.810	.283	1	.595	1.539	.314	7.527
Grn10001_15000	1.118	.799	1.959	1	.162	3.057	.639	14.623
Grn15001_20000	.817	.752	1.180	1	.277	2.263	.519	9.878
Slope	-.022	.022	1.060	1	.303	.978	.937	1.020
TWIVeryWet	-.460	.434	1.127	1	.288	.631	.270	1.476
TWIWet	-.210	.358	.345	1	.557	.810	.402	1.634
TWIDryWet	-.021	.313	.004	1	.947	.980	.530	1.810
GeolAlluvium	.031	.424	.005	1	.942	1.031	.449	2.366
GeolBracklesham	-.526	.383	1.887	1	.170	.591	.279	1.252
GeolChalk	.444	.408	1.183	1	.277	1.559	.700	3.470
GeolClay	1.667	.567	8.633	1	.003	5.298	1.742	16.112
GeolHead	.989	.368	7.220	1	.007	2.689	1.307	5.532
GeolLambeth	1.698	.668	6.466	1	.011	5.462	1.476	20.215
GeolLondon	-.938	.524	3.210	1	.073	.391	.140	1.092
GeolLower	1.619	.320	25.639	1	.000	5.046	2.697	9.443
GeolSand	.144	.322	.201	1	.654	1.155	.615	2.169
GeolSelbourne	-.872	.636	1.879	1	.170	.418	.120	1.454
GeolThanet	3.556	1.157	9.442	1	.002	35.014	3.625	338.249
AspctFlat	.527	.294	3.219	1	.073	1.694	.952	3.014
AspctN	-.111	.310	.128	1	.720	.895	.488	1.643
AspctNE	.202	.321	.396	1	.529	1.224	.652	2.295
AspctE	-.046	.344	.018	1	.893	.955	.487	1.874
AspctSE	.155	.320	.236	1	.627	1.168	.624	2.186
AspctS	.595	.336	3.134	1	.077	1.813	.938	3.504
AspctSW	.494	.324	2.331	1	.127	1.639	.869	3.091
AspctW	-.016	.356	.002	1	.964	.984	.490	1.976
LCFreshwater	-.397	1.360	.085	1	.770	.673	.047	9.659
LCDwarfShrub	.236	1.265	.035	1	.852	1.266	.106	15.108
LCWoodland	-.312	1.157	.073	1	.787	.732	.076	7.065
LCBuiltUp	-.204	1.165	.031	1	.861	.816	.083	8.001
LCGrassland	-.388	1.156	.112	1	.737	.679	.070	6.537
LCArableHorticulture	-.001	1.162	.000	1	1.000	.999	.102	9.747
DEM0_50	-.538	.926	.338	1	.561	.584	.095	3.582
DEM51_100	-.951	.888	1.148	1	.284	.386	.068	2.201
DEM101_150	-.942	.885	1.132	1	.287	.390	.069	2.209
DEM151_200	-.828	.903	.841	1	.359	.437	.074	2.565
DEM201_250	-1.217	.982	1.537	1	.215	.296	.043	2.028
Constant	.353	1.795	.039	1	.844	1.424		

Table 3.19. Regression formula: Conditions for Archaeological Discovery – HER model.

$$P = \frac{1}{1 + Exp\ (-(Logistic\ Regression\ Model)}$$

Logistic Regression Model = 0.353		- 0.022 * Slope
+ 0.623 * Strahler 0_500	+ 1.361 * Greensand 0_1000	+ 0.527 * Aspectflat
+ 0.779 * Strahler 500_1000	+ 0.704 * Greensand 1001_5000	- 0.111 * AspectN
+ 0.447 * Strahler 1000_1500	+ 0.431 * Greensand 5001_10000	+ 0.202 * AspectNE
+ 0.606 * Strahler 1500_2000	+ 1.118 * Greensand 10001_15000	- 0.046 * AspectE
+ 0.404 * Strahler 2000_2500	+ 0.817 * Greensand 15001_20000	+ 0.155 * AspectSE
+ 0.288 * Strahler 2500_3000	- 0.460 * TWI Very Wet	+ 0.595 * AspectS
- 0.010 * Strahler 3000_3500	- 0.210 * TWI Wet	+ 0.494 * AspectSW
+ 0.818 * Strahler 3500_4000	- 0.021 * TWI Dry/Wet	- 0.016 * AspectW
+ 0.637 * Strahler 4000_4500	+ 0.031 * Alluvium and Peat	- 0.397 * Land Cover Freshwater
+ 0.122 * Strahler 4500_5000	- 0.526 * Bracklesham Group	+ 0.236 * Land Cover DwarfShrub
- 0.184 * Strahler 5000_5500	+ 0.444 * Chalk	- 0.312* Land Cover Woodland
+ 0.989 * RPT On Path	+ 1.667 * Clay with Flints	- 0.204 * Land Cover Built Up
- 0.440 * RPT In Verge	+ 0.989 * Head	- 0.388 * Land Cover Grassland
+ 0.062 * RPT In Sight	+ 1.698 * Lambeth Group	- 0.001 * Land Cover Arable
- 1.515 * Clay 0_1000	- 0.938 * London Clay	- 0.538 * Height 0_50
- 1.339 * Clay 1001_5000	+ 1.619 * Lower Greensand	- 0.951 * Height 51_100
- 1.740 * Clay 5001_10000	+ 0.144 * Sands and Gravels	- 0.942 * Height 101_150
- 1.360 * Clay 10001_15000	- 0.872 * Selbourne Group	- 0.828 * Height 151_200
- 1.484 * Clay 15001_20000	+ 3.556 * Thanet Sand	- 1.217 * Height 201_250

3.5.1.2. **Statistical Assessment of the Model**

The Chi-square value for the model was 277.502 (p=0.000, 58 degrees of freedom) with a -2 Log Likelihood of 1200.288, showing that the model was a significant fit to the data, and the separation between sites and non-sites was significantly not due to chance. This meant that the variables that were entered into the model considerably altered the outcome. The Hosmer and Lemeshow significance value (p=0.386) examined the relationship between model and data. The test is significant when the P value was above the cut-off (0.05) (Peterson et al., 2007), therefore this result showed a significant relationship between model and data. It was important to consider the potential effects of overdispersion, which occurs when model variance is larger than expected (Field, 2013). This was examined by looking at the chi-square goodness of fit, also provided by the Hosmer and Lemeshow Test (Bender and Grouven, 1998; Chen et al., 2005). The test run on the HER data produced a chi-square value of 8.502 with 8 degrees of freedom and a dispersion parameter of 1.06 meaning overdispersion was slightly present (any dispersion parameter >1 has overdispersion). However dispersion is only problematic once the dispersion parameter reaches and exceeds 2 (Field, 2013).

Studentised residual had 1.13% of data > ±1.96 and 0% > ±2.58. Standardised residual had 4.22% of data > ±1.96 and 0.56% > ±2.58. Four points (3 Mesolithic points and 1 non-site point had standardised residual scores greater than 3. The raw data was checked and found to be correct and so therefore these points were left in the model. The three Mesolithic sites occurred in locations where the model expected a non-site location to be prevalent, and the non-site point occurs in a strongly Mesolithic area. They were left in the model as the initial data points were correct and these points were an example of natural variation within the Mesolithic distribution and the random nature of the non-site database. Cook's distance was only >1 for 2 points, both non-site points situated on strongly Mesolithic archaeology-yielding geologies and therefore always likely to be highlighted as a poor fit in the model. DFBeta identified no points being >1. Leverage should be 0.055 for this dataset and the average leverage generated from the regression results was 0.055, which showed a close fit between model and data. The results of the residual tests backed up the highly significant chi-squared test (p=0.000) and showed that the model fit the data very well. The Kappa statistic = 0.439 (p<0.001), 95% CI (0.384, 0.494), indicated a moderate agreement between model and site location which was considerably better than chance (Landis and Koch, 1977). The Kappa statistic for the model suggested a ~44% increase over a chance classification, and was consistent with the literature which suggested gains of up to 51% against chance classification (Warren and Asch, 2000). The frequency distribution of sites against non-sites (Figure 3.21) overlapped, suggesting complete separation between the non-sites and sites did not exist, although it did show that site cells were more frequent at higher values for the predicted conditions for finding archaeology, and non-sites were more prevalent at low values for the predicted conditions (Warren and Asch, 2000). This indicated the model results were likely to be accurate.

The PaMELA frequency distribution pattern (based on the 410 Mesolithic points in the PaMELA database) was similar to that of the Mesolithic site results from the main model, and suggested a good fit between the withheld data and the model. The PaMELA dataset identified over 75% of the PaMELA sites as being in an area where there was >50% chance of finding material, higher than the HER model result rate of 71.9%. The correlation between testing data and model data, and the other statistical analyses, indicated that this model was a good predictor of the variation in Mesolithic archaeology discovery conditions.

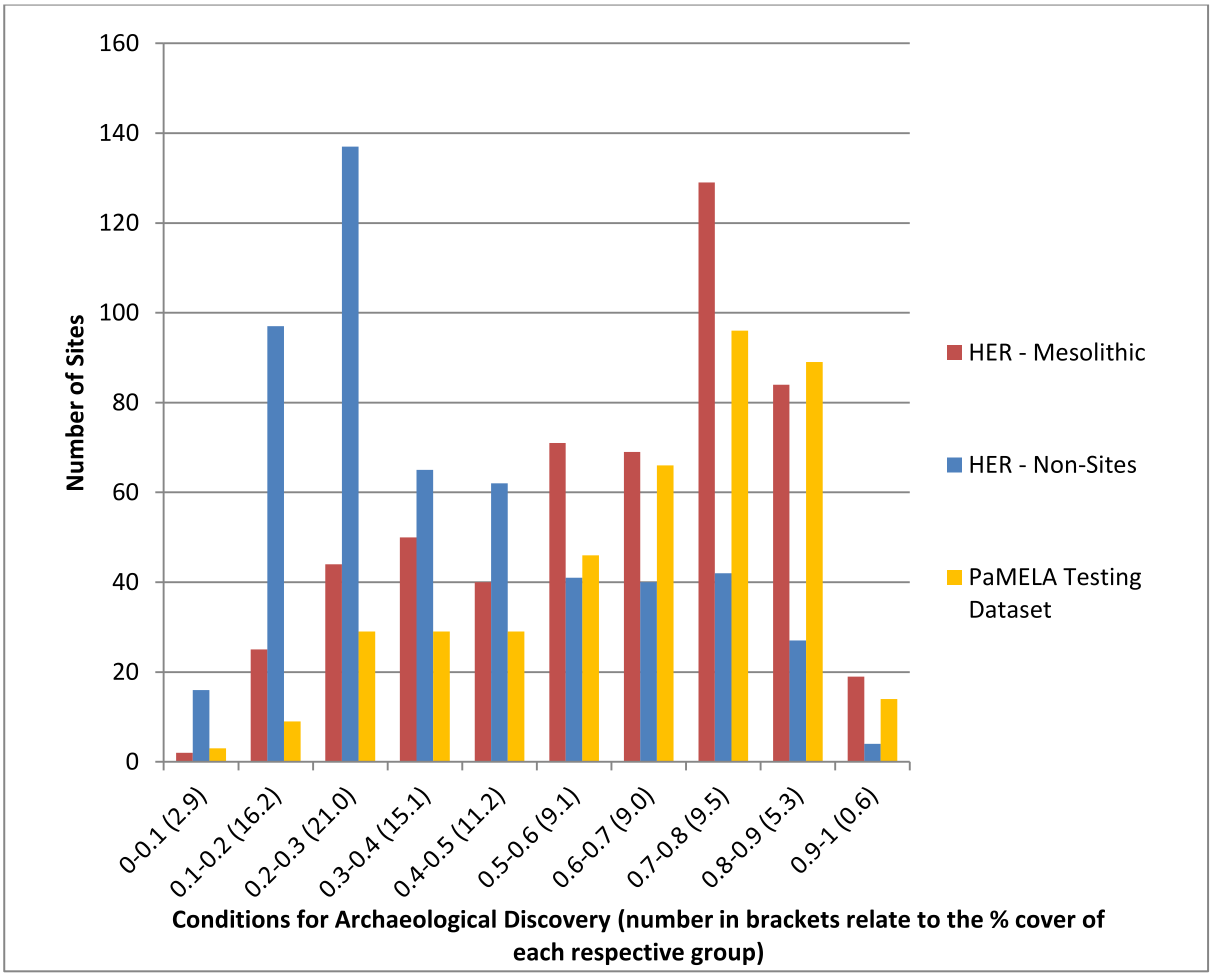


Figure 3.21. Frequency distribution of site points, non-site points and the PaMELA dataset testing sample against the predicted conditions for archaeological discovery (HER Model).

The frequency distributions did show however, that there were a number of occasions when sites were found when modelled conditions for discovery were poor. This was not unexpected, as there will be a number of occasions when material has been discovered in areas that were not expected. This could be material that was lost or discarded en-route, perhaps during a hunting trip or other movement across the landscape and was therefore now found in an anomalous discarded location. This could include occasions when people may have used less favoured paths, where very low amounts of material may accumulate, in contrast to the possibility of favoured routeways, which may be expected to accumulate a background scatter of lost material. It may also have been due to natural variability of the Mesolithic record, indicating people utilised wide areas of the landscape but with varying degrees of intensity. There was also a decline in observed Mesolithic activity when the conditions for archaeological discovery were very high (between 0.9-1). This was likely to be due to the model itself, as these predictive values were not produced within the model very frequently as a score of 1 would indicate near perfect conditions for finding archaeology. Therefore this group (0.9-1) occupied a very small spatial area (only 0.6% of the entire County) and fewer sites were found on this smaller area. The same explanation applied to the low number of non-site points in the lowest non-site category (0-0.1), where again it only covered a small spatial area: 2.9% of the County.

3.5.1.3. **Model Output and Interpretation**

Utilising the regression formula, the equation was plotted in the ArcGIS raster calculator to create a map of predicted conditions for Mesolithic archaeological discovery (Figure 3.22).

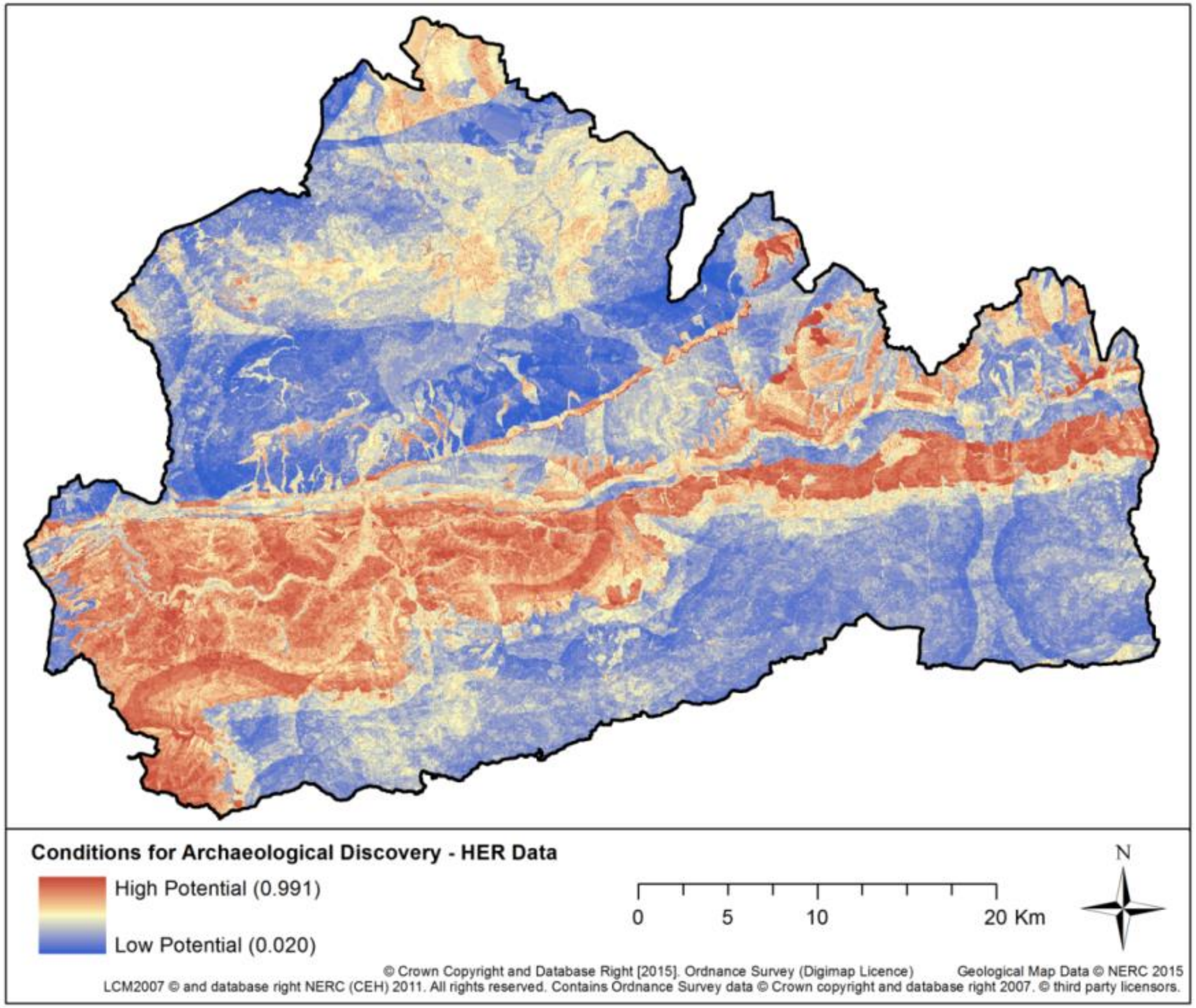


Figure 3.22. Conditions for archaeological discovery based on the HER data.

The model highlighted a number of regions where there was high potential for finding archaeological material and a number of strong relationships were observed from looking at the data. Variables that were statistically significant (to an α of 0.05, i.e. where there was an increase in predicted log odds of finding records) include the Lower Greensand, Thanet Sands, Clay-with-Flints, Head and the Lambeth Group. A significance level of 0.10 adds the lowest distance to Greensand category (Grn0_1000), roads, paths and tracks (on path category) and flat and south aspect variables. Variables where there was a decrease in the log odds of finding archaeological records included distance to Clay-with-Flints (5,000-10,000m) and London Clay, both significant at 0.10. These relationships were observed within the conditions for archaeological discovery map, which highlighted vast areas of the Lower Greensand and Clay-with-Flint outcrops as being particularly high potential regions. High potential was also observed to the far north of the County. Low potential was observed in the south and southeast, broadly synchronous with the Wealden Group. A similar low potential pattern was also observed running west to north-east along the London Clay in the centre of the County. In all of these high and low regions however, there was variance on a much smaller local spatial scale (Figure 3.23). Towards the North of the County, there are large expanses of riverine and alluvial sediments that may have led to the underrepresentation of Mesolithic material in this region, due to it potentially being deeply buried. However, the model indicates this area broadly provides mid-range conditions for the discovery of archaeology, suggesting that both the current archaeological data and model are not significantly underrepresenting these regions. Further excavations in these alluvial regions would allow for their significance to the Mesolithic distribution pattern to become clearer.

These were areas where the local conditions were more or less favourable to the discovery of archaeology based on all of the parameters placed into the model, and this highlights why it is important the map was used at the correct spatial scale for the desired outcome. The map was useful at a countrywide scale for examining broad trends of where Mesolithic records were likely to be identified. At smaller spatial scales, the map was highly useful to identify where, and if, Mesolithic records were likely to be identified around targeted locations, such as a palaeoenvironmental site. This was highlighted by the example in Figure 3.23 as it shows discovery chances were high to the south west and north east of the area, lower across a band running NW-SE and very low in some land parcels.

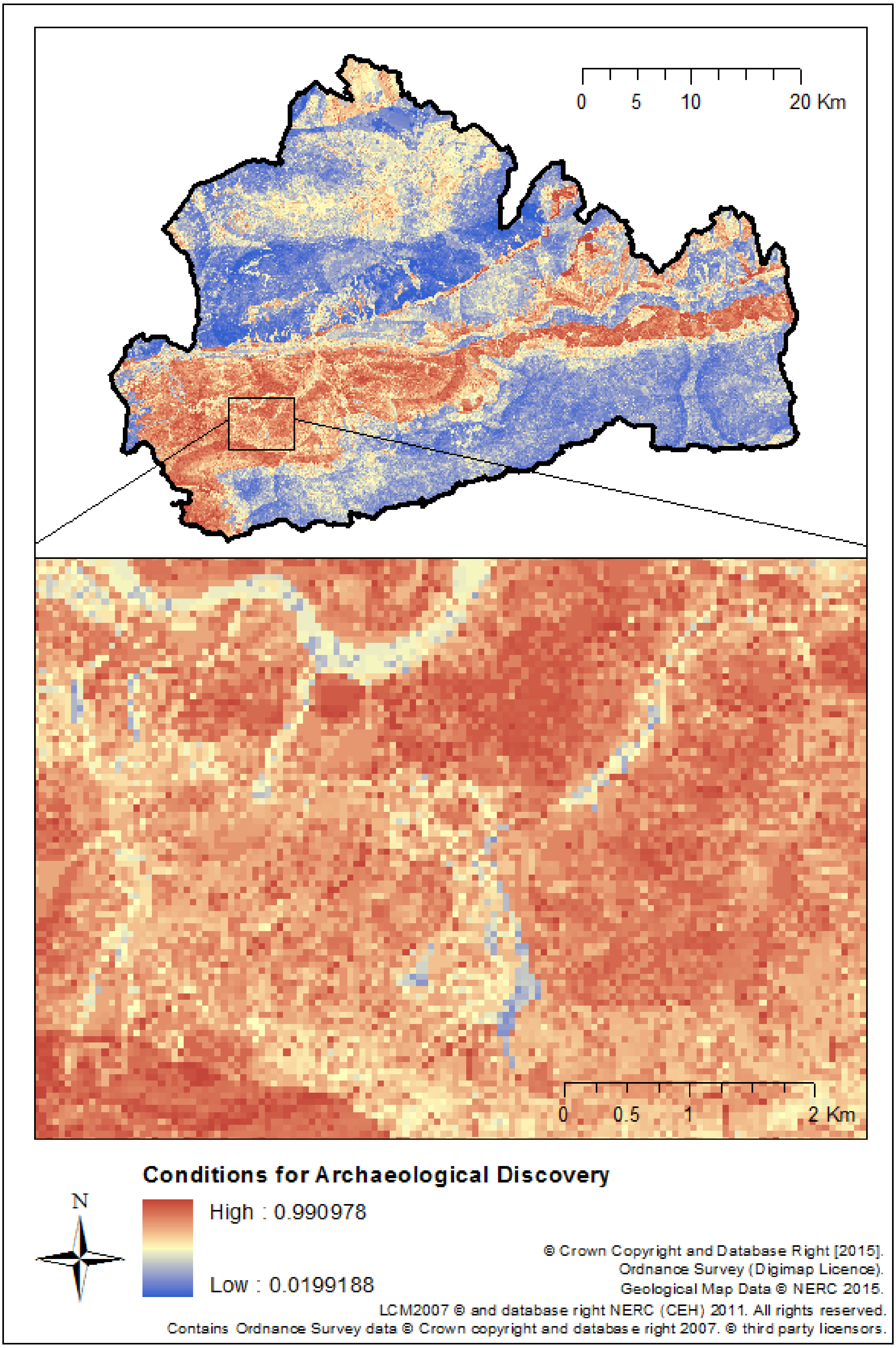


Figure 3.23. Detailed zoom on an area of the conditions for archaeological discovery map to highlight small local scale variability in the predictive model. Individual cell sizes are 50x50m

3.5.2. Mesolithic Activity Areas (Model 2)

3.5.2.1. **Data Input and Model Development**

This model excluded both the distance to roads, paths and tracks and the land cover predictor variables in order to examine the potential for modern day visibility of archaeological records. The same record dataset was used as in the previous model, so all assumptions for a binary logistic regression model were met. The SPSS output table (Table 3.20) indicated a positive result, with 70.9% of sites correctly classified. Again, this matched many of the models found across the literature (70-73%) (Warren and Asch, 2000). Table 3.21 contains the result of the regression analysis and the β values, representing the log-odds value for the regression equation that was used to calculate the predictive model equation (Table 3.22).

Table 3.20. Mesolithic Activity Areas - HER data classification table.

Observed	Predicted		
	Mesolithic	Non-Site	% Correct (%)
Mesolithic	378	155	70.9
Non-Site	153	380	71.3
Overall Percentage			71.1

Table 3.21. Variables in the Equation: Mesolithic Activity Areas - HER data.

Variables	**β**	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(β)**
Str0_500	.509	.704	.524	1	.469	1.664
Str500_1000	.664	.697	.906	1	.341	1.942
Str1000_1500	.382	.704	.295	1	.587	1.465
Str1500_2000	.518	.704	.542	1	.462	1.679
Str2000_2500	.339	.706	.230	1	.631	1.403
Str2500_3000	.173	.698	.062	1	.804	1.189
Str3000_3500	-.054	.721	.006	1	.940	.947
Str3500_4000	.708	.732	.936	1	.333	2.030
Str4000_4500	.483	.739	.427	1	.514	1.620
Str4500_5000	-.034	.772	.002	1	.965	.967
Str5000_5500	-.290	.777	.139	1	.710	.749
Clay0_1000	-1.600	1.039	2.368	1	.124	.202
Clay1001_5000	-1.435	.989	2.105	1	.147	.238
Clay5001_10000	-1.797	.983	3.338	1	.068	.166
Clay10001_15000	-1.408	.976	2.080	1	.149	.245
Clay15001_20000	-1.549	.905	2.933	1	.087	.212
Grn0_1000	1.484	.817	3.298	1	.069	4.410
Grn1001_5000	.792	.809	.957	1	.328	2.207
Grn5001_10000	.506	.803	.396	1	.529	1.658
Grn10001_15000	1.149	.794	2.091	1	.148	3.154
Grn15001_20000	.899	.749	1.442	1	.230	2.457
Slope	-.024	.021	1.334	1	.248	.976
TWIVeryWet	-.389	.424	.840	1	.359	.678
TWIWet	-.164	.349	.222	1	.638	.848
TWIDryWet	-.007	.305	.001	1	.981	.993
GeolAlluvium	.035	.421	.007	1	.934	1.035
GeolBracklesham	-.440	.373	1.391	1	.238	.644
GeolChalk	.574	.398	2.077	1	.150	1.776
GeolClay	1.767	.560	9.969	1	.002	5.853
GeolHead	1.006	.362	7.736	1	.005	2.734
GeolLambeth	1.831	.663	7.626	1	.006	6.241
GeolLondon	-.781	.510	2.348	1	.125	.458
GeolLower	1.653	.313	27.830	1	.000	5.225
GeolSand	.221	.315	.490	1	.484	1.247
GeolSelbourne	-.755	.628	1.446	1	.229	.470
GeolThanet	3.756	1.146	10.735	1	.001	42.767
AspctFlat	.513	.292	3.095	1	.079	1.670
AspctN	-.094	.308	.094	1	.759	.910
AspctNE	.220	.320	.473	1	.491	1.246
AspctE	-.036	.340	.011	1	.915	.964
AspctSE	.183	.317	.332	1	.565	1.201
AspctS	.538	.333	2.609	1	.106	1.713
AspctSW	.505	.321	2.470	1	.116	1.657
AspctW	-.004	.353	.000	1	.990	.996
DEM0_50	-.597	.924	.417	1	.518	.550
DEM51_100	-.968	.887	1.191	1	.275	.380
DEM101_150	-.989	.884	1.251	1	.263	.372
DEM151_200	-.908	.900	1.019	1	.313	.403
DEM201_250	-1.335	.980	1.858	1	.173	.263
Constant	.160	1.346	.014	1	.905	1.173

Table 3.22. HER Logistic regression formula for Mesolithic Activity Areas (P).

$$P = \frac{1}{1 + Exp\ (-(Logistic\ Regression\ Model)}$$

Logistic Regression Model = 0.160		- 0.024 * Slope
+ 0.509 * Strahler 0_500	+ 1.484 * Greensand 0_1000	+ 0.221 * Sands and Gravels
+ 0.664 * Strahler 500_1000	+ 0.792 * Greensand 1001_5000	- 0.755 * Selbourne Group
+ 0.382 * Strahler 1000_1500	+ 0.506 * Greensand 5001_10000	+ 3.756 * Thanet Sand
+ 0.518 * Strahler 1500_2000	+ 1.149 * Greensand 10001_15000	+ 0.513 * Aspectflat
+ 0.339 * Strahler 2000_2500	+ 0.899 * Greensand 15001_20000	- 0.094 * AspectN
+ 0.173 * Strahler 2500_3000	- 0.389 * TWI Very Wet	+ 0.220 * AspectNE
- 0.054 * Strahler 3000_3500	- 0.164 * TWI Wet	- 0.036 * AspectE
+ 0.708 * Strahler 3500_4000	- 0.007 * TWI Dry/Wet	+ 0.183 * AspectSE
+ 0.483 * Strahler 4000_4500	+ 0.035 * Alluvium and Peat	+ 0.538 * AspectS
- 0.034 * Strahler 4500_5000	- 0.440 * Bracklesham Group	+ 0.505 * AspectSW
- 0.290 * Strahler 5000_5500	+ 0.574 * Chalk	- 0.004 * AspectW
- 1.600 * Clay 0_1000	+ 1.767 * Clay with Flints	- 0.597 * Height 0_50
- 1.435 * Clay 1001_5000	+ 1.006 * Head	- 0.968 * Height 51_100
- 1.797 * Clay 5001_10000	+ 1.831 * Lambeth Group	- 0.989 * Height 101_150
- 1.408 * Clay 10001_15000	- 0.781 * London Clay	- 0.908 * Height 151_200
- 1.549 * Clay 15001_20000	+ 1.653 * Lower Greensand	- 1.335 * Height 201_250

3.5.2.2. Statistical Assessment of the Model

The Chi-square value for the model was 267.015 (p=0.000) with a -2 Log Likelihood of 1210.774, showing that the model significantly increased in power with the addition of model variables. A Hosmer and Lemeshow significance value of p=0.678 suggested the model showed a significant relationship between the varying input variables (Peterson et al., 2007). Overdispersion was not present in the dataset as a dispersion parameter of 0.72 was below 1 (Field, 2013), based on the Hosmer and Lemeshow Chi-Square goodness of fit statistic (Bender and Grouven, 1998; Chen et al., 2005) of 5.722 with 8 degrees of freedom. Studentised residual had 0.84% of data > ±1.96 and 0% > ±2.58. Standardised residual had 4.1% of data > ±1.96 and 0.28% > ±2.58. Three points (two sites and one non-site) had standardised residual scores of near to or greater than 3 suggesting they were points that did not match the trend defined by the other sites or non-sites, respectively, and therefore these points were not represented well in the model. The raw data was checked, found to be correct and therefore these points provided evidence for natural variation within the Mesolithic dataset, and random patterning within the non-site dataset. Cook's distance was >1 for 1 point, a non-site point in an area of strong Mesolithic potential. Leverage should have been 0.047 for this dataset and the average leverage generated from the regression results was 0.047, showing an excellent fit between model and data. The results of the residual tests back up the highly significant chi-squared test (p=0.000) and showed that the model fit with the data was strong. The Kappa statistic = 0.422 (~42%) (p<0.001), 95% CI (0.367, 0.477), showed a moderate agreement with site location and model prediction and was higher than a chance probability (Landis and Koch, 1977) again, reaching levels similar to that observed in the wider modelling literature of up to 51% (Warren and Asch, 2000).

Frequency distributions between the Mesolithic sites and random non-sites were examined (Figure 3.24) and cross-compared with the PaMELA dataset. Complete separation between the Mesolithic and non-site records did not occur, but site records occurred with greater frequency at higher predictions of Mesolithic activity, with non-sites more prevalent at lower predictions (Warren and Asch, 2000), showing the model had good predictive power and backed up the results table, highlighting that the model successfully identified ~71% of sites correctly. Testing the model using the PaMELA dataset showed that the distribution curve of both Mesolithic sites and the PaMELA testing database were similar, suggesting the model did a good job of predicting new Mesolithic site locations. A similar pattern was observed at both ends of the predictive scale, whereby the model could not predict values at the extreme end of the scale due to these values occupying a small area of the County (0-0.1 covered only 2.1% of the County and there was 0.3% coverage for the 0.9-1 class), and therefore occurrences for these values were low.

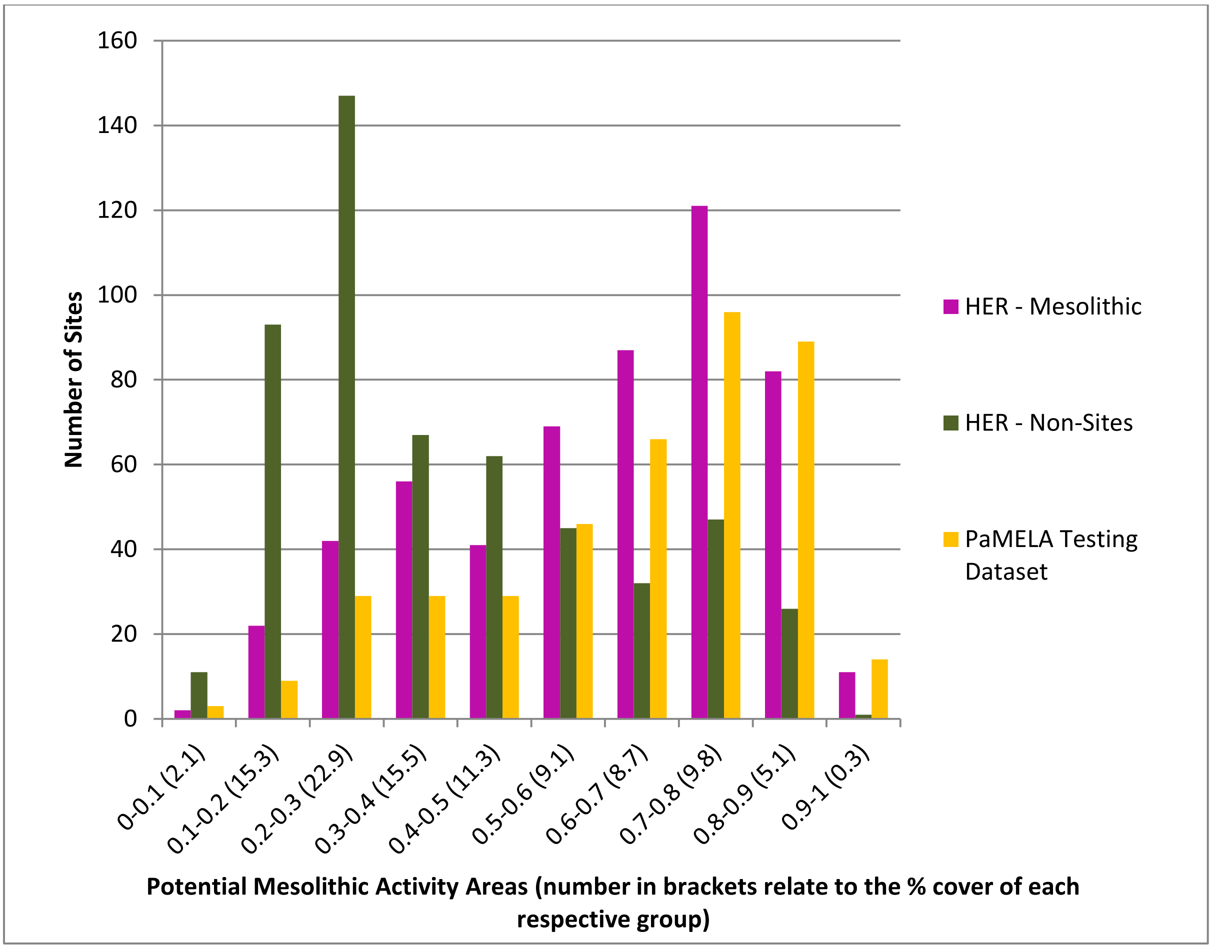


Figure 3.24. Frequency distribution of site points, non-sites points and a PaMELA testing sample against the predicted conditions for potential Mesolithic activity areas (HER Model).

3.5.2.3. **Model Output and Interpretation**

Plotting the binary logistic regression equation created a map of potential Mesolithic activity areas (Figure 3.25). The model was very similar to the model examining the chances of finding archaeology across Surrey with a correlation factor of 0.97 between the two maps. This correlation factor showed that the two modern variables included in the conditions for the archaeological discovery map had only a small impact on the final outcome, and means the conditions for finding archaeology map only significantly differed in those areas where land cover and the distance to roads, paths and tracks made a large difference to the potential of finding records. A highly active zone was observed running along the bottom of the North Downs escarpment, broadly synchronous with the Lower Greensand. Other active areas were observed across parts of the Clay-with-Flints, the Thanet Sands and the Lambeth Group. Lower levels of activity were predicted to occur in the Wealden Clay area in the south and southeast, and across much of the north of the County which included the Chalk outcrops and the lower land in the London basin.

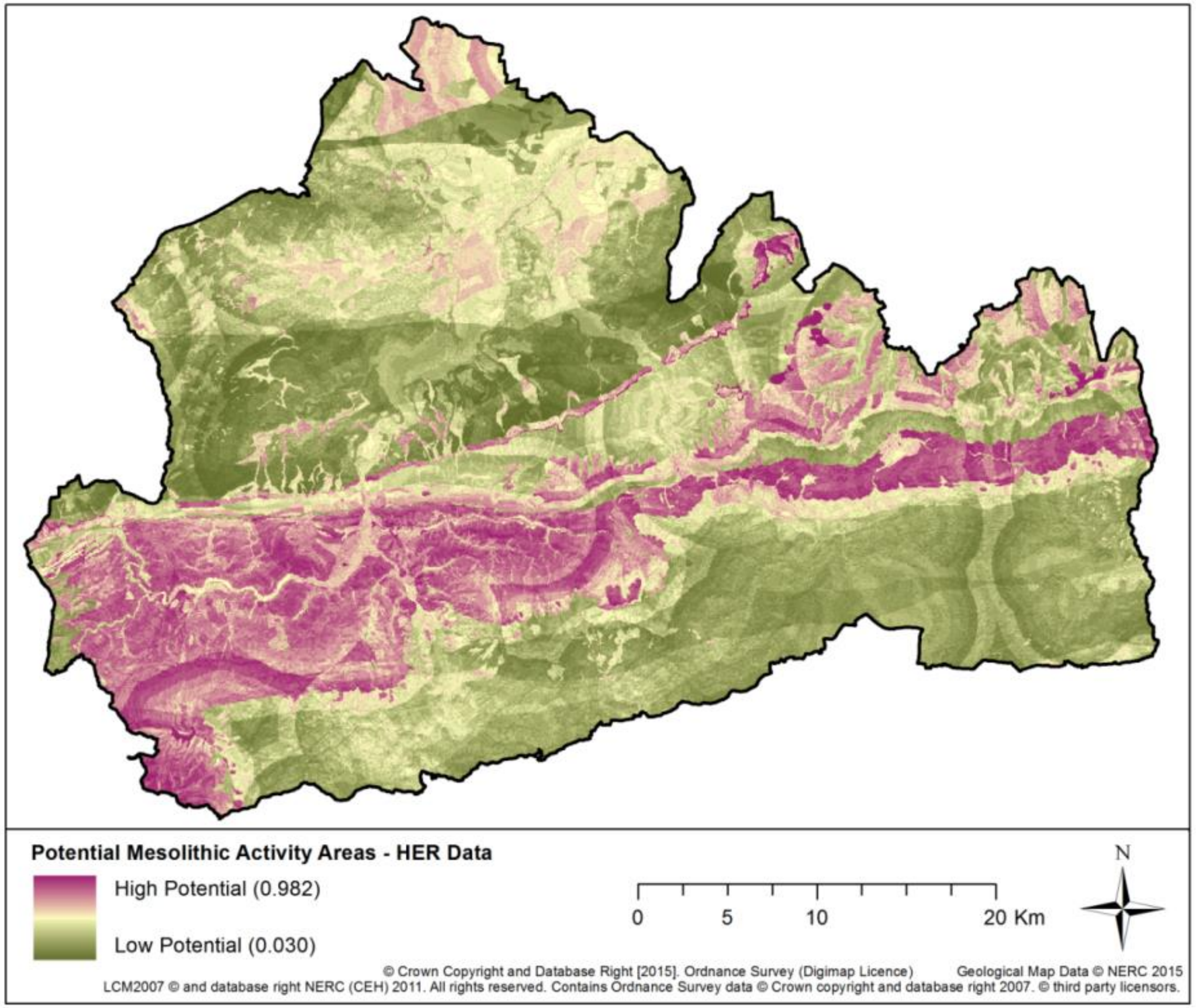


Figure 3.25. Map of potential Mesolithic activity areas based on HER data.

3.6. Summary

The results of the data collation exercise, the spatial mapping and the predictive modelling highlighted the diversity, range and scale of Upper Palaeolithic and Mesolithic archaeology across the County of Surrey and southeast England. The work identified a small amount of Upper Palaeolithic material and a much larger corpus of Mesolithic records. These records appeared to be clustered within the landscape, particularly across the east-west Lower Greensand, up into the Thanet Sands and across the north of the County. Through analysis of the database, evidence appeared to show that there was prevalence for hunting type assemblages in the south of the County, where the majority of microliths and points were identified in addition to occupation sites. Domestic type assemblages were also noted in the north and may indicate processing of material whilst people were moving across the landscape, or could potentially represent sites that have not yet been identified. This highlights the point that material should not be expected everywhere due to the use of pathways through the landscape and the nature of movement, where dominant movement may be concentrated around regularly used routes. The PaMELA database, derived from Roger Jacobi's collection notes provided a secondary database to the HER, and provided a time-scale element based on the identification of typological lithic artefacts. This highlighted a large expansion of sites in the Early Mesolithic, which were spread broadly out across much of the County. A decline in both the number and geographical extent of records in the Horsham and Later Mesolithic periods is recorded, where they appear to be restricted primarily to locations south of the North Downs, although this is noted that it may be due to the characteristics of the typological classification method.

Through utilising the Chi-squared test, an examination of the distribution of HER records and environmental variables could be undertaken. These tests highlighted significant differences between expected and observed distributions of records on a number of variables including elevation, geology, slope, total wetness index, distance to greensand and Clay-with-Flints and land cover types. These relationships indicated that records identified on higher elevation and steeper slopes appeared to represent items used, discarded or lost on hunting trips. Interestingly there appeared to be no strong relationship between south facing slopes and Mesolithic sites, contrary to the literature (Kvamme and Jochim, 1990; Brandt et al., 1992). An important relationship between archaeological records and wet/dry regions was identified, suggesting this was a highly active zone during the Mesolithic period. The development of these environmental variables facilitated the creation of two predictive models. The first model examined the conditions for archaeological discovery in the modern day landscape, and the second model examined potential Mesolithic activity areas. The models highlighted important regions such as the broad east-west Greensand corridor as having high potential, and areas of the northern basin and Southern Weald as areas of low potential. Both models were statistically robust and provided significant results, greatly increasing the chance of either finding records or understanding distribution patterns more accurately than by chance. This knowledge is highly significant when considering the planning stages for development (including new developments, expansion of existing developments, utility work and industrial activity), helping to inform potential developers of the likelihood of Mesolithic archaeology at a potential site. This can then be directly utilised within the application evaluation and can ensure that suitable precautions have been considered prior to the commencement of work.

4. Reconstructing Past Environments: Study Locations and Field Sampling Methods

Due to the paucity of vegetation records from lowland mires within Surrey and inland southeast England, it was important to identify new wetland sites with potential for palaeoenvironmental investigation, in order to address the aims and objectives of the research, and to test the research hypotheses.

4.1. Methods of site identification

A number of different techniques were utilised to identify sites, including remote sensing, analysis of maps, 'word of mouth', and specific targeting of high archaeological source areas ('hotspots'). Often, a combination of these criteria resulted in positive site identification.

4.1.1. Remote Sensing

Remote sensing data was obtained from the Landsat 7 ETM+ satellite at 30m resolution (Lillesand et al., 2004). A cloud cover free Landsat image was downloaded from the 13th February 2002, a time when leaf cover was at its minimum, which allowed for maximum intrusion into wooded or forested land (Lunetta and Balogh, 1999). A lower resolution, Landsat image was superior to aerial photography due to the near infrared (NIR) and mid-infrared (MIR) bands, which differentiate between vegetation types more clearly than the visible green band. A supervised classification algorithm defined land cover types, identifying areas that matched the spectral properties of five user defined type covers (Table 4.1). This method has been shown to be successful and the Landsat classification can be more effective than other satellite platforms such as SPOT (Baker et al., 2006).

Table 4.1. Key ground reference categories for Landsat classification.

Land Cover Type	**Location**	**Description**
Urban Areas	SU 99602 49418	Centre of Guildford
Inland Water	TQ 04181 73184	King George VI Reservoir
Woodland	TQ 09801 49915	Kings Hills, Effingham Forest
Grassland	TQ 02597 56725	Floodplain near Old Woking
Heathlands & Wetlands	SU 90408 41510	Centre of Thursley Bog

The results (Figure 4.1) identified a number of potential heathland and wetland areas including commons at Chobham, Westend, Pirbright, Hankley and Frensham, as well as Ash Ranges.

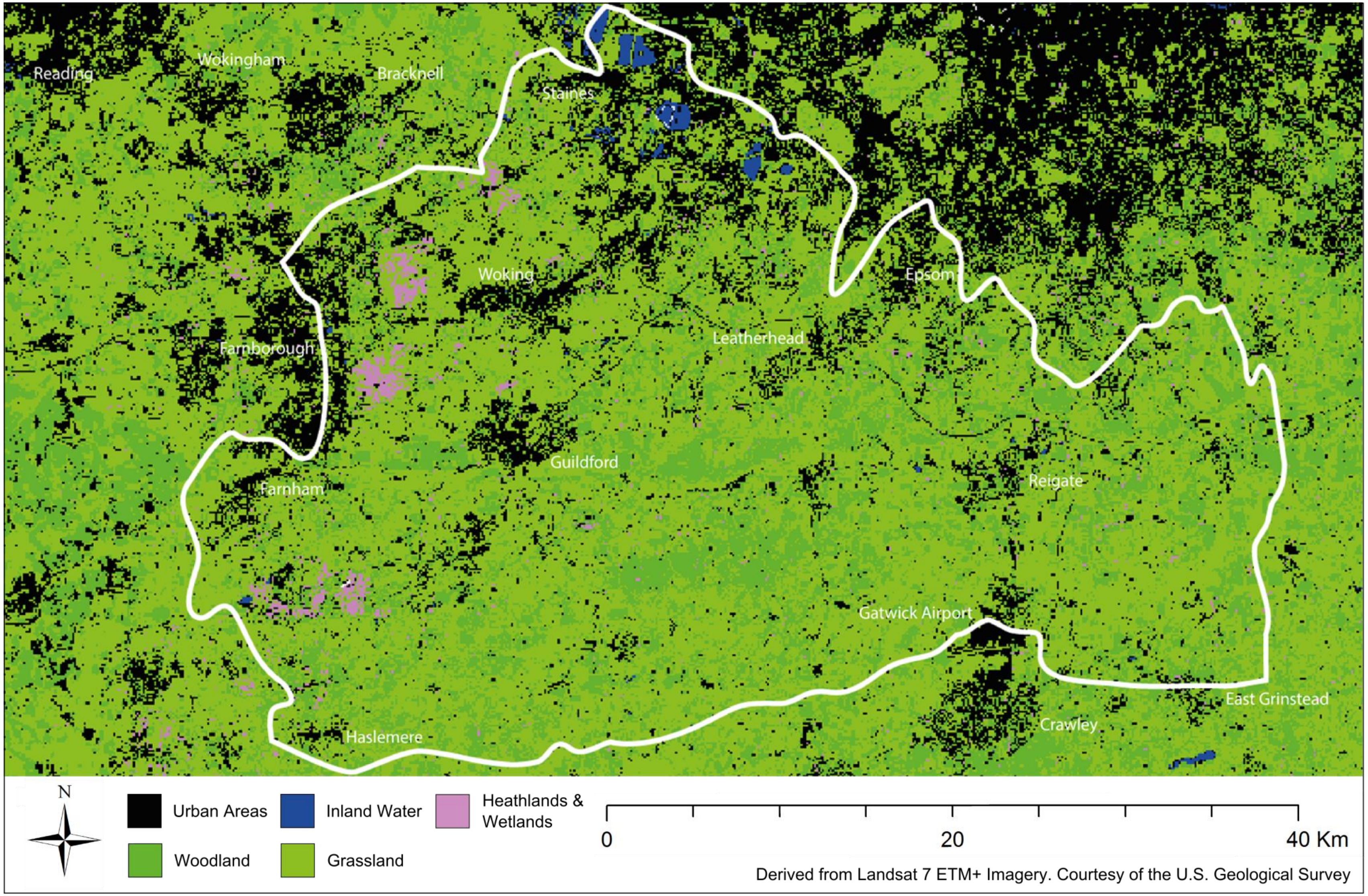


Figure 4.1. Landsat 7ETM+ Supervised Classified map highlighting certain land cover types.

4.1.2. ‘Word of Mouth’

‘Word of mouth’ was a highly important tool in identifying wetlands because these sites were often small, hidden within woodland or on private land, and therefore were not mapped or easily identifiable. Written communication detailing the project and potential site types was sent to prospective parties asking for information. The groups contacted included:

- Surrey Wildlife Trust
- Kent Wildlife Trust
- Surrey and Kent Ramblers
- South Downs Society
- Forestry Commission – Southern and Eastern
- The Environment Agency
- Natural England
- Defra
- The National Trust – London and the South East
- Country Land and Business Association (CLA) – South East Office
- National Farmers Union South East (a notice was placed in their newsletter)
- Farming and Wildlife Advisory Group – South East

This proved to be a highly successful method of identifying highly knowledgeable people and a number of potential sites that were in otherwise unidentifiable locations.

4.1.3. Targeted Searching

The archaeological setting of wetland sites was of great importance to understand interaction between wetlands and past populations. To identify sites near archaeological activity, data from the HER was plotted in ArcGIS and overlaid on high resolution mapping data (Figure 4.2). Archaeological evidence took two forms, either spatially discrete areas where there were numerous findspots, or regions where at least one highly important and significant archaeological site is present.

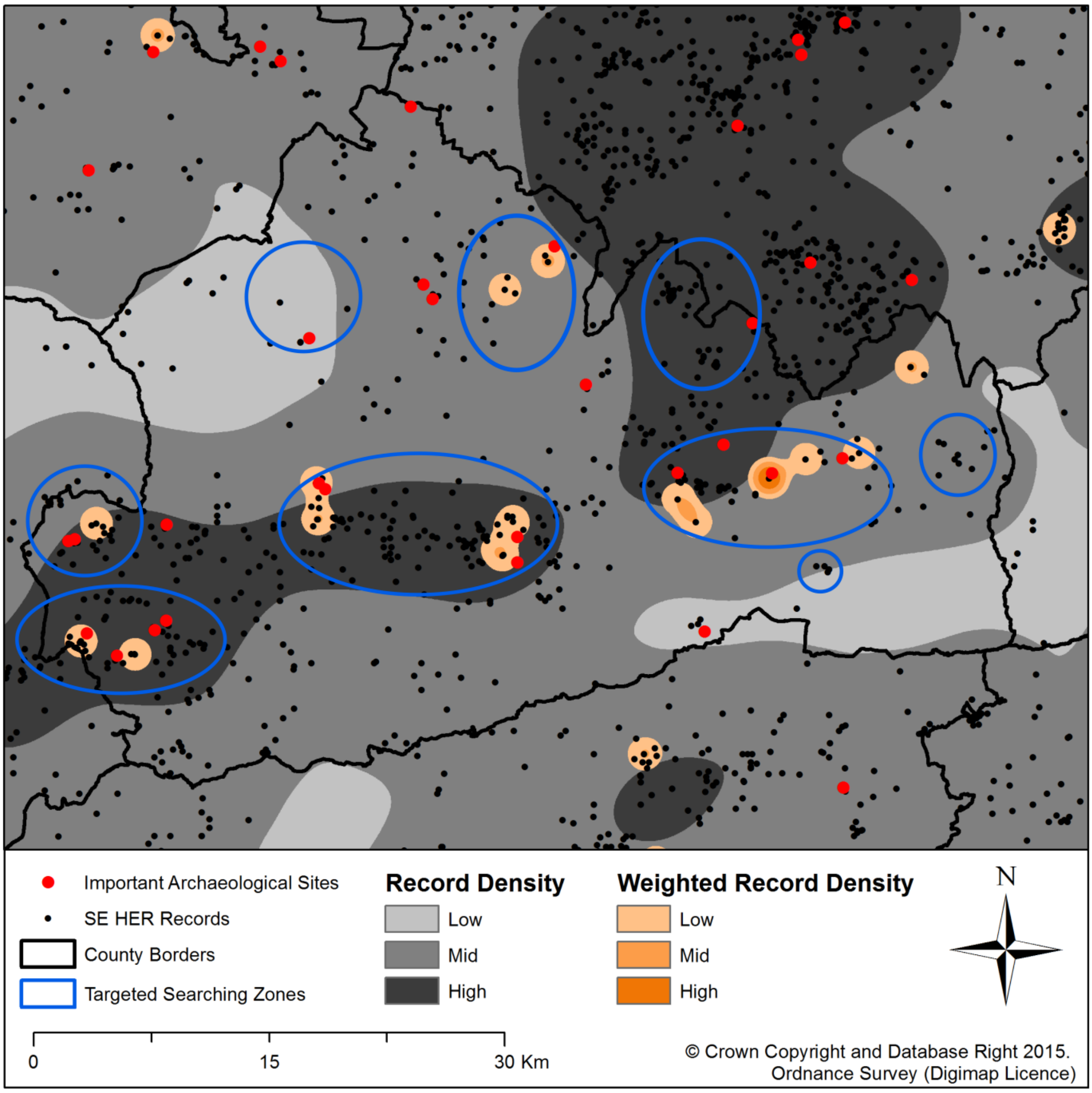


Figure 4.2. Identification of targeted search zones based on the archaeological record.

Kernel densities established where archaeological clusters were found across the landscape; an approach becoming more commonplace in archaeology (Baxter et al., 1997; Wheatley and Gillings, 2002; McMahon, 2007; Sayer and Wienhold, 2012). The standard record density analysed all points and plotted a simple density plot, whilst the weighted record density was positively skewed towards records with higher numbers of finds. This led to a number of targeted searching zones where palaeoenvironmental data would aid in understanding the archaeological record and human interaction with the natural environment.

4.1.4. High Resolution Mapping

High resolution Ordnance Survey maps (up to 1:10,000 scale) were used both on their own and more frequently in conjunction with the other methods to pinpoint specific locations for site investigations. High resolution maps were scanned for potential wetland/bog indicators, including wetland symbols or target words/phrases (Figure 4.3).

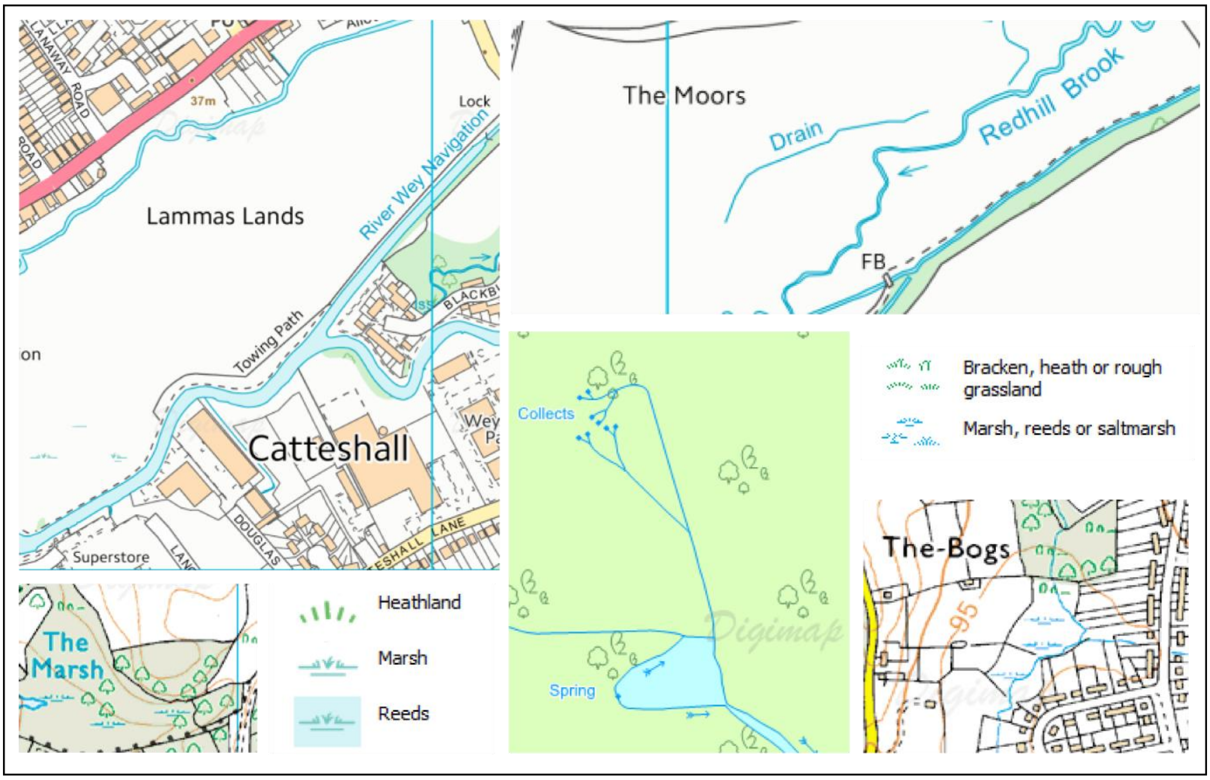


Figure 4.3. Different scale examples of map indicators highlighting potential wetland sites.

4.2. Investigated Regions

As stated, a number of potential study zones were identified (Figure 4.4) through a combination of the various site identification methods.

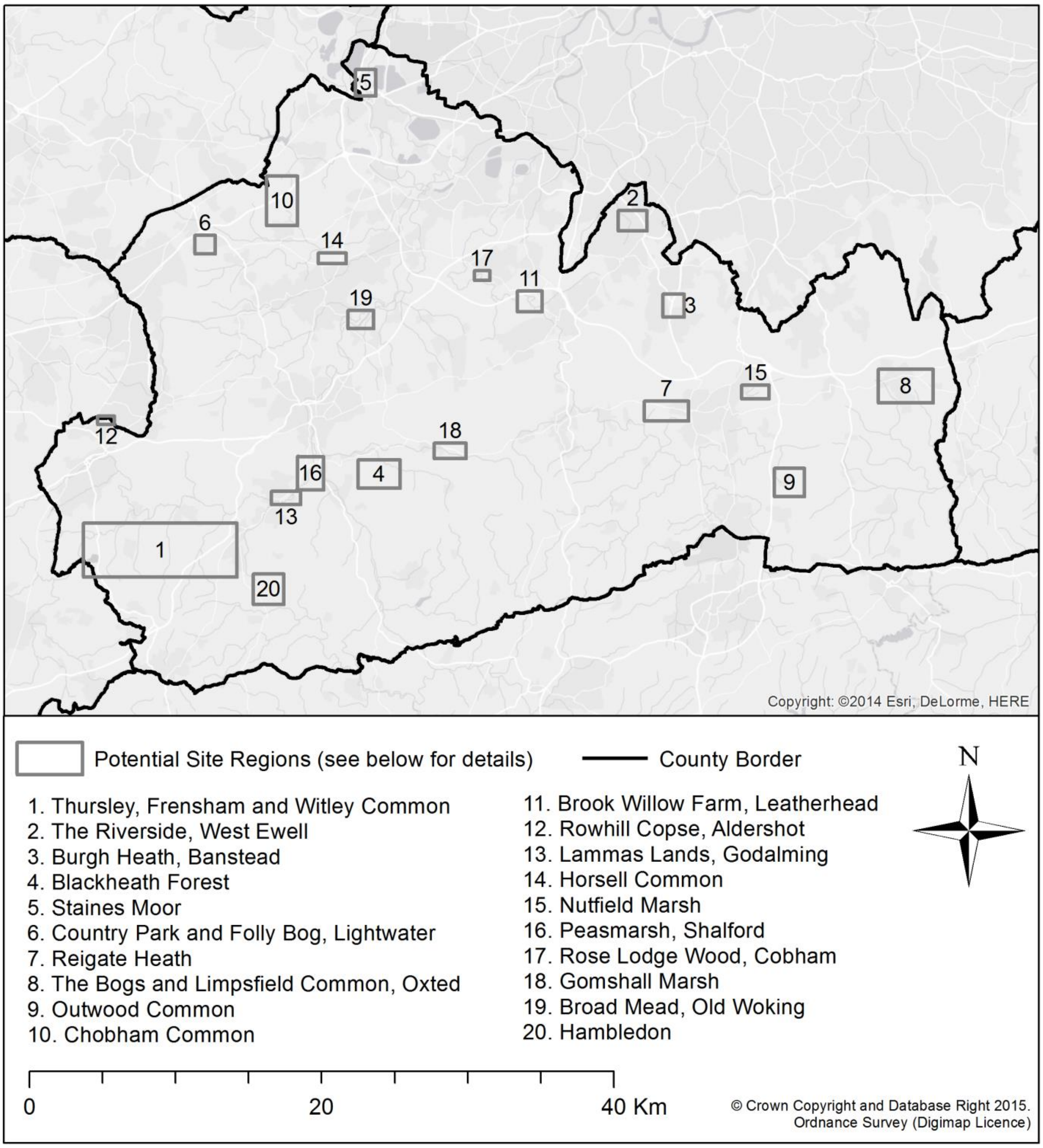


Figure 4.4. Locations and distribution of the 20 study zones chosen for further study.

To ensure the best sites were examined during this research, these 20 study zones were visited in order to undertake reconnaissance investigations, involving the identification of land owners and presence of peat deposits.

1. Thursley, Frensham and Witley Commons

This area was identified as being both rich in archaeology and palaeoenvironmental history. Mesolithic activity has been identified on Hankley Common, and sites at both Elstead and Thursley were known to have peat sequences that preserved palaeoenvironmental remains. Field investigations identified a new and unidentified bog on private land in close proximity to Elstead Bog (SU 89875 42158) (Farr, 2008) and also identified a large but inconsistent spread of peat across Thursley National Nature Reserve (Centre: SU 90713 41585), an area managed by Natural England. A small peat bog was also identified on Witley Common (SU 926 402), land owned and managed by the National Trust. These sites warranted further investigation.

2. The Riverside, West Ewell

The region around West Ewell and the Hogsmill Nature Reserve (TQ 20683 63840) was rich in Mesolithic archaeology. There was also evidence from approximately 4km downstream (at the Hogsmill site) that fluvial sediments (alluvium and silts) dated to the early Holocene (Green et al., 2011). Provisional palynological work showed pollen preservation was poor and quantities low. The region was chosen to see if a continuous record with better preservation could be collected from an area rich in Mesolithic archaeology. Unfortunately, no suitable sites were identified and therefore no further work was undertaken.

3. Burgh Heath, Banstead

Burgh Heath (TQ 24014 57547) was chosen due to high amounts of Mesolithic activity and its proximity to the local clay-with-flints outcrops. Upon investigation there were no regions of palaeoenvironmental interest and the study zone was discounted.

1. Blackheath Forest

Blackheath Forest (TQ 03811 46062) was located on the Lower Greensand and had an abundance of local archaeology. Large areas of the forest were pine woodland with heathland clearings (Figure 4.5) but no suitable palaeoenvironmental sites were located.

Figure 4.5. The open scrub and heath in Blackheath Forest.

2. Staines Moor

Staines Moor (TQ 03285 73029), along the floodplain of the Colne, was chosen as a study region as there is clear evidence of Early Holocene sediments at the site (Keith-Lucas, 2000). Limited dating and low resolution palaeoenvironmental analysis means that further work would improve understanding of vegetation history for northern Surrey. The site was not chosen for further work however due to the discovery of other sites where research had not already been undertaken in the immediate region (Keith-Lucas, 2000; Scaife, 2000a; Branch et al., 2003) and the relatively low density of local archaeology.

3. Lightwater and Pirbright

Within the Westend and Pirbright Common area two large bog systems were identified by Landsat imagery: Hagthorn (SU 92705 60584) and Colony Bogs (SU 92330 59139). These were large and untouched bog systems, however this area has been heavily bombed and shelled for military training resulting in potentially unexploded ordnance, meaning that they were too dangerous to analyse.

The Country Park in Lightwater had a small valley bog (SU 91925 62085) split in half by a large bank (Figure 4.6), owned by Surrey Heath Borough Council. The bog had 30-40cm of peat in the upper basin, with 70cm in the lower basin. If these sediments dated to the Late Upper Palaeolithic or Mesolithic the age-depth resolution was likely to have been relatively poor.

Figure 4.6. The bog in Lightwater Country Park looking eastwards from the bank.

Folly Bog, Lightwater (SU 92585 61327) was on land managed by Steve Proud and owned by the Surrey Wildlife Trust (Figure 4.7). The site had up to 200cm of peat at the deepest points but this peat was thought to be very dry and degraded (Groome, G. Pers. Comm.), due to the intensive drainage across much of the bog system.

Figure 4.7. Folly Bog, to the immediate north of the Pirbright Camp perimeter fence.

South of Pirbright Common, another bog at Congo Stream (SU 92534 56037) was identified. This site had at least 60cm of peat, and there was the potential for deeper sequences to be present (Figure 4.8). This was not pursued further due to the late identification of the site not allowing for additional investigation.

Figure 4.8. The bog discovered in the region of Congo Stream, Pirbright.

4. Reigate Heath

Reigate Heath was chosen due to a large amount of important archaeology in the local region. Upon field investigation, the site was a dry sandy heathland with much of the area transformed into a golf course. A very small damp peaty area of heathland was discovered in the northeastern part of the common (TQ 23899 50436) but did not have any depth or spread.

5. The Bogs and Limpsfield Common, Oxted

The Bogs, Oxted (TQ 38679 52845) was a large boggy floodplain area on either side of a stream that was one source for the River Eden. The area was extensive but no indication of peat depth or type of sediment was known. The nearby Limpsfield Common (TQ 40998 52461) did not have any peat deposits and was discounted from the study.

6. Outwood Common

Investigations at Outwood Common (TQ 32324 45986) were recommended due to a clustering of Mesolithic flintwork in the local area. Fieldwork identified no areas of palaeoenvironmental potential. The Common was a Hornbeam, Oak and coppice woodland, and although a small stream ran through the centre of the common, no peat deposits were present and so the site was not used for further study.

7. Chobham Common

Chobham Common is the largest national nature reserve in SE England (SU 97633 63491) and is situated 4km from Brockhill, one of the most important Late Upper Palaeolithic archaeological sites in Surrey and SE England (Mills, 2012). Investigations at the site revealed a large expanse of bog in an area known as Langshot Bog (Figure 4.9). This area had a peat record greater than 1m in depth and was therefore considered ideal for further investigation.

Figure 4.9. The northwestern edge of Langshot Bog.

8. Brook Willow Farm, Leatherhead

The floodplain regions around Brook Willow Farm (TQ 14640 58101) were chosen due to the palaeoenvironmental possibilities indicated from floodplain sites at Staines, and it was situated on different bedrock geology (London Clay) to many of the other regions. Access was limited at the site and consultation with landowners would be required for any fieldwork so it was not pursued.

9. Rowhill Copse, Aldershot

Rowhill Copse was a small nature reserve to the south of Aldershot (SU 84950 49884). Towards the western edge of the nature reserve was a small seepage bog (Figure 4.10), which had formed at the start of the River Blackwater. The bog was approximately 5m across and depth around the centre of the bog varied from 50cm to 100cm. The land was owned by Rushmoor Borough Council and managed by the Rowhill Nature Reserve Society. The site was not chosen for further study due to the deeper sequences present at some of the other study sites, but would offer potential further study possibilities.

Figure 4.10. The small bog at the start of the River Blackwater.

10. Lammas Lands, Godalming

The Lammas Lands in Godalming (SU 97781 44320) sit on the western end of a large spread of Mesolithic finds and sites. They were large expanses of floodplain meadow that developed along the banks of the River Wey. The Lands had the potential for fossiliferous floodplain sediments but the ground was very dry and would require percussion coring. There was no certainty that the cores would be suitable for pollen preservation or that the sediments would be of a prehistoric age.

11. Horsell Common

The bogs on Horsell Common (TQ 00764 60787) were identified by the ranger Paul Rimmer, and were near to the Late Upper Palaeolithic site of Brockhill. Permission was gained from the Horsell Common Preservation Society to undertake a small study to identify the deposits in part of the site. This work started in the summer of 2013 and formed part of an undergraduate project (Curwen, 2014). Unfortunately the site only provided a very short sequence of ~50cm and the palynological record did not suggest a prehistoric date for the sediments.

12. Nutfield Marsh

The site of Nutfield Marsh (TQ 2905 1512) was near to the large Mesolithic site of North Park Farm and offered an ideal location for palaeoenvironmental reconstruction. The area was not analysed here as the site has been previously studied (Farr, 2008) although a higher resolution and a more robust chronology could tie the site to the local archaeology more successfully. Any studies would benefit from a full survey across the floodplain of Redhill Brook and 'The Moors' (Figure 4.11) as deeper sediments may exist.

Figure 4.11. The floodplain of Redhill Brook in the Nutfield Marsh region.

13. Peasmarsh, Shalford

Peasmarsh had a number of identified boggy regions, surrounding the River Wey and the River Wey navigation. There was a high amount of archaeological activity across this central belt of Lower Greensand, and sites in this region would be valuable for contextualising the vegetation history. The fields south of St Catherine's Lock Cottage (SU 99836 47217) had >20cm of peat at the edges of the bog. The boggy area spanned ~200 x 100m. The land was owned by the National Trust for the River Wey Navigations. No work was undertaken at the site due to the discovery and commencement of work on other sites prior to the identification of Peasmarsh.

14. Rose Lodge Wood, Cobham

An area to the east of Rose Lodge Wood in Cobham (TQ 11332 59576) was highlighted on Ordnance Survey maps as being a marsh, and was also identified as being within a targeted archaeological search area. Unfortunately access to the site was extremely limited.

15. Gomshall Marsh

Gomshall Marsh (TQ 11332 59576) was situated within an area of high archaeological density near to a number of important sites. A field visit identified a large expanse of peat along the floodplain of the Tilling Bourne (Figure 4.12) with a depth of ~70cm. The relatively shallow depth of peat meant that the site was not studied in greater detail, although opportunities exist for further investigation.

Figure 4.12. The boggy and marshy area within Gomshall Marshes

16. Broad Mead, Old Woking

Broad Mead (TQ 03233 56903) was an area of floodplain frequently inundated by the River Wey and was chosen as a potential study site due to the other floodplain records that had been identified as Late Upper Palaeolithic and Mesolithic from within the County. The site would require percussion drilling and no indication of age or depth of sequences was known.

17. Hambledon

Two regions around Hambledon were recommended by Audrey Monk. The regions were Buss' Common, Hambledon (SU 95902 38782) and Stonehurst Hanger (SU 97296 36878). At Buss' Common there was a peat sequence >100cm in depth in a lightly wooded area. This site had the potential for palaeoenvironmental reconstruction. To the south of Hambledon, the Stonehurst Hanger area did not provide any suitable sequences and was discounted.

In addition to these 20 regions within Surrey, Hothfield Common in Kent and Tilgate Forest Lodge in Sussex were examined. Discussion with the Kent Wildlife Trust was initiated as there was the potential that sites in the west of the County may have provided valuable information relating to eastern Surrey. Unfortunately no sites in the west of the County provided suitable sediments; however the site of Hothfield Common was identified (centre: TQ 96822 45799). Hothfield Common was the location of Kent's last four valley bogs and initial investigations at the site showed that the two largest mires, 'bog two' and 'fen bog' had deepest points of 170cm and 100cm respectively. Fieldwork allowed for the collection of cores, however, due to the development of excellent results from the Surrey sites, no further work was undertaken upon these sequences. The site of Tilgate Forest Lodge, Pease Pottage (TQ 26612 32012) was identified by the landowner Richard Mortimore. Investigation identified a number of small bogs, none more than ~50cm in depth, formed on small slopes where drainage had been impeded. The site was not studied further.

4.3. Selected Sites

Out of these 20 study zones, those that offered no potential for palaeoenvironmental investigation were discarded. Some of those that did offer the potential for further study were not chosen due to the time constraints of the project, or provided shallower sequences. The final sites chosen for inclusion were:

- Thursley Common
- Ockley Common
- Chobham Common
- Elstead Bog B

Thursley and Ockley Commons were chosen for investigation due to the interesting assessment of the site from a previous investigation (Moore and Wilmott, 1976). This suggested that a sequence extracted from Ockley Common dated to the Bronze Age, even though the pollen analysis identified taxa potentially attributable to the Late Glacial and Early Holocene. The region was also important in terms of human activity throughout prehistory, especially prior to the Bronze Age. There were important dated records of Mesolithic sites in the local area (Wiltshire, 1997; Reynier, 2002), and numerous findspots suggested that the region was heavily utilised across these times (Graham et al., 1999). A detailed and well dated vegetation history could therefore be highly useful in determining the vegetation cover and human interaction with the vegetation at the wetland/dryland interface at this time.

The site was also important as it was one of the largest expanses of mire and heathland vegetation in southeast England and there was no information on the site's formation or depth of sediment. The depth of sediment will not only have important connotations for the age-depth resolution of a palaeoenvironmental study, but also for carbon storage, as bogs provide one of the highest carbon densities for any land cover type (Milne and Brown, 1997). This was a particularly important topic not only for the personnel managing the common, but also on a national and international level due to climate change (Belyea and Malmer, 2004).

Approximately 1km from Thursley Bog was the site of Elstead Bog, a small peat filled basin situated in small private woodland. The site had been studied on numerous occasions (Seagrief and Godwin, 1960; Carpenter and Woodcock, 1981; Farr, 2008) and provided a record of vegetation history spanning the Early Holocene (Farr, 2008). Unfortunately the record did not provide any environmental information for the Late Glacial period. Investigations around this site identified a new basin, Elstead Bog B, which appeared to have a depth of ~200cm. This site was chosen for further analysis to gain an understanding of the base of the Elstead Bog sequence, and understand vegetation history across the Late Glacial and Early Holocene boundary.

Initial fieldwork and discussions with rangers at Chobham Common identified Langshot Bog, Little Arm and Long Arm as potential sites for palaeoenvironmental studies. Long Arm and Little Arm were discounted as they were thought to have been created relatively recently, due to human interference with drainage on the northern side of the common (Webster, 2015). No published work existed on the origins, depth or stratigraphy of Langshot Bog so a transect survey was undertaken to identify shape and depth. The deepest point within this survey was over 200cm making the site one of the deepest lowland wetlands within southeast England. Brockhill, the nearby Late Upper Palaeolithic site, was highly important in providing evidence for the archaeology of the region, but very little was known about the environmental conditions at the time. The site was chosen due to the significance of the palaeoenvironmental record that it could provide.

The sites that were not taken forward for further study, but still offered the potential for detailed palaeoenvironmental work included: The Bogs in Oxted, Nutfield Marsh, Gomshall Marsh, Folly Bog, Congo Stream, Buss' Common, Hothfield Common, Peasmarsh, Rowhill Copse, Witley Common and Staines Moor.

4.4. Field Sampling

In order to collect sediments from these chosen study sites, a specific site sampling plan was formulated depending on the size, shape and nature of each bog. All of these methods relied heavily on fieldwork, specifically coring, in order to understand the depositional characteristics of each site and ensure optimal samples were extracted at each location. Site descriptions, location (OS grid reference), photographs and field notes were all recorded.

Transects were run across the surface of the bogs with a number of evenly spaced points (point spacing varied based on bog shape and size), a method used on many different scales of bog complexes (Carpenter and Woodcock, 1981; Viktorov et al., 2013). Transect points were identified using a DGPS, with accuracy ranging from 3cm-100cm. For sites where immediate high scale transect coring would have been impractical, a preliminary survey was undertaken. This involved a gridded set of boreholes covering the site at a resolution based on the size of the bog (Clymo, 1980), and borehole locations were submitted to individual site managers to ensure their records of investigations were up-to-date. Boreholes were located using a handheld GPS with an accuracy of ±3m, acceptable when the distance between boreholes was 100m. The boreholes were then cored to determine just the depth of sediment from the surface to the bedrock. This was in order to determine the deepest sections of sediment that could then be studied in higher resolution using a transect survey where individual sediment units were described. This method was only employed on bogs where the surface area of the basin was over $1km^2$.

Cores for field descriptions and laboratory work were collected using a Russian corer (or D-section corer), a hand coring device that was inserted to the required depth and rotated in order to cut an undisturbed section of core (Figure 4.13). The size of each core from a standard Russian corer is 500mm x 50mm. If the sediments allow, a larger Russian corer was used. This had a core size of 500mm x 100mm, and therefore allowed for more sediment to be collected in each core. The large corer could only work in softer and looser sediments due to the larger profile. The Russian corer is widely used in palaeoenvironmental sampling because of the high quality of extracted sample (Moore et al., 1991) and the speed and ease of operation (Jowsey, 1966). Each completed core was comprised of sections from two boreholes, situated no more than 30cm apart. Cores overlapped by 10cm so the nose of the Russian corer did not disturb the top of the next section of core. If progress was interrupted due to the presence of wood or rock then a further borehole was utilised in order to complete the sequence.

Figure 4.13. A sampled core taken using the 500mm x 50mm Russian Corer.

For sediments examined during the transect surveys, cores were extracted and sediments logged in the field. These cores were then discarded and the transect was continued. For laboratory cores, once each 50cm sample was extracted, it was carefully placed into rigid plastic downpipe, wrapped in polythene sheeting to prevent drying out and fully labelled. This was important as pollen preservation can suffer if the core dries out (Moore et al., 1991). The cores were then stored in a cold store (<4˚C) at the University of Reading.

5. Rationale and Methodology: Laboratory Techniques

5.1. Rationale

The rationale behind the four main methodologies: palynology, microscopic charred particles, radiocarbon dating and stable isotopes allow for an understanding of how these techniques are applied to the study of lowland wetlands in southeast England during the Late Glacial and Early Holocene.

5.1.1. Palynology

Pollen analysis is widely used in Quaternary science, archaeology and forensic science and can provide information on former vegetation cover, succession, refugia and migration, climate change, human interference with the environment, land use and diet (Branch et al., 2005). Pollen is produced by angiosperms and gymnosperms (flowering plants and conifers respectively) and spores are produced by cryptogams (mosses, fungi and ferns). Angiosperm and gymnosperm pollen grains are transported by wind, water, animals and insects, whilst cryptogams spores are transported only by wind (Bell and Walker, 2005) and ~99% are deposited within 1km of the source location (Armstrong and Brasier, 2013). Pollen is collected and stored in a number of different archaeological archives, and within Britain, pollen has been found and analysed from sites including peat bogs (Groves et al., 2012), lacustrine sediments (Taylor et al., 1994), floodplains (Needham, 1992), caves (Pettitt and White, 2012a), soils (Graham et al., 2014), cess pits (Greig, 1994) and coprolites (Lewis, 2010) where, based on preservation conditions, pollen can remain for thousands of years.

Identification of pollen grains is achieved through the study of modern analogues, including modern reference collections, images and taphonomic keys (Moore et al., 1991; Reille, 1995). To identify specific grains, characteristics including orientation, shape, size, sculpturing, apertures and other features are examined using a transmitted light microscope (Moore et al., 1991; Branch et al., 2005). Grains are counted until the set total has been reached, often 300-500 total land pollen grains. This count includes trees, shrubs and herbs but does not include aquatic species or spores, as they often represent the microscale vegetation cover and can be over represented (Branch et al., 2005). Understanding and correctly interpreting pollen data requires knowledge of all the processes that have led to pollen being deposited and preserved at a site.

Within lowland wetlands, the likely source region of the pollen spectra is important as it is determined by site selection and sampling. Bog size and shape, and the vegetation present around the basin will determine the pollen catchment area on a micro-, meso- or macroscale region. If the basins are very small, it is likely that pollen will travel no further than 20-30m from the source, representing a local pollen signal (Jacobson and Bradshaw, 1981). For small sites (~50m) between 30-45% of the total pollen may come from within 400m of the site (extra-local) (Sugita, 1994). Bogs where the surface diameter is between 100-200m will have a more open tree canopy, due to the larger size of the basin. This will mean that the majority of the pollen signal will be provided by the extra-local (20-several hundred meters) and regional (greater than several hundred meters) pollen signal (Jacobson and Bradshaw, 1981), and the record will likely represent the sub-regional vegetation community (Branch et al., 2005). It has been shown that when species abundance maps are correlated to the pollen percentage record derived from this type of large bog, the regional signal may be as large as 20-30km (Prentice, 1985). The varying size of the wetlands used in this project mean that the sites offer an opportunity to examine the local, extra-local and regional pollen signal. The relevant source area for each site is discussed further in each site chapter and additionally in the discussion.

Pollen enters a lowland wetland through a variety of transport mechanisms, first proposed by Tauber (1965) through looking at lake sediments, and developed since then (Jacobson and Bradshaw, 1981; Prentice, 1985; Sugita, 1994; Bunting, 2008). Wetlands, as opposed to lakes, are particularly difficult to interpret due to the vegetation present on the surface (Figure 5.1) (Bunting, 2008).

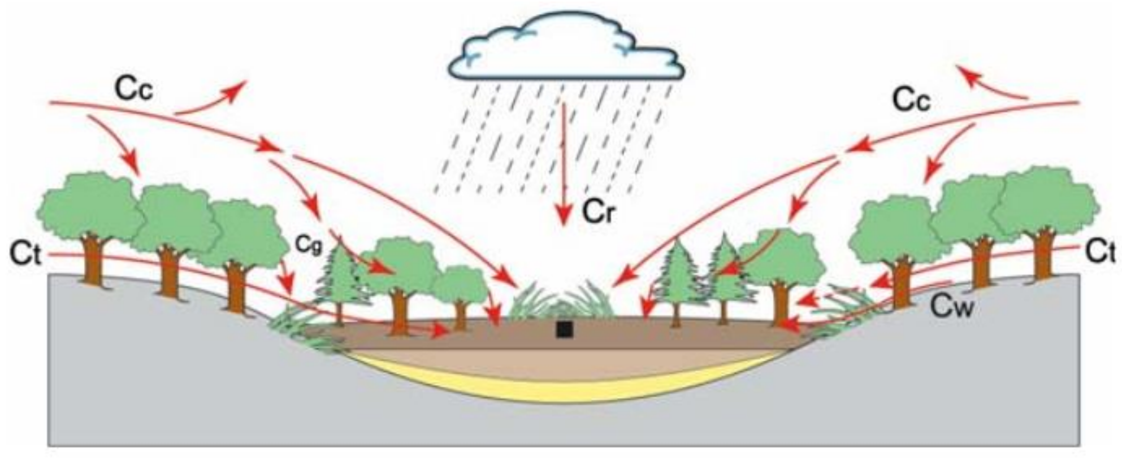


Figure 5.1. Transportation of pollen into wetlands (from Bunting, 2008: pg. 2081).

In relatively large, open basins (Figure 5.1) the above canopy air flow (Cc) is thought to account for the majority of arboreal pollen input, although some will derive from direct deposition under gravity. This is likely to reflect arboreal taxa from a wide pollen source (sub-regional upwards depending on basin size). In forested regions, such as may have been present during the Early Holocene in Britain, the shrub and herb taxa are likely to be representative of the local area, immediately adjacent (Cw – surface runoff component) and on the sampling site (Cg – gravity component). This is due to the low wind speeds present in the forested trunk space (Ct) reducing the dispersal of these species that release pollen near to the ground. Therefore the herbaceous and shrub taxa will represent a smaller pollen source region than the arboreal taxa, likely providing a local signal (Prentice, 1988). The precipitation component (Cr) can provide both arboreal and herbaceous taxa to the pollen record. The local shrub and herb taxa may also dilute the signal from the wider landscape due to the substantial local input from these species. Species present on the surface of small wetlands may also intercept airborne pollen, potentially reducing the importance of this component (Bunting, 2008). If basin sizes are very small, such as in small forest hollows, or where dense tall vegetation may shadow over the site, then the pollen source area is likely to change (Figure 5.2).

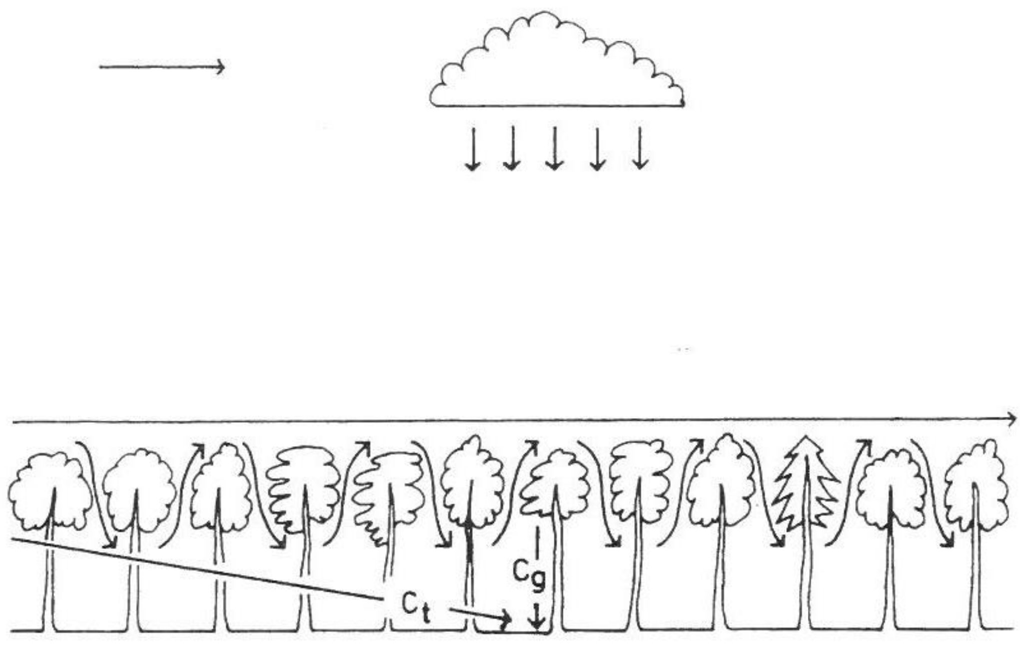


Figure 5.2. Pollen transfer into a site beneath or shadowed by the canopy: from Prentice (1985).

Pollen deposition models indicate that in these types of site, the primary method of pollen deposition comes from the gravity component (Cg), with some additional deposition from pollen carried through the trunk space (Ct). The gravity component will contain both pollen of the species growing above the hollow, in addition to pollen intercepted from above the canopy area (Prentice, 1985). However, this component is much less regionally indicative than the above canopy air flow (Cc) delivered to a large open basin, and subsequently these smaller denser basins provide a much more local pollen signal.

In addition to these differing transport methods, pollen is produced at different rates by different species and this varying pollen production rates are primarily understood in a relative context (i.e. between different species). For example, *Pinus, Betula, Corylus* and *Alnus* are high pollen producers, *Quercus, Fagus* and *Tilia* produce moderate amounts whilst *Ilex* produces much less (Branch et al., 2005). Transport varies for pollen grains depending on the type of pollination. Higher pollen producers should be well represented in diagrams, whilst self-pollinating plants are often under-represented, although this is dependent on plant location and deposition processes.

Preservation of pollen grains is also highly variable and depends upon a number of factors. Ideal preservation occurs under anaerobic and acidic environments, i.e. peat bogs, lacustrine sediments and floodplains. Preservation can change due to environmental and anthropogenic factors, i.e. the draining and drying out of an anaerobic peat bog. Preservation is a high concern when optimal conditions are not present, as this can lead to preferential preservation and subsequent difficulty with palynological interpretations (Branch et al., 2005). This is not thought to be an issue within this study as all archives are well-preserved peat records.

Once these factors are understood, interpretation of the final pollen assemblage can be undertaken. Pollen results are often presented diagrammatically as percentage pollen counts, derived from the total of tree, shrub and herb pollen. The changes in an absolute pollen diagram may not necessarily relate to plant ecology modifications as the diagrams are mutually dependent, as an increase in one taxa necessitates a decrease in others (Branch et al., 2005), so absolute pollen diagrams, which require exotic pollen to be added to the sample, can be used (Stockmarr, 1971; Moore et al., 1991; Branch et al., 2005). Absolute pollen diagrams include pollen concentration (grains per cm^2), which calculates the ratio of fossil to exotic pollen, and pollen influx (grains cm^{-2} $year^{-1}$), which uses the sediment accumulation rate to calculate length of deposition time. Pollen influx diagrams are not dependent on relationships between species, and therefore an increase in one type will not produce decreases in other taxa, unlike a percentage diagram, and any changes represented on an influx diagram represent independent changes in the grains deposited per year (Williams, 1972). Even with the chronological models for the study sites, there may have been changes in the sedimentation rate between dated horizons and so care must be taken in interpretation of the influx data. It has been shown that across the Late Glacial to Early Holocene period, influx diagrams have identified trends in pollen production not picked up in percentage data (Prentice, 1988). When used in combination, pollen influx and percentage diagrams will often offer the most reliable method of understanding vegetation succession and development at a site (Branch et al., 2005). The pollen diagrams will be used to examine the vegetation from the study sites across the Late Glacial and Early Holocene, and identify any changes in this vegetation composition. These vegetation records are able to identify events that may be due to climatic or environmental change, or anthropogenic impacts. This is particularly important in respect to the climatic change that occurred across southeast England during this time, and the potential for anthropogenic impact that may have occurred in the region.

5.1.1.1. **Indicator Species**

Indicator species are a highly important class of pollen grain, as they have the potential to identify human influences on the landscape (Behre, 1981; Edwards and MacDonald, 1991) (Li et al., 2008). These species highlight those taxa that are indicative of particular forms of land use, for example cultivation, meadow development or pastureland (Branch et al., 2005). Detailed palaeoenvironmental species lists are provided in a number of publications (Behre, 1981; Gaillard, 2007). There are however, a number of issues when using indicator species in palaeoenvironmental work.

Unfortunately, many of the species that are indicative of human activity are plants identified to species level, whereas pollen analysis may only be able to identify to family or genus level, meaning that the signals are not always readily distinguishable. This means the interpretation will also be based on other pollen present within the sequence and evidence for local archaeological activity (Behre, 1981). Each species' ecological niche can also determine the accuracy of any interpretations, as species with tight ecological ranges can provide more information than species with wider ecological ranges. Understanding ecological niches involves using comparable modern day analogues of specific vegetation communities in order to assess their composition and diversity of species (Behre, 1981).

The use of indicator species within this study are particularly important as there is the potential for human groups at this time to have been causing extensive woodland clearance, potentially through the creation of clearings to attract increased faunal diversity. The presence of these clearings is an ecological trait that indicator species may be able to identify, potentially through an increase in ruderal weeds after a deforestation event. In a Mesolithic context, identification of changes in woodland composition have been identified particularly as a response to burning (Innes and Blackford, 2003). Identified disturbance phases in Mesolithic pollen diagrams show that initial post-burning taxa comprised of ruderal weeds and *Melampyrum,* which is subsequently replaced by *Corylus, Salix, Calluna* and other shrubs until the trees re-establish themselves (Behre, 1981; Farr, 2008). This vegetation succession has been observed in modern field observations (Innes and Blackford, 2003).

Previous studies have identified a number of Mesolithic indicator species that help to examine the potential for the creation of clearings and meadow land (Table 5.1).

Table 5.1. Mesolithic indicator species and their indicator land type. (After Farr, 2008).

Indicator family, genus or species	**Indicator land type**	**Reference**
Apiaceae	Meadow/Pasture	(Gaillard, 2007)
Artemisia	Ruderal	(Gaillard, 2007)
Anthemis type	Ruderal	(Gaillard, 2007)
Chenopodiaceae	Post disturbance *(ruderal)*	(Simmons and Innes, 1996a)
Cyperaceae	Natural communities, Wet meadows	(Behre, 1981; Gaillard, 2007)
Rumex	Meadow/Pasture	(Gaillard, 2007)
Melampyrum	Post-fire *(ruderal)*	(Innes and Blackford, 2003) (Simmons and Innes, 1996a)
Menyanthes trifoliata	Wet meadows	(Gaillard, 2007)
Plantago lanceolata	Post disturbance *(ruderal)*	(Behre, 1981)
Poaceae	Meadow/Pasture/grazed forest	(Behre, 1981; Gaillard, 2007)
Pteridium aquilinum	Grazed forest	(Behre, 1981)
Urtica type	Ruderal	(Behre, 1981)
Ranunculus type	Meadow/Pasture	(Gaillard, 2007)

If these indicator species are identified in the palynological record, it is important to place them in full context of the pollen diagram, the surrounding environment and the archaeological landscape, to consider the potential forcing factors behind the presence of these species and potential vegetation change.

5.1.2. Microscopic Charred Particles

Palaeoenvironmental work that examines fire history is very important for understanding the relationships between climate, vegetation and human activity. Microscopic charred particles (MCP's) can provide information on wild-fires and deliberate woodland interference from humans, either for agriculture, clearance or management (Branch et al., 2005). This is important within the Late Mesolithic period as fire was potentially used not only for domestic use, but also for creating clearings (Whitehouse and Smith, 2004). In a wider context, many studies have suggested that fire may have been an important controlling factor in determining overall woodland composition during this period (Mason, 2000; Bradshaw et al., 2003; Finsinger et al., 2006a).

The study of microscopic charred particles provides a record of burning in the local environment. It is highly difficult however, to attribute this charcoal signal to either human activity or natural events on the presence of the charcoal alone. In order to understand more about the source of any charcoal, it must be placed in context with other complimentary proxy records including pollen and sediment profiles (Branch et al., 2005). Understanding the source area is equally difficult with dispersal, deposition and diagenesis all complicating factors in MCP analysis, and are affected by the fuel source, type of fire and weather conditions (Clark, 1988). Due to these complex interactions it is difficult to compare charcoal records between sites, and therefore fire histories often exist on a site-by-site basis. It has been shown that both small and large bog sites are able to produce useful and informative fire history records (Smart and Hoffman, 1988; Simmons, 1994; Innes et al., 2010).

5.1.3. Radiocarbon Dating

Radiocarbon dating is one of the most commonly used dating methods in Quaternary science and archaeology (Branch et al., 2005). Radiocarbon dating has undergone a transformation from the earliest laboratories and samples, through to a much higher level of both precision and accuracy with the advent of Accelerator Mass Spectrometry (AMS) (Barber and Charman, 2005; Pilcher, 2005). AMS dating involves the counting of ^{14}C atoms when accelerated to a high speed, using a van de Graff generator to separate them from similar mass elements, allowing individual atoms to be counted instead of waiting for them to decay (Branch et al., 2005). The smaller size of sample needed for AMS dates opens up more possibilities for potential dating.

The precision of AMS dates is approximately 2.5‰ due to the potential for errors in particle counting and random radioactive decay, and a realistic error is identified through a ± number of years after the date in radiocarbon years (Stuiver and Polach, 1977; Pilcher, 2005). Radiocarbon years do not correlate with calendar years and therefore a calibration curve must be used (Reimer et al., 2013). Calibration curves are continuously updated and specific programmes can be used to calibrate individual dates and sequences of dates (Ramsey, 2009a). Any ages quoted are before present from year 0, which is taken as AD1950 (Stuiver and Polach, 1977). The current calibration curve is IntCal13 (Reimer et al., 2013). This calibration curve is based on tree ring measurements dating back to 13,900 cal. BP, supplemented by Lake Suigetsu macrofossil data for older records up to 40,000 years BP (Kitagawa and van der Plicht, 1998). Non-varved marine foraminifera, Uranium-thorium dated corals and speleothems are all also used to address areas of the curve where data is sparse or variable (Reimer et al., 2013).

Before submitting any sample for dating, it is important to consider the site stratigraphy, and the nature of the material being submitted. This must be considered in order to ensure that the date is likely to be robust and uncontaminated (Pilcher, 2005). If there is the possibility of additional chronological control, such as tephra layers, then this will enhance the dating programme (Smith et al., 2013). It is also important to consider if the carbon will provide a reasonable estimate of the actual age of the event being measured, particularly important where the item may have died (and therefore stopped accumulating carbon), prior to the event that is trying to be dated, e.g. an archaeological hearth (Pilcher, 2005). Samples that will have not lived for very long are also ideally suited for radiocarbon dating, and therefore short lived parts of plants, e.g. twigs, and short lived species are often chosen.

5.1.4. Stable Isotopes

Bogs, wetlands and mires often contain large peat deposits which are valuable archives of environmental change, due to their sensitivity to hydrological events (McClymont et al., 2010). The geochemistry of a peatland is comprised of the original plant assemblage and its transformation into peat through the acrotelm and catotelm. Isotopes of Oxygen ($\delta^{18}O$), and Hydrogen ($\delta^{2}H$) from peat sediments are able to record temperature and precipitation (Barber and Charman, 2005) through fractionation of specific isotopes. The abundance of stable isotopes is constant across the earth system, however differences are observed when examined in smaller systems (Brand, 1996). Many elements have a more abundant light isotope and one (or more) heavier isotope(s), and variation between these isotopes is often very small. Due to this, variation is expressed in delta value δ, in units of per mil (‰) (Slater et al., 2001). The isotopic composition of the peatland can indicate precipitation source and hydrology of the site, through changes in air temperatures and water table depth (Daley et al., 2010; McClymont et al., 2010). Within peat forming plants, the isotopic fractionation of oxygen and hydrogen is dominated by both climatic and plant-physiological parameters (van Geel and Middeldorp, 1988). It is thought that the main influencing factors that modify the isotopic ratio are based on precipitation and evaporation, which occur as water passes through the hydrologic cycle (Gibson et al., 1993). It has also been shown that the oxygen and hydrogen records can be out of phase within the same record (Eley et al., 2014), with precipitation and evaporation signals separated between oxygen and hydrogen.

Numerous different types of peat forming plants occur within any peat sample, all of which will have distinct chemical characteristics. Within bulk peat samples there are therefore differing contributions to the isotopic record and it is difficult to isolate the individual signals (Blackford, 2000). A study of Carbury Bog, Ireland showed that the $^{2}H/^{1}H$ ratio was negatively correlated with the Medieval Climate Anomaly and the Little Ice Age. It is suggested that the isotope record was showing local trophic and hydrological conditions, potentially influenced by different length growing seasons (van Geel and Middeldorp, 1988). These records appear to be highly variable depending on the species composition present at time of deposition and decomposition (van Geel and Middeldorp, 1988) and may therefore represent changing vegetation communities rather than a change in temperature or precipitation (Barber and Charman, 2005). Through the identification and selection of a specific species, a more precise climatic and hydrological signal can be obtained (McClymont et al., 2010). Individual picked sedge (*Carex)* records have been used to provide a record of climate change during the Holocene independent to pollen records in Patagonia, where the sedge fragments appeared to provide a humidity indicator (Pendall et al., 2001).

Although not many studies have looked at oxygen and hydrogen isotopes on peat samples, they have shown that the analysis of both oxygen and hydrogen stable isotopes can be important and useful for investigating palaeoclimatic and palaeoenvironmental change. This is particularly important in respect to the Late Glacial and Early Holocene periods as the isotopic record may help to identify periods of rapid climate change that can be difficult to identify from other types of proxy. The isotopic record will help to ascertain how variable the climate was during this time in southeast England, including events such as the Loch Lomond

Stadial and shorter events like the 8.2 Kya event. Due the diverse nature of peatland composition, it is important to utilise a systematic sampling approach and a multi-proxy methodology in order to understand the isotopic record (McClymont et al., 2010).

The analysis of a single sequence from Langshot Bog will be undertaken within the project, to provide 'proof-of-concept' for stable isotope work on peat bogs in southeast England.

5.2. Methodologies

A number of techniques were used to derive a palaeoenvironmental and cultural record from the lowland wetland sites.

5.2.1. Palynology

Pollen samples were sub-sampled from cores that were refrigerated between 2-4˚C in order to prevent deterioration. Samples were extracted in the laboratory using clean scalpels and spatulas into a 1cm^3 volumetric sampler, a standard size used in pollen analysis (Bennett and Willis, 2002). Samples were subsequently prepared for heavy liquid flotation using the following method:

1. Disperse samples in 1% sodium pyrophosphate solution alongside 2 lycopodium tablets. Slowly heat samples on a hotplate until the lycopodium tables have dispersed and the samples are fully deflocculated.
2. Pass samples through a nested pair of sieves, comprising of a 125µm sieve on top and a 10µm micron mesh on the bottom. The coarse sieve removes larger mineral and organic material whilst the fine mesh allows only very fine organic and mineral matter through, leaving pollen (and some organic and mineral matter) on the mesh.
3. Transfer the residue within the 10µm micron mesh to labelled round bottom 15ml test tubes.

Heavy liquid flotation, using sodium polytungstate (SPT - $3Na_2WO_49WO_3$ H_2O) at a specific gravity of 2.0g/cm^3 was used to separate organic matter from the mineral matter. This is a method frequently used in palynological studies (Lowe and Turney, 1997; Anshari et al., 2001; van der Kaars and De Deckker, 2002; Branch et al., 2005; Branch, 2013; Branch and Marini, 2014; Graham et al., 2014) after being developed in the 1990's (Munsterman and Kerstholt, 1996). The specific gravity of the SPT causes lighter organic matter to float on the surface of the SPT whilst heavier mineral matter remains at the base of the test tube. The heavy liquid flotation method is as follows:

1. Centrifuge samples at 2500rpm with brake on for 5 minutes and pour off supernatant.
2. Add 5ml of sodium polytungstate to each sample.
3. Centrifuge samples at 2500rpm with the brake off for 20 minutes.
4. Label an appropriate number of conical base centrifuge tubes.
5. Pour off suspended organic fraction from round bottom samples into conical tubes.
6. Collect supernatant for recycling; discard mineral matter left in original samples.
7. Dilute organic matter with deionised water and centrifuge at 2500rpm with brake on for 5 minutes. Collect supernatant for recycling.
8. Repeat point 7 two more times to ensure all SPT is removed from the sample.

Acetolysis was used in order to remove any extraneous organic matter (Erdtman, 1960). The method is now widely used in palynological studies (Moore et al., 1991; Branch et al., 2005). For all centrifuge stages, the centrifuge was set at 2500rpm with the brake on for 5 minutes:

1. Centrifuge the samples and pour off the supernatant
2. Add 10ml of glacial acetic acid (CH_3COOH) to each sample. Shake and mix well then centrifuge the samples. Glacial acetic acid dehydrates the sample.
3. Whilst the samples are in the centrifuge, make up the Erdtman solution. Each sample needs 5ml of solution in the ratio 9 parts acetic anhydride ($(CH_3CO)_2O$) to1 part sulphuric acid (H_2SO_4).
    a. To create the solution, add the acetic anhydride to a conical flask and slowly introduce the sulphuric acid, ensuring conical flask is swirling as the sulphuric acid is added. Care must be taken at this step as reaction is exothermic and heat will be given off.
4. Pour off the glacial acetic acid supernatant and add 5ml of Erdtman solution to each sample. Mix samples well.
5. Place all samples in a boiling water bath for 3-4 minutes, then remove samples and centrifuge.
6. Pour off supernatant, fill samples with deionised water and mix well.
7. Centrifuge samples and repeat points 6 and 7 until sample is neutral.
8. Fill each sample up to 1.5ml with deionised water and transfer water and sample to micro-centrifuge tubes. Add 1 drop of Safranin staining to each micro-centrifuge tube.

9. Centrifuge micro-centrifuge samples and pour off supernatant.
10. Mount samples onto glass slides using glycerol jelly (Branch et al., 2005).

A Leica DME microscope at ×400 and oil immersion ×1000 magnification was used for all palynological identifications. Identification of pollen types involved the use of the University of Reading reference collection and consultation with pollen keys and pollen atlases (Moore and Webb, 1978; Faegri et al., 1989; Moore et al., 1991; Reille, 1995). Plant nomenclature followed the flora of the British Isles (Stace, 2010). Pollen results were expressed as both a percentage of total land pollen and pollen influx.

Pollen percentage and influx calculations were calculated in Tilia version 1.7.16 (Grimm, 2011) based upon a pollen sum of ~300 total land pollen (TLP). This count excluded aquatic species and spores; subsequently calculated as a percentage of their totals + TLP. The influx diagram used both the radiocarbon model and concentration data to provide influx data in grains per cm per year. TILIAGRAPH (Grimm, 2011) was used to draw pollen diagrams for the percentage and influx data. Constrained incremental sum of squares clustering (CONISS) was used to help divide the percentage pollen diagram into a number of local pollen assemblage zones (Grimm, 1987).

5.2.2. Microscopic Charred Particles

A number of different methods could have been used for counting microscopic charred particles (Rhodes, 1998; Branch et al., 2005). The method chosen in this study was quantitative and based upon a modified method from Robinson, (1984) where the MCP were counted relative to the trees, shrub and herb pollen count. Slides were produced for pollen analysis using an exotic pollen marker (Stockmarr, 1971) with the MCP counted at the same time as pollen grains. This method was chosen as it has been successfully used in a number of studies (Simmons and Innes, 1996b; Innes et al., 2004; Innes et al., 2010), and could be used in conjunction with the palynological work. Different size classes for the charcoal were not implemented, due to the potential for fragmentation during the pollen preparation process, potentially artificially increasing charcoal counts in small size classes (Innes et al., 2004; Innes et al., 2010). The basic definition of MCP size was based on the exotic *Lycopodium* tablet of approximately 30μm (Innes et al., 2010) and results were calculated as per the pollen analysis.

5.2.3. Radiocarbon Dating

All cores were assessed for the presence of plant macrofossils through a visual survey to identify and extract large and obvious macrofossils. A number of samples from each core were sieved through a 125μm sieve to remove the organic matter matrix and enable the extraction of any plant macrofossils that were not apparent from the visual scan. Unfortunately, no sequences provided continuous macrofossil records suitable for radiocarbon dating. This led to the use of bulk peat samples across all of the sequences. Bulk peat samples were extracted from the core using a metal scalpel and spatula, and double bagged within plastic sample bags. Samples were weighed (g) and labelled with site and depth. The samples were then stored in a cool, dark location at 2-4°C before sending to the radiocarbon dating laboratory. Aluminium foil was not used for wrapping the samples as acidic peats can cause the foil to disintegrate. Radiocarbon samples were chosen through consultation with Peter Marshall (Historic England) on the basis of three criteria: organic matter content, lithostratigraphy and pollen and microcharcoal stratigraphy. This led to the majority of samples being picked at either lithostratigraphic boundaries or microcharcoal peaks, with some samples from specific pollen taxa peaks. All samples were picked from those areas with the highest organic matter content (relative to each sequence). The samples from boundaries were chosen as these regions are likely to indicate changing sedimentation rates or other disruptive events, knowledge of which are important for accurately modelling the sequence. Samples from microcharcoal and pollen peaks allow for excellent chronological control on the important palaeoenvironmental (and potential cultural) signals within the sequence. The careful selection of samples based on these criteria meant that samples chosen for analysis were the most suitable from each sequence.

The ages of each bulk sample was determined by AMS ^{14}C dating. Measurements were undertaken at the ^{14}CHRONO Centre in Belfast, Northern Ireland and the SUERC Radiocarbon Dating Laboratory in Glasgow (Freeman et al., 2004; 2007). Further information on the AMS radiocarbon dating method can be found in Branch (et al., 2005) and Pilcher (2005). The radiocarbon dates were calibrated using OxCal v4.2 (Ramsey, 2009b) into calibrated years before present (cal. BP). OxCal v4.2 was also used for age-depth modelling of radiocarbon dates, which provided the approximate timing of events that were not dated directly using radiocarbon dating. OxCal v4.2 was used alongside the INTCAL 13 atmospheric calibration curve (Reimer et al., 2013). A P-sequence deposition model was used (Ramsey, 2008) which allowed for a variable rate of sedimentation, ideal in peat sequences where the rate of deposition can fluctuate due to a number of factors. Variable K was used within the P-sequence model so that the model accounted for changes in the rate of deposition (Ramsey and Lee, 2013). Both the model and the radiocarbon dates were calibrated to a 95% confidence interval.

5.2.4. Stable Isotopes

1cm sub-samples were extracted from the peat core sequence at 2cm intervals, the same intervals as the pollen analysis. Individual sedge and grass macrofossils were extracted from each sub-sample, washed and placed into an individual petri box. All sub-samples were checked under a Leica S6D zoom-stereo microscope at x10 magnification to ensure only sedge/grass fragments had been picked. The samples were then processed:

1. Samples were oven dried at 40°C to remove all moisture.
2. Weigh out individual samples to between 0.16-0.20mg using a microbalance.
3. Place weighed sample in a silver sample capsule, close top and tightly wrap into balls.
4. Place silver capsule into a labelled Eppendorf tube to ensure no hydrogen exchange with the atmosphere.
5. Thoroughly clean equipment between samples to ensure no cross-contamination.
6. Repeat process for remaining samples and the standards.

The use of standards in isotopic analysis is vital for correct interpretation of the results. If the heavy isotope is depleted relative to the standard, a negative δ value is generated, and if the sample is enriched in the heavy isotope, a positive δ value will be observed.

Three standards were used:

- IAEA 601 benzoic acid ($\delta^{18}O_{VSMOW}$ of +23.3‰)
- IAEA-CH-7 polyethylene foil ($\delta^{2}H_{VSMOW}$ of -100.3‰).
- 'In House Benzoic Acid' ($\delta^{18}O_{VSMOW}$ of +25.6‰).

Standards were weighed into silver capsules, and three empty silver capsules were used as reference blanks. Benzoic acid is an excellent standard for use in organic material O and H analysis because it is highly stable and not hygroscopic (Raynaud, 2012). Good practice dictates that two or more standards should be used, increasing accuracy and data reliability (Gionfiantini and Stichler, 1995).

Oxygen and hydrogen ratios were expressed relative to the international standard, Vienna Standard Mean Ocean Water (VSMOW). The international standard was subsequently used to create international reference material through calibration, allowing for measurements to be normalised. The delta results were then described on a scale normalized by arbitrarily giving the standards values of 0‰ (Raynaud, 2012). The equation for calculating the delta value is:

Equation 5.1. Equation for calculating the delta value.

$\delta = \left(\frac{Rsa-Rstd}{Rstd}\right) x\ 1000\ or\ \delta = \left(\left(\frac{Rsa}{Rstd}\right) - 1\right) x\ 1000$ After (Raynaud, 2012).

Where: Rsa = ratio of heavy to light isotope of the sample
                Rstd = the equivalent ratio for the standard

For processing of the samples and standards, the GC oven was set to 90°C and the furnace was set to 1400°C. Isodat 3.0 was used to analyse the results (Raynaud, 2012).

5.2.5. Sediment Description

Detailed and accurate sediment descriptions are vital in order to fully understand the history of a site, and sedimentological records can be used in conjunction with other proxy records to enhance understanding of the environmental and climate history (Branch et al., 2005).

Core stratigraphy was described by reference to the Troels-Smith classification scheme (Troels-Smith, 1955), used across both Quaternary and archaeological science (Tooley, 1986; Lotter, 1989; Bradley, 2005). Troels-Smith examines three main sedimentological properties: physical characteristics, composition and degree of humification:

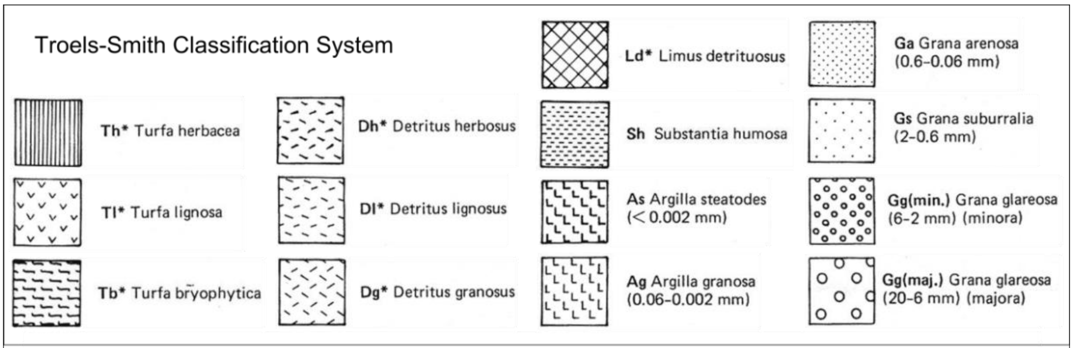
- Physical Characteristics – units were measured in terms of relative depth within the core. The colour was noted from a Munsell Colour Chart (Munsell, 1912; Munsell Color, 2000) and the boundary between units was defined as sharp or diffuse.
- Composition – lithological units were described using the Troels-Smith method with abbreviated terms. Lithological sections were defined on proportionality, with each individual lithological component having a value of 1-4 where 1=25%, 2=50%, 3=75% and 4=100%. Each lithological unit must add up to four. Any number of traces (+) were allowed for small inclusions of

these lithological units where they did not make up ¼ of the unit composition. The six basic component types, and their shorthand code are as follows:

1. **Turfa (peat)**
   1.1. Turfa bryophytica – Tb (moss peat),
   1.2. Turfa lignosa – Tl (wood peat)
   1.3. Turfa herbacea – Th (grass, sedge and fern peat).
2. **Substantia humosa – Sh (organic matter)**
   2.1. Completely disintegrated organic matter.
3. **Limus (gytta/lake sediment)**
   3.1. Limus detrituosus – Ld (organic lake mud)
   3.2. Limus siliceous organogenes – Lso (diatomite)
   3.3. Limus calcareus – Lc (marl)
   3.4. Limus ferrugineus – Lf (precipitated iron oxides)
4. **Argilla (mineral particles)**
   4.1. Argilla steatodes – As (clay – <0.002mm)
   4.2. Argilla granosa – Ag (silt – 0.002-0.06mm)
5. **Grana (mineral particles)**
   5.1. Grana arenosa – Ga (fine sand – 0.06-0.6mm)
   5.2. Grana suburralia – Gs (coarse sand – 0.6-2mm)
   5.3. Grana glareosa – Gg (small to medium gravel – >2mm)
6. **Detritus**
   6.1. Detritus lignosus – Dl (wood remains)
   6.2. Detritus herbosus – Dh (herbaceous remains)
   6.3. Detritus granosus – Dg (small wood and herbaceous fragments)

- Humification – recorded for Turfa and Limus detrituosus, on a 0-4 scale where 0 is unhumified and 4 is highly humified. Humification was estimated based on the degree of decomposition in each unit, based on visual assessment and a low powered Leica S6D zoom-stereo microscope at x10 magnification.
- The composition and humification allow for a detailed shorthand description of each unit, for example:
  - Very humified herbaceous peat, with some less humified wood peat and a trace of fine sand: $Th^{4}3\ Tl^{2}1\ Ga+\ Humo4$

Once all cores had been described, lithostratigraphic drawings were created using symbology from a modified version of the Troels-Smith method (Birks and Birks, 1980)(Figure 5.3).



Class	Symbol	Element	Description
Turfa	Tb^{0-4}	T. bryophytica	Mosses, +/- humous substance
	Tl^{0-4}	T. lignosa	Stumps, roots, intertwined rootlets, of ligneous plants +/- trunks, stems, branches, etc., connected with these. +/- humous substance
	Th^{0-4}	T. herbacea	Roots, intertwined rootlets, rhizomes, of herbaceous plants +/- stems, leaves, etc. connected with these. +/- humous substance.
Detritus	Dl	D. lignosus	Fragments of ligneous plants > 2 mm
	Dh	D. herbosus	Fragments of herbaceous plants > 2 mm
	Dg	D. granosus	Fragments of ligneous and herbaceous plants, and sometimes of animal fossils <2 mm> ca. 0.1mm
Limus	Ld^{0-4}	L. detrituosus	Plants and animals or fragments of these; particles <ca. 0.1mm. +/- humous substance
	Lso	L. siliceus organogenes	Diatoms, needles of sponge, siliceous skeletons, etc., of organic origin, or parts of these. Particles <ca. 0.1mm
	Lc	L. calcareus	Marl, not hardened like calcareous tufa. Particles <ca. 0.1mm
	Lf	L. ferrugineus	Iron oxide. Particles <ca. 0.1mm
Argilla	As	Clay	Mineral particles <0.002 mm
	Ag	Silt	Mineral particles 0.002 to 0.06 mm
Grana	Ga	Fine sand	Mineral particles 0.06 to 0.6 mm
	Gs	Coarse sand	Mineral particles 0.6 to 2 mm
	Gg	Gravel	Mineral particles > 2 mm
Substantia humosa	Sh	Humous substance	Completely disintegrated organic substances and precipitated humic acids

Figure 5.3. Troels-Smith Lithological Units and relevant symbols (Birks and Birks, 1980).

5.2.6. Organic Matter

Determining organic matter content is often the most common analysis applied to sediments, especially when used in combination with a range of other proxy records (Bengtsson and Enell, 1986). The organic matter content is calculated through the loss-on-ignition method where the loss in weight was proportional to the amount of organic matter within each sample. All results were calculated and an organic matter curve drawn using Microsoft Excel. The method for loss-on-ignition follows that of Bengtsson and Enell (1986):

1. Samples were subsampled sequentially from the core using a metal spatula and scalpel to extract approximately $1cm^3$ of sediment into a small foil tray.

2. Samples were oven dried for 12-24 hours at 105°C and then weighed to 4 decimal places.
3. The samples were then fired at 550°C for 2 hours in a muffle furnace and weighed upon removal.
4. Samples were kept in a desiccator when not being weighed, dried or fired. LOI was then calculated using Equation 5.2:

Equation 5.2. Loss-on-ignition equation

$$\text{LOI (\%)} = \frac{(DW_{105} - DW_{550})}{DW_{105}} \times 100$$

DW_{105} is the oven dry weight and DW_{550} is the muffle furnace dry weight.

5. Results were calculated and an organic matter curve drawn using Microsoft Excel.

6. Results: Langshot Bog, Chobham Common

6.1. Introduction

This chapter presents the palaeoenvironmental study of Langshot Bog at Chobham Common. Chobham Common is a large expanse of heathland in northwest Surrey (Figure 6.1), and is the largest National Nature Reserve in southeast England, managed by the Surrey Wildlife Trust. Soil types are mainly humo-ferric podzols on well-drained land, with stagnogley podzols where underlying lenses of loams and clays are present (Macphail and Scaife, 1987). Langshot Bog is located towards the south of the Common (National Grid Reference: SU 97699 63475; elevation: *c.* 30m a.s.l) and is a small area of superficial peat, situated within a more extensive area of clays, silts and sands of the Bracklesham Group.

Within 5km of the common there are nine Mesolithic records and two Upper Palaeolithic Records (Figure 6.2). The largest of these sites is the Late Upper Palaeolithic open-air occupation site at Brockhill, where over 300 flints were discovered, including arrow heads, saws and scrapers as well as burins, flakes, cores and pot boilers (Mills, 2012). The two lithic working sites are also Late Upper Palaeolithic in age. The Mesolithic records from the local area include adzes, cores, scrapers, blades and miscellaneous worked flint. These are predominantly identified as findspots, small or undefined lithic scatters, and are thought to be indicative of a hunter-gatherer or passing-through signal.

The eastern boundary of the bog is marked by a drainage ditch. On the east of this ditch, the land has been extensively drained to create arable fields, currently grazed by horses. This land is mapped as peat with the potential that Langshot Bog would previously have been much larger than today (Figure 6.3). Due to the artificial lowering of the water table in these drained fields, it is unlikely that the sediments in this area would be as well preserved as those from the bog itself. Therefore, land to the east of the drainage ditch has been excluded from the study.

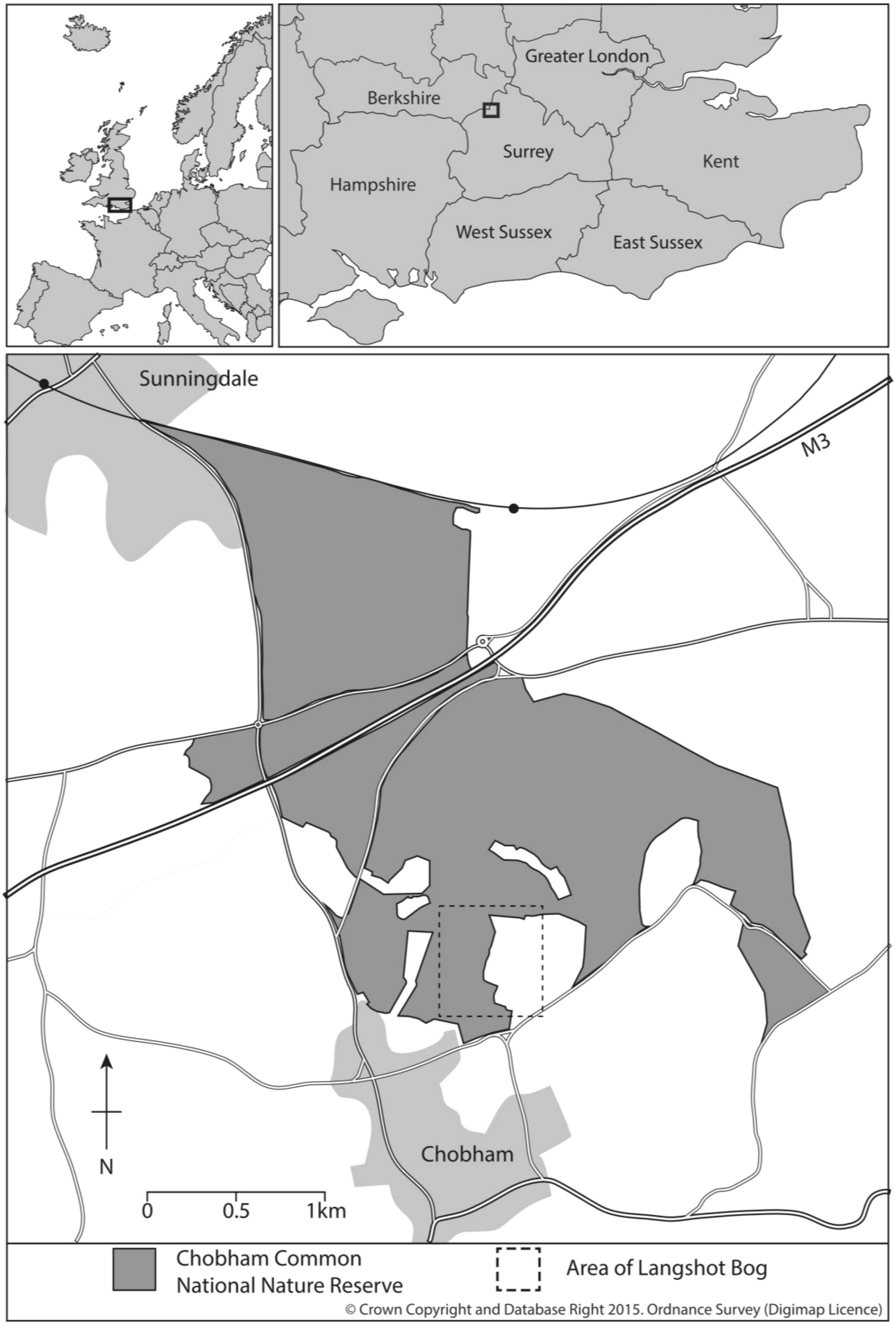


Figure 6.1. Location of Chobham Common within England and the southeast.

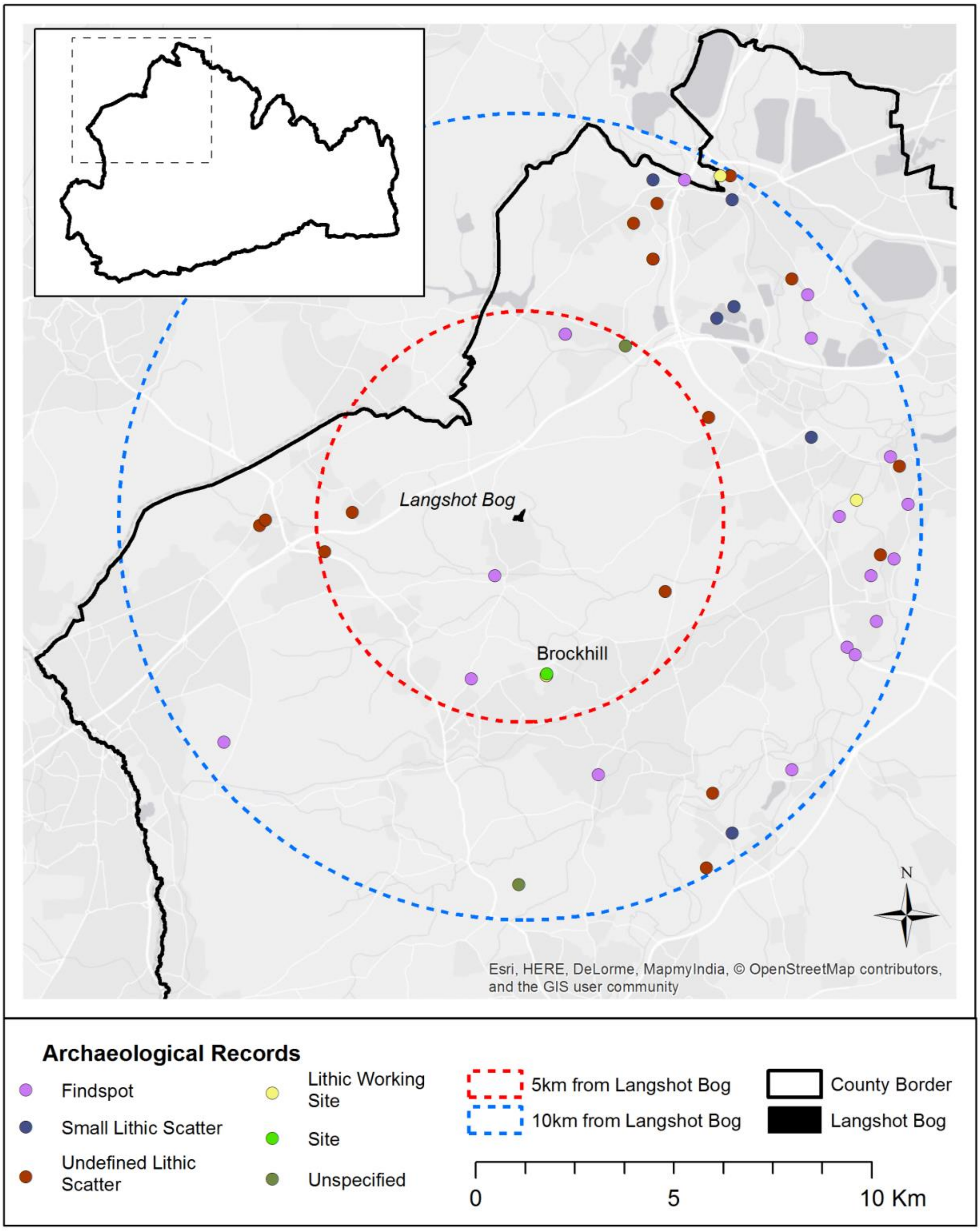


Figure 6.2. Local archaeological records within 5 and 10km of Langshot Bog.

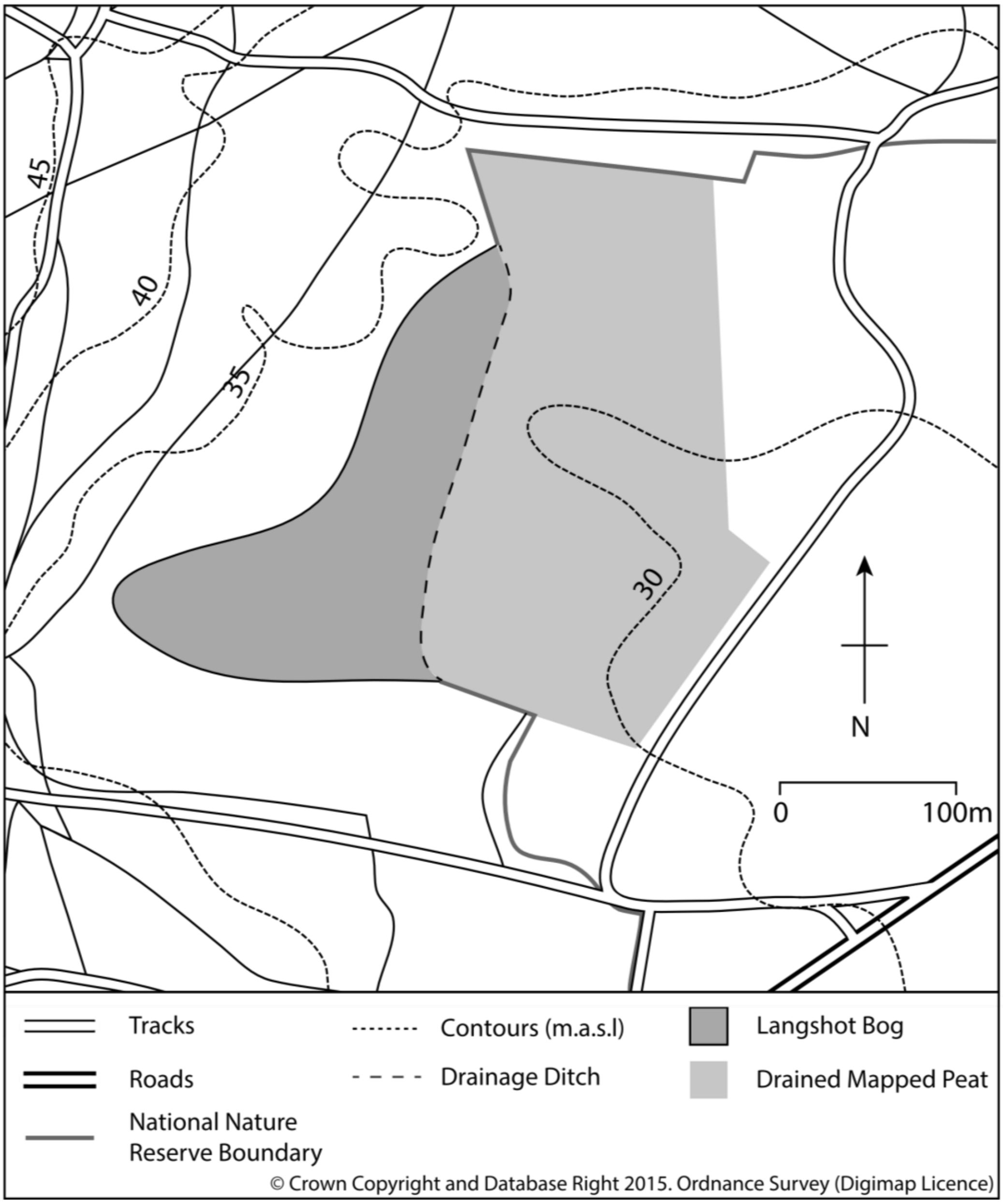


Figure 6.3. Location of Langshot Bog within area insert (Figure 6.1) and local mapped peat deposits.

The modern day vegetation across Chobham Common is dominated by *Calluna vulgaris*, *Erica cinerea* and *Ulex minor* (Figure 6.4). Areas of *Betula pendula* and *Pinus sylvestris* woodland are also present, as are *Agrostis curtisii*, *Molinia caerulea* and *Dianthus armeria*. The soils are sandy and relatively thin, with both managed and wild fires controlling the vegetation. On Langshot Bog, species of *Sphagnum* occupy the bog surface (*Sphagnum compactum S. papillosum*, *S. recurvum* and *S. palustre*) alongside other species such as *Drosera rotundifolia*, *Narthecium ossifragum*, *Eriophorum angustifolium*, *Osmunda regalis*, and *Gentiana pneumonanthe*. Much of the bog surface is wooded, with *Betula pubescens* and *Alnus glutinosa* the dominant tree taxa (Figure 6.5).

Figure 6.4. Northwards view of Chobham Common.

Figure 6.5. Surface of Langshot Bog.

6.2. Results of the Field and Laboratory Sedimentology

No previous palaeoenvironmental investigations have occurred at the site of Langshot Bog, therefore a coring survey was used to understand the size and shape of the basin. Two transects, running east-west, and north-south, were sampled at 20m intervals (Figure 6.6).

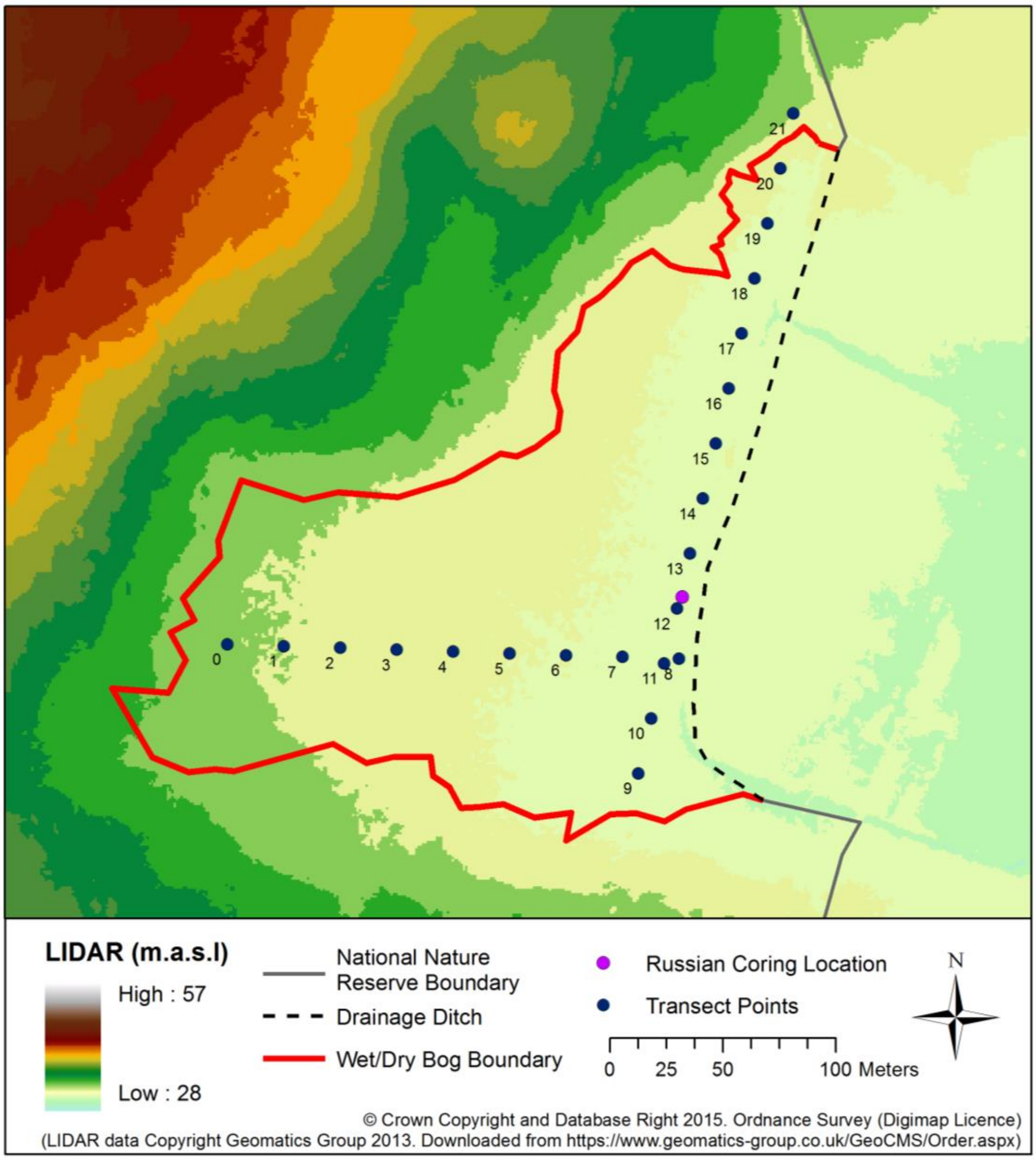


Figure 6.6. Coring transects and the bog boundary. The Russian coring location (LB2) is highlighted.

This resulted in 9 cores running west to east, and 13 cores running south to north. Cores were extracted until the corer hit sandy Bracklesham group sediments, identified within sediments in the base of each core, or observed whilst coring. Two transect plots were drawn, showing the general pattern of sediment deposition across the basin (Figure 6.7 and Figure 6.8). Sedimentological descriptions for these transects can be found in Appendix 13.6.

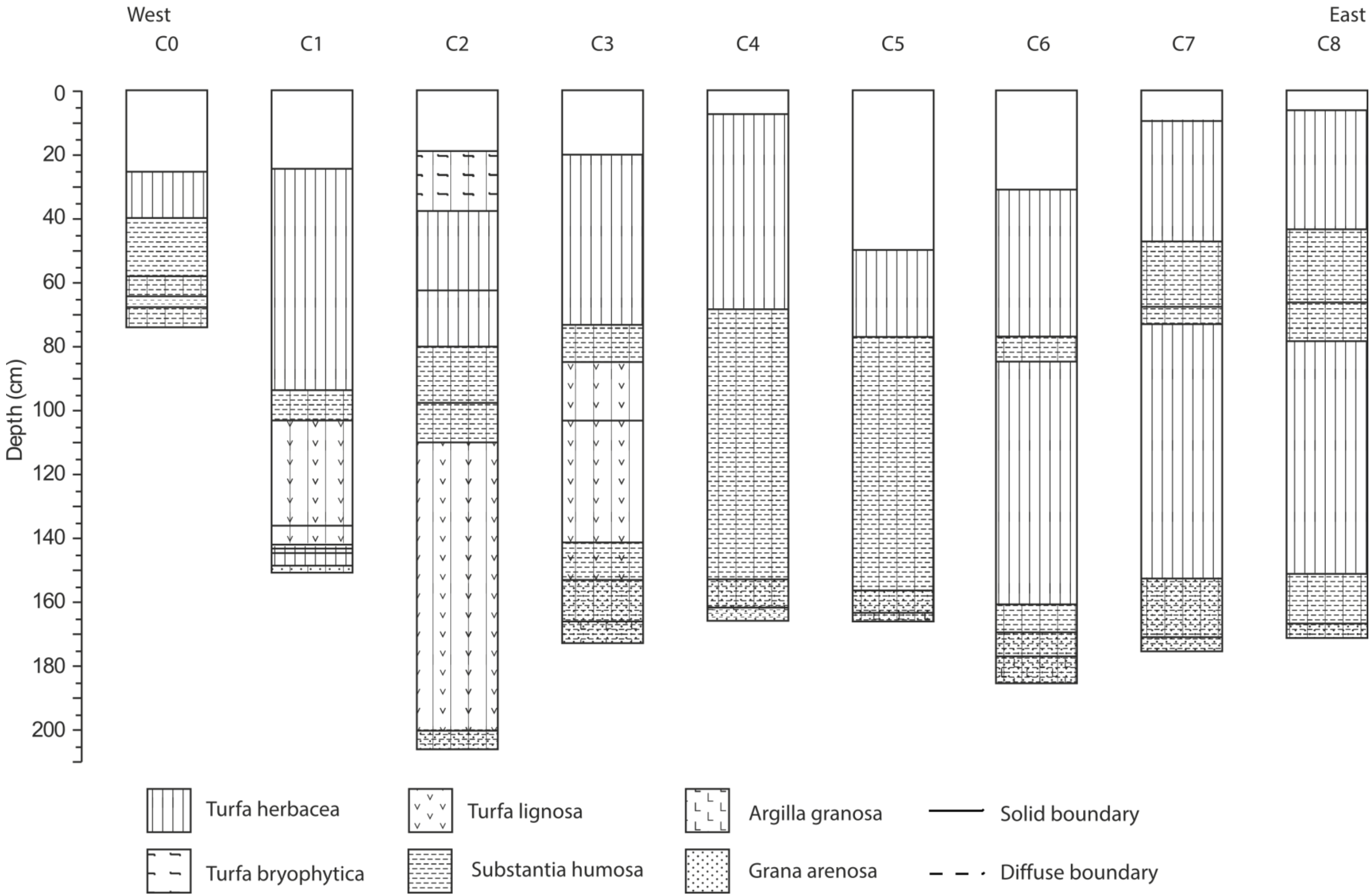


Figure 6.7. Langshot Bog, west to east transect coring results.

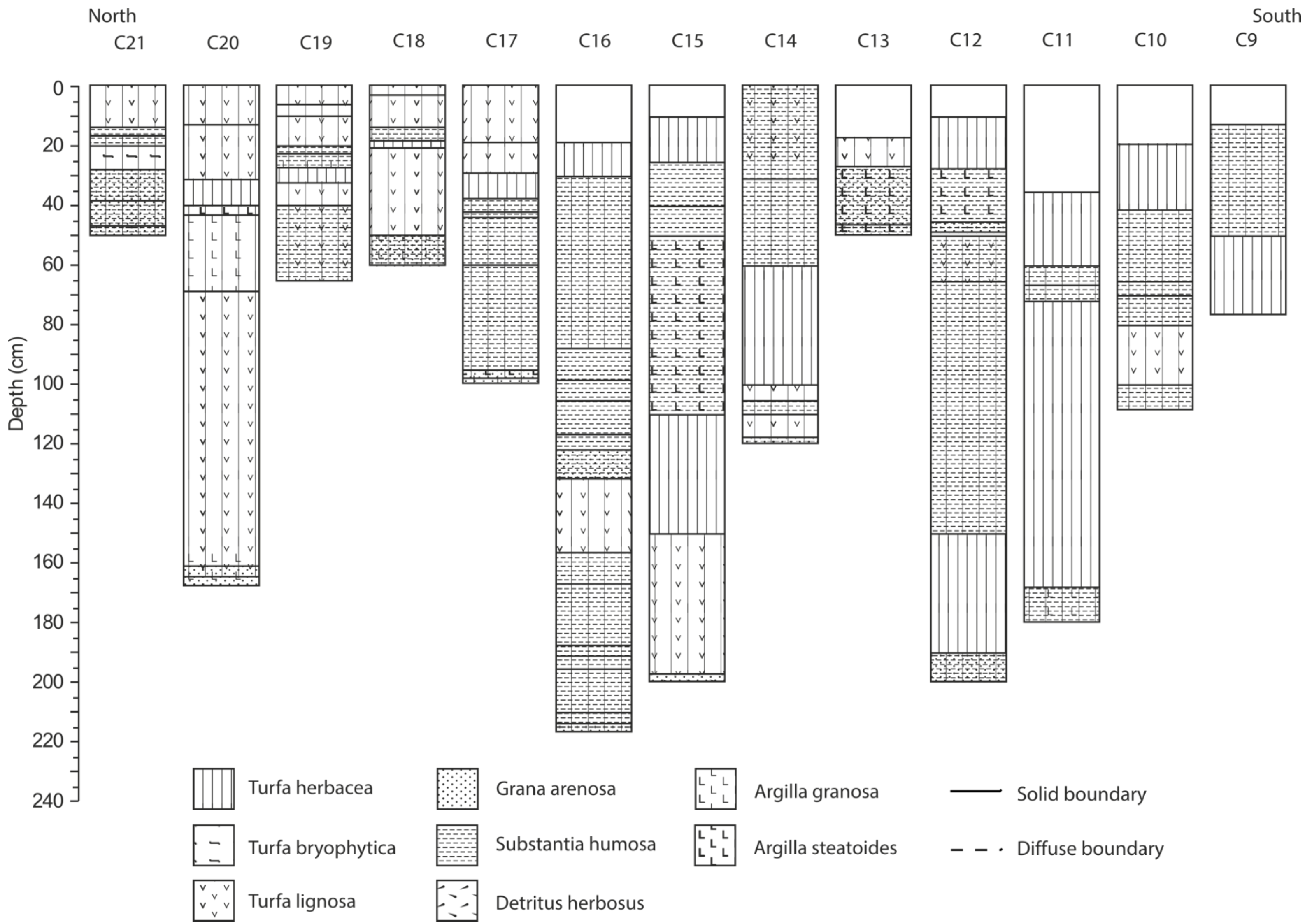


Figure 6.8. Langshot Bog north to south transect coring results.

The West-East Transect

The west to east transect shows a deepening of the basin from a short initial core (~75cm) at the west of the basin to a relatively constant depth of 150 to 210cm. The base of the sequence was indicated by a mineral rich layer *(Grana arenosa),* overlain by herbaceous (*Turfa herbacea*) and woody peat *(Turfa lignosa)* identified in C1-8. Within C1-3 a wood and herbaceous peat was recorded. Towards the eastern edge of the bog in C6-8, the wood peat was not observed and the peat was highly herbaceous. C4 and C5 had a higher level of decomposition in the basal units, although herbaceous peat was still present. Above the peat layers in C1-3, and C6-8 a unit of more decomposed material was recorded, which transitioned into herbaceous peat. A small unit of moss peat *(Turfa bryophytica)* was observed in C2.

The North-South Transect

The north to south sequence was more complicated, with an undulating profile of shallow and deeper cores. The basal sands of the Bracklesham beds were identified in the majority of the boreholes, which was overlain by decomposed organic matter (*Substantia humosa*), herbaceous peats and wood peats in varying frequencies and thicknesses across the profile. An inorganic unit was noted in a number of the boreholes (C20, 19, 15, 13 and 12), and ranged between 25-110cm deep. The top unit was a mixed wood and herbaceous peat in C21-C17, 14 and 13, and herbaceous peat in all other cores.

The surveys indicated the deepest parts of the basin were present on the north-south transect. A location next to core 12 was chosen as the master core sequence for Langshot Bog, as this was one of the deepest organic sequences identified during the survey (Figure 6.6). A triplicate set of cores were extracted from the location SU 97699 63475. Stratigraphic data can be found in Appendix 13.6.

Based on the transect surveys undertaken across the site, they indicate that the basin at Langshot Bog was potentially fairly large during the Early Holocene and it may have covered at least ~26100m^2. Pollen source area calculations indicate that the input to the basin would be made up of a range of local, extra-local and regional pollen, with the regional component of increasing importance as the basin increases in size over time (Jacobson and Bradshaw, 1981).

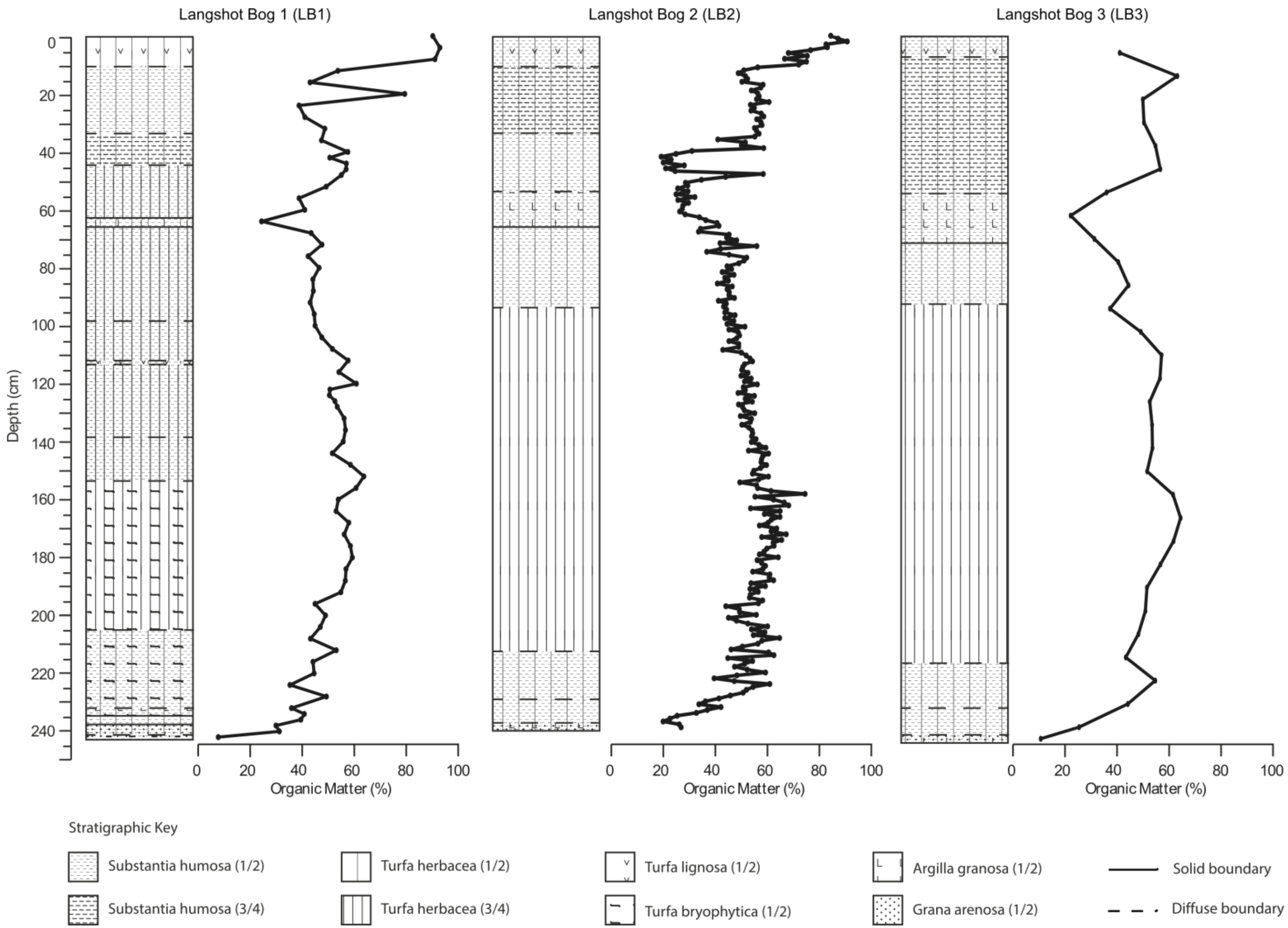


Figure 6.9. Three master cores extracted from Langshot Bog and their organic matter curves. Methodology for determining the lithostratigraphy, age-depth model and organic matter can be found in Chapter 5.

The three master cores provided a very similar stratigraphy and total depth (Figure 6.9), all within the range 240-245cm. The sand of the underlying Bracklesham beds was observed at the base of all three cores. The bulk of the core was comprised of herbaceous peat and decomposed organic matter in varying states of humification. Moss peat (*Turfa bryophytica*) was recorded in all cores from ~100cm down, although in a higher proportion in core 1 as opposed to cores 2 and 3, where only a trace was present. An event was observed in all three cores at ~55-70cm with the presence of silt (*Argilla granosa*). Organic matter determinations helped to ascertain that the three cores were a good stratigraphic match. All three cores were initially sampled at 8cm resolution with core 1 subsequently being analysed at 4cm resolution. Upon analysis of the three cores, looking at both the lithostratigraphic and organic matter results, core 2 (LB2) was chosen to be the single master sequence for the site. This core had very high organic matter percentages and was less humified than the other cores. Organic matter determinations were subsequently increased to one centimetre resolution along the length of the core. Organic matter and pyrite data can be found in Appendix 13.7.

Core 2 provided a 241cm sequence, and a detailed lithostratigraphic description identified nine main units (Figure 6.10). The basal units (1: 241-238cm and 2: 238-229cm) were rich in both sands and silts, with evidence for the basal Bracklesham beds found in the bottom of the core. These basal sediments were low in organic matter, at less than 40%. A small increase in pyrite (FeS_2) was recorded in unit 2 (peaking at 150 spherules/cm), however the majority of the core (units 3: 229-213cm, 4: 213-94cm and 5: 94-65cm) was rich in organic deposits, particularly herbaceous peat, with both wood and moss peat in trace amounts. The herbaceous peat through units 3-5 was not very decomposed and individual sedges and grasses were clearly observable. The organic matter in these units quickly rose from the sandy units below to ~50-60% and remained relatively stable from 224 to 65 cm. Unit 4 also had a high concentration of pyrite that precipitated out of the peat, with concentrations consistently above 100 spherules/cm. An influx of silt was noted between 65-53cm (unit 6: 65-53cm) with a corresponding drop in organic matter to 40%. The concentration of pyrite in this level and those above was very low. A small organic matter increase was then followed by another drop in organic matter (unit 7: 53-33cm) after which organic sedimentation returned and organic matter values rose from 60% (unit 8: 33-10cm) to 90% near the surface of the core (unit 9: 10-0cm).

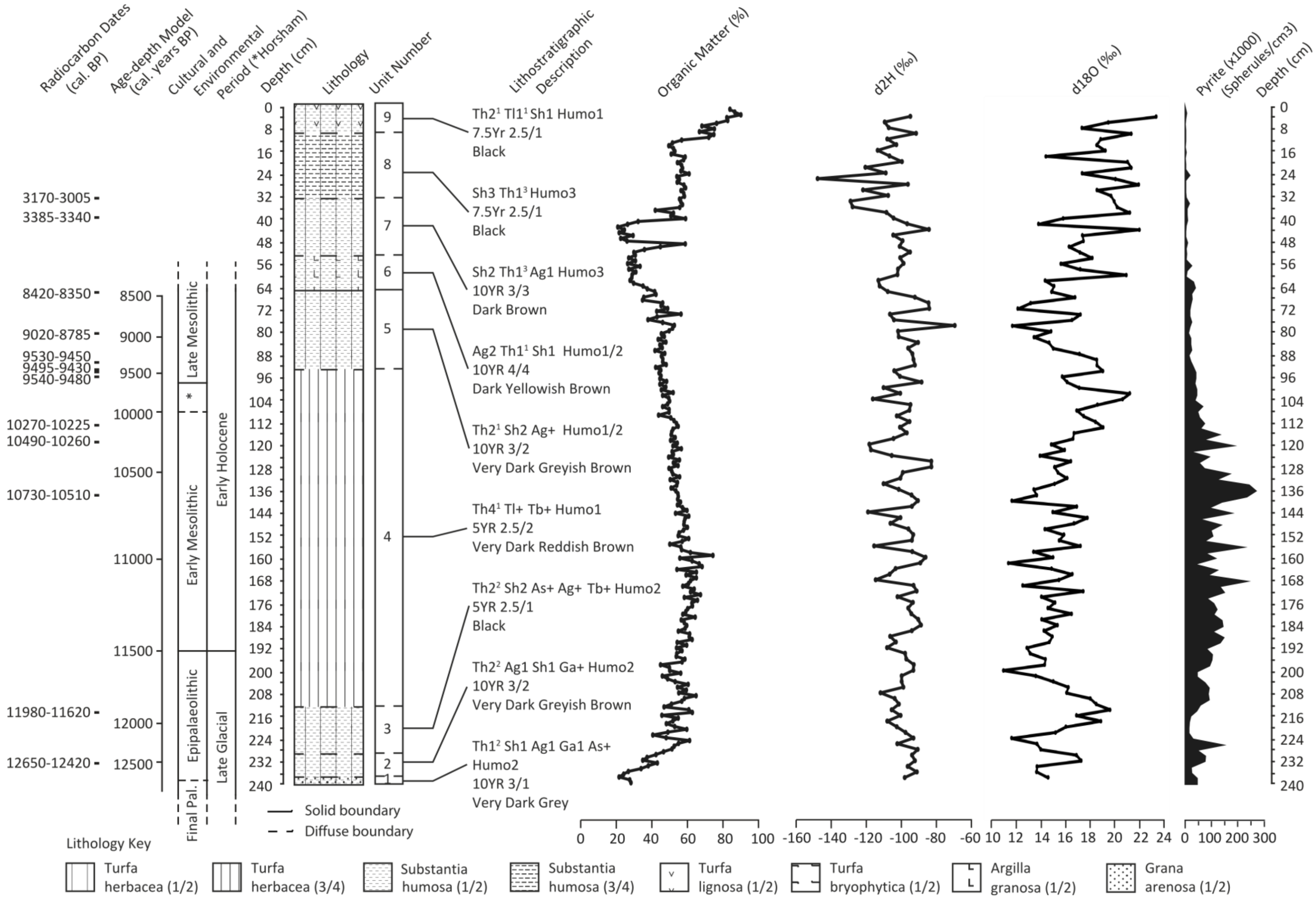


Figure 6.10. Combined proxy diagram for Langshot Bog Core 2.

6.3. Results of the Radiocarbon Dating Programme

Samples for dating were taken from the core at significant lithostratigraphic and biostratigraphic unit boundaries (Table 6.1). All dates were submitted as bulk peat samples as any macrofossils present were too small and discontinuous throughout the profile to be suitable for radiocarbon dating. These bulk peat samples were sampled to provide both humic (alkali-soluble fraction) and humin (acid- and alkali-soluble fraction) radiocarbon dates, providing two dates for each depth analysed. A weighted mean was calculated using the humic and humin dates as per the method in Ward and Wilson (1978).

Table 6.1. Results of the radiocarbon dating programme at Langshot Bog.

Lab. No.	Depth (cm)	Sample	Radiocarbon age (BP)	δ13C (‰)	Calibrated date – cal. BP (95% confidence)
SUERC-57170	32-33	Bulk peat (alkali-soluble fraction)	2875±31	−29.7	
SUERC-57171	32-33	Bulk peat (alkali- and acid-insoluble fraction)	3011±31	−30.3	
Weighted mean	*32-33*	*(T’=9.6, T’(5%)=3.8, v=1; Ward and Wilson 1978)*	*2944±22*		*3170-3005*
SUERC-59076	39-40	Bulk peat (alkali-soluble fraction)	3084±29	−29.5	
SUERC-59077	39-40	Bulk peat (alkali- and acid-insoluble fraction)	3185±29	−29.1	
Weighted mean	*39-40*	*(T’=6.1, T’(5%)=3.8, v=1; Ward and Wilson 1978).*	*3135±11*		*3385-3340*
UBA-28786	49-50	Bulk peat (alkali-soluble fraction)	1870±24	-29	
UBA-28787	49-50	Bulk peat (alkali- and acid-insoluble fraction)	2329±26	-29.8	
Weighted mean	*49-50*	*(T’=168.8, T’(5%)=3.8, v=1; Ward and Wilson 1978).*	*Not Significant*		
UBA-27730	65-66	Bulk peat (alkali-soluble fraction)	7603±49	−29.9	
UBA-27731	65-66	Bulk peat (alkali- and acid-insoluble fraction)	7573±42	−30.3	
Weighted mean	*65-66*	*(T’=0.2, T’(5%)=3.8, v=1; Ward and Wilson 1978)*	*7586±32*		*8420-8350*
SUERC-59078	80-81	Bulk peat (alkali-soluble fraction)	8031±30	−29.2	
SUERC-59082	80-81	Bulk peat (alkali- and acid-insoluble fraction)	8055±30	−29	
Weighted mean	*80-81*	*(T’=0.3, T’(5%)=3.8, v=1; Ward and Wilson 1978)*	*8043±22*		*9020-8785*
UBA-28788	90-91	Bulk peat (alkali-soluble fraction)	8401±37	-28.3	

Lab. No.	Depth (cm)	Sample	Radiocarbon age (BP)	δ13C (‰)	Calibrated date – cal. BP (95% confidence)
UBA-28789	90-91	Bulk peat (alkali- and acid-insoluble fraction)	8556±43	-29.6	
Weighted mean	*90-91*	*(T'=7.5, T'(5%)=3.8, v=1; Ward and Wilson 1978)*	*8468±29*		*9530-9450*
SUERC-59083	93-94	Bulk peat (alkali-soluble fraction)	8419±29	−29.1	
SUERC-59084	93-94	Bulk peat (alkali- and acid-insoluble fraction)	8432±29	−29	
Weighted mean	*93-94*	*(T'=0.1, T'(5%)=3.8, v=1; Ward and Wilson 1978)*	*8426±21*		*9495-9430*
UBA-28790	95-96	Bulk peat (alkali-soluble fraction)	8560±40	-28.4	
UBA-28791	95-96	Bulk peat (alkali- and acid-insoluble fraction)	8486±50	-29.7	
Weighted mean	*95-96*	*(T'=1.3, T'(5%)=3.8, v=1; Ward and Wilson 1978)*	*8531±32*		*9540-9480*
SUERC-59085	112-113	Bulk peat (alkali-soluble fraction)	9086±29	−29.3	
SUERC-59086	112-113	Bulk peat (alkali- and acid-insoluble fraction)	9128±29	−29	
Weighted mean	*112-113*	*T'=1.0, T'(5%)=3.8, v=1; Ward and Wilson 1978)*	*9107±21*		*10,270-10,225*
UBA-28792	118-119	Bulk peat (alkali-soluble fraction)	9222±40	-28.7	
UBA-28793	118-119	Bulk peat (alkali- and acid-insoluble fraction)	9216±43	-28.9	
Weighted mean	*118-119*	*(T'=0.0, T'(5%)=3.8, v=1; Ward and Wilson 1978)*	*9219±30*		*10,490-10,260*
UBA-26774	137-138	Bulk peat (alkali-soluble fraction)	9398±46	-	10,730-10,510
UBA-26775	137-138	Bulk peat (alkali- and acid-insoluble fraction)	failed	-	
SUERC-57172	214-215	Bulk peat (alkali-soluble fraction)	10,207±31	−30.5	
SUERC-57173	214-215	Bulk peat (alkali- and acid-insoluble fraction)	10,042±31	−30	
Weighted mean	*214-215*	*(T'14.2, T'(5%)=3.8, v=1; Ward and Wilson 1978)*	*10,126±22*		*11,980-11,620*
UBA-26776	232-233	Bulk peat (alkali-soluble fraction)	10,602±50	-	
UBA-26777	232-233	Bulk peat (alkali- and acid-insoluble fraction)	10,497±61	-	
Weighted mean	*232-233*	*(T'=1.8, T'(5%)=3.8, v=1; Ward and Wilson 1978)*	*10,560±39*		*12,650-12,420*

Age-depth modelling was used to provide approximate timing for events that have not been dated directly using radiocarbon dates. OxCal v4.2 (Ramsey, 2009b) was used alongside the INTCAL 13 atmospheric calibration curve (Reimer et al., 2013). A P-sequence deposition model was used (Ramsey, 2008) and variable K allowed for changes in the rate of deposition to be taken into account (Ramsey and Lee, 2013). Both the model and the radiocarbon dates were calibrated to a 95% confidence interval. The humin date from 137-138cm (UBA-26775) failed due to a high level of pyrite within the sample, nevertheless, this date is still likely to be accurate as all of the other humic/humin samples provided internally consistent dates. The two dates from 49-50cm (UBA-28786 and UBA-28787) were not close enough in age to provide a weighted mean and led to a chronological inversion. This date was classified as an outlier and tested within the OxCal model, which suggested that the date does not fit in the model (P=0). Examination of the dates, the stratigraphy, and the pollen record identified a hiatus within the core at ~65cm, which was subsequently modelled (Figure 6.11). The model returned with an Amodel value of 77, and was considered to be a good fit to the data. The model suggested that the sequence started organic accumulation at ~12,820 cal. BP (241cm) and relatively stable accumulation was observed until ~8,390 cal. BP (65cm) when accumulation was interrupted due to the hiatus. The model suggested accumulation restarted from 8,390-3,370 cal. BP (64cm), and potentially continued through until the present day, although above the final radiocarbon date (~3100 cal. BP – 32cm) these modelled dates were extrapolated and were not robust. The section above the hiatus appeared to broadly date to ~3000 cal. BP and therefore was not applicable to this study. For this reason the model was run again (Figure 6.12), excluding the dates above 65cm, and had an A-model value of 74 again showing a good fit to the dates. Best estimate ages were also provided (Table 6.2) for all of the major palaeoenvironmental events within this model, and suggested the base of the sequence dated from ~13,200-12,440 cal. BP, and organic sedimentation started prior to 12,640-12,430 cal. BP. Herbaceous peat development began during the very Early Holocene at 11,800-11,150 cal. BP. This herbaceous peat and organic matter accumulation continued until 8430-8350 cal. BP where the hiatus was recorded at 65cm.

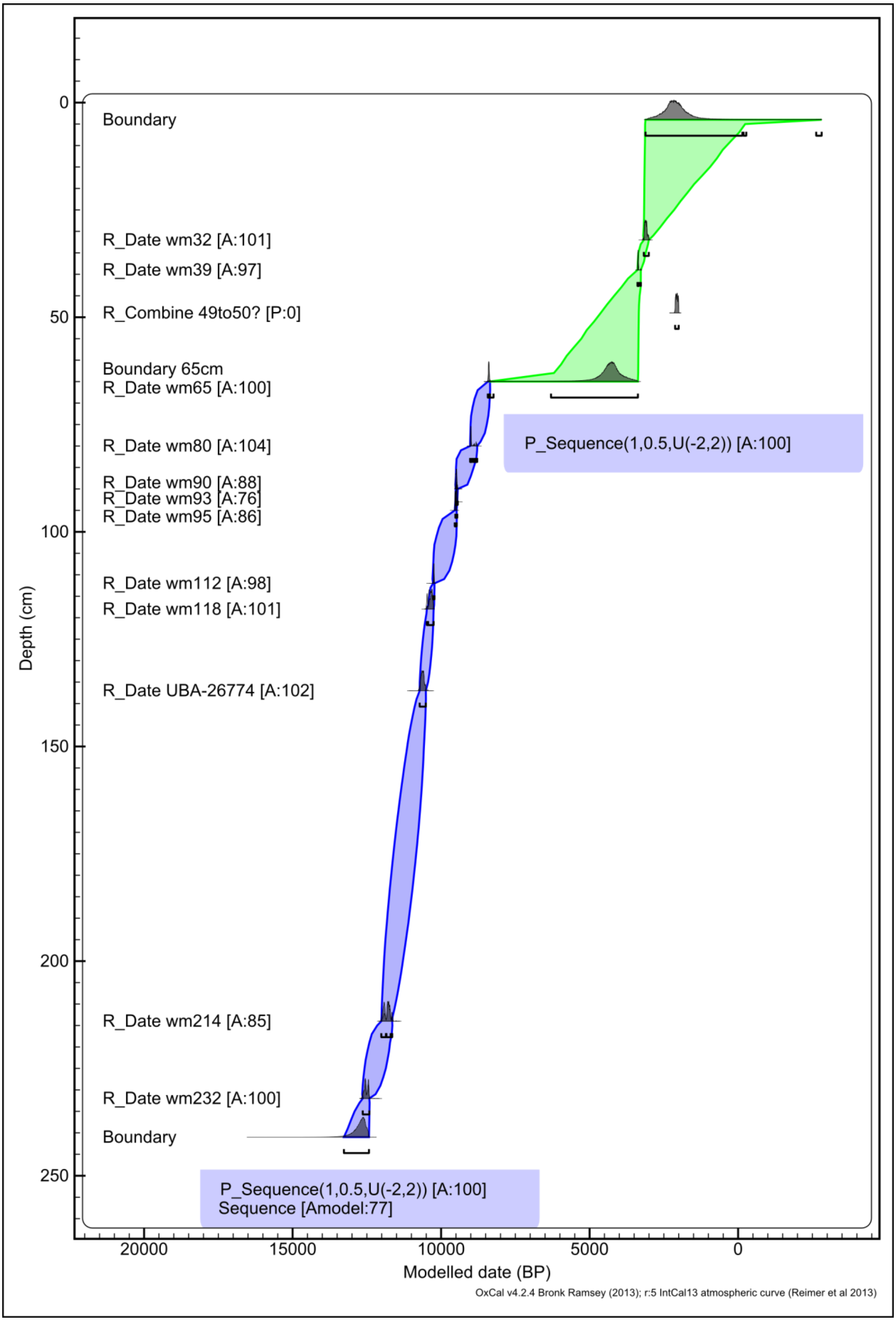


Figure 6.11. Langshot Bog modelled with a hiatus at 65cm.

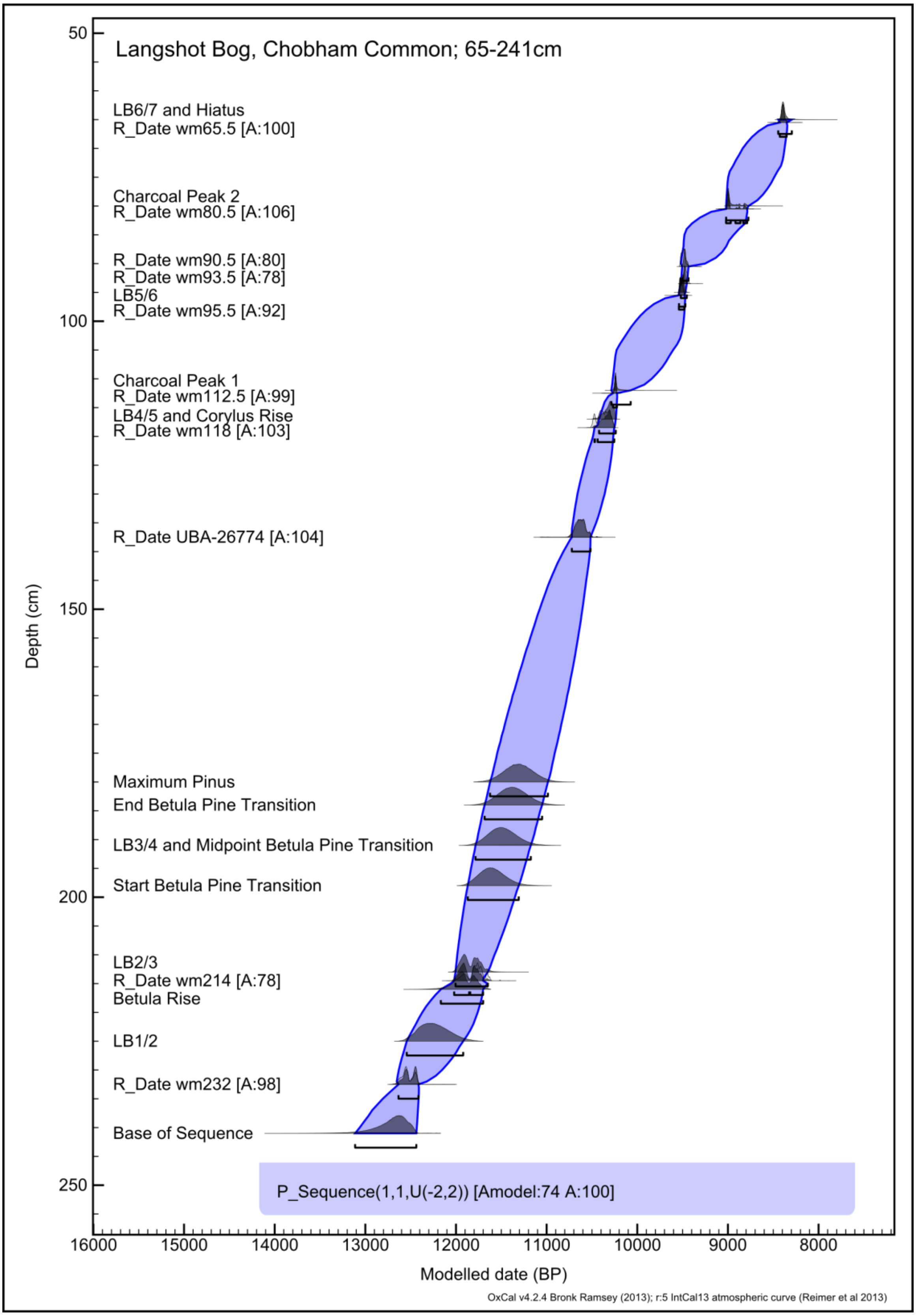


Figure 6.12. OxCal model for the base of the sequence (65cm-241cm) at Langshot Bog.

Table 6.2. Results of the OxCal model for Langshot Bog.

Name	Unmodelled (BP)			Modelled (BP)			Midpoint (cal. BP)	Indices A_{model}=75.2 $A_{overall}$=81.4	
	from	**to**	**%**	**from**	**to**	**%**	**Rounded**	**A**	**C**
Boundary LB6/7 and Hiatus				8428	8352	95.4	8390		99.8
R_Date wm65	8425	8351	95.4	8428	8352	95.4	8390	99.5	99.8
R_Date wm80	9021	8783	95.4	9022	8785	95.4	8900	105.4	99.8
R_Date wm90	9530	9450	95.4	9508	9437	95.4	9470	83.7	99.8
R_Date wm93	9497	9428	95.4	9520	9455	95.4	9490	77.1	99.8
R_Date wm95	9544	9484	95.4	9540	9480	95.4	9510	88.9	99.8
R_Date wm112	10,270	10,224	95.4	10,269	10,224	95.4	10,250	98.3	99.9
LB4/5 and *Corylus* Rise				10,435	10,237	95.4	10,340		97.9
R_Date wm118	10,495	10,265	95.4	10,477	10,255	95.4	10,370	102.5	99.1
R_Date UBA-26774	10,734	10,513	95.4	10,723	10,515	95.4	10,620	102.9	99.7
Maximum *Pinus*				11,647	10,961	95.4	11,300		98.7
End *Betula Pinus* Transition				11,708	11,027	95.4	11,370		99.5
LB3/4 and Midpoint *Betula Pine* Transition				11,804	11,150	95.4	11,480		99.6
Start *Betula Pine* Transition				11,888	11,290	95.4	11,590		99.3
LB2/3				12,009	11,641	95.4	11,830		96.2
R_Date wm214	11,981	11,622	95.5	12,017	11,650	95.4	11,830	81.6	96.6
Betula Rise				12,211	11,653	95.4	11,930		97.3
LB1/2				12,567	11,911	95.4	12,240		99.6
R_Date wm232	12,647	12,421	95.4	12,637	12,416	95.4	12,530	99.4	99.7
Boundary Start of Sequence				13,204	12,438	95.4	12,820		98.7
P_Sequence(1,1,U(-2,2))	*-2*	*2*	*95.4*	*-1.01024*	*-0.45424*	*95.4*		*100*	*96.6*

6.4. Results of the Stable Isotope Analysis

Stable isotope analysis was undertaken at 2cm intervals along the length of the core at the same resolution as the pollen analysis. Individual plant macrofossils (sedges) were extracted from the core at each depth and analysed for their change in hydrogen and oxygen isotope ratios. The hydrogen results were plotted against depth (Figure 6.10) and both the hydrogen and oxygen results were plotted against their modelled age (Figure 6.13). Figure 6.14 shows the three proxies plotted against the Late Upper Palaeolithic and Mesolithic parts of the sequence. The data can be found in Appendix 13.8. The large error range observed within the oxygen data suggest there was variability in the plant composition within the individual samples, although this was not supported by the small deviations in the hydrogen data, which suggest no mixing of plant types within the samples. Both the general trends and the differences in error appear to show that the hydrogen and oxygen values were not synchronous and appear to be decoupled, matching trends recorded previously in other studies (Eley et al., 2014), possibly suggesting that the hydrogen was reflecting changes in the local plant community, and not changes in the climate, which is suggested by the oxygen isotopes.

As δ^2H values decreased, there appears to be a trend towards wetter conditions during the Late Glacial (pre 11,700 cal. BP). This may also have been a time of increased evaporation with an increasing $\delta^{18}O$. Significantly, the onset of the Holocene is recorded within both the oxygen and hydrogen isotopes as a period of warmer climate and dryer bog surface conditions (shown through a decreasing $\delta^{18}O$ trend indicating a reduction in evaporation and an increasing δ^2H trend suggesting dryer conditions), dating the onset of the Holocene at the site to ~11,800 cal. BP. After this initial Early Holocene trend, there appeared to be a period of climatic instability, identified through the frequent fluctuations in both the hydrogen and oxygen curves, although the overall trends indicate a period of low evaporation (although slowly increasing) and dryer conditions. This instability reduced from ~10,200 cal. BP with a general increase in hydrogen values and a corresponding decrease in oxygen isotopes. This was likely to be related to continued climatic amelioration during the Early Holocene as the climate became drier and less evaporation occurred at the site.

The hiatus in the sequence at ~8390 cal. BP was represented by a suspension in bog accumulation and therefore the record was truncated until ~5250 cal. BP. Between 5250-3700 cal. BP both the hydrogen and oxygen isotope records appeared to be in phase, the only part of the record where this occurred. The record suggested that there was an increased evaporitic trend, alongside a drying out of the vegetation within the bog. Post ~3700 cal. BP there was a major shift in the hydrogen isotopes which appeared to show a sharp transition to wetter conditions, much wetter than at any point during the Early Holocene. No major oxygen shifts were noticed at this time, and evaporation appeared to remain high, but stable.

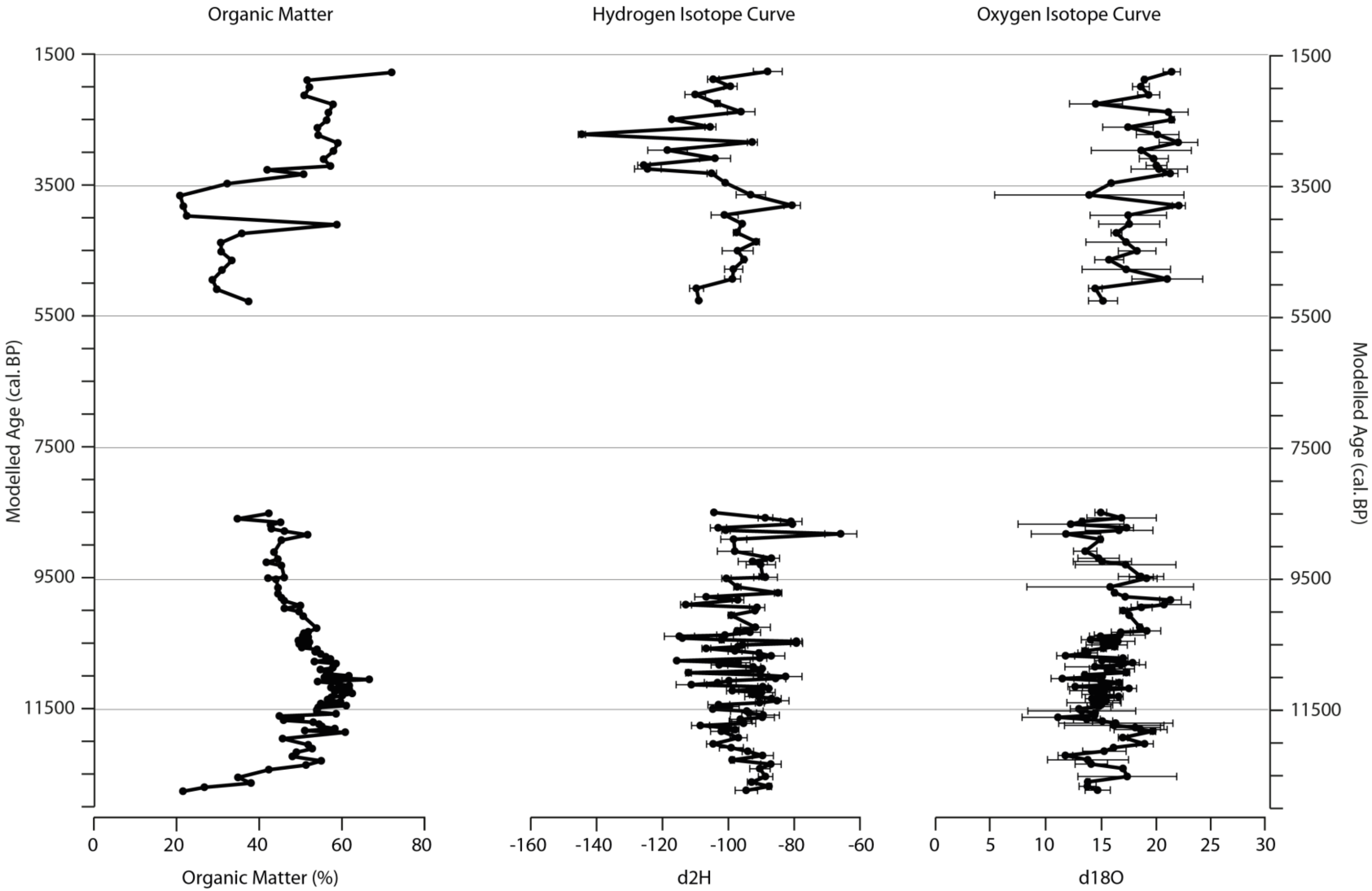


Figure 6.13. Results of the Hydrogen and Oxygen stable isotope analysis plotted against the age-depth model, and organic matter for the entire core. Standard deviation error bars are plotted for the oxygen and hydrogen data.

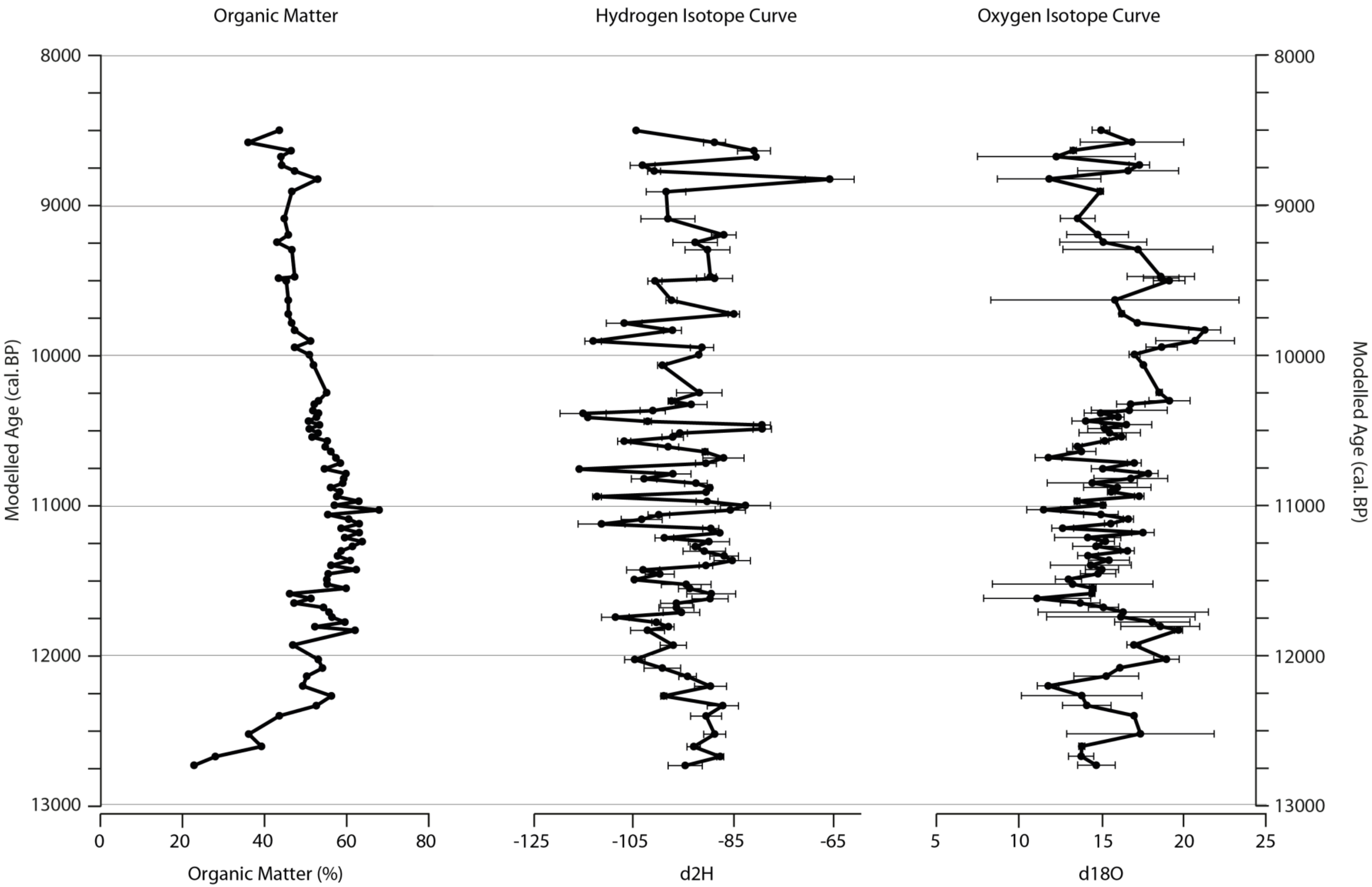


Figure 6.14. Results of the Hydrogen and Oxygen stable isotope analysis plotted against the age-depth model, and organic matter for the period dating between 8000-13000 cal. BP. Standard deviation error bars are plotted for the oxygen and hydrogen data.

6.5. Results of the Pollen Stratigraphical Analysis

Pollen samples were taken at 8cm resolution throughout core LB2 to provide a skeletal assessment and to determine the initial radiocarbon dating programme. This sampling resolution was then increased to 2cm for the entire core to provide a high-resolution vegetation record for Langshot Bog. The results were then tabulated and transformed into both a percentage diagram (Figure 6.15 - Figure 6.17) and an influx diagram (Figure 6.18 - Figure 6.20). Full pollen counts can be found in Appendix 13.9. As the influx data was calculated based on the radiocarbon model, it can only be calculated for the robust modelled section of core, in this case 65-241cm. The palynological results were divided into 9 local pollen assemblage zones based on visual and statistical (CONISS) methods and are described in Table 6.3.

Local pollen assemblage zone LB-1 (225-241cm) dated from bog formation at ~12,820 to ~12,240 cal. BP and *Betula* and *Pinus* represent the arboreal taxa. *Juniperus*, *Salix* and Ericaceae were all recorded. The dominant taxon was Cyperaceae, and *Artemisia* was also present. LB-2 (213-225cm) continued from LB-1 until ~11,830 cal. BP. *Betula* and *Pinus* were consistently present, and increases in *Juniperus* and *Calluna* are observed. A reduction in Cyperaceae is identified, and Poaceae, *Ranunculus* and *Filipendula* were also recorded. Increases were also recorded in both percentage and influx of spore and aquatic taxa including *Typha latifolia*. LB-3 (191-213cm) dated to the Late Glacial/Early Holocene boundary, with a date for the top of the unit of ~11,480 cal. BP. *Betula* increased (*Betula* influx increases from ~25 to 200 grains cm^{-2} year^{-1}) and *Pinus* also steadily increased whilst *Juniperus* declined. A large increase in *Sphagnum* (and the spore *Tilletia sphagni*) was recorded. *Pinus* was the dominant taxon across LB-4 (spanning 117-191cm), and was present throughout the Early Holocene until ~10,340 cal. BP. *Betula* declined as *Corylus* gradually increased. Cyperaceae and Poaceae were present. *Filipendula*, *Artemisia* and *Ranunculus* were all underrepresented but observed through influx data. Overall land pollen influx increased across this zone, from ~250 grains cm^{-2} year^{-1} to >1000 grains cm^{-2} year^{-1}. Increases in *Corylus* and *Ulmus* occurred in LB-5 (from 95-117cm), between ~10,340 cal. BP and ~9510 cal. BP. *Betula* and *Calluna* were present and *Pinus* began to decrease. Cyperaceae and Poaceae were the dominant herbaceous species. Charcoal also increased in this zone. In LB-6, which continued from LB-5 until the hiatus at ~8390 cal. BP (65-96cm), *Corylus* was the dominant taxon alongside *Quercus, Betula*, *Calluna* and *Ulmus* whilst *Pinus* declined. Poaceae was the primary herbaceous taxon, continual across the zone and the level of charcoal was consistently high. *Alnus* increased for the first time in LB-7 (39-65cm), and *Betula* increased as *Corylus* decreased, and *Calluna*, *Quercus*, *Ulmus* and Ericaceae were all present in the landscape. Poaceae was the dominant herbaceous taxon. Deciduous woodland characterised LB-8 (5-39cm) with *Alnus*, *Betula*, *Quercus* and *Corylus* all present, although *Tilia*, *Calluna* and *Ulmus* declined. As with zones 6 and 7, Poaceae was the dominant herbaceous species. The spores, *Sphagnum*, *Osmunda* and *Polypodium* were all recorded in low quantities. *Betula* was dominant in LB-9 (0-5cm) and *Quercus* and *Corylus* were consistently present as *Pinus* began to decline. Poaceae also declines within this zone. Charcoal is not recorded in zone 9.

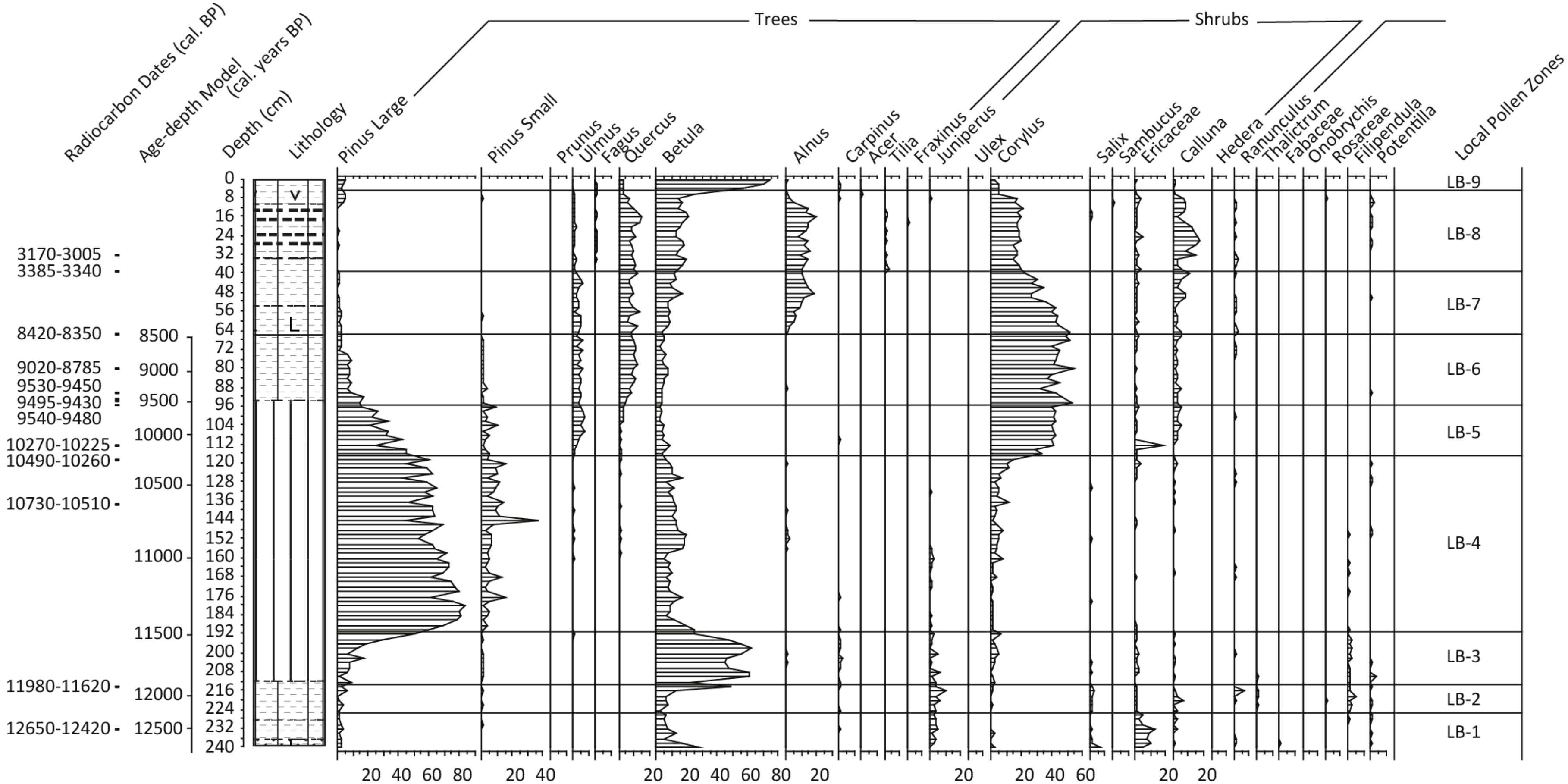


Figure 6.15. Pollen Percentage diagram for Langshot Bog (part 1).

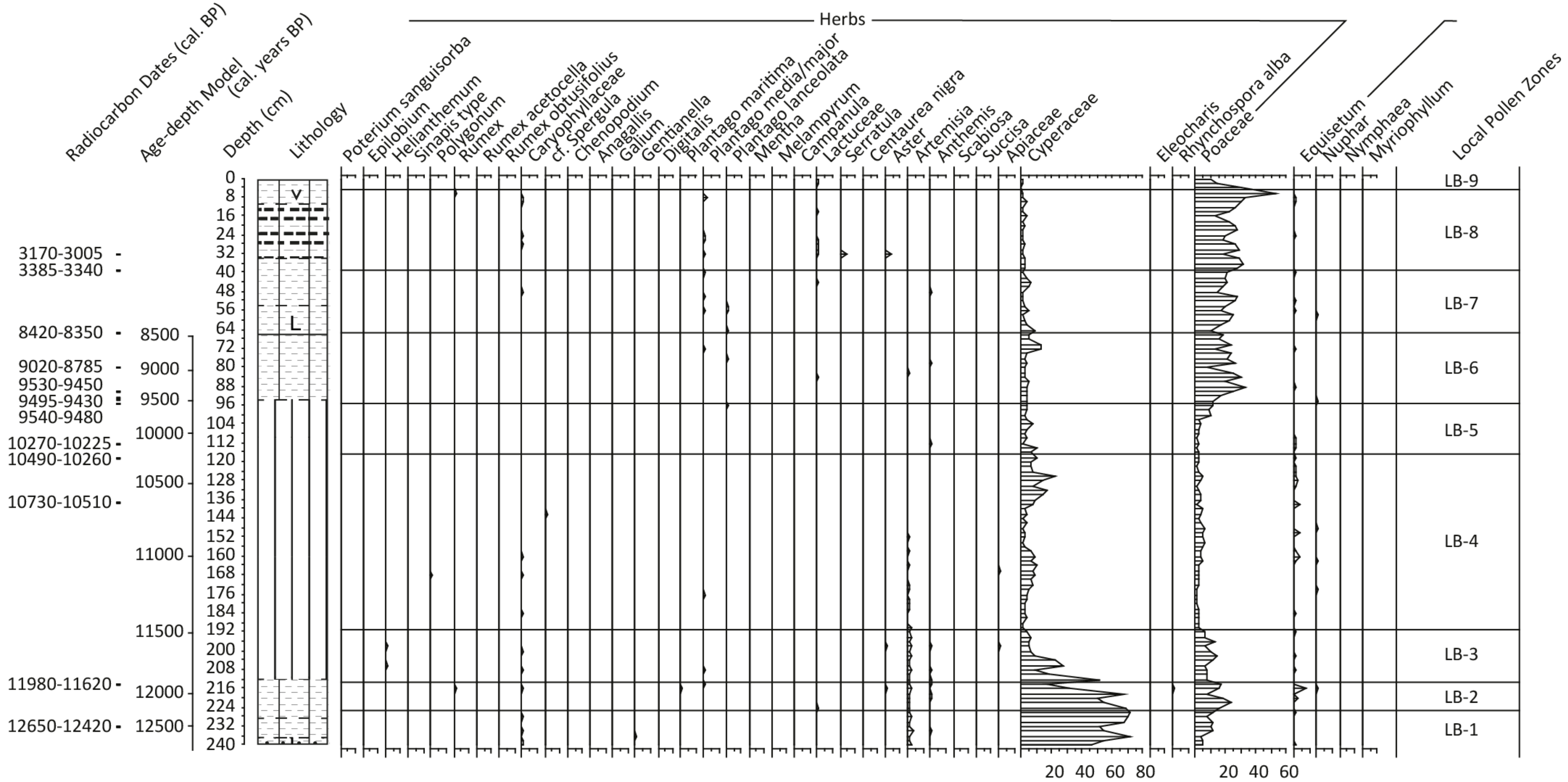


Figure 6.16. Pollen Percentage diagram for Langshot Bog (part 2).

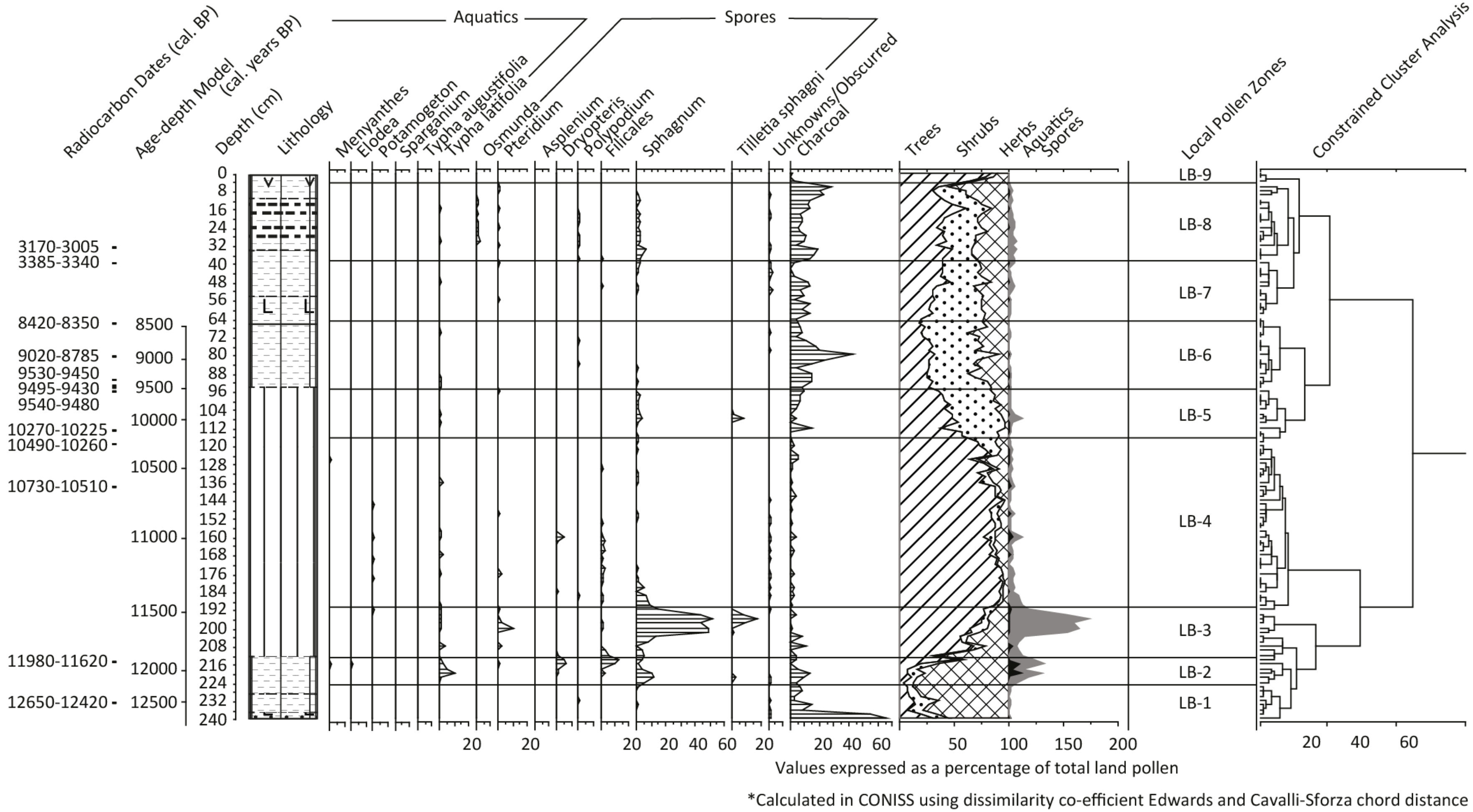


Figure 6.17. Pollen Percentage diagram for Langshot Bog (part 3).

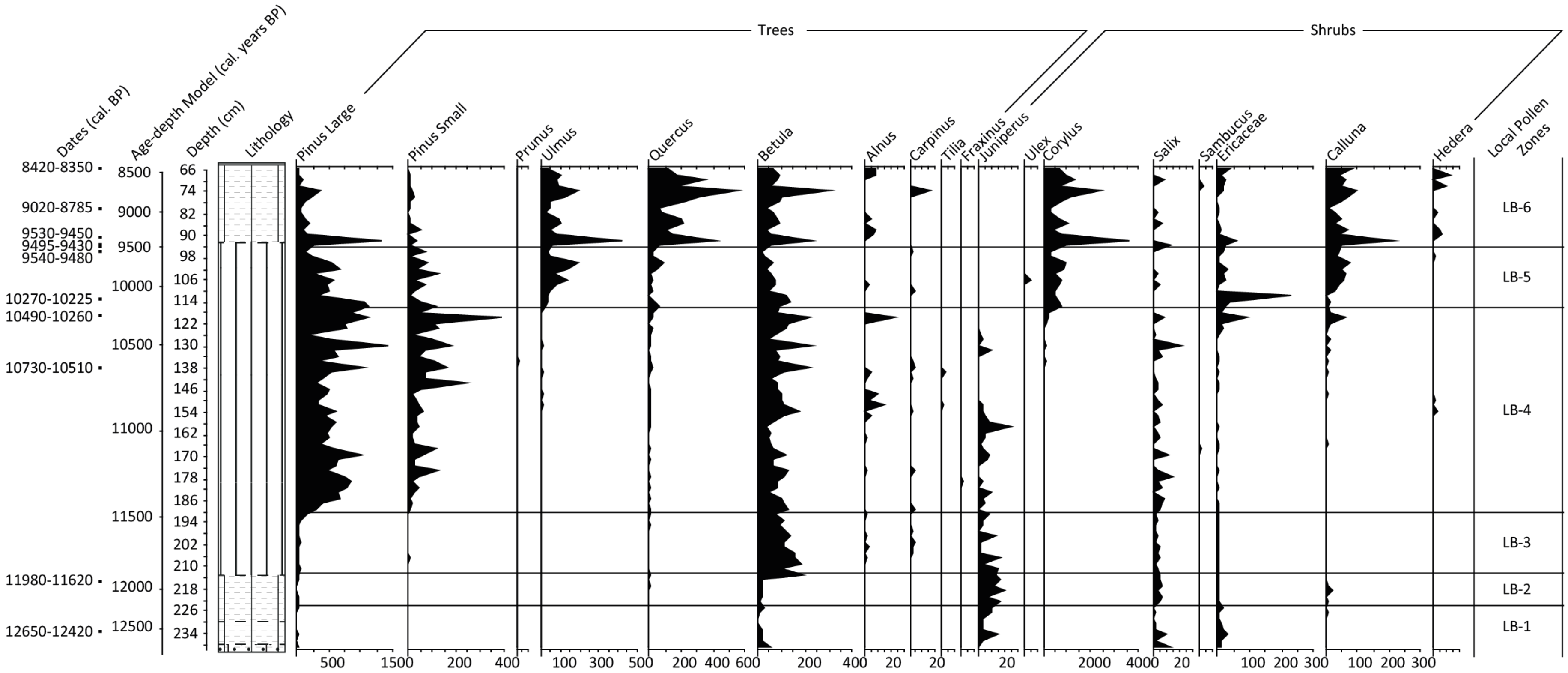


Figure 6.18. Pollen Influx diagram for Langshot Bog (part 1).

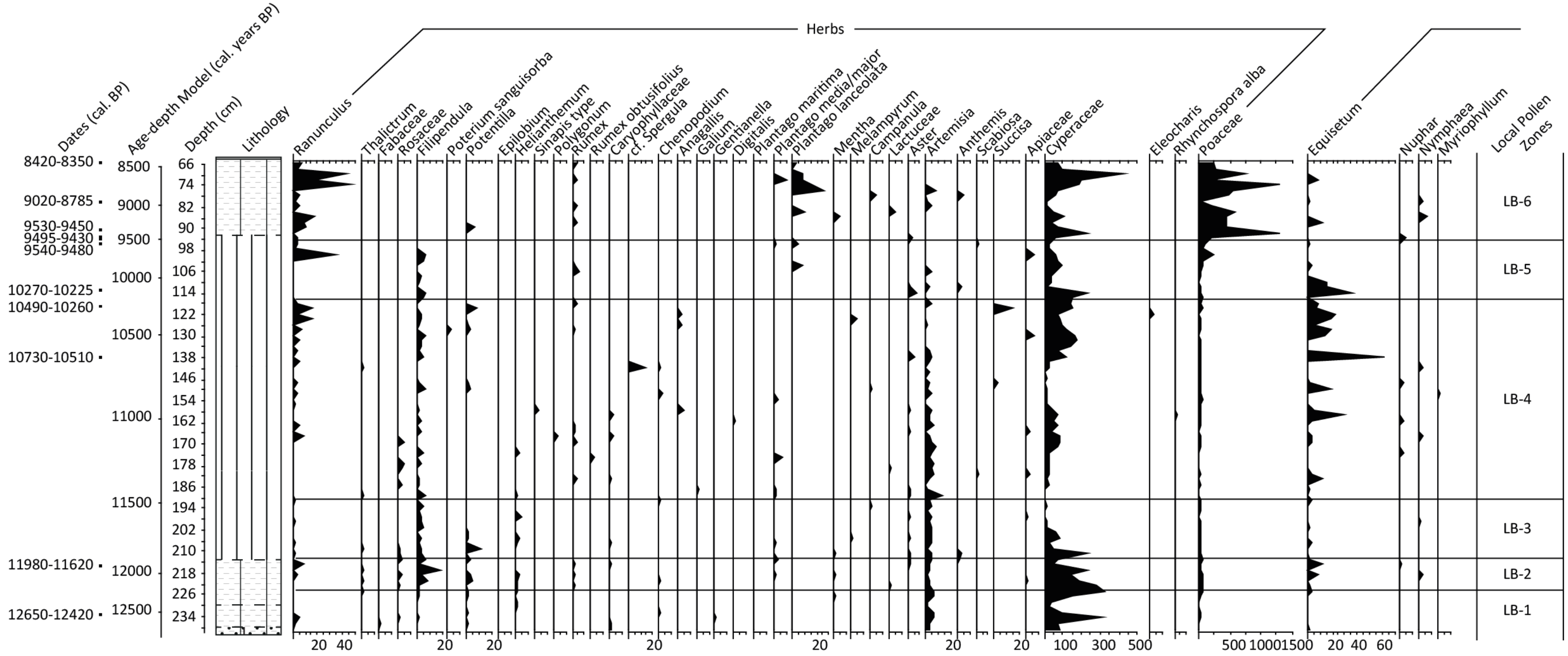


Figure 6.19. Pollen Influx diagram for Langshot Bog (part 2).

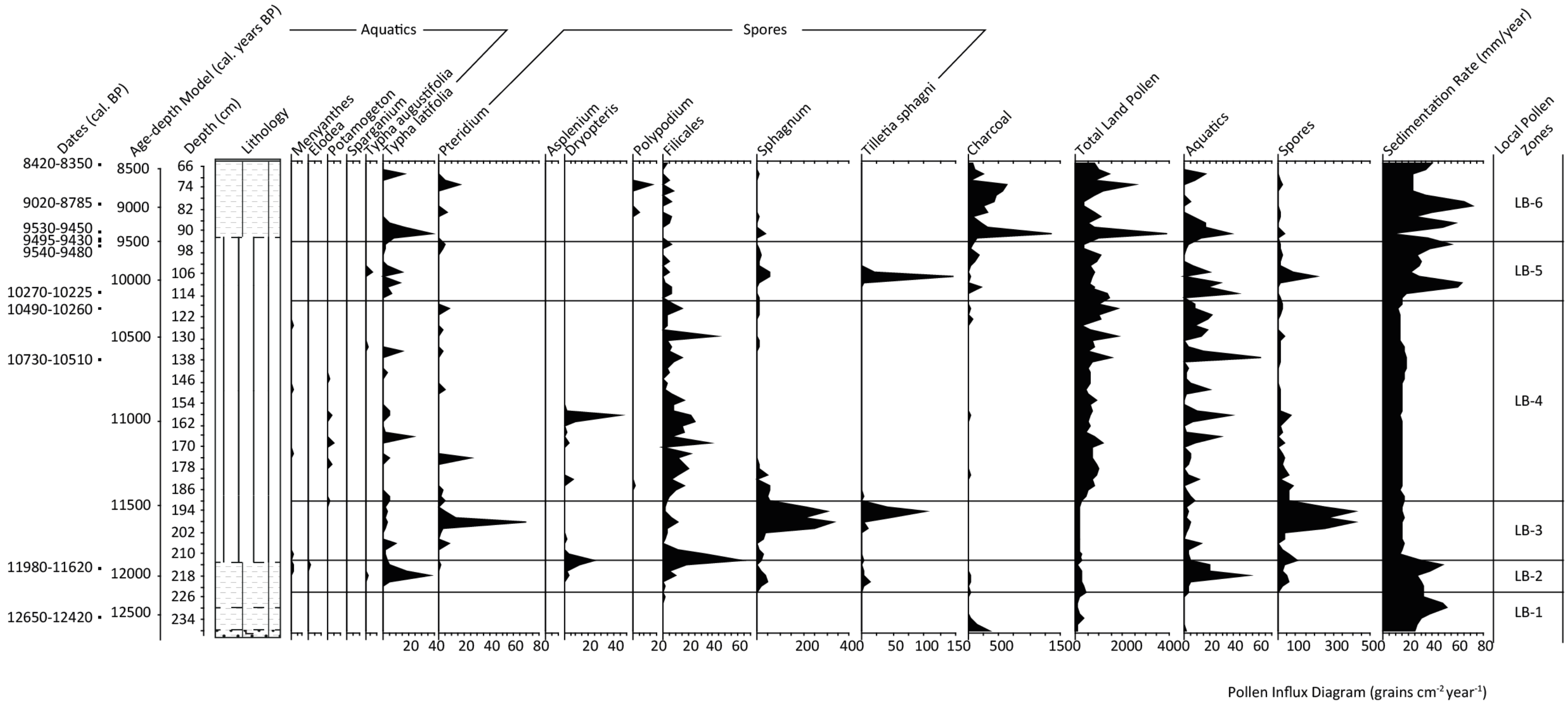


Figure 6.20. Pollen Influx diagram for Langshot Bog (part 3).

Table 6.3. Description of vegetation zones for the Langshot Bog sequence.

Depth (cm)	Pollen Zone	Vegetation
0-5	LB-9	*Betula* – *Corylus* – *Pinus* *Betula* increased rapidly to ~75%, and *Pinus* declined to ~10%. *Quercus* and *Corylus* were present in small amounts (all ~5%). Burning was low across the zone. Organic matter rose rapidly from 50% to 90%.
5-39	LB-8	*Corylus* – Poaceae – *Quercus* *Alnus* (~20%), *Betula* (~20%), *Quercus* (~10%), *Corylus* (~20%) and Poaceae (~20%) were the dominant species in this zone, remaining constant throughout. Both *Tilia* and *Ulmus* declined to 0% whilst *Calluna* also declined from an early high peak of ~15%. A number of herbs, aquatics and spores were found in small amounts in this zone. There was a high level of burning throughout this zone. Organic matter increased to ~60%.
39-65	LB-7	*Corylus* – *Alnus* – *Ulmus* *Alnus* was first observed in large quantities within this zone, reaching a peak of ~20%. *Betula* began to increase from LB-6 (5 to 15 %) and there was a corresponding decrease in *Corylus* (50 to 30%). *Calluna* (5-10%), Ericaceae (<5%), *Quercus* (10%) and *Ulmus* (5%) all remained stable. Burning declined but was still consistently present throughout. Organic matter declined across the zone from a relatively stable 50% to a minimum of ~25%.
65-95	LB-6	*Corylus* – *Quercus* – *Pinus* *Corylus* was the dominant taxa, at a constant ~45% although influx values fluctuated between 500 to >3000 grains cm^{-2} $year^{-1}$. *Pinus* decreased across the zone, from a high of 20% to almost 0%, also recorded in a decline in total *Pinus* influx (from >1000 to <50 grains cm^{-2} $year^{-1}$). *Quercus* percentages increased to ~15% with a corresponding increase in the influx data. Poaceae increased to ~20-25% and represents the first increase in Poaceae pollen influx which peaks at 1000 grains cm^{-2} $year^{-1}$. *Betula* (10%), *Calluna* (5%) and *Ulmus* (5-10%) stayed constant throughout the zone and the influx of shrub and herbaceous taxa including *Hedera, Plantago* and *Ranunculus* was noted. A large increase in burning was also observed. The sedimentation rate was variable across the zone.

Depth (cm)	Pollen Zone	Vegetation
95-117	LB-5	*Corylus – Ulmus – Pinus* *Corylus* influx increased and the taxon became dominant during this zone, rising up to ~50%. *Pinus* decreased from ~60% to ~25% although influx values were still relatively high at 500 grains cm^{-2} $year^{-1}$. *Betula* was still present but at lower levels than previous zones. *Ulmus* increased to 10% and a rapid increase in the rate of influx was observed (up from 0 to 100 grains cm^{-2} $year^{-1}$). Calluna began to take hold in this zone (5%) with influx values similar to *Ulmus*. Cyperaceae and Poaceae remained low (~10% each) but present within the landscape and Poaceae began to increase towards the end of the zone (up to 15%). The sedimentation rate increased to >60mm per year before it declined to ~40mm per year. Burning was recorded increasing (0 up to 10%).
117-191	LB-4	*Pinus – Betula - Salix* *Pinus* was the dominant taxa in LB-4, reaching a dominance of almost 80%, and declined to ~60% by the end of the zone. The influx values of *Pinus* matched this increase, with influx values between 250-1250 grains cm^{-2} $year^{-1}$. *Corylus* gradually increased but this was not reflected in the influx data. *Salix*, *Filipendula*, *Artemisia* and *Ranunculus* were all underrepresented in the percentage data as constant (although small) influxes were observed for these taxa. *Betula* declined from a high of 60% to between 10-20% although influx values remained relatively constant with the previous zone. Cyperaceae and Poaceae remained low (~10% each) but present within the landscape and an influx of *Alnus* indicated its presence in the middle of the zone (still <5%). The total influx of land pollen increased across this zone, from ~250 grains cm^{-2} $year^{-1}$ to >1000 grains cm^{-2} $year^{-1}$. Aquatic species were sporadically represented across the zone, recorded in both the pollen and influx data. The sedimentation rate was constant at 20mm per year.
191-213	LB-3	*Betula – Sphagnum* – Cyperaceae *Betula* expanded rapidly during this zone, reaching a maximum of ~60% and corresponded with an increased influx of *Betula* into the bog (from ~25 to 200 grains cm^{-2} $year^{-1}$). *Artemisia* was present and remained constant from LB-2. Constant influxes of *Salix* and *Filipendula* were observed but not reflected in the pollen percentage data. *Pinus* began to steadily increase (from 5% to 50%) although actual influx remained consistently low. *Corylus,* Ericaceae and Poaceae were present, although their influx values were very low. Cyperaceae continued to decline (from an initial spike of 50% to <5%) and there was a large decline in the influx values. *Juniperus* also declined across this zone. A large increase in *Sphagnum* (and its spore *Tilletia sphagni*) from 5% to 50% was also recorded with an influx of up to 300 grains cm^{-2} $year^{-1}$.

Depth (cm)	**Pollen Zone**	**Vegetation**
213-225	LB-2	*Juniperus* – Cyperaceae – *Typha latifolia* An increase in percentage and influx values was observed in *Juniperus* (up to 10%), Poaceae (up to 20%) *Calluna* and *Ranunculus* (both up to 5%). *Filipendula* influx increased to 5% and *Artemisia* was also consistently present throughout this zone. A number of spores and aquatics also increased during the zone, including *Sphagnum*, *Equisetum*, *Typha* and *Filicales*, all up to ~10% from 0%. The total influx for aquatic species was high during this period. *Betula* and *Pinus* were still present in the landscape, although both have very low influx levels. *Salix* had a constant influx but was underrepresented within the percentage data. A reduction in Cyperaceae was recorded (60% to 20%) during the zone and matched in the influx data.
225-241	LB-1	Cyperaceae – *Betula* – *Juniperus* Cyperaceae was the dominant taxon during this period (45-70%). *Betula* initially started high (30%) but declined to 10% across the zone. Ericaceae, *Salix*, *Artemisia* and *Juniperus* were all present with consistent influx values. *Pinus* percentages (~5%) and influx values were low. *Juniperus* rapidly took over from *Betula* during the early part of the zone. A large increase in organic matter was observed (from 20% to 60%), and highlighted the onset of organic accumulation in the basin. Burning was recorded at the beginning of the zone but dropped away. Total land pollen was very low, between 60-200 grains cm^{-2} $year^{-1}$. The sedimentation rate increased across this zone from 20 to 50mm per year.

6.6. Interpretation of the Palaeoenvironmental data

6.6.1. Sedimentary History and Bog Development

Through the examination of the lithology, the age-depth model and particular taxa identified in the pollen analysis, a reconstruction of the bog development can be made, and the history of the wetland vegetation succession provided. The sediments at the base of the Langshot Bog basin (unit 1) (Figure 6.21) are sand rich and low in organic matter, thought to represent the local Bracklesham geology at the site. Organic accumulation started prior to 12,500 cal. BP during the Loch Lomond Stadial. Lake sediment has been observed at the base of two other sequences from the site (Chan et al., 2015), immediately overlying a sandier unit. It is likely that small pools were present across the basin, occupying natural small hollows in an undulating sandy land surface. Cyperaceae was likely to have been present in shallower water and on wetter ground. The natural decomposition of the Cyperaceae and other organic material is likely to have caused the basin to infill, recorded in unit 2 alongside a corresponding increase in organic matter at ~12,650 cal. BP. Cyperaceae is a species frequently identified in wetland regions on the banks of streams, fens and bogs, tolerating a water depth of up to 50cm, and is particularly common in arctic and tundra environments (Chapin and Chapin, 1980). Decomposition would result in the formation of peat, which would rapidly infill and spread across the lower lying Langshot Bog basin. The low humification of the peat in this unit suggests high bog surface wetness, with a continued dominance of Cyperaceae on the bog margins. The formation of peat and organic lake/pond sedimentation during the Late Glacial is highly significant and will be discussed in detail in Chapter 9, in conjunction with other sites from this research and across Britain.

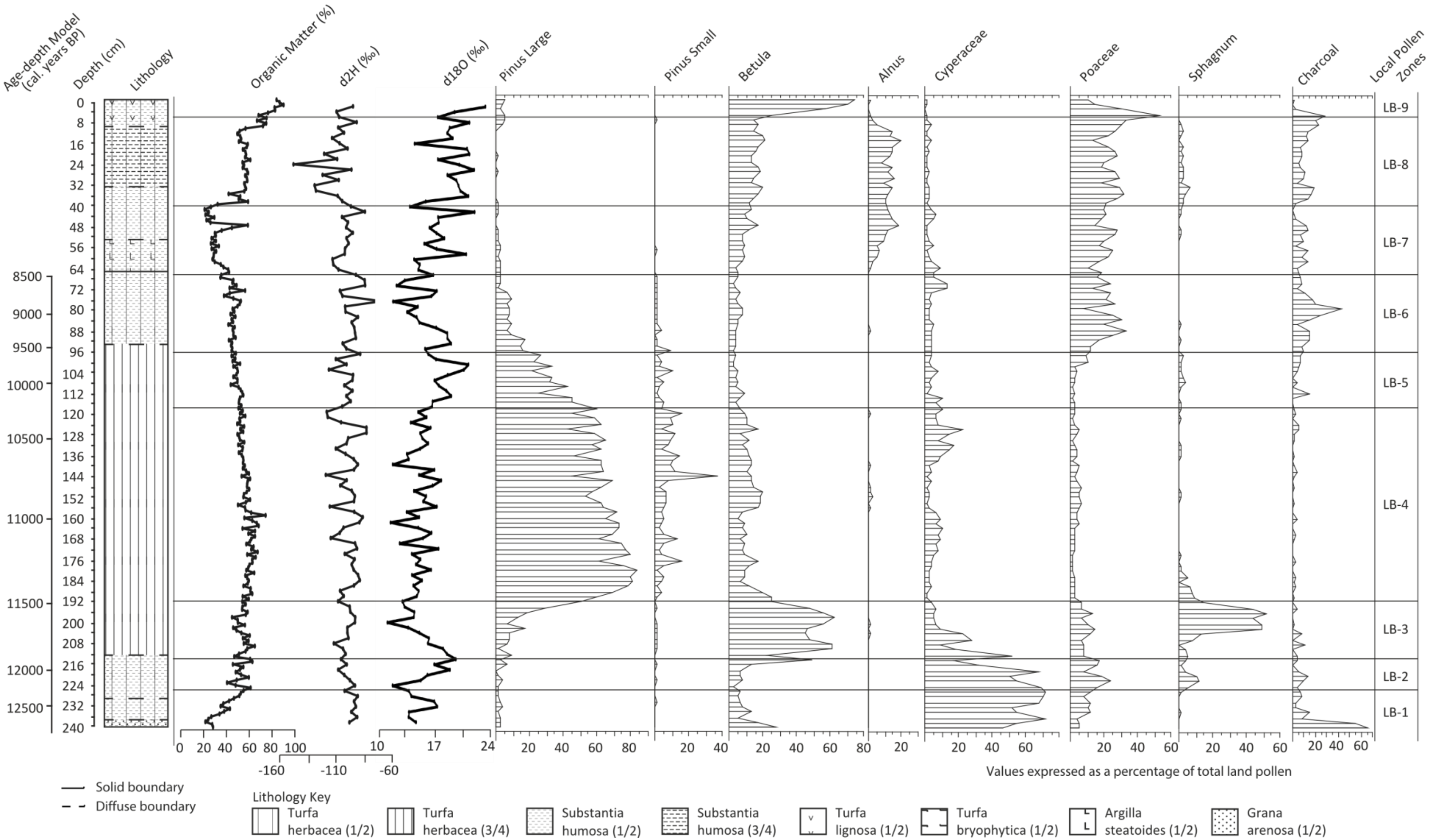


Figure 6.21. Selected taxa pollen percentage diagram with lithology and age-depth model of Langshot Bog.

Peat formation continued in unit 3 from ~11,825 cal. BP until ~11,475 cal. BP, with continued decomposition of Cyperaceae and other herbaceous taxa. There is a high influx of aquatic species during this time into the record, likely indicating that shallow bog pools or wet peaty conditions were present at this point. *Sphagnum*, *Equisetum* and *Typha latifolia* would have been present on the bog surface, suggesting the formation of a reedswamp environment. *Sphagnum* thrives in boggy conditions and *Equisetum* would have been present on the wetter soils around the edges of the bog (Averis, 2013). The presence of *Typha latifolia* also indicates that the water depth was relatively shallow at this time (less than 80cm) (Grace and Wetzel, 1981). *Typha latifolia* is also important as it is a potential food source for humans, as the flowers, shoots and roots can all be eaten (Hardy, 2010) and it is thought to have been utilised as a food source since Neanderthal times, being high in protein and carbohydrates and is generally harvested during the autumn/winter due to rhizome availability (Hardy, 2010). *Filipendula* may also have been present on the bog margins indicating a slight rise in the water level and increasing humidity levels (Goslar et al., 1999). The increasingly wet conditions match the isotope records of this period, which suggests that there is a shift to wetter conditions with increased evaporation. Cyperaceae was still present on the edges of the bog, although declining in abundance, potentially as the water level became deeper. An influx of both sands and silts through units 2 and 3 may represent in-washing from the higher elevated slopes around the edge of the basin, potentially caused by strong storm events or a loss of surface vegetation; this event is examined in greater detail in Chapter 9 through comparison with other records.

The end of unit 3 is marked by a rise in *Sphagnum*, and the decline of Cyperaceae and a variety of aquatic species from ~11,750 cal. BP, potentially indicating a period of slightly reduced bog surface wetness. This correlates with a decline in the oxygen isotope trend indicating lower levels of evaporation. A decline in *Sphagnum* on the bog and advancement of *Pinus* occurs just prior to unit 4 at ~11,700 cal. BP and indicates the continued response of the vegetation to warming conditions during the Early Holocene. The oxygen isotope record continues to indicate a period of decreased evaporation, potentially suggesting a continued period of dryer bog surface conditions with lower evaporation levels allowing *Pinus* to rise as *Sphagnum* declines, and the oxygen record indicates that evaporation levels remain low (and therefore the bog surface relatively dry) throughout the period of *Pinus* dominance at the site. The warming of the Early Holocene led to the drying out of the bog surface and led to the encroachment of *Pinus* and *Betula* onto the surface of the bog. Both *Pinus* and *Betula* are able to occupy a wide range of ecological niches, including the changing conditions present on the bog surface at this time. The presence of trees on the surface of the bog is highlighted by the trace of wood peat found within this unit, although the herbaceous component within the peat record indicates that Cyperaceae and Poaceae are still present across the bog surface, possibly inhabiting shallow pools.

A period of relatively stable peat accumulation then continues from the onset of the Holocene until ~9630 cal. BP. During this time, intermittent increases and decreases of *Typha latifolia*, *Equisetum* and *Potamogeton* during the Early Holocene suggest localised changes in wetness. Periods where *Typha* and *Potamogeton* are present indicate phases when the water depth would have been as deep as 50-80cm (Birkinshaw et al., 2013). This varying water level in the bog is highlighted within the isotope data, which shows a period of instability between ~11,750 and ~10,500 where the record fluctuates between dryer and wetter phases. The record was derived from Cyperaceae and Poaceae macrofossils, which are showing high sensitivity to the changes in wetness across the period. An increase in humification in unit 5, aligned with an increase in *Substantia humosa*, may indicate a drying out of the bog surface from ~9630 to ~8390 cal. BP. The hydrogen isotopes identify a broad drying trend, alongside a reduced amount of evaporation suggested by the oxygen isotopes. An increase in mineral influx and a decline in organic matter is identified, potentially related to the increase in burning also recorded at this time. This could have caused increased runoff and in-washing of mineral matter into the basin from surrounding higher ground.

A hiatus in the sedimentary record is identified between unit 5 and 7, thought to have occurred at the start of unit 6 at 65cm, where there is a large influx of mineral material. Modelling of the radiocarbon dates suggest that this hiatus may have been up to 4850 years in duration, dating from ~8390 cal. BP. A very young (and chronologically inverted) date at the top of unit 6 makes identifying the exact recommencement of peat deposition difficult. This hiatus may be due hydrological change across the catchment at this time leading to a lack of further sedimentation until the bog became wetter and less stable. This could have been due to the lowering of local groundwater reserves, deforestation, bog bursts or human activity. This is a topic that is examined further in Chapter 9.

A major increase in mineral matter is observed in units 6 and 7, with silt values increasing to ~50%, and continues until ~3090 cal. BP. This is a period when the hydrogen and oxygen isotope values are in phase and suggest a drying bog with high amounts of evaporation. *Alnus*, likely representing *Alnus*-carr conditions, would have stabilised the bog surface through natural hydroseral succession. Increased evaporation would have occurred due to the increased foliage present, as opposed to the herbaceous taxa present prior to *Alnus* colonisation (Zhang et al., 2001). It is important to note that the presence of *Alnus* was not recorded prior to this hiatus at ~8500 cal. BP, which is significant as *Alnus* expansion across the British Isles has been identified from ~8900 cal. BP (Bush and Hall, 1987) and therefore occurred later at Langshot Bog. The presence of *Alnus* post-hiatus is therefore not unexpected as it is well established across the British Isles by ~7200 cal. BP (Birks, 1989). *Alnus* is often found in *Alnus*-carr conditions with moist to wet soils, and around larger water bodies, and would have colonised the bog surface as the bog dried out (Averis, 2013). An increase in organic matter, comprised of both *Substantia humosa* and herbaceous peat is recorded in unit 8. A small increase in *Sphagnum* and a major decrease in hydrogen isotope values suggest areas of the bog surface may have been very wet, although *Alnus*-carr would still have been present. Unit 9 identifies both wood peat and herbaceous peat, likely to be a combination of *Betula* and Poaceae on the bog surface. This unit may represent the modern day, as the pollen assemblage is indicative of the species currently present on the bog surface.

6.6.2. Vegetation History

The pollen data (Figure 6.15 - Figure 6.17 and Figure 6.18 - Figure 6.20) permit the reconstruction of the dryland vegetation history at Langshot Bog from the Late Glacial period through to the Early Holocene. LB-1 at Langshot Bog is likely to represent a cold, tundra-style landscape of shrubland and short turf grassland, relatively species-poor with evidence for natural burning, and the potential for the grazing of animals, characterised by *Betula* and *Juniperus*. These species are cold tolerant, important as this zone may represent the start of the Loch Lomond Stadial (Walker et al., 1994), dating from ~12,820 cal. BP to ~12,240 cal. BP (LB-1). The vegetation is likely to be very sparse, and there is likely to be a low level of overall vegetation cover due to the very low influx levels during this period. *Betula* is cold tolerant, though *Betula nana* is more cold tolerant than *B. pubescens*, both of which can grow in a range of soil conditions (Averis, 2013) and both *Betula pubescens* and *B. nana* have been identified in the British Isles during the Late Glacial period (Birks, 1965). Unfortunately, the lack of macrofossils means that a distinction between the two species is not possible. *Juniperus* is a subarctic species and due to this can survive in dry and cold conditions (Rawat and Everson, 2012) and so has often been used as a Late Glacial indicator (O'Connell et al., 1999). *Juniperus* is able to colonise unstable ground surfaces and can survive poor soils with low nutrient contents (Averis, 2013). The low percentages of *Juniperus* at this time (predominantly <5%) suggest that dwarf *Juniperus* was present, and year round temperatures would have been relatively cold (Kolstrup, 1980). Very low amounts of *Pinus* woodland may have been present, potentially on both the drier and wetter soils around the bog, but may also indicate long distance transport of *Pinus* pollen as the influx values are very low. (Averis, 2013). The Ericaceae record is significant, as it may be present due to its ability to regenerate after fires. Species of the Ericaceae family can survive on dry to wet peaty soils and some are palatable to faunal species, including deer (Averis, 2013). Both *Betula* and Ericaceae are resistant to wind exposure, relevant with the sparse woodland cover, and may indicate the presence of small heathland patches across the landscape as observed elsewhere (Bennett, 1983; Walker et al., 2003).

LB-2 is broadly similar to LB-1 with a tundra-style vegetation cover, and dates to the second half of the Loch Lomond Stadial (~12,240 to ~11,825 cal. BP). A consistent influx of *Salix* suggests that *Salix* is underrepresented in the pollen percentage data, and would have formed a component of the local woodland cover, likely on the wetland margins. *Juniperus* increased possibly due to a reduction in burning, and various herbaceous taxa are noted, including *Ranunculus*, *Thalictrum* and *Filipendula*. These herbaceous species would have quickly colonised open patches of bare ground, probably on the wetland margin. These patches may have provided a source for the mineral runoff identified within the bog.

A rapid (<200 years) increase in *Betula* is identified in LB-3, alongside the reduction of both *Juniperus* and Ericaceae shrubland and this unit represents the onset of the Holocene. This appears to be the establishment of pioneer woodland, as *Pinus* also begins to rise during this period as evaporation levels decline (observed through a decreasing oxygen isotope trend thought to indicate drying out of the bog surface) and is observed during the Late Glacial to Early Holocene period at a number of British sites (Waller, 1993; Branch and Green, 2004). Low influx levels of *Pinus* pollen suggest the local presence of *Pinus* would have been relatively small and its presence may be indicating a regional signal and long distance transport of the pollen. The rise in *Betula* dates from ~11,825 cal. BP and persists for approximately 600 years during the Late Glacial to Early Holocene transition until ~11,475 cal. BP. The appearance of *Filipendula, Artemisia* and Caryophyllaceae may indicate small discrete areas of disturbed ground, although the overall amount of herbaceous taxa begins to decline, notably Poaceae, suggesting these areas of open ground are decreasing in size. Small increases in *Corylus* and *Carpinus* suggest some slightly drier ground on a neutral soil was present, potentially at a greater distance from the bog (Averis, 2013). This suggests that the soil characteristics may have been very different in the Early Holocene, a point discussed further in Chapter 9. The transition of *Betula* to *Pinus*-dominated woodland occurs during the very Early Holocene, at ~11,475 cal. BP and marks the start of LB-4, a period of relatively dry bog surface conditions as evaporation levels remain low. At this time, the vegetation began to expand in the local area around the site, indicated by an increase in the total land pollen sum suggesting greater local vegetation cover. Although *Pinus* appears dominant, *Betula* would have still been present within the woodland as *Pinus* has a tendency to over-represent itself in pollen diagrams (Waller, 1993). This is particularly evident as the influx of *Betula* pollen remains constant from LB-3 to LB-4, indicating *Betula* was still a major component of the woodland alongside *Pinus.* This period of mixed *Betula/Pinus* woodland lasts for ~1000 years until ~10,340 cal. BP. This woodland was likely to be very dense, indicated by the lack of herbaceous species that may have formed the understory vegetation. The increase in *Corylus* during the zone indicates the continued warming of the climate during the Early Holocene (Birks, 1989), as *Corylus* is a species that prefers warmer conditions with extended growth seasons and a less variable climate (Tallantire, 2002).

As temperatures warm during the Early Holocene (Davis et al., 2003), thermophilous species are observed in abundance in LB-5 from ~10,340 cal. BP. *Corylus* rapidly expands at this point, along with the arrival of *Ulmus*, potentially indicating a reduction in precipitation which is also recorded in the hydrogen data (Hall, 1978). *Pinus* rapidly declines in abundance due to its inability to compete with the newly arriving species (Birks, 1989). Microscopic charcoal increased during LB-5, and it is possible that this is evidence for human induced woodland clearance, potentially for attracting animals to the water source. Although the drier conditions may also have led to an increased chance of natural burning, this will be discussed in Chapter 9 with reference to the archaeological activity in the region. A small but sustained increase in *Calluna* may suggest that animals were present around the site, as many species of *Calluna* are palatable to fauna, including deer (Averis, 2013). This may lend credence to the idea that clearances within the woodland were being caused and maintained by herbivores (Vera, 2000). *Quercus* arrives slightly later than the other thermophilous taxa, at the start of LB-6, from ~9630 cal. BP. *Corylus* may now be forming the understorey vegetation (Godwin, 1975b) as the canopy of the deciduous woodland closed. An increase in Poaceae may indicate the continued development of clearings within the woodland. Influx increases of all major taxa within this zone indicate a broad mix of species within this deciduous woodland cover.

Burning is still prevalent within the record, and again could be due to either anthropogenic or natural causes, although the increase in Poaceae and relative stability of many arboreal species may indicate selective burning to create clearances. This mixed open deciduous woodland remains established until ~8390 cal. BP.

LB-7 is thought to occur after the suspected hiatus within the core, and therefore the exact timing of events, such as the *Alnus* rise and *Corylus* decline, are not known. The dryland vegetation post hiatus (dating to between 7220-3530 cal. BP) is mixed deciduous woodland, similar to the woodland at Langshot Bog prior to the hiatus. *Ulmus, Quercus, Corylus* and *Betula* would have dominated this woodland, with *Calluna*, *Ranunculus* and Poaceae potentially occupying clearings within the woodland. There is a continued presence of local burning, and is likely to be the cause for the increased mineral sedimentation within this unit. This is another period where human groups may have been present around Langshot Bog. The increasing *Betula* values may indicate the regeneration of *Betula* immediately after these fire events, as *Betula* is a pioneering taxon and can regenerate swiftly (Hytteborn et al., 2005).

Similar mixed deciduous woodland is observed in LB-8, dating from ~3200 cal. BP, although a reduction in *Corylus* and increase in *Calluna* is recorded. The increase in *Calluna* may be related to the high level of burning in the zone as it regenerates quickly (Chambers, 1993), as does *Betula* (Hytteborn et al., 2005) which is also prevalent in the zone. This burning may have been specifically targeted at *Corylus*, as other species appear relatively stable. The final zone, LB-9, indicates a rapid increase in *Betula* and a small increase in *Pinus* alongside declines in almost all other species. This zone may be representative of the modern day vegetation and another hiatus may have occurred between zones eight and nine. This hiatus may be due to 17^{th} and 18^{th} century peat cutting, which is well documented as occurring throughout western Surrey at this time (Great Britain Board of Agriculture, 1809).

6.7. Synthesis

The site at Langshot Bog on Chobham Common provided a new palaeoenvironmental sequence that dated back to the Late Glacial period. The bog was extensive and the transect survey revealed a maximum depth of 241cm, with large parts of the basin over 200cm deep.

Organic sediment accumulation occurred prior to ~12,500 cal. BP during the Loch Lomond Stadial, a period of cold climatic conditions. Small pools were probably present on an undulating topography that slowly began to infill. The record provided evidence for a tundra-style landscape, with both *Betula* and *Juniperus* present on the dryland, and Cyperaceae and a variety of aquatic species abundant on the bog surface and within pools. Natural burning may also have occurred. In-washing of mineral sediments from the higher surrounding land would have been caused by rain or high winds, facilitated by patchy tundra vegetation and bare ground. The expansion of *Sphagnum* on the surface of the bog was thought to represent a slight drying of the bog surface at a time when pioneer arboreal taxa were becoming established from ~11,850 cal. BP. *Betula* dominated for ~600 years, representing the onset of the Holocene, until *Pinus* expanded rapidly leading to a mixed *Pinus* and *Betula* woodland. A dense canopy was highlighted by a decline in herbaceous taxa. *Betula* (and *Pinus*) may have been present on the bog surface in drier periods, with a subsequent decline in *Sphagnum*.

Evidence for climatic amelioration was observed from 10,340 cal. BP with the arrival of thermophilous deciduous taxa in relatively large quantities, including *Ulmus* and *Corylus*. The climate was likely to have been both warmer and drier at this point. *Quercus* was recorded later, from 9,630 cal. BP and mixed deciduous woodland with an understory of *Corylus* was likely to have been the dominant vegetation surrounding the bog. An increase in Poaceae and a relative stability of the tree taxa may have indicated selective burning, rather than widespread burning of all tree taxa. A sustained increase in *Calluna* and the high quantity of *Corylus* both suggested the potential for herbivore grazing existed, as did the potential for humans to exploit the *Corylus* for hazelnuts. An increasing mineral component throughout this period may indicate the creation of bare ground following woodland clearance or fire events and the in-washing of these sediments prior to species recolonization.

Above the suspected hiatus at 65cm, which may be caused by a hydrological change, *Alnus*-carr conditions formed on the bog surface, and the surrounding dryland is dominated by mixed deciduous woodland. This remained stable until the top of the sequence, where another potential hiatus may have occurred, possibly due to 17th and 18th century peat cutting, after which the *Betula* and *Pinus* vegetation appeared similar to that of the modern day site.

7. Thursley Bog and Ockley Bog, Thursley National Nature Reserve

7.1. Introduction

This chapter presents the palaeoenvironmental study of Thursley Bog and Ockley Bog. The investigation provided an opportunity to understand the extent of peat deposits within the nature reserve, and improve our knowledge of past vegetation change and human activity within Surrey and the southeast.

Thursley Common, Elstead Common and Ockley Common (centre approximately located at SU 90788 41591) are an extensive area of open heathland, peat bogs and woodland, covering over 325 hectares in the southwestern corner of Surrey (Graham et al., 2004). The study area is within the Thursley National Nature Reserve (NNR) and the Thursley, Hankley and Frensham Sites of Special Scientific Interest (SSSI) (Figure 7.1).

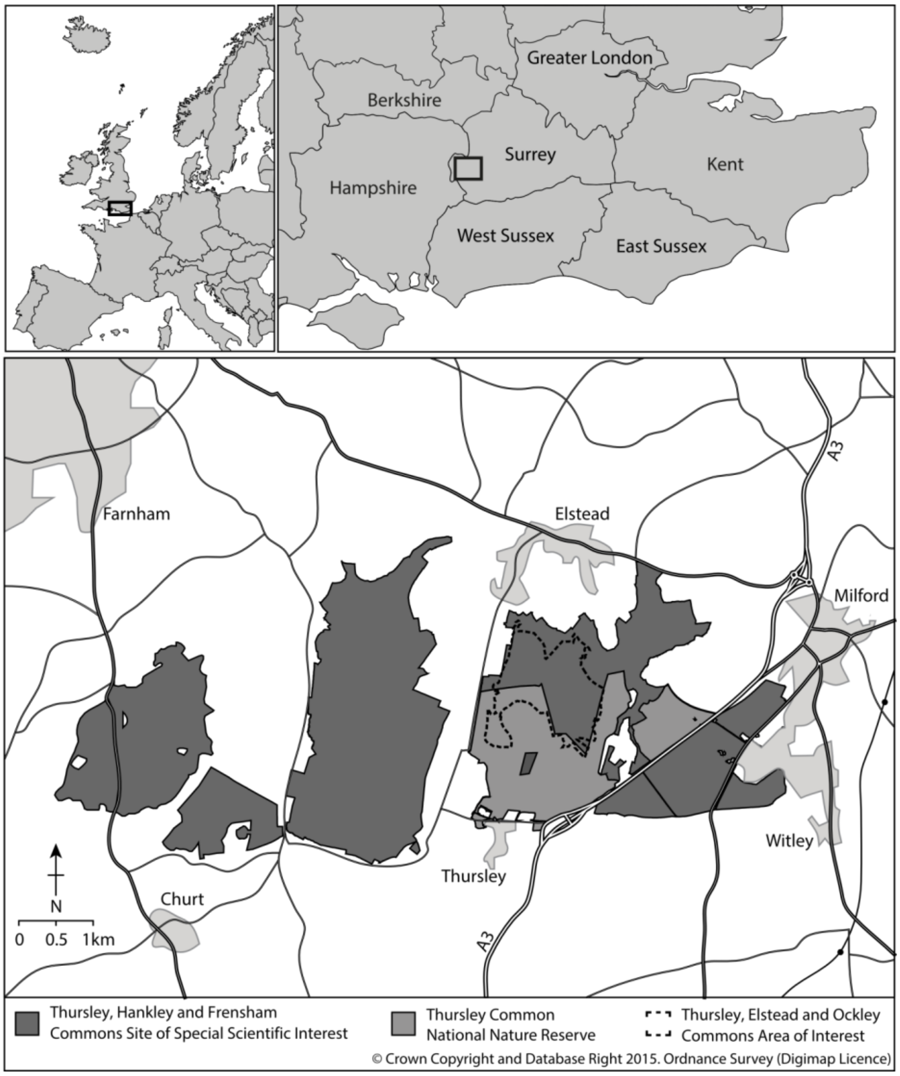


Figure 7.1. Location of the study area within Surrey and the southeast.

The three commons (Figure 7.2) are located to the north of Thursley Village and form part of the Surrey Lower Greensand heathland. They are situated on the Lower Greensand, including both the Folkestone Beds in the south and west, and the Sandgate Beds in the north and east (Gallois, 1965; Graham et al., 2004). Soils are typically thin sandy podzols and in many places the Lower Greensand is exposed at the surface, where soils have been worn away on footpaths and bridleways (Giles et al., 2011; National Soil Resources Institute, 2015). This may have assisted the identification of archaeological remains across the Commons, as material may be exposed at the surface.

The land across the commons is low lying and frequently waterlogged, often with large pools forming on the surface, and the commons form the largest raised peat bog in southeast England (Graham et al., 2004). Ridges and ditches across the bog surface are thought to be evidence for former peat cutting and extraction (Moore and Wilmott, 1976). The land rises gently to the north and west, while towards the south the land rises steeply to form a low escarpment overlooking the commons.

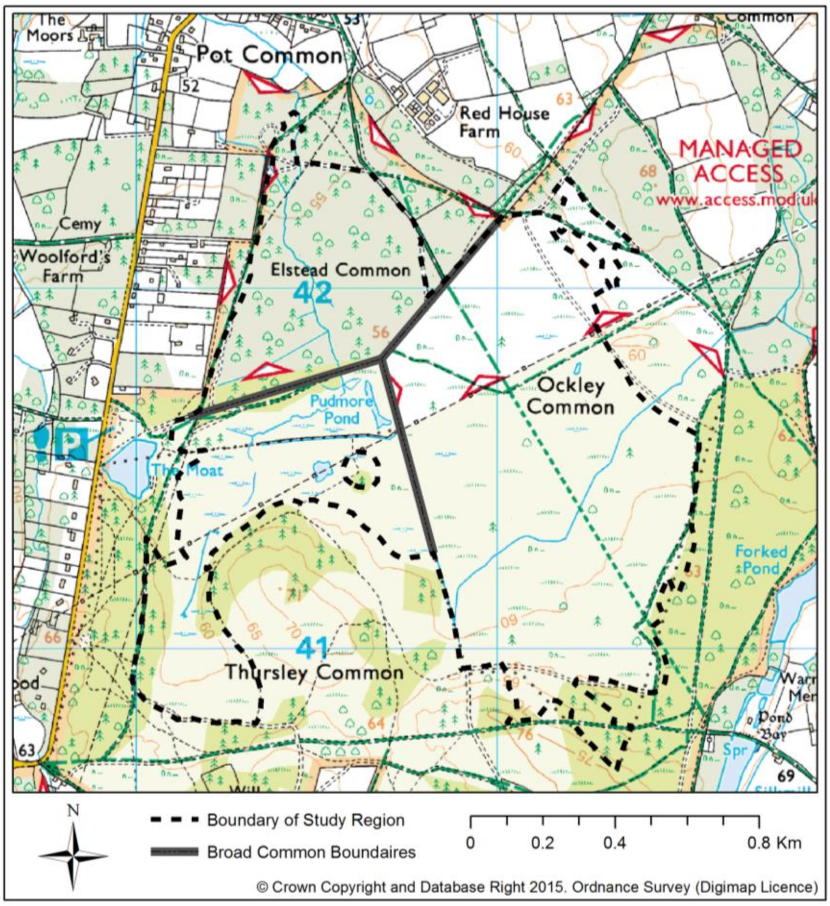


Figure 7.2. Indication of the areas of the three commons, Thursley Common, Ockley Common and Elstead Common represented on OS 1:25,000 scale maps.

The flora and fauna across the reserve are highly diverse (Figure 7.3). Wet heath and mire systems are widespread and large areas of mire are covered in *Sphagnum* moss (*Sphagnum magellanicum* and *S. papillosum*), *Drosera intermedia*, *D. rotundifolia, Narthecium ossifragum, Eriophorum vaginatum, Eleocharic multicaulis, Vaccinium oxycoccos* and *Rhynchospora fusca.* Open water areas are characterised by *Carex rostrata, Menyanthes trifoliata, Utricularia minor* and *Hypericum elodes.* Dryer grassy regions are home to *Holcus lanatus, Molinia caerulea, Agrostis canina* and *Deschampsia flexuosa.* Heathland species consist of *Calluna vulgaris, Erica cinerea, E. tetralix, Ulex minor, Genista anglica and Pteridium aquilinum. Betula pendula, B. pubescens, Quercus robur* and *Pinus sylvestris* have colonised some areas of wet heath as well as the dryland around the edges of the bog sites. The dryland is also inhabited by *Fagus sylvatica, Fraxinus excelsior, Ilex aquifolium* and *Corylus avellana,*

Fauna include many species of bird, including Dartford warblers *(Sylvia undata),* nightjars *(Caprimulgus europaeus)* and curlew *(Numenius arquata).* Rare butterflies and reptiles also thrive, including smooth snakes *(Coronella austriaca),* sand lizards *(Lacerta agilis)* and the silver studded blue butterfly *(Plebejus argus).* Fire is a major factor influencing vegetation at the site, caused both naturally and through arson.

Figure 7.3. A southwards view over Ockley Common running from dry heath in the foreground, through to wet mire towards the treeline surrounding the common in the distance.

Previous work at the commons has focused on obtaining both archaeological and palaeoenvironmental information. Large amounts of prehistoric flintwork have been identified showing that the area was occupied throughout the Mesolithic (Figure 7.4), Neolithic and Bronze Ages (Graham et al., 1999).

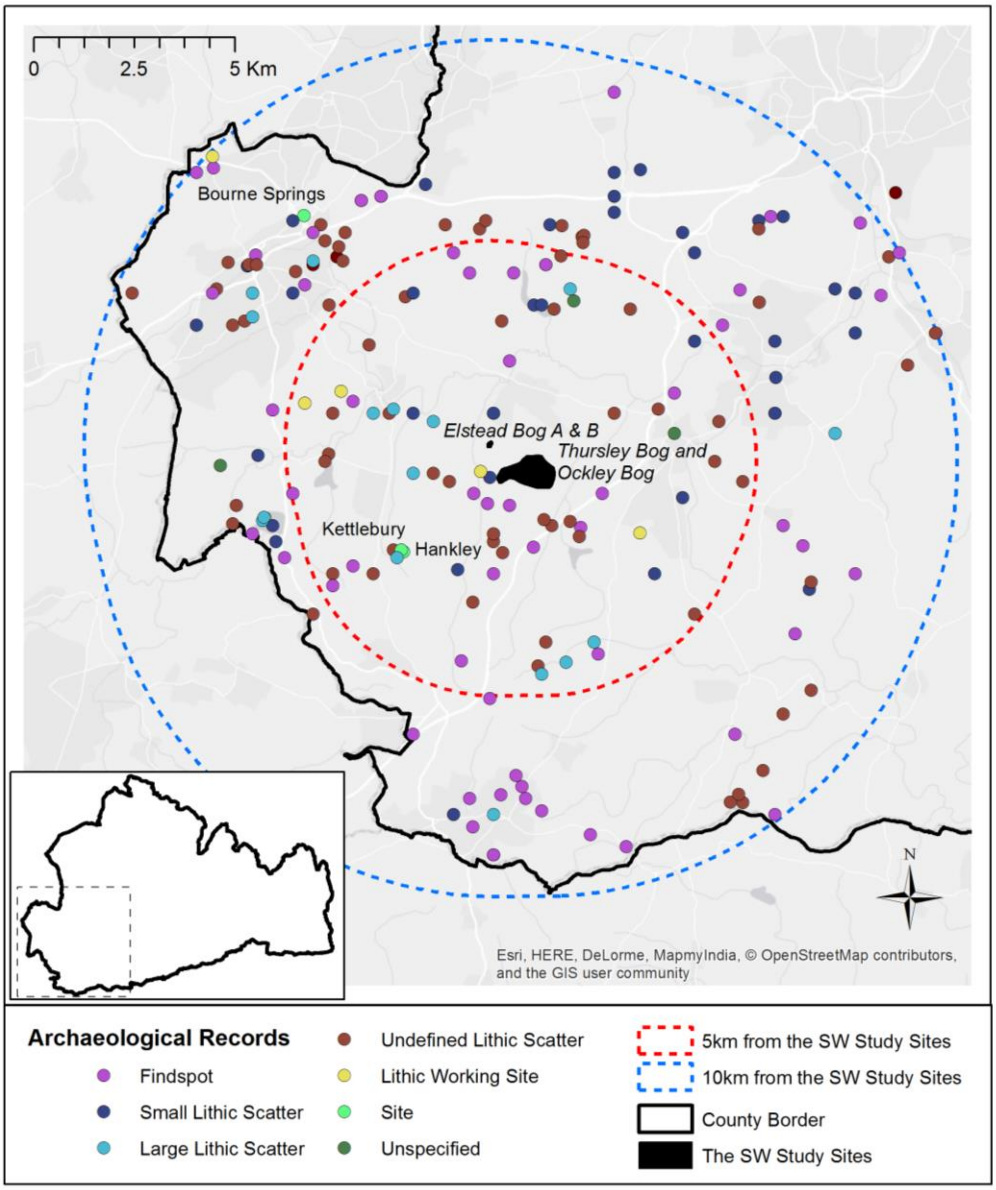


Figure 7.4. Archaeological records within 5km and 10km of the wetlands in SW Surrey.

Mesolithic activity appeared to be concentrated on the slightly raised ground of the Commons, overlooking streams and wetter regions. Within 5km of the Commons, there is a wide diversity of records from the HER. 71 Mesolithic records in total are present, and within 10km, there are 5 Late Upper Palaeolithic records. These Late Upper Palaeolithic finds consist primarily of blades, flakes and other implements, suggesting some level of activity (passing-through, tool repair etc.) occurred within the wider region of the Commons. There is greater diversity in the Mesolithic assemblage, with remains including microliths, adzes, cores, flakes and blades, identified through findspots and varying sized lithic scatters. There are also three sites within 10km; Kettlebury, Hankley and Bourne Springs and a range of lithic working sites in the region, all of which shows that the area was extensively used during the Mesolithic period.

Two burial mounds have also been examined on the south side of Ockley Common, situated on higher ground overlooking the expanse of Ockley Bog. One of these was investigated and the mound showed evidence of a turf stack construction and suggested the presence of a potential primary burial (Graham et al., 2004). Results from the excavation and pollen evidence from the mounds suggested that construction was during the Bronze Age, indicating the likelihood that both mounds are likely to have been barrows. Previous pollen analysis of a 122cm core taken from Ockley Bog was interpreted as indicating widespread forest clearance in the Neolithic and Bronze Age periods (Moore and Wilmott, 1976), and that this forest clearance led to the formation of the peat bog.

7.2. Results of the Field and Laboratory Sedimentology

The previous work at the site only examined a very small part of Ockley Bog, leaving a large expanse of bog that had not been analysed. A 100m gridded transect survey across Thursley Bog and Ockley Bog (Figure 7.5), allowed for the investigation of basin size and shape in an attempt to identify the deepest sediment sequence. Cores were taken using a gouge auger to measure depth from bog surface to the interface between the peat and the Lower Greensand. These results were modelled in ArcGIS and provided a map of basin depth (Figure 7.6). Results can be found in Appendix 13.10.

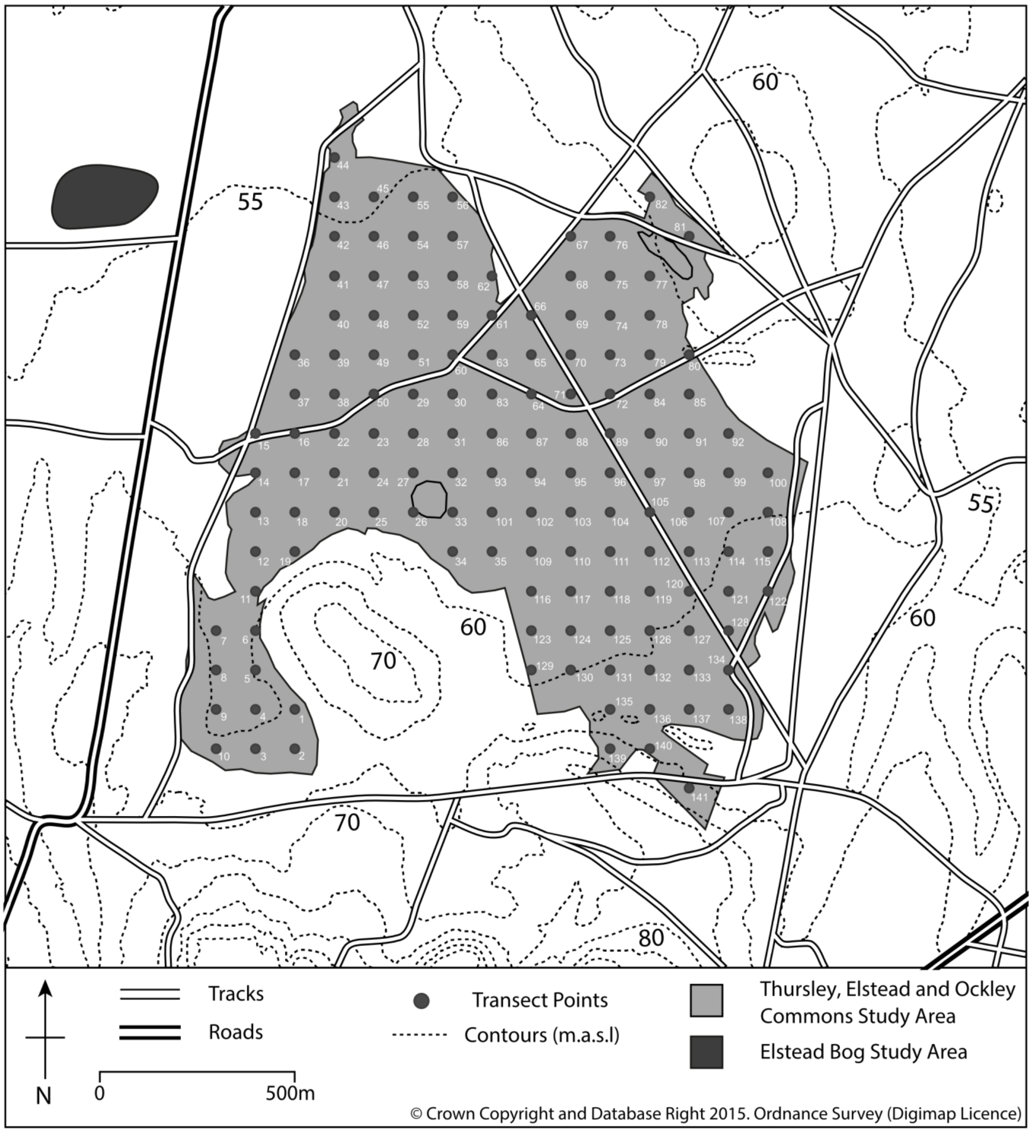


Figure 7.5. Location of the Thursley and Ockley Bogs study area and the coring grid. The two encircled areas within the study area represent slightly higher elevation 'sand islands'.

Basin depth (Figure 7.6) was highly variable across the study area. Much of the common had no discernible peat deposits; instead a wet peaty soil of 5-10cm was underlain immediately by the Lower Greensand, particularly the case across Elstead Common. Deeper deposits were noted mainly in three key areas, to both the east and west of the small sand island in the centre of Thursley Common, and towards Ockley Common on the south side of the area studied. From this survey, the main Thursley Bog coring point to be used in this study was identified (SU 90798 41432) and subsequently referred to as Thursley Bog. The Ockley Bog coring point for this study (SU 91007 41160) was based on the approximate location of previous work (Moore and Wilmott, 1976) and corresponded very well to the deepest point of that basin, subsequently referred to as Ockley Bog. Both Thursley Bog and Ockley Bog are thought to have formed in very small basins, potentially only a few meters across, observed when taking the master core sequences from the two sites. This means that they would have had a very small bog surface area during the Lateglacial and Early Holocene, potentially less than ~50m^2. These very small basins suggest that the pollen source areas for the sites is likely to be dominated by local pollen, at a scale of 20-30 metres (Jacobson and Bradshaw, 1981).

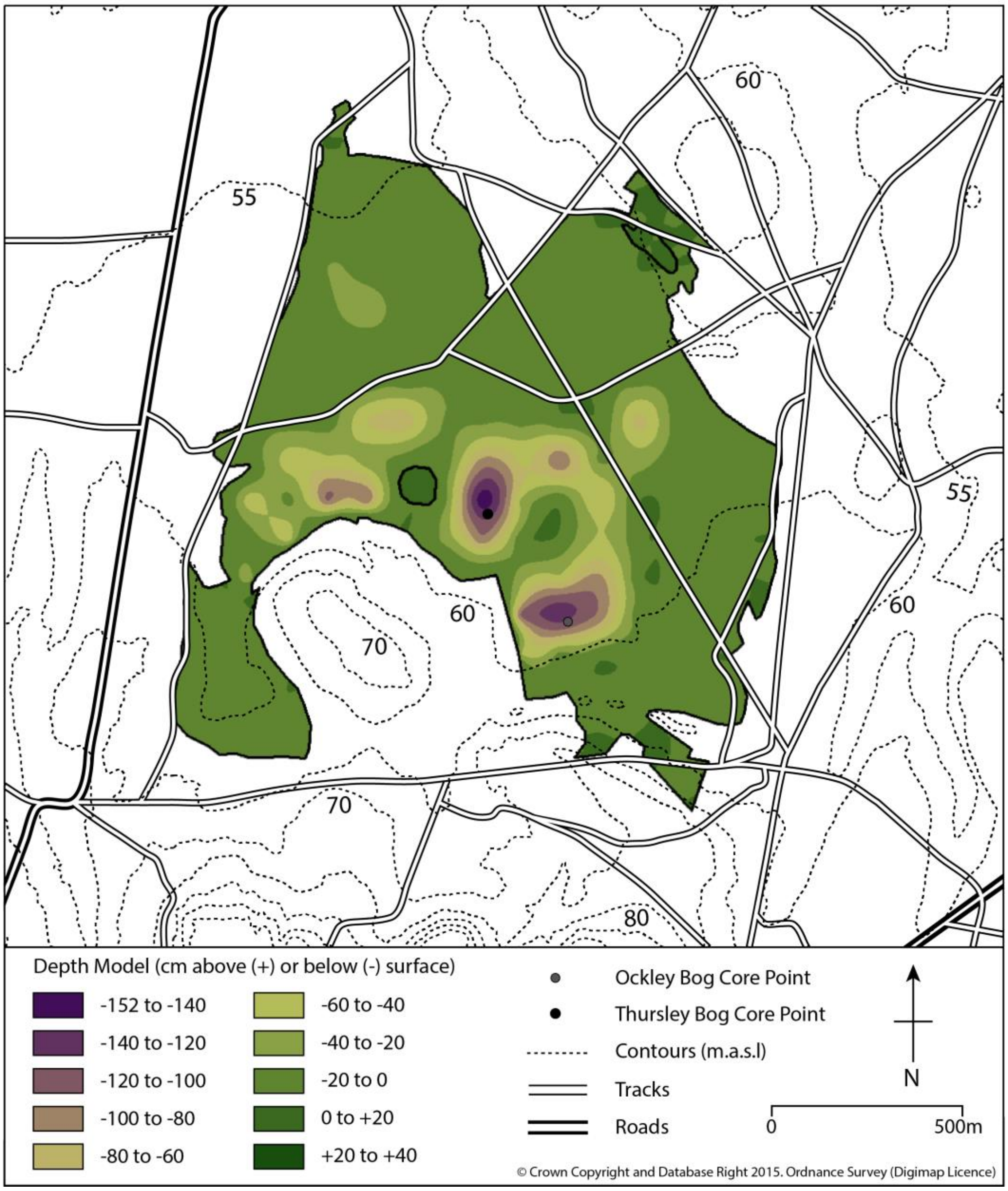


Figure 7.6. Depth model derived from gridded transect survey and final coring positions. The two encircled areas within the study area represent slightly higher elevation 'sand islands'.

7.2.1. Thursley Bog

The Thursley Bog core had a total depth of 195cm, four radiocarbon dates were obtained and an organic matter curve was calculated at a resolution of 1cm (Figure 7.7). Raw data for the stratigraphy and organic matter can be found in Appendix 13.11 and Appendix 13.12.

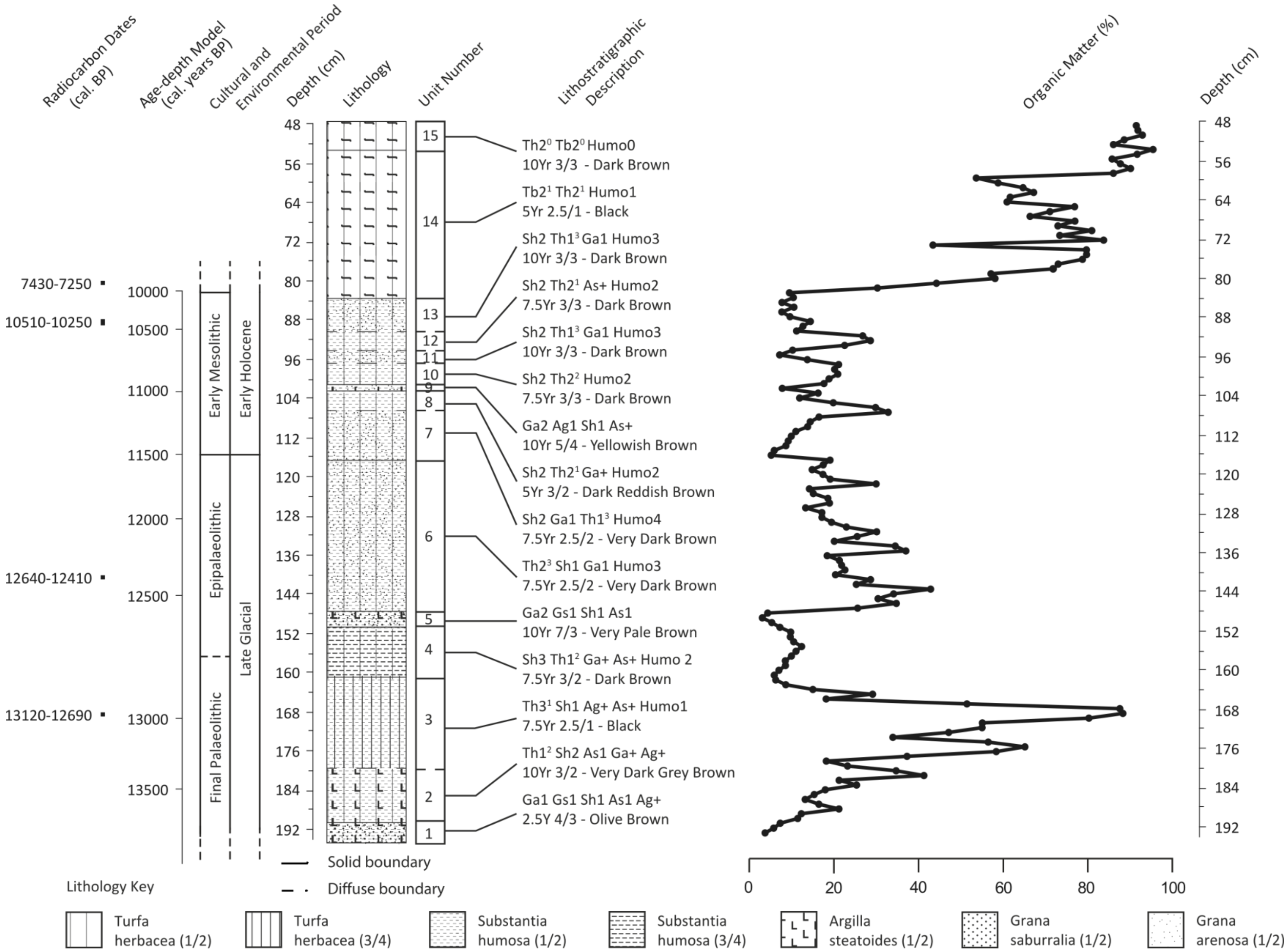


Figure 7.7. Core stratigraphy, organic matter and age model for the Thursley Bog core. Methodology for determining the lithostratigraphy, age-depth model and organic matter can be found in Chapter 5.

Lithostratigraphic analysis identified 15 separate units within the 195cm core. Organic matter was highly variable throughout the sequence, ranging from 1.5-94%. Unit 1 (195-191cm) identified the base of the sequence with both coarse and fine sands from the Lower Greensand. Throughout units 2 (191-180cm) and 3 (180-161cm), organic matter increased up to 87%, with an increase in herbaceous peat and a corresponding reduction in the clay component. Unit 4 (161-151cm) was organic, comprised primarily of *Substantia humosa* with a trace of sand and clay underlying unit 5 (151-148cm), a clearly defined sand band. Both units had a higher proportion of inorganic sediment and a corresponding drop in organic matter values to less than 10%. Units 6 (148-116cm), 7 (116-106cm) and 8 (106-102cm) were all sandy organic sediments with herbaceous peat. Units 6 and 8 had organic matter values of 20-40%, while unit 7 had a higher sand component with organic matter values of 3-15%. Another sand band was identified in unit 9 (102-101cm), alongside a drop in organic matter. Above this sand band, decomposed organic matter and herbaceous peat was dominant in units 10 (101-96cm), 11 (96-94cm), 12 (94-90cm) and 13 (90-81cm), with sand an additional component in units 11 and 13. These alternations correlated to the organic matter curve, which switched from higher to lower values (between 5% and 27%) across these units. Units 14 (81-52cm) and 15 (52-46cm) were highly organic, with organic matter values above 60%, and up to 94%. Moss and herbaceous peat was present in both these units, with unit 14 more humified than the overlying unit 15.

7.2.2. Ockley Bog

The Ockley Bog sequence had a total depth of 133cm (Figure 7.8), although no sediment was collected in the top 65cm because the peat was loose and unconsolidated. A sandy peat was identified in stratigraphic unit 1 (133-126cm) with low organic matter levels (11-14%), likely to be the layer immediately overlying the sands of the Lower Greensand that identifies the base of the sequence. Unit 2 (126-109cm) was an herbaceous peat with organic matter levels over 60%, and a trace of sand was still present throughout this unit. Organic matter then dropped to 4.8% in a small sand band (unit 3: 109-108cm). Organic sedimentation returned in unit 4 (108-104cm) and organic matter rose to nearly 40% until another sand band at 103-104cm, and corresponding drop in organic matter (unit 5: 104-103cm). A small increase in organic sedimentation (up to 10-15% organic matter) was observed in units 6 (103-94cm) and 7 (94-93cm) until another sand band at 92cm (unit 8: 93-92cm). Organic matter increased in unit 9 (92-84cm) from 5% to 90%. The herbaceous peat then continued to the top of the core in units 10 (84-76cm) and 11 (76-65cm). Data can be found in Appendix 13.13 and 13.14.

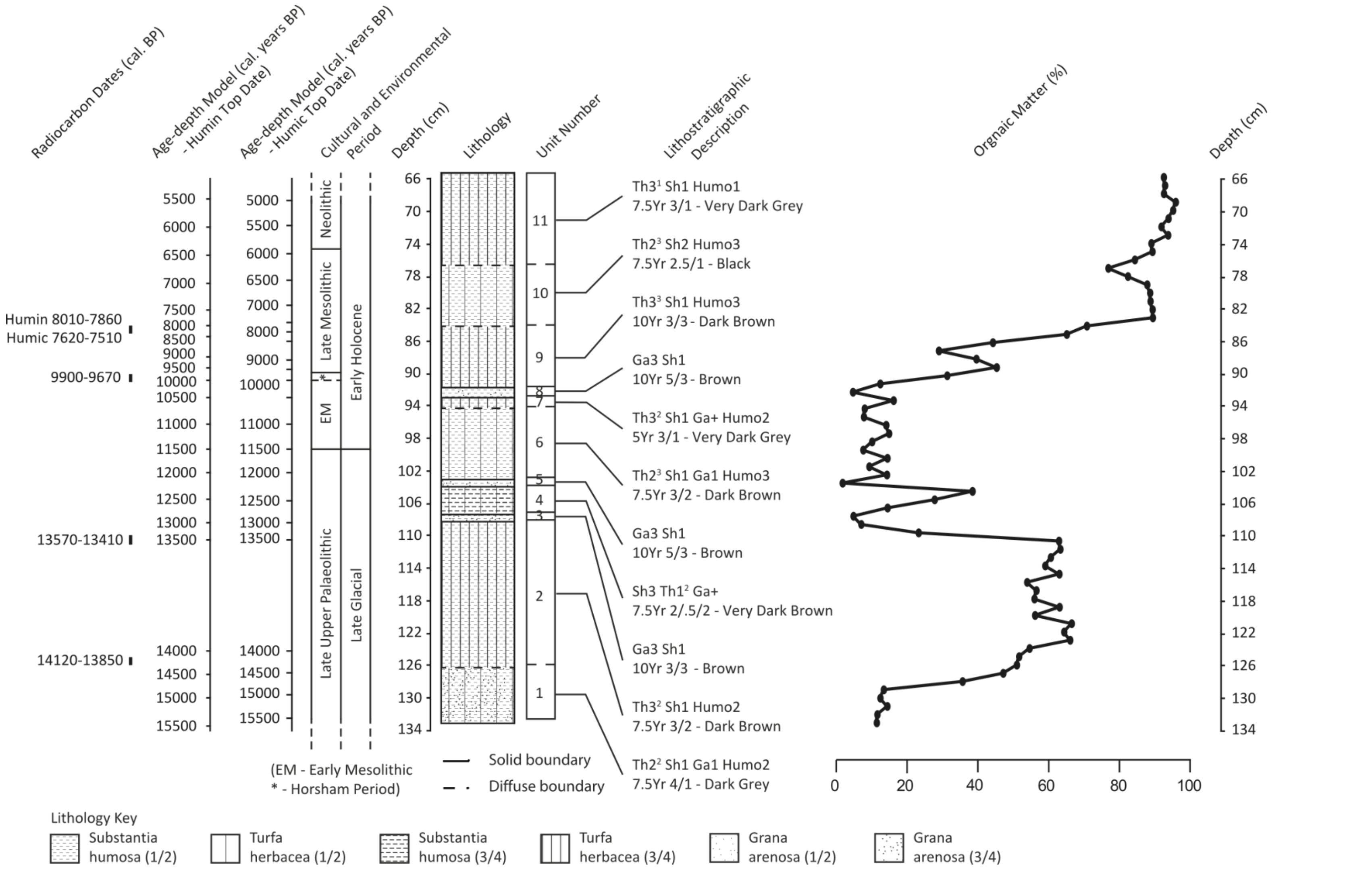


Figure 7.8. Core stratigraphy, organic matter and age model for the Ockley Bog core. Methodology for determining the lithostratigraphy, age-depth model and organic matter can be found in Chapter 5.

7.3. Results of the Radiocarbon Dating Programme

Four samples for radiocarbon dating were taken from the Thursley Bog core (Table 7.1), and another four samples were selected from the Ockley Bog core (Table 7.3). These samples were chosen based on important lithostratigraphic units and biostratigraphic zones. All of the dates were submitted as bulk peat samples due to a lack of macrofossil remains throughout the core sequences. Humic (alkali-soluble fraction) and humin (acid- and alkali-soluble fraction) fractions were analysed at each depth, and provided two dates for each depth analysed.

Ox Cal v4.2 was used (Ramsey, 2009b) alongside the INTCAL 13 atmospheric calibration curve (Reimer et al., 2013) to create an age-depth model using a P-sequence deposition model (Ramsey, 2008). Utilising a variable K (Ramsey and Lee, 2013) meant that a variable deposition rate was accounted for. A 95% confidence interval was used for both the model and calibrated dates.

7.3.1. Thursley Bog

The Thursley Bog results presented issues due to differences between the humic and humin dates measured at each depth that radiocarbon dates were taken, meaning a weighted mean could not be calculated (Table 7.1). A total lipid extract on sediment at the top and bottom of the core examined the cause for the large offset between the two dates and provided a breakdown of the compounds present in both fractions. Results showed that the humic fractions had a higher amount of total lipids, predominantly microbial lipids, potentially caused by in-washing of material of a different age. The concentrations of these microbial lipids were significantly lower in the humin fraction and so this fraction was used for the radiocarbon modelling. The wider offset in humic and humin dates observed at the top of the core correlated with a higher amount of total lipids.

Table 7.1. Results of the radiocarbon dating programme at Thursley Bog.

Lab. No.	Depth (cm)	Sample	Radiocarbon age (BP)	δ13C (‰)	Calibrated date – cal. BP (95% confidence)
SUERC-53804	80-81	Bulk peat (alkali- and acid-insoluble fraction)	6393±35	-34.0	7430-7250
SUERC-53803	80-81	Bulk peat (alkali-soluble fraction)	7449±35	-29.9	8370-8180
SUERC-53809	88-89	Bulk peat (alkali- and acid-insoluble fraction)	9211±35	-31.2	10,510-10,250
SUERC-53805	88-89	Bulk peat (alkali-soluble fraction)	9401±35	-30.3	10,730-10,520
SUERC-46130	140-141	Bulk peat (alkali- and acid-insoluble fraction)	10,566±50	-29.6	12,640-12,410
SUERC-46126	140-141	Bulk peat (alkali-soluble fraction)	11,079±50	-28.9	13,130-12,710
SUERC-46132	168-169	Bulk peat (alkali- and acid-insoluble fraction)	11,053±50	-29.0	13,120-12,690
SUERC-46131	168-169	Bulk peat (alkali-soluble fraction)	11,320±50	-29.0	13,330-13,100

Examination of the dates, the stratigraphy and the organic matter curve led to the suggestion that a hiatus was present within the sequence between 80-88cm. This was due to the 2000-3000 year gap between radiocarbon dates and the rapid increase in organic matter from lithostratigraphic unit 14. The model with this hiatus built in (placed at 81cm due to the unit change) provided an 'Amodel' value of 98 (Figure 7.9), suggesting the model was a good fit to the dates. The section above the hiatus was difficult to model as there was only one basal date at 80-81cm, and therefore the model could only be extrapolated above this point. Due to the error associated with this extrapolation, the model was re-run with this top section excluded (Figure 7.10) and best date estimates were gathered for important events observed in the Thursley Bog core below 81cm (Table 7.2).

The model showed that sedimentation started very early at Thursley Bog, with organic sediment identified prior to 13,500 cal. BP, and the base of the sequence potentially dated to ~14,600 cal. BP (194cm). An increase in organic sedimentation was identified, peaking at ~12,970 cal. BP (169cm), before declining by ~12,820 cal. BP (161cm). A period of increased mineral influx into the basin then lasted until ~12,640 cal. BP (150cm). Sandy peat accumulation then occurred until a large sand influx event at ~10,940 cal. BP (101cm), followed by further sandy peat accumulation until the hiatus at ~10,120 cal. BP (81cm).

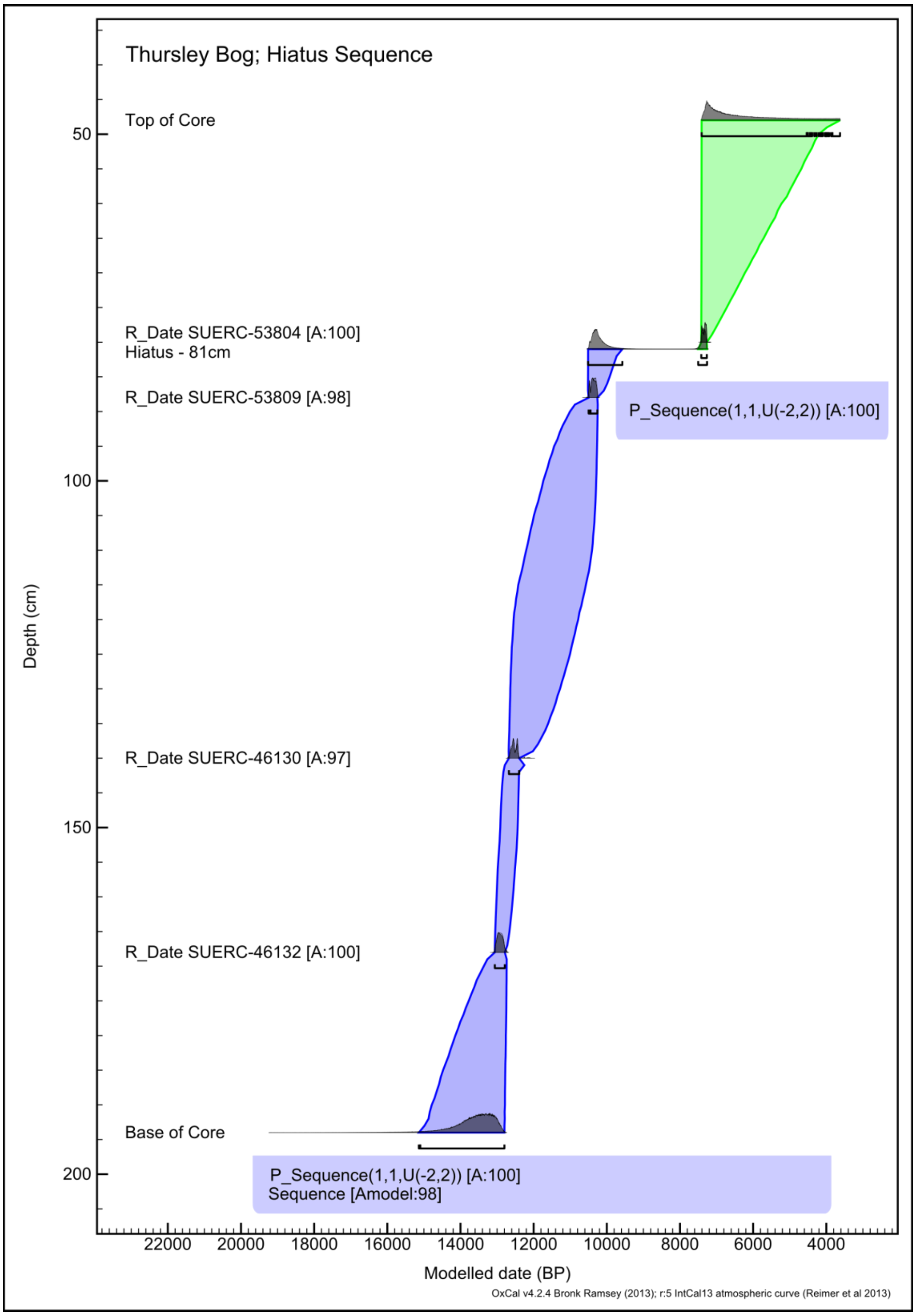


Figure 7.9. Thursley Bog modelled sequence including the potential hiatus at 81cm.

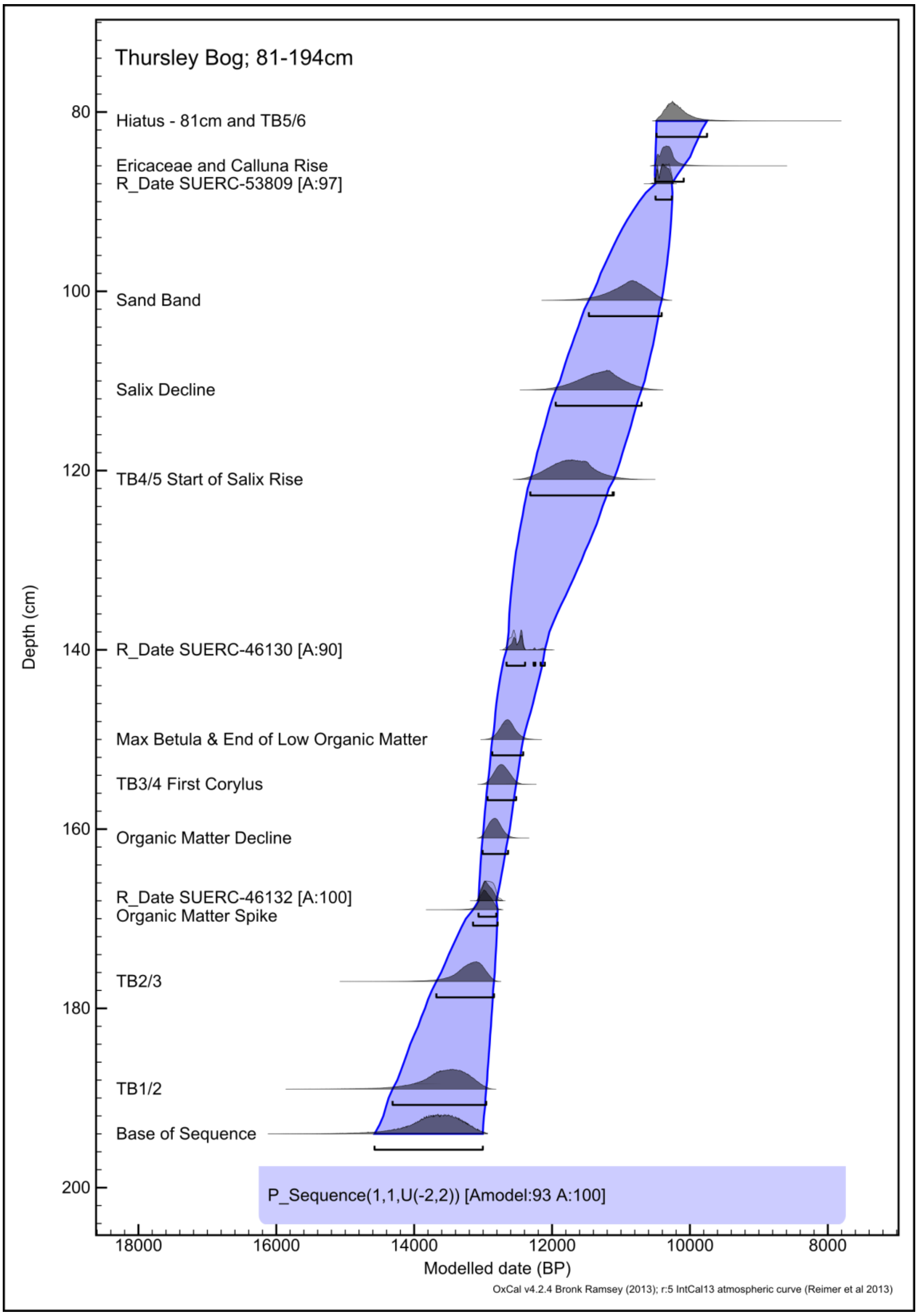


Figure 7.10. Modelled sequence of the Thursley Bog core from 81-195cm.

Table 7.2. Results from the Thursley Bog age-depth model.

Name	Unmodelled (BP)			Modelled (BP)			Midpoint (cal. BP)	Indices A_{model}=93.2 $A_{overall}$=93	
	from	to	%	from	to	%	Rounded	A	C
Boundary				10,484	9752	95.4	10,120		97.8
Ericaceae and *Calluna* Rise				10,505	10,090	95.4	10,300		99.7
R_Date SUERC-53809	10,493	10,255	95	10,499	10,262	95.4	10,380	96.9	99.7
Sand Band				11,466	10,410	95.4	10,940		99.4
Salix Decline				11,947	10,701	95.4	11,320		99.4
TB4/5 Start of *Salix* Rise				12,315	11,105	95.4	11,710		99.2
R_Date SUERC-46130	12,665	12,414	95	12,660	12,105	95.4	12,380	89.6	99.6
Max *Betula* End of Low Organic Matter				12,867	12,419	95.4	12,640		99.6
TB3/4 First *Corylus*				12,936	12,521	95.4	12,730		99.7
Organic Matter Decline				13,008	12,638	95.4	12,820		99.8
R_Date SUERC-46132	13,060	12,782	95	13,067	12,809	95.4	12,940	99.6	99.7
Organic Matter Spike				13,146	12,789	95.4	12,970		98.8
TB2/3				13,678	12,842	95.4	13,260		98.6
TB1/2				14,313	12,955	95.4	13,630		98.2
Boundary				14,575	13,004	95.4	13,790		95.3
P_Sequence1,1,U(-2,2)	*-2*	*2*	*95.4*	*-0.92695*	*0.00105*	*95.4*		*100*	*95*

7.3.2. Ockley Bog

At Ockley Bog, three of the dated depths provided a weighted mean (Ward and Wilson, 1978). The top date at 84-85cm did not provide a weighted mean as the humic and humin dates were over 400 years apart. The age-depth model was calculated twice for the sequence using both of the dates for the 84-85cm level. The pollen influx was calculated using only the humin top date as the difference in dates did not cause a significant difference to the influx results.

Table 7.3. Results of the radiocarbon dating programme at Ockley Bog.

Lab. No.	Depth (cm)	Sample	Radiocarbon age (BP)	δ13C (‰)	Calibrated date – cal. BP (95% confidence)
UBA-28782	84-85	Bulk peat (humic/alkali-soluble fraction)	6708±31	−28.0	7620–7510
UBA-28783	84-85	Bulk peat (humin/alkali- and acid-insoluble fraction)	7122±38	−29.3	8010–7860
	84-85	*(T'=71.9, T'(5%)=3.8, v=1; Ward and Wilson 1978)*			
SUERC-59087	90-91	Bulk peat (alkali-soluble fraction)	8785±29	−28.9	
SUERC-59088	90-91	Bulk peat (alkali- and acid-insoluble fraction)	8742±29	−29.6	
Weighted mean	*90-91*	*(T'=9.6, T'(5%)=3.8, v=1; Ward and Wilson 1978)*	*8764±21*		*9900–9670*
UBA-28784	110-111	Bulk peat (alkali-soluble fraction)	11,750±51	−28.2	
UBA-28785	110-111	Bulk peat (alkali- and acid-insoluble fraction)	11,526±52	−29.4	
Weighted mean	*110-111*	*T'=9.5, T'(5%)=3.8, v=1; Ward and Wilson 1978)*	*11,643±37*		*13,570–13,410*
SUERC-59092	125-126	Bulk peat (alkali-soluble fraction)	12,112±31	−29.1	
SUERC-59093	125-126	Bulk peat (alkali- and acid-insoluble fraction)	12,111±31	−29	
Weighted mean	*125-126*	*(T'=6.1, T'(5%)=3.8, v=1; Ward and Wilson 1978).*	*12,112±22*		*14,120–13,850*

The Ockley Bog model provided dates for a number of key events observed within the core (Figure 7.11). The two models did not differ significantly, as shown in the results (Table 7.4 and Table 7.5). Both models offered satisfactory 'Amodel' values of 102, which suggested both were a good fit for the data. The model indicates that the sediments at the base of the sequence dated to between 16,830-13,980 cal. BP (132cm) with some organic sedimentation, although the organic matter in the sequence did not rise until ~14,000 cal. BP (125cm). The organic matter remained high with consistent peat accumulation until ~13,480 cal. BP (110cm). Two sand bands at ~12,890 cal. BP (108cm) and ~12,130 cal. BP (103cm) were followed by a period of peat accumulation until ~10,360 cal. BP (92cm) when another sand band was identified. Organic matter rose from ~9780 cal. BP (90cm) and continued through the Early Holocene.

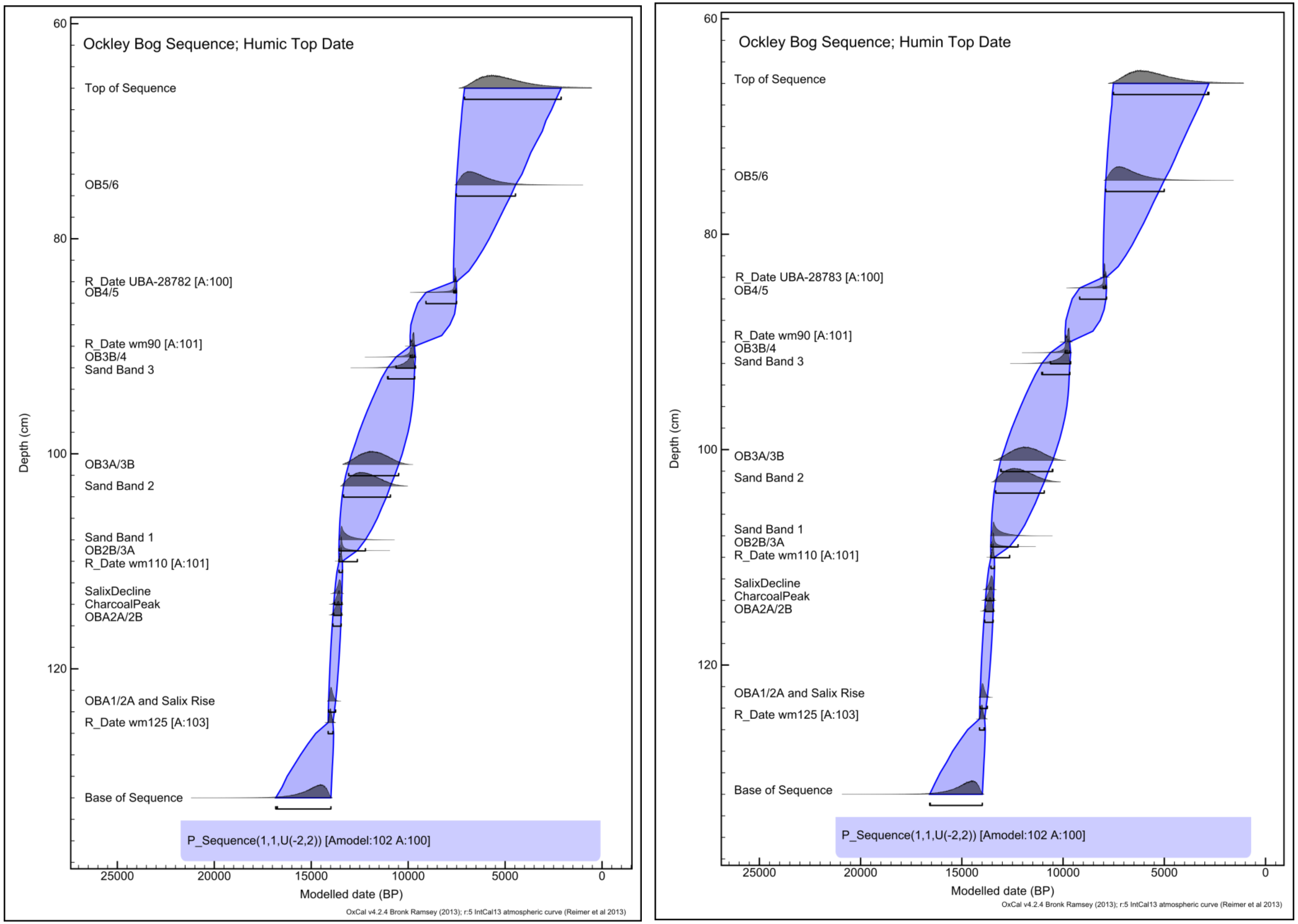


Figure 7.11. The two models run on the Ockley Bog sequence.

Table 7.4. Humic model results on the Ockley Bog sequence.

Name	Unmodelled (BP)			Modelled (BP)			Midpoint (cal. BP)	Indices A	
								A_{model}=102.1	
								$A_{overall}$=102	
	from	to	%	from	to	%	Rounded	A	C
Boundary				7092	2109	95.4	4600		96.1
OB5/6				7514	4463	95.4	5990		98.9
R_Date UBA-28782	7651	7508	95.4	7653	7509	95.3	7580	99.6	99.8
OB4/5				9082	7500	95.4	8290		98.9
R_Date wm90	9894	9673	95.4	9893	9671	95.4	9780	101	99.7
OB3/4				10,623	9625	95.4	10,120		99.1
Sand Band 3				11,061	9663	95.4	10,360		97.8
OB3A/3B				13,070	10,490	95.4	11,780		97.6
Sand Band 2				13,331	10,915	95.4	12,120		98.3
Sand Band 1				13,560	12,203	95.4	12,880		98.9
OB2B/3A				13,574	12,621	95.4	13,100		99.5
R_Date wm110	13,569	13,406	95	13,565	13,393	95.4	13,480	101	99.9
Salix Decline				13,794	13,418	95.4	13,600		99.5
Charcoal Peak				13,839	13,435	95.4	13,640		99.2
OB2A/2B				13,880	13,452	95.3	13,670		99
OB1/2A and *Salix* Rise				14,103	13,740	95.4	13,920		99.7
R_Date wm125	14,107	13,845	95	14,127	13,881	95.4	14,000	103	99.8
Boundary				16,832	13,984	95.4	15,410		96.9
P_Sequence1,1,U(-2,2)	*-2*	*2*	*95.4*	*-0.6091*	*-0.3011*	95.4		*100*	*99.5*

Table 7.5. Humin model results on the Ockley Bog sequence.

Name	Unmodelled (BP)			Modelled (BP)			Midpoint (cal. BP)	Indices	
								A_{model}=102.3	
								$A_{overall}$=102.3	
	from	to	%	from	to	%	Rounded	A	C
Boundary				7512	2800	95.4	5160		95.7
OB5/6				7892	5004	95.4	6450		99
R_Date UBA-28783	8015	7862	95.4	8015	7865	95.3	7940	100	99.8
OB4/5				9183	7855	95.4	8520		98.7
R_Date wm90	9894	9673	95.4	9893	9671	95.4	9780	101	99.6
OB3/4				10,621	9627	95.4	10,120		99.2
Sand Band 3				11,053	9665	95.4	10,360		98.1
OB3A/3B				13,084	10,510	95.4	11,800		97.8
Sand Band 2				13,327	10,930	95.4	12,130		98.7
Sand Band 1				13,558	12,225	95.4	12,890		98.1
OB2B/3A				13,573	12,642	95.4	13,110		99.3
R_Date wm110	13,569	13,406	95	13,565	13,392	95.4	13,480	101	99.8
Salix Decline				13,795	13,421	95.4	13,610		99.5
Charcoal Peak				13,836	13,437	95.4	13,640		99.1
OB2A/2B				13,874	13,454	95.3	13,660		98.8
OB1/2A and *Salix* Rise				14,104	13,742	95.4	13,920		99.7
R_Date wm125	14,107	13,845	95	14,127	13,875	95.4	14,000	103	99.8
Boundary				16,590	13,989	95.4	15,290		97.0
P_Sequence1,1,U(-2,2)	*-2*	*2*	*95.4*	*-0.6091*	*-0.2811*	95.4		*100*	*99.6*

7.4. Results of the Pollen Stratigraphical Analysis

Pollen samples were taken at 2cm intervals throughout both cores to provide a high resolution palaeovegetation record for the two sites. Results were tabulated and transformed into pollen percentage and influx diagrams. Raw pollen count data can be found in Appendix 13.15 (Thursley Bog) and Appendix 13.16 (Ockley Bog).

7.4.1. Thursley Bog

The Thursley Bog pollen percentage results (Figure 7.12 - Figure 7.14) were divided into seven pollen zones and subsequently described (Table 7.6). Due to the lack of a robust age-depth model above 82cm, the influx data was only calculated below 82cm and zones 6 and 7 were not represented on the influx diagram (Figure 7.15 - Figure 7.17).

Zone TB-1 spanned from bog formation at ~13,790 cal. BP to ~13,630 cal. BP (194-189cm); *Betula* was the dominant arboreal taxa, alongside high amounts of Cyperaceae and Poaceae. Charcoal indicated burning in the environment. TB-2 spanned from the end of TB-1 until ~13,260 cal. BP (189-177cm) and indicated an increase in *Betula*. *Salix* and *Pinus* were also present. Herbaceous taxa were dominated by Cyperaceae and there was a decline in Poaceae. *Betula* continued to rise in TB-3 until ~12,730 cal. BP (177-155cm); *Salix*, *Carpinus*, and *Juniperus* were all present. An influx of *Pinus* indicates that this was also a significant component of the local woodland. Cyperaceae, Poaceae, *Potentilla* and *Artemisia* were the dominant herbaceous species, although both *Potentilla* and *Artemisia* were underrepresented in the percentage data compared to the influx data. Both the influx and percentage of charcoal increased. Between ~12,730 to ~11,710 cal. BP, in zone TB-4 (155-121cm), *Betula* declined rapidly but remained the main arboreal taxa, alongside *Corylus* and *Salix*. Herbaceous taxa included Cyperaceae, Poaceae and *Artemisia*. TB-5 dated to between ~11,710-10,120 cal. BP (121-81cm) and was characterised by the continued presence of *Betula* alongside decreasing *Salix*. Influx data indicates both *Pinus* and *Corylus* expand gradually throughout the zone. Dominant herbaceous taxa were similar to TB-4 with Cyperaceae, Poaceae and *Artemisia*. In TB-6 (81-63cm) *Pinus* and *Quercus* increased, *Betula*, *Alnus* and *Corylus* were all also present. Poaceae was the major herbaceous taxa, with a rapid decline in Cyperaceae. An increase was observed in *Sphagnum* and Filicales. TB-7 (63-48cm) was characterised by a range of tree and shrub taxa, including *Betula, Pinus, Quercus, Corylus* and *Calluna.* Poaceae was the dominant herbaceous taxon.

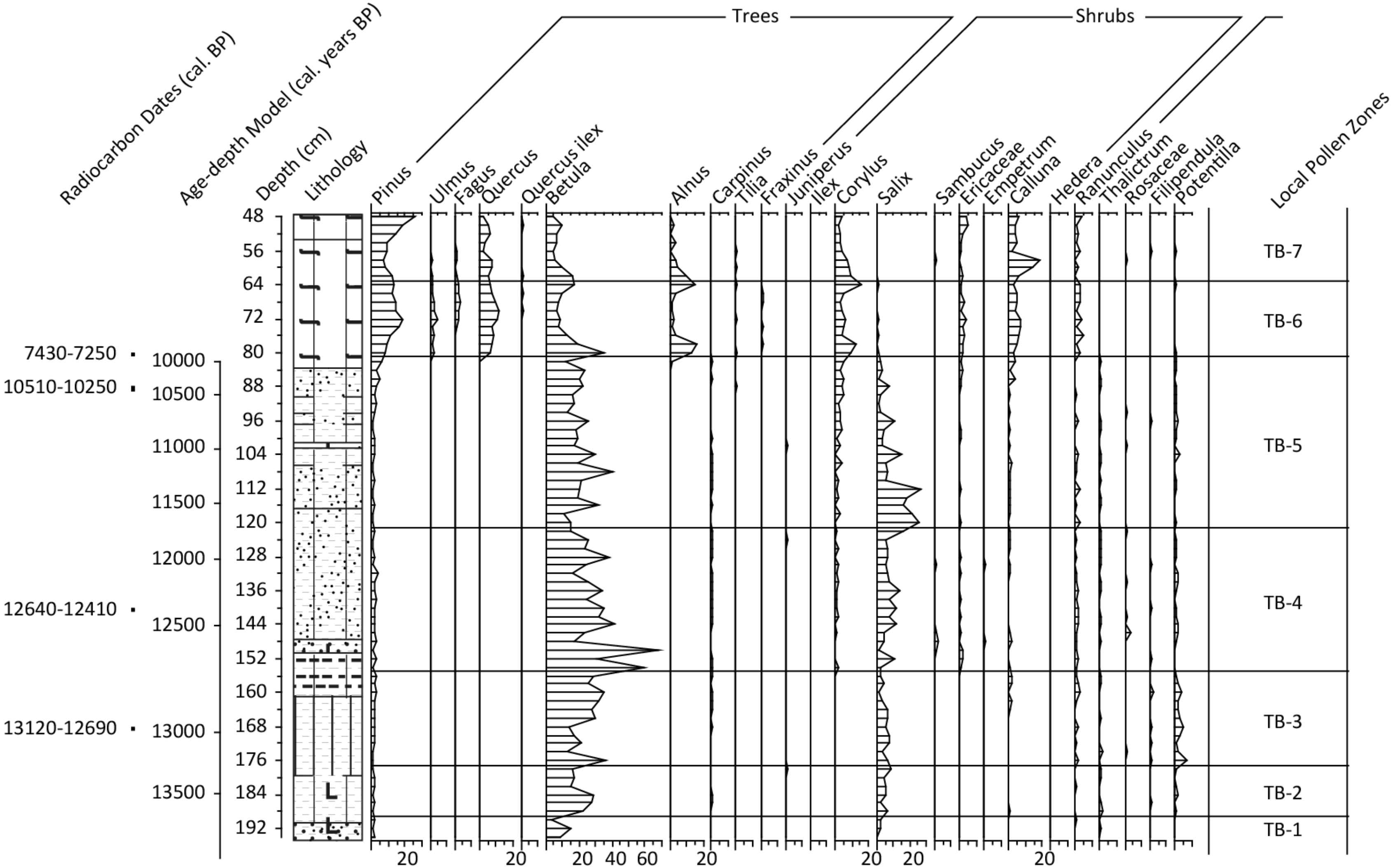


Figure 7.12. Percentage pollen diagram from Thursley Bog (part 1)

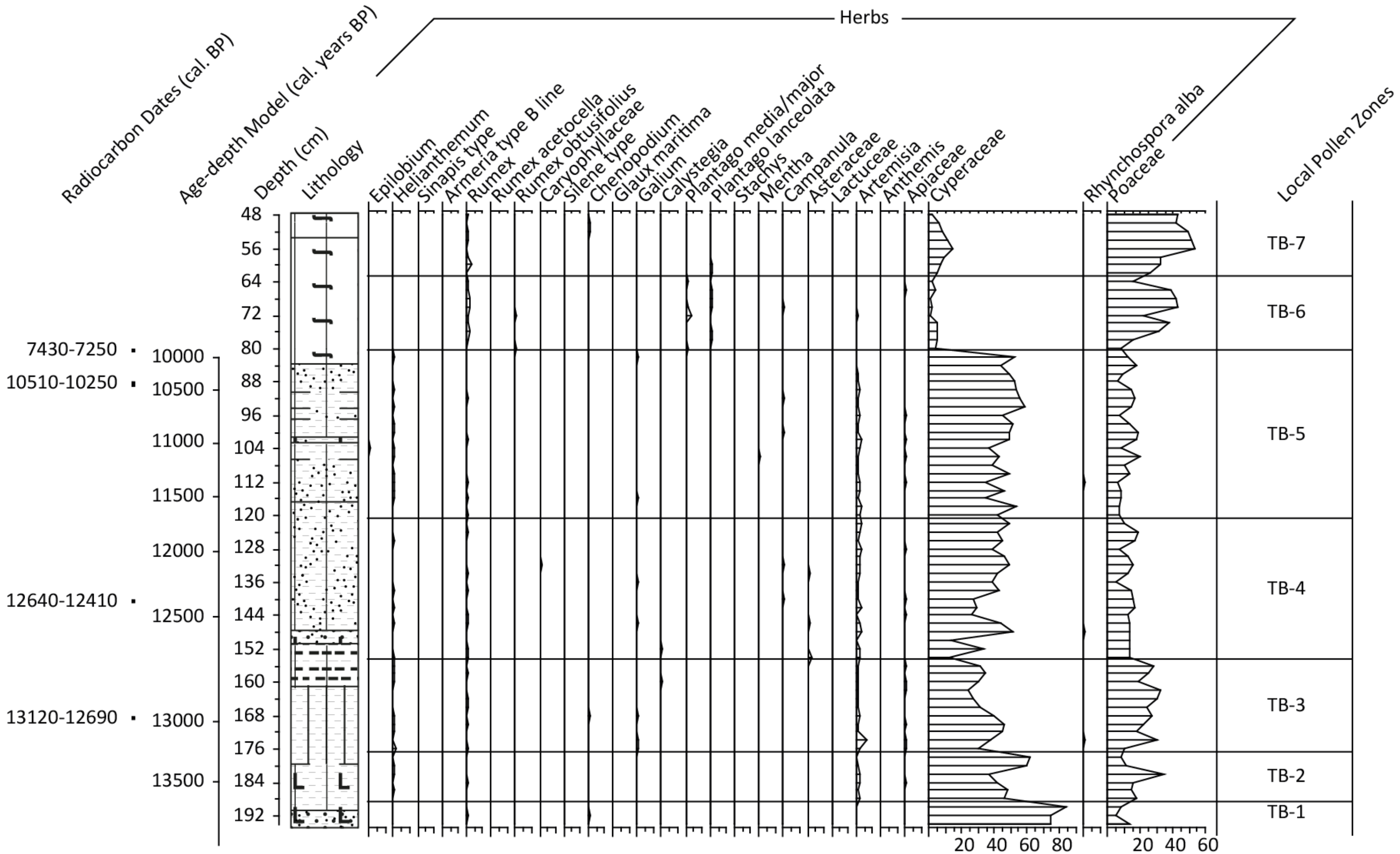


Figure 7.13. Percentage pollen diagram from Thursley Bog (part 2).

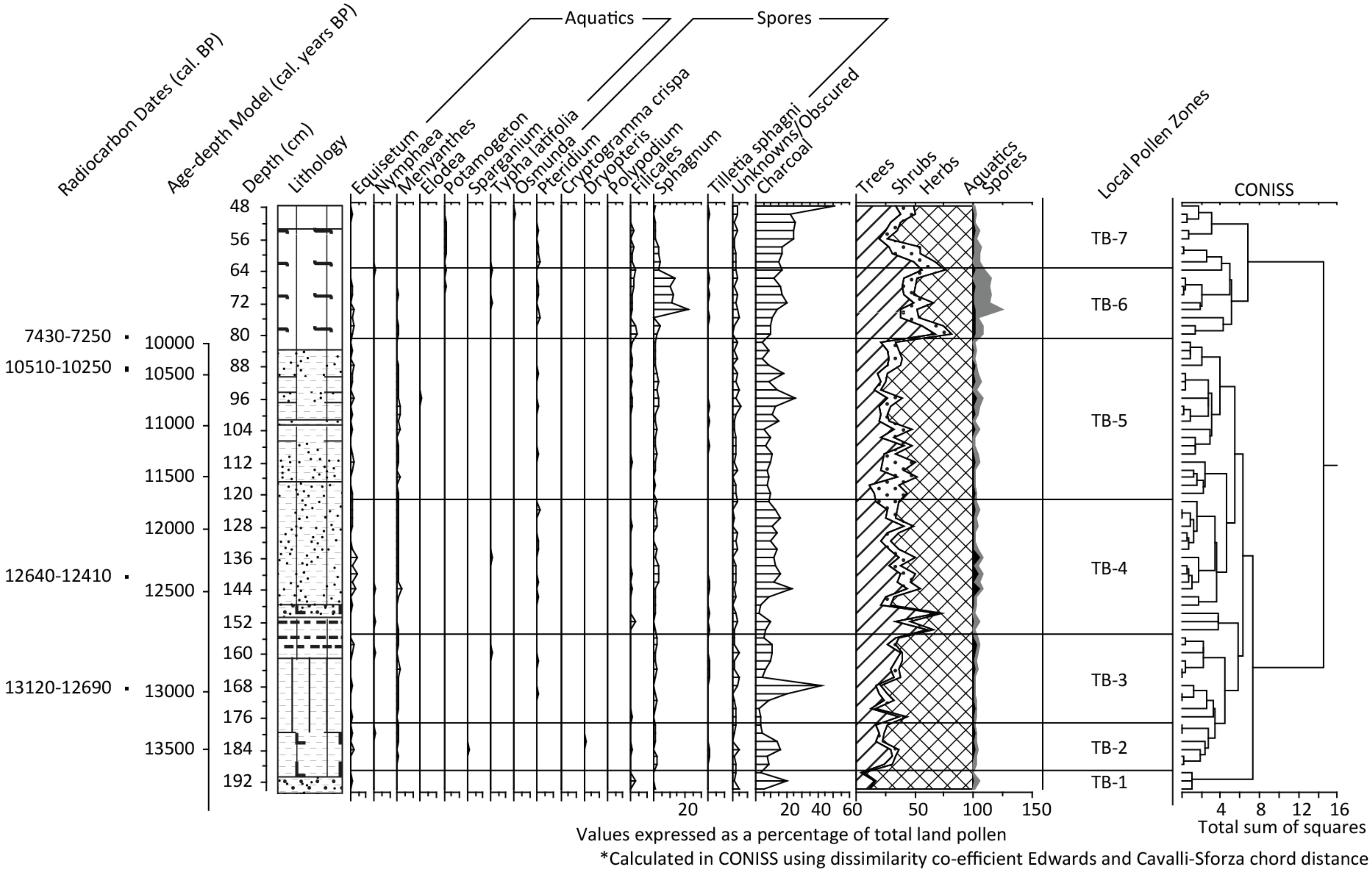


Figure 7.14. Percentage pollen diagram from Thursley Bog (part 3).

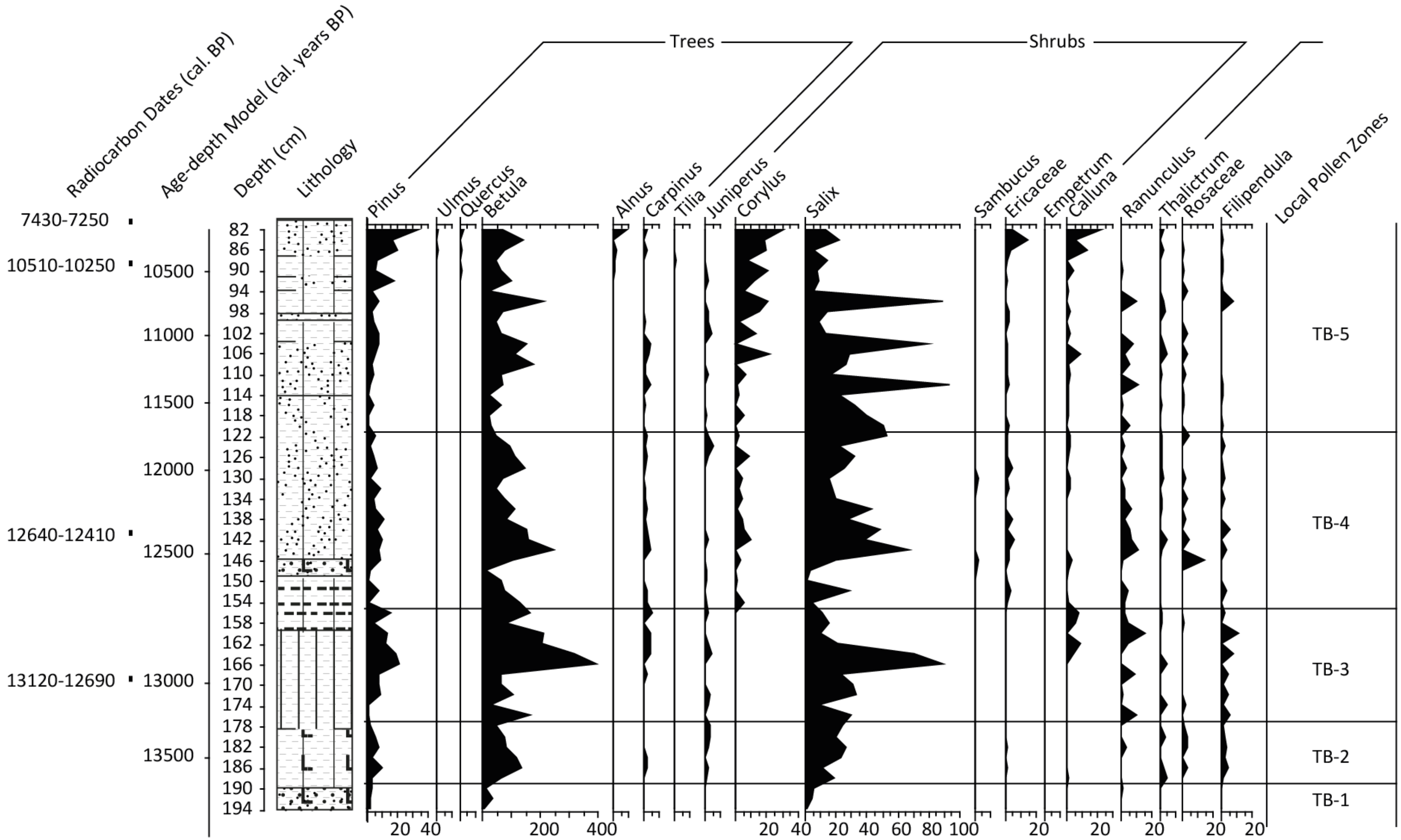


Figure 7.15. Pollen influx diagram for Thursley Bog (part 1).

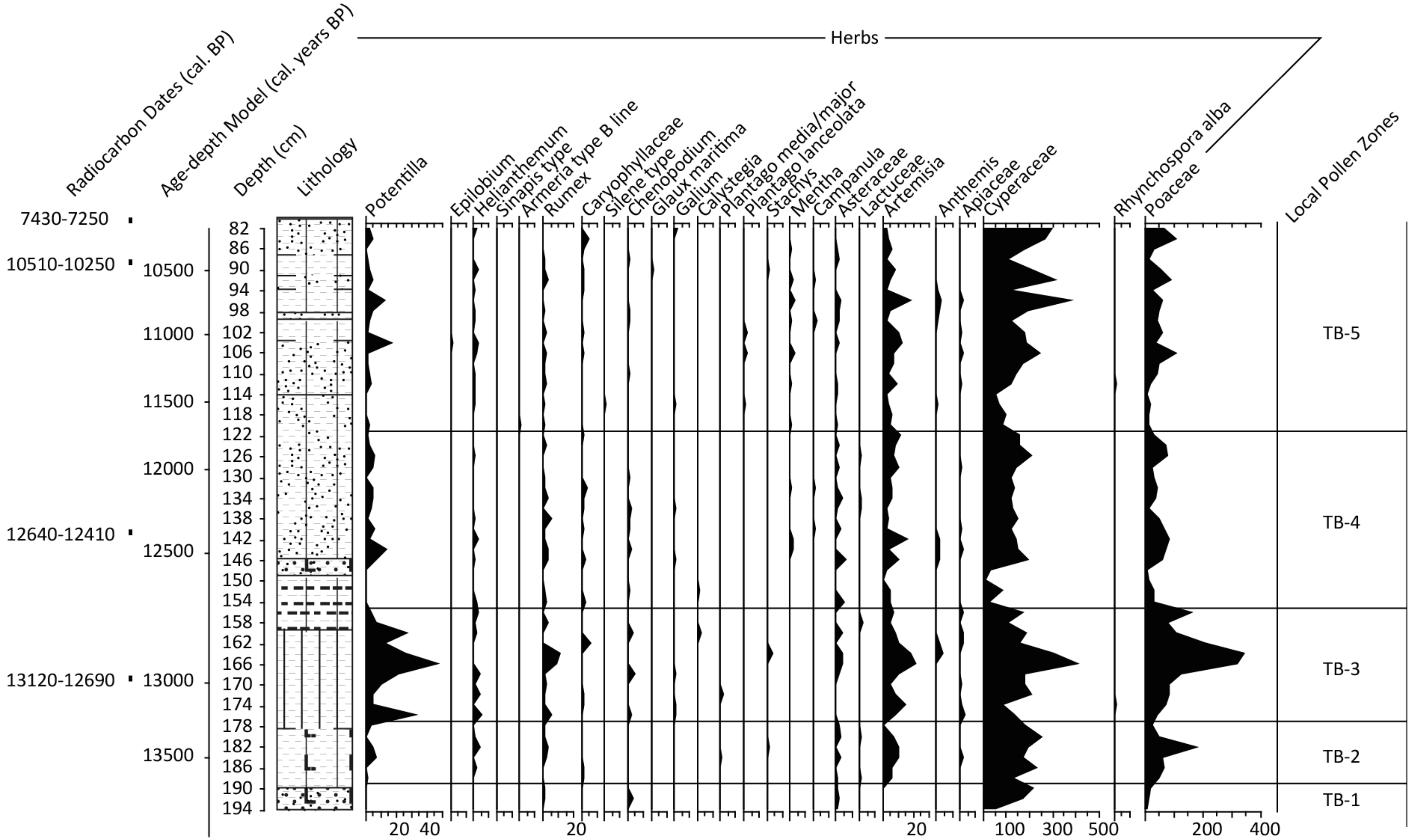


Figure 7.16. Pollen influx diagram for Thursley Bog (part 2).

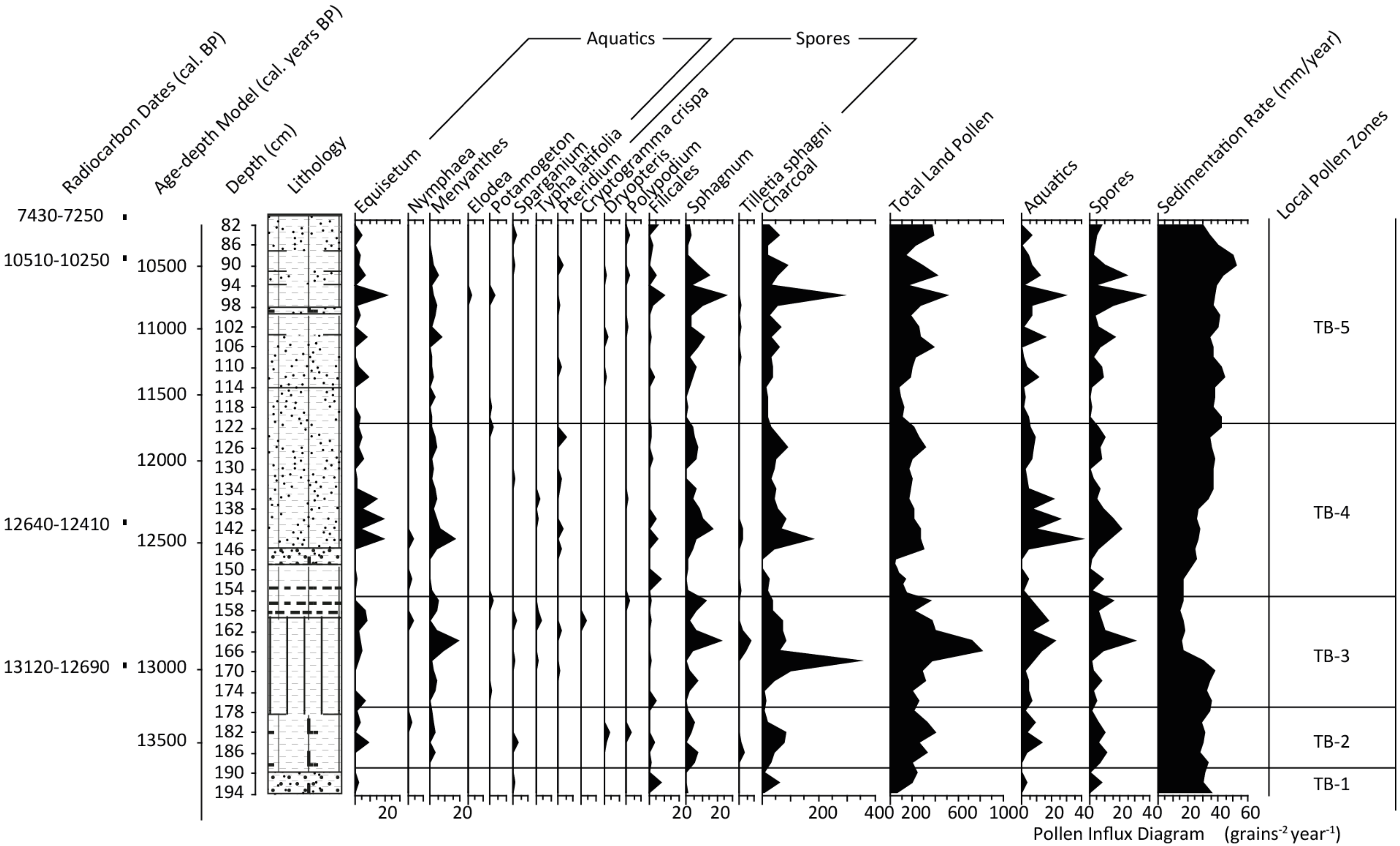


Figure 7.17. Pollen influx diagram for Thursley Bog (part 3).

Table 7.6. Descriptions of the seven Thursley Bog pollen zones.

Depth (cm)	**Pollen Zone**	**Vegetation**
48-63	TB-7	*Pinus* – *Calluna* – Cyperaceae *Pinus* increased to a maximum of 20%. *Alnus* declined from 15% to almost 0% and both *Ulmus* and *Fagus* declined to 0%. *Betula* dropped to a constant 10% from a peak of 20%. *Calluna* increased to 15% before stabilising at between 5-10%. *Ranunculus* and *Rumex* were present in low quantities. Cyperaceae increased slightly to 15% before declining to 0%. Poaceae continued to increase from 25% to almost 55%. *Sphagnum* decreased to 0% and no other aquatics or spores were present in any quantity. Charcoal increased from 20% up to 55% at the end of the zone.
63-81	TB-6	*Pinus* – Deciduous trees – Cyperaceae *Pinus* increased to ~20% and *Quercus* increased up to 10%. *Betula* declined from a peak of 35% to 10%. *Corylus* dropped from 15% to 7%, then increased to 15%. *Alnus* increased to 15% before falling to almost 0%, then increased to 10% by the end of the zone. Increases up to 5% were also observed in *Ulmus*, *Fagus*, Ericaceae, *Calluna*, *Ranunculus* and *Rumex*. Cyperaceae declined immediately from 55% to 5%. Poaceae rose from 15% to 35-40%. A sharp increase in *Sphagnum* was observed to ~20%, then dropped off to 5%, and *Filicales* was present in low amounts. Charcoal increased from 10 to 20%.
81-121	TB-5	*Corylus* – *Betula* – Cyperaceae *Betula* remained constant at ~20% with varying influx values of between 50-150 grains cm^{-2} $year^{-1}$. *Salix* initially started high at over 20% but declined to almost 0% by the end of the zone. Influx varied from peaks of 90 grains cm^{-2} $year^{-1}$ to 10 grains cm^{-2} $year^{-1}$. *Pinus* increased across the zone, and reached a maximum of just below 10%. Influx values also steadily increased up to 40 grains cm^{-2} $year^{-1}$. *Corylus* increased to 5% and influx increased to 30 grains cm^{-2} $year^{-1}$. *Artemisia* declined to 0% across the zone. Cyperaceae remained fairly stable around 45-50% with a fluctuating influx of between 50-300 grains cm^{-2} $year^{-1}$. Poaceae remained relatively constant between 10-20%, with influx values of 50-100 grains cm^{-2} $year^{-1}$. Charcoal influx was stable at 50 grains cm^{-2} $year^{-1}$ and percentage values remained constant at 10-20%, apart from a peak of 250+ grains cm^{-2} $year^{-1}$ at 96cm. Sedimentation rate fluctuated between 35-45mm per year. Total land pollen influx fluctuated from increased across the zone from 196 grains cm^{-2} $year^{-1}$ to 800 grains cm^{-2} $year^{-1}$ and increased overall.

Depth (cm)	Pollen Zone	Vegetation
121-155	TB-4	Cyperaceae – *Betula* – *Salix* *Betula* declined from a peak of ~70% to <20%. Influx varied from 0 to 200 grains cm^{-2} $year^{-1}$. *Salix* increased from <5% up to 15% and influx was variable, ranging from 0 to 70 grains cm^{-2} $year^{-1}$. *Pinus* percentage cover remained low (<3%) and its influx dropped to <10 grains cm^{-2} $year^{-1}$. *Corylus* was identified with an influx of ~10 grains cm^{-2} $year^{-1}$. *Artemisia* was present at low levels (<3%). Cyperaceae slowly increased from 30% to 45% with an influx of ~150 grains cm^{-2} $year^{-1}$. Poaceae remained constant between 10-20% with influx values of ~50 grains cm^{-2} $year^{-1}$. Charcoal rose to 15% with an average influx of 50-100 grains cm^{-2} $year^{-1}$. The sedimentation rate rose from 15 to 35mm per year and total land pollen values rise from a low of 68 grains cm^{-2} $year^{-1}$ to a relatively stable >250 grains cm^{-2} $year^{-1}$, prior to declining slightly at the end of the zone.
155-177	TB-3	*Betula* – *Salix* – Herbaceous Taxa *Betula* rose slowly from 20% to 30% with a spike in influx values of nearly 400 grains cm^{-2} $year^{-1}$. A similar spike in *Salix* (5%) was also observed (90 grains cm^{-2} $year^{-1}$). A small increase in *Pinus* influx (but not percentage cover) was recorded (from 1 to 21 grains cm^{-2} $year^{-1}$). *Carpinus* and *Juniperus* are present. Cyperaceae declined from 40% to 30% with a spike in influx of 400 grains cm^{-2} $year^{-1}$ against a background of 200 grains cm^{-2} $year^{-1}$. Poaceae remained stable at 25-30% with an influx spike of 350 grains cm^{-2} $year^{-1}$. *Ranunculus*, *Filipendula*, *Thalictrum*, *Potentilla Rumex* and *Artemisia* were present (<5%). *Potentilla* had the highest influx value of these species at >40 grains cm^{-2} $year^{-1}$, against a background of higher influx values for all of these species. A spike in charcoal percentages to 50% was observed, correlating with increased influx values of 350 grains cm^{-2} $year^{-1}$. Sedimentation declined from 30 to 15mm per year, and a sharp increase in the total land pollen influx (up to 1308 grains cm^{-2} $year^{-1}$) was recorded, prior to falling to ~200 grains cm^{-2} $year^{-1}$.

Depth (cm)	Pollen Zone	Vegetation
177-189	TB-2	*Betula* – *Salix* – Cyperaceae *Betula* levels increased from 5% to 30% before dropping off to 15%. Influx values rose to 170 grains cm^{-2} $year^{-1}$. *Salix* had a constant presence at 5%, with a rising influx rate from 15 to 30 grains cm^{-2} $year^{-1}$. Cyperaceae values rose to 60% from 40% at the start of the zone, influx values remained stable at 200 grains cm^{-2} $year^{-1}$. An increase in Poaceae to 30% was short lived and it declined to 10%. *Pinus* values remained low at <5%, with influx values of 10 grains cm^{-2} $year^{-1}$. Increases in percentage and influx values were observed in *Potentilla*, *Helianthemum*, *Rumex* and *Artemisia*. A small increase in charcoal (percentage increase to 15%, influx up to 100 grains cm^{-2} $year^{-1}$) was observed before declining. Total land pollen influx continued to rise from 274 to >500 grains cm^{-2} $year^{-1}$ alongside a stable sedimentation rate of ~30mm per year.
189-194	TB-1	*Betula* – Cyperaceae – Poaceae Cyperaceae was dominant, reaching a maximum of 85% with an influx of 200 grains cm^{-2} $year^{-1}$. The rest of the assemblage was comprised of Poaceae (5-10%) and *Betula* (10-15%), although influx values of both were low. A small influx in *Pinus* and *Salix* was observed, but their levels were low (<5%). Charcoal was present (20%). Total land pollen influx increased in this zone from 73 to >250 grains cm^{-2} $year^{-1}$, whilst the sedimentation rate remained stable.

7.4.2. Ockley Bog

The Ockley Bog pollen percentage diagrams (Figure 7.18 - Figure 7.20) and pollen influx diagrams (Figure 7.21 - Figure 7.23) were divided into six zones (with two sub-zones) and subsequently described (Table 7.7).

From the base of the sequence until ~13,920 cal. BP in OB-1 (133-123cm), *Betula*, and *Pinus* were the dominant trees, and *Juniperus* and *Salix* the dominant shrub taxa. Cyperaceae and Poaceae were the herbaceous taxa recorded. In OB-2a, spanning ~13,920-13,660 cal. BP (123-115cm) an increase in *Betula* was recorded, predominantly in the influx records but corroborated with the percentage data. *Corylus* and *Salix* both increased, although the influx of *Corylus* remains low. Cyperaceae declined rapidly although its influx increased and Poaceae was present. In OB-2b (115-109cm), *Betula* and *Corylus* increased and *Salix* declined. A number of increases were observed in herbaceous taxa including Cyperaceae, Poaceae, *Potentilla*, Rosaceae and *Artemisia*, particularly recorded in the influx data and charcoal also increased. *Betula* and *Corylus* were dominant species in OB-3a, dating from

~13,110 cal. BP (109-101cm). Ericaceae and *Pinus* were also present. Herbaceous taxa included Cyperaceae, Poaceae and Artemisia. *Sphagnum* increased rapidly before declining. In OB-3b (101-91cm), dated to between ~11,800-10,120 cal. BP, *Salix* increased and declines were observed in *Betula* and *Corylus*. Cyperaceae, Poaceae and *Artemisia* were still the dominant herbaceous taxa. In OB-4 (91-85cm), *Pinus*, *Corylus* and *Betula* were the dominant tree and shrub species. Cyperaceae and Poaceae represented the herbaceous taxa. A small increase in *Sphagnum* is also recorded. In OB-5 (dating from ~8520 cal. BP, 85-75cm), *Pinus, Ulmus, Quercus, Alnus, Corylus* and *Calluna* represent the tree and shrub signal. Increases in the influx of all these species are observed. A sharp decline in Cyperaceae and slight percentage increase in Poaceae is recorded, alongside a large increase in influx. *Sphagnum* and Charcoal both increase. In OB-6, from ~6450 cal. BP (75-66cm) *Quercus* and *Calluna* increased, alongside *Ulmus, Pinus, Alnus* and *Betula* and a decline in *Corylus*. Poaceae was the dominant herbaceous taxa.

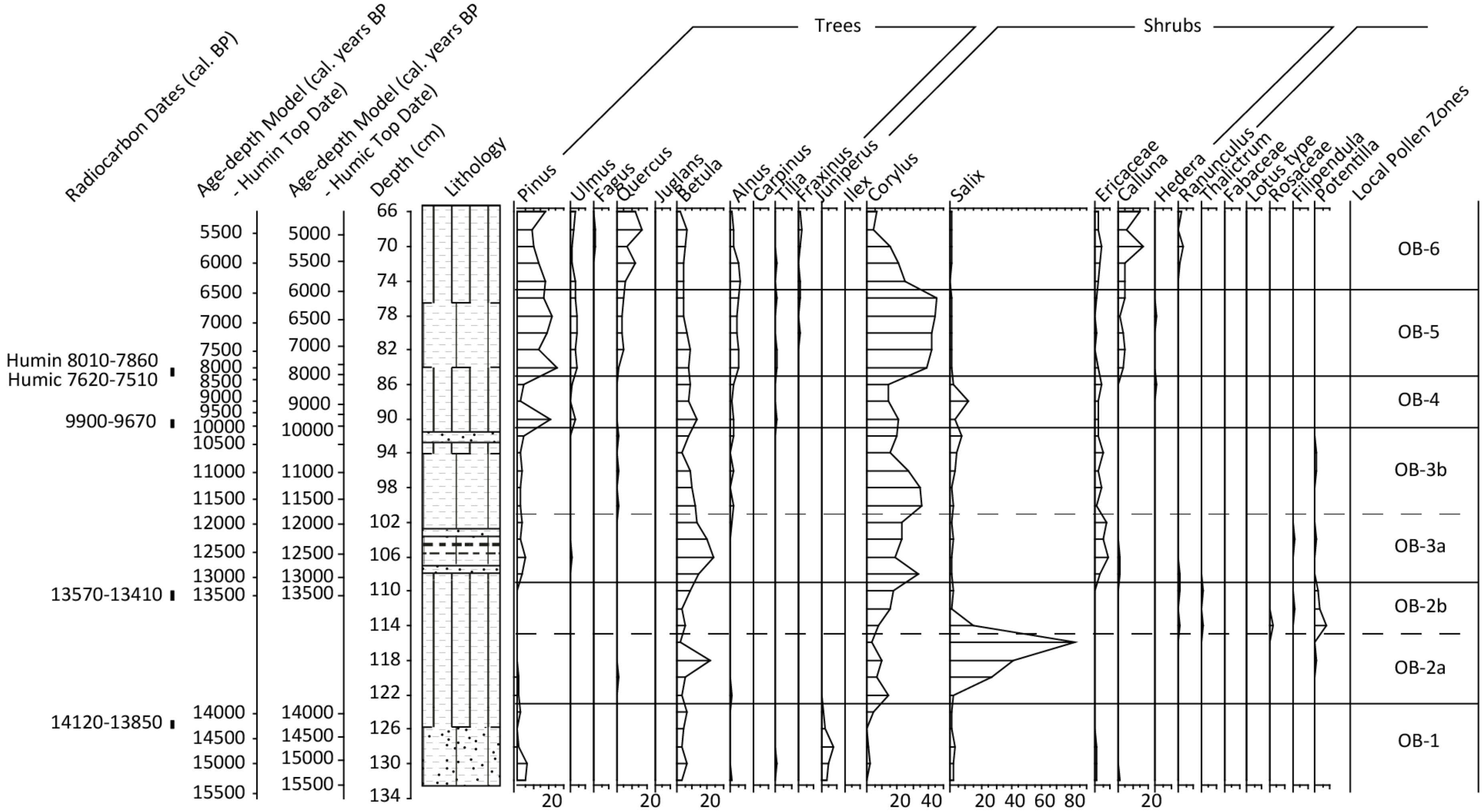


Figure 7.18. Percentage pollen diagram for Ockley Bog (part 1).

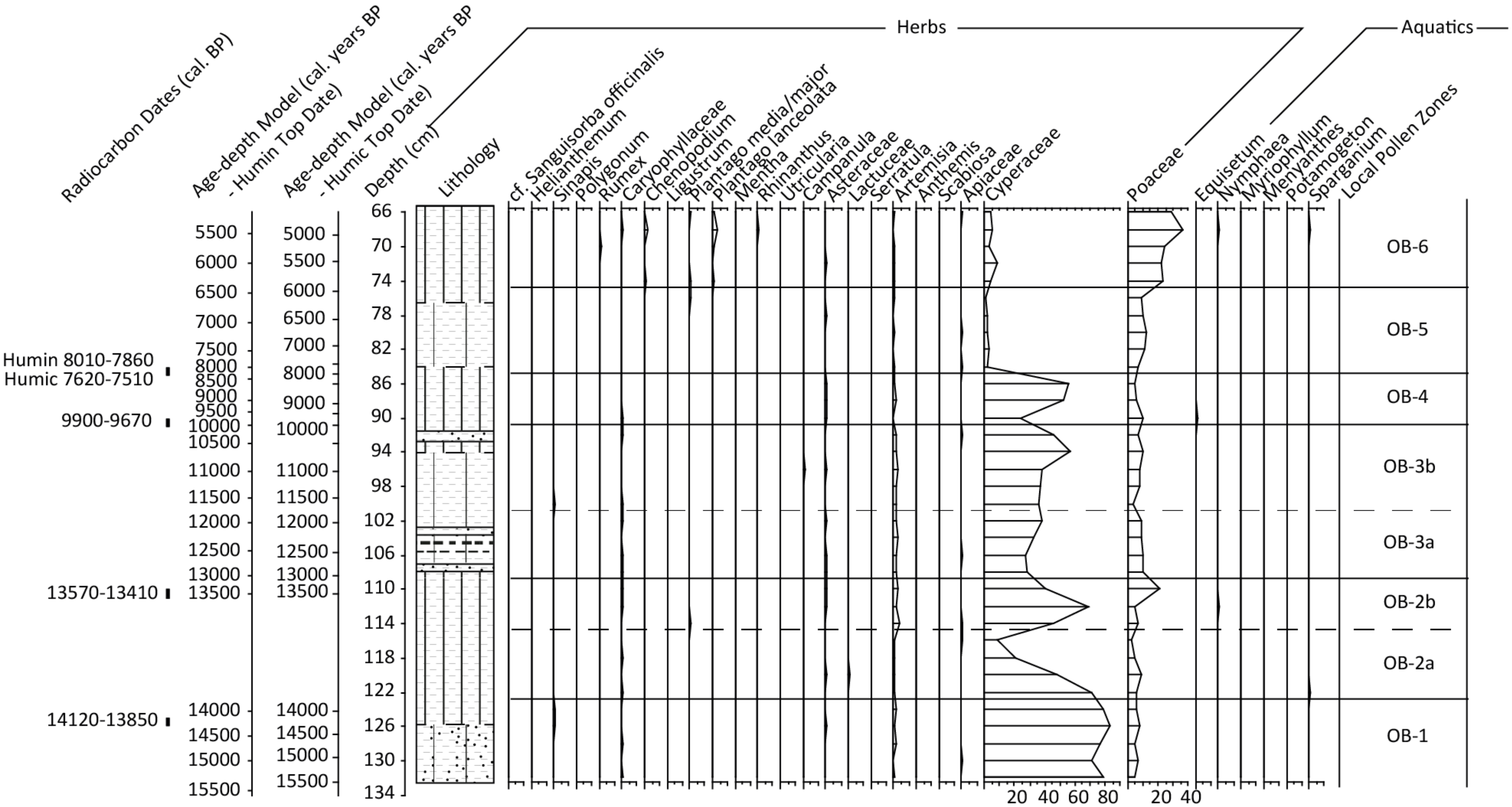


Figure 7.19. Percentage pollen diagram for Ockley Bog (part 2).

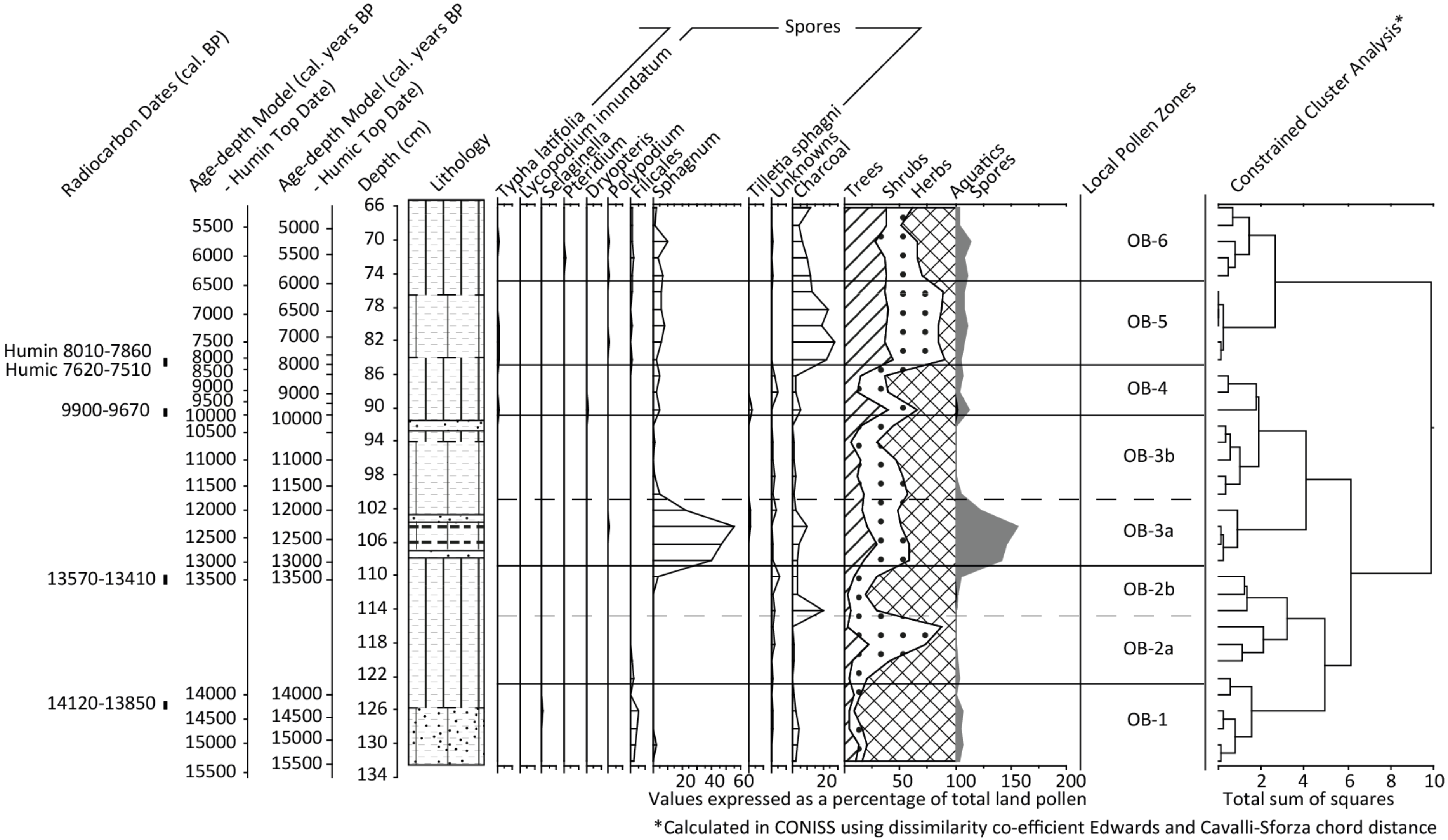


Figure 7.20. Percentage pollen diagram for Ockley Bog (part 3).

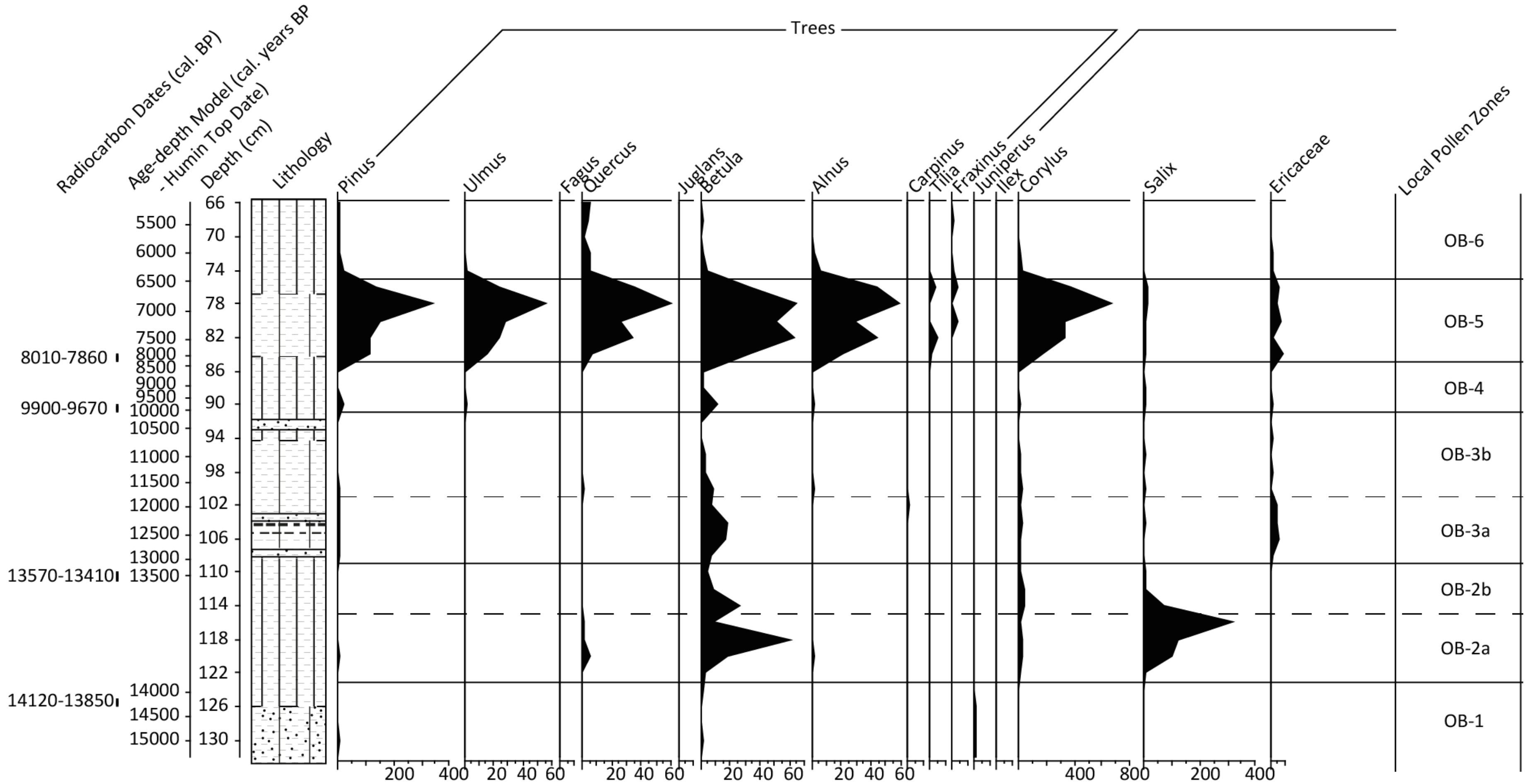


Figure 7.21. Pollen influx diagram for Ockley Bog (part 1).

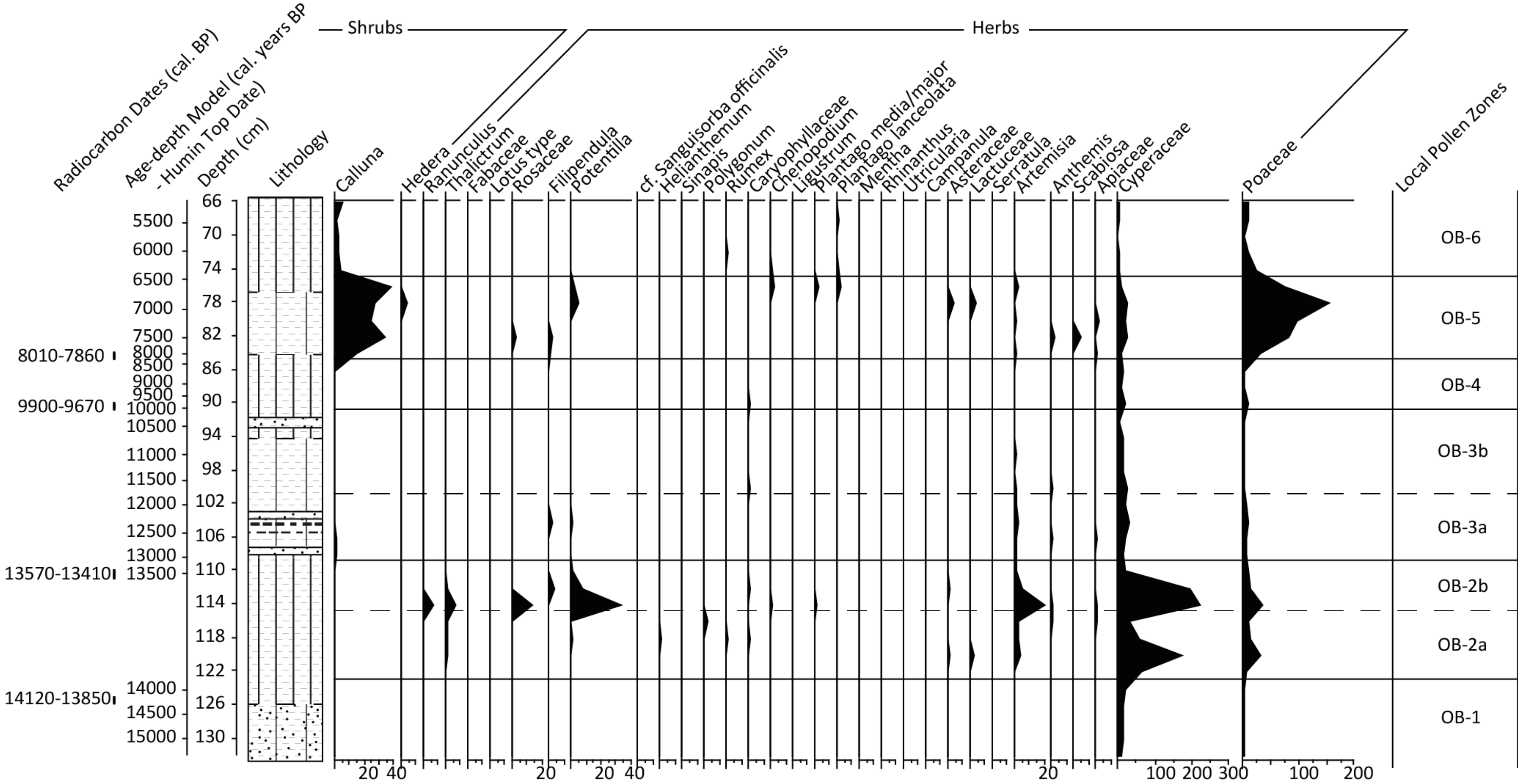


Figure 7.22. Pollen influx diagram for Ockley Bog (part 2).

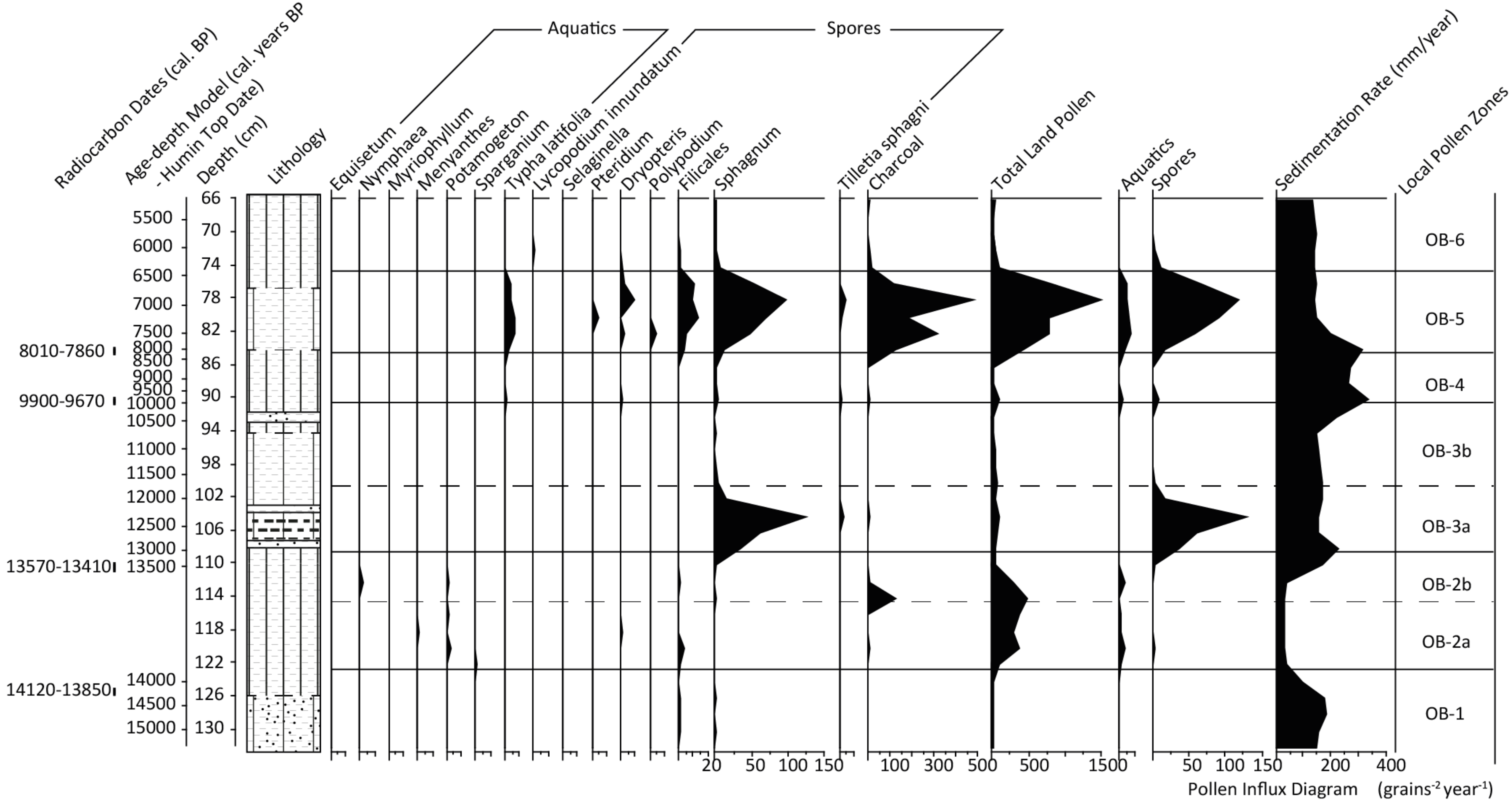


Figure 7.23. Pollen influx diagram for Ockley Bog (part 3).

Table 7.7. Description of the six Ockley Bog pollen zones.

Depth (cm)	Pollen Zone	Vegetation
66-75	OB-6	*Quercus* – Poaceae – *Calluna* *Quercus* pollen increased from 5% to 15%, alongside a comparatively high *Quercus* influx of 3-4 grains cm^{-2} $year^{-1}$. *Ulmus*, *Betula* and *Alnus* all present between 5% and 10%. *Corylus* declined rapidly from 40% to 5%. *Calluna* rose from 5% to 15%. *Pinus* remained stable across the zone at 15%. *Quercus*, Poaceae and *Calluna* accounted for the majority of land pollen influx at this time, which had fallen to ~15-100 grains cm^{-2} $year^{-1}$. Poaceae increased to a maximum of 35%. *Sphagnum* values remained high although the influx was low. Charcoal declined but was still present at 10%. The sedimentation rate was stable at ~150mm per year.
75-85	OB-5	*Corylus* – *Pinus* – Charcoal *Corylus* increased to 40% and remained constant across the zone. *Pinus* rapidly increased to 20% and remained stable. *Ulmus*, *Quercus*, *Betula* and *Alnus* were all stable at 5%-10%. *Calluna* remains constant at 5%. Poaceae increased from 7% to 15%. Alongside stable pollen percentages, rapid influx increases were observed in all of these species (*Pinus* from 0 to 339 grains cm^{-2} $year^{-1}$, *Corylus* from 3 to 669 grains cm^{-2} $year^{-1}$, *Ulmus* from 0 to 55 grains cm^{-2} $year^{-1}$, *Quercus* from 0 to 60 grains cm^{-2} $year^{-1}$, *Betula* from 1 to 64 grains cm^{-2} $year^{-1}$, *Alnus* from 0 to 60 grains cm^{-2} $year^{-1}$ and *Calluna* from 0 to 37 grains cm^{-2} $year^{-1}$), alongside a large increase in total land pollen, with total influx ~1500 grains cm^{-2} $year^{-1}$. Small influxes are also observed in a number of herbaceous taxa, including *Potentilla*, Asteraceae and Lactuceae. Cyperaceae values declined from 60% to <5% at the start of the zone and did not recover. *Sphagnum* levels increased to 10% and an increase in the influx of spores and aquatic pollen was also observed. A large increase in charcoal was observed and remained high.
85-91	OB-4	Cyperaceae – *Corylus* – *Salix* *Pinus* values peaked at 20%, then declined to 5% and then started to increase again. *Ulmus* was observed in low quantities (<5%). *Betula* remained constant across the zone at 10% and a small increase in influx was observed to 11 grains cm^{-2} $year^{-1}$. *Alnus* began to increase to 5%, *Corylus* remained stable (20%) and a small increase was observed in *Salix* to 10%. Cyperaceae values increased to 60%, although the influx remained stable at 10-20 grains cm^{-2} $year^{-1}$. Poaceae values were stable but low at <10%. A small increase in *Sphagnum* was observed of up to 5%. Total influx values were relatively low, increasing to 90 grains cm^{-2} $year^{-1}$ with the increase in *Betula*, although the sedimentation rate was high (over 300mm per annum). A small increase in charcoal was observed.

Depth (cm)	Pollen Zone	Vegetation
91-101	OB-3b	*Betula* – *Corylus* – Cyperaceae *Betula* declined from 15% to 5-10%. *Pinus* values remained low at < 5%. *Corylus* declined from a high of 35% to 20%. *Salix* began to increase, reaching 10% by the end of the zone. Ericaceae was present at ~5%. Cyperaceae remained relatively stable at between 40-60% and influx remained low. Poaceae was constantly present at 10%. Low levels of *Artemisia* were the only other herbaceous taxa, reaching ~5%. Influx values were low and stable across the zone at >40 grains cm^{-2} $year^{-1}$. The sedimentation rate peaked towards the end of the zone from 175mm to ~325mm per year.
101-109	OB-3a	*Betula* – *Corylus* – Cyperaceae – *Sphagnum* *Betula* peaked at 25%, and *Corylus* was also present between 20-30%. Ericaceae appeared and rose to 10%. *Pinus* accounted for 5% of the overall cover. *Artemisia* was still present but at low levels. Cyperaceae remained constant at ~40% with a very low influx of only ~25 grains cm^{-2} $year^{-1}$. Poaceae fell but remains between 10-15%. Influx values for all land pollen remained stable apart from *Betula*, which increased in the middle of the zone, and it was the main taxa contributing to the total land pollen influx. A large increase was observed in *Sphagnum* (from 0 to 125%), which rapidly declined before the end of the zone. The sedimentation rate was high at >175mm per year and constant across the zone, and total land pollen influx remained consistently low at ~50-90 grains cm^{-2} $year^{-1}$. The charcoal observed in zone 2b continued to the end of this zone.
109-115	OB-2b	*Betula* – *Salix* – Herbaceous Taxa *Salix* decreased rapidly in both percentage and influx from its peak of 80% to a minimum of ~1%. *Betula* increased from 5% to 15%, although an overall decrease in the influx of *Betula* pollen was observed. An increase in *Corylus* (5 to 20%) was not replicated within the influx data, which remains very low. Increases in the influx of a number of herbaceous taxa were noted, including *Potentilla, Artemisia, Ranunculus, Thalictrum* and Rosaceae, alongside very small increases in their pollen percentage cover. Poaceae increased across the zone (max 20%), with a decrease in the influx of Poaceae pollen. Cyperaceae increased from a minimum of 15% to a peak of 60%, until it declined to 40%, also observed in the influx data. The sedimentation rate increased rapidly from less than 50 to over 200 mm per year. A small increase in charcoal is identified. Total land pollen declined across this zone to 50 grains cm^{-2} $year^{-1}$.

Depth (cm)	Pollen Zone	Vegetation
115-123	OB-2a	*Salix* – Cyperaceae – *Betula* *Salix* increased rapidly in this zone from ~0% to over 80% and the influx of *Salix* pollen also rapidly increased to 300 grains cm^{-2} $year^{-1}$. A small increase in *Betula* (from 5% to 20%) was observed and matched with an increase in influx from 5 to 60 grains cm^{-2} $year^{-1}$. *Corylus* (10%) was the only other widespread taxon present at this time. Cyperaceae declined rapidly, (max 70%, min 10%) although Cyperaceae influx increased briefly during this decline. The total land pollen influx increased from ~20 grains cm^{-2} $year^{-1}$ to 480 grains cm^{-2} $year^{-1}$ and the sedimentation rate was low at <50mm per year.
123-132	OB-1	Cyperaceae – *Juniperus* – *Betula* Cyperaceae was the dominant taxa in this zone, consistently between 70-80%, although the overall influx of Cyperaceae in this zone was fairly low (~25 grains cm^{-2} $year^{-1}$). Both *Betula* and *Juniperus* were present in low amounts (between 5% and 10%) and both *Salix* and *Pinus* were also present. Total land pollen influx was very low during this period at <30 grains cm^{-2} $year^{-1}$. The sedimentation rate declined through this period from 150mm per year to 50mm per year.

7.5. Interpretation

7.5.1. Sedimentary History and Bog Development

Organic sedimentation occurred very early across Thursley Common, and was centred on two main depositional basins: Thursley Bog and Ockley Bog. These are likely to have been small hollows in a gently undulating sandy landscape within which organic sediment accumulated (Figure 7.24 and Figure 7.25). The two records appear to have developed as initially separate basins at a similar time to each other, and based on the age modelling, do not appear to have grown and coalesced into one bog until the Mid-Holocene, post 7300 cal. BP after the hiatus at Thursley Bog. This potentially highlights interesting implications for the use of the landscape and potential mobility by Late Upper Palaeolithic and Mesolithic groups. Although they were two separate basins during the Late Glacial and Early Holocene, their proximity facilitates interpretation of both bogs simultaneously.

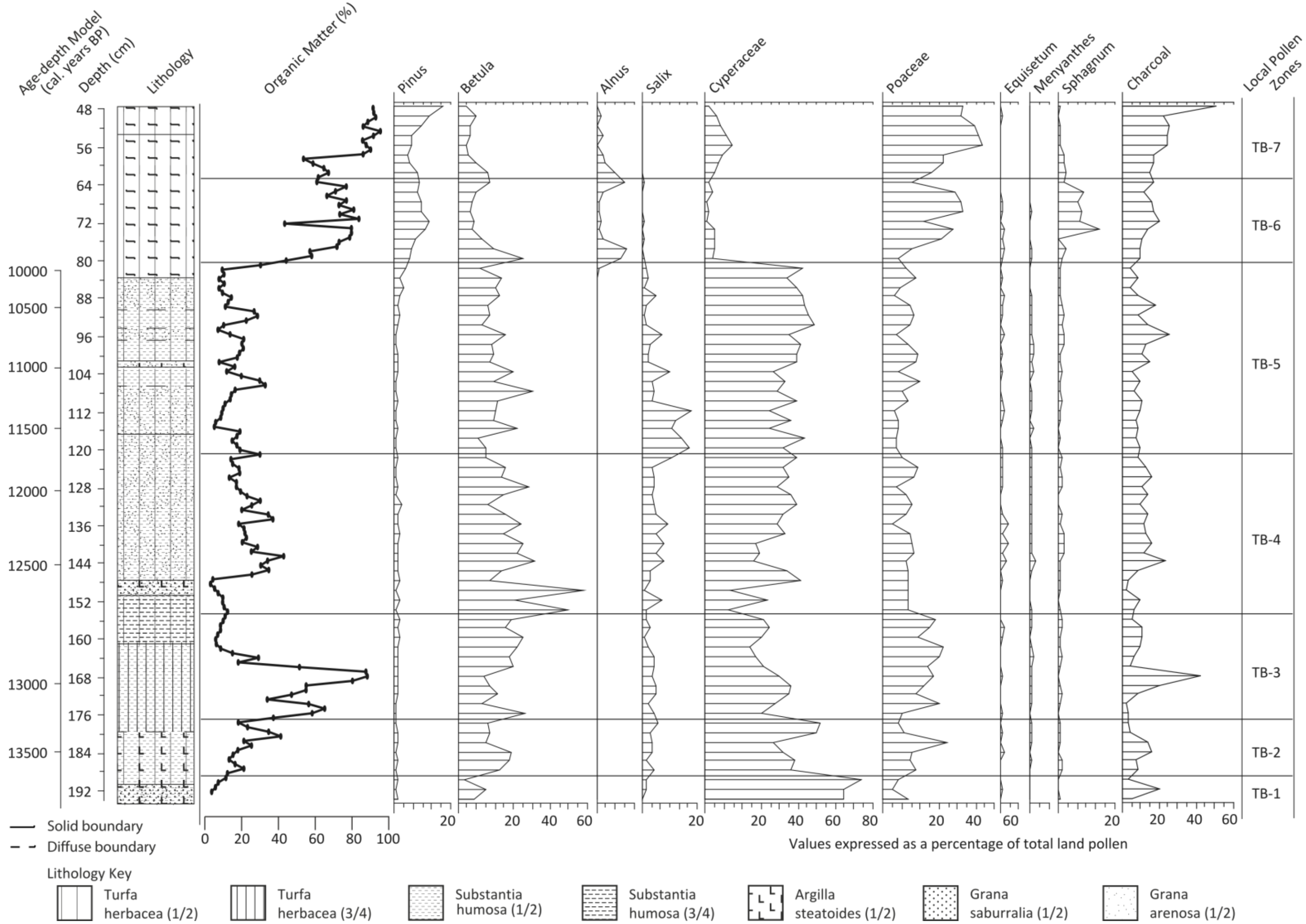


Figure 7.24. Age-depth model, lithostratigraphy and selected taxa diagram of Thursley Bog.

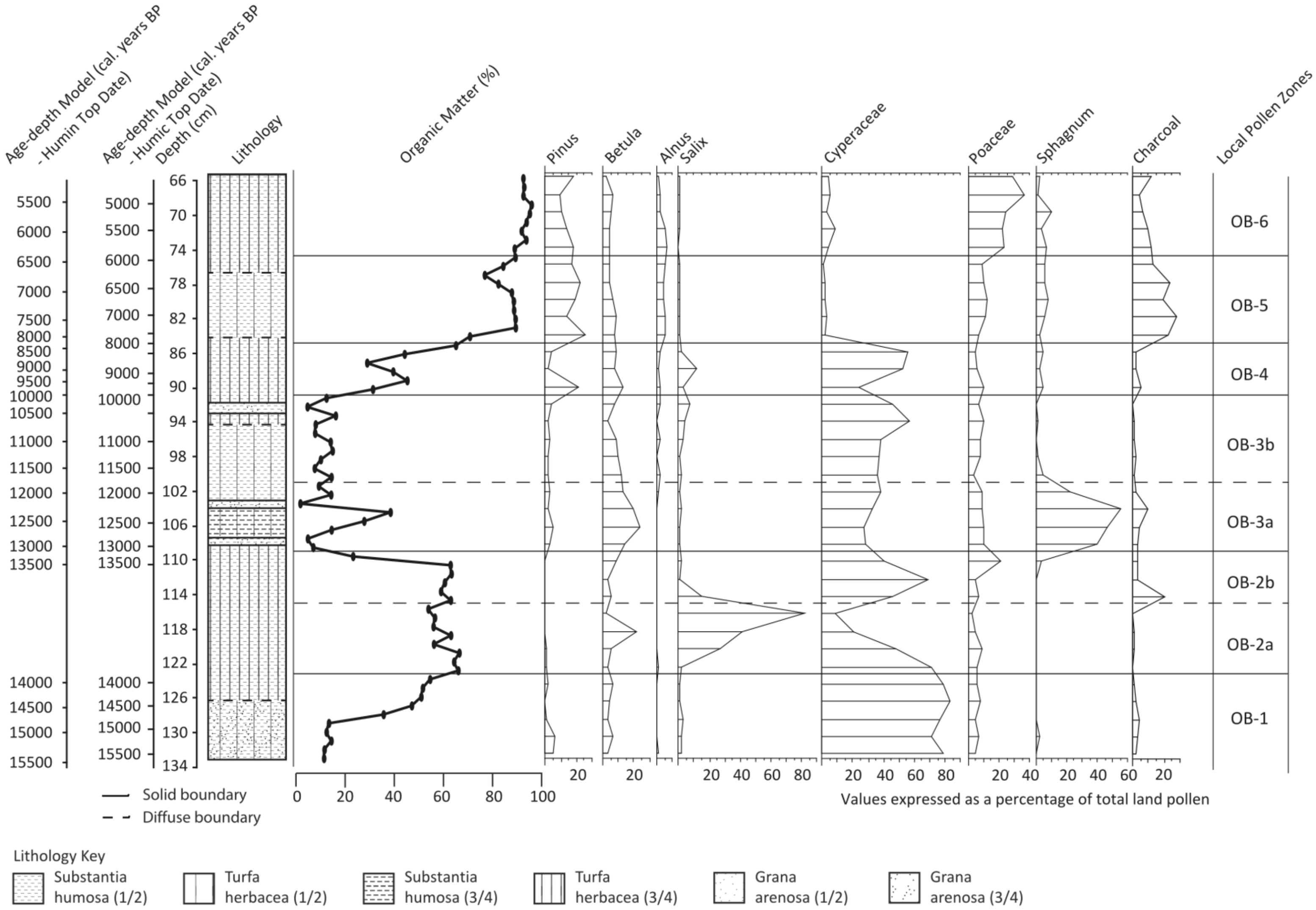


Figure 7.25. Age-depth model, lithostratigraphy and selected taxa diagram of Ockley Bog

Initial sedimentation at Ockley Bog (unit 2) dates to 14,120-13,850 cal. BP, with accumulation at Thursley Bog (units 2 and 3) likely to have occurred prior to 13,500 cal. BP. Below these organic sediments are the sandy sediments of the Lower Greensand (both units 1). Finer grained mineral matter is also observed in the basal sediments from Thursley Bog and may have derived from the steeper sides of the Thursley Bog basin. Organic matter accumulation then continues for at least 500 years until ~13,000 cal. BP when an increase in sand and other mineral matter is recorded in both sequences. This Late Glacial peat formation is especially important due to the lack of sites across the UK that show organic sedimentation during this time, discussed in further detail in Chapter 9. These results indicate that the sediments at Thursley Bog and Ockley Bog are older than the Neolithic/Bronze Age date previously suggested (Moore and Wilmott, 1976). An increase in *Salix* at Ockley Bog suggests that during the early stages of peat formation a damp and relatively stable surface was present as it is a species that thrives in damp to wet ground (Averis, 2013). *Salix* is also observed at Thursley Bog across this period and has previously been identified in Late Glacial sequences from northwest Europe (Van Geel et al., 1980; Walker et al., 1994). Cyperaceae would have been present on the bog margins and around smaller pools of shallow water. Cyperaceae grows well in wetland areas such as pond and stream banks, fens and bogs, is often dominant in modern day arctic and alpine tundra habitats (Chapin and Chapin, 1980) tolerating a water depth of up to 50cm. Smaller quantities of *Equisetum,* a herbaceous taxon favouring wetter soils, and *Menyanthes*, a common fen and bog plant (Averis, 2013), were also present within these small shallow pools.

A large mineral sediment influx event is recorded in the Ockley Bog sequence (unit 3) dating to ~12,880 cal. BP and another sand deposition unit (unit 5) is identified at ~12,120 cal. BP. A similar, but less severe, sand influx (units 4 and 5) is observed at ~12,800 cal. BP in the Thursley basin. These events occur during the Loch Lomond Stadial and may indicate destabilisation of surrounding slopes due to colder and wetter conditions, although the increasing organic content in unit 4 at Ockley Bog suggests a stabilisation, possibly warming, trend between the two influx events, examined in reference to other sites in the discussion (Chapter 9). The sand deposition at Thursley Bog and Ockley Bog may be derived from the high sand dunes that are present to the south of the site. This is recorded in the vegetation as increased bog wetness and destabilisation of the bog surface, with *Sphagnum,* a moss species that thrives in wet boggy conditions (Averis, 2013), colonising Ockley Bog within ~600 years.

Organic sedimentation then continues throughout the rest of the Late Glacial and into the Early Holocene (Thursley: units 6-8, Ockley: units 6-7). In addition to the organic deposition, sand is also deposited in the sequence and this may be due to the open vegetation found across the Common, allowing sand to be washed and/or blown into the bogs. Another large mineral deposition event then occurs in both cores (Thursley: unit 9, Ockley: unit 8), and dates to ~10,360 cal. BP at Ockley Bog and ~10,990 cal. BP at Thursley Bog, although the modelled ranges for these dates mean that the event could be synchronous at both sites. To examine whether this is indicative of a regional event, the records will be compared with other sites in Chapter 9. Further organic sedimentation follows this event (Thursley: units 10-13, Ockley: units 9-11), with some sand in the Thursley Bog core, potentially derived from the steeper sides of the basin between ~10,900-10,100 cal. BP. The vegetation on the bog surface at this time would have been dominated by Cyperaceae, along with some *Salix* and smaller amounts of *Alnus* found across the slightly drier areas, and some *Equisetum* and *Menyanthes* in shallow pools. *Alnus* grows predominantly on moist to wet soils in woods and on the edges of water bodies (Averis, 2013). The presence of *Alnus*, dating from ~11,500 cal. BP is early compared to many sites in SE England where *Alnus* is typically not established until 8900 cal. BP (Birks, 1989), although a few records identify *Alnus* macrofossils pre 10,700 cal. BP in Yorkshire (Bush and Hall, 1987). *Alnus* may have been present during the Late Glacial in Britain, as it would have been able to survive in the climatic conditions during the period, potentially in small local communities, before subsequent expansion occurred with the onset of warmer Holocene conditions. Further expansion then followed once the refugia had reached northwest Europe and the seed source meant immigration was a viable option, potentially indicating the broader *Alnus* establishment of ~8900 cal. BP (Bush and Hall, 1987). It has also been suggested that human groups may have played a part in the 8900 cal. BP *Alnus* development through clearance and burning of other taxa (Smith, 1984).

A hiatus is identified within Thursley Bog dating from 10,510-9570 cal. BP to 7500-7260 cal. BP, and has a potential duration of 3200-2160 years. Interpretation of the Ockley Bog sequence also indicates the potential of a hiatus, as a similar rise in organic matter is identified in the sequence as at Thursley Bog, potentially between units 9 and 10. Additional dating at this point would help to ascertain the exact age of unit 9. The hiatus in bog development at Thursley Bog, and reduction in deposition at Ockley Bog, may be due to a change in the hydrology across the local catchment. Rapid warming of the climate may have caused a drying out and stabilisation of the bog surface through a lowering of groundwater.

Sedimentation would then not restart until the groundwater reserve had recharged. Deforestation (potentially anthropogenic) could also cause a lowering of groundwater through higher levels of soil erosion, leading to a lowering of the soil retention capacity and subsequent depletion in groundwater levels. The hiatus could also be due to the cutting of drainage channels through the peat, artificially drying out the surface and leading to a lack of sediment deposition, or the cutting of peat from the bog surface, physically removing sections of the sediment. Another possibility could be a large bog burst (van Geel et al., 2014), caused by increasing rainfall intensity, which would have led to the upper and less consolidated layers of peat at the bog running off as the bog burst. Post hiatus from 7503-7260 cal. BP, moss and herbaceous peat is present (units 14 and 15 at Thursley Bog) and the organic matter rises sharply as there is minimal mineral input to the core during this time. An increase in bog surface wetness is observed with *Sphagnum* once again present on the bog surface. There is a rapid decline in Cyperaceae and *Alnus* has superseded *Salix* as the dominant tree species found in these wetter areas.

7.5.2. Vegetation History

The dryland vegetation would have developed alongside the vegetation present on the bog surface. The basal zones at both sites (OB-1 and TB-1) date to pre ~13,800 cal. BP, and are Late Glacial in age. The landscape would have been cold and the vegetation represents a tundra style environment with tree taxa and shrub taxa restricted to *Betula*, *Juniperus* and some *Salix,* with both *Betula* and *Salix* potentially being dwarf variants specifically adapted to the conditions prevalent. The overall low total land pollen influx indicates that the landscape would have been sparsely covered, with the signal derived from both a local and regional area. Both *Betula pubescens* and *Betula nana* have been identified in the British Isles during the Lateglacial interstadial (Birks, 1965). *Betula* is cold tolerant (*Betula nana* even more so) and can grow in a range of soil conditions (Averis, 2013). *Juniperus* is a subarctic species and is particularly able to deal with cold and dry conditions (Rawat and Everson, 2012) and has often been used as a Late Glacial indicator (O'Connell et al., 1999). It has been suggested that when percentages are >3-5%, as recorded at Ockley Bog, 'tall' *Juniperus* may have been present, indicating relatively high July temperatures of up to 10 °C (Kolstrup, 1980).

Poaceae and species of fern would have been present across some of the dryland, although the identification of these species do not inform much about the nature of the dryland, as both species are able to live in a wide variety of habitats and climatic conditions (Averis, 2013).

An increase in *Salix* suggests that the climate may have become warmer and wetter at this time, supported by the arrival of *Corylus* and increasing *Betula* (OB-2a and TB-2), and a reduction in Cyperaceae between ~14,000-13,700 cal. BP, likely due to the stabilization of the bog surface by both *Salix* and some *Betula*. The presence of *Corylus* in this zone is of major importance as it is not a characteristic shrub of these conditions and has not been identified in many British pollen diagrams from the Late Glacial. Those sites where it has been identified with values of only 1-5% suggest that contamination, distant transport or secondary re-deposition may be the cause (Birks, 1989). The low influx values of *Corylus* indicate that it is likely *Corylus* would have been present in the regional area. The first consistent presence of *Corylus* has been identified in Wales, Ireland and Western Scotland from ~10,700 cal. BP and was thought to have spread across the British Isles by ~10,200 cal. BP (Birks, 1989), much later than the expansion identified at Ockley Bog which has already reached 10% of the assemblage by ~13,900 cal. BP. The early presence of *Corylus* at Thursley Bog and Ockley Bog may be due to local glacial refugia, allowing for the rapid spread of the species as temperatures ameliorated. The Bay of Biscay has been identified as the closest refugia location (Huntley and Birks, 1983), although it is possible closer, more northerly sites may have existed, with the potential for this to be a cryptic refugia location, lending credence to the ‘cryptic northern refugia’ hypothesis (Kelly et al., 2010). It may also be that Lateglacial interstadial conditions only allowed *Corylus* to migrate northwards in relation to other species (Chambers, 1993). This topic will be examined in relation to a number of other Late Glacial records in Chapter 9. The presence of ‘tall’ *Juniperus* and *Corylus* suggest that the pollen record matches the chronological record, with this period representing the Lateglacial Interstadial. This is also a time when there is an increase in the total land pollen influx, indicating a greater density of species in the local region. The re-emergence of Cyperaceae, a decline in *Salix* and an increase in the influx of herbaceous species, including *Potentilla* and *Artemisia* is noted from ~13,700-13,000 cal. BP (OB-2b), and may represent a gradual return to colder climatic conditions as the Lateglacial Interstadial nears the Loch Lomond Stadial. Both *Potentilla* and *Artemisia* are characteristic of British Late Devensian cold stages (West, 1988; Lewis et al., 2001). The landscape would still have been characterised by tundra vegetation with *Betula* present amongst this patchy disturbed ground covered with Poaceae, *Artemisia* and *Potentilla*.

The onset of the Loch Lomond Stadial is identified in OB-3a and TB3-4, dating to 13,250-12,000 cal. BP. Small increases in *Pinus*, Ericaceae and *Betula* are observed, and both

Calluna and *Empetrum* are present, representing a period of colder conditions than the preceding Late Glacial interstadial. The proportion of non-arboreal species also increases across the Loch Lomond Stadial at both sites. There is a decline in the total land pollen influx at both sites during this time, indicating that there was sparseness to the local vegetation cover. Increases in the influx of *Pinus, Betula* and *Salix* suggest these would have been the dominant taxa in this sparse environment. *Empetrum* is highly indicative of the Loch Lomond Stadial and is a species commonly found across tundra, moss heaths and moorland, thriving in exposed cool and cold climates (Averis, 2013). It has been identified in a number of northwest Europe Younger Dryas and Loch Lomond Stadial contexts (Verbruggen, 1979; Huntley and Birks, 1983; Bohncke et al., 1988; Walker et al., 1994). The potential of *Empetrum* as a food source must be highlighted, as anthropological studies have shown it is an important winter food source for indigenous people in North America as its berries remain harvestable from autumn through winter (Turner et al., 2011). Open and disturbed ground would have been quickly colonised by a variety of herbaceous taxa including Poaceae, *Artemisia, Helianthemum, Rumex, Potentilla, Ranunculus* and Asteraceae. *Artemisia, Helianthemum* and *Rumex* are all heliophilous species (Brauer et al., 1999), growing well during the Loch Lomond Stadial as the overall abundance and density of the arboreal taxa decreased. They are all species that are quick to colonise open or disturbed ground and are often identified in the Loch Lomond Stadial in Britain (West, 1988; Lewis et al., 2001). *Pinus* is able to survive in a wide variety of conditions (Averis, 2013), and may have increased due to the ability to survive better in the possible colder and harsher conditions of the time, potentially to the detriment of *Corylus*, which sees an initial decline across the same period. *Corylus* is a thermophilous species and prefers warmer conditions, and its decline is synchronous with the onset of colder conditions at the start of the Loch Lomond Stadial. The presence of Ericaceae demonstrates its ability to grow across a range of climatic conditions and its ability to survive in dry to wet soils, in bogs and within *Betula* and *Pinus* woodland (Averis, 2013); Ericaceae often forms part of a heathland ecosystem. Increases in charcoal across this period suggest that an increased frequency of natural fires was occurring, potentially linked to the regeneration and emergence of *Betula, Empetrum*, Ericaceae and *Calluna*. These wind tolerant taxa suggest a degree of openness to the landscape, and there is the potential that small patches of heath-like vegetation had formed, which has been identified in other Late-Glacial records (Bennett, 1983; Walker et al., 2003). The burning events observed during this time are unlikely to have been human induced due to a lack of human activity within the archaeological record at this time (see Chapter 3). Natural causes are likely to have led to the burning, and wildfires have been recorded occurring naturally within modern tundra ecosystems where they are often caused due to increasing summer temperatures (Wein, 1976; Racine et al., 1985). A general decrease in total land pollen influx increasing the sparseness of local vegetation cover may have led to the increased mineral deposition observed in the sedimentary record, as areas of bare ground would have allowed sand to have been deposited in the basin due to increasingly windy conditions.

The transition from the Late Glacial to the Early Holocene is recorded in pollen zones TB-5, OB-3b and OB-4. The start of these zones date to ~12,000-11,700 cal. BP and an immediate increase in *Corylus* is observed in both diagrams. The presence of thermophilous taxa, *Corylus* (Seppä et al., 2015) alongside *Quercus* (Hall, 1978), suggest a general warming of the climate during the Early Holocene. The dominant tree taxon is *Betula*, although *Pinus* is also present across the landscape, forming mixed deciduous-coniferous woodland, and influx data indicates it gradually becomes a more dominant component throughout the zone. Relatively high levels of Poaceae, *Artemisia*, *Potentilla* and *Helianthemum* are still present, identifying the presence of open and disturbed ground suggesting that the woodland canopy is still relatively open. The increase in total land pollen influx also indicates the local nature of this open woodland cover. The timing of the start of OB-3b and the presence of *Corylus* and *Quercus* suggests that the onset of the Early Holocene may have been prior to 11,700 cal. BP and this early onset may be due to the southeast location of the sites. However, the age-depth model at this point is limited and the error range is relatively wide so it is hard to ascertain whether this was the case (Thursley Bog: 12,320-11,100 cal. BP and Ockley Bog: 13,080-10,510 cal. BP). Examination with other sites in Chapter 9 will help to develop the understanding of the onset of the Holocene in southeast England.

Indications of a change in the woodland occur from ~10,000 cal. BP with a shift towards deciduous taxa. From this point, *Ulmus* and *Tilia* are present in the Ockley Bog sequence, and are both thermophilous taxa (Hall, 1978). They would have become important species within the deciduous woodland alongside *Quercus* (Godwin, 1975b). The closing canopy of this new deciduous woodland may have pushed *Corylus* into a secondary role as the understorey vegetation (Godwin, 1975b). This vegetation succession alongside the signal of hydroseral succession from the presence of both *Alnus* and *Salix* on the bog surface most likely identifies the continued amelioration of the Early Holocene climate as observed across the British Isles (Puhe and Ulrich, 2012).

The vegetation of the Early-Mid Holocene, dating from ~7800 cal. BP, is thought to be recorded in OB-5, OB-6, TB-6 and TB-7, although no radiocarbon dates are present in the top units from either sequence. This shows mixed deciduous and evergreen woodland, consisting of *Pinus, Ulmus, Quercus, Betula, Tilia* and *Fraxinus* (Parker et al., 2002). *Corylus* and a variety of ferns are likely to have formed part of the understorey canopy, although the high prevalence of *Corylus* (in both pollen and influx data) is important as it is currently not found in such quantities in natural environments (Finsinger et al., 2006a). The high influx values for many of these species indicate that this woodland would have been growing very close to the site. This mixed deciduous woodland, consisting of a variety of thermophilous taxa is represented at numerous other sites in Britain (Simmons and Innes, 1987; Simmons, 1994; Peglar et al., 1989). Overall declines in *Pinus* across OB-5, OB-6 and TB-6 indicate the gradual reduction in the taxon as it is outcompeted by the thermophilous deciduous woodland, forming closed canopy woodland and shading out *Pinus*. The presence of *Ranunculus* and high quantities of Poaceae indicate that there may have been patches of open disturbed ground, and small areas of heathland development may have occurred with increasing quantities of both *Calluna* and Ericaceae. Development of open ground may be represented by the decline in influx of all taxa, indicating there was less vegetation cover in the local area around the sites. This development of open disturbed ground and heathland regeneration has been related to the clearance of *Corylus* woodland. This has been identified in Northern England (Radley et al., 1974) alongside Later Mesolithic flintwork and an increase in charcoal. At both Thursley Bog and Ockley Bog, there is a possibility of fire induced clearance, targeted at *Corylus*, observed through the increase in microscopic charred particles and *Corylus* in OB-5 and TB-6. The high proportions of *Corylus* and development of open ground and heathland may also be due to woodland grazing by large herbivores. These herbivores would have caused a fragmented forest interspersed with open grassland regions (Vera, 2000), a hypothesis discussed further in Chapter 9.

7.6. Synthesis

Two basins were identified across Thursley National Nature Reserve: Thursley Bog and Ockley Bog. A core was extracted from the centre of each basin; a 195cm core was extracted from Thursley Bog, and a 132cm core from Ockley Bog. In both cases the top of the sequence (to a depth of 48cm and 66cm respectively) was not collected in the Russian corer and was subsequently not analysed. Four radiocarbon dates on each core show that organic sedimentation began during the Late Glacial and that these are some of the oldest sites in southeast England with organic accumulation. The development of the two basins appeared to be broadly synchronous, occurring during the Lateglacial Interstadial. Based on the deposition model for the site, the two basins appeared to have coalesced during the Mid-Holocene.

The two basins were likely to have been depressions in an undulating Greensand landscape. Initial sedimentation dated to before ~13,500 cal. BP during the Lateglacial Interstadial and organic accumulation continued until ~13,000 cal. BP amid a damp and relatively stable bog surface. From 13,000 cal. BP a period of increased bog wetness and destabilisation of the bog surface was observed, and a large influx event occurred at ~12,900-12,800 cal. BP, potentially due to wetter conditions causing in-washing into the basins, and possibly represented a deteriorating climate during the Loch Lomond Stadial. Organic sedimentation then continued throughout the rest of the Late Glacial from ~12,000 and into the Early Holocene. During the Early Holocene, another mineral deposition event occurred and was overlain by further organic sedimentation. Bog surface vegetation was dominated by Cyperaceae, *Salix* and *Alnus*. The Early-Middle Holocene was represented at the top of both sequences, and the organic matter content in the core was much higher than recorded in the Late Glacial and Early Holocene. *Alnus* was now the dominant species on the more stable parts of the bog surface, with wetter regions occupied with *Sphagnum* moss.

During the Lateglacial Interstadial, the Thursley Common area was likely to be tundra, with sparse tree cover of *Betula*, *Juniperus* and some *Salix*, with Poaceae and ferns also present. Increasing values of *Salix* suggested that the climate may have become warmer and wetter between 13,800-13,500 cal. BP, and *Corylus* and *Betula* indicated a slight warming trend. A return to colder conditions was then observed with the re-emergence of Cyperaceae, increases in *Potentilla* and *Artemisia* and decreases in *Salix*. Between 13,500-12,000 cal. BP *Pinus* and *Betula* were the main tree taxa, and an open landscape was hypothesised due to the increases in wind tolerant taxa including *Empetrum*, Ericaceae and *Calluna*, and the increased record of burning would also have helped these species growth. A range of herbaceous taxa would have also been present on open and exposed ground. This period was thought to represent the Loch Lomond Stadial. The Late Glacial to Early Holocene transition (~12,000 cal. BP onwards) was recorded through an immediate increase in *Corylus* in both diagrams, indicating a warming trend. Overall woodland cover was still low with *Betula* and *Pinus* the two other prevalent tree species. Poaceae, *Potentilla*, *Helianthemum* and *Artemisia* suggested that open and disturbed ground was present. Further deciduous species arrived from ~10,000 cal. BP including *Ulmus* and *Tilia*. This may have represented both a warmer and wetter period, as both *Alnus* and *Salix* were thought to be present on the bog surface at this time. Mixed evergreen and deciduous woodland with *Betula*, *Ulmus*, *Quercus*, *Pinus*, *Tilia* and *Fraxinus* was observed from ~7800 cal. BP. An understorey of *Corylus* and ferns would have been present alongside some heathland development, with *Calluna* and Ericaceae in more open areas. Disturbed ground colonised by *Ranunculus* and Poaceae may be correlated to the increasing evidence for fire across this period.

8. Elstead Bog B, Elstead

8.1. Introduction

This chapter presents the palaeoenvironmental study of Elstead Bog B, a small basin close to the published site of Elstead Bog A (Farr, 2008). The work in the Elstead area provided an opportunity to improve and develop our understanding of the original site, and the landscape settings of both sites, as well as develop our knowledge of human activity and environmental change in Surrey and the southeast. The site of Elstead Bog B lies approximately 1.9km south of Elstead village in the southwest corner of Surrey, OS grid SU 89804 42172. The site lies in woodland bordered by Thursley Road and Woolfords Lane (Figure 8.1).

Figure 8.1. Location of Elstead Bog B and the previously studied site of Elstead Bog A.

Late Upper Palaeolithic and Mesolithic activity in the immediate 5km surrounding area shows the same pattern as at Thursley Common and Ockley Common (see Figure 7.4 in the previous chapter). Within 5km of the sites in SW Surrey, 71 Mesolithic records have been identified, including a range of small to large lithic scatters, findspots, lithic working sites and two sites, at Kettlebury and Hankley. Another site, Bourne Springs can be found within 10km of the palaeoenvironmental records. The Late Upper Palaeolithic record from 10km around the sites indicate a low level, possible passing-through or tool repair signal, with 5 records including blades, flakes and other small implements.

The bog is situated on gently downward sloping ground towards the Wey Valley to the north, with the ground rising steeply to the south. The underlying geology at the site is well sorted Folkestone Bed sands (Carpenter and Woodcock, 1981) of the Lower Greensand. The water table is very close to the surface, leading to open pools of water present across the sites. Peat cutting appears to have taken place within this woodland and further afield in the landscape (Carpenter and Woodcock, 1981) and drainage channels have been cut through the woodland. Soils at the site are thin and podzolised, immediately resting on the Lower Greensand surface. The vegetation on the surface of the bog is dominated by *Molinia caerulea* and *Sphagnum (Sphagnum compactum S. papillosum, S. recurvum* and *S. palustre),* with the occasional *Betula pubescens* on more stable areas (Figure 8.2). Around the margins of the bog, *Calluna vulgaris* and *Erica tetralix* prevail, with *Pinus sylvestris* dominant in the wider woodland.

Figure 8.2. Bog surface and surrounding vegetation at the Elstead Bog sites.

The site of Elstead Bog B is in close proximity (50-100m) to the previously investigated site of Elstead Bog (A), a site extensively investigated through multiple studies. The site was first studied in the 1940's (Godwin, 1940; Godwin, 1949) although the first pollen diagram was not constructed until 1960 (Seagrief and Godwin, 1960). A detailed mapping project with further palynological work was undertaken by Carpenter and Woodcock (1981) followed by higher resolution palynological work and radiocarbon dating (Farr, 2008).

Elstead Bog A formed in a small basin, ~100m long and 30m wide at the surface. The deepest part of the basin is 3.5m deep with approximately 2.7m of peat accumulation (Farr, 2008). Bog formation is attributed to the collapse of a cryogenic mound during the Late Glacial (Carpenter and Woodcock, 1981) due to the presence of a rampart feature around the margins of the bog. Radiocarbon dating provided evidence that the bog dated to the Early Holocene, with a radiocarbon date of ~10,970 cal. BP (Farr, 2008) and modelling suggests that the base of the sequence may date to 13,500-10,970 cal. BP. All four of the radiocarbon dates date to the Mesolithic period and the modelling shows that up to ~9100 cal. BP sedimentation was relatively stable. A period of decreased sedimentation is then observed until ~6130 cal. BP (Figure 8.3 and Table 8.1).

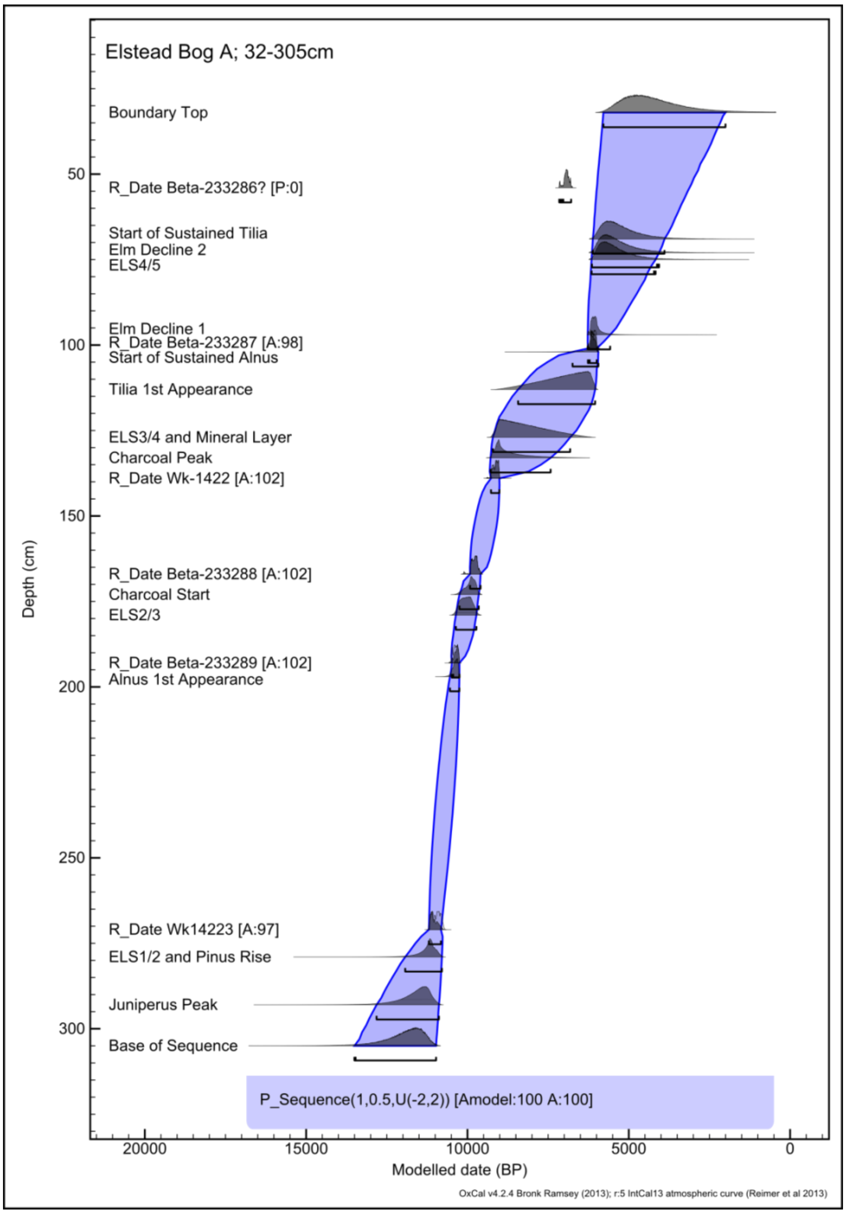


Figure 8.3. Age/depth model from Elstead Bog A, from (Farr, 2008).

Table 8.1. Modelled dates and events within the Elstead Bog sequence. Modelled with dates and events after Farr (2008).

Name	Unmodelled (BP)			Modelled (BP)			Indices A_{model}=100.2 $A_{overall}$=100.2	
	from	to	%	from	to	%	A	C
Boundary Top				5787	2003	95.4		98.7
R_Date Beta-233286	7156	6788	95.4	7156	6787	95.4		99.9
Tilia Sustained				6114	3894	95.4		97.9
Ulmus Decline 2				6142	4061	95.4		97.8
ELS4/5				6154	4170	95.4		97.9
Ulmus Decline 1				6273	5578	95.4		99.7
R_Date Beta-233287	6265	5991	95.4	6266	5994	95.4	97.9	99.8
Alnus Sustained				6743	5943	95.4		99.6
Tilia 1st Appearance				8431	6043	95.4		99.7
ELS3/4 and Mineral Layer				9213	6817	95.4		99.6
Microcharcoal Peak				9284	7423	95.4		99.8
R_Date Wk-1422	9279	9011	95.4	9271	9011	95.4	102.2	99.9
R_Date Beta-233288	10113	9565	95.4	9920	9595	95.4	101.7	99.9
Charcoal Start				10248	9650	95.4		99.9
ELS2/3				10359	9724	95.4		99.9
R_Date Beta-233289	10501	10258	95.4	10485	10250	95.4	101.5	99.9
Alnus 1st Appearance				10542	10251	95.4		99.5
R_Date Wk14223	11175	10759	95.4	11196	10823	95.4	97.4	99.9
ELS1/2 and *Pinus* Rise				11930	10792	95.4		99.9
Juniperus Peak				12818	10884	95.4		99.8
Boundary Base				13504	10973	95.4		97.9
P_Sequence(1,0.5,U(-2,2))	-2	2	95.4	-1.17741	-0.91741	95.4	100	98.1

Palynological and microscopic charcoal results (Figure 8.4) from previous studies on Elstead Bog A (Farr, 2008) have shown an interesting picture of vegetation succession from the Early Holocene onwards.

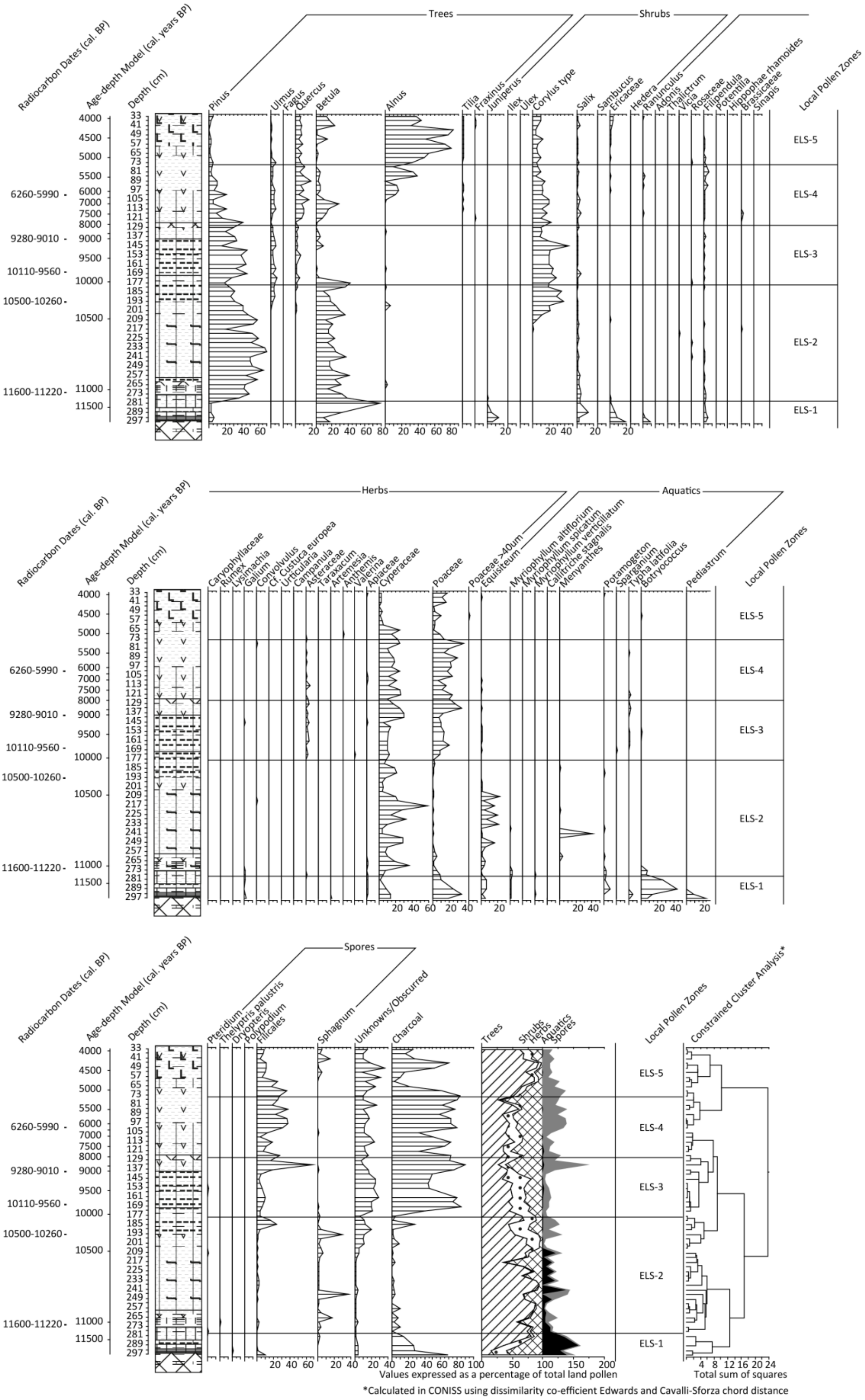


Figure 8.4. Percentage pollen diagram from Elstead Bog A, from (Farr, 2008).

The pollen analysis from Elstead Bog A (Farr, 2008) identified the presence of a small lake in the Early Holocene. Open ground meadow and *Juniperus*, *Betula* and *Salix* woodland were present during this time but increasing amounts of *Pinus* and *Betula* led to a decline in herbaceous taxa from ~11,000 cal. BP. *Betula* declined from ~8700 cal. BP with an expansion in deciduous woodland including *Quercus, Fraxinus, Tilia, Ulmus* and *Corylus*. *Alnus* expanded in the Late Mesolithic at ~6200 cal. BP (Farr, 2008).

8.2. Results of the Field and Laboratory Sedimentology

The results from Elstead Bog A recognised the importance of identifying other local sites, with the potential of Late Glacial records. A survey led to the discovery of Elstead Bog B and two transects helped understand the shape and depth of the basin (Figure 8.5). An east to west transect was comprised of 9 boreholes equally spaced at 5m intervals (Figure 8.6). The north to south transect of 11 boreholes had 10m spacing (Figure 8.7). The two transects intersected at the deepest point, which was used as the coring location, core point 1 (CP1). Stratigraphic records can be found in Appendix 13.17.

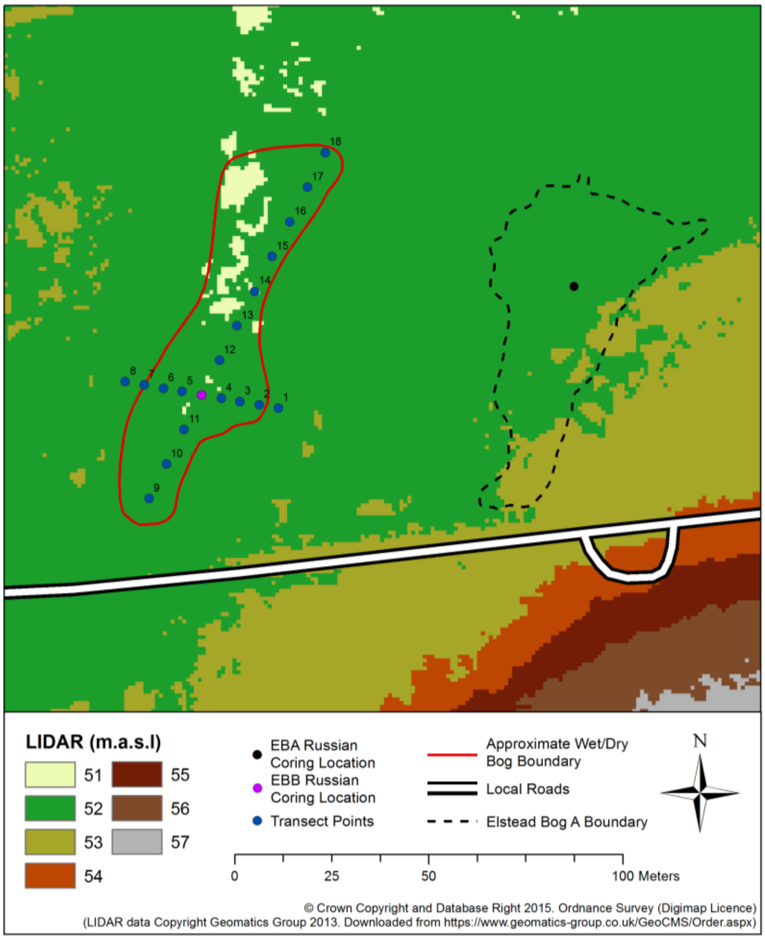


Figure 8.5. LIDAR plot of the Elstead sites, the location of transects and coring points.

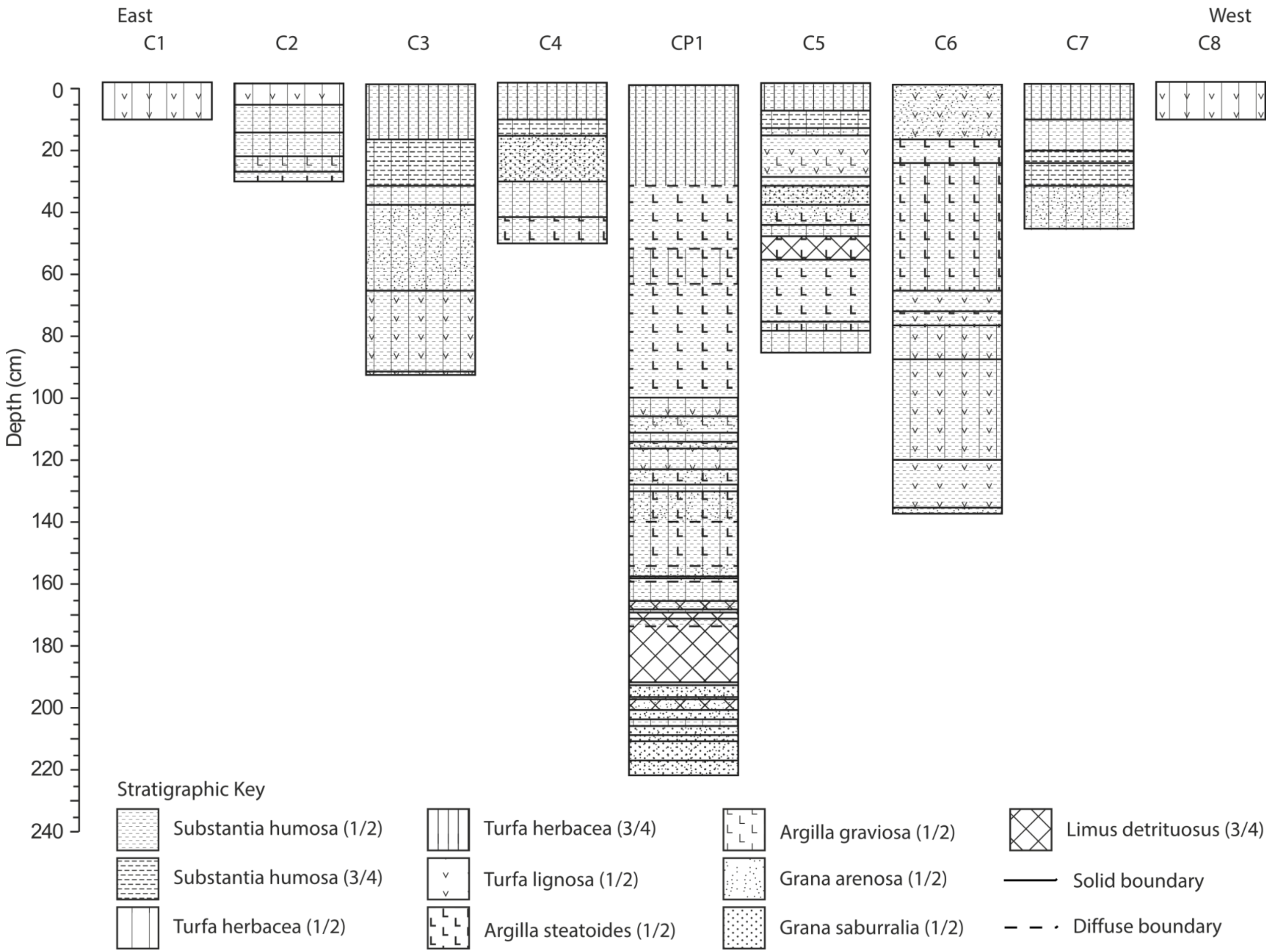


Figure 8.6. The east-west transect of boreholes at Elstead Bog B.

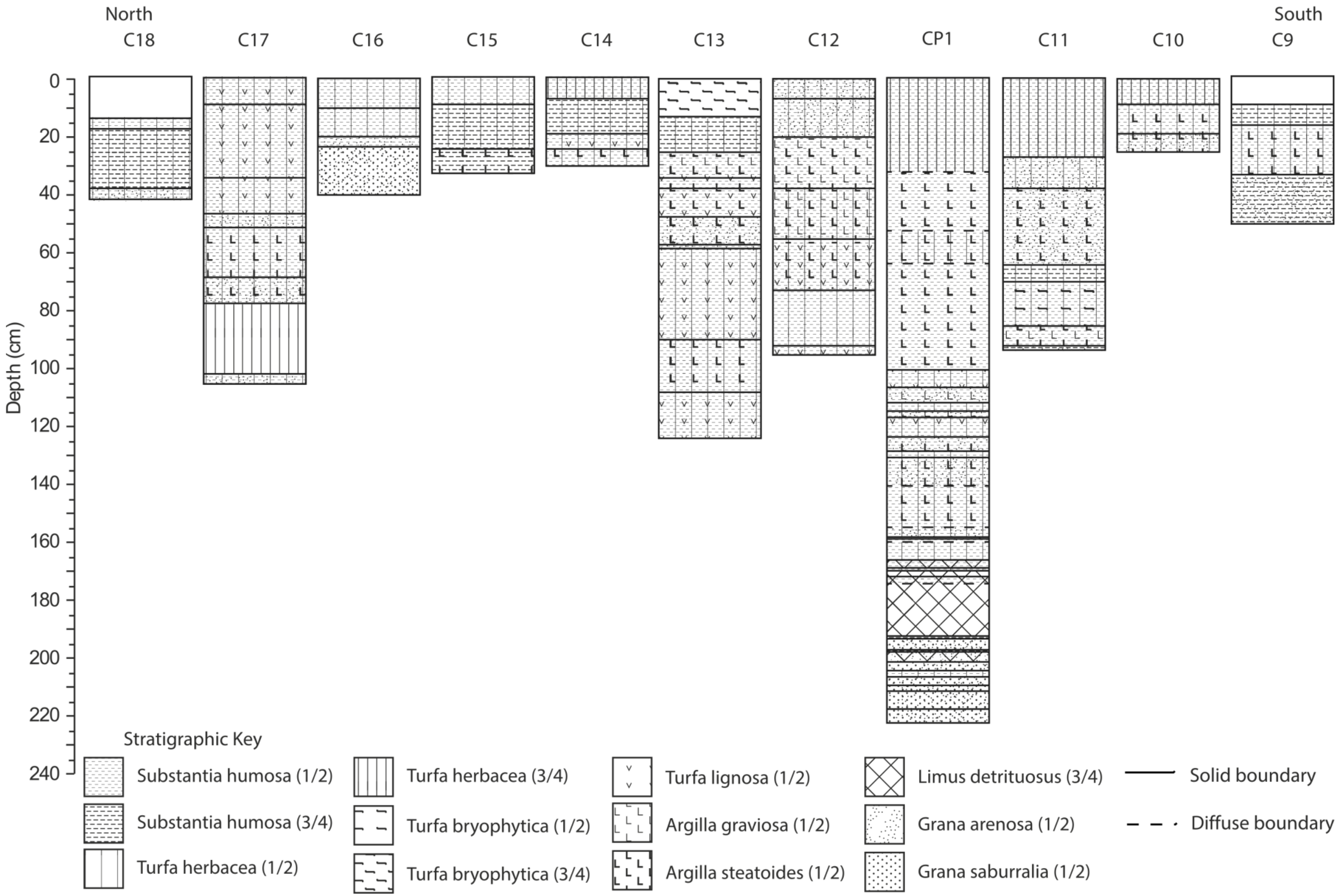


Figure 8.7. The north-south transect of boreholes at Elstead Bog B.

The East-West Transect

The east-west transect deepened towards the centre of the bog, and the intersection between the two transects (CP1) provided the deepest core. The bog shallowed towards its eastern and western edges. The fine and coarse sands that comprise the Lower Greensand were identified at the base of four of the cores. Lake sediment overlaid this sandy sediment in the deepest core (CP1). An herbaceous sandy and mineral rich peat transitioned into herbaceous and wood peat. Herbaceous and wood peat was identified in C3, CP1, C5 and C6. Overlying this organic unit, mineral input was observed, in varying thickness, at a depth of 20-40cm in C2-7. The units above this mineral band were organic sediments with wood peat (C1, C2 and C8), sandy wood peat (C6) and herbaceous peat (C3-5, CP1 and C7).

The North-South Transect

Greater complexity was observed in the north-south sequence. The deepest point was CP1 and is the only north-south core to extend past 120cm. From 120cm upwards organic sedimentation continued with an herbaceous and wood peat overlain by a minerogenic unit in C13, C11 and CP1. This was overlain by a variety of organic units including herbaceous, wood and moss peats in C11-13, C17 and CP1. Above this, an organic unit with silt, clay or both, up to ~30cm was identified in C9-15 and C17, overlain by an herbaceous peat with disintegrated organic matter (with the addition of moss peat in C13 and sand in C12). The sequence was shallow through C16, C15 and C14 until the basin deepened (C13-C11). A deeper unit with wood peat overlying an herbaceous peat was observed in C17 that shallowed towards C18.

The two transect sequences showed that much of the basin has relatively little depth. The main coring point (CP1: SU 89804 42172) was the crossover point of the two transects, situated roughly in the middle of the bog, and the deepest point. The 221cm main core consisted of 32 lithostratigraphic units (Appendix 13.17) and organic matter was calculated at 2cm for the entire depth (Figure 8.8, Appendix 13.18). Units 1-10 (1: 221-216cm; 2: 216-210cm; 3: 210-208cm; 4: 208-205cm; 5: 205-203cm; 6: 203-200cm; 7: 200-196.5cm; 8: 196.5-196cm; 9: 196-192cm; 10: 192-191cm) were predominantly sandy and represented the base of the sequence where the corer had penetrated the Lower Greensand. These units were low in organic matter (mostly between 0-10%). Units 11-15 (11: 191-173cm; 12: 173-171cm; 13: 171-169cm; 14: 169-168cm; 15: 168-165cm) were comprised predominantly of lake sediment, with small organic matter inclusions. Organic matter rose through these units, from

10% to over 80%. Herbaceous peat overlaid this lake sediment (16: 165-159cm; 17: 159-158cm; 18: 158-157.5cm), which in turn was overlaid by a sandy, clayey herbaceous peat in units 19-23 (19: 157.5-164cm; 20: 154-140cm; 21: 140-130cm; 22: 130-127cm; 23: 127-123cm) with a decline in organic matter content (<20%).

Wood peat was present through units 24-28 (24: 123-116cm; 25: 116-114cm; 26: 114-111cm; 27: 111-106cm), alongside sandy herbaceous units, identified through an increase in the organic matter content to 35%. Units 29-31 (29: 100-64cm; 30: 64-52cm; 31: 52-32cm) were clay and silt rich and became increasingly organic-rich higher up the profile, from 10% through to 40%. The surface unit (32: 32-0cm) consisted of herbaceous peat, with an increase in organic matter to 55-85%.

The stratigraphic results indicate that Elstead Bog B is likely to have been a mid-sized basin, although it is difficult to fully understand the potential size due to the issues with the chronology at the site. It appears that the bog, during the Lateglacial part of the sequence, may have covered up to ~400m^2. This site is likely to show a local signal, but will still have a major component of extra-local pollen as well as a regional signal. The basin at Elstead Bog A was thought to have been relatively large during the Early- to Mid-Holocene (although not as large as observed at Langshot Bog), with a potential size of ~1500m^2. The size of this site indicates that it will be receiving a relatively large extra local pollen signal, in addition to a local component and smaller regional component (Jacobson and Bradshaw, 1981).

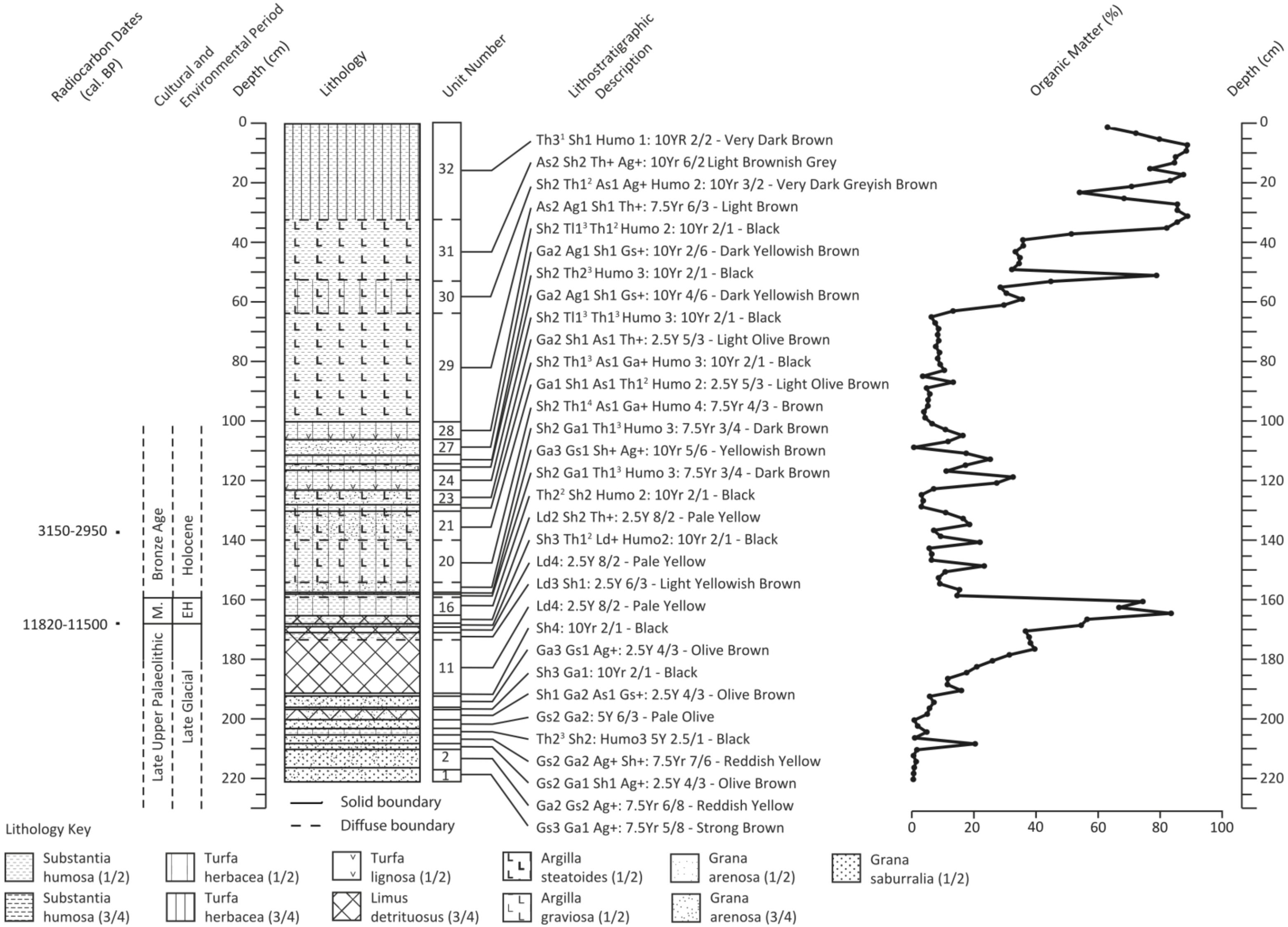


Figure 8.8. Stratigraphy, organic matter and radiocarbon data from CP1, Elstead Bog B.

8.3. Results of the Radiocarbon Dating Programme

Three radiocarbon dates were initially selected from the Elstead Bog B core to understand the general age of the sequence (Table 8.2). These samples were chosen based on high organic matter percentages to ensure reliable results. Dates were submitted as bulk peat samples due to a lack of macrofossil remains throughout the core. Each depth had humic (alkali-soluble fraction) and humin (acid- and alkali-soluble fraction) samples submitted, which provided two dates each at three depths.

Table 8.2. Results of the radiocarbon dating programme at Elstead Bog B.

Lab. No.	**Depth (cm)**	**Sample**	**Radiocarbon age (BP)**	**δ13C (‰)**	**Calibrated date – cal. BP (95% confidence)**
SUERC-53810	60-61	Bulk peat (alkali-soluble fraction)	3594±35	-29.6	3990-3830
SUERC-53811	60-61	Bulk peat (alkali- and acid-insoluble fraction)	3365±35	-29.7	3700-3490
SUERC-53812	138-139	Bulk peat (alkali-soluble fraction)	2894±35	-29.7	
SUERC-53813	138-139	Bulk peat (alkali- and acid-insoluble fraction)	2902±35	-29.7	
Weighted mean	*138-139*	*(T'=0.0, T'(5%)=3.8, v=1; Ward and Wilson 1978).*	*2898±25*		*3150-2950*
SUERC-53814	168-169	Bulk peat (alkali-soluble fraction)	10,087±35	-31.5	
SUERC-53815	168-169	Bulk peat (alkali- and acid-insoluble fraction)	10,105±35	-31.4	
Weighted mean	*168-169*	*(T'=0.1, T'(5%)=3.8, v=1; Ward and Wilson 1978).*	*10,096±25*		*11,820-11,500*

No further samples were submitted for radiocarbon dating after these initial three samples due to a number of reasons. The date from 60-61cm could not provide a weighted mean, and suggested the material is of different ages. Hypotheses for this anomalous result may be similar to Thursley Bog; however, the date also appears to be chronologically inverted, being older than the date from 138-139cm. This suggested that the sediments at the top of the sequence might be mixed. The time gap between the dates at 168-169cm and 138-139cm suggested the possibility of a hiatus in the sequence. Although the result from 168-169cm provided a date within the relevant time period, on consultation with Peter Marshall (Historic England Scientific Dating Team) it was decided the low organic matter values at the base of the sequence would not be suitable for further radiocarbon dating. Therefore there appeared to be both Early Holocene and Late Glacial sedimentation within the core, but dating the sequence is problematic.

8.4. Results of the Pollen Stratigraphical Analysis

The pollen sampling strategy was based upon the results of the radiocarbon dating programme. Between 152-204cm samples were taken at every 2cm, above 152cm samples were taken at 16cm intervals up to 120cm. This was to attempt to identify any indication of a hiatus or truncation of the core. Results were presented as a pollen percentage diagram, divided into a number of pollen assemblage zones (Figure 8.9 - Figure 8.11) and described (Table 8.3). Raw data can be found in Appendix 13.19.

The first three zones (EBB-1 to EBB-3) represent the Late Glacial period, prior to the basal radiocarbon date of 11,820-11,500 cal. BP. Zone EBB-1 was characterised by increasing *Alnus* values alongside *Betula*, *Pinus*, Ericaceae, *Empetrum*, and *Salix*. Poaceae, Cyperaceae and *Ranunculus* were the main herbaceous taxa. *Juniperus* appeared in EBB-2 alongside, *Salix*, *Pinus*, Ericaceae, *Empetrum* and an increase in *Betula.* Poaceae, *Ranunculus* and a decline in Cyperaceae represent the dominant herbaceous taxa. *Juniperus* increased in EBB-3 alongside *Betula*. *Empetrum and Ericaceae* declined. Herbaceous taxa were represented by *Filicales, Ranunculus, Poaceae* and Cyperaceae. *Myriophyllum* was observed during this zone. A small peak was also observed in charcoal. *Betula* expanded rapidly in EBB-4 and a small increase in *Salix* was also observed alongside *Pinus*. *Juniperus*, *Corylus* and Ericaceae all declined Cyperaceae remained stable and Poaceae declined. Charcoal also declined during this zone. This zone represented the onset of the Holocene and dated from 11,820-11,500 cal. BP. *Betula* and *Salix* declined in EBB-5, *Pinus* fluctuated and there was an increase in *Alnus*, *Quercus* and *Corylus* in addition to a charcoal increase. A hiatus was thought to be present within this zone and some material may have been truncated, which caused a distinct shift in the pollen assemblage.

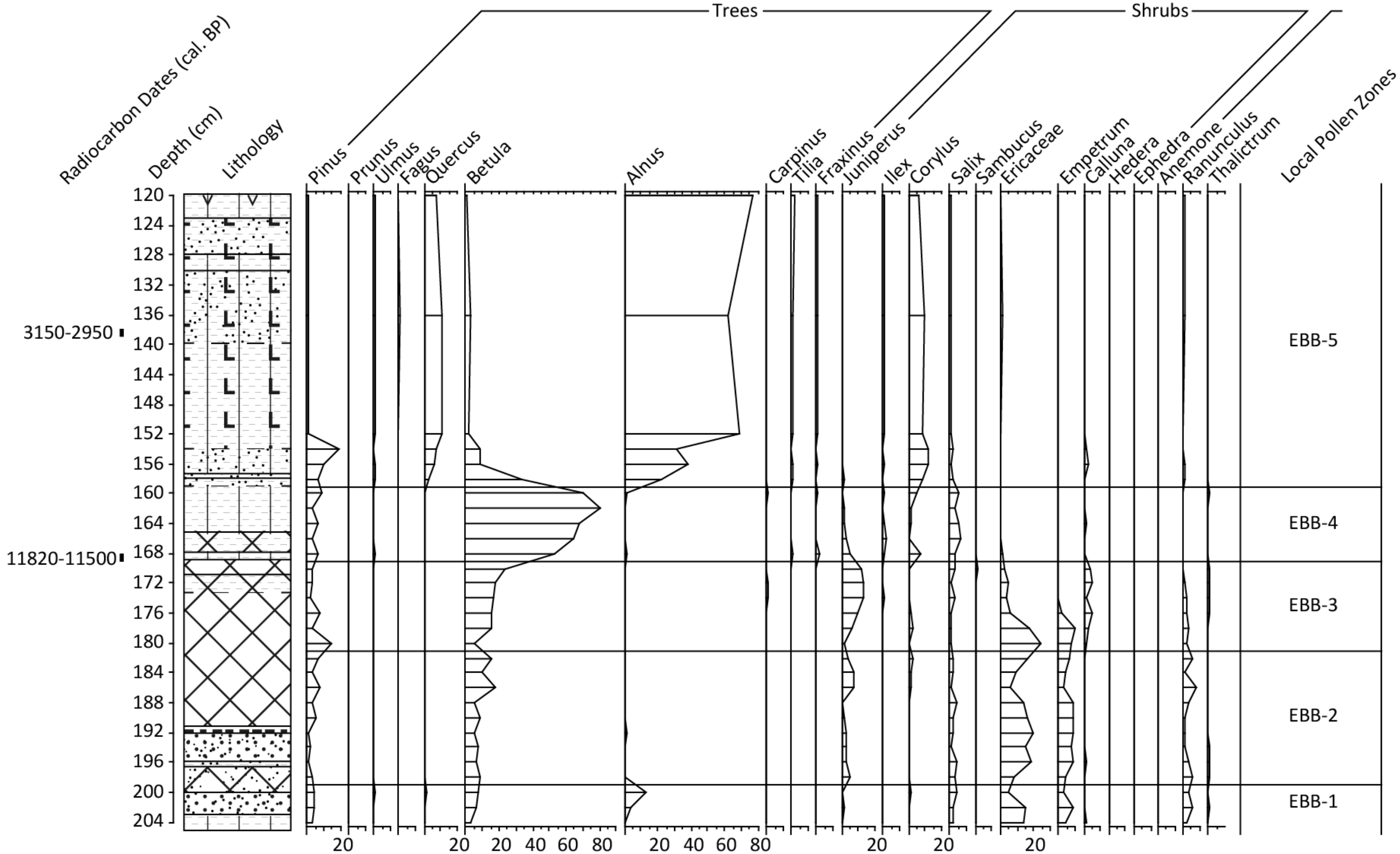


Figure 8.9. Pollen percentage results from Elstead Bog B (part 1).

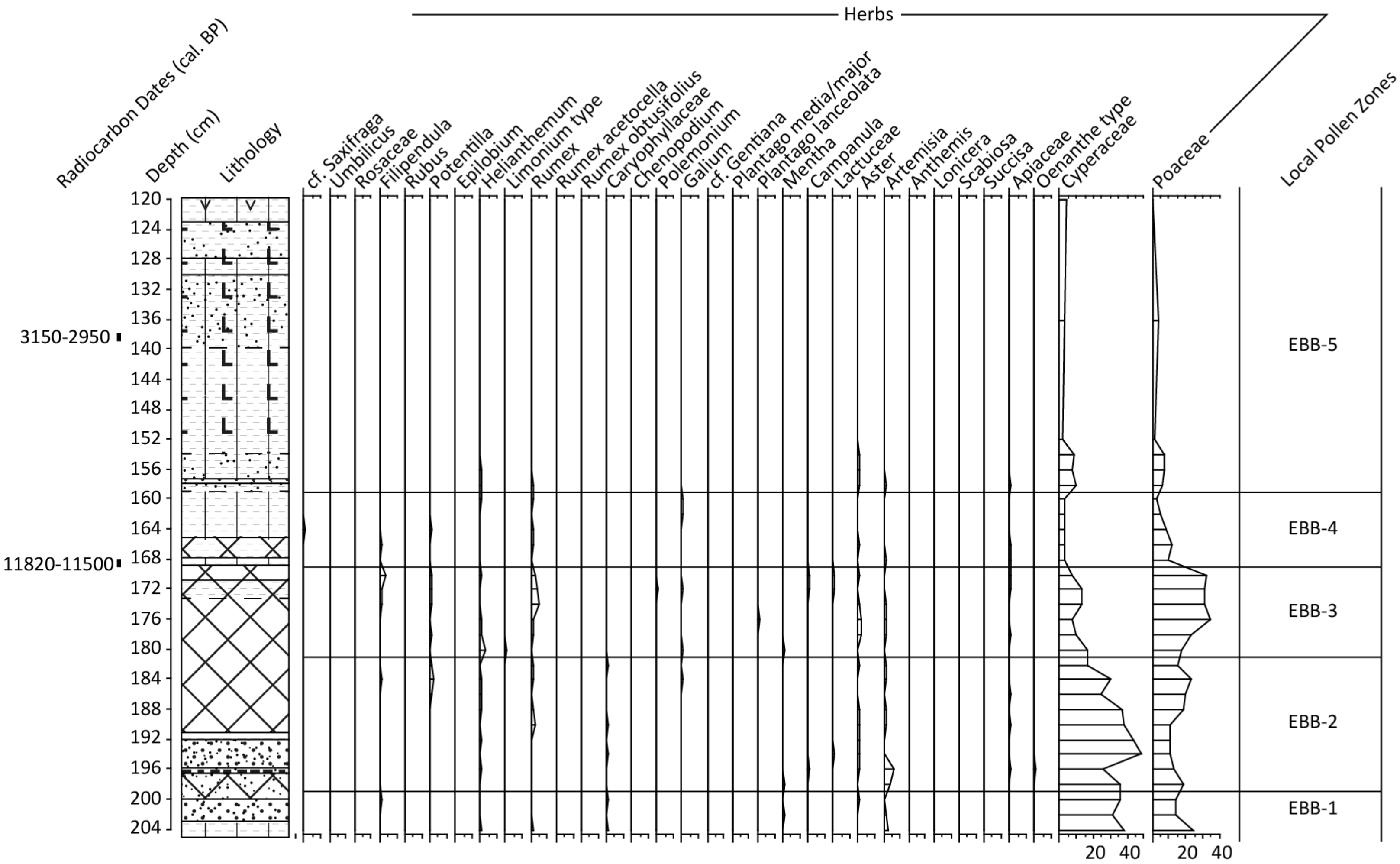


Figure 8.10. Pollen percentage results from Elstead Bog B (part 2).

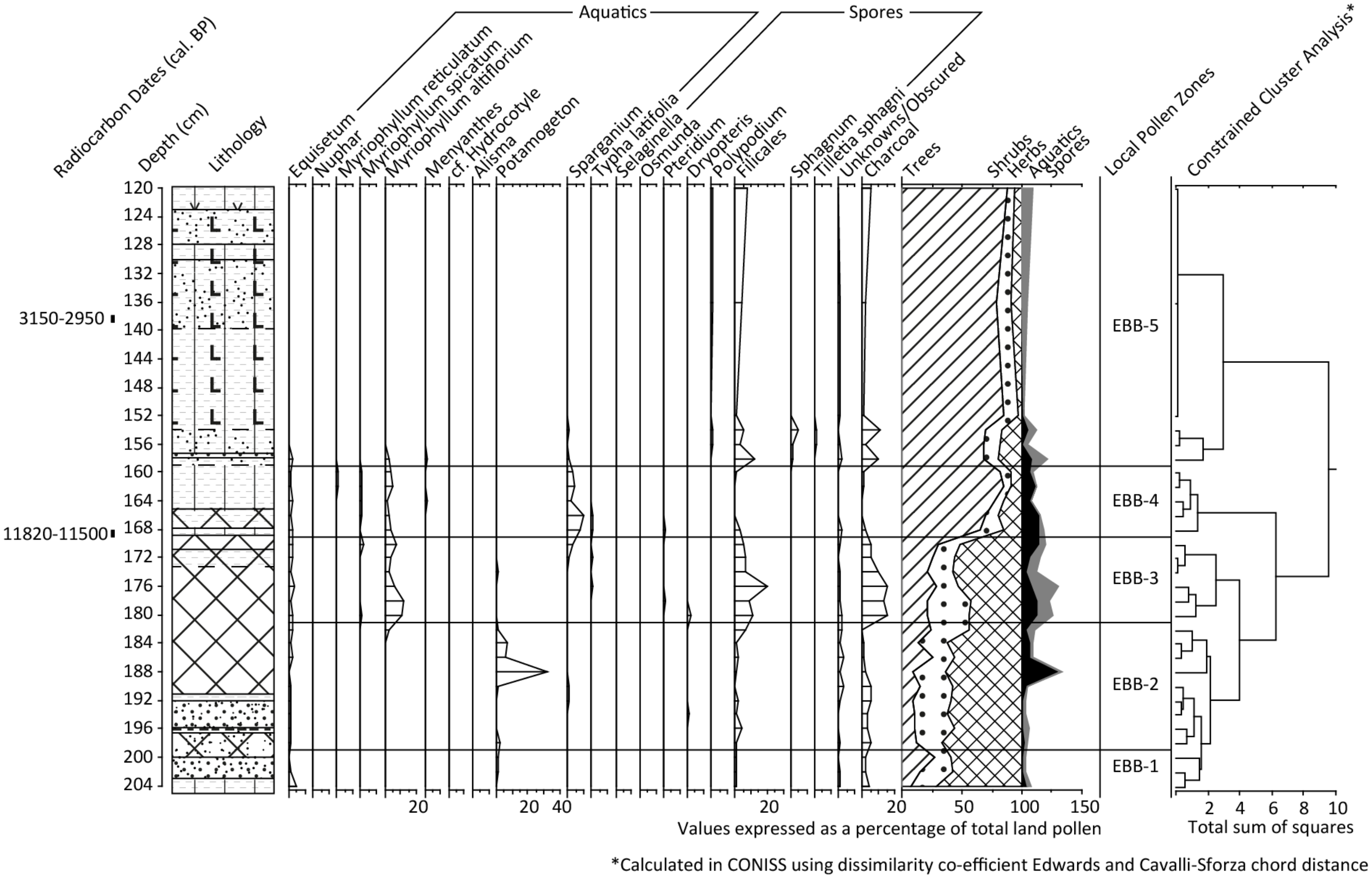


Figure 8.11. Pollen percentage results from Elstead Bog B (part 3).

Table 8.3. Description of the Elstead Bog B local pollen zones.

Depth (cm)	Pollen Zone	Vegetation
120-159	EBB-5	*Alnus – Quercus – Corylus* *Alnus* increased rapidly to >60% with a corresponding decline in *Betula* to 10%, then <5%. *Quercus* and *Corylus* increased from 0% to 10% and *Pinus* increased to 20% before declining to 0%. *Salix* slowly declined from 5% to 0%. Cyperaceae and Poaceae both declined from 10% to <5%. *Ulmus*, *Tilia* and *Fraxinus* were present at low quantities. A small increase in charcoal was identified at the start of the zone, up to 10% from 0%. *Filicales* and *Sphagnum* were also present (5-10%).
159-169	EBB-4	*Betula – Salix – Pinus* A major expansion of *Betula* was identified climbing to a peak of 80% and a small increase in *Salix* was observed (5%). *Corylus* declined to 0% during the expansion of *Betula* and both *Juniperus* and Ericaceae declined to 0%. *Pinus* remained low between 5% and 10%, Poaceae declined from 15% to 5%. Cyperaceae stabilised but remained low (5%). *Tilia*, *Fraxinus* and *Ulmus* were all noted in very small quantities. *Sparganium* (max 10%) and *Myriophyllum* (<5%) were both present. *Filicales* and charcoal both declined.
169-181	EBB-3	*Juniperus* – Ericaceae – *Betula* *Betula* remained at 15% before increasing towards the end of the zone. *Pinus* remained fairly constant (5%) as did *Salix* (<5%). Increases were identified in *Juniperus* (15%) and Poaceae (20% to 35%). Herbaceous taxa including *Filipendula*, *Rumex* and *Helianthemum* had minor increases. The first prolonged presence of *Calluna* (5%) coincided with the complete decline of *Empetrum* (10% to 0%) and reduction in Ericaceae (25% to 5%). Cyperaceae continued to decline (15% to 5%) and *Ranunculus* also declined (5% to 0%). *Carpinus*, *Corylus*, *Sambucus* and *Ilex* were identified in very small quantities. Increases in *Myriophyllum* (up to 10%) and *Filicales* (up to 15%) were also identified. A peak in charcoal subsequently declined (15% to 5%).
181-199	EBB-2	*Juniperus – Betula* – Cyperaceae *Juniperus* appeared for the first time (up to 10%) alongside Ericaceae (20%), *Empetrum* (10%), *Salix* (<5%), *Pinus* (5%) and *Ranunculus* (5%) which all remained relatively stable. *Artemisia* was present in small quantities (max. 5%). *Betula* increased from <10% to 15%. Cyperaceae rose initially to 50% before falling steadily to 15%. Poaceae remained relatively stable between 10-20%. A spike in *Potamogeton* (30%) was identified during the second half of the zone. Charcoal was still present in small quantities (5% and less).
199-204	EBB-1	Cyperaceae – Poaceae – *Alnus* Cyperaceae (35%) and Poaceae (25% to 15%) were the dominant taxa. *Alnus* was the main arboreal taxa, and rose to 15%. *Betula* and *Pinus* were present but in low quantities (between 5%-10%). Ericaceae and *Empetrum* were present (15% and 10% respectively). *Salix* and *Ranunculus* were observed in small quantities (<5%). Charcoal was low (5%) but consistently present.

8.5. Interpretation

8.5.1. Sedimentary History and Bog Development

Through pollen analysis, lithostratigraphy and radiocarbon dating, a picture of bog development can be gained (Figure 8.12). The basal lithostratigraphic units (1-4) of fine and coarse sands indicate the bedrock geology of the Lower Greensand beneath the present day bog (Gallois, 1965). Organic matter and organic lake sediment (units 5 and 7) is interspersed by sand (units 6, 8 and 9), potentially at a time when there was a slight destabilization of the slopes on the edges of the bog, either through increased storminess or changes in vegetation cover (Orme et al., 2016). A large period of lake sedimentation is then observed (units 10, 11, 12 and 13) and deposition of lake sediment continues to the Late Glacial and Early Holocene boundary. High values of *Potamogeton* at this time suggest a body of still or slow flowing water (Fitter, 1987). Cyperaceae would have been present on the edges of this water body, and is a species observed in tundra and arctic regions (Chapin and Chapin, 1980). A shift from *Potamogeton* to *Myriophyllum* may suggest shallowing of the water body (Fitter, 1987).

From the onset of the Holocene (units 14-16) an increase in herbaceous peat and organic remains was recorded. The organic matter may have been derived from the decomposition of *Sparganium*. *Sparganium* would have grown in the shallow water margins of the lake (Cook, 1961), and its presence may indicate a reduction in the size of the open water body and the gradual development of peat encroaching from the lake margins. *Equisetum* could have also grown in damp marshy soils around the lake edges (Clapham et al., 1987). Above this unit, a date of ~3000 cal. BP from unit 21 suggests a major hiatus has occurred at some point in the core. This hiatus was identified at a large sand band (units 17 and 18) due to major changes observed within the pollen stratigraphic record. Units above the hiatus suggest increased mineral deposition into the bog with clays, silts and sand in-washing (units 19-23). High quantities of *Alnus* pollen suggest that *Alnus*-carr woodland may have been present, as values >25% TLP have been suggested as showing *Alnus* growing within the basin or mire (Huntley and Birks, 1983). A period of wood peat (units 24-28) is then observed and it is likely the surface of the bog was drier at this point. Further mineral input is then observed (units 29-31).

The original site of Elstead Bog A (Figure 8.13) indicates that a small lake was present towards the end of the Late Glacial Interglacial that began to infill with organic lake sediment and reedswamp peat. Stable moss peat accumulation is then observed during the Early Holocene from ~11,450 cal. BP. Drier peat conditions are identified from ~10,450 cal. BP with the development of humified wood peat. A major erosional event occurs with the inwashing of mineral material at ~8530-7720 cal. BP, after which herbaceous and wood peat accumulation continues (Farr, 2008).

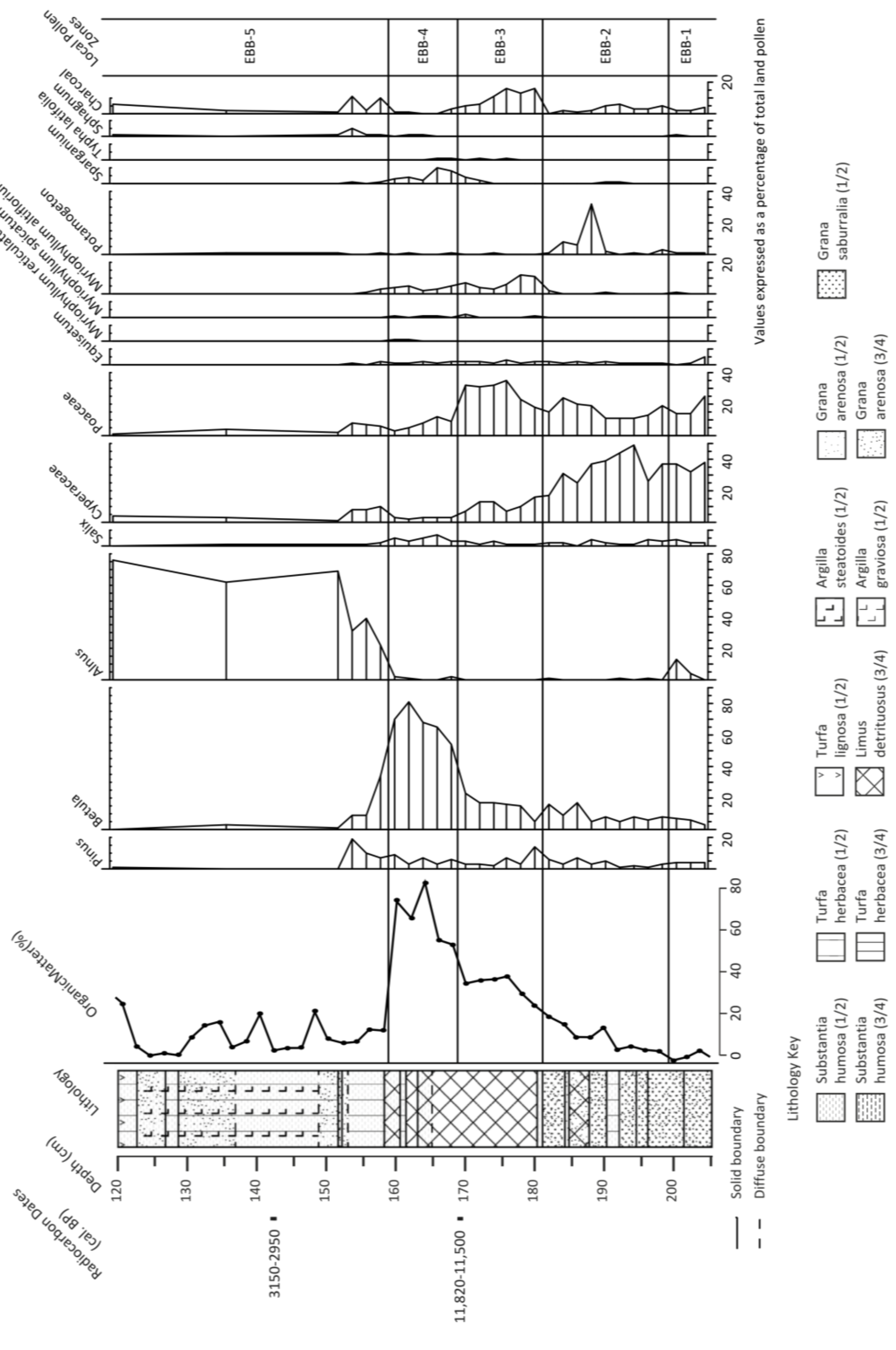


Figure 8.12. Selected taxa, lithostratigraphy and dates from Elstead Bog B highlighting important species related to bog formation.

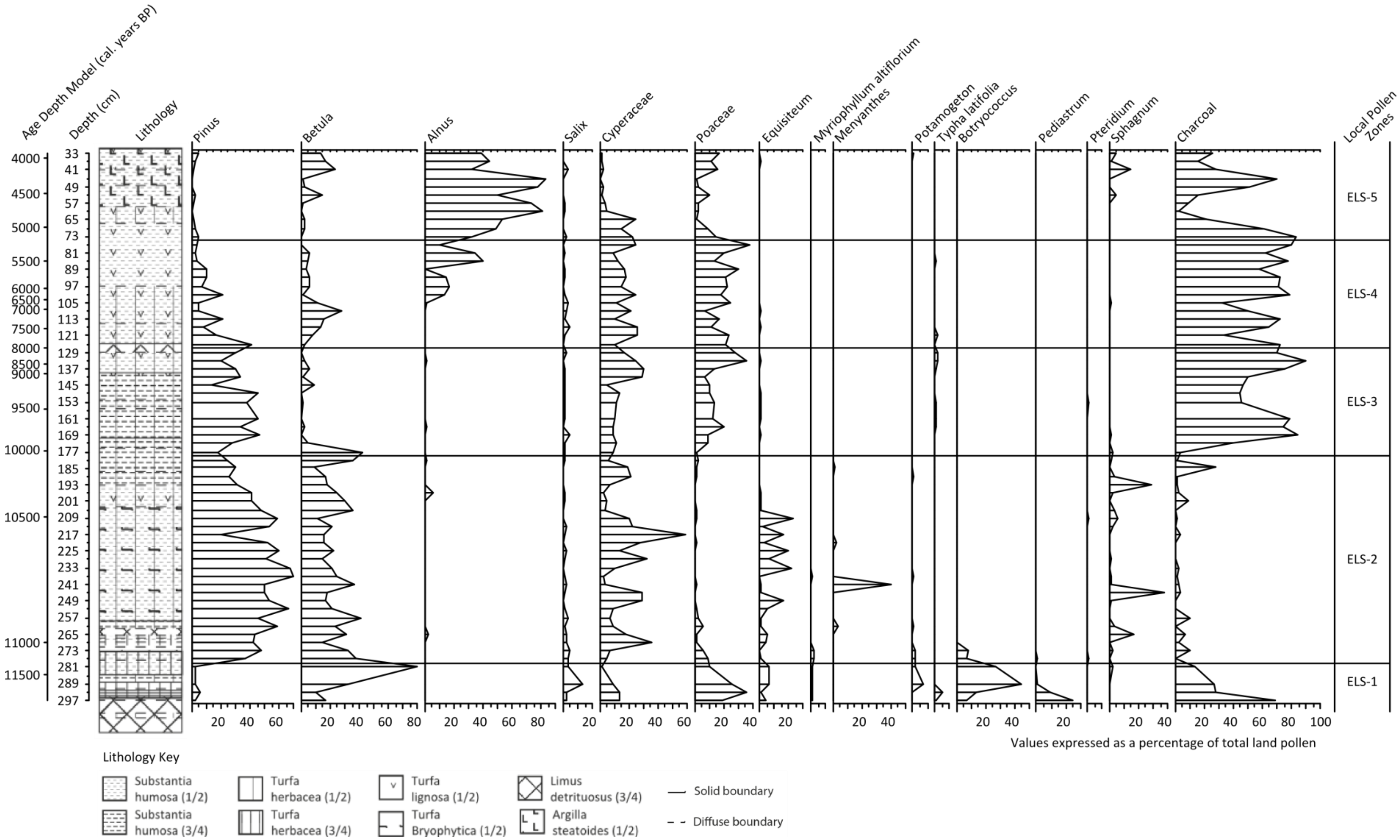


Figure 8.13. Selected taxa, lithostratigraphy and dates from Elstead Bog A highlighting important species related to bog formation.

8.5.2. Vegetation History

Dryland vegetation at the base of the sequence (EBB-1) consisted of Ericaceae, *Empetrum*, *Salix*, *Betula* and *Pinus*. *Salix* and *Alnus* would have been present on moist to wet ground with the *Pinus* and *Betula* likely to have been present across a range of soil types (Averis, 2013). Both *Salix* and *Betula* may have been dwarf species, with *Betula nana* identified in Britain during the Late Glacial (Birks, 1965), and *Salix herbacea* found in arctic conditions in areas of extreme exposure (Pearson et al., 2004) and also identified in British Late Glacial environments (Blackburn, 1952; Beerling, 1998). The presence of *Betula* and *Empetrum* suggests cold climatic conditions may have been present as they are cold tolerant species (Averis, 2013). Ericaceae would have been present on moist slopes and may be present due to its ability to regenerate after fire events (Averis, 2013). Herbaceous taxa consisting of *Ranunculus*, Poaceae and *Artemisia* suggest the potential for an open, cold and disturbed landscape (Clapham et al., 1987; Averis, 2013). It is likely the landscape was very open at this time, with the potential for high wind disturbance due to the sparse tree cover. The high levels of *Betula*, Ericaceae and *Empetrum* corroborate the idea of a relatively open landscape as they are wind tolerant species (Bennett, 1983; Walker et al., 2003), and this open nature potentially led to the increased mineral deposition observed in the basin (Orme et al., 2016).

As the lake develops (EBB-2) the flora remains relatively consistent, as they are all species that can cope with moist ground (Averis, 2013). Therefore the increasingly wetter conditions would not have altered their distribution too significantly. The most significant development in the vegetation is the arrival of *Juniperus*, which is often used as a Late Glacial indicator species (O'Connell et al., 1999) as it is a sub-arctic taxon (Rawat and Everson, 2012), and may suggest that year round temperatures were lower during this period. The landscape is still likely to be dominated by exposed tundra and this period may relate to the onset of the Loch Lomond Stadial, with a deterioration in climate through both a lowering of temperatures and increased precipitation (Lowe and Walker, 2015). In EBB-3, The relatively high *Juniperus* values suggest that the climate was still cold at this time (Rawat and Everson, 2012), and the landscape continued to be relatively species poor. *Calluna* has also been identified in Late Devensian records (Godwin, 1975a) and likely represents a scrubby heathland element. Increases in and high levels of Poaceae, Cyperaceae and *Rumex* suggest disturbed and open ground is still present, as identified at other Loch Lomond Stadial records (Pennington et al., 1977). Woodland would have been sparse, consisting of *Betula* and *Pinus*, with some ferns present in the understorey. At the very end of the zone, the start of a rapid *Betula* increase is observed.

This rapid increase in *Betula* is observed at the boundary between the Loch Lomond Stadial and the Holocene (~11,820-11,500 cal. BP). This *Betula* woodland, alongside *Pinus* (EBB-4), would have been the pioneering arboreal taxa as the climate began to ameliorate (Bennett, 1983; Birks, 1989). *Salix* would likely have been present in wetter areas (Averis, 2013). The decline in Poaceae and other herbaceous taxa suggests that the woodland was closed and little or no understorey vegetation was present (Godwin, 1975b). Post-hiatus (EBB-5) a dramatic increase in *Alnus* was observed, and thermophilous taxa including *Quercus*, *Tilia*, *Fraxinus* and *Corylus* (Averis, 2013) were observed. This appears to be representative of an Early Holocene climax woodland observed at numerous other British sites including the Elstead Bog A site (Farr, 2008) and Hockham Mere (Bennett, 1983), although without further dating and with the issues of disturbance in the upper parts of the core, this cannot be certified.

The pollen record from Elstead Bog A (Figure 8.13) indicates an open ground vegetation community dating to the Late Glacial/Early Holocene boundary. The landscape is characterised by *Betula*, *Juniperus, Salix* and Ericaceae. The site is likely to have been an open pool of water or small lake, undergoing consistent and frequent hydrological changes (Farr, 2008). Pioneer arboreal taxa are identified in the second pollen zone, dating from ~11,000 cal. BP with *Betula* and *Pinus*, whilst *Juniperus* and Ericaceae decline. The canopy is likely to have been fairly dense, identified through a reduction in Poaceae, attributed to a lack of light rather than a lack of pollen transportation due to the open nature on the bog surface allowing for a range of pollen deposition methods at this time (see Figure 5.1). The bog surface through this period is wet, with *Sphagnum* and *Equisetum* present. Thermophilous taxa are first identified from ~10,500 cal. BP. with the initial establishment of *Corylus* and *Ulmus*, followed by *Quercus*. Burning is noted in high quantities from this point. Continued expansion of the deciduous woodland is identified from ~8500-8000 cal. BP with the expansion of *Quercus*, and the identification of *Tilia* and *Fraxinus* from ~7500 cal. BP. The woodland at this time would have been mixed deciduous with an understorey of *Corylus*. Small scale clearings may have been present and woodland clearance may have occurred, with increasing *Betula* potentially indicative of it recolonising bare ground after burning. *Alnus*-carr conditions develop from ~6300 cal. BP with the drying up of the basin surface and a reduction in reedswamp vegetation. Deciduous climax woodland of *Fraxinus*, *Tilia*, *Quercus* and *Ulmus* are present on the dryland at this point (Farr, 2008).

8.6. Synthesis

Field investigations resulted in a 220cm from the Elstead Bog B site, complementing the previously studied site Elstead Bog A (Farr, 2008). The core dated to the Late Glacial and showed vegetation change from the Late Glacial to the Early Holocene in southwest Surrey.

Sedimentation started at both sites with the formation of small water bodies, potentially part of a wider landscape of small depressions within the Lower Greensand. Organic lake sediment then began to fill the bottom of these basins, with the occasional mineral inwashing event. These lakes would have been relatively deep, shown by the presence of *Potamogeton* and *Myriophyllum*, and were present until the end of the Last Glacial period. As climatic amelioration occurred during the Early Holocene, increasing organic matter is deposited in the shallowing lake, likely to have derived from Cyperaceae and *Sparganium* on the edges of the bog and *Sphagnum* across the drier bog surface. In the Elstead Bog B core, a hiatus was identified and it was difficult to fully ascertain deposition above this point. At Elstead Bog A, wood peat was deposited, suggesting a continually drying bog surface where trees were present. An erosional event was observed around ~8130 cal. BP, potentially caused by weather conditions around the 8.2 Kya event and may have led to increased surface runoff. Herbaceous and ligneous peat then continued to accumulate across the Early Holocene.

The Late Glacial vegetation around the two sites was likely to have been relatively species poor, with species adapted to the colder climatic conditions present at the time. *Pinus* and *Betula* would have been present across the landscape, with *Empetrum* and Ericaceae also observed. Open areas interspersed with the thin tree and shrub cover would have been covered with *Ranunculus*, Poaceae and *Artemisia*. *Salix* and *Alnus* would have been present in the wetter areas. *Juniperus* arrived within this tundra-style landscape, which was sparsely vegetated. The onset of the Holocene was identified by the rapid expansion of *Betula*. *Pinus* would have been interspersed with the *Betula* and *Salix* found on wetter ground. There was no understory vegetation present underneath the dense and closed canopy. Thermophilous taxa was recorded with the arrival of *Corylus* and *Ulmus*, along with *Quercus* from ~10,500 cal. BP. *Tilia* and *Fraxinus* then joined this mixed deciduous woodland from ~7500 cal. BP. This mixed-deciduous woodland, alongside the development of *Alnus*-carr on wetter regions from ~6300 cal. BP represented the Mid-Holocene climax woodland in the region.

9. Discussion

This chapter will examine the results of this study in a broader context, drawing information from other palaeoenvironmental, palaeoclimatological and archaeological records. The discussion will assist in understanding peatland development, vegetation succession and human activity in response to climate change during the Late Glacial and Early Holocene in Surrey and southeast England. This will be undertaken chronologically, with the chapter split into three main parts: the Late Devensian Late Glacial, the transition between the Late Devensian Late Glacial and Early Holocene, and the Early Holocene. These results are integrated with the archaeological modelling and previous archaeological research (Wymer and Bonsall, 1977; Ellaby, 1987; Cotton, 2004; Farr, 2008; Wessex Archaeology and Jacobi, 2014). Late Upper Palaeolithic human activity is examined in relation to the Late Devensian Late Glacial (~15,000-11,700 cal. BP); the Early Mesolithic human impact on the environment is scrutinised across the Late Devensian Late Glacial to Early Holocene transition (~12,000-10,000 cal. BP) and the Horsham and Late Mesolithic cultures discussed during the Early/Mid Holocene (~10,300-6000 cal. BP). This will enable an improved understanding of human activity that occurred in and around Surrey during the Late Upper Palaeolithic and Mesolithic cultural periods.

9.1. Late Devensian Late Glacial

9.1.1. Timing of peat formation

The initial onset of peat formation at the four study sites occurred during the Late Devensian Late Glacial, which is atypical as the majority of sites within southeast England do not start accumulating organic sediments until the Holocene (Table 9.1).

The earliest record of peat accumulation is at Ockley Bog, dating to ~14,120-13,850 cal. BP, during the Lateglacial Interstadial, and is the earliest record of peat accumulation in Surrey. Dated to ~14,700-12,900 cal. BP (Bell and Walker, 2005; Lowe and Walker, 2015), the Interstadial is a period of climatic warming from the preceding Dimlington Stadial (~30,000-14,700 cal. BP). The Older Dryas, a short lived climatic downturn, is dated to ~14,000-13,900 cal. BP within the Lateglacial Interstadial (Pettitt and White, 2012b), and correlates with the onset of peat formation at Ockley Bog. Organic sedimentation also started soon after at the nearby site of Thursley Bog, where evidence shows that organic material was present by ~13,330-13,100 cal. BP. There are a few other sites in southeast England and across Britain where organic sedimentation has been identified to both the Lateglacial Interstadial and the preceding Dimlington Stadial (Figure 9.1). The southeast of England during the Lateglacial Interstadial would have been in a zone of discontinuous permafrost or seasonally frozen ground, with a mean annual temperature of between -10 to -0.5˚C (Lowe and Walker, 2015). The onset of the Loch Lomond Stadial (~12,900-11,700 cal. BP) (McDougall, 2001; Shuman et al., 2002; Barrows et al., 2007; Lowe and Walker, 2015) led to colder climatic conditions with maximum mean isotherms in southeast England of 12˚C (Isarin et al., 1998) and discontinuous permafrost (Renssen and Vandenberghe, 2003). The Loch Lomond Stadial is frequently recorded as a period of increased sediment runoff and mineral deposition, recorded as increases of sand in both the Thursley Bog and Ockley Bog sequences. This minerogenic input is attributed to low levels of vegetation cover and high levels of wind erosion. However, two sites within this study (Langshot Bog and Elstead Bog B) have produced evidence for organic sedimentation starting at this time, with continuing organic and minerogenic sedimentation at Thursley Bog and Ockley Bog.

The records highlight various sites with the presence of organic material, particularly peat or lake sediment (gyttja) during the Late Devensian Late Glacial. The earliest records of organic accumulation have been found in the north and west of Britain, including sites in Wales, Scotland and Ireland dating to the Dimlington Stadial. The records from these sites suggest that during the early part of the Lateglacial Interstadial, climatic conditions were cool and dry (Lowe and Lowe, 1989; Hughes et al., 2000). This organic record is predominantly comprised of organic gyttja and minerogenic material, identified in records from Scottish sites including Black Loch (Whittington et al., 1991), West Lomond (Edwards and Whittington, 1997) and Tynaspirit (Sutherland et al., 1993), in addition to a number of other studies in the Northern Scottish Isles. As ice, snow and permafrost retreated from these northerly and western sites, the formation of natural lakes in hollows across the landscape took place, such as in a kettle hole at Tynaspirit (Sutherland et al., 1993).

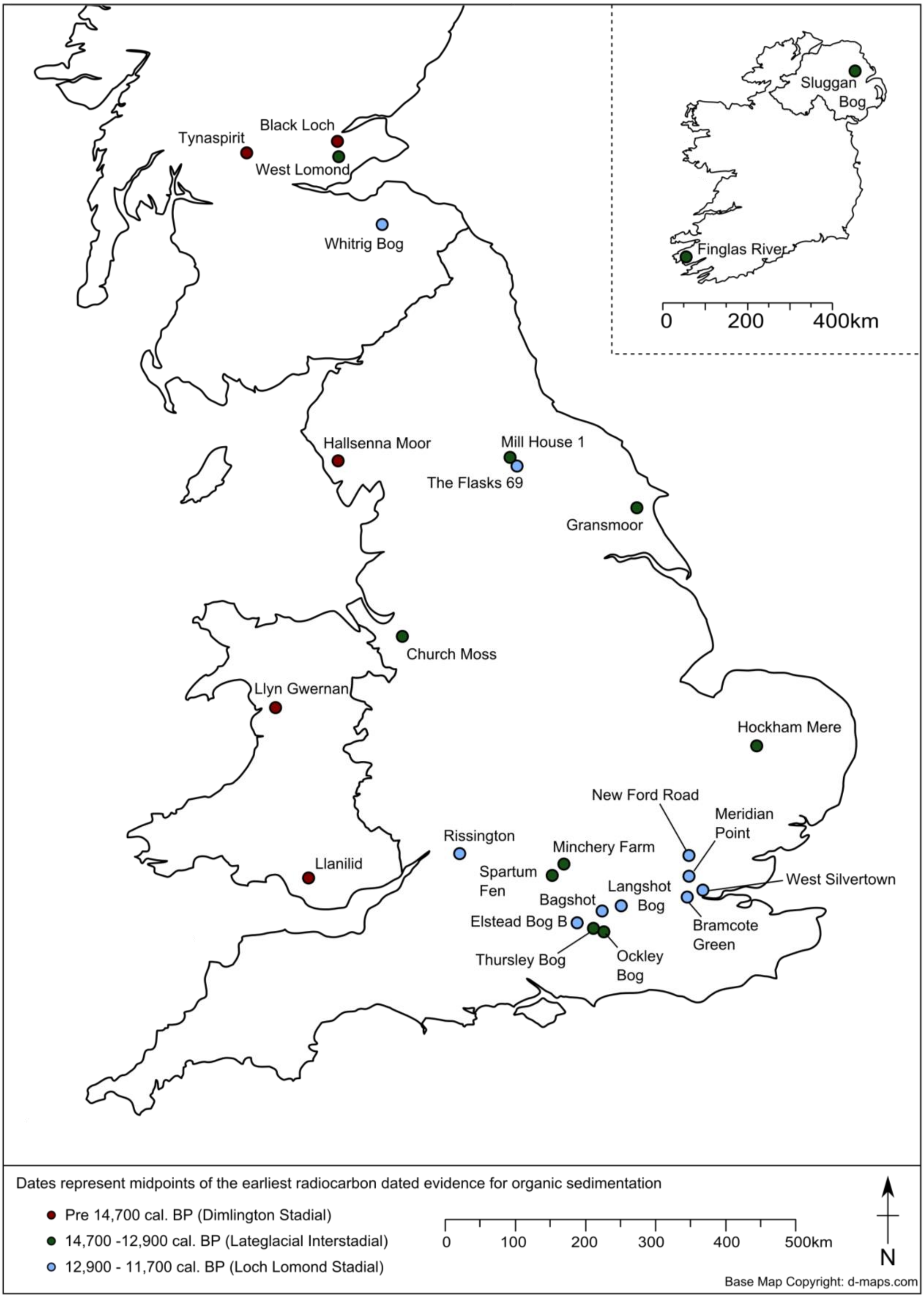


Figure 9.1. Location and date of organic sedimentation onset for sites across England, Wales, Southern Scotland and Ireland (see inset) identified in Table 9.1.

Table 9.1. The first dated occurrence of organic accumulation for selected British and Irish sites.

Site Name	**RC Date**	**Age from (cal. BP):**	**Age to (cal. BP):**	**Broad Period**	**Reference**
Llyn Gwernan	13,300 ± 120 (SRR-1705)	16,340	15,630	Dimlington Stadial	(Lowe and Lowe, 1989)
Hallsenna Moor	13,220 ± 180 (AA-18723)	16,360	15,290	Dimlington Stadial	(Walker, 2004)
Llanilid	13,200 ± 75 (SRR-3455)	16,160	15,560	Dimlington Stadial	(Walker et al., 2003)
Tynaspirit	12,750 ± 120 (Hv-4989)	15,650	14,700	Dimlington Stadial	(Sutherland et al., 1993)
Black Loch	12,670 ± 150 (SRR-2626)	15,550	14,290	Dimlington Stadial	(Whittington et al., 1991)
Spartum Fen	12,660 ± 90 (AA-11607)	15,350	14,570	Dimlington Stadial	(Parker, 2000a; Parker and Preston, 2014)
Hockham Mere	12,620 ± 85 (Q-2203)	15,280	14,490	Lateglacial Interstadial	(Bennett, 1983)
Church Moss	12,450 ± 60 (Beta-93895)	14,990	14,220	Lateglacial Interstadial	(Hughes et al., 2000)
Sluggan Bog	12,330 ± 44 (SRR-6427HNB/ SRR-6427HCA)	14,650	14,090	Lateglacial Interstadial	(Walker et al., 2012)
Mill House 1	12,330 ± 45 (SUERC-8567)	14,600	14,050	Lateglacial Interstadial	(Innes et al., 2009)
West Lomond	12,190 ± 95 (AA-9945)	14,500	13,760	Lateglacial Interstadial	(Edwards and Whittington, 1997)
Ockley Bog	12,112 ± 22 (SUERC-59092/ SUERC-59093)	14,120	13,850	Lateglacial Interstadial	This thesis
Minchery Farm	11,597 ± 33 (SUERC-53119)	13,530	13,315	Lateglacial Interstadial	(Parker and Preston, 2014)
Gransmoor	11,565 ± 85 (AA-12001)	13,620	13,370	Lateglacial Interstadial	(Walker et al., 1993; Turney et al., 2006)
Finglas River	11,120 ± 75 (AA-22388)	13,110	12,790	Lateglacial Interstadial	(Turney et al., 2000)
Thursley Bog	11,053 ± 50 (SUERC-46132)	13,330	13,100	Lateglacial Interstadial	This thesis
Bramcote Green	11,020 ± 60 (Beta-70409)	13,030	12,740	Loch Lomond	(Branch and Lowe, 1994; Thomas et al., 1996)
Whitrig Bog	10,930 ± 95	13,020	12,690	Loch Lomond	(Mayle et al., 1997)
The Flasks 69	10,920 ± 45 (OxA-12997)	12,940	12,830	Loch Lomond	(Innes et al., 2009)
Rissington	10,710 ± 110 (OxA-4150)	12,800	12,400	Loch Lomond	(Wilkinson et al., 1994)
Bagshot	10,672 ± 71 (SUERC-6339)	12,850	12,400	Loch Lomond	(Groves, 2008)
Langshot Bog	10,560 ± 39 (UBA26776/7)	12,650	12,420	Loch Lomond	This thesis
Meridian Point	10,450 ± 80 (Beta-96080)	12,680	12,080	Loch Lomond	(Corcoran et al., 2011)
New Ford Road	10,410 ± 60 (Beta-179972)	12,620	12,070	Loch Lomond	(Corcoran et al., 2011)
West Silvertown	10,310 ± 90 (Beta-101867)	12,800	11,690	Loch Lomond	(Wilkinson et al., 2000)
Elstead Bog B	10,096 ± 25 (SUERC-53815)	11,820	11,500	Loch Lomond	This thesis

The warming at the boundary of the Dimlington Stadial and the Lateglacial Interstadial has been attributed to the northwards migration of the North Atlantic oceanic polar front, allowing warmer water to be present around western Europe and the British Isles (Parker and Preston, 2014). This warming climate would allow the colonisation of trees, shrubs and herbs and may have allowed the short term migration of some tree taxa, especially *Betula* (Parker, 2000b). The presence of organic deposition is likely to be a direct consequence of the warming climate and subsequent increase in biomass (and a reduction in landscape erosion due to improved climatic and environmental conditions). Both Thursley Bog and Ockley Bog began organic accumulation during the Lateglacial Interstadial, with formation of the sites likely to be in small hollows identified across the Lower Greensand, potentially caused by aeolian movement of the Greensand.

Due to the colder and harsher environment during the Loch Lomond Stadial, organic sequences are often mixed with minerogenic material such as at Llanilid (Walker et al., 2003), or a hiatus may be present in the sequence. However Langshot Bog and Elstead Bog B both have organic deposition dating to the Loch Lomond Stadial, and some continuation of sedimentation continues at Thursley Bog and Ockley Bog, suggesting there was sufficient surface vegetation to cause organic sedimentation at these sites. A number of other southern British sites also provide evidence for early organic sedimentation and have been identified as small hollows in the landscape where pools developed, such as the sites in the Lower Lea Valley (Corcoran et al., 2011). Palaeochannels have also been recorded (Wilkinson et al., 1994; Turney et al., 2000), with these open water bodies leading to the formation of taliks, areas of unfrozen permafrost often found underneath and near to water bodies (Huggett, 2007). There is also evidence for a relatively warm southern climate displayed at a number of sites, such as Brook, Kent which shows high humidity levels during the Loch Lomond Stadial, potentially related to increasing sea levels, with mean annual temperatures around freezing (Kerney et al., 1964). *Pinus* pollen and molluscan records from Hampshire and Dorset (Godwin, 1956) suggest that the mean summer temperature would have been around 12°C and the presence of *Corylus* at both Thursley Bog and Ockley Bog indicate that the climate was not too cold to permit the growth of thermophilous shrubs. Permafrost requires mean annual air temperatures to be in the range of -4 to -6 ˚C or lower for at least several decades, and the presence of channels and pools of water suggest the temperature was not averaging lower than 0˚C (Lowe and Walker, 1997) although there may have been seasonal freezing and thawing cycles (Kerney et al., 1964). These areas of unfrozen ground might have provided more hospitable places for the growth of vegetation and led to the deposition of organic matter in the records from Surrey and southern Britain generally.

As with the Lower Lea Valley sites, Langshot Bog may also have formed within a natural depression within the landscape, as the area across Chobham Common is naturally undulating and the sandy nature of the Bracklesham Beds may have led to an ideal environment for aeolian transportation of sand. The presence of lake sediments at the base of some sequences, although not in the deepest sections of the basin, may indicate the presence of a small palaeochannel or isolated ponds within areas of the depression. The basin shape at Elstead Bog B also suggests that it may have formed from a small hollow present within the Greensand, however, the nearby site of Elstead Bog A has been attributed to the collapse of a relict cryogenic mound (RCM) or 'pingo', due to the identification of a rampart around the bog margins (Carpenter and Woodcock, 1981; Farr, 2008). This is the only identified RCM in the southeast (Watson and Morgan, 1977; Hutchinson, 1980; Carpenter and Woodcock, 1981; Bryant and Carpenter, 1987; Ballantyne and Harris, 1994) apart from a potential site in central London where no rampart has been identified (Hutchinson, 1980). There was no obvious rampart at the Elstead Bog B site although this may be due to the manipulation of the surface from the 17/18th centuries onwards. A number of units at the base of Elstead Bog B are currently interpreted as limnic sediments, and appear to date to a similar time as those from Elstead Bog A, potentially suggesting a similar formation pattern. Therefore further work identifying periglacial landscape features would help to understand the nature of the landscape in this region during the Late Devensian Late Glacial. It is not thought that any of the other sites are likely to have derived from RCM's due to a lack of identified ramparts and the timing of organic sedimentation, as the accumulation of organic matter during the Loch Lomond Stadial occurs at a time when any RCM would be growing. Other sites dating to the period, such as Hockham Mere, have not been attributed to cryogenic mound collapse due to both the size of the basin and the lack of a surrounding rampart (Bennett, 1983). Other sites also exist in East Anglia with sediments thought to be of Late Glacial age, however many are undated, such as Lopham Little Fen (Tallantire, 1953), Sea Mere (Hunt and Birks, 1982; Bennett, 1988) and Old Buckenham Mere (Godwin, 1968). Others such as Saham Mere (Bennett, 1988) have issues with their radiocarbon chronologies which make it difficult to understand the formation of the organic sequences.

The four records identified within this study have helped to understand the timing of peat formation in the Late Devensian Late Glacial across Surrey and across southeast England.

Ockley Bog and Thursley Bog show that during the Lateglacial Interstadial, ameliorating climatic conditions allowed for the deposition of organic sediments prior to a slight increase in mineral matter, potentially representing the Loch Lomond Stadial. Both Langshot Bog and Elstead Bog B indicate that organic sedimentation was occurring during the Loch Lomond Stadial. These records are important because they permit improved understanding of the Loch Lomond Stadial vegetation history in southeast England. When compared to other records from Britain, the onset of peat development in the southeast, including the four Surrey sites and other sites such as Bagshot (Groves, 2008) and Spartum Fen (Parker and Preston, 2014) appear to be later than identified in the north and west, such as at Llyn Gwernan (Lowe and Lowe, 1989) and Hallsenna Moor (Walker, 2004). This is potentially attributed to early warming along the Atlantic coast (Parker and Preston, 2014). The continued organic sedimentation and peat deposition at southern sites during the Loch Lomond Stadial could be attributed to more favourable, slightly warmer climatic conditions in the south than the north and west of Britain (Isarin and Bohncke, 1999), where these seaboard regions experienced the greatest degree of cooling (Isarin et al., 1998).

9.1.2. The Palaeoenvironment of the Late Devensian Late Glacial Period

Through the analysis of the Surrey sites and examination of other Late Devensian Late Glacial period sites across Britain and Ireland it has been possible to develop our understanding of vegetation history (Figure 9.2). This is of importance due to the paucity of well-dated sites that provide information on vegetation succession during this period throughout Britain, and especially in southeast England. The Ockley Bog sequence provides a record dating back to the Dimlington Stadial, where the record highlights the dominance of open ground with only patchy tree cover comprised of some *Juniperus, Betula* and *Salix*. Although this is thought to be representative of a broadly local signal due to the small size of the basin leading to a relatively small pollen source area (likely to be less than 50m) (Jacobson and Bradshaw, 1981), it is similar to the records from Hallsenna Moor (Walker, 2004), Llyn Gwernan (Lowe and Lowe, 1989) and Gransmoor (Walker et al., 1993).

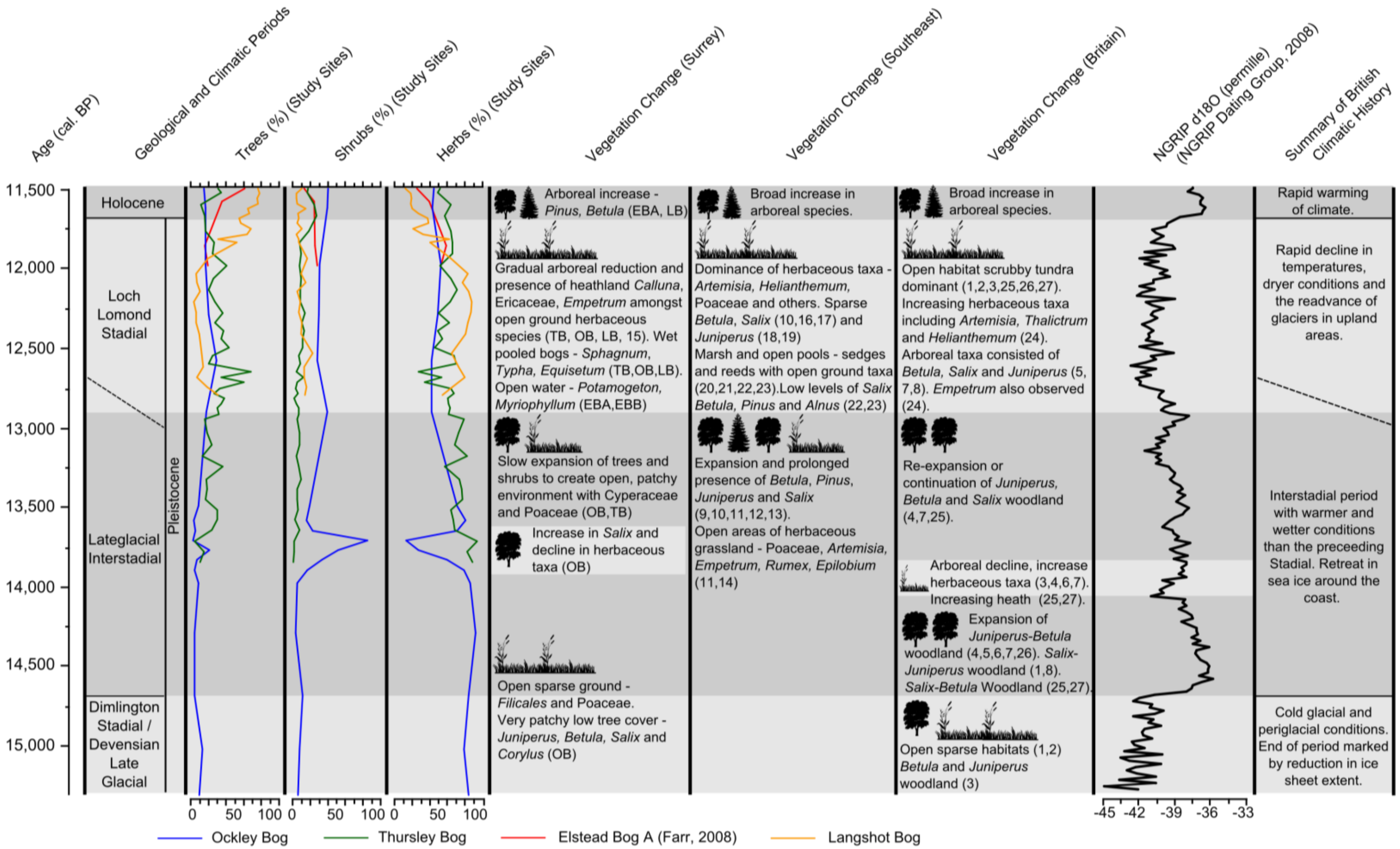


Figure 9.2. Vegetation and climate synthesis for the Late Glacial. Numbers and abbreviations refer to sites as follows: ***OB- Ockley Bog; TB – Thursley Bog; LB – Langshot Bog; EBA – Elstead Bog A*** *(Farr, 2008);* ***EBB – Elstead Bog B***. ***1 - Hallsenna Moor*** *(Walker, 2004);* ***2 - Gransmoor*** *(Walker et al., 1993);* ***3 - Llyn Gwernan*** *(Lowe and Lowe, 1989);* ***4 - Mill House 1*** *(Innes et al., 2009);* ***5 - Hockham Mere*** *(Bennett, 1983);***6 - Church Moss*** *(Hughes et al., 2000);* ***7 - Llanilid*** *(Walker et al., 2003);* ***8 - Finglas River*** *(Turney et al., 2000);* ***9 - Minchery Farm*** *(Parker and Preston, 2014);* ***10 - Spartum Fen*** *(Parker and Preston, 2014);* ***11 - Brook*** *(Kerney et al., 1964);* ***12 - Rissington*** *(Parker, 2000a);* ***13 - Church Moor*** *(Parker and Preston, 2014);***14 - Sevenoaks*** *(Preece, 1994);***15 - Bagshot*** *(Groves, 2008);* ***16 - Northmoor*** *(Shotton et al., 1970);* ***17 - Standlake*** *(Sandford, 1965);* ***18 - Bramcote Green*** *(Thomas et al., 1996; Branch and Green, 2004);* ***19 - Holywell Coombe*** *(Preece and Bridgland, 1999);* ***20 - West Silvertown*** *(Branch and Lowe, 1994; Wilkinson et al., 2000);* ***21 - Colnbrook, West Drayton*** *(Gibbard and Hall, 1982);* ***22 - New Ford Road*** *(Corcoran et al., 2011);* ***23 - Meridian Point*** *(Corcoran et al., 2011);* ***24 - The Flasks 69****, (Innes et al., 2009); 25 -* ***Sluggan Bog*** *(Walker et al., 2012); 26 -* ***Tynaspirit Bog*** *(Sutherland et al., 1993); 27 -* ***Whitrig Bog*** *(Mayle et al., 1997).*

Both the Ockley Bog and Thursley Bog records provide dated evidence for the Lateglacial Interstadial. The local landscape around the two small basins would have been dominated by herbaceous taxa including *Filicales* and Poaceae, alongside some *Juniperus, Betula* and *Salix*. The presence of *Juniperus* indicates that there may have been relatively high July temperatures of 10°C (Kolstrup, 1980), with Coleopteran analysis indicating mean summer temperatures of up to 17˚C across the British Isles (Coope et al., 1998). An earlier and greater expansion of the woodland is identified at other Lateglacial Interstadial sites consisting of *Betula* and *Juniperus* or *Salix* (Figure 9.2). During the Lateglacial Interstadial, a short period of deteriorating climatic conditions has been identified at 14,000 cal. BP (Björck et al., 1998; Rasmussen et al., 2014) by a decline in δ^{18}O isotopic values in the Greenland ice core data (Björck et al., 1998; Rasmussen et al., 2014), known as the Older Dryas event (or Greenland Interstadial-1d) (Björck et al., 1998). Through the analysis of Coleopteran data, a shift towards cooling conditions was identified at this time from Whitrig Bog (Lowe et al., 1999), and chironomid data identified similar trends from Abernethy Forest and Loch Ashik (Brooks et al., 2012). At Whitrig Bog, a sharp decline in temperature of up to 3˚C has been recorded (Brooks and Birks, 2000), which is supported by data from other Scottish sites (Edwards et al., 2000). Coleopteran and chironomid data should be on a similar timescale to other forms of proxy evidence such as pollen data, as studies have shown that for major climatic events (such as the Loch Lomond Stadial) hardly any biotic lags occur between plant and animal species within a sampling resolution of 8-30 years (Ammann et al., 2000). Across Britain, palynological evidence for the Older Dryas has been identified at Llyn Gwernan (Lowe and Lowe, 1989); Sluggan Bog (Walker et al., 2012); Llanilid (Walker et al., 2003); Mill House 1 (Innes et al., 2009) and Church Moss (Hughes et al., 2000) and dated to ~14,000-13,800 cal. BP. At these sites, the Older Dryas was represented by an increase in herbaceous taxa, particularly sedges and grasses. At Ockley Bog, decreases in *Pinus* and *Salix*, and increasing Cyperaceae values occur at this time. At Sluggan Bog a rise in *Betula* and *Salix* identifies a return to Interstadial conditions at ~13,800 cal. BP (Walker et al., 2012), similar in timing to the *Salix* rise at Ockley Bog.

This expansion and rapid contraction of *Salix* at Ockley Bog is thought to represent a very local signal, potentially related to local stabilisation (and subsequent destabilisation) of the bog surface due to warming conditions, after which there is a steady expansion of trees and shrubs, including *Betula* and *Corylus*, potentially representing continued dryer and warmer conditions. Coleopteran records indicate the mean temperature of the warmest month may have been as high as 14.5˚C (Coope et al., 1998), with chironomid data from Hawes Water in Northern England indicating a maximum temperature of 13.4°C (Bedford et al., 2004), similar to the modern day UK mean warmest month temperature of 14.7 ˚C (Kendon et al., 2016). The presence of *Corylus* within the Late Glacial (both the Lateglacial Interstadial and in lesser amounts in the Loch Lomond Stadial) at Thursley Bog, Ockley Bog and Langshot Bog is highly significant. *Corylus* is not often identified in sediments that pre-date the Holocene (Birks, 1989), although it has been found at a handful of sites including Minchery Farm (Parker and Preston, 2014), albeit often only in low pollen values (1-5%) (Huntley and Birks, 1983). Previously its presence has been attributed to long distance transportation, contamination or re-deposition (Huntley and Birks, 1983), however the high quantities of *Corylus* at Ockley Bog suggest this is not the case. *Corylus* was previously thought to have expanded in Britain during the Early Holocene through transport by water currents from Western Europe (Huntley and Birks, 1983). The potential for this *Corylus* to actually be *Myrica*, due to difficulties distinguishing between *Corylus* and *Myrica* (Punt et al., 2002), is also not thought to explain this early *Corylus* curve. This is because it is likely that the majority of *Corylus/Myrica* pollen identified during the postglacial can be attributed to *Corylus* (Godwin, 1956; Walker, 1975) and there are no definitive records of *Myrica gale* macrofossils during the Late Glacial in Britain, with the earliest found at Wareham (Seagrief, 1959; Skene et al., 2000) and thought to date to the Early Holocene. The early identification of *Corylus* at Thursley Bog and Ockley Bog may relate to its distance from glacial refugia, which for *Corylus* has been tentatively suggested as the Bay of Biscay (Huntley and Birks, 1983), in addition to sites in the Alps such as Lago Piccolo di Avigliana where *Corylus* was present from ~13,700 cal. BP (Finsinger et al., 2006b). The locality of the southeast English sites, being closer to known refugia than other sites in the north and west of the country, may have meant that *Corylus* was able to reach southern Britain and establish itself during the Lateglacial Interstadial, and the migration rates of 1500m per annum (Huntley and Birks, 1983) would mean that *Corylus* could have reached southeast England from the Alps in under 1000 years. The land bridge connecting Britain and Europe would have also been instrumental in facilitating the movement of *Corylus* and other species into the southeast (Mitchell, 2006). It is therefore possible that *Corylus* was able to migrate and thrive in southeast Britain during the warmer climate of the Lateglacial Interstadial, reaching southern Britain prior to the Loch Lomond Stadial, as observed at Ockley Bog. The presence of *Corylus* may also be related to 'northern cryptic refugia' (Kelly et al., 2010), whereby

Corylus was present at Ockley Bog due to very local favourable conditions, discussed further in Section 9.2.1.4 (Rull, 2009).

During the Stadial, temperatures in the southeast may have been as high as 9-10˚C and may have allowed the small population present at Ockley Bog to survive. This would have been assisted by the broader climatic tolerances of *Corylus* over other species particularly *Ulmus* and *Quercus*, as *Corylus* is more tolerant of drought, cold winters and cool summers (Huntley, 1993).

With this increase in arboreal taxa, there is a corresponding decrease in herbaceous species during the Lateglacial Interstadial. There is also evidence for open pools of water inhabited by *Menyanthes*, with *Equisetum* and Cyperaceae on the water edges. Broadly similar succession patterns can be identified from other sites within Britain (Figure 9.2) although many sites appear to show a greater expanse of woodland than Thursley Bog and Ockley Bog, where *Pinus* levels were low, potentially due to a suppression of the regional signal and an enhanced local signal due to the smaller pollen source area (of less than 50m) at the Ockley and Thursley basins than other sites across Britain. A lack of Interstadial *Pinus* at Bramcote Green has been attributed to the relatively dense *Betula* woodland leading to its suppression (Thomas et al., 1996). It is important to note that both tree and dwarf *Betula* have been identified at Church Moor and dwarf *Betula* has been identified at Whitrig Bog, highlighting the possibility of different *Betula* species inhabiting the environment (Parker and Preston, 2014).

Evidence for a climatic downturn during the Loch Lomond Stadial has been identified in a variety of records. The Loch Lomond Stadial saw a return to colder conditions, with the temperatures colder than any other point since the Dimlington Stadial (Brooks et al., 1997). Coleopteran data (Coope et al., 1998) and plant indicator species (Isarin and Bohncke, 1999) alongside records from Llanilid and Gransmoor suggest that mean summer temperatures would have been ~10°C with winter temperatures as low as -20°C (Walker et al., 1993; Walker et al., 2003). Chironomid evidence suggests even colder summer temperatures down to approximately 7.5°C at Whitrig Bog (Brooks and Birks, 2000) and Hawes Water (Bedford et al., 2004), although both of these sites are at higher latitudes. This period of rapid climate change is observed across a regional scale through similarities in the vegetation record between Elstead Bog B and Langshot Bog, and a local scale from Ockley Bog and Thursley Bog. The records indicate a vegetation biome similar to cold tundra-style shrubland with short-turf grassland, similar to other sites within the southeast region and Britain generally (Figure 9.2). The larger basin sizes of Langshot Bog and Elstead Bog B and the correlation between the vegetation records of the two sites that are over 25km apart suggest these basins provide a regional signal, whereas Ockley Bog and Thursley Bog provide very local signals. The records indicate that arboreal taxa consisted of *Betula* (potentially the dwarf species *Betula nana*) and small amounts of *Pinus.* There was a localised reduction in *Corylus* at Ockley Bog. It is possible that *Pinus* could be indicative of long distance pollen transportation (Averis, 2013). The sites also provide evidence for the development of patchy heathland, observed through the presence of Ericaceae, *Calluna* and *Empetrum*. *Empetrum* indicates that this heathland would have been growing within a cool and cold climate as it (in addition to *Calluna* and many Ericaceae species) tolerates windy exposed habitats and cool-cold climatic conditions (Averis, 2013). With the lack of tall woodland cover around the Surrey sites, and the relatively flat topographical surroundings, these sites would have been relatively exposed. The sparser woodland matrix and expansion of herbaceous taxa would allow wind and water erosion to cause in-washing of mineral material from the higher slopes that surround all of the basins. This is particularly relevant as both the Bracklesham Beds at Langshot Bog and the Lower Greensand at Thursley, Ockley and Elstead Bogs would have been highly susceptible to erosion. Dwarf shrub heath is currently found in both low and high arctic vegetation (Razzhavin, 2012) such as in northern Fennoscandia (Haapasaari, 1988), indicating the presence of a modern analogue for this vegetation community. Both heathland taxa are also present at Bagshot (Groves, 2008), Llanilid (Walker et al., 2003), The Flasks 69 (Innes et al., 2009) and also in a variety of north-western Europe pollen diagrams (Verbruggen, 1979; Huntley and Birks, 1983; Bohncke et al., 1988; Walker et al., 1994).

The overall levels of arboreal taxa were relatively low at all of the sites during the Stadial, and Poaceae and Cyperaceae, along with other herbaceous taxa, would have been present across much of the open-ground. The presence of Cyperaceae, *Sphagnum*, *Equisetum* and *Typha latifolia* indicate that the wetland/dryland region at Langshot Bog would have been dominated by reedswamps and small pools, and a similar picture is recorded on a local scale from Thursley Bog and Ockley Bog with increasing levels of *Sphagnum*, and at other southeast sites (Figure 9.2). These species corroborate the likely mean annual temperatures present in the southeast at this time of approximately 10°C (Coope et al., 1998; Walker et al., 2003). *Alnus* is also identified in low quantities at Langshot Bog, Ockley Bog and Elstead Bog B during the Stadial, and nearby London sites also indicate its presence, which is important as it is becoming more frequently observed as a wetland component of Late Glacial assemblages (The Museum of London, 2000). The two basins at Elstead would have been small open water bodies during the Stadial, inferred by records of *Potamogeton*, *Myriophyllum*, *Botryococcus* and *Equisetum.* The rise in arboreal taxa at Langshot Bog and Elstead Bog also hint to the possibility that the Stadial was shorter, or the climate began to ameliorate earlier, in the southeast than regions further north, where the onset of arboreal species is thought to be later.

9.1.3. Human activities and impact during the Late Glacial

Late Upper Palaeolithic finds are sparsely represented across Surrey and the southeast of England during the Lateglacial Interstadial and Loch Lomond Stadial, although sites have been identified dating from the Creswellian through to the Terminal Upper Palaeolithic (Figure 9.3).

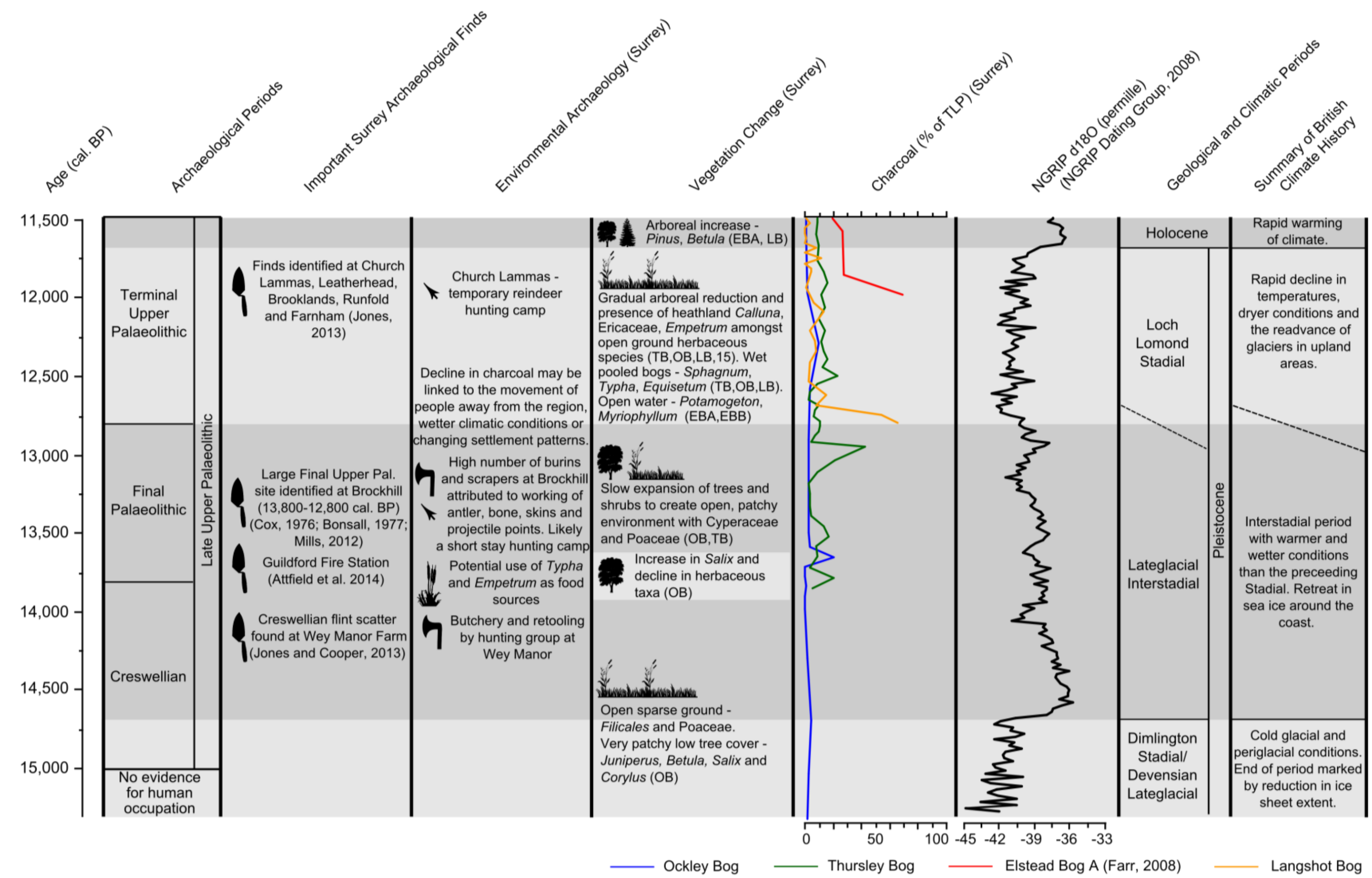


Figure 9.3. Synthesis of Late Glacial archaeological evidence from Surrey, alongside climatic and vegetation history.
OB- Ockley Bog; TB – Thursley Bog; LB – Langshot Bog; EBA – Elstead Bog A *(Farr, 2008);* ***EBB – Elstead Bog B; 15 - Bagshot*** *(Groves, 2008).*

Creswellian flintwork (15,000-13,800 cal. BP) is characterised by distinctive lithic forms, including Cheddar and Creswell points and found unmixed at only a handful of sites (Barton, 1999) (Figure 9.4). In the southeast, two shouldered and truncated points and three other flints found at Oare in Kent are thought to represent a findspot of Creswellian culture (Jacobi, 1982; Pettitt and White, 2012a; Barton, 2009), and a scatter of ~400 flints including Creswellian and Cheddar points at Wey Manor Farm appears to represent a butchery and retooling location (Jones and Cooper, 2013), potentially centred around a hearth. Evidence for small scale burning is recorded at Ockley Bog, where low levels of microcharcoal are recorded during the Creswellian (Figure 9.3), although there is no evidence for any further interaction with the vegetation at this time. Scattered shouldered point finds have also been identified at Stonewall Park, Romsey (Huxtable and Jacobi, 1982), Wandsworth and Wallington (The Museum of London, 2000). Hunting during the Creswellian may have been through the use of Creswellian and Cheddar points, thought to be utilised as knives (Butler, 2005). The open landscape conditions (herbaceous taxa >80% of TLP) at Ockley Bog during the Creswellian period may have assisted with this form of hunting, as the landscape would be more quickly and easily traversed whilst chasing prey than if the landscape was wooded or forested. More broadly across Britain, evidence suggests most stays would have been more than brief visits due to the identification of hide working and other time-intensive processes (Barton, 2009). Evidence for a non-sedentary lifestyle is provided at the cave sites of the southwest, where there is evidence for non-local sea shells and pieces of Baltic amber (Charles, 1989), and it may be that materials were either exchanged between groups, or long distance trips were undertaken to acquire them (Barton, 1999).

The movement of people across the landscape may help to explain the lack of interaction with the vegetation cover, as even though people would have been present for more than brief visits, these timescales were not long enough to cause long term vegetation modification. The burning record from Ockley Bog may lend credence to this theory, as although burning is identified within the record, it does not appear to be to the extent that it causes long term change to the vegetation composition.

Final Palaeolithic sites (~13,800-12,800 cal. BP) are more abundant than Creswellian sites, with less bias towards caves, and flintwork has a greater diversity with curved-backed points, blades and penknife points (Figure 9.4). The site of Hengistbury Head dates to the start of the Final Upper Palaeolithic and is likely to be the largest site of the period found in Britain (Pettitt and White, 2012a). Lithics at the site comprise of 649 retouched tools, including scrapers, blades and burins, from a total of 13,419 artefacts (Barton, 1992). These flints and the site's sheltered and concealed location overlooking the Solent River, where the Stour and Avon converge, suggest the site may have been used as a residential hunting location. By comparison, Brockhill is an open air site with an assemblage of backed blades, burins and end-scrapers in southern England (Jones, 2013a), and is typologically dated to ~13,800-12,800 BP (Smith, 1924; Smith, 1925; Hooper, 1933; Cox, 1976; Bonsall, 1977a; Bonsall, 1977b). The site is situated in a relatively flat topographical location, and overlooks Parley Brook, a tributary of the River Bourne (Mills, 2012). The prevalence of scrapers, shouldered and straight-backed points and burins suggest the site may have been used as a short stay hunting camp, with a focus on the processing of large fauna and/or hard organic materials (Cotton, 2004; Mills, 2012). Recent excavations at Guildford Fire Station (Attfield et al., 2014) have also identified a Final Upper Palaeolithic site situated near to the River Wey, with two or three flint clusters and over 5550 artefacts. Blades, scrapers and burins are all present within the assemblage, as are two curved backed bi-points of Federmesser type (Attfield et al., 2014). The distinctive tool types are thought to have developed as a direct response to the increasing afforestation of the British Isles around this time (Barton, 2009). Bone and antler items are often found as an additional part of the hunting equipment, and are frequently thought to be projectiles (Barton, 2009). The general afforestation is identified at both Thursley Bog and Ockley Bog where *Betula* woodland is expanding, and may provide weight to the hypothesis of increasing hunting with projectiles during this period due to the increasing density of woodland making other hunting techniques less efficient (Barton, 1999). During this period, there is no evidence for any manipulation of the woodland or long term change in the vegetation cover, suggesting that the primary modification was to hunting techniques rather than changes to the vegetation cover.

It is thought that during the Final Palaeolithic, people began to increasingly utilise the vegetation as a source of food, with the consumption of fruits, seeds, fungi and berries, in addition to a wider variety of mammal species (Barton, 2009). Both at Ockley Bog and Thursley Bog there is evidence for a variety of species present in the landscape, with the potential for *Corylus* exploitation at Ockley Bog as *Corylus* increases during this period. This change in subsistence is thought to have occurred as boreal forest supports a lower biomass than tundra style steppe, and it is important to not be reliant on specific faunal species that may suffer collapse.

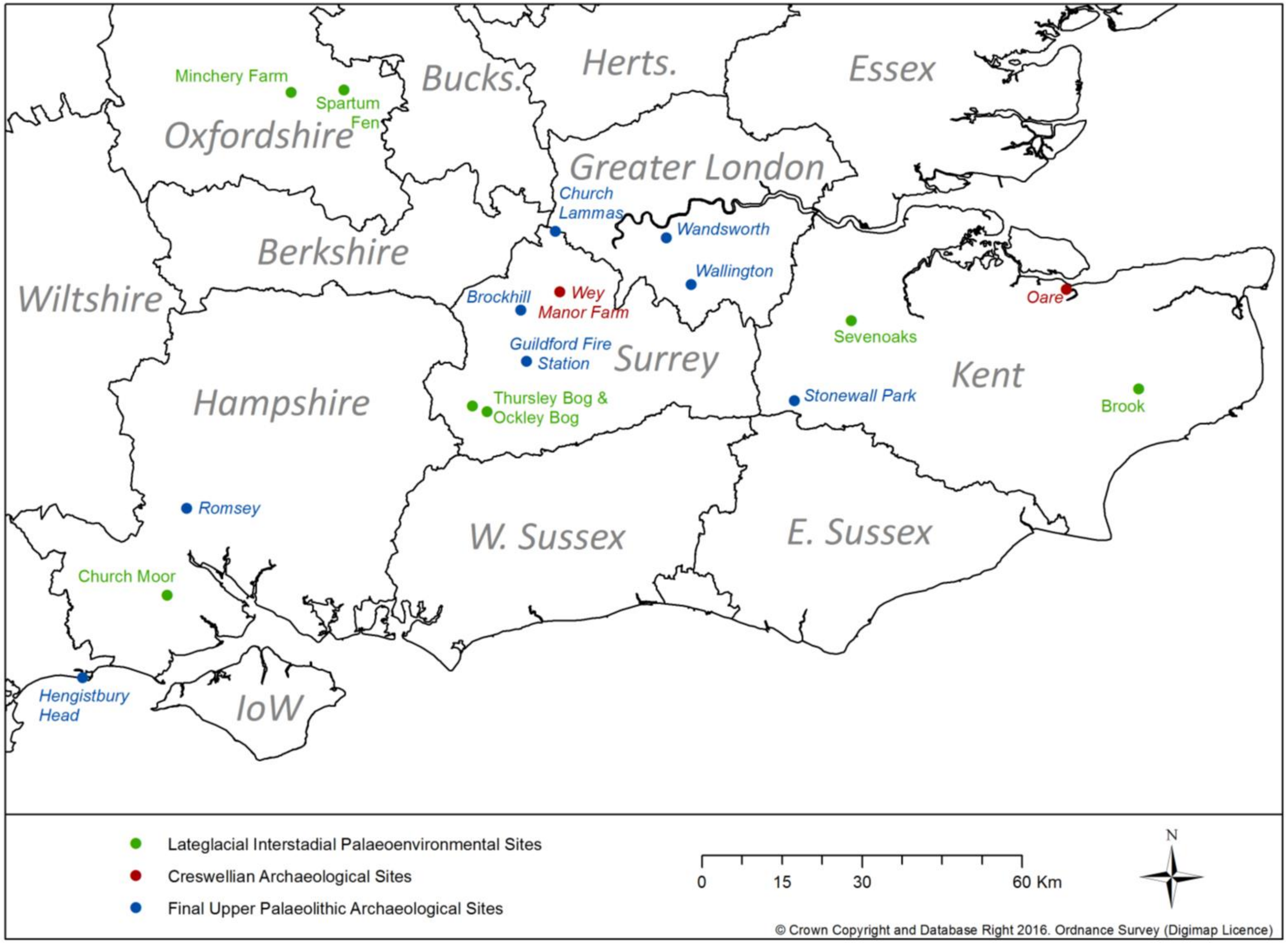


Figure 9.4. Creswellian and Final Upper Palaeolithic sites and their relationship to Lateglacial Interstadial palaeoenvironmental sites.

The palaeoenvironmental record during the Final Upper Palaeolithic identifies an increase in sporadic burning at both Ockley Bog and Thursley Bog. The presence of burning within palaeoecological records can be attributed to both climatic and anthropogenic causes, and it can be difficult to distinguish between the two (Bell and Walker, 2005). The record from Thursley indicates a high but variable input of microcharcoal from ~13,700 cal. BP, peaking at the end of the Final Upper Palaeolithic where microcharcoal accounts for 20% of the TLP. At Ockley Bog a major increase is identified at ~13,600 cal. BP, and burning was also identified at Minchery Farm (Parker and Preston, 2014), indicated by an increase in magnetic susceptibility and microscopic charcoal. At Minchery Farm the burning was attributed to lightning strikes during the Lateglacial Interstadial and not due to human activity, due to a lack of identified Upper Palaeolithic archaeological evidence in the area surrounding the site. Burning at Holywell Coombe was similarly identified as the product of natural, local fires due to a paucity of known local archaeological evidence (Preece and Bridgland, 1999). Evidence from a series of Lateglacial Scottish sites also have a lack of reliably dated archaeological remains in close proximity, however it is suggested that climate change, differential vegetation cover and potential human activity may all have contributed to the fire signal across Scotland (Edwards et al., 2000). The charcoal records identified at both Thursley Bog and Ockley bog are unlikely to have been caused by human activity due to the paucity of known archaeological records dating to the Lateglacial Interstadial. Evidence for the natural occurrence of wildfires in tundra-style ecosystems has been observed from modern studies (Gowlett, 2016), and the increasing frequency observed at these sites is likely to be due increasing summer temperatures (Wein, 1976; Racine et al., 1985).

Terminal Upper Palaeolithic technology (12,650-11,500 cal. BP) revolved around long-blade technology (>12cm) and opposed platform blade cores (Barton, 2009). The identification of small mammals such as lemmings and pika in dated archaeological contexts (Barton, 2009) corroborate the cold tundra like conditions identified from the vegetation history derived from the Surrey sites. Terminal Upper Palaeolithic finds are often concentrated in southeast England (Figure 9.5) and near to good quality flint sources or within river channels and low lying river terraces (Barton and Roberts, 2004). Hunting was clearly important at the site of Church Lammas, with microliths and burins discovered in two distinct clusters (Jones, 2013c). Reindeer and horse remains were discovered at the site (Cotton, 2004) and the site is thought to be a temporary reindeer hunting camp (Jones et al., 2013). The hunting of reindeer and horse and associated butchery is also thought to have occurred at Three Ways Wharf at this time (Lewis and Rackham, 2011), where small groups of between four and six people would occupy the site for a short period of time. The location of Gatehampton Farm in Goring, near to a natural crossing of the River Thames, would have provided an excellent ambush spot. The site has a large long blade assemblage and is likely to have been used on multiple short occasions as a kill/butchery site (Barton, 1995). The discovery of a small Terminal Upper Palaeolithic assemblage at the site of Rock Common in West Sussex (Harding, 2000) is important as it represents one of the only sites where remains from this period are found separate to the river network. The discovery of long blades at Leatherhead, Brooklands, Runfold and Farnham in Surrey, and Avington VI, Wawcott XII and Crown Acres in the Kennet Valley may also indicate short butchery stays or flint knapping sites (Jones, 2013c). This level of activity in Surrey and wider afield is interesting as it shows that people were clearly active in the landscape. However the palaeoenvironmental records within this study do not indicate a high level of interaction with the vegetation. This may be because the low density of vegetation cover meant there was no requirement for widespread interactions, or any. It may also indicate the relatively small sizes of the groups present, such as groups of up to six people present at Three Ways Wharf, led to a level of environmental modification or interaction with the vegetation that was on a scale too small and localized for it to be picked up in the palaeoenvironmental archives.

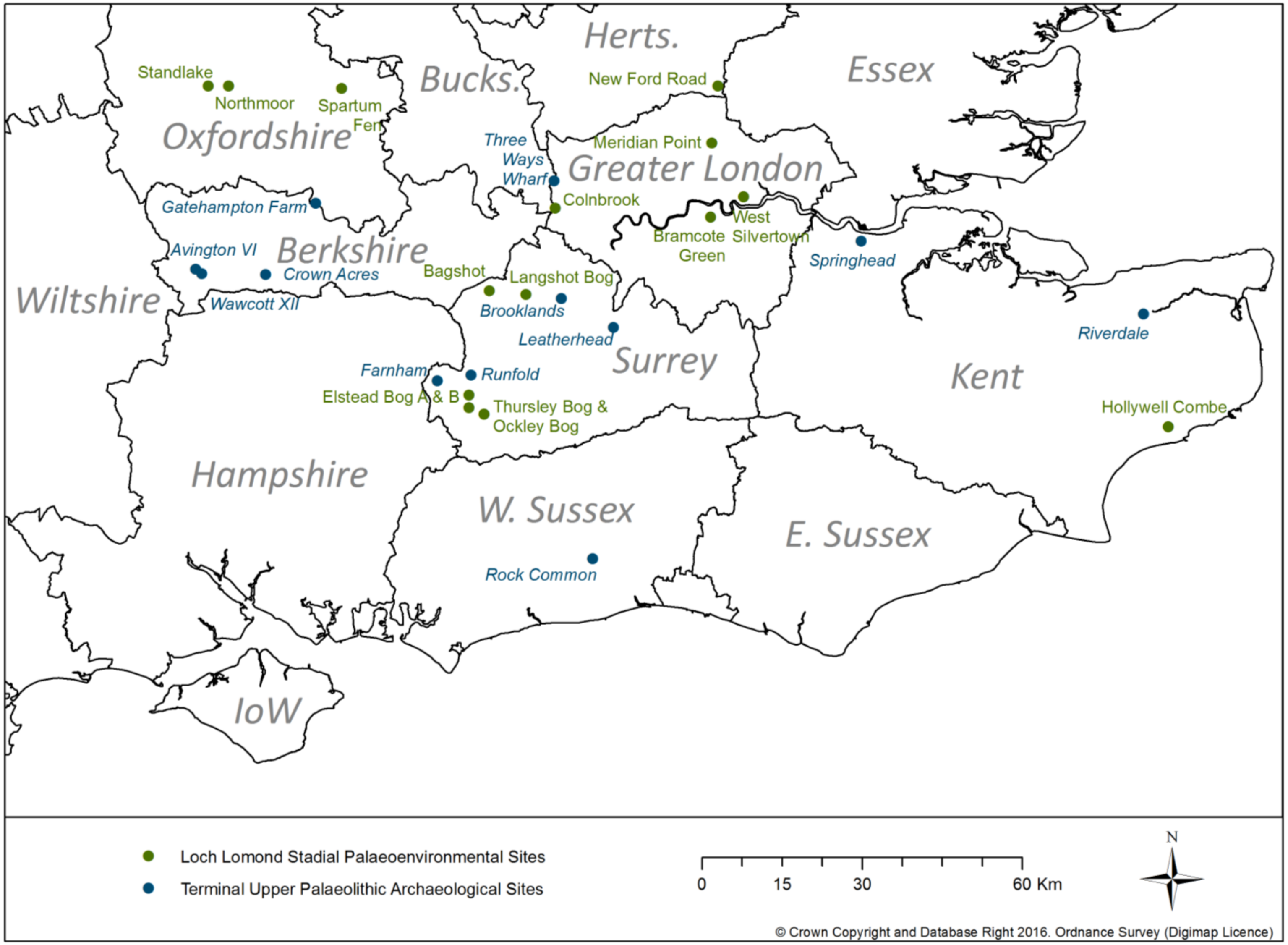


Figure 9.5. Terminal Upper Palaeolithic sites and their relationship to Loch Lomond Stadial palaeoenvironmental sites.

In addition to hunting, which evidence suggests may have been the primary economic driving force at this time (Richards et al., 2000), the wetland/dryland interface zone present around these wetland areas would have provided habitats for plant species that would have been beneficial to humans hunting and foraging near to the sites. The presence of *Typha latifolia* at Langshot Bog during the Loch Lomond Stadial is important as it is a species that can be utilized as a food source (Hardy, 2010). This may have led to the site being an important source of food for the local site of Brockhill during poor climatic conditions, as it is able to be harvested during the winter. The use of *Typha* in order to make flour has been identified at Bilancino, an Italian site dated to the Upper Palaeolithic (Aranguren et al., 2007). *Typha* use has also been identified at the Late Palaeolithic site of Wadi Kubbaniya in Egypt (Hillman, 2015). Ethnographical studies also identify the use of *Typha* in a variety of countries including Asia, American and Australia (Mellars and Dark, 1998; Gott, 1999). The presence of the heathland taxa *Empetrum* during the Terminal Upper Palaeolithic is thought to be due to the hardy nature of the species, tolerant to the windy and poor Stadial conditions. Anthropological studies have observed Inuit people using *Empetrum* as a food source during the winter (Kuhnlein and Receveur, 2007), however when *Empetrum* coverage is low the species is not specifically targeted or manipulated but utilised if required (Pennington and Tutin, 1980).

Terminal Upper Palaeolithic sites often offer no evidence for hearths alongside very little burnt remains, suggesting stays were short lived. Groups are likely to have been hunting migratory animals over fairly large areas (Barton, 2009), with the potential for ambushing animals near river crossings such as at Three Ways Wharf (Lewis and Rackham, 2011). The micro-charcoal records also indicate only a low level of burning at Thursley Bog, Ockley Bog and Langshot Bog, although there is a large decline in Langshot Bog recorded at the start of the Loch Lomond Stadial (Figure 9.3). This may be related to the movement of the Final Upper Palaeolithic group of people away from the area at ~12,800 cal. BP, or may reflect changes in fuel availability as *Betula* woodland declined. Alternatively, it is possible that this presence of charcoal through the Loch Lomond Stadial may have been brought about by the reworking of earlier deposits, especially brought by in-washing of sediments from outside the basin due to an increased frequency of storm events (Birks, 1970; Cundill and Whittington, 1983; Edwards et al., 2000). This does not appear to be the case at these southeast sites however due to the relatively low levels of burning during the preceding Lateglacial Interstadial and an apparent lack of contamination in the pollen record. Interestingly burning identified at other sites within north-western Europe has been closely related to Upper Palaeolithic records in both Germany (Baales and Street, 1996) and the Netherlands (Stapert, 1986; Bos and Janssen, 1996). At the site of Oldeholtwolde in the Netherlands, *Salix* was found within a Late Upper Palaeolithic hearth context (Stapert, 1986), and at Milheeze, shifts from *Pinus* forest to open-ground vegetation has been attributed to Palaeolithic groups, who utilised *Pinus* for firewood, timber and the bark for food (Bos and Janssen, 1996). Within Germany, Upper Palaeolithic hearths were identified across the landscape with very little context for any other human activity (Baales and Street, 1996), likely to represent small scale burning by hunting groups as they traverse the landscape.

The use of palaeoenvironmental sequences has expanded our knowledge of human activity in the environment and has complimented and added information to the archaeological archive. Evidence for human activity in the landscape during the Late Glacial in Surrey was identified at large sites such as Brockhill and Wey Manor Farm, two sites in relatively topographically flat landscapes situated near to river/stream courses. Analysis of both the on-site archaeological remains and local palaeoenvironmental records has shown that Late Upper Palaeolithic groups may have been using fire within the landscape, but not in any widespread fashion, and it is likely that both natural climatic causes, such as lightning strikes, and also small scale anthropogenic activity have led to the burning signals within the palaeoenvironmental records. The natural pools and presence of plant species palatable to animals around sites such as Langshot Bog and other wetlands would have made these regions prime areas for hunting. The presence of burins and scrapers at many of the archaeological records may have been used for the working of organic material, including bone and antler, potentially in the preparation of hunting weapons, and these lithics suggest that both hunting and domestic activities would have occurred in this landscape. The foraging of particular plant species near these wetlands, including *Typha* and *Empetrum*, may also have provided an important source of food, especially during the winter months. Further identification of other Late Upper Palaeolithic artefacts in the immediate vicinity of the wetland sites would assist in further determining the nature of the relationship between humans and wetland regions.

9.2. Late Glacial and Early Holocene Transition

The Late Glacial to Early Holocene transition within this study is broadly defined as the end of the Loch Lomond Stadial through to ~10,000 cal. BP, and it is important as it is a period of rapid climatic warming, where mean annual temperatures may have increased by 1.7-2.8°C per 100 years (Lowe and Walker, 1997). This led to a rapid change in the vegetation composition across the boundary between the Late Glacial and Holocene. The onset of the Holocene is dated to 11,700 cal. BP (Walker et al., 2008), a time when change is also identified in the archaeological record, notably the transition between the Terminal Upper Palaeolithic and the Early Mesolithic dated to 11,500 cal. BP. Within Surrey and the southeast, there is an increase in the volume and spread of archaeological records from the Early Mesolithic onwards, a cultural period broadly spanning 11,500-10,000 cal. BP. Through examining the vegetation present at this time, an indication of the common vegetation taxa present in Surrey and the southeast can be gathered, as can information on the rate of vegetation succession and human interaction with the vegetation.

9.2.1. Vegetation Succession

The four study sites all provide palaeoenvironmental evidence dating to this transitionary period between the Loch Lomond Stadial and the start of the Holocene. This information, combined with data from other palaeoenvironmental records in the southeast allows for the vegetation and general environment to be reconstructed (Figure 9.6), and due to the range of study sites, the vegetation can be reconstructed across local, sub-regional and regional scales (Jacobson and Bradshaw, 1981).

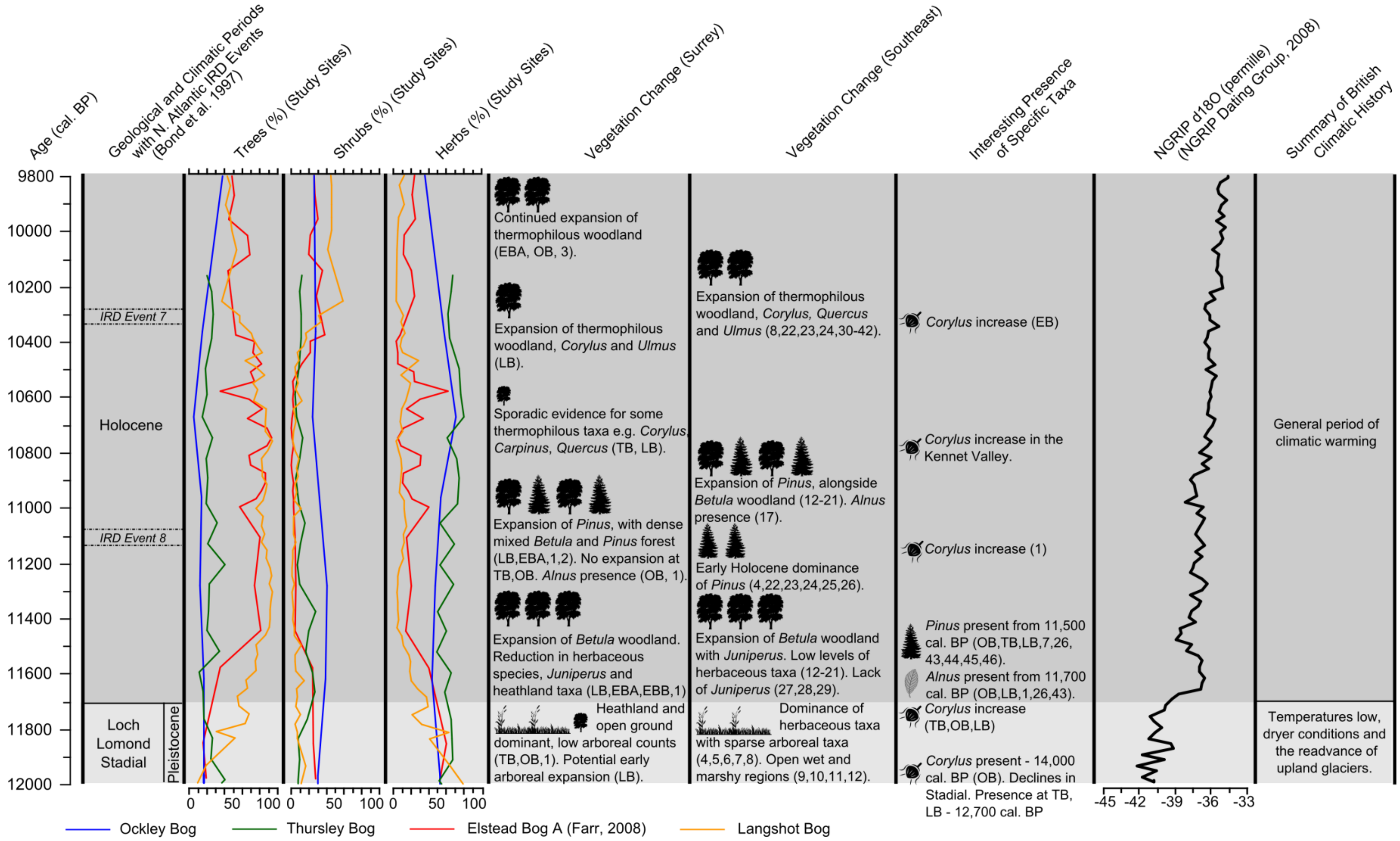


Figure 9.6. Vegetation and climate synthesis for the Late Glacial and Early Holocene Transition. Numbers and abbreviations refer to sites as follows (see overleaf):

OB - Ockley Bog; TB - Thursley Bog; LB - Langshot Bog; EBB - Elstead Bog B; EBA - Elstead Bog A *(Farr, 2008);* ***1 - Bagshot*** *(Groves, 2008);* ***2 - Moor Farm*** *(Keith-Lucas, 2000);* ***3 - Nutfield Marsh*** *(Farr, 2008);* ***4 - Spartum Fen*** *(Parker and Preston, 2014);* ***5 - Northmoor*** *(Shotton et al., 1970);* ***6 - Standlake*** *(Sandford, 1965);* ***7 - Bramcote Green*** *(Thomas et al., 1996; Branch and Green, 2004);* ***8 - Holywell Coombe*** *(Preece and Bridgland, 1999);* ***9 - West Silvertown*** *(Branch and Lowe, 1994; Wilkinson et al., 2000);* ***10 - Colnbrook, West Drayton*** *(Gibbard and Hall, 1982);* ***11 - New Ford Road*** *(Corcoran et al., 2011);* ***12 - Meridian Point*** *(Chambers et al., 1996; Corcoran et al., 2011);* ***13 - Enfield Lock*** *(Chambers et al., 1996);* ***14 - West Quay Road*** *(Godwin, 1940);* ***15 - George V Docks*** *(Godwin, 1940);* ***16 - Portsmouth Harbour*** *(Godwin, 1945; Nicholls and Scaife, 2008; Scaife, 2015a);* ***17 - Panel Bridge*** *(Waller, 1993);* ***18 - Holywell Combe*** *(Preece and Bridgland, 1999);* ***19 - Priory Road*** *(Batchelor and Young, 2015);* ***20 - Fleet and Rownhams*** *(Scaife, 2015a);* ***21 - New Pond*** *(Scaife, 2001);* ***22 - Newbury Sewage Works*** *(Carter, 2001; Chisham, 2004);* ***23 - Woolhampton*** *(Carter, 2001; Chisham, 2004);* ***24 - Thatcham Reedbeds*** *(Carter, 2001; Chisham, 2004);* ***25 - Minchery Farm*** *(Parker, 2000b);* ***26 - West Silvertown*** *(Wilkinson et al., 2000);* ***27 - Cranes Moor*** *(Barber and Clark, 1987);* ***28 - Church Moor*** *(Barber and Clark, 1987);* ***29 - Warwick Slade Bog*** *(Barber and Clark, 1987);* ***30 - Warwick Slade Bog*** *(Barber and Clark, 1987);* ***31 - Wateringbury*** *(Kerney et al., 1980; Garnett et al., 2004);* ***32 - Stonehenge*** *(Scaife, 2015a);* ***33 - Durrington*** *(Scaife, 2015a);* ***34 - Chatham Dockyard and the Medway Tunnel*** *(Scaife, 2015d);* ***35 - Eton Rowing Lake*** *(Parker and Robinson, 2003);* ***36 - Uxbridge*** *(Wessex Archaeology, 2006);* ***37 - Riverside Way*** *(Wessex Archaeology, 2006);* ***38 - Ferry Lane*** *(Scaife, 2004);* ***39 - Three Ways Wharf*** *(Lewis, 1991; Lewis et al., 1992; Lewis and Rackham, 2011);* ***40 - Lewes I and II*** *(Waller and Hamilton, 2000; Waller and Long, 2010);* ***41 - Ufton Green*** *(Chisham, 2004);* ***42 - The Lower Brede and Tillingham*** *(Waller and Long, 2010);* ***43 - Panel Bridge*** *(Waller, 1993);* ***44 - Enfield Lock*** *(Chambers et al., 1996);* ***45 - Surrey House*** *(Batchelor et al., 2012);* ***46 - Priory Road*** *(Batchelor and Young, 2015).*

Across the southeast, mean summer temperatures may have increased by up to 7.5˚C, in comparison to the Loch Lomond Stadial (Coope et al., 1998). These warmer conditions of the Holocene are marked by a rapid increase in *Betula* woodland. Alongside *Betula,* low levels of other arboreal taxa are also identified at the start of the Holocene including *Juniperus, Salix*, *Pinus, Corylus* and *Carpinus*. There is also a decline in herbaceous species, thought to be due to a reduced amount of light from a dense *Betula* canopy. This denser woodland may have also had implications for the pollen recruitment, with denser woodland leading to increased representation of pollen from gravity (i.e. the canopy) and through the trunk space, also leading to an observed (in the pollen record) decline in herbaceous taxa. The heathland species also decline at this time. This increase in *Betula*, and subsequent *Betula* decline and *Pinus* rise is observed across the County from Elstead Bog A, Elstead Bog B and Langshot Bog and all three records identify this rise to the Early Holocene. This is significant as records from the Lower Greensand are similar to the record derived from the Bracklesham Beds, highlighting the regional signal that was also observed during the Loch Lomond Stadial from Langshot Bog and Elstead Bog B. Interestingly, no increase is recorded in the *Betula/Pinus* woodland at Thursley Bog and Ockley Bog; instead an increase in *Corylus* is recorded, highlighting the local signal that these are thought to provide. This is thought to relate to the potential source regions that the different sites represent, whereby the smaller size of both Thursley Bog and Ockley Bog provide a more local record of vegetation (less than 50m), whilst the two Elstead sites and Langshot Bog provide a regional signal (hundreds of metres) of vegetation change. It is important to note the timing of the woodland expansion at Langshot Bog as the levels of arboreal taxa, particularly *Betula,* begin to increase from ~11,900 cal. BP prior to the commonly defined end of the Stadial (Lowe and Walker, 2015). This early date for the expansion of arboreal taxa may suggest earlier Holocene warming, highlighting climatic variation in the Loch Lomond Stadial, as suggested by plant indicator species which identified rising temperatures in the latter half of the Stadial (Isarin and Bohncke, 1999). Chironomid records from Whitrig Bog also indicate a slight warming during the Loch Lomond Stadial (Brooks and Birks, 2000; Brooks and Birks, 2001) and a rise of 2.5°C is suggested from Hawes Water (Bedford et al., 2004).

A further period of warming prior to ~11,000 cal. BP, indicated in the Langshot Bog record by the isotopic data, leads to the expansion of *Pinus*. *Pinus* woodland may have become dominant due to its tolerance to acidic soils (Manning, 1974; Pokorny, 1986), thought to also help the sporadic occurrence of *Corylus* (Groves, 2008). At the sites of Spartum Fen (Parker and Preston, 2014); Minchery Farm (Parker, 2000b); West Silvertown (Wilkinson et al., 2000) and those along the Kennet (Carter, 2001; Chisham, 2004) the dominance of *Pinus* meant that *Betula* did not expand at the start of the Holocene (Figure 9.6). Herbaceous taxa continued to decline as the amount of light available at ground level declined further, although at Ockley Bog and Thursley Bog, the continued presence of some open ground taxa such as Poaceae, *Artemisia*, *Potentilla* and *Helianthemum* suggested openings within the woodland canopy at a more local scale. These patches of more open woodland may have led to increased levels of surface runoff, represented by episodes of mineral sedimentation present at these sites. At some sites, the development of *Pinus* was significantly later, with *Pinus* not dominant at New Ford Road until ~10,400 cal. BP (Corcoran et al., 2011) and *Pinus* expansion not identified until ~9500 cal. BP at the Omega III Works site, and dominance not achieved until ~7200 cal. BP (Corcoran et al., 2011). This is likely to be due to *Pinus* being outcompeted by other species during the Early Holocene. This dominant mixed *Betula/Pinus* woodland continued for up to 1000 years, until ~10,500-10,000 cal. BP. At this time, the colonisation of thermophilous species such as *Quercus*, *Corylus* and *Ulmus* led to a decline in the *Pinus/Betula* forest and expansion of mixed deciduous woodland (Figure 9.6).

The new records from Surrey highlight three species, *Pinus*, *Alnus* and *Corylus*, that are present earlier than their often recorded Early Holocene expansion (Birks, 1989; Branch and Green, 2004). During the Late Glacial it is likely that the majority of thermophilous taxa would have retreated to glacial refugia locations in Europe (Anderson et al., 2007) and their early presence in Surrey and southeast England may be related to the location of those glacial refugia, variable rates of succession and the migration rates of these species.

9.2.1.2. **The *Pinus* Rise**

Pinus has been recorded at all sites in this study, and at a number of other sites in the southeast from the Lateglacial interstadial, considerably prior to the original estimates of *Pinus* suggested by isochrone distribution maps, which indicated *Pinus* presence in southeast England from the Early Holocene (Figure 9.7) (Birks, 1989). *Pinus* (alongside *Abies* and *Picea*) has also been identified dating to the Late Glacial Maximum (LGM) in southwest England, from Bodmin Moor (Kelly et al., 2010). Here it was attributed to the presence of 'cryptic northern refugia' where the species survived during the harsher (but unglaciated) conditions in southwestern England. The presence of Late Glacial *Pinus* in the southeast is likely to be related to local competition, as *Pinus* thrives on acidic soils (Manning, 1974; Pokorny, 1986), which is the dominant soil type present at many of these sites. It is also likely that *Pinus* was not outcompeted by other species at these sites, whereas at other sites, such as Bramcote Green, *Betula* was able to supress the growth of *Pinus* (Thomas et al., 1996). The development and expansion of *Pinus* within Surrey predominantly occurs during the Loch Lomond Stadial, where *Pinus* may have expanded as other species struggled with the downturn in climatic conditions. The expansion of *Pinus* may have originated from the cryptic refugia present at Dozmary Pool on Bodmin Moor during the LGM (Kelly et al., 2010). Long distance transport of *Pinus* pollen is not thought to account for this observed distribution, as at these sites the abundance of *Pinus* is greater than 5% (of the total land pollen assemblage), indicating a local presence of the species.

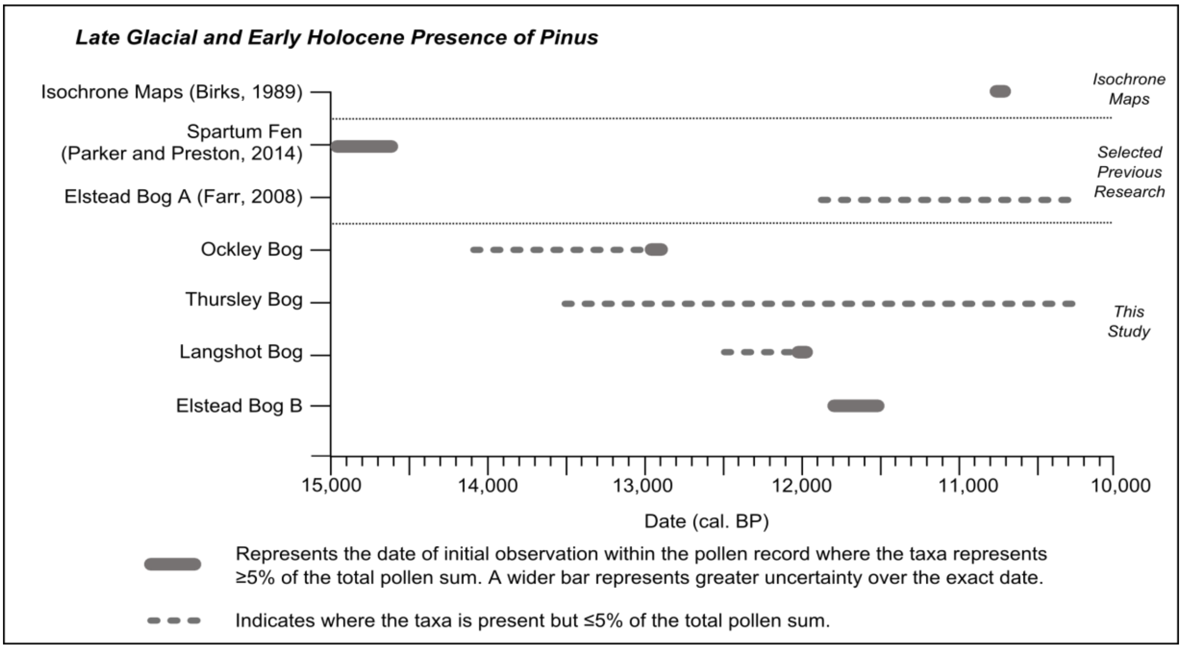


Figure 9.7. Records of Late Glacial and Early Holocene Pinus in southeast England.

The development of *Pinus* woodland at an earlier date than originally indicated may be due to Gatcombe Withy Bed on the Isle of Wight being the sole site where *Pinus* was present and mapped in the southeast (Scaife, 1980b; Scaife, 1987; Birks, 1989). Through utilising a greater distribution of records, a clearer picture of the growth and development of *Pinus* now exists, with a Late Glacial expansion identified in multiple records.

9.2.1.3. The *Alnus* Rise

Alnus has been recorded at Ockley Bog, Langshot Bog and other sites in southeast England during the Late Glacial, a significant discovery as previously *Alnus* was thought to expand during the Early Holocene, at ~9180 cal. BP within the Thames Valley (Birks, 1989). The first evidence for the species dates to ~11,700 cal. BP at Ockley Bog and Langshot Bog (Figure 9.8) and provide a strong indication that *Alnus* was part of the vegetation cover at various sites within the southeast during the Early Holocene where it is likely to have exploited wetter areas (Waller, 1993). Evidence for *Alnus* at this time, and during the Late Glacial, has now also been identified from sites within London, such as West Silvertown (Wilkinson et al., 2000) and in southwest England (Leroi-Gourhan, 1985).

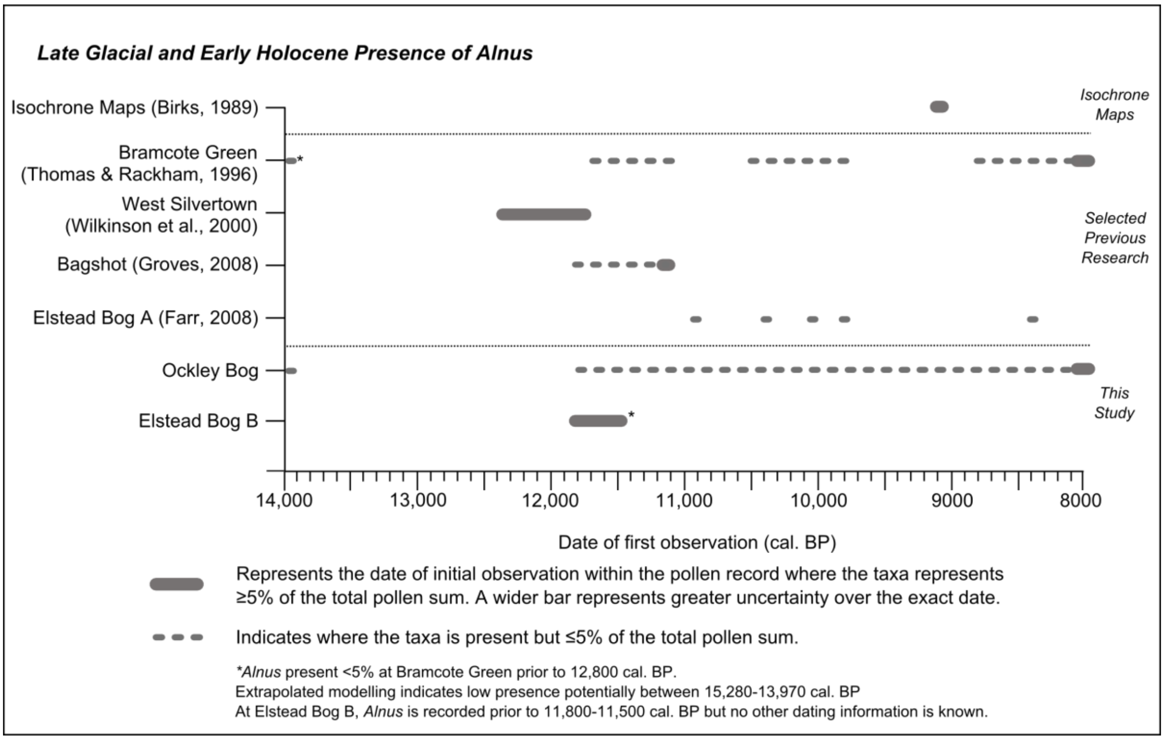


Figure 9.8. Late Glacial and Early Holocene records of Alnus in southeast England.

A similar pattern can also be observed across the British Isles for a Late Glacial and Early Holocene presence of *Alnus*, albeit in low quantities (Birks, 1989). It is possible that the arrival of *Alnus* was from a refugia in western France, utilising marine transport as a means of dispersal at a rate of up to 2km per year (Huntley and Birks, 1983) or there may have been small local refugia communities, particularly in estuarine habitats (Smith, 1984), where it could have survived during the Late Glacial. The scattered nature of *Alnus,* rather than a clear expansion of the species, raises a possibility that *Alnus* may have been more widely spread during the Late Glacial and Early Holocene than previously thought. However, it is likely that *Alnus* was only present in low quantities and subsequently poorly represented (if at all) in many pollen diagrams (Birks, 1989). It is also possible that *Alnus* fruits were dispersed by water across the British Isles, leading to the dispersed and scattered population (Birks, 1989).

9.2.1.4. **The *Corylus* Rise**

Corylus was present at Ockley Bog from the Lateglacial Interstadial, first appearing at ~14,000 cal. BP. A decline is observed during the Loch Lomond Stadial followed by an increase immediately prior to the start of the Holocene (~12,000 cal. BP). The Late Glacial and Early Holocene presence of *Corylus* is also recorded at a number of other sites including Thursley Bog and Langshot Bog (Figure 9.9).

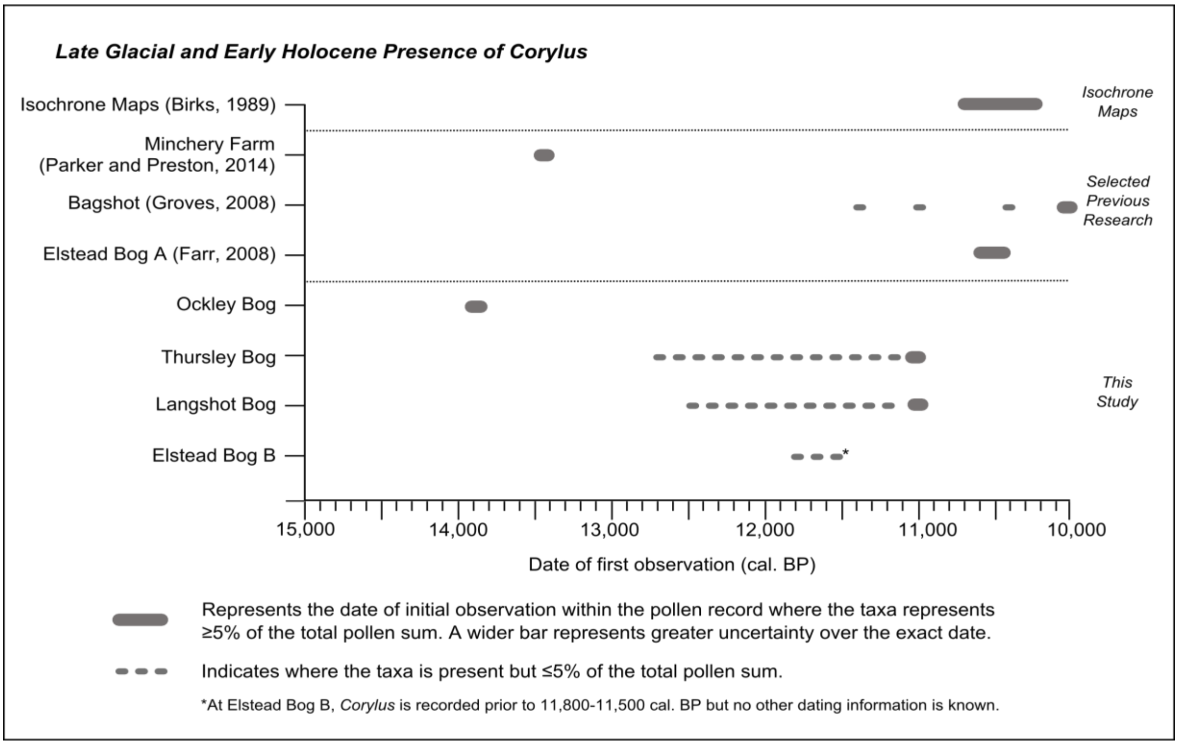


Figure 9.9. Late Glacial and Early Holocene presence of Corylus in southeast England.

Previous studies have highlighted some occurrences where the *Corylus* rise has a noticeable tail, where there is discontinuous cover of ~2% (Tallantire, 2002) as is identified at both

Thursley Bog and Langshot Bog. When species are identified in very low concentrations during the Late Glacial, it is complicated by the potential long distance transport of the pollen or reworking of the record (Huntley and Birks, 1983; Tallantire, 2002; Tzedakis et al., 2013). The high percentage cover identified at Ockley Bog, where *Corylus* occasionally reaches over 10% during the Late Glacial, may suggest that local presence of the species is more likely than long distance transport, similar to the *Corylus* present at Minchery Farm (Parker and Preston, 2014). *Corylus* may also have been identified at this time due to reworking of the sediments, however the continuous percentage of *Corylus* at Ockley Bog does not suggest reworking, as reworked sediment would result in a more variable pattern (Kelly et al., 2010). Periods of sediment influx would be represented by distinct peaks of *Corylus,* with periods of in-situ deposition represented by much lower levels or an absence of *Corylus* pollen. The radiocarbon dates on the sequence also indicates that deposition is in sequence, and reworking has not occurred. This could be further assessed through digging a pit to further examine the sedimentary sequence at the site and increase the chances of identifying plant macrofossils.

It may be that locally favourable conditions at Ockley Bog led to local *Corylus* formation at that site. This presence of *Corylus* at Ockley Bog may represent a 'northern cryptic refugia', (Stewart and Lister, 2001) or 'microrefugia' (Rull, 2010). Microrefugia are locations defined as small regions, where locally favourable environmental conditions allow small populations to survive in regions where they would not normally be expected to, as they are protected from unfavourable regional conditions (Rull, 2009). However, it is thought that temperate species could only have survived south of discontinuous permafrost, and in Western Europe, below 46° north (Tzedakis et al., 2013) although the presence of 'microrefugia' or 'cryptic refugia' has been identified in a range of Western European sites across various species. This has included coniferous species at Dozmary Pool (Kelly et al., 2010), and *Fagus* in Landes de Gascogne (de Lafontaine et al., 2014). At Ockley Bog, *Corylus* may have established itself during the Lateglacial Interstadial, present at a scale too small to identify in regional records, shown through the lack of *Corylus* at this time from the Langshot Bog and Elstead Bog B diagrams. The small stand of *Corylus* at Ockley Bog may have developed due to locally favourable conditions, and subsequently survived the Loch Lomond Stadial. *Corylus* then increased regionally with the onset of warmer conditions at the Early Holocene boundary, as pollen production increased from *Corylus* stands that may have been present in the *Betula* and *Betula*/*Pinus* forests of the southeast, which were initially producing limited amounts of pollen, and did not begin to fully expand until climatic conditions improved (Tallantire, 2002). This might suggest an earlier or quicker warming in this period in the south, as opposed to sites in the north and west of Britain, as tentatively suggested for Langshot Bog.

9.2.2. Human activities and impact during the Late Glacial and Early Holocene

The transition between the Late Glacial and Early Holocene coincides with the onset of the Mesolithic in Britain, more specifically the Early Mesolithic. The Early Mesolithic is well represented across the County, highlighted by the findings from the PaMELA archive (Wessex Archaeology and Jacobi, 2014). In order to explore the nature and scale of human/environment interaction, examination of the archaeological archive, the predictive archaeological maps and important archaeological sites will assist in examining relationships between the Early Mesolithic people and their environment in the Early Holocene.

Within Surrey, sites that only span one phase of the Mesolithic are rare (Cotton, 2004) and when sites are identified, the acidic nature of the soils often means that no bone or antler remains are preserved. Past research (Ellaby, 1987) and the results from the predictive modelling of Mesolithic activity areas indicates that across Surrey, sites are broadly situated on freely draining or fast draining sands, gravels and slope ridges, often within a relatively close distance to a water source or natural resource. The rich diversity of vegetation present across the Lower Greensand, as identified in at Thursley Bog, Ockley Bog and Elstead Bog may also have led to a broader range and diversity of animal species than present in areas with a lower diversity of vegetation (Ellaby, 1987) leading to preferential living and hunting conditions (Rankine, 1949b). Many of the major Early Mesolithic habitation sites in Surrey (Figure 9.10 and Figure 9.11) are identified across the Lower Greensand. There is also clear evidence for long distance movement of people and material exchange between groups, through the identification of a Portland Chert blade at Farnham, which was interpreted as evidence for a large spatial exchange system (Rankine, 1952). In addition to the main domestic settlements and activity sites, there are also a number of Early Mesolithic scatters and findspots across Surrey, potentially representing items lost or discarded during hunting trips or at activity sites (Figure 9.11).

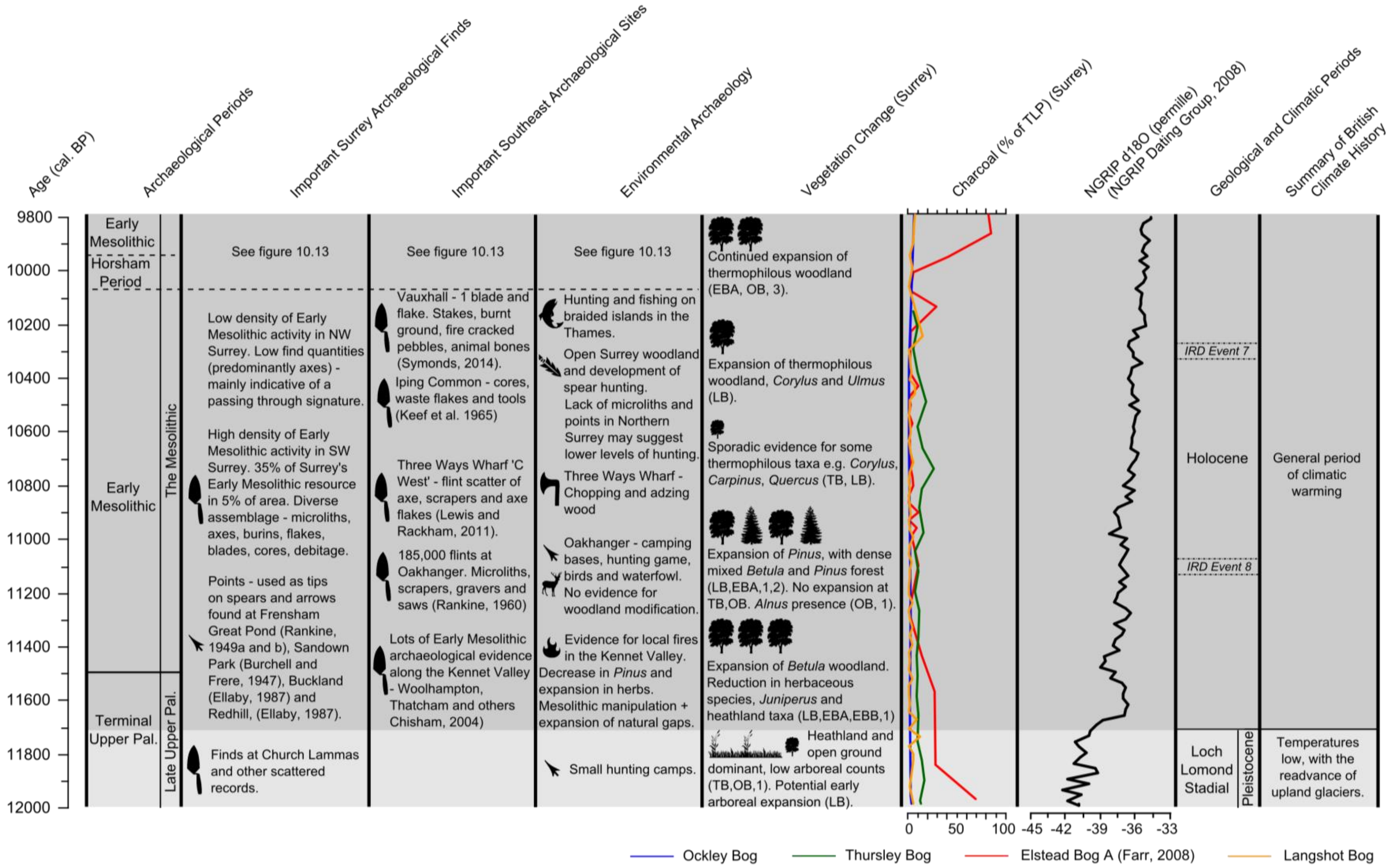


Figure 9.10. Synthesis of archaeological evidence across the Late Glacial and Early Holocene border alongside climatic and vegetation history. ***OB - Ockley Bog; TB - Thursley Bog; LB - Langshot Bog; EBB - Elstead Bog B; EBA - Elstead Bog A*** *(Farr, 2008);* ***1 - Bagshot*** *(Groves, 2008);* ***2 - Moor Farm*** *(Keith-Lucas, 2000);* ***3 - Nutfield Marsh*** *(Farr, 2008).*

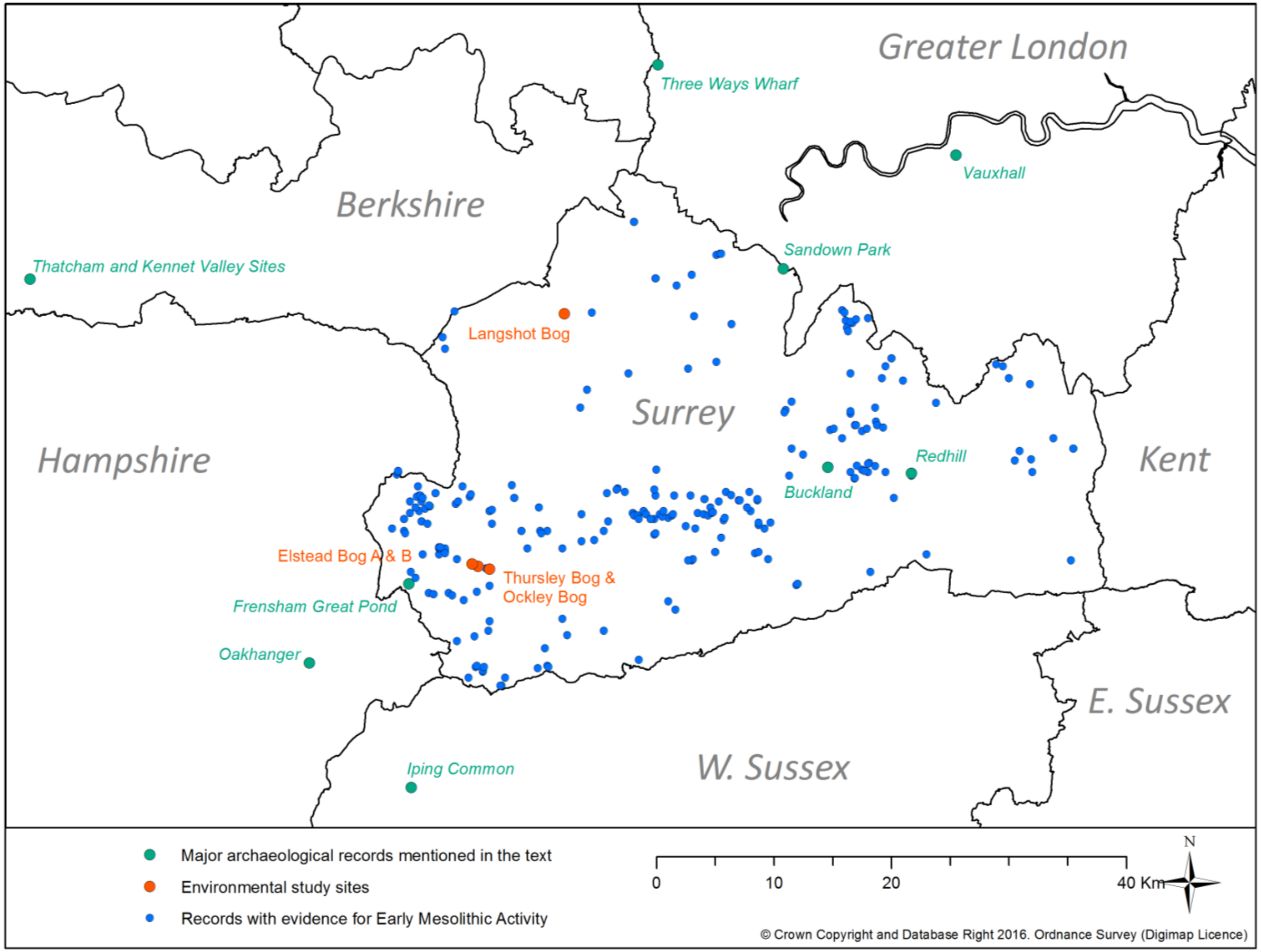


Figure 9.11. Archaeological and environmental records mentioned in the text dating to the Early Mesolithic.

Examination of the archaeological records from the PaMELA dataset highlights a distinct difference in the distribution of archaeological material across the County. Hotspot mapping from both the PaMELA and HER datasets suggests that the north of the County has a low density of Mesolithic material, and this is placed into context with only 8 records within 10km of the Langshot Bog site identified as being Early Mesolithic (Wessex Archaeology and Jacobi, 2014) (Figure 9.11). All but one of these finds are indicative of a passing through signature due to the low quantities of artefacts, whilst one potential occupation site at Wishmoor in Camberley, where there was the presence of burning, has evidence for 1 microlith, blades, flakes, spalls and burnt flint. Averaging the pixel values of the predictive models indicate that in a 10km region around Langshot Bog, there is only a 33% likelihood of this region being a highly used activity area. All records indicate a lack of microliths and points, which may indicate both that these lithics and associated tools may have been made elsewhere and transported to and from these hunting zones, or it may potentially be indicative of a lower level of hunting in this region (Figure 9.10). A potential lack of both hunting and settlement may be related to the local vegetation cover, as the record from Langshot Bog indicates a period of woodland expansion during the Early Mesolithic. A lack of herbaceous taxa also indicates dense woodland and there is no evidence for local fires. This may have meant the region was less frequently visited as the vegetation made it harder to traverse the landscape and hunt animals. It is likely that across the north of Surrey there was a small Early Mesolithic presence, potentially related to visits where people were moving across the landscape on hunting trips or resource gathering, indicated by small discard type finds, with the landscape not broadly utilised as an area suitable for settlement sites, possibly due to a lower density of raw material availability than elsewhere in the County, and due to the fact that much of the north is classified with a total wetness index of very wet, which may not be as conducive to settlement as wet/dry regions towards the east and south of the County.

Records from the south of the County, particularly southwest Surrey, show a much higher level of Early Mesolithic activity. Within 1km of Thursley Bog, Ockley Bog and Elstead Bog A & B there are 2 records of Early Mesolithic date and within 3km this has risen to 11 records. There are 25 records at 5km and 94 Early Mesolithic records within 10km of the sites (Figure 9.11). These 94 records account for 35% of all Early Mesolithic records in the Surrey PaMELA database, in an area less than 5% of the total County area. The predictive models corroborate this high level of activity, with 69% likelihood for identifying Mesolithic archaeology in the 5km region around the sites. It is possible that the high density of records relates to a southwest Surrey collection or study bias, however it is unlikely to fully account for the high level of activity as many other regions of Surrey have had substantial archaeological excavations (often development led, such as housing developments around Woking) and not produced such dense quantities of Early Mesolithic activity. These records include 26 findspots, 39 lithic scatters, 4 lithic working sites and 2 sites and indicate a diverse assemblage, with microliths, tranchet axes, burins, flakes, blades, cores and débitage. This diversity of assemblage suggest a sustained presence around these sites, possibly as both settlements and task sites, such tool and weapon production sites.

This diversity of assemblage type and the presence of sites may be related to the vegetation cover. At Thursley Bog and Ockley Bog, the presence of *Corylus*, a light-loving taxon and the herbaceous species *Ranunculus, Potentilla, Thalictrum, Artemisia,* and *Helianthemum* suggest open woodland or small clearings within the woodland matrix. This open woodland may have been more advantageous to hunting and settlement, leading to the wider abundance of lithics in the southwest of the County that reflect a hunting signal, such as points used for spears and arrows (Ellaby, 1987). The region is also heavily dominated by ground that is on a wet/dry interface (as indicated by the total wetness index), which was highlighted by the modelling as being a region favoured by Mesolithic groups. It is likely that a variety of hunting techniques and other survival practices such as plant foraging and fuel acquisition may have been used around these wetland/dryland interface regions. At the two Elstead Bog sites, the onset of the Holocene and the Early Mesolithic are concurrent with an expansion of dense *Pinus* and *Betula* woodland and a low level of herbaceous taxa. Small bodies or pools of water would have been present at both Elstead sites, as indicated by the aquatic taxa present at this time. The presence of small lakes or ponds may have also attracted animal species, making them ideal hunting spots, which is supported by the presence of >100 microliths present in >20 records within 5km of the sites. The location of archaeological sites near to wetland/dryland interface zones has often been identified, such as around the Early Mesolithic site of Oakhanger in Hampshire (Rankine et al., 1960) and at Star Carr (Mellars and Dark, 1998). At Star Carr, a clear signal of the presence of *in-situ* burning of reedswamp at the wetland/dryland interface was identified. This manipulation of the wetland/dryland zone was attributed to human activities due to the localized and high frequency of the burning, with declines in grass cover identified during periods of increased burning. An anthropogenic cause for this burning is not unexpected, as groups at the site would likely want to maintain a clear view of the lake and opposite bank in order to track game or to observe other human groups, and burning would provide an easier method for this clearance than hand-cutting of the reeds (Mellars and Dark, 1998). A similar pattern of small increases and declines in charcoal and *Poaceae* pollen as identified at Star Carr can be observed at Thursley Bog during the Early Mesolithic, potentially suggesting small scale manipulation of the wetland/dryland vegetation in Surrey, although similar signals are not observed from the other sites in this study. Manipulation of the woodland through fire was recorded at Thatcham in the Kennet Valley, where localised fires were thought to have caused a decrease in local *Pinus* cover and a subsequent increase in herbaceous species (Chisham, 2004). This was potentially for the creation of natural clearings and to subsequently manage their shape and size. The distinct lack of modification in the cover of *Corylus* at Thatcham has been attributed to specific targeting to cause deliberate growth of the edible species. Similar evidence for the possible exploitation of *Corylus* has been found at Woolhampton where the rise in charcoal coincides with the *Corylus* rise (Collins et al., 1996b; Chisham, 2004). Such woodland management is less evident at the Surrey sites. However the high number of axes or adzes (43 in total from 72 records) in the local 5km area around the Thursley Bog, Ockley Bog and Elstead Bog sites suggest the potential for local woodland management by Early Mesolithic groups, a pattern also identified at Three Ways Wharf 'C West' (Lewis and Rackham, 2011).

Overall, within Surrey and more broadly across the southeast, it appears that there were only minimal levels of woodland modification, but it is highly likely that Early Mesolithic populations maximised the use of woodland and open areas through hunting and food gathering. The proximity of diverse Early Mesolithic activity around the Elstead sites, and both Thursley Bog and Ockley Bog, may have been due to the regional geology and topography of the south, providing a diverse range of habitats including lakes and wetlands, which would have provided excellent opportunities for hunting and gathering of foodstuffs. Elstead Bog A and B may both have been small ponds or lakes during the Early Mesolithic and these would have been attractive areas for hunting animals that may have used the sites as a water source. In addition to this, open woodland around Thursley Bog and Ockley Bog would have been more conductive to living, moving and hunting, indicated through the diverse array of lithic types in southwest Surrey.

9.3. The Early-Mid Holocene

The Early-Mid Holocene is often identified by thermophilous deciduous woodland expansion as the climate ameliorated towards the Mid-Holocene thermal maximum at ~6000 cal. BP

(Davis et al., 2003). Climatic deterioration has been detected within this general amelioration between 9000-8000 cal. BP in a number of records (Prasad et al., 2006; Mayewski et al., 2004), thought to peak in intensity at 8200 cal. BP (Bond et al., 1997). In the southeast, change is also identified in the archaeological record, where developments in Mesolithic tool styles were recognized. This occurs at ~10,000 cal. BP, with the development of the Early Mesolithic subset, the Horsham Culture. This was followed by the Later Mesolithic (Bell and Walker, 2005) dating from ~9600-6000 cal. BP (Switsur and Jacobi, 1979; Barton and Roberts, 2004; Tolan-Smith, 2008; Collard et al., 2010; Woodbridge et al., 2014) and evidence for Mesolithic activity at these times is widespread across Surrey. Through examination of the archaeological record, modelling and examination of the vegetation history, a picture of how these groups lived and interacted with the landscape can be created.

9.3.1. Vegetation succession

The nature of vegetation succession during the Early-Mid Holocene is provided from the Ockley Bog, Langshot Bog and Elstead Bog A sequences, as well as a number of other sites within Surrey and southeast England (Figure 9.12).

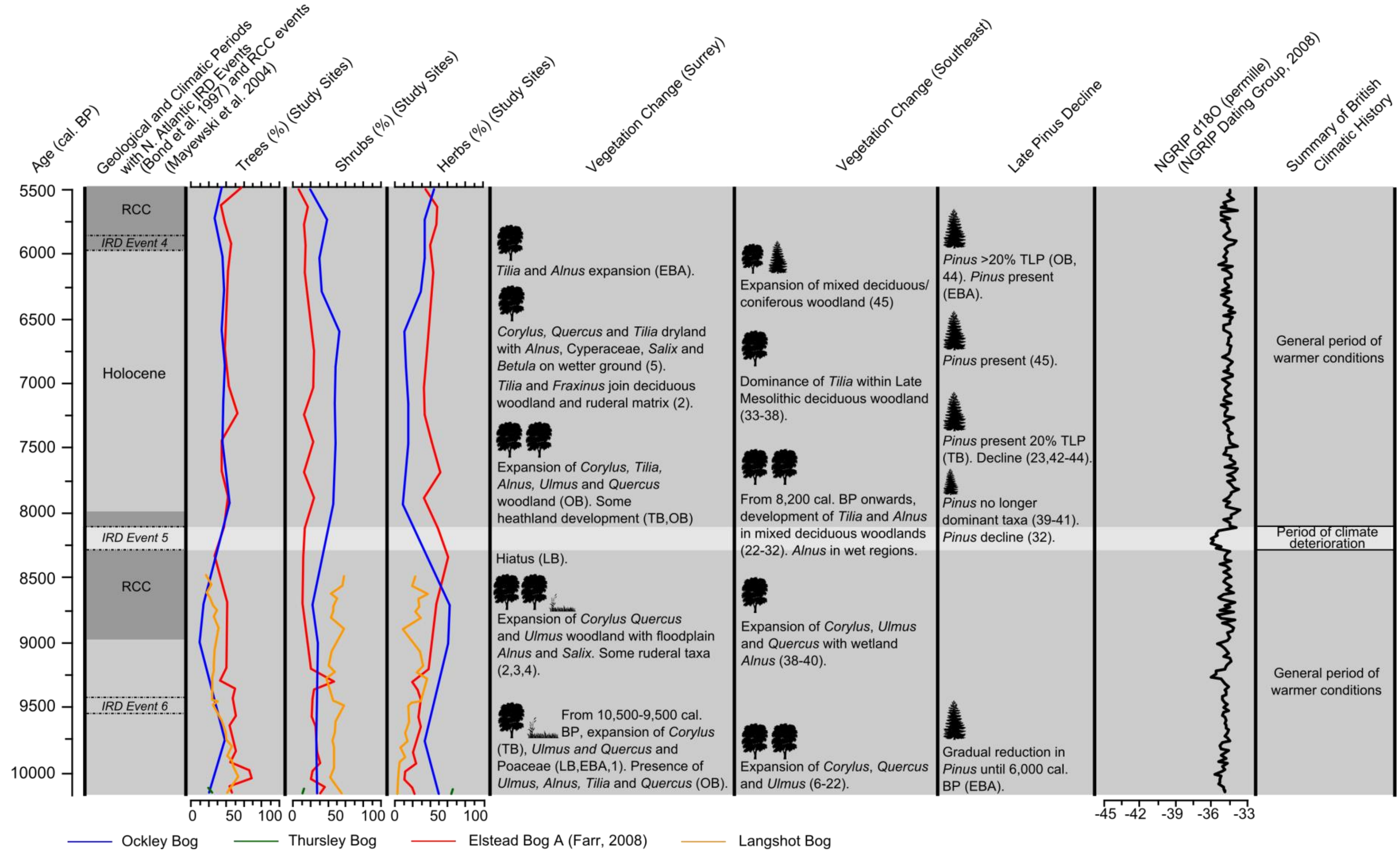


Figure 9.12. Vegetation and climate synthesis for the Early-Mid Holocene. Numbers and abbreviations refer to sites as follows (see overleaf):

***OB - Ockley Bog; TB - Thursley Bog; LB - Langshot Bog; EBA - Elstead Bog A** (Farr, 2008);* **1 - Nutfield Marsh** (Farr, 2008); **2 - Runnymede Bridge** (Scaife, 2000a); **3 - Bramcote Green** (Branch and Lowe, 1994); **4 - Farm Bog** (Jennings and Smythe, 2000); **5 - Bagshot** (Groves, 2008); **6 - Holywell Coombe** (Preece and Bridgland, 1998); **7 - Warwick Slade Bog** (Barber and Clark, 1987); **8 - Wateringbury** (Kerney et al., 1980; Garnett et al., 2004); **9 - Stonehenge and Durrington** (Scaife, 2015a); **10 - Chatham Dockyard and the Medway Tunnel** (Scaife, 2015d); **11 - Eton Rowing Lake** (Parker and Robinson, 2003); **12 - Uxbridge** (Wessex Archaeology, 2006); **13 - Riverside Way** (Wessex Archaeology, 2006); **14 - Ferry Lane, Brentford** (Scaife, 2004); **15 - Sandersons Road, Denham** (Scaife, 2004); **16 - Three Ways Wharf** (Lewis, 1991; Lewis et al., 1992; Lewis and Rackham, 2011); **17 - Lewes I and II in Sussex** (Waller and Hamilton, 2000; Waller and Long, 2010); **18 - Newbury Sewage Works** (Chisham, 2004); **19 - Woolhampton** (Chisham, 2004);**20 - Thatcham** Reedbeds (Chisham, 2004); **21 - Ufton Green** (Chisham, 2004); **22 - The Lower Brede and Tillingham** (Waller and Long, 2010); **23 - Panel Bridge** (Waller, 1993); **24 - Queensborough in Kent** (dated to post ~7500 cal. BP) (Pratt et al., 2003; Scaife, 2015d); **25 - Munsley Peat bed** (Scaife, 1980b; Scaife, 1982); **26 - Intertidal peats in Hampshire** (Long et al., 2000); **27 - The Isle of Wight** (Scaife, 1987); **28 - West Quay Road, Southampton** (Nicholls and Scaife, 2008); **29 - Bouldnor Cliff** (Momber et al., 2011b; Momber et al., 2011a); **30 - Borthwood Farm** (Scaife, 1987); **31 - Yarmouth Marsh and Norton Spit** (Scaife, 2015b); **32 - Cothill in Oxfordshire** (Day, 1991); **33 - Brede Bridge** (Waller and Marlow, 1994); **34 - Horsemarsh Sewer** (Waller et al.); **35 - Silvertown** (Wilkinson et al., 2000); **36 - Hampsted Heath** (Girling and Greig, 1977); **37 - Tanners Hard** (Maritime Archaeology Trust, 2012); **38 - Farlington Marsh** (Scaife, 2000b); **39 - Enfield Lock** (Chambers et al., 1996); **40 - New Ford Road** (Corcoran et al., 2011); **41 - Nazeing** (Allison et al., 1952); **42 - Gatcombe Withy Bed** (Scaife, 1987); **43- Cranes Moor** (Barber and Clark, 1987);**44 - Conford** (Groves et al., 2012); **45 - London Cable Car** (Batchelor et al., 2015).

The Early-Mid Holocene in Surrey and the southeast is characterised by thermophilous woodland expansion, specifically the rapid expansion of *Corylus*, followed by *Ulmus* and *Quercus*. This is frequently accompanied by a reduction in *Pinus* as it was outcompeted by these species, leading to its decline. A slight increase in herbaceous taxa including Poaceae indicates the more open nature of this woodland as opposed to the *Pinus/Betula* woodland of the Early Holocene. This onset of thermophilous taxa is again observed at a regional scale, at both Elstead Bog A and Langshot Bog, and indicates that the pollen source regions for these sites are likely to still be relatively large and not overly affected by a denser woodland changing the pollen source. *Alnus* is occasionally recognised as a component of this woodland at some sites during this expansion, such as at Eton Rowing Lake, Dorney (Parker and Robinson, 2003), where it is likely to be present due to local factors supporting its growth. The timing varies across the southeast with many sites highlighting this expansion prior to ~9500 cal. BP, although it is slightly later at the northern Surrey site of Runnymede Bridge at ~8860 cal. BP and at Ockley Bog from ~7750 cal. BP.

Once the initial expansion of thermophilous woodland has occurred, other species enter the woodland matrix, including *Tilia, Alnus* and *Fraxinus*. Many areas still show evidence for ruderal and herbaceous taxa indicating the woodland was still open in structure. *Alnus* (and occasional *Salix*) is thought to be present in the wetter regions of the landscape, such as on riverbanks, floodplains or water margins. Some sites provide evidence for a greater abundance of *Tilia*, whereby it was the dominant deciduous taxon within this mixed deciduous woodland of the Mid Holocene. These site records indicate deciduous woodland development from a *Betula*/*Pinus* and *Corylus* woodland, through to a *Corylus, Quercus* and *Ulmus* woodland, followed by mixed deciduous woodland of *Corylus, Quercus, Ulmus, Tilia* and *Alnus*. At some sites however, there is no immediate decline in *Pinus* with the onset of deciduous woodland expansion, including at Ockley Bog, Thursley Bog and Elstead Bog, where values of *Pinus* at Ockley Bog of over 20% indicate the local presence of the species (Bennett, 1984; Groves et al., 2012).

Sites showing a prolonged occurrence of *Pinus* (Figure 9.12) often identify an increase in *Alnus* once *Pinus* begins to decline. This may be due to *Alnus* being more suited to higher light intensities or increased levels of waterlogging (Groves, 2008). At Conford, the prolonged presence of *Pinus* has been attributed to the underlying geology (Groves et al., 2012), possibly also the case for many of the other sites that show a prolonged *Pinus* curve. These sites are situated on freely-draining sandy geologies, the Lower Greensand in the case of Conford, Elstead, Thursley and Ockley. These freely draining geologies in the modern day often lead to low nutrient level soil, and this may have led to similar conditions in the past, meaning that deciduous invading species would have had less of an advantage over *Pinus*. This could mean that deciduous species did not outcompete *Pinus* as quickly as at other sites, allowing it to survive within the local woodland matrix. Prolonged regular burning during the Late Mesolithic may have also influenced the *Pinus* record. *Pinus* (especially *Pinus sylvestris*) is one of the most fire tolerant trees in Boreal European forests, with forest fires leading to the creation of ideal conditions for their regeneration (Richardson, 2000) as fires consume the humus layer of the soil resulting in bare mineral soil. These soil conditions allow *Pinus* to thrive whilst other species can struggle (Richardson, 2000). The record of fire and the *Pinus* record from Ockley Bog indicate that a high frequency of fire events, and the low nutrient nature of the local geology resulted in the prolonged presence of the species, similarly to Elstead Bog A (Farr, 2008) and Conford Bog (Groves et al., 2012).

9.3.1.1. **The 8.2 Kya Event**

The 8.2 Kya event has been widely identified as a period of climatic downturn within a longer period of climate change from 9000-8000 cal. BP (Bond et al., 1997; Mayewski et al., 2004) and is clearly identified in the Greenland ice core record (Figure 9.12).

The isotope records from Langshot Bog indicate that from ~9000 cal. BP there is a slight trend for increasing evaporation (with an increasing $\delta^{18}O$) and a shift towards broadly declining hydrogen values indicating more variable and wetter conditions. There was also a slight decrease in organic matter across the period. No major changes are identified in the vegetation cover, as the overall cover of deciduous woodland remains constant. The record is made more difficult to interpret, as the age of the mineral input in unit 6 at Langshot Bog is unknown. This mineral input may reflect increasing runoff into the basin during the latter half of the RCC event alongside an *Alnus* increase, as conditions get wetter. Further dating is required to fully understand this part of the record.

The record from Ockley Bog identifies an increase in herbaceous species, particularly Cyperaceae, and a general reduction in arboreal taxa across 9000-8000 cal. BP. A small increase is also identified in *Salix* and *Sphagnum*, potentially indicating a slightly wetter period. At Elstead Bog A, a number of taxa decline from ~9000 cal. BP including *Betula*, *Corylus* and *Ulmus*, whilst *Pinus*, Poaceae and ferns increase. Deciduous taxa including *Corylus*, *Ulmus*, *Quercus* and *Betula* then rise after the event, post 8000 cal. BP. A rapid decline in organic matter at ~8390 cal. BP (lasting ~100 years) may indicate increased runoff on the slopes of the basin due to increasingly wetter conditions. From ~8280 cal. BP, organic matter then increases and within ~150 years was back to pre-event levels.

However, there are difficulties with all of these records, which make interpretation of this event problematical. At Langshot Bog, organic sediment is deposited up until ~8400 cal. BP, only providing information about conditions during the early stages of the rapid climate change event, whilst the overlying minerogenic unit is undated. At Ockley Bog only 6cm of sediment covers this period and at Elstead Bog A, the whole event is only covered by 12cm of sediment. This low age-depth resolution means that interpretation of the event is difficult and very high resolution studies would need to be employed to identify any evidence within these records. Unfortunately at both Elstead Bog B and Thursley Bog, no sediment is deposited during this time, and analysis of the event is not possible at these sites. This is also the case at other local sites including Conford, where a hiatus spans ~11,110-8050 cal. BP, and at Bagshot, where a hiatus spans ~9800-7550 cal. BP (Groves, 2008).

Around the Atlantic fringe of Europe, evidence for a downturn in climatic conditions at 8200 cal. BP is limited (Ghilardi and O'Connell, 2013). Chironomid data from Hawes Water indicates a cool oscillation at 8300 cal. BP (Lang et al., 2010) and a slight decline in temperatures (of ~1˚C) was identified at 8200 cal. BP from mollusc records at Holywell Coombe (Rousseau et al., 1998). A pollen record from Cooney Lough, Western Ireland, was characterised by an increase in *Betula* and *Pinus* and a decline in *Corylus* and *Quercus* centred on 8200 cal. BP with similar shifts in pollen assemblage noted in other Irish sites (Ghilardi and O'Connell, 2013). However at Dooagh, Western Ireland, there was no evidence of an 8200 cal. BP event, attributed to the event being of insufficient duration or magnitude to significantly impact on the vegetation, although a longer climatic oscillation was observed (Head et al., 2007). Changes in vegetation, primarily through a reduction in local woodland cover at Loch an t'Suidhe at 8250 cal. BP were attributed to Mesolithic impact on the woodland and not climatic change (Edwards et al., 2007).

The information derived from the Surrey sites shows some evidence for a slight climatic downturn across the period, and small changes in both the isotopic data and pollen data indicate the event was characterised by a time of increased wetness, with some increased mineral runoff and subsequent deposition although changes in the pollen record are minimal. There is no evidence for an increase in human interference with the vegetation cover. As the mollusc records from Holywell Coombe indicated, the magnitude of the event (a decline of ~1˚C) may not have been enough to trigger widespread vegetation change in southeast England. It is also possible that the lack of palynological evidence for the 8200 cal. BP event from Surrey and southeast England relates to the short duration of the event. In order to study the event further within the southeast, well dated records across the 9000-8000 cal. BP range would need to be analysed at high resolution to identify the presence of any short-term fluctuations in the pollen assemblage across this period.

9.3.1.2. **The Vera hypothesis**

The Vera hypothesis (Vera, 2000) proposes that large herbivores would have had caused fragmented forest with patches of open grassland due to high levels of grazing. These grasslands would then develop into shrubland. Trees would be growing on the edges of these scrubby regions and over time the trees become established and expand into the grassland regions forming a grove. The increasing shade from the tree canopy and further trampling and grazing by herbivores then causes the process to repeat itself. The hypothesis was developed from the observations of *Quercus* and *Corylus* within the Holocene record. These are both light demanding trees, and so their development and abundance could not have occurred within a closed canopy forest. The Vera Hypothesis suggested that it was herbivores that were both creating and maintaining woodland openness, allowing the development and expansion of both *Quercus* and *Corylus* (Vera, 2000). Studies examining the data from Ireland, where very few herbivores affected the landscape, and Britain, with a significantly higher number of herbivores, have shown that large herbivores had the potential to influence woodland species composition, but overall forest canopy was maintained (Mitchell, 2005). Evidence from insect records indicate open taxa species at British sites, but they do not occur at the scale and extent required to suggest the landscapes argued for in the Vera Hypothesis (Whitehouse and Smith, 2010). Other studies indicate natural fires would have been the main cause of forest openings during the Early Holocene, although gaps may have been maintained by herbivore grazing (Mason, 2000; Bradshaw et al., 2003; Finsinger et al., 2006a).

During the Early Holocene at Thursley Bog, *Betula* was dominant across the landscape, and it is likely that much of the ground was relatively open. Post ~7300 cal. BP the woodland development indicates that *Pinus* was an important component of the deciduous-coniferous woodland alongside *Quercus, Corylus* and *Betula*. Clearings within this woodland may be indicated by *Erica*ceae, *Calluna, Ranunculus, Rumex* and Poaceae. A prolonged presence of *Pinus* within the Mesolithic landscape is also recorded at Elstead Bog A and Ockley Bog, and a number of other southeastern sites (Figure 9.12). *Pinus* is highly prone to browsing by large herbivores and would be unlikely to have been present for this length of time if large herbivores were actively creating clearings within the woodland (Scott et al., 2000; Palmer and Truscott, 2003; Groves et al., 2012). A number of records in the southeast also identify *Tilia* as being an important Late Mesolithic species. *Tilia* is a shade tolerant taxa and potentially highly vulnerable to bark stripping by herbivores, and therefore unlikely to survive if large herbivores were present within the landscape (Groves et al., 2012). However, at both Ockley Bog and Thursley Bog there is also evidence for woodland clearings. These clearings are present when there is a higher incidence of charcoal in the records and suggest that fire, not herbivore activity, was forming these small clearings, which were then quickly colonised with herbaceous species. The record at Langshot Bog shows an Early Holocene reduction in *Pinus*, an expansion of *Corylus* and *Quercus* and a lack of *Tilia*. The reduction in *Pinus* and near absence of *Tilia* may indicate herbivore presence in the landscape. In addition, *Corylus* and *Calluna* are also palatable to herbivores. As with Thursley and Ockley however, this is a time when the fire history record begins to increase. The decline in *Pinus* occurs against a warming climate, potentially leading to an increased chance of natural fires. This could lead to the growth of deciduous species, which would quickly and easily outcompete *Pinus* across the landscape around the site.

The sites of Thursley Bog and Ockley Bog do not appear to support the Vera Hypothesis, primarily due to the presence of species that would be vulnerable to browsing throughout the Mesolithic, and increasing charcoal records at a time of woodland opening. However, this may be due to the smaller pollen source area of these sites, meaning that clearings across the landscape would not be identified easily unless they were very close to the two basins.

Langshot Bog may provide some evidence in support of the hypothesis, as there is a decline in readily browsed species and evidence for clearings within the woodland. Yet the charcoal record increases at this time, and so it is likely that increased incidences of burning led to the initial creation of clearings, which may have been subsequently maintained by herbivore activity. Similar maintenance of clearings through herbivore activity may also be occurring at Thursley Bog and Ockley Bog.

9.3.2. Human activities and impact during the Early Holocene

Mesolithic groups were present across Surrey and the southeast during the Early Holocene, at the time when thermophilous deciduous woodland was expanding. This woodland expansion occurred from ~10,300 in Surrey and at a similar time across much of the southeast. This change in the vegetation coverage occurred at a similar time to developments within the archaeological record, with the onset of the Horsham period at ~10,000 cal. BP. This type of assemblage is predominantly confined to the Wealden district and the southeast (Tolan-Smith, 2008), and the development of these Horsham groups are thought to be directly linked to deciduous forest growth. This forest growth could have led to an increased sense of isolation and fragmentation between communities, and may have led to the increased regional diversity and different ways of living (Reynier, 1998). Surrey also provides evidence for Late Mesolithic human activities from ~9600 cal. BP, at a time when the climate is warming and the deciduous woodland is relatively dense. Through comparisons of archaeological records proximal to studied palaeoenvironmental sites from Surrey and further afield, as well as the Mesolithic predictive models, an understanding can be developed of how these Mesolithic groups may have interacted with the changing woodland cover.

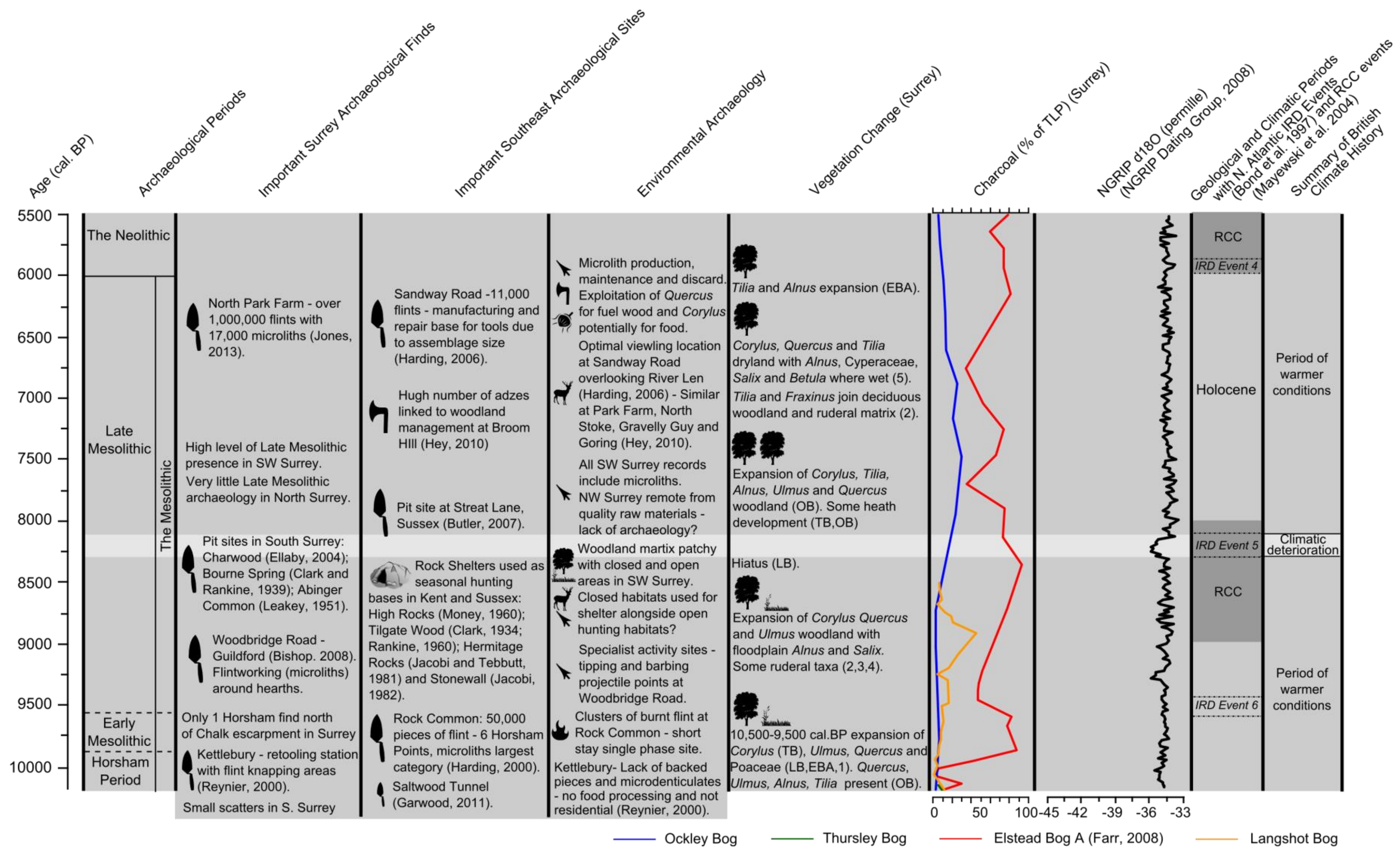


Figure 9.13. Synthesis of Early/Mid Holocene archaeological evidence alongside climatic and vegetation history. ***OB - Ockley Bog; TB - Thursley Bog; LB - Langshot Bog; EBA - Elstead Bog A*** *(Farr, 2008);* ***1 - Nutfield Marsh*** *(Farr, 2008);* ***2 - Runnymede Bridge*** *(Scaife, 2000a);* ***3 - Bramcote Green*** *(Branch and Lowe, 1994);* ***4 - Farm Bog*** *(Jennings and Smythe, 2000);* ***5 - Bagshot*** *(Groves, 2008)*

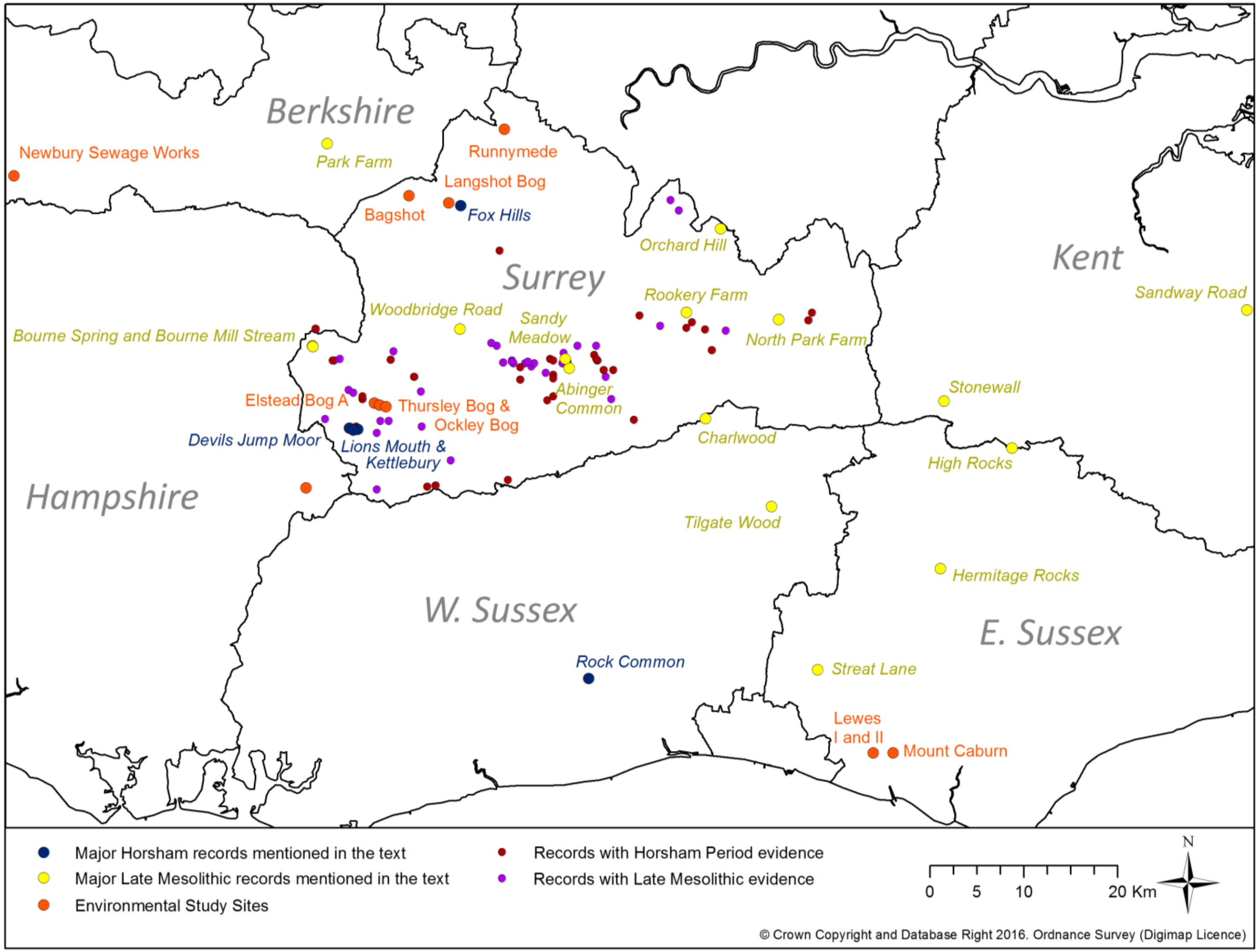


Figure 9.14. Location of the main palaeoenvironmental and archaeological sites mentioned in the text.

Examination of archaeological records in Surrey and the southeast show that Horsham tool types are almost exclusively contained within Sussex and Surrey (Figure 9.14). Records greater than small flint scatters are rare and predominantly identified on the sandier substrates (Harding, 2000). Two Horsham points have been identified on Ockley Common and another 8 records occur within 10km of Ockley Bog. A number of these are grouped locally on Hankley Common: Kettlebury, the Lions Mouth and Devil's Jumps Moor. Kettlebury is dated to ~9500-8500 cal. BP (Gillespie et al., 1985; Reynier, 1998), is one of the largest Horsham collections in the southeast (Reynier, 2002), and is thought to be a retooling station due to two distinct flint knapping clusters and a waste dump area. A lack of microdenticulates and backed points may indicate a lack of food processing as these tools have been shown to be used for cutting soft plant materials (Barton, 1992), inferring the site may not have been residential, although further Horsham sites are needed to confirm this (Reynier, 2002). It has been suggested that the presence of Horsham points and smaller microliths may imply that bows and arrows were being used in greater abundance than spears at this time (Ellaby, 1987). Evidence from the palaeoenvironmental records suggest thermophilous woodland expansion (Figure 9.13) and a dense understorey of *Corylus* as identified at Thursley Bog and Elstead Bog A may have led to difficulties chasing and hunting animals with spears. The arrow (and bow) would provide greater accuracy within these difficult to traverse environments (Churchill, 1993), although at longer distances visibility through this woodland may still pose difficulties. The discovery of 8 Horsham points at Saltwood Tunnel in Kent was thought to represent a lost store of arrowheads or unhafted points, or a possible votive offering, in an area overlooking potential animal paths (Garwood, 2011). This may have similarities with the large dunes to the south of Thursley Bog and Ockley Bog which may have been used to view the landscape, with artefacts found around the sites representing items lost during hunting trips. Evidence for Horsham period activity is rare in north Surrey, with the Fox Hills site the only Horsham record for the County north of the Chalk escarpment where Early Mesolithic microliths, blades and flakes are present in addition to Horsham type microliths. At Rock Common in West Sussex, 6 hollow based Horsham points were identified alongside over 50,000 pieces of flint where microliths were the largest category of retouched tools. Occupation may have been restricted to a short stay where tasks revolved around hearths, indicated by well-defined clusters of burnt flint. The large microlith assemblage has been associated with the manufacture of hunting tools and equipment (Harding, 2000). Further visits may be represented by separate camps on the eastern side of Rock Common. Rock Common's broader array of tools as opposed to Kettlebury reinforces the view that

Kettlebury may have functioned primarily as a re-tooling and hunting station rather than a settlement site. Other Horsham period records are frequently small surface finds, representing stops to repair or enhance hunting kits (Harding, 2000), potentially suggesting that Horsham assemblages are an activity facies or a functional tool kit.

Late Mesolithic activity appears to be more diverse across the southeast than for both the Early Mesolithic and the Horsham Period (Figure 9.14). There also appears to be less of a reliance on the Greensand as people spread out across more geologically diverse regions, including the chalk escarpments and further across the Weald (Gardiner, 1988), whilst the majority of sites are still situated within wet/dry interface regions. Unfortunately there is a lack of chronological detail on many of these records, and attempting to understand changes in settlement and activity within the Late Mesolithic period is extremely difficult. This is unfortunate as other areas in Britain, such as Western Scotland, have identified population collapse after and related to the 8.2 Kya event (Wicks and Mithen, 2014). A potential population collapse within Surrey might not be expected at this time, however, due to the apparent small-scale nature of the 8.2 Kya event in the County, although it is unable to test this further. The general pattern across Surrey during the Late Mesolithic period appears to show larger numbers of smaller sites, often resulting in clustering of numerous sites across relatively large areas, where they are often associated with hearths and pits (Gardiner, 1988; Hey, 2010). There is however, a lack of Late Mesolithic activity in northern Surrey. Within a 10km radius of Langshot Bog there are no identified Late Mesolithic sites and only a 33% chance of finding Mesolithic archaeology. Late Mesolithic groups were clearly active in Southern Surrey, with 2 records from Thursley Common and 1 on Ockley Common. Another 21 Late Mesolithic records are found within 10km of Thursley, Ockley and Elstead, representing 39% of Surreys identified Late Mesolithic record. These records all identify microliths, suggesting that hunting would have played an important role in this region. There is also a strong likelihood that more permanent base camps would also have been present, based on sites with the presence of axes, fabricators and picks (Butler, 2005). The archaeological models also highlight that this area is an important and active region, with a 69% chance the local 5km area was a Mesolithic activity area. This is significant as the region has a mixed woodland signal of both open and closed woodland, potentially representing a desire for both closed shelter habitats and more open habitats for hunting. A number of large Late Mesolithic flint assemblages and ‘pit-sites’ are also identified in southern Surrey (Figure 9.13), such as at Bourne Spring in Farnham (Clark and Rankine, 1939), Abinger Common

(Leakey, 1951), and also further afield in Sussex at Streat Lane (Butler, 2007). Over 21,000 pieces of flintwork including microliths, axes and blade and flake cores, were identified in a pit enclosure at Charlwood, Surrey (Ellaby, 2004) and subsequently dated to ~7300-6700 cal. BP. The presence of calcined bone, potentially roe deer, in 'cooking pits' has shown evidence for potential occupation at the site (Ellaby, 1983). Flintworking and pits around a series of hearths has been identified at the site of Woodbridge Road in Guildford (Bishop, 2008) and has been OSL dated to ~7700 cal. BP. The dominance of microliths suggest the site may have been repeatedly used by small task groups for the specialist activity of tipping and barbing projectile points (Bishop, 2008). The location of the site, near the River Wey, may have been chosen for potential hunting opportunities and the spearing of fish. In addition to pit sites in Surrey and Sussex, both Kent and Sussex provide evidence for Late Mesolithic rock shelters, used primarily as seasonal hunting bases (Figure 9.14). The pit sites were originally thought to represent dwellings, however this is unlikely due to the small floor-sizes, often of less than $<1m^2$ (Ellaby, 1987). They may however have been used as rudimentary and temporary shelter derived from possible tree-throw hollows (Evans et al., 1999). At Bourne Spring, pits and the presence of adzes, axes and picks were attributed to either flint quarrying or woodworking (Ellaby, 1987). The pits at Woodbridge Road and Charlwood are thought to be contemporaneous to their occupation and appear to have been used as a rubbish dump, filled with burnt flint and waste (Bishop, 2008). The Abinger pit may have been Neolithic, with Mesolithic flintwork washing into the pit at a later date. The few Late Mesolithic discoveries in London indicate that hunting and foraging expeditions appear to account for the majority of the Late Mesolithic assemblage. Understanding human activity in London is difficult however, as some Late Mesolithic evidence is likely to be deeply buried as a result of relative sea level rise. Records from other areas indicate that many base sites are often situated in optimal viewing locations. The Sandway Road site in Kent overlooks the River Len, and over 11,000 flints were identified there. It was thought to have been a manufacturing and repair base for hunting tools and paraphernalia due to the size and nature of the assemblage (Harding, 2006). The site found at Park Farm sits on a spur overlooking a small valley (Roberts, 1993) and other sites including North Stoke, Gravelly Guy and Goring (Hey, 2010) would have all offered views of the surrounding landscape. The large sand dunes to the south of Thursley Bog and Ockley Bog would have also provided excellent views across the common, and may have been areas Late Mesolithic people would have used as a lookout.

There are some sites in the southeast that show repeated use of a single place within the landscape during the entire Mesolithic, termed ‘persistent places’, and often show an intensity of activity during the Late Mesolithic (Jones, 2013b). North Park Farm has produced over 17,000 microliths and more than 1,000,000 flints in total. Within the shallow valley head, 12 hearths were discovered and radiocarbon dates have shown evidence for visits during the entire Mesolithic period. Early Mesolithic activity was represented by short term visits replenishing hunting toolkits, with some small scale butchery and hide processing. The production, maintenance and discard of microliths indicate a greater use of the site during the Late Mesolithic. Other persistent places include Sandy Meadow, where over 1000 pieces of flintwork date to all Mesolithic periods (Winser, 1987), Rookery Farm (Hooper, 1933), Bourne Mill stream (Rankine, 1936) and Orchard Hill (Ellaby, 1987; Jones, 2013b). Through examining the environmental locations of these sites (with the exclusion of Orchard Hill as it is outside the County border), patterns can begin to be observed as to where they are located. Even though this is only a small dataset it would appear that these persistent places are all situated near to (or on) either the Clay-with-Flints or Lower Greensand geologies, have low slope angles (<10%) and are on land with a total wetness index of dry/wet or wet. These patterns are also consistent with the patterns observed within the Late Upper Palaeolithic and Mesolithic dataset, and highlights that the distance to local resources and the potential for both local hunting and gathering both appear to be important choices when determining settlement location.

These studies have shown both the type of environment and site based activities of Late Mesolithic groups; however it is difficult to quantify the level of anthropogenic impact on the environment. Evidence for anthropogenic vegetation change has been identified in upland contexts, such as Dartmoor (Caseldine and Maguire, 1986), the Pennines (Innes and Blackford, 2003) and the North York Moors (Innes et al., 2010). The use of plant resources has also been identified across the Western Isles in Scotland (Gregory et al., 2005). In contrast, lowland sites such as Hockham Mere, frequently provide no evidence for human modification of the woodland (Bennett, 1983), although woodland management has been suggested at Broom Hill in the Lower Test Valley, due to the identification of a high number of adzes within an assemblage dominated by rods and scalene triangles (Hey, 2010). Macrobotanical evidence at North Park Farm has also shown the use of *Quercus* as firewood from ~9400 cal. BP, due to the fact it burns slowly, and Rosaceae and *Corylus* were both exploited, as well with *Corylus* shells potentially indicative of food refuse (Jones, 2013b).

Increasing herbaceous taxa in pollen records has been identified at the Newbury Sewage Works site (Healy et al., 1992) alongside burning on the floodplain, and was thought to lead to an increased diversity of herbivores browsing in the open woodland. Increasing herbaceous taxa presence is also recorded at Runnymede Bridge (Scaife, 2000a), in addition to Mount Caburn (Waller and Hamilton, 2000; Waller and Long, 2010), Bagshot (Groves, 2008) and Cranes Moor (Barber and Clark, 1987), and has been linked to burning and clearance events. Lewes I and II indicate the presence of *Fraxinus* and *Fagus* within the woodland composition and may be indicative of forest openings or clearings, potentially attributed to the hunting of game (Thorley, 1981). High charcoal counts at Cothill have also been associated with Mesolithic activity, where *Pinus* recolonised cleared areas of woodland (Day, 1991). The *Alnus* expansion at Conford may be due to human-set fires (Smith, 1984; Groves et al., 2012) but could also be linked to natural causes such as lightning strikes.

The woodland around Ockley Bog and Thursley Bog, and the denser woodland around Elstead Bog, may have led to a change in the tool types and a the possibility of a greater reliance on hunting with arrows, at least at shorter distances. Arrows would be more useful in wooded conditions as the tree density mandates close quarters hunting (Churchill, 1993). Trapping may have also offered opportunities for the capture of animals within these forests, as trapping in Boreal and Northern Forests offers the highest trapping intensity for modern hunter-gatherer societies, although evidence for traps rarely survives in the archaeological record (Holliday, 1998). The denser woodland may have also offered settlement opportunities due to additional vegetation providing shelter and locations with reduced wind-chill. Additionally, studies have shown the importance of hazelnuts to the Mesolithic (Godwin, 1975b), but it is not fully known whether human activities modified the presence or abundance of hazelnuts. Evidence for the potential exploitation of *Corylus* was identified at Thursley Bog, Ockley Bog and Langshot Bog, where there were large increases in *Corylus* quantities during the Late Mesolithic. The levels of *Corylus* at Ockley Bog are higher than in modern day landscapes (Finsinger et al., 2006a), and therefore may be strongly related to an external forcing factor, such as the exploitation of *Corylus* by Mesolithic groups. The area was well populated at this time and hazelnuts would have been a valuable food source. Similar exploitation of hazelnuts by Late Mesolithic people has been recorded at other British sites (Radley et al., 1974), alongside flint tools and a rise in charcoal. At Langshot Bog and the Chobham Common region, there is evidence for an increase in fire events during the Late Mesolithic (Figure 9.13) and clearances are identified through increasing levels of Poaceae, *Plantago*, *Ranunculus* and other herbaceous species, as well as small patches of heathland vegetation. The lack of this sort of archaeological evidence in the northwest region of Surrey may be attributable to poor discovery opportunities; however this is not thought to fully account for the observed distribution of Mesolithic records, as the region has evidence for archaeological discoveries post-Mesolithic. The low density of Mesolithic archaeological activity in northern Surrey continues on from the Early Mesolithic, even once the environment has transitioned from a dense *Pinus* and *Betula* woodland to more open deciduous woodland. It may be that the region was infrequently visited, as prolonged human settlement in the region is unlikely as it is spatially remote from good raw material sources such as flint, and therefore a less attractive part of the landscape than southern and eastern Surrey.

9.3.3. Early Holocene Hiatuses

In at least three of the records identified in this study, a hiatus was identified spanning a part of the Early Holocene (Figure 9.15). It is important to examine the timing and possible causes of this hiatus and assess whether it occurs further afield in other records.

At Langshot Bog, the hiatus is thought to date from 8430-8350 cal. BP and based upon the modelling, lasts for over ~3000 years until ~5250 cal. BP, although the error on this final date is poor due to the chronological control on the dates immediately above the hiatus. It appears that much of the sedimentation above the hiatus dates roughly from the Bronze Age. The hiatus at Thursley Bog dates from ~10,510-9570 cal. BP to ~7500-7260 cal. BP, and has a potential duration of 2160-3200 years, a similar duration to that modelled at Langshot Bog. Elstead Bog B indicates a dramatic shift in pollen assemblage, indicating a potential hiatus within the sequence. With the current radiocarbon dates, the best this can be constrained is between 11,820-11,500 and 3150-2950 cal. BP. There may also be a hiatus present within the Ockley Bog core between units 9 and 10, potentially between ~9500 cal. BP and ~8000 cal. BP, since while the current radiocarbon dates are not at the required resolution to detect a hiatus within the sequence, there is a reduction in sediment deposition. This period crosses the point where a large decline in Cyperaceae is recorded, a trend also identified in the Thursley Bog hiatus. At Elstead Bog A there is a decline in sediment accumulation rate between 9000-6000 cal. BP, although there are no extreme shifts in the vegetation cover, so without further chronological control in the form of additional radiocarbon dates it is not clear whether a hiatus is present.

An Early Holocene hiatus is also identified at other sites, beginning and ending at slightly different periods (Figure 9.15), although the potential for intrinsically studying the timing of these events is difficult, as often the hiatus is not directly dated. At Minchery Farm (Parker and Preston, 2014), for example, the chronology suggests either a break in sedimentation or very slow sedimentation rates during the Early- and Mid-Holocene, similar to the site of Ockley Bog. The site shows no clear stratigraphic breaks and there are no anomalous shifts in the pollen assemblage. From the available dates, the best that this hiatus can be constrained is between 10,600-3900 cal. BP. At the site of Conford, a hiatus has been dated to 11,110-8050 cal. BP, lasting for ~3060 years (Groves et al., 2012) and a hiatus identified at Bagshot lasted for ~2250 cal. years BP between 9800-7550 cal. BP (Groves, 2008). A hiatus was identified at West Silvertown between 10,200-6300 cal. BP (Wilkinson et al., 2000) and an Early Holocene hiatus or rapid decline in sedimentation was also recorded at Bramcote Green between 9200-6900 cal. BP, followed by a small amount of organic accumulation, and another hiatus between 6900-4800 cal. BP (Thomas et al., 1996).

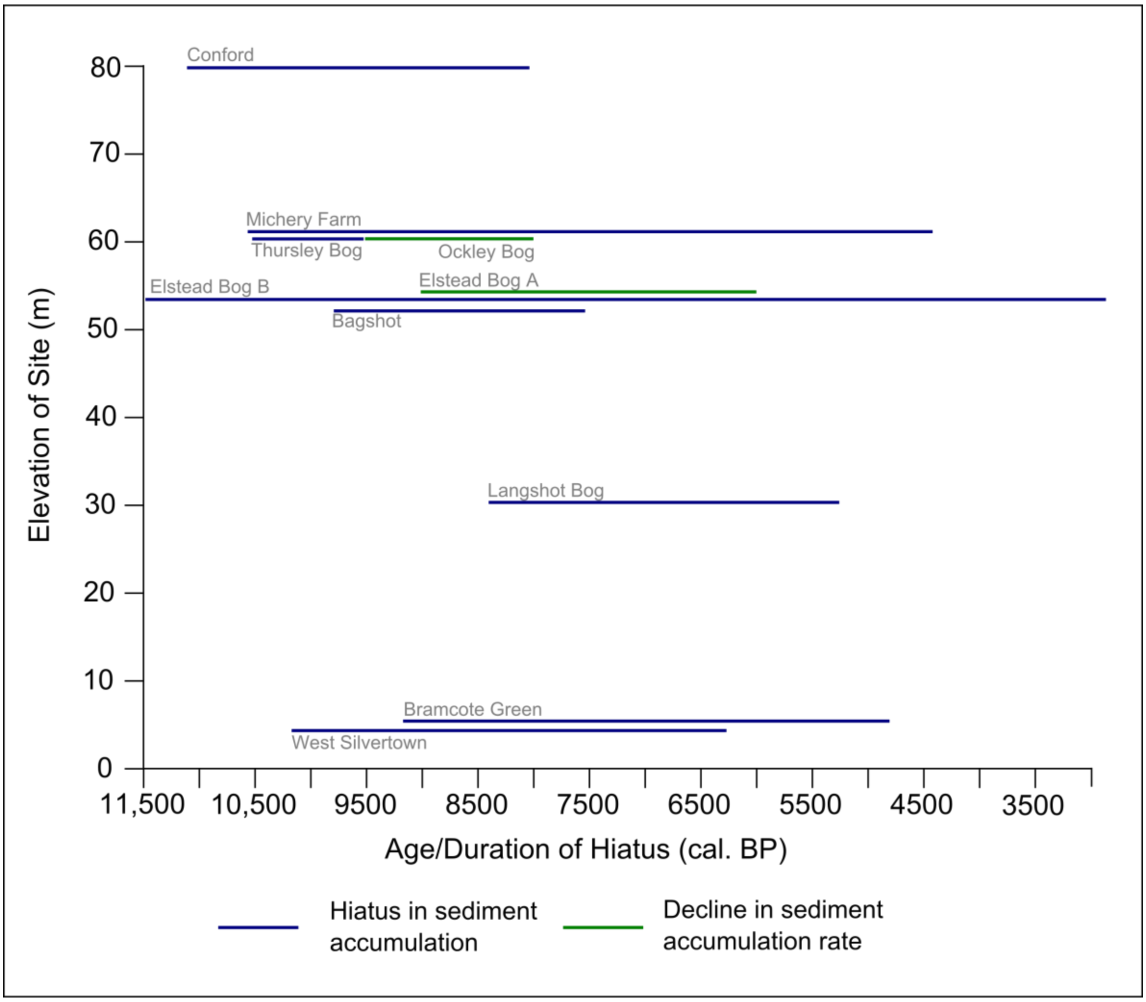


Figure 9.15. Hiatus durations in southeast England plotted against site elevations.

The cause of these hiatuses may be due to a number of different factors including a change in hydrology, ablation of surface material or removal of the peat. A change in hydrology across the bog may result in the bog surface drying out. If the bog surface were to dry out due to a lack of available water source, then peat formation would stop and the surface of the bog may be colonised by trees resulting in further stabilisation of the surface. A change in hydrology may have many different causes, such as human activity, deforestation (either natural or anthropogenic), a change in climate, the lowering of groundwater or bog bursts.

Human activity may have also led to the development of hiatuses in the sedimentary record potentially through deforestation or physical manipulation of the peat surface. Deforestation (either from humans or climatically driven) could cause a reduction in groundwater levels through increased soil erosion, which in turn lowers the soil retention capacity and leads to a depletion in groundwater levels, thereby leading to conditions not favourable for the formation of peat. It would still be expected however, that some sort of deposition would have occurred during this time, such as a shallow soil profile. This is also thought unlikely, as there is no evidence for widespread deforestation at any of the sites in this study prior to the time of the hiatus. People may also artificially modify the water level within the bog through cutting drainage channels, or cutting the surface peat from the bog, which would result in the total absence of peat or other sediments in the record. Peat cutting is used as a method of accumulating a source of fuel, and the practice of peat cutting and drying has been documented from the Medieval period, with archaeological evidence of peat cutting and drying found from the Bronze Age in Scotland (Branigan et al., 2002). Either topographic variation or prehistoric peat cutting, removing the earliest growth of peat, was suggested as a factor at Bharpa Carinish in Scotland due to the presence of an anomalous radiocarbon date at the base of one of the peat profiles. Peat may have also been spread over possible Neolithic age fields in Shetland, however there is very little evidence for the use of or cutting of peat at or prior to the Bronze Age, and no prehistoric tools have been attributed to peat manipulation or use (Branigan et al., 2002). An anthropogenic cause behind these hiatuses or periods of reduced accumulation, such as management of the local hydrological regime, is unlikely due to the perceived lack of impact that the Mesolithic groups were having on the environment at this time. It is also unlikely that peat cutting can be attributed as a cause, firstly due to a lack of suitable tools found within the archaeological record and secondly due to the variable timing of peat re-accumulation.

If the climate was getting drier and warmer during the Early Holocene, ablation of the surface material may have resulted in the hiatuses across the sites due to wind action removing the top layers of accumulation. This is probably unlikely however, as many of the sites are not particularly exposed, meaning that wind alone is unlikely to have enough force to remove any potential sediment deposited onto the basin, even if conditions meant the bog surface was relatively dry. In addition, the species on and around the bog prior to the hiatuses often suggest relatively dense woodland, meaning that the wind would not be as strong as in an open and exposed environment. A warmer and drier climate may have also led to a reduction in the groundwater reserves. Re-sedimentation would then not restart until these groundwater supplies had recharged and the surface returned to wetter conditions. If mass groundwater lowering due to climatic conditions was the primary cause behind these hiatuses, it may be expected that the onset (and end) of the hiatuses would have a relationship with the elevation of the site (due to elevation being connected to groundwater supply distance). When the timings of each hiatus are plotted against elevation (Figure 9.15), there is no evidence of any relationship between the two variables and so it therefore seems unlikely that a large scale decline in groundwater is likely to have led to these hiatuses. Local groundwater changes however, may have affected individual sites. Groundwater levels could be modified through varying landscape coverage of thermophilous trees, with higher tree cover leading to a subsequent expansion in evapotranspiration rates, causing a lowering of the groundwater. The hiatus at Bagshot was attributed to a lower water table (Groves, 2008), where a decrease in Cyperaceae and Poaceae was recorded, alongside an increase in humification. There is evidence at Langshot Bog for the onset of the hiatus, as it coincides with a period of thermophilous woodland expansion. This suggests warmer conditions and potentially drier bog surface conditions with low levels of Cyperaceae and aquatic species, although the isotopic record indicates a short period of wetter conditions immediately prior to the hiatus. Drier and warmer conditions may be inferred from Thursley Bog, where gradually increasing levels of *Corylus* suggest a warming climate prior to the hiatus and a declining record of *Salix* may indicate the region was becoming dryer. An increase in *Betula* woodland and decline in Poaceae and Cyperaceae prior to the inferred hiatus at Elstead Bog B may also indicate drying and warming conditions. A decline in Cyperaceae at Ockley Bog may also indicate dryer conditions at this time. Changes in local climatic conditions may have resulted in the decline of organic sedimentation at these sites however; it is highly unlikely that no sediment was laid down during the drier conditions. If woodland colonised and stabilised the surface of the bog, then the development of a shallow soil may be expected, or if the area was dry and exposed, a minerogenic unit from aeolian deposited material might be observed. At Bagshot, there is no evidence for the hiatus from examining the stratigraphy, and there appears to be no major shifts at Thursley Bog or Ockley Bog, suggesting that no sediment was laid down during the hiatus. At Langshot Bog, there may be evidence for deposition during the hiatus, due to the presence of a slightly minerogenic peat, although this is not clear as the top boundary date appeared to be an outlier, therefore the hiatus has not been fully bracketed with radiocarbon dates on both sides. This meant that the deposition date of the slightly minerogenic unit could not be constrained in order to find out if this unit represented accumulation during the hiatus at Langshot Bog.

It is also possible that bog bursts may have led to these hiatuses, and could account for a lack of deposition in the sequences. Bog bursts lead to mass bog surface wastage often caused by higher levels of rainfall, and have been identified in the Netherlands (van Geel et al., 2014) and at sites in Ireland (Stasney, 2015). Bog bursts are thought to lead to significant changes in accumulation rate or lead to hiatuses within a core due to the removal of material from the surface of a site (Stasney, 2015). At Littleton Bog in Ireland, the bog bursts were attributed to increased moisture levels due to changing climatic conditions, which subsequently resulted in a shift to drier conditions. This has currently not been attributed as a cause to any bogs in the southeast of England, however at Langshot Bog just prior to the hiatus, the stable isotope data suggests there is a short period of increased wetness, 100-300 years in duration.

These records suggest that the hiatuses, or periods of reduced sedimentation at the Surrey sites, may have been caused by relatively local factors and the hiatuses occurred on a site by site basis due to local conditions. This may have been through changes to the local water table or bog bursts. Bog bursts may have occurred due to increased rainfall over a short length of time immediately prior to the hiatus, leading to mass wastage of the bog surface. There is also the possibility that the expansion of thermophilous woodland may have led to a lowering of the local water table, leading to a hiatus in sedimentation with the record then not restarting until wetter conditions were present. As the water table returned to a higher level, sedimentation could recommence. Through the further application of high resolution stable isotope work, increased radiocarbon dating around suspected hiatuses and the application of testate amoebae analysis, the chronological and hydrological regime of the sites could be better constrained.

9.4. Summary

The environment during the Lateglacial Interstadial was studied through the records at Thursley Bog and Ockley Bog, where the environment was open and inhabited by *Juniperus, Salix* and *Betula*. Open ground taxa were also present, and this was a picture replicated across other sites both in the southeast, such as Minchery Farm and Spartum Fen, but also across the UK including Llanilid and Hallsenna Moor. The presence of human groups is provided through evidence from Brockhill, and other sites in Surrey providing evidence for short-stay hunting camps, with groups likely to have been hunting and gathering natural resources. Evidence for fires from the palaeoenvironmental records is thought to represent natural wildfires, due to a lack of local archaeological activity around the sites with evidence for fire. These fire events appear to increase in intensity as temperatures warm during the Lateglacial Interstadial. The onset of the colder conditions of the Loch Lomond Stadial is identified at all of the sites, primarily through a change in the vegetation and increasing levels of mineral matter. Vegetation cover at the sites is typical of cold tundra style shrubland alongside areas of short grassland. There is evidence for a regional pollen signal through similarities in vegetation at Langshot Bog and Elstead Bog B during this period. Again this is a similar picture as recorded at other sites in the region, including Northmoor, Bramcote Green and Bagshot. The discovery of these new sites dating to the Late Glacial is highly significant, as it develops our understanding of the vegetation history of southeast England. The presence of *Corylus* at Thursley Bog, Ockley Bog and Langshot Bog during the Late Glacial may have been due to the locality of glacial cryptic refugia or the presence of specific climatic tolerances, and with the presence of *Corylus* at Ockley Bog from 14,000 cal. BP, has provided one of the earliest dates for *Corylus* in Britain. Within the regional landscape it is clear that humans were present in the landscape during the Loch Lomond Stadial, and this is especially evident through the Upper Palaeolithic site at Brockhill. It is likely that these humans were not heavily impacting on the landscape but potentially utilising plants for food and the areas around the sites for hunting.

Evidence for the Late Glacial to Early Holocene transition is provided by all four sites. The dominant trend is a shift from a colder, tundra style landscape to coniferous/deciduous woodland. The open *Betula, Juniperus* and *Salix* environment is replaced by a large expansion of *Betula* and subsequent increase in *Pinus,* observed occurring at the very start of the Holocene on a regional scale at Elstead Bog A, Elstead Bog B and Langshot Bog. *Alnus* and *Salix* dominate wetter regions alongside a decline in herbaceous species, and both Ockley

Bog and Elstead Bog B provide further evidence that *Alnus* was present in southeast England during the Late Glacial period and the start of the Holocene. Once more, this is recorded at many other sites within southeast England, although the date of the arrival of *Pinus* varies across sites. As the climate warms from the Late Glacial into the Early Holocene, there is an increase in human activity, with multiple records dating to the Early Mesolithic (11,500-9600 cal. BP). These records highlight a spatial difference in terms of the number of records between the north and south of the County. There is more evidence for Mesolithic activity in the southwest (and south in general) of the County than the north, potentially related to the dominance of wet/dry interface regions, a more open woodland than in the north, and the presence of small lakes. This would have led to an environment highly conducive to hunting and gathering, a trend also backed up in the lithic record. Rather than widespread woodland modification, it is more likely that the Early Mesolithic groups would have utilised the woodland to its maximum potential through trapping and hunting animals and resourcing plant foods. There was no evidence for large-scale manipulation of the woodland through fire.

The Early Holocene is characterised by the onset of thermophilous, deciduous woodland from ~10,000 cal. BP. This rise is identified at Langshot Bog and Elstead Bog, again highlighting the regional signal provided by these two sites over 25km apart. The vegetation record from all sites during this period is complicated by hiatuses and changes in the sedimentation rate in the cores, potentially caused by a reduction in groundwater reserves. *Corylus*, *Quercus* and *Ulmus* expand to become the dominant arboreal taxa, until *Alnus* and *Tilia* subsequently join the woodland matrix. Across the southeast, there is also a growth of thermophilous woodland during this time, although the timing and composition varies slightly to those sites within this study. At some sites, there is a continuation of *Pinus* prior to a later decline in the species. This is recorded at Ockley Bog, Thursley Bog and Elstead Bog where *Pinus* was at a level suggesting its presence in the local environment up to 6000 cal. BP. Other sites in the southeast also provided evidence for this later decline in *Pinus* and it has been attributed to the freely draining sandy geologies that may have helped reduce competition from other taxa at these sites. It may also be related to fire and regular burning and regeneration of *Pinus*. There appears to be some evidence for the 8.2ka event within the Surrey sites, where there may be a slight climatic downturn between 9000-8000 cal. BP, however due to the hiatuses and sedimentation rates it is difficult to examine the event in high resolution. Similarly to the Early Mesolithic, there is widespread evidence for Late Mesolithic people across Surrey during the Early Holocene. Due to both the density of activity in the southwest of the County, and also the increasing prevalence of fire in the region, it is thought that people may have been actively interacting with the woodland around Thursley Bog, Ockley Bog and Elstead Bog. Causes for this burning are varied, and it may have occurred naturally or have been anthropogenic in origin, for example the creation or maintenance of clearings. It is also possible that the distribution of *Corylus* was being exploited and managed, with hazelnuts seen as a valuable food source.

The research investigated four wetland sites, and three of these sites (Langshot Bog, Thursley Bog and Elstead Bog B) provided new palaeoenvironmental records, whilst Ockley Bog provided an opportunity to enhance previous work (Moore and Wilmott, 1976). The records from the four sites have provided important contributions to our knowledge and understanding of vegetation succession, with evidence for the presence of species such as *Corylus*, *Alnus* and *Pinus* at similar or earlier dates than previously observed within southeast England. Both Elstead sites and Langshot Bog appear to offer vegetation reconstructions on a regional scale, with Thursley Bog and Ockley bog highlight local scale changes against a regional background signal. Analysis of the archaeological records identified that this wet/dry region was frequently visited by Late Upper Palaeolithic and Mesolithic groups, a significant discovery when examining palaeoecological sites within this wet/dry boundary zone. Examination of the wetland sites, taking into account the surrounding archaeological records, has developed our understanding of if and how Late Upper Palaeolithic and Mesolithic groups interacted with the vegetation. The results indicated that it was likely people would have been exploiting the vegetation for hunting and gathering, and during the Later Mesolithic, may have been creating, or maintaining, clearings within the woodland through fire in order to attract animals to hunt.

10. Significance and Threat Criteria for the Evaluation of Wetland Sites of Palaeoenvironmental and Cultural Importance

10.1. Introduction

The discovery of important new Late Glacial/Early Holocene lowland wetland palaeoenvironmental sequences in Surrey during this PhD has led to a need to evaluate these unique sites with respect to both their scientific and cultural significance, and the potential threats to their sustainable management and conservation. This chapter discusses the rationale behind the creation of a 'schedule of wetland sites', and evaluates a set of criteria for assessing the significance of, and threat to, wetlands of palaeoenvironmental and cultural interest. This evaluation is important due to the potential threats facing many of these sites, even those covered under statutory legislation. The notion of 'scheduled wetland sites' will be based on the significance of the palaeoenvironmental record, including evidence for human modification of the natural environment. However it will not take into account modern characteristics, such as biodiversity, nor will they apply to those sites with known in-situ archaeology, as these types of site are already covered under other designation criteria such as biological Sites of Special Scientific Interest (SSSI) or Scheduled Ancient Monuments (SAM).

The proposed criteria therefore offer a method for the evaluation of palaeoenvironmental records from lowland wetland sites, which can then be put forward for protection by county councils, Natural England or Historic England if they are deemed to be significant and/or threatened. They have been drawn up through consultation with guidelines for the selection of biological SSSIs (Nature Conservancy Council, 1989) and Earth Science SSSIs (JNCC, 1977; Ellis et al., 1996), and take into account documents produced by the IUCN peatland programme (Gearey et al., 2010) and Historic England (English Heritage, 2012; Heathcote, 2012).

10.2. Rationale behind the evaluation

The rationale behind the development of these evaluation criteria was borne from the new palaeoenvironmental and cultural data generated from lowland wetlands within this PhD project, and from the analysis and review of other lowland wetlands within the South East. The studied sites within Surrey appear to offer some of the best lowland-inland sediment sequences and palaeoenvironmental records for the Late Glacial and Early Holocene in

Britain. Due to this, it is important to quantify not only the significance of these sites, but also to understand the potential threats to these sites based on their location and management. For example, Elstead Bog A and B - two sites situated on private land with no current legislative protection. Indeed, in several cases palaeoenvironmental and cultural information has now been lost due to poor management practices and the impact of development schemes. The criteria have been designed to evaluate the sites examined within this study, and other similar lowland wetlands (bogs, fens, mires and others), to provide a guide for local authorities, wildlife trusts, heritage and earth science agencies to guide the future conservation and management of these sites.

These criteria were also designed to complement the National Heritage Protection Plan (NHPP) (English Heritage, 2013), in particular activity 3A5: 'Identification of Wetland/Waterlogged Sites' (English Heritage, 2013) which highlights the importance of wetland heritage, and the potential threat to these wetland sites. This plan examines the heritage sector in Britain and assesses heritage sites that are at risk of degradation or destruction, or are of high significance to the general public. To summarise:

- The primary objective of the evaluation is to provide a method of assessing, against a set of pre-determined criteria, a range of lowland wetland sites to determine both their palaeoenvironmental and cultural significance, and quantify the level of potential threat to these sites.
- Once evaluated, those sites which show a level of special palaeoenvironmental or cultural interest (either individually or as a group) may be put forward for statutory designation or be considered for special protection against potential threats. The sites can also be compared to other sites at a range of spatial scales (locally to internationally).

10.2.1. The need for wetland site conservation

Lowland wetlands in southern England are able to provide a wealth of information on both the environmental history and climate of the region. These records are able to generate a model of the past vegetation and climate history of the region, including shifts in ecological biomes; vegetation reactions to periods of rapid climate change and past land cover types. They can also be used to examine how humans and animals may have interacted with the vegetation including, but not limited to, recording changes in the fire history, the onset and development of farming and the potential exploitation of species by humans. These different types of information are available across a range of different time scales. This has led to the acknowledgement that:

> *"In terms of importance, both archaeological and palaeoenvironmental sites are enormously important as they further our knowledge about how people lived in the past" (Tony Howe, Heritage Conservation Team Manager, Surrey County Council, Structured Discussion, August 2016).*

Many of these lowland wetland sites are already perceived to be significant, however, this is often from a conservation and biodiversity viewpoint as they are an endangered type of habitat, particularly in the southeast. These sites are also significant as they often form part of the upper catchment of many river systems and help to manage and regulate the water flow downstream. The palaeoenvironmental records from these lowland wetlands are significant, as they are able to capture people's imagination and are arguably a neglected resource of archaeological and historical interest:

> *"A small wetland in the corner of Chobham Common has revealed a story about the past vegetation and human interaction with their environment that highlights there are still mysteries to be found in urban Surrey! These new records also provide an additional route to explain to the public why the countryside is an important and interesting natural resource" (Stephen Fry, Senior Ranger at Chobham Common, Structured Discussion, August 2016)*

> *"I did not realise that lowland wetlands were such a wide ranging resource, they should definitely be further understood and protected. If they were above ground structures, it would not be under question!" (Nigel Randall – Archaeological Officer at Surrey County Council, Structured Discussion, August 2016)*

It is important to distinguish between the current SSSI's and SAM's. SSSI's are the responsibility of Natural England, and sites can gain their protected status on either geological grounds (JNCC, 1977; Ellis et al., 1996), or their habitat type (Nature Conservancy Council, 1989). SAM designation is the responsibility of Historic England, where features are designated on their historical importance. The critical aspect of any site designated as a SAM is that the site must provide evidence of a structure (English Heritage, 2012). This means that almost all lowland wetlands do not get included in either of these categories, as they often have no structural evidence, and therefore they will be ineligible for SAM, and they do not necessarily have the characteristics suitable for SSSI designation. Nevertheless, they permit:

- **Scientific research** - lowland wetlands provide excellent research opportunities in a number of scientific fields. As already discussed, this includes palaeoecology, and opportunities also exist for many other disciplines, including (but not limited to):
    - archaeology (e.g. bog bodies, prehistoric trackways)
    - environmental science (e.g. carbon balance)
    - biology/zoology (e.g. species diversity)

  These wetland habitats are also highly important for the conservation of diverse and rare flora and fauna, and can contribute to the designation of sites as SSSI's, NNR's and other nature-based classifications.

- **Education** – alongside the scientific research based opportunities, there is also the opportunity for these sites to provide educational value. This may include teaching students about prehistory, whereby their local archaeological sites can be placed in their palaeoenvironmental setting, or through examining how the past climate has caused modifications to the environment.

- **Training** – these lowland wetland sites offer excellent chances for training locations. Training can include learning coring/sampling methods, and describing unconsolidated sediment and peat stratigraphy.

- **Aesthetic purposes/leisure** – the aesthetic nature of many of these lowland wetland sites is also of high importance because they are places that are often visited for an array of leisure activities.

10.2.2. The threat facing lowland wetland sites

These lowland wetland sites can be found across a varied array of geologies, elevation and land use types. The wetlands can be privately owned, such as Elstead Bog or managed by local, regional or national bodies, such as Langshot Bog on Chobham Common, currently managed by the Surrey Wildlife Trust (SWT).

Due to the specific nature of these wetland zones, there are a number of threats that affect these regions (Table 10.1).

Table 10.1. Potential threats facing peatlands, after: Gearey et al. (2010).

Threat	**Causes**
Erosion	Peat extraction and erosion.
De-watering	Water abstraction and reclamation for agricultural purposes. Climatic drought
Afforestation	Alters soil chemistry. Changes drainage pattern and land use.
Peat Cutting	Removal of resource.
Burning	Wild and controlled fires.
Changes in precipitation / evaporation ratio	Climate change leading to modification in the peat growth.
Development	Infrastructure developments, including wind farms and pipelines.
Air pollution	Cars, other vehicles. Inadequate drainage from road systems.
Habitat fragmentation	Erosion or land use change.
Others	Traffic across surface of bog, including walking, horse riding, vehicle traffic and military activity.

These threats will almost all lead to damage of the palaeoenvironmental record, either through exposure, erosion, desiccation or destruction of the sedimentary record. It is important to note that many of these threats can apply to sites that may already be designated under other legislation. Tony Howe (pers. comm.) indicated that pipe laying (by utility companies) was likely to be one of the key developments that would affect lowland wetlands, as due to their natural landscape settings, housing or other development is unlikely. From a palaeoenvironmental perspective, threats can occur due to poor management or through a lack of understanding of a site's significance. This is best highlighted at both Langshot Bog and Thursley Bog.

Both of these sites are covered by a variety of biological designations, primarily due to the flora and fauna that are present. Langshot Bog, managed by SWT, is within the Chobham Common National Nature Reserve (NNR), a Special Protection Area (SPA), and a SSSI. Thursley Bog is a NNR and a SSSI and is managed by Natural England. At both of these wetlands, small pits or pools have been dug into the surface, in order to encourage increased diversity of species present on the wetland surface. However, this removal of the top layers of peat has led to a loss of information on vegetation succession, climate change and human activities for at least the last 3000 years. This damage has primarily been caused through a lack of awareness about the palaeoenvironmental significance of these wetlands. Through the designation of these sites, awareness of their significance will be raised and should help to protect them as an important palaeoenvironmental and cultural resource.

In addition, at Langshot Bog there is evidence for the drainage of land for the conversion of wetland to arable/pastoral fields, currently used for grazing horses. This was achieved through cutting drainage ditches to lower the water table. There is the potential that this has damaged or destroyed up to 60% of the original wetland present at Langshot Bog. Further grazing of the wetland by cattle may potentially disturb the surface of the bog.

Bramcote Green is another example of the threat facing lowland wetland sites. The lowland wetland was studied as part of redevelopment work in the Bramcote Green area, and provided an excellent record of Late Glacial and Mesolithic vegetation history from a site near the River Thames, in the northwest corner of historic Surrey (Branch and Lowe, 1994; Thomas et al., 1996; Branch and Green, 2004). Unfortunately, although the palaeoecological and cultural value of Bramcote Green was highly significant, the site was destroyed due to urban development. Using the framework developed within this PhD, the palaeoenvironmental and cultural significance of the site, and the high level of threat faced by Bramcote Green would have meant that the site should have been considered for designation and subsequent protection. Bramcote Green highlights a key issue that many sites will be under imminent threat, and it may not be possible to deter subsequent damage or destruction. However, having a detailed record of their significance can also assist in developing suitable sampling strategies to ensure the loss of the resource is mitigated as much as possible. This implies enough time is allowed for work to be undertaken to assess the sites significance, prior to the destruction of the resource.

10.2.3. Special Interest

The concept of special interest has been examined in the guidelines of both biological SSSIs (Nature Conservancy Council, 1989) and the Earth Science SSSIs (Ellis et al., 1996). The designation of ‘special interest’ is significant as it is the expression of a site’s value based on informed judgement, rather than the strict application of a series of objective rules (Ellis et al., 1996). This clarification of site value is based upon instrumental values, such as a site’s significance to education or scientific research. This means that representativeness features strongly in the criteria developed for lowland wetland sites.

Special interest is also not static, and the significance or knowledge of a site may change across time as societal values or scientific information changes. This is perhaps most clearly observed in wetland sites with ongoing developments in dating techniques. Therefore it is imperative that the designation and continued status of sites is dynamic, and subject to removal or addition based on new data. It is important to remember however, that there are no numerical limits on the total number of sites, and therefore although the total will change as sites are added and removed in order to remain relevant to conservation principles, it is not expected to result in dramatic changes in the list of designated sites. Data from Earth Science SSSIs suggest that this has resulted only in small changes across time to the dataset of designated sites (JNCC, 1977; Ellis et al., 1996).

10.2.4. National and International Interest

It is a requirement that those lowland wetland sites put forward for designation by the national bodies (Historic England or Natural England) are of at least national or international standing. Consequentially the potential range of designated lowland wetland sites would aim to portray a representative sample of nationally and internationally significant sites. With the nature of wetland sites, it is important to note that a site may achieve national or international significance either on its own, or within a group of closely-related sites that form a network of wetland records. Therefore sites are not excluded from recommendation due to similarities in content and this is explored in the ‘group value’ criteria.

A number of wetland sites may not reach national or international significance through this classification scheme but may be significant at a regional or local level. These sites are still an important part of the palaeoenvironmental and cultural resource, and may require some level of designation. Designation of these sites should be undertaken by a regional or local body, often at County Council level, where the intrinsic value of these sites to the local environment and population can be assessed and subsequently designated, such as a County Site of Archaeological Importance (CSAI).

10.3. Criteria

It is imperative to identify sites across England that provide the best records in terms of representativeness, significance and exceptional features. Therefore sites should be able to meet a number of criteria, which for this purpose are similar to those set out in the designation of scheduled monuments criteria where they are referenced in detail (DCMS, 2013):

- Period
- Palaeoenvironmental evidence
- Additional documentation
- Survival/condition
- Group value

10.3.1. Period

10.3.1.1. Chronological Period

The chronological period of the wetland is of high value when determining its significance. The identification of 'rare chronological periods' is difficult, and can vary depending on the spatial scale of the investigation and the type of site. This document does not attempt to highlight gaps in knowledge, but rather to identify a method for considering the chronological rarity of a site based on the assessor's knowledge of the local and regional resource. It is known that some time periods are represented in more sites than others, whilst some will date to periods where information is scarce. This abundance or scarcity can be measured on a regional to local scale, and if the time period of a site is considered rare across all spatial scales this will result in it being considered as highly significant.

A good example of this is the identification of the three new sites in Surrey that date to the Late Glacial period. In this case, sites dating to this period are relatively rare across Britain. Within Southern England they are very rare and on a regional level they become the only known examples. In general, Holocene records are better represented in the palaeoenvironmental record, however this does not mean that they are well represented at a local to regional level.

In addition to this, those sites that provide evidence spanning across multiple archaeological periods (such as the Neolithic to the Iron Age) or cross documented periods of environmental change (such as the Late Glacial to the Holocene) may be more favoured for designation due to their greater potential for answering major research questions. These are periods of major environmental or societal change, and therefore being able to adequately develop a picture of the palaeoenvironment and cultural landscape during these periods is of key significance. The presence of these chronological periods can therefore be considered an 'exceptional feature' of the record. Exceptional features are valuable as by their nature they are either of a rare type or provide a very good example of a feature or event, thus forming a critical part of the national resource and requiring conservation. It is likely that sites with these exceptional features will be designated as a scheduled lowland wetland, either by reaching a nationally or internationally significant score, or be designated as a CSAI at county level. Exceptional features are especially relevant as they can be used to capture the imagination of the public, and can be highly useful for scientific study and as educational 'text-book' sites. This is evident from the three new Surrey records (Langshot Bog, Thursley Bog and Ockley Bog), which all straddle the Late Glacial and Early Holocene boundary, allowing for detailed investigation of this climatic event and its environmental and cultural impact across Surrey.

10.3.1.2. **Chronological Quality Assessment**

In lowland wetlands the chronological framework is most frequently determined through radiocarbon dating, and the number of radiocarbon dates analysed within a sequence will be important in determining how reliably dated any of the outputs from that sequence are likely to be. Sites that are well dated are able to define the age-depth resolution of the sequence and can date specific events (within a defined margin of error). These types of well dated site are obviously more significant than those sites that are poorly dated.

It is hard to provide a blanket statement relating to the exact number of dates that a sequence requires in order for it to be classified as 'highly significant'. This is because the amount required is based upon a number of factors specific to each individual wetland, including the deposition rate, depth of sequence, and availability of suitable materials for dating. In order to achieve the highest significance scores for this category, individual lowland wetland records need to be dated to a high enough resolution to determine any changes in deposition type (such as mineral influx events), identify major climatic or cultural events, and be able to identify changes in the deposition rate or the presence of hiatuses in the sequence.

10.3.2. Palaeoenvironmental Evidence

10.3.2.1. **Stratigraphy**

The stratigraphy of a lowland wetland is very important in determining the type and quality of information that can be derived from a site. The stratigraphy includes the types of deposit present (sand, peat, gyttja etc.), the stratigraphic integrity and the age-depth resolution of the sediments.

Different types of sediment will provide a range of potential archives for palaeoecological and cultural proxies. Ideal sequences within lowland wetland contexts will have highly organic sediments (such as peats or gyttja) throughout the length of their profile. As increasing amounts of mineral matter become present in the sequences, they will often become less desirable for palaeoenvironmental work due to possible degradation or absence of many proxy records.

Stratigraphic integrity is of vital importance to age-depth studies. Disturbed stratigraphy will often result in difficult to interpret and potentially misleading results. This disturbance could be caused by surface vegetation, animal activity or human interference leading to either older deposits present above younger deposits, or a mixing of deposits. Disturbance (often only of part of a sequence) can be identified through describing the sediments, and through radiocarbon dating both across and within stratigraphic units. An example of a site with poor stratigraphic integrity is Elstead Bog B, which clearly shows high levels of disturbance across the top of the core, with inverted radiocarbon dates and poorly defined stratigraphic units.

The depth of the site is important as deeper records will either span a greater amount of time, or provide more material covering a shorter period of time. The relationship between depth and time determines the age-depth resolution of the record. This is important because it is imperative that the age-depth resolution of the site is at a high enough level to study all the observed events in detail.

At Langshot Bog, one of the key palaeoenvironmental events dated is the Late Glacial to Early Holocene boundary. The age-depth resolution across this period (~12,000-11,000 cal. BP) is ~17 years/cm. When compared with the site of Elstead Bog A, the age-depth resolution over the same period is ~36 years/cm. This shows that the age-depth resolution at Langshot Bog is good (when compared to other regional sites) for answering specific questions related to the Late Glacial/Early Holocene transition, and therefore the Langshot Bog stratigraphic record would be scored as significant. The age-depth resolution may not be constant throughout the core, and some parts of the sequence may provide an excellent age-depth resolution whist other sections are much poorer. This is indeed the case for Elstead Bog A where the Early Mesolithic record is at a resolution of ~9 years per cm. Both these sites are therefore likely to score highly in this category as their stratigraphic resolution (at least in parts) is good enough to answer some of the specific research questions.

10.3.2.2. **Proxy records**

Through the analysis of a range of microfossil and macrofossil proxy records, a greater understanding of the climate, vegetation and cultural history at the site can be obtained. These proxies will often provide complimentary information, and therefore a greater range of proxies available from a single site will permit the development of a more robust model of the environmental history. The most frequently encountered proxies that can be extracted from lowland wetlands include:

- Pollen grains and spores
- Microscopic charred particles (MCP)
- Seeds and plant remains
- Insects
- Waterlogged wood
- Testate amoebae

Sites that are highly significant will be able to provide a number of these proxy records, in order to ensure more than one line of evidence is being examined. If a site does not have the preservation conditions for any of these proxy records to have been preserved, then it is unlikely to be suitable for designation. The Langshot Bog site provides a good example of where three of these proxies have been used to generate a broader range of palaeoclimatic information. This sequence provided pollen grains and spores, microscopic charred particles and plant macrofossils. The pollen provided a high-resolution record of vegetation change, the MCPs provided clear evidence of the fire history at the site, and the plant macrofossils (sedge fragments) were used for isotopic analysis to provide a record of climatic change.

10.3.2.3. **Cultural Indicators**

Lowland wetlands will often produce excellent records of pollen grains and spores, with these having been used to identify human interference with the vegetation cover (Behre, 1981; Edwards and MacDonald, 1991). This is often achieved through the use of anthropogenic pollen indicators or ‘indicator species’ (Branch et al., 2005). The ‘indicator species’ approach identifies those taxa that are considered to be associated with human induced land use, such as cultivation, meadow development or the creation of pasture. Due to the taxonomic resolution of pollen and the fact species can grow across a wide range of ecological niches, this method can be problematic, however a number of distinct ‘indicator species’ have been used from lowland wetland contexts to indicate human interference within the vegetation record. Lists of specific palaeoenvironmental indicator species are present within the literature (Behre, 1981; Gaillard, 2007). Some of the key indicator species include (Branch et al., 2005):

- Cultivated species – *Triticum* or *Hordeum*
- Managed arboreal species – *Castanea* and *Juglans*
- Ruderal weed species suggesting pastoralism or cultivation – *Plantago lanceolata*
- Taxa indicating pioneer re-colonisation, associated with human induced disturbance – *Corylus*

Additionally, the concept of 'indicator groups' can also be used. This examines the ratio of arboreal to non-arboreal pollen and can indicate human disturbance when records show a decline in arboreal pollen and corresponding increase in heliophilous taxa. These indicator species are likely to vary depending on location of the site and time period. Sites where there is clear evidence for the presence of these, or other indicator species/groups, will have more cultural significance than those sites where there is no/little evidence for these anthropogenic pollen indicators.

It is important to note that these indicator species need not be confined to specific types of pollen grains, and within lowland wetlands there may be other proxy records that can help to indicate human interaction with the vegetation cover. This could include plant macrofossil remains, such as the seeds of managed arboreal species, or phytolith evidence of cereal cultivars. These additional indicator species are all included within this section of cultural indicators and all help add to the significance of a site from a cultural perspective.

An example of where the palaeoecological record has inferred human impact on the environment is provided from the *Corylus* record at Ockley Bog. The record identifies an increase in *Corylus* during the Late Mesolithic, and the use of hazelnuts has been identified at a number of Late Mesolithic sites (Godwin, 1975b). The quantities of *Corylus* at Ockley are considerably higher than observed in modern *Corylus* ecosystems (Finsinger et al., 2006a), and may indicate the exploitation of this resource by the Late Mesolithic population. Pollen records from other archaeological periods, such as at Diss Mere in Norfolk, have shown other evidence for human activity, such as *Cannabis* and *Linum* cultivation during the Medieval period (Peglar, 1993).

10.3.4. Additional Documentation

Sites with extensive documentation, which help to further understand its character but are not directly related to the palaeoenvironmental resource, are more likely to provide greater assistance in the interpretation of the site record. This documentation could include work such as geological deposit models, detailed maps (of geology, land use, vegetation types etc.), scientific/archaeological reports, reports detailing the condition of the wetland, recent records of vegetation or climate change and historical records, amongst other information.

At Thursley Bog and Ockley Bog, for example, site management plans detail how the sites have been used in the recent past and how the sites will be managed in the present day and into the future. This helps to determine what impacts the bog may have faced, such as peat cutting or drainage. Across Thursley Bog and Ockley Bog, the management plan detailed that there was no grazing present across the site. Any movement across the bog surface is also highly discouraged through the creation and expansion of a network of paths and boardwalks across the driest parts of the wetland. This suggests that there should not be any abnormal levels of peat disturbance across the top of the palaeoecological sequences and this information can be taken into account when interpreting the results. At Chobham Common, there is a document detailing the recent history of the Common, covering the past 200 years. This is highly informative for the Langshot Bog site, as it specifically details where troops were stationed on the Common during the Second World War. It indicates that the bog area would not have been extensively affected, suggesting this would not have damaged the stratigraphic integrity of the palaeoenvironmental sequences.

10.3.5. Survival/Condition

The condition of a wetland site can affect its long-term survival and can impact the palaeoenvironmental potential of a site. Sites may be in situations where they are under immediate threat of destruction or a short-term threat of degradation. It can be the case that the designation of a site may ensure the sites survival, assuming it also meets other criteria for designation, or that a correct sampling strategy is implemented to ensure that maximum palaeoenvironmental information can be obtained from the site. When a site is being assessed, it is important to take into account the current condition of site and its survival status in order to be able to adequately assess its significance and threat.

In addition to the threats facing a sites survival, the condition of a site is also of concern. This primarily focuses around the presence and characteristics of the deposits. It is important that the sediments are kept in a way that will not promote or increase the speed of their degradation. For example, with peat sequences this means that in order for the site to be in the best condition, the samples must be waterlogged and not under threat of drainage or seasonal aridity.

Even if a site is protected from different types of statutory designation, such as SSSI's or an NNR, this does not necessarily mean that the site is protected or in good condition from a palaeoenvironmental standpoint. It is important to ascertain the current types of management present at a site in order to fully assess its condition and survival. As detailed earlier in Section 11.2.2, this can include the cutting of peat on lowland wetlands for the promotion of biodiversity. Clearly this is a threat to the palaeoenvironmental sequence present at a site and needs to be mitigated against using the relevant wetland designation if appropriate.

10.3.6. 'Group Value'

Wetland sites can be found in isolation or in a network of other sites; a site network may have developed through time due to geomorphological or other environmental and geological processes, or be within a wider cluster of interrelated networks. These sites will have a high 'group value', as they will often help to provide a greater insight into past environmental and cultural change than when isolated sites are studied individually. Many of these networks have very high research and educational value and sites that are included as part of a network will achieve greater significance due to their group value. The interrelated network of prehistoric 'pingo' sites in East Anglia is an excellent example of where a group or network of sites develops a higher educational and impact value (Bennett, 1988). These sites provide a range of excellent palaeoenvironmental records, however, they have also been used as the focus for a number of designated walks and trails, increasing the public's knowledge of the types of lowland wetlands and glacial landforms. This would be unlikely to happen if these sites were isolated.

The sites of Ockley Bog, Thursley Bog and Elstead Bog are an excellent example of three wetland sites that are situated within a close spatial scale to each other, and benefit from additional 'group value'. These sites all provide excellent individual palaeoecological records, primarily due to the excellent proxy preservation and the chronological period that the sites cover. Both Ockley Bog and Thursley Bog provide records dating from the Late Glacial to the

Early Holocene (from pre ~14,000 cal. BP and pre ~13,000 cal. BP respectively), and Elstead Bog provides an excellent record of the Early-Mid Holocene (from ~11,500 cal. BP). Due to the age of these sequences, when the sites are combined they provide a record of Late Glacial to Mid Holocene palaeoenvironmental change for southwest Surrey. This helps to develop our knowledge of environmental change and cultural impacts more than when the sites are studied individually, and exemplifies the need and understanding of 'group value'.

10.4. The Evaluation of Wetland Sites

The evaluation is carried out in a number of steps based upon the five criteria outlined previously, which are considered to be the most significant aspects when assessing a lowland wetland site. Site details are recorded (Table 10.2) and then each criterion has a certain number of parameters that can be met on a very high/high/mid/low scale (Table 10.3). This new scale for assessing these sites then assigns each parameter a number of points (very high=4, low=1) and the total sum of these points will help determine the significance and designation potential of the site.

Table 10.2. Site details for designating wetland sites of significance.

Site Name:		Site Code:
Parish:	District:	County:
Current Designations (e.g. SSSI, NNR, National Park etc.):		
Grid Reference:		
Surveyed By:	Date of Survey:	
Site Ownership: Site Contact Details:		
Site Description General Description of site (incl. depth, stratigraphy etc.): Current Management: Immediate Conservation Measures Required:		
Literature References:		
Enquiries (Surveyor Contact Details):		

Table 10.3. Assessment criteria for designating wetland sites of significance.

Values	**Detailed Values**	**Criteria Scores**			
		Very High – 4 points	*High – 3 points*	*Mid – 2 points*	*Low – 1 point*
Period	*Chronological period of record*	Record dates to a period of time where no other regional or local records exist.	Record dates to a period of time where few other regional or local records exist.	Records dating to the same period of time are common regionally or locally but not abundant.	Dates that record represents are well represented regionally or locally.
	Chronological length of record	Record spans across multiple archaeological or environmental periods of change (i.e. a full Holocene sequence or an Upper Palaeolithic to Neolithic sequence).	Record spans across one period of archaeological or environmental change (i.e. the Late Glacial to the Early Holocene or the Iron Age to Roman transition).	Record dates to a single archaeological or environmental period, but provides a good account of that period (i.e. record almost spans the Bronze Age but not the Neolithic or Iron Age).	Record only provides a partial account of a single archaeological period or environmental event.
	Chronological quality assessment	Site is well dated and major changes in stratigraphy are bracketed by radiocarbon dates. Models lead to constrained date estimates.	Site is sufficiently dated and radiocarbon models provide a good estimate of the ages of events within the core.	Site is sufficiently dated but needs more dates to complete the sequence, or chronological uncertainties are large, leading to poor modelling results.	Site is poorly dated and chronological uncertainties are large.
Palaeo-environmental Evidence	*Stratigraphy*	Stratigraphy is highly organic, with minimal inorganic intrusion and the sequence is not disturbed.	Stratigraphy is fairly organic, with some mineral inclusions and the sequence is not disturbed.	Stratigraphy varies between organic and inorganic sediments and/or some parts of the record appear disturbed.	The majority of the sequence is inorganic and/or large sections of the stratigraphy appear disturbed.
	Age-depth resolution	Age-depth resolution is consistently high across all events of interest.	Age-depth resolution varies, but is broadly at a high enough for detailed analysis.	Age-depth resolution is relatively poor, and will not provide the best results.	Age-depth resolution is poor throughout the core.
	Proxy records	The site has evidence from multiple different proxy records throughout the profile.	Multiple proxy records have been studied for part of the sequence.	Only one proxy record has been analysed at the site.	Proxy records are not well preserved within the sequence.

Values	Detailed Values	Criteria Scores			
		Very High – 4 points	*High – 3 points*	*Mid – 2 points*	*Low – 1 point*
	Cultural indicators	Evidence for human interaction with the woodland is inferred from ‘indicator species’ and on site archaeological records.	Evidence for human interaction with the woodland is inferred from ‘indicator species’ from more than 1 proxy record or local archaeology.	Evidence for human interaction with the woodland is inferred from ‘indicator species’ from a single proxy record.	There is no evidence for any human interaction with or modification of the vegetation.
Additional Documentation	*Availability of additional information*	Range of documents including, but not limited to, deposit models, vegetation surveys and recent high quality scientific or archaeological reports.	Some relevant documentation or older archaeological and environmental records exist.	Out-dated documents or reports exist about the site with a limited range of information.	No additional documentation or information available about site.
Group Value	*Local and regional groupings*	Other sites in the **local** area provide complimentary records to current site and help to develop a broader picture.	Other sites in the **regional** area provide complimentary records to current site and help to develop a broader picture.	Other sites on a local to regional scale may provide complimentary records.	The site is isolated and there are no known sites in the local or regional area that provide complimentary information.
Survival and Condition	*Current Condition*	Entire site is in good condition and no evidence of poor management is evident.	Majority of site is currently in good condition but has the potential to degrade to poor condition.	Site is currently in poor condition but could be restored to good condition.	Site is in poor condition and unlikely to be a candidate for restoration due to overall degradation.
	Potential threat level	Site is at imminent threat of destruction.	Site is at threat of degradation due to current management or lack of any designation.	Site is not considered to be at threat of destruction or degradation but needs monitoring.	Site is currently managed well, and is perceived to be under no threat of degradation or destruction.

These criteria are designed so that all sites can be evaluated using all of the detailed values, resulting in 11 scores ranging between 1-4. Therefore, the maximum score a site can attain is 44 and the minimum score would be 11. Significance boundaries are based on the type of scores required to get to that level, and groups get smaller as the significance level is raised, so that the groupings represent both the rarity and importance of sites in the top categories.

- **International significance** can be attained by reaching a score of 39 or more. The site will have achieved a very high score for the majority of categories. These would be designated as a "scheduled wetland site". Scheduling ensures that the long term protection for the site is considered and is relevant for sites which have claims to both international and national importance, and provide sequences that detail the national story (English Heritage, 2012).
- A site can be defined as **nationally significant** if it attains a score of 33-38. This score means that it is likely that the site will have achieved a 'very high or high' score for a number of detailed value categories. These would be designated as a "scheduled wetland site". Whilst scheduling would be recommended for these sites, it is important to note that scheduling is deliberately selective, and due to the rapidly increasing number of archaeological and cultural remains this is unavoidable (English Heritage, 2012). In these cases, designation at the county level could also be used (see regionally significant sites). Additionally sites can be covered under the National Planning Policy Framework, where these sites will be treated as defined heritage assets (English Heritage, 2012).
- A site that reaches a score of 26-32 may be **regionally significant.** These sites can be subsequently forwarded to local bodies for designation on a county scale, as it is expected to be significant and worthy of some protection at this regional scale. These sites will tend to represent a mix of 'very high', 'high', and 'mid' scores. These sites could become county sites of archaeological importance (CSAI) (Tony Howe, 2016. Pers. Comm.).
- Sites which score 19-25 represent those sites that should be **locally significant**. These sites will be comprised of a range of 'very high' to 'low' scores. These sites are unlikely to provide the best, most extensive or useful records at a regional, national or international level but will provide important and significant information to local records. These should be recorded on county HER databases. If there is the potential that further work at these sites would provide more palaeoenvironmental or cultural

information, then they could be designated as areas of archaeological potential. This would work as a planning development flag and assist with undertaking further work on the site (Tony Howe, 2016. Pers. Comm.).

- A score of 11-18 means that the site is probably **insignificant**, and are predominantly comprised of ‘mid’ and ‘low’ scores.

A number of examples of this designation system have been undertaken to evaluate the suitability of this scoring method and the results are presented in Table 10.4. The scoring sheets and tabulated data on the sites are found in Appendix 13.20.

Table 10.4. Criteria scoring results for a range of palaeoenvironmental sites examined in this project.

Site Name	**Site Score**	**Classification**
Langshot Bog, Chobham	40	Internationally significant
Thursley Bog	33	Nationally significant
Ockley Bog	36	Nationally significant
Elstead Bog B	24	Locally significant
Elstead Bog A (Farr, 2008)	33	Nationally significant
Nutfield Marsh (Farr, 2008)	27	Regionally significant
Bagshot (Groves, 2008)	29	Regionally significant
Conford (Groves et al., 2012)	30	Regionally significant

These scores show how these criteria and the methodology can be utilised to provide a scoring system applicable to wetland sites. Based on the sites examined here, the results highlight the need for designation at a variety of scales, and a general lack of sites that are insignificant, which is primarily due to the way sites are surveyed and recorded. Within this project, a number of lowland wetlands were excluded from further study due to observations in the field. These observations, such as a shallow peat sequence or highly in-organic profile, suggest that there would have been a high probability that these sites would achieve a low score. However, until a basic assessment of the site has been carried out, involving a small survey, extraction of a core and preliminary palaeoecological and chronological work, there is no certainty that they will be poor records. A similar issue arises when looking at the literature, as those sites that would score poorly are not written up for publication, and therefore they are not recorded fully.

The outcome of this indicates that in order to accurately classify and designate lowland wetland sites of palaeoenvironmental and cultural importance, all sites should have a basic survey. Through doing this, it is understood that not all sites will score highly, however, this is a valuable addition to our corpus of knowledge about lowland wetlands, and ensures that the best sites are appropriately designated.

10.5. Management of Scheduled Lowland Wetland Sites

The designation of a scheduled lowland wetland would help to ensure that the site remained protected from threat, and that the significance of the record can be disseminated in order to develop peoples understanding of the palaeoenvironmental and cultural records available from these sites. Disseminating the information available from these lowland wetlands is important for general education about their significance, and why they may be under threat from everyday management activities. A structured discussion with Stephen Fry, senior ranger at Chobham Common (overseeing Langshot Bog) identified that prior to the palaeoenvironmental work done in this study; the significance of the palaeoenvironmental sequence was not initially understood:

> *"We knew it was an important feature, but now there is acceptance throughout Surrey Wildlife Trust and Natural England management that Langshot Bog is a rare and significant type of site. The significance of the site has led to us attempting to expand the nature reserve through the acquisition of the peat-rich arable fields to the east of Langshot Bog" (Stephen Fry, Structured Discussion August 2016).*

Once designated, there would be a number of requirements in order to ensure that scheduled lowland wetlands remain in favourable conditions, and these would vary depending on individual sites. The requirements would include activities such as:

- Scrub clearance, as this can be vital to stop the wetland surface from stabilising and becoming too dry.
- Promote peat formation, whilst reducing the removal of peat.
- Monitoring of the hydrological conditions and maintain high water tables to ensure the bog does not dry out.

Stephen Fry and his team at the Surrey Wildlife Trust highlighted the need for mitigation if new designation (and subsequent requirements) were to be put in place. This mitigation would require the input of all parties with an interest in the lowland wetland, but once a management plan had been decided, it should be implemented by the practitioners and not require continual processing 'on the ground', where daily management plans have to be referred via a number of interested parties. Therefore it is imperative that the requirement to preserve does not become onerous. This is most important if there are stakeholders with conflicting interests, such as Natural England and Historic England (conservation against the historic landscape). Stephen Fry provided an excellent example of mitigation:

> *"In the past, we have dug pools in the surface of the wetlands across the common. Based on your research at the site we now understand that this is damaging the palaeoenvironmental record. There is the potential that these pools could be dug in areas of wet heath that are present on the common, rather than on the bog surface" (Stephen Fry, Structured Discussion, August 2016).*

It was also identified that in some scenarios, the creation of pools within the bog was required for particular taxa that interact with *Sphagnum* and other wetland species. In this case, mitigation in terms of where these pools were dug would be ideal, with basin modelling and core surveys identifying those areas of the site where this practice would cause least damage to the palaeoenvironmental record. This means that during mitigation, the palaeoecological and archaeological significance of the site must be clearly understood by all parties, helping to ensure that all parties have their views taken into account.

The designation of these scheduled lowland wetlands should ensure that these sites are protected from many of the threats that they currently face, and through successful mitigation, a compromise should be reached between the interested parties. In addition, due to the potential for long-term environmental change due to global warming, it would be worth setting up monitoring stations on designated sites. The designation will offer excellent opportunities to promote these scheduled wetland sites to the public, and help inform people on the potential palaeoecological and cultural information these sites can contain.

10.6. Summary

This chapter has examined the potential for establishing and testing criteria for designating scheduled lowland wetlands. These criteria specifically examine the type of sediment sequences found in bogs and lakes, although there is the potential to expand this to marshes, estuaries and archaeological lake settlement sites. All of these records are valuable sources of information for both cultural and palaeoenvironmental study, but they are often under threat from both human activity and environmental factors. This may revolve around inappropriate site management such as peat cutting, implementation of drainage ditches or allowing habitat fragmentation, or might be related to drought, fire or air pollution. These criteria are therefore highly significant as they provide an opportunity to ensure that these valuable cultural and palaeoenvironmental records are successfully preserved.

There is a clear rationale behind this designation, and it will bring these sites into line with other archaeological and environmental records such as Scheduled Ancient Monuments, Biological SSSIs and Earth Science SSSIs. The assessment is based upon a number of criteria derived from the designation of scheduled monuments reports, creating a simple and easy to use scoring system that will allow for clear assessment of these lowland wetlands. In order to examine how the criteria work, a number of sites were used to test the system and a range of scores were generated, suggesting the classification system can differentiate between different types and classes of sites, providing useful and meaningful output. The concept of these scheduled lowland wetlands was also discussed with practitioners, including Stephen Fry (Senior Ranger at Chobham Common), Tony Howe (Heritage Conservation Team Manager at Surrey County Council) and Alex Egginton and Nigel Randall (Archaeological Officers at Surrey County Council). It has been shown that successful dissemination of the palaeoecological and cultural information available from these records is a significant part of this designation process, and that mitigation between interested parties will help to create a sustainable management plan for the sites.

11. Conclusions

This chapter aims to provide a synthesis of the results presented within the preceding chapters in the context of the hypotheses stated in Chapter 1. Finally, a brief summary of how this work has enhanced our understanding of past environmental change, and human interaction with the natural environment, across these cultural periods is provided.

11.1. Hypotheses

Hypothesis 1 and 2 (Archaeological Distribution)

1) *H_0 – Late Upper Palaeolithic and Mesolithic archaeological finds are evenly distributed across the County.*
2) *H_0 – The environmental characteristics of Surrey had and have no relationships with findspot locations.*

The analysis of Late Upper Palaeolithic and Mesolithic records across the County of Surrey has shown a diverse range of records from single artefact findspots through to large settlement sites. A number of sources were used to collate information about the Late Upper Palaeolithic and Mesolithic period, including the Historic Environment Record (HER), Roger Jacobi's PaMELA database (Wessex Archaeology and Jacobi, 2014), grey literature and the Gazetteer of Mesolithic Sites in England and Wales (Wymer and Bonsall, 1977). Collation of these datasets showed that Upper Palaeolithic remains were low in number (HER total = 12, PaMELA total = 14), whilst there were many more Mesolithic records (HER total = 533, PaMELA total = 559). The PaMELA archive allowed for temporal differentiation, showing that within Surrey, the Creswellian, Final and Terminal periods of the Late Upper Palaeolithic are represented, as well as the Early, Horsham and Late Mesolithic periods.

Findspots (143 records – single artefacts) and undefined lithic scatters (202 records – scatters of unknown artefact quantity) accounted for the majority of the HER records within the database. Small (<20 lithics) and large (>20 lithics) lithic scatters (93 and 53 records respectively) are also well represented. 22 lithic working sites (with evidence of tool working) and 16 occupation sites (with occupation or burning evidence) were also recorded, and only 4 records were unclassified. The high proportion of findspots and lithic scatters is likely to be due to the nature of hunter-gatherer living, where there would be high levels of landscape mobility with ephemeral occupation and activity sites. These records appear to be clustered in sections of the County, which indicates that the 16 Mesolithic occupation sites are situated across the south and east of the County. Density mapping highlighted clustering of Mesolithic records in selected parts of the County, with the densest areas of Mesolithic evidence identified across the Lower Greensand (231 records), particularly in southwest Surrey, but also across the Thanet Sands (14 records) and Clay-with-Flints (36 records). Through looking at the different artefact types, in northern Surrey there appears to be a greater density of gravers, scrapers and manufacturing debris as opposed to other artefact types, potentially indicating a higher proportion of domestic-type assemblages. The artefacts also indicated that there was a lack of microliths and points in the north, which may be indicative of a lower level of hunting, or at least lower rates of discard/loss of these artefacts.

There were not enough records within the Late Upper Palaeolithic database to provide any statistically significant modelling results, and there did not appear to be any patterns within this small dataset as the records are relatively evenly dispersed across the County. Due to its substantially greater size, the Mesolithic database was used for further mapping and modelling. The Mesolithic records were compared to a variety of environmental variables, including elevation, aspect, slope and geology, in order to try and understand if the distribution of the Mesolithic records was related to the environment. Through the use of the Chi-squared test it was shown that a number of variables had record distributions that were spatially uneven, suggesting that the environment may have been important in determining both the spatial structure of Mesolithic hunter-gatherer behaviour and why these records are found at these points in the modern day landscape. Geology was a key significant variable, with records identified more frequently than expected across the Lower Greensand and Clay-with-Flints. This is thought to relate to the use of these areas as significant raw material acquisition locations and settlement locations. Elevation was also significant, as although the results did not corroborate the hypothesis that Mesolithic sites are commonly situated on ridge tops, (Kvamme and Jochim, 1990), there did appear to be a high proportion of findspots and scatters on higher ground, suggesting these regions were used as lookout or observation locations. Records in wet/dry interface locations were also overrepresented. These records contained a range of site types and artefact assemblage sizes, including findspots, scatters and occupation sites, and indicate the importance that these wet/dry locations may have had for hunting, gathering and settlement. Interestingly, aspect was not a significant variable, and it appeared that the records were not situated with any particular aspect. This is important as a general hypothesis for Mesolithic hunter-gatherer groups indicated that they may base themselves on south facing slopes for maximum solar insolation (Kvamme and Jochim, 1990).

These observations led to the creation of two predictive models in order to try and better understand the distribution of Mesolithic records and to explore patterns in past Mesolithic activity across the County. These two models differ in the addition of two variables relating to modern day human activity, ones thought to directly affect the modern day visibility of records within the landscape. These two variables were the land cover type, and the distance from the record to the nearest road, track or path. This first model was termed the conditions for archaeological discovery model and represents the potential for finding Mesolithic archaeological finds at any point across the County. The second model, without these modern day variables, is the Mesolithic activity areas model as it is thought to represent the potential for whether Mesolithic people may have been present and creating archaeological signatures at that point in the landscape. In practice, both models proved to be statistically robust and provided similar results, predicting a correct result (based on the input data) over 70% of the time. This was a value that compared favourably to other studies in the literature (Warren and Asch, 2000; Gardner, 2009) and therefore the models were considered useful for the prediction of records across Surrey. In order to check the model further, a withheld testing dataset was used. As the HER dataset had been used to create the model, the testing dataset consisted of the PaMELA database. This comparison revealed that the model would correctly predict the Mesolithic status of the PaMELA dataset over 75% of the time, indicating the model is robust and accurate. Both of the models highlighted important high potential regions such as the east-west Greensand band below the North Downs, and low Mesolithic potential areas such as the London Basin and the Southern Weald.

Both null hypotheses can be rejected, and the following alternate hypotheses can be proposed:

1) *H_1 – Late Upper Palaeolithic and Mesolithic archaeological finds are not distributed evenly across the County.*
2) *H_1 – There is a relationship between the environmental characteristics of Surrey and archaeological findspots.*

Hypotheses 3 and 4 (Environmental Change)

3) *H_0 – No evidence for the Loch Lomond Stadial is provided from lowland wetland proxy records in Surrey.*
4) *H_0 – Records from lowland wetland sites in Surrey do not provide evidence for rapid climate changes during the Holocene.*

Through the analysis of maps, remote sensing data, discussions with relevant parties and reconnaissance work, a number of bogs and wetlands were identified as potential study sites for this project. Upon further investigation, four sites: Thursley Bog, Ockley Bog, Langshot Bog and Elstead Bog B were chosen for detailed palaeoenvironmental work. All four of these sequences were either previously unstudied or required further work in order to fully understand the records. Through the application of various techniques including palynology, sedimentology and stable isotope analysis these four records have been able to provide new information on vegetation succession, development, and response to climate change within Surrey. The application of radiocarbon dating to the sequences has also enabled the records to be compared with other palaeoenvironmental records and archaeological datasets. The radiocarbon dating programme indicated that all four of the sites had organic records dating back to the Last Glacial period, important as evidence for organic sedimentation at this time is rare in Britain.

The earliest records for the four sites were provided by the Ockley Bog and Thursley Bog sequences with initial sedimentation dating prior to ~13,500 cal. BP, with the development of the two basins broadly synchronous. This is a highly significant find as these two records are the earliest dated organic sequences yet identified in Surrey. It is thought that sedimentation occurred within two undulating hollows formed in the Lower Greensand geology. During the Late Glacial period there is evidence for organic accumulation during the Lateglacial Interstadial, where the bog surface would have been damp but relatively stable. The surrounding landscape was likely to be a tundra style ecosystem, with patchy cover of *Betula, Juniperus,* Poaceae and *Salix. Corylus* was also present during the Late Glacial at the sites (~14,000 cal. BP at Ockley Bog). This is an important and unexpected finding, as it is the earliest date for *Corylus* presence in the southeast, and might indicate locally favourable conditions that were not present across other parts of Britain. The site is thought to be stratigraphically in-situ due to the sequence of radiocarbon dates. This may provide evidence for the presence of a small and local *Corylus* cryptic refugia during whereby *Corylus* became established during the Lateglacial Interstadial and survived during the Loch Lomond Stadial in South East England, which will be further assessed through additional work at the site (see Section 11.2). A destabilisation of the bog surface occurs from ~13,000 cal. BP whereby there is an increased amount of mineral matter within the record. This occurs during the Loch Lomond Stadial and wind erosion could have been a factor behind the high levels of mineral content within the sequence at this point, especially as the surrounding taxa are wind-tolerant species including *Pinus, Betula, Empetrum,* Ericaceae and *Calluna*. *Pinus* may have increased during this time due to the lack of competition resulting from the harsher climatic conditions. All of the sites in this study indicate the presence of *Pinus* during this period and may indicate a more widespread presence of *Pinus* during the Loch Lomond Stadial than previously identified. This period of increased mineral input occurs until ~12,000 where organic sedimentation restarts and continues into the Early Holocene. The identification of two sites, Thursley Bog and Ockley Bog, dating to the Lateglacial Interstadial and Loch Lomond Stadial is a very important find, as organic polleniferous sediments from these periods are very rare across Britain, and the palaeoenvironmental record these sites have provided has provided new information on vegetation in the Late Glacial period. As conditions ameliorated during the Early Holocene, organic matter levels rise and *Alnus* and *Sphagnum* become dominant on the surface of the bog. *Alnus* is likely to have been sparsely but consistently present across the southeast during the Early Holocene. The levels of *Corylus* increase at this point, indicated from both sequences, and provide evidence for a warming period at the start of the Holocene. This *Corylus* is within woodland interspersed with *Pinus* and *Betula*, and it is likely that open areas of ground were still present due to the presence of disturbed ground herbaceous species. Other deciduous species, *Ulmus* and *Tilia*, join this woodland from ~10,000 cal. BP and by ~7800 cal. BP mixed deciduous and evergreen woodland is observed with *Ulmus, Quercus, Betula, Fraxinus, Tilia* and *Pinus* alongside small areas of disturbed heathland.

The record from Langshot Bog, a large basin on Chobham Common in north Surrey, provides an organic record dating prior to ~12,500 cal. BP. Again, this is a significant discovery, as organic sedimentation during the Loch Lomond Stadial is uncommon across Britain. At this time Cyperaceae was abundant in the immediate vicinity of the site, with *Betula* and *Juniperus* prevalent across the drier ground around the site. A rise in *Sphagnum* indicates increasingly wetter conditions at the site, immediately prior to the onset of the Holocene at a time when *Betula* is dominant on the dryland. *Pinus* then colonises the dryland and mixed

Pinus/Betula woodland is present during the Early Holocene. Due to a lack of herbaceous taxa this woodland may have been dense, shading out other species. A decline in *Sphagnum* may indicate a drying out of the bog surface and encroachment by *Pinus* and *Betula* onto the surface of the bog. Thermophilous taxa, including *Ulmus* and *Corylus* are present from ~10,300 cal. BP and *Quercus* is present from ~9600 cal. BP suggesting that a mixed deciduous woodland was present by this point. High levels of *Calluna* and *Corylus* both suggest that there may have been herbivores grazing in the woodland. The Langshot Bog site provides an excellent record of Early Holocene woodland expansion, with a good age-depth resolution allowing for changes in woodland composition to be identified, dated and described. The record is then truncated by a hiatus at 8400 cal. BP, thought to have been due to a change in the hydrological regime, and does not appear to continue until the Bronze Age (~3350 cal. BP).

The Elstead Bog B site, alongside the nearby site of Elstead Bog A (Farr, 2008), also provides evidence for the vegetation on and around the two sites during the Late Glacial and Early Holocene periods. Sedimentation occurred within two small water bodies during the Late Glacial, thought to be part of a wider series of hollows or pits within the Lower Greensand. The depth of these water bodies may have been quite deep, as indicated by both *Myriophyllum* and *Potamogeton*, present until the end of the Last Glacial period. Around the sites *Pinus* and *Betula* were sparsely present, alongside *Empetrum* and Ericaceae, with *Alnus* and *Salix* on wetter ground. Open ground areas were colonised with a variety of herbaceous species including *Artemisia* and *Ranunculus*. As the climate warmed in the Early Holocene this led to increases in organic matter, with Cyperaceae, *Sphagnum* and *Sparganium* taking advantage of shallowing water levels. During the Early Holocene, the surface of Elstead Bog A dried out enough to support woodland on the surface, indicated by macrofossils found within the core. *Calluna* increases during the Early Holocene alongside a rapid increase in *Betula* and a mixed *Betula* and *Pinus* woodland would have been present in the Early Holocene, with *Salix* found on wetter ground. Thermophilous species begin to arrive from ~10,500 cal. BP, with *Corylus, Ulmus* and *Quercus*. *Tilia* and *Fraxinus* are observed from ~7500 cal. BP.

Significantly, the analysis of these sites has led to the development of both a regional and a local signal for the Late Glacial and Early Holocene. Similarities between the vegetation records at Elstead Bog B, Elstead Bog A and Langshot Bog at multiple times during these periods indicate a potential regional signal as the sites are over 25km apart. The smaller sizes of the Ockley Bog and Thursley Bog sites, and the differences within these records both to each other and the other study sites suggest that they are providing a much more local signal of vegetation change across the Late Glacial and Early Holocene. All of these records have helped to develop our knowledge of Late Glacial and Early Holocene vegetation for Surrey, and have pushed back our knowledge of the vegetation history to the Lateglacial Interstadial. The sites have shown that the Late Glacial was characterised by a tundra style landscape, with *Betula*, *Juniperus* and *Salix* present within an open and cold landscape. Some evidence is presented for a downturn in climatic conditions at the time of the Loch Lomond Stadial with higher levels of mineral matter in the cores amid potentially windier and wetter conditions. The onset of the Holocene is marked by an initial increase in *Betula* followed by a *Pinus* rise, and the gradual introduction of other thermophilous species throughout the Early Holocene. Early records of *Corylus* and *Pinus* during the Late Glacial have been identified as have prolonged stands of *Pinus* into the Early Holocene, particularly on the Lower Greensand geologies. Identification of the 8.2 Kya event is difficult, particularly due to low age-depth resolutions from both Ockley Bog and Elstead Bog A, and a lack of deposition during this period at the other sites.

With the presence of increasing mineral matter and expansion of shrub and herbaceous taxa during the Loch Lomond Stadial null hypotheses 3 can be rejected, and the following alternate hypothesis can be proposed:

3) *H_1 – There is evidence for the Loch Lomond Stadial from lowland wetland proxy records in Surrey.*

The Early Holocene records indicate vegetation succession as the climate continues to warm towards the Mid-Holocene thermal maximum; however, there is no conclusive evidence for any periods of rapid climate change due to a lack of age-depth resolution and sediment hiatuses, so hypothesis 4 can be accepted:

4) *H_0 – Records from lowland wetland sites in Surrey do not provide evidence for rapid climate changes during the Holocene.*

Hypothesis 5 (Human Activity and the Environment)

5) *H_0 – Based on evidence from lowland wetlands and the archaeological record, there is no indication for human activity with their environment during the Late Upper Palaeolithic or Mesolithic periods.*

Through the development of the archaeological databases, the density mapping and predictive modelling, an idea of where and when Lateglacial and Holocene hunter-gatherers were present within Surrey was gathered. Through combination of this knowledge with the records of environmental change from the four palaeoenvironmental study sites, human impact on the environment can be examined to see how both Late Upper Palaeolithic and Mesolithic people may have been interacting with their environment. The Late Upper Palaeolithic is represented by a low number of sites across Surrey, with the largest being the Brockhill open-air occupation site in northern Surrey, close to Langshot Bog where over 1500 lithics indicated the presence of a short stay hunting camp (Mills, 2012). At this time, the environment would have been fairly open, with *Betula* and *Salix* (both potentially dwarf variants) interspersed with herbaceous taxa. The charcoal record from Langshot Bog shows a decline during the Loch Lomond Stadial, which correlates with when people are thought to have left the area (Mills, 2012) and may indicate the displacement of people during the harsher climatic conditions of the Loch Lomond Stadial.

The other records, including the lithic working sites at Wey Manor Farm and Church Lammas, in addition to findspots and lithic scatters of long blades, knives and points, indicate the widespread presence of the Late Upper Palaeolithic across the County. The presence of *Typha* and *Empetrum* may have been utilised as food sources by Late Upper Palaeolithic groups, especially during the winter months when hunting may have been more difficult due to harsher conditions and potentially fewer species (Aranguren et al., 2007; Kuhnlein and Receveur, 2007; Hardy, 2010; Hillman, 2015). The potential for all four sites to be focal points for animal grazing and drinking may have also made them excellent areas for hunting. It is likely that humans were active in the landscape around all of the sites used within this study, with activity occurring around the Langshot Bog site, as evidenced from the Late Upper Palaeolithic open-air occupation site at Brockhill. Results from the palaeoenvironmental study, in conjunction with the archaeological record, has enhanced our understanding of Late Upper Palaeolithic interaction with the environment, and it is unlikely that groups were actively modifying the environment around these wetland sites. However, they are likely to have been using the wetland sites as areas for hunting and foraging, especially due to the potential for trapping/miring of animals, the gathering of a variety of foodstuffs, and access to water.

There is much greater evidence for activity during the Mesolithic period, with a large concentration centred in the southwest of the County, near to Thursley Bog, Ockley Bog and

Elstead Bog and a lower level of activity is observed around the Langshot Bog site in the north. There is the potential that this lower observed activity level in the North could be due to Mesolithic records being deeply buried underneath more recent alluvial sequences, however the spatial mapping and modelling results highlight this is not the sole cause of this observed lower level of activity. During the Early Mesolithic, there may have been some interaction with the vegetation, although this varies across the County. A small fluctuation in the charcoal record and fluctuations in the herbaceous taxa at Thursley Bog may be indicative of local scale human induced clearance of the wetland edge vegetation, as also seen at Star Carr (Mellars and Dark, 1998), although this was not seen elsewhere in the County. In the north of the County around Langshot Bog there is thought to be less evidence for hunting around the site due to a lack of microliths, potentially explained with reference to the relatively dense woodland leading to difficulties traversing large areas of ground. In southwest Surrey there is a much greater diversity of lithic types and hunting may have occurred in the more open woodland around the Thursley Bog and Ockley Bog sites. The small ponds at Elstead Bog A and B may have been ideal watering holes for animals that could then be ambushed or mired in the wetland edges. Even with the high density of Early Mesolithic activity identified in the South West of Surrey, none of the sites offered evidence for widespread manipulation of the woodland by fire or any other means, as observed at other UK sites such as Thatcham in the Kennet Valley (Chisham, 2004) and it appears that overall in Surrey, Early Mesolithic woodland manipulation was minimal. This is a surprising finding given the density of archaeology found in the South West of Surrey across the Greensand, and indicates that people were not modifying the vegetation in this region. This lack of interaction with the woodland was highlighted by comparison between the regional vegetation signals from both Elstead Bog A (in a region of dense Early Mesolithic archaeology) and Langshot Bog (in a region with a low density of Early Mesolithic archaeology), which both provided similar vegetation signals.

As with the Early Mesolithic, the highest density of Late Mesolithic activity is concentrated in southwest Surrey, although other large sites are also found, such as North Park Farm in the east of the County. The palaeoenvironmental record from the four sites indicates an increased incidence of woodland clearings during the Late Mesolithic, and an increase in fire events at Langshot Bog. The overall Late Mesolithic archaeological record around Langshot Bog is low in abundance however, and this increase in fire events may be naturally induced. However high charcoal counts are also observed at the nearby site of Bagshot during this time (Groves, 2008). The open woodland around the Thursley Bog and Ockley Bog sites may have meant that hunting using arrows may have been the chosen method, whilst at Elstead Bog spears and ambushing could have been more successful due to the denser woodland cover. Unfortunately the known local Late Mesolithic artefact records are not local enough to either site to support or reject this hypothesis. At Thursley Bog, Ockley Bog and Langshot Bog there are large increases in *Corylus*, and this may be related to Late Mesolithic activity as hazelnuts are often found in archaeological contexts (Godwin, 1975b; Collins et al., 1996a). The levels observed at Ockley Bog are higher than observed in the modern day, but similar to that observed at Thatcham Reedbeds (Chisham, 2004). At Thatcham, it was suggested that deliberate targeting led to this high value (40% of TLP), due to a lack of modification of the *Corylus* curve compared to other taxa and therefore the Ockley Bog record may indicate external factors, however there is not enough evidence to say whether humans modified the abundance of *Corylus* during this period. As with the Early Mesolithic, people were utilising the areas around the wetland sites to the best of their ability, and modifying their hunting and foraging methods according to the type of woodland and vegetation present around the sites.

Hypothesis 6 (Significance and Threat)

6) *H_0 – Lowland wetland sites in Surrey do not provide sequences that are significant due to their cultural and palaeoenvironmental importance, or are under threat of destruction or degradation.*

A set of criteria and scoring system to provide a standardised method of evaluating lowland wetland sites has been created. The classification uses 11 criteria, with 4 potential results per criterion and the results are split into 5 different categories, ranging from internationally significant through to insignificant. The rationale behind creating this classification system was based upon the National Heritage Protection Plan point 3A5 (English Heritage, 2013) which is related to the identification of wetland and waterlogged sites. This is important because the sites identified in this thesis provide some of the best lowland-inland sediment sequences dating to the Late Glacial and Early Holocene in Britain. Therefore a need exists to quantify both the significance that these sites possess in both a palaeoecological and cultural aspect, but also to understand how potential threats to these sites may impact on the palaeoecological and cultural record.

This research has shown that these sites are under threat from both environmental change and human activity. Through discussion with practitioners, human induced damage to the lowland wetland is often taking place with no acknowledgement or knowledge of the damage that is being done to the palaeoenvironmental record, such as the cutting of pools within the surface of Langshot Bog. This has highlighted the need for successful dissemination of the results of this study, across a range of scientific and non-scientific outlets (including academic journals, wildlife magazines and information boards) in order to raise awareness of the potential that lowland wetlands have for informing us on both past cultural and environmental change. It is also important to examine the scope and difficulties of monitoring the environmental conditions of lowland wetlands, as this is critical in ensuring their long term survival.

The rarity of the Surrey palaeoecological sites, coupled with the cultural record that was derived from them, has shown the significance of these lowland wetlands. In addition, the disturbance and destruction of peat at some of these sites has shown the potential level of threat that these sites face. Therefore the hypothesis can be rejected, and an alternate hypothesis proposed:

6) *H_1 – Lowland wetland sites in Surrey provide sequences that are of significant palaeoenvironmental and cultural importance, and/or are under potential threat of destruction or degradation.*

11.2. Future Work

In order to continue to develop our understanding of past environmental conditions, the Late Upper Palaeolithic and Mesolithic archaeological settings, and interplay between archaeological and environmental records in southeast England, a number of recommendations can be made for future research:

- The predictive models derived from Surrey's archaeological data have been shown to perform adequately compared to other archaeological models. The creation of predictive models for other regions may help to further understand the locations where Mesolithic people were most active and if the datasets were of suitable size, could potentially be broken down by record type or time period.
- An attempt could be made to correlate predictive model areas where discovery chances are high with the activities of local interest archaeological groups. This could be achieved through discussion with relevant parties and may provide further information on the reasons behind the observed distribution of artefacts.

- In addition to this, there is the potential that in alluvial sediments Mesolithic activity may be deeply buried. Further archaeological work within these alluvial environments would help to indicate if this was an underrepresented geological type or not. The mid-range scores from the predictive models in this region will assist in highlighting these regions to council planning officers, leading to an understanding of the need for deeper excavations in these areas as part of pre-building/development archaeological work.

- The database of Late Upper Palaeolithic and Mesolithic records in Surrey will need to be updated with new sites as it is only up to date as of 2013. The continual discovery and assessment of new records are important in further understanding the nature of occupation during these time periods. The models should also be kept up to date, especially if discoveries are made in low potential areas.
- The identification of *Corylus* during the Late Glacial at Ockley Bog needs further investigation to assess its potential significance as a local cryptic refugia. This requires a pit to be dug at the site in order to further the understanding of the depositional sequence at the site, and understand the context of the *Corylus* pollen in the record.
- The Langshot Bog basin is currently split due to a drainage channel and conversion of some of the bog to arable fields. Development of the basin model at Langshot Bog, Chobham Common through coring this field would enable more information to be gained on the shape and size of the bog, the potential damage to the site and the palaeoenvironmental resource through changes in hydrological conditions, and may help to further develop our understanding of site formation. This information will assist with the ongoing management of the resource at Langshot Bog, and may indicate that an active monitoring programme of groundwater conditions should be implemented at the site.
- The reanalysis of some of the larger lithic assemblages recovered in close proximity to the palaeoenvironmental sites may help to develop and strengthen hypotheses on human activity and interaction with the environment. This is particularly important in cases where little information has been recorded about the records, and the records are in identified museum holdings.
- The use of stable isotope analysis on the Langshot Bog sequence has shown that the technique can be a useful aid when applied with a range of other proxies, and provides a method for developing a climatic signal from a peat record. Further use of stable

isotope analysis on other lowland sites in the southeast would enable comparison of the records to further understand climatic change during this period.

- Through undertaking non-pollen-palynomorph assessments on the sequences used in this study, a greater understanding of potential herbivore activity could be gathered. This would allow for further discussion on when and where herbivores may have been present and their potential impact on the vegetation record. Beetle and invertebrate assessments could also assist in understanding the formation of woodland clearings and animal activity.
- The sites identified in this study are based primarily in the west of the County. Further work would benefit from the identification of sites towards the east of the County and potentially further afield, including west Kent and north Sussex in order to develop a picture of vegetation change for eastern Surrey.

11.3. Summary

Overall this thesis has enhanced our understanding of where people were present during the Late Glacial and Early Holocene. It was clear that behaviour (as evidenced by site size and the type of artefacts) does vary, and indicates that behaviour was not spatially homogeneous. Occupation sites appear to be located in the south and east of the County, often on or near to raw-material outcrops. Significant relationships were observed between a number of environmental variables and record locations including; geology, elevation and wetness index. Relationships were not observed between records and other variables such as aspect, which had previously thought to be correlated with Mesolithic hunter-gatherer site locations due to increasing solar insolation on south facing slopes (Kvamme and Jochim, 1990).

The identification of four records with palaeoenvironmental sequences dating to the Late Glacial and Early Holocene has provided the opportunity to develop our knowledge of vegetation change during a period where very few organic records exist. The presence of *Corylus* within the tundra style landscape during the Lateglacial Interstadial represents one of the earliest dates in Britain for the presence of the species, and is thought to indicate the presence of locally favourable climatic conditions not present in other regions of the country. An increase in mineral matter, the presence of *Pinus* and expansion of shrub and herbaceous taxa indicates the onset of poorer climatic conditions during the Loch Lomond Stadial. Within the southeast, and across Britain, there is a paucity of sites where organic sedimentation continues across this period, and therefore this vegetation record is highly significant. There is some evidence for an early onset of warmer conditions at Langshot Bog prior to the start of the Holocene at 11,700 cal. BP, and may indicate possible warmer conditions in southeast England than across the rest of Britain. Across the sites, the onset of the Holocene is marked by an initial increase in *Betula* followed by a *Pinus* rise, and the gradual introduction of other thermophilous species throughout the Early Holocene, with the decline of *Betula* and *Pinus*. At some sites, *Pinus* remains a significant component of the Early Holocene woodland up until the Mid-Holocene thermal maximum, thought to be related to the sandy geologies surrounding the palaeoenvironmental sites.

The results from the archaeological and palaeoenvironmental records in Surrey have helped to enhance our knowledge on the hunter gatherer impacts on the wetland/dryland interface. It is evident that since the Late Upper Palaeolithic, people would have been using these wetland/dryland areas for hunting and foraging, potentially trapping animals and gathering wetland plants. During the Early Mesolithic, there is some evidence for anthropogenic clearance of wetland edge vegetation, similar to the practices observed at Star Carr (Mellars and Dark, 1998), however, even with the high densities of Early Mesolithic activity around the Surrey Greensand, there was no clear evidence for the clearance and manipulation of woodland as observed at the sites in the Kennet Valley (Healy et al., 1992; Chisham, 2004). The Later Mesolithic indicates an increase in burning records, and a potentially increased incidence of woodland clearance, with higher levels of herbaceous taxa. This may be related to the increasing density of the woodland, and the desire for open areas suitable for attracting animals to hunt. Increasing levels of *Corylus* during this time are also important, as levels of >40%, such as identified at Ockley Bog, are not identified in modern natural contexts (Finsinger et al., 2006a) and may suggest selective manipulation of the woodland by human communities, as also proposed in the Kennet Valley (Collins et al., 1996a).

Overall, this thesis has successfully demonstrated the potential to integrate palaeoenvironmental and archaeological records to enhance our understanding of landscape change and hunter-gatherer behaviour in the Late Pleistocene and Early Holocene of southeast England.

12. References

Allen MJ and Gardiner J. (2000) *Our Changing Coast: A survey of the intertidal archaeology of Langstone Harbour, Hampshire,* York: CBA Research Report 124 Council for British Archaeology.

Alley RB and Ágústsdóttira AM. (2005) The 8k event: cause and consequences of a major Holocene abrupt climate change. *Quaternary Science Reviews* 24: 1123-1149.

Alley RB, Mayewski PA, Sowers T, et al. (1997) Holocene climatic instability: a prominent widespread event 8200 years ago. *Geology* 25: 483-486.

Allinson PD. (2008) Convergence Failures in Logistic Regression. *SAS Global Forum 2008.* San Antonio, Texas.

Allison J, Godwin H, Warren SH, et al. (1952) *Late-Glacial Deposits at Nazeing in the Lea Valley, North London*.

Ambers J. (2000) Scientific Dating Evidence: Radiocarbon sample selection and measurement In: Needham SP (ed) *Runnymede Bridge Research Excavations Volume 1. The Passage of the Thames Holocene Environment and Settlement at Runnymede.* London: The British Museum Press, 90-91.

Ames RE. (1991-1393) A Mesolithic assemblage from Moor Farm, Holyport, near Maidenhead. *Berkshire Archaeological Journal* 74: 1-8.

Ammann B, Birks HJB, Brooks SJ, et al. (2000) Quantification of biotic responses to rapid climatic changes around the Younger Dryas — a synthesis. *Palaeogeography, Palaeoclimatology, Palaeoecology* 159: 313-347.

Anderson DE, Goudie AS and Parker AG. (2007) *Global Environments Through The Quaternary: Exploring Environmental Change,* Oxford: Oxford University Press.

Anshari G, Peter Kershaw A and van der Kaars S. (2001) A Late Pleistocene and Holocene pollen and charcoal record from peat swamp forest, Lake Sentarum Wildlife Reserve, West Kalimantan, Indonesia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 171: 213-228.

Aranguren B, Becattini R, Mariotti Lippi M, et al. (2007) Grinding flour in Upper Palaeolithic Europe (25000 years bp). *Antiquity* 81: 845-855.

Armstrong H and Brasier M. (2013) *Microfossils*: John Wiley & Sons.

Atkinson TC, Briffa KR and Coope GR. (1987) Seasonal temperatures in Britain during the past 22,000 years, reconstructed using beetle remains. *Nature* 325: 587-592.

Attfield B, Barton N, Donnelly M, et al. (2014) A new Later Upper Palaeolithic site at Guildford Fire Station, Surrey, UK. Oxford Archaeology.

Averis B. (2013) *Plants and Habitats*: Ben Averis.

Baales M and Street M. (1996) Hunter-Gatherer Behavior in a Changing Late Glacial Landscape: Allerød Archaeology in the Central Rhineland, Germany. *Journal of Anthropological Research* 52: 281-316.

Babyak MA. (2004) What you see may not be what you get: a brief, nontechnical introduction to overfitting in regression-type models. *Psychosomatic medicine* 66: 411-421.

Bagley SC, White H and Golomb BA. (2001) Logistic regression in the medical literature:: Standards for use and reporting, with particular attention to one medical domain. *Journal of Clinical Epidemiology* 54: 979-985.

Baker C, Lawrence R, Montagne C, et al. (2006) Mapping wetlands and riparian areas using Landsat ETM+ imagery and decision-tree-based models. *Wetlands* 26: 465-474.

Ballantyne CK and Harris C. (1994) *The periglaciation of Great Britain,* Cambridge: University Press.

Barber DC, Dyke A, Hillaire-Marcel C, et al. (1999) Forcing of the cold event of 8,200 years ago by catastrophic drainage of Laurentide lakes. *Nature* 400: 344-348.

Barber K and Charman D. (2005) Holocene Palaeoclimate Records from Peatlands. In: Mackay A, Battarbee R, Birks J, et al. (eds) *Global Change in the Holocene.* London: Hodder Education, 210-226.

Barber KE and Clark MJ. (1987) Cranes Moor, New Forest: Palynology and Macrofossil Stratigraphy. In: Barber KE (ed) *Wessex and the Isle of Wight Field Guide.* Cambridge: Quaternary Research Association, 33-44.

Barker G. (2006) *The Agricultural Revolution in Prehistory,* Oxford: Oxford University Press.
Barrows TT, Lehman SJ, Fifield LK, et al. (2007) Absence of Cooling in New Zealand and the Adjacent Ocean During the Younger Dryas Chronozone. *Science* 318: 86-89.
Barton N. (1992) *Hengistbury Head, Dorset. Volume 2: The Late Upper Palaeolithic & Early Mesolithic Sites,* Oxford: Oxford University Committee for Archaeology.
Barton N. (1995) The Long Blade Assemblage. In: Allen TG, Barton N, Brown AG, et al. (eds) *Lithics and landscape: archaeological discoveries on the Thames Water pipeline at Gatehampton Farm, Goring, Oxfordshire 1985-92.* Oxford: Oxford Archaeological Unit, 54-64.
Barton N. (1999) The Lateglacial or Late and Final Upper Palaeolithic Colonization of Britain. In: Hunter J and Ralston IBM (eds) *The Archaeology of Britain. An Introduction from the Upper Palaeolithic to the Industrial Revolution.* Second Edition ed. London: Routledge.
Barton N. (2009) The Lateglacial or Late and Final Upper Palaeolithic Colonization of Britain. In: Hunter J and Ralston I (eds) *The Archaeology of Britain. An Introduction from the Upper Palaeolithic to the Industrial Revolution.* London: Routledge, 18-52.
Barton RNE, Ford S, Collcutt SN, et al. (2009) A Final Upper Palaeolithic site at Nea Farm, Somerley, Hampshire and some reflections on the occupation of Britain in the Late Glacial Interstadial. *Quärtar* 56: 7-35.
Barton RNE, Jacobi RM, Stapert D, et al. (2003) The Late-glacial reoccupation of the British Isles and the Creswellian. *Journal of Quaternary Science* 18: 631-643.
Barton RNE and Roberts A. (2004) The Mesolithic Period in England: Current Perspectives and New Research. In: Saville A (ed) *Mesolithic Scotland and Its Neighbours: The Early Holocene Prehistory of Scotland, its British and Irish Context and some Northern European Perspectives.* Edinburgh: The Society of Antiquaries of Scotland, 339-358.
Barton RNE and Roberts AJ. (1996) Reviewing the british late upper palaeolithic: New evidence for chronological patterning in the lateglacial record. *Oxford Journal of Archaeology* 15: 245-265.
Batchelor CR, Green C, Young D, et al. (2015) Prehistoric landscapes beneath the London Cable Car. *London Archaeologist* 14: 65-72.
Batchelor CR, Green CP, Young DS, et al. (2012) Surrey House, 20 Lavington Street, London Borough of Southwark, SE1 0NZ (Site Code: LVI11): Environmental Archaeological Analysis Report. Quaternary Scientific (QUEST), School of Human and Environmental Sciences, University of Reading, Whiteknights, PO Box 227, Reading, RG6 6AB, UK.
Batchelor CR and Young DS. (2015) Priory Road, Dartford, Kent: Environmental Archaeological Asessment Report Quaternary Scientific (QUEST), School of Human and Environmental Sciences, University of Reading, Whiteknights, PO Box 227, Reading, RG6 6AB, UK.
Baxter MJ, Beardah CC and Wright RVS. (1997) Some Archaeological Applications of Kernel Density Estimates. *Journal of Archaeological Science* 24: 347-354.
Bedford A, Jones RT, Lang B, et al. (2004) A Late-glacial chironomid record from Hawes Water, northwest England. *Journal of Quaternary Science* 19: 281-290.
Beerling DJ. (1998) Salix herbacea L.*. *Journal of Ecology* 86: 872-895.
Behre K-E. (1981) The interpretation of anthropogenic indicators in pollen diagrams. *Pollen et Spores* 23: 225-245.
Bell M and Walker MJC. (2005) *Late Quaternary Environmental Change,* Harlow: Pearson Prentice Hall.
Belyea LR and Malmer N. (2004) Carbon sequestration in peatland: patterns and mechanisms of response to climate change. *Global Change Biology* 10: 1043-1052.
Bender R and Grouven U. (1998) Using Binary Logistic Regression Models for Ordinal Data with Non-proportional Odds. *Journal of Clinical Epidemiology* 51: 809-816.
Bengtsson L and Enell M. (1986) Chemical Analysis. In: Berglund BE (ed) *Handbook of Holocene Palaeoecology and Palaeohydrology.* Sussex: Wiley, 423-454.
Bennett KD. (1983) Devensian Late-Glacial and Flandrian Vegetational History at Hockham Mere, Norfolk, England. *New Phytologist* 95: 457-487.
Bennett KD. (1984) The post-glacial history of Pinus sylvestris in the British Isles. *Quaternary Science Reviews* 3: 133-155.
Bennett KD. (1988) Holocene pollen stratigraphy of central East Anglia, England, and comparison of pollen zones across the British Isles. *New Phytologist* 109: 237-253.

Bennett KD and Willis KJ. (2002) Pollen. In: Smol JP, Birks HJ and Last WM (eds) *Tracking Environmental Change Using Lake Sediments.* Dordrecht, The Netherlands: Kluwer Academic Publishers, 5-32.

Berridge P and Roberts A. (1986) The Mesolithic period in Cornwall. *Cornish Archaeology* 25: 7-34.

Beven KJ and Kirkby MJ. (1979) A physically based, variable contributing area model of basin hydrology/Un modèle à base physique de zone d'appel variable de l'hydrologie du bassin versant. *Hydrological Sciences Journal* 24: 43-69.

Bird DG, Crocker AG, Crocker G, et al. (1980) Archaeology in Surrey 1976-78. *Surrey Archaeological Collections* 72: 231-253.

Birkinshaw N, Kemp E and Clark S. (2013) The ecology of grass-wrack pondweed Potamogeton compressus. . Natural England Comissioned Reports, Number 130.

Birks HJB. (1965) Late-Glacial Deposits at Bagmere, Cheshire, and Chat Moss, Lancashire. *New Phytologist* 64: 270-281.

Birks HJB. (1970) Inwashed Pollen Spectra at Loch Fada, Isle of Skye. *New Phytologist* 69: 807-820.

Birks HJB. (1989) Holocene Isochrone Maps and Patterns of Tree-Spreading in the British Isles. *Journal of Biogeography* 16: 503-540.

Birks HJB and Birks HH. (1980) *Quaternary Palaeoecology,* London: Edward Arnold.

Bishop BJ. (2008) A microlithic industry from Woodbridge Road, Guildford. *Surrey Archaeological Collections* 94: 125-157.

Björck S, Walker MJC, Cwynar LC, et al. (1998) An event stratigraphy for the Last Termination in the North Atlantic region based on the Greenland ice-core record: a proposal by the INTIMATE group. *Journal of Quaternary Science* 13: 283-292.

Blackburn KB. (1952) The dating of a deposit containing an elk skeleton found at Neasham near Darlington, County Durham. *New Phytologist* 51: 364-377.

Blackford J. (2000) Palaeoclimatic records from peat bogs. *Trends in Ecology & Evolution* 15: 193-198.

Bohncke S, Wijmstra L, Woude JVD, et al. (1988) The Late-Glacial infill of three lake successions in The Netherlands: Regional vegetational history in relation to NW European vegetational developments. *Boreas* 17: 385-402.

Bond G, Showers W, Cheseby M, et al. (1997) A Pervasive Millennial-Scale Cycle in North Atlantic Holocene and Glacial Climates. *Science* 278: 1257-1266.

Bond GC, Showers W, Elliot M, et al. (1999) The North Atlantic’s 1-2 kyr Climate Rhythm: Relation to Heinrich Events, Dansgaard/Oeshger Cycles and the Little Ice Age. In: Clark PU, Webb RS and Keigwin LD (eds) *Mechanisms of Global Climate Change at Millennial Time Scales Geophysical Monograph 112.* Washington: The American Geophysical Union.

Bonsall C. (1977a) Parley, Horsell, Woking (SU 983595). *Surrey Archaeological Bulletin* 136.

Bonsall C. (1977b) Woking, Brockhill, near Parley Bridge, Horsell (SU 983595). *Surrey Archaeological Bulletin* 139.

Booth P. (1997) A Prehistoric-Early Roman Site near Lock Crescent, Kidlington. *Oxoniensia* 62: 22-49.

Bos JAA and Janssen CR. (1996) Local Impact of Palaeolithic Man on the Environment During the End of the Last Glacial in the Netherlands. *Journal of Archaeological Science* 23: 731-739.

Bradley R. (2005) *The moon and the bonfire. An investigation of three stone circles in north east Scotland,* Edinburgh: Society of Antiquaries of Scotland.

Bradshaw RH, Hannon GE and Lister AM. (2003) A long-term perspective on ungulate–vegetation interactions. *Forest Ecology and Management* 181: 267-280.

Branch N. (2013) Early–Middle Holocene vegetation history, climate change and human activities at Lago Riane (Ligurian Apennines, NW Italy). *Vegetation History and Archaeobotany* 22: 315-334.

Branch NP, Batchelor CR, Cameron NG, et al. (2012) Holocene environmental changes in the Lower Thames Valley, London, UK: Implications for understanding the history of Taxus woodland. *The Holocene* 22: 1143-1158.

Branch NP, Cameron N, Canti MG, et al. (2003) Staines ABC Cinema Palaeoenvironmental Analysis. Archaeoscape.

Branch NP, Canti MG, Clark P, et al. (2005) *Environmental Archaeology,* London: Hodder Education.

Branch NP and Green CP. (2001) Meadlake Place, Egham, Surrey, Palaeoenvironmental Analysis. Archaeoscape.
Branch NP and Green CP. (2004) Environmental History of Surrey. In: Cotton J, Crocker G and Graham A (eds) *Aspects of Archaeology and History in Surrey: Towards a Research Framework for the County.* Guildford: Surrey Archaeological Society, 1-18.
Branch NP and Lowe JJ. (1994) Bramcote Green Redevelopment archaeological project 1992/3, Palynology. London: Archaeoscape, University of London.
Branch NP and Marini NAF. (2014) Mid-Late Holocene environmental change and human activities in the northern Apennines, Italy. *Quaternary International* 353: 34-51.
Brand WA. (1996) High precision isotope ratio monitoring techniques in mass spectrometry. *J Mass Spectrom* 31: 225-235.
Brandt R, Groenewoudt BJ and Kvamme KL. (1992) An experiment in archaeological site location: Modelling in the Netherlands using GIS techniques. *World Archaeology Special Issue: Analytical Field Survey* 24: 268-282.
Branigan K, Edwards KJ and Merrony C. (2002) Bronze Age fuel: the oldest direct evidence for deep peat cutting and stack construction? *Antiquity* 76: 849-855.
Brauer A, Endres C, Günter C, et al. (1999) High resolution sediment and vegetation responses to Younger Dryas climate change in varved lake sediments from Meerfelder Maar, Germany. *Quaternary Science Reviews* 18: 321-329.
Briffa K and Atkinson T. (1997) Reconstructing Late Glacial and Holocene Climates. In: Hulme M and Barrow E (eds) *Climates of the British Isles. Present, Past and Future.* London: Routledge, 84-111.
Brooks SJ and Birks HJB. (2000) Chironomid-inferred Late-glacial air temperatures at Whitrig Bog, Southeast Scotland. *Journal of Quaternary Science* 15: 759-764.
Brooks SJ and Birks HJB. (2001) Chironomid-inferred air temperatures from Lateglacial and Holocene sites in north-west Europe: progress and problems. *Quaternary Science Reviews* 20: 1723-1741.
Brooks SJ, Lowe JJ and Mayle FE. (1997) The Late Devensian Lateglacial palaeoenvironmental record from Whitrig Bog, SE Scotland. 2. Chironomidae (Insecta: Diptera). *Boreas* 26: 297-308.
Brooks SJ, Matthews IP, Birks HH, et al. (2012) High resolution Lateglacial and early-Holocene summer air temperature records from Scotland inferred from chironomid assemblages. *Quaternary Science Reviews* 41: 67-82.
Bryant RH and Carpenter CP. (1987) Ramparted ground ice depressions in Britain and Ireland. In: Boardman J (ed) *Periglacial Processes and Landforms in Britain and Ireland.* Cambridge: Cambridge University Press, 183-190.
Bunting MJ. (2008) Pollen in wetlands: using simulations of pollen dispersal and deposition to better interpret the pollen signal. *Biodiversity and Conservation* 17: 2079-2096.
Burchell JPT and Frere S. (1947) The Occupation of Sandown Park, Esher, during the Stone Age, the Early Iron Age, and the Anglo-Saxon Period. *The Antiquaries Journal* 27: 24-46.
Burns RP and Burns R. (2008) Business research methods and statistics using SPSS. London: Sage, 568-588.
Bush M and Hall A. (1987) Flandrian Alnus: expansion or immigration? *Journal of Biogeography*: 479-481.
Butler C. (2005) *Prehistoric Flintwork*, Stroud: Tempus.
Butler C. (2007) A Mesolithic site at Streat Lane, Streat, East Sussex. *Sussex Archaeological Collections* 145: 7-31.
Canti MG. (1992) Anthropogenic Modification of the Early Holocene Soil Environment. *SEESOIL* 8.
Carpenter CP and Woodcock MP. (1981) A Detailed Investigation of a Pingo Remnant in Western Surrey. *Quaternary Studies* 1: 1-26.
Carter RJ. (2001) New Evidence for Seasonal Human Presence at the Early Mesolithic Site of Thatcham, Berkshire, England. *Journal of Archaeological Science* 28: 1055-1060.
Caseldine CJ and Maguire DJ. (1986) Lateglacial/Early Flandrian Vegetation Change on Northern Dartmoor, South-West England. *Journal of Biogeography* 13: 255-264.

Catt JA, Gibbard JL, Lowe JJ, et al. (2006) Quaternary: Ice Sheets and their Legacy. In: Brenchley PJ and Rawson PF (eds) *The Geology of England and Wales.* Second Edition ed. Bath: The Geological Society, 429-467.

Chambers FM. (1993) *Climate change and human impact on the landscape: studies in palaeoecology and environmental archaeology,* London: Chapman and Hall.

Chambers FM, Mighall TM and Keen DH. (1996) Early Holocene pollen and molluscan records from Enfield Lock, Middlesex, UK. *Proceedings of the Geologists' Association* 107: 1-14.

Champion T. (2007) Prehistoric Kent. In: Williams JH (ed) *The Archaeology of Kent to AD 800.* Woodbridge: The Boydell Press and Kent County Council, 67-132.

Chan CW, Barnes J, Petrosino SA, et al. (2015) A survey of Langshot Bog (Chobham Common) and the implications for understanding its environmental history. *Department of Geography and Environmental Science.* University of Reading.

Chapin FS, III and Chapin MC. (1980) Revegetation of an Arctic Disturbed Site by Native Tundra Species. *Journal of Applied Ecology* 17: 449-456.

Chapman MR and Shackleton NJ. (2000) Evidence of 550-year and 1000-year cyclicities in North Atlantic circulation patterns during the Holocene. *The Holocene* 10: 287-291.

Charles R. (1989) Other Late Upper Palaeolithic finds from Gough's Cave, Cheddar, Somerset. *Proc. Univ. Bristol Spalaeol. Soc* 18: 400-408.

Charman DJ. (2010) Centennial climate variability in the British Isles during the mid–late Holocene. *Quaternary Science Reviews* 29: 1539-1554.

Chen EY-H, Hui CL-M, Dunn EL-W, et al. (2005) A prospective 3-year longitudinal study of cognitive predictors of relapse in first-episode schizophrenic patients. *Schizophrenia Research* 77: 99-104.

Chisham C. (2004) Early Mesolithic Human Activity and Environmental Change: A Case Study of the Kennet Valley. PhD Thesis. *Department of Archaeology.* University of Reading.

Church T, Brandon RJ and Burgett GR. (2000) GIS Applications in Archaeology: Method in Search of Theory. In: Wescott KL and Brandon RJ (eds) *Practical Applications of GIS for Archaeologists.* New York: Taylor and Francis, 144-166.

Churchill D. (1962) The Stratigraphy of the Mesolithic Sites III and V at Thatcham, Berkshire, England. *Proceedings of the Prehistoric Society (New Series)* 28: 362-370.

Churchill SE. (1993) Weapon technology, prey size selection, and hunting methods in modern hunter-gatherers and implications for hunting in the Palaeolithic and Mesolithic. In: Peterkin GL, Bricker HM and Mellars P (eds) *Hunting and animal exploitation in the Later Palaeolithic and Mesolithic of Eurasia.* 11-24.

Clapham A, Tutin TG and Moore D. (1987) *Flora of the British Isles,* Cambridge: Cambridge University Press.

Clark JGD. (1934) III. Some Unrecorded Finds of Microliths from England. *Proceedings of the Prehistoric Society of East Anglia* 7: 421-423.

Clark JGD and Rankine WF. (1939) Excavations at Farnham, Surrey (1937–38): The Horsham Culture and the Question of Mesolithic Dwellings. *Proceedings of the Prehistoric Society (New Series)* 5: 61-118.

Clark JS. (1988) Particle motion and the theory of charcoal analysis: source area, transport, deposition, and sampling. *Quaternary Research* 30: 67-80.

Clymo RS. (1980) Preliminary Survey of the Peat-Bog Hummell Knowe Moss Using Various Numerical Methods. In: van der Maarel E (ed) *Classification and Ordination.* Springer Netherlands, 129-148.

Cochran WG. (1952) The $\chi 2$ test of goodness of fit. *The Annals of Mathematical Statistics*: 315-345.

Cohen N. (2011) Community Archaeology on the Thames. In: Drummond P (ed) *The London Reader 1.* London: The London Symposium, 2-12.

Collard M, Edinborough K, Shennan S, et al. (2010) Radiocarbon evidence indicates that migrants introduced farming to Britain. *Journal of Archaeological Science* 37: 866-870.

Collins PE, Fenwick IM, Keith-Lucas DM, et al. (1996a) Late Devensian river and floodplain dynamics and related environmental change in northwest Europe, with particular reference to a site at Woolhampton, Berkshire, England. *Journal of Quaternary Science* 11: 357-375.

Collins PEF, Fenwick IM, Keith-Lucas DM, et al. (1996b) Late Devensian river and floodplain dynamics and related environmental change in northwest Europe, with particular reference to a site at Woolhampton, Berkshire, England. *Journal of Quaternary Science* 11: 357-375.
Conneller C, Ellis C, Allen MJ, et al. (2007) A Final Upper Palaeolithic Site at La Sagesse Convent, Romsey, Hampshire. *Proceedings of the Prehistoric Society* 73: 191-227.
Conneller C, Milner N, Taylor B, et al. (2012) Substantial settlement in the European Early Mesolithic: new research at Star Carr. *Antiquity* 86: 1004-1020.
Cook C. (1961) Sparganium in Britain. *Watsonia* 5: 1-10.
Coope GR, Lemdahl G, Lowe JJ, et al. (1998) Temperature gradients in northern Europe during the last glacial–Holocene transition (14-9 14C kyr BP) interpreted from coleopteran assemblages. *Journal of Quaternary Science* 13: 419-433.
Corcoran J, Halsey C, Spurr G, et al. (2011) *Mapping past landscapes in the lower Lea valley. A geoarchaeological study of the quaternary sequence.* , London: Museum of London Archaeology.
Cotton J. (2004) Surrey's Early Past: A Survey of Recent Work. In: Cotton J, Crocker G and Graham A (eds) *Aspects of Archaeology and History in Surrey: towards a research framework for the county.* Guildford: Surrey Archaeological Society, 19-38.
Cox N. (1976) Woking: Brockhill, near Parley Bridge, Horsell (SU 983595). *Surrey Archaeological Bulletin* 126.
Cramp K. (2006) The worked flint from Beechbrook Wood, Hothfield, Kent. *CTRL Specialist Report Series.* Oxford Wessex Archaeology.
Crombé P, Perdaen Y, Sergant J, et al. (2001) Wear analysis on early Mesolithic microliths from the Verrebroek site, East Flanders, Belgium. *Journal of Field Archaeology* 28: 253-269.
Cundill P and Whittington G. (1983) Anomalous arboreal pollen assemblages in Late Devensian and Early Flandrian deposits at Creich Castle, Fife, Scotland. *Boreas* 12: 297-311.
Curwen I. (2014) Vegetation succession and human activity during the Bronze Age at Horsell Common, Surrey: an integrated archaeology and paleoecology approach. *Department of Geography and Environmental Science.* University of Reading.
Daley TJ, Barber KE, Street-Perrott FA, et al. (2010) Holocene climate variability revealed by oxygen isotope analysis of Sphagnum cellulose from Walton Moss, northern England. *Quaternary Science Reviews* 29: 1590-1601.
Dansgaard W, White JWC and Johnsen SJ. (1989) The abrupt termination of the Y.D. climate event. *Nature* 339: 532-536.
Davis BAS, Brewer S, Stevenson AC, et al. (2003) The temperature of Europe during the Holocene reconstructed from pollen data. *Quaternary Science Reviews* 22: 1701-1716.
Day S. (1991) Post-glacial vegetational history of the Oxford region. *New Phytologist* 119: 445-470.
DCMS. (2013) Scheduled Monuments & nationally important but not scheduled monuments.
de Lafontaine G, Amasifuen Guerra CA, Ducousso A, et al. (2014) Beyond skepticism: uncovering cryptic refugia using multiple lines of evidence. *New Phytologist* 204: 450-454.
Dennis F, Andrews JN, Parker A, et al. (1997) Isotopic and noble gas study of Chalk groundwater in the London Basin, England. *Applied Geochemistry* 12: 763-773.
Devoy RJN. (1979) Flandrian Sea Level Changes and Vegetational History of the Lower Thames Estuary. *Philosophical Transactions of the British Society* 285: 355-407.
Devoy RJN. (1982) Analysis of the geological evidence for Holocene sea-level movements in southeast England. *Proceedings of the Geologists' Association* 93: 65-90.
Devoy RJN. (1987) Part Three: The State of Current Knowledge: Regional and Global Views. In: Devoy RJN (ed) *Sea Surface Studies A Global View.* London: Croon Helm, 233-408.
Dimbleby GW. (1963) Pollen Analysis of a Mesolithic Site at Addington, Kent. *Grana Palynologica* 4: 140-148.
Duncan RB and Beckman KA. (2000) Site Location in Pennsylvania and West Virginia. In: Wescott KL and Brandon RJ (eds) *Practical Applications of GIS for Archaeologists.* New York: Taylor and Francis, 33-58.
Ebert JI. (2000) The State of the Art in "Inductive" Predictive Modelling: Seven Big Mistakes (and Lots of Smaller Ones). In: Wescott KL and Brandon RJ (eds) *Practical Applications of GIS for Archaeologists.* New York: Taylor and Francis, 129-134.

Edmunds WM, Hinsby K, Marlin C, et al. (2001) Evolution of groundwater systems at the European coastline. In: Edmunds WM and Milne CJ (eds) *Palaeowaters in Coastal Europe: evolution of groundwater since the late Pleistocene.* Bath: The Geological Society, 289-312.
Edwards KJ. (2004) Paleoenvironments of the Late Upper Palaeolithic and Mesolithic Periods in Scotland and the North Sea area. In: Saville A (ed) *Mesolithic Scotland and its Neighbours.* Edinburgh: Society of Antiquaries of Scotland, 55-72.
Edwards KJ, Langdon PG and Sugden H. (2007) Separating climatic and possible human impacts in the early Holocene: biotic response around the time of the 8200 cal. yr BP event. *Journal of Quaternary Science* 22: 77-84.
Edwards KJ and MacDonald GM. (1991) Holocene palynology: II human influence and vegetation change. *Progress in Physical Geography* 15: 364-391.
Edwards KJ and Whittington G. (1997) A 12 000-year record of environmental change in the Lomond Hills, Fife, Scotland: Vegetational and climatic variability. *Vegetation History and Archaeobotany* 6: 133-152.
Edwards KJ, Whittington G and Tipping R. (2000) The incidence of microscopic charcoal in late glacial deposits. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164: 247-262.
Eley Y, Dawson L, Black S, et al. (2014) Understanding 2 H/1 H systematics of leaf wax n-alkanes in coastal plants at Stiffkey saltmarsh, Norfolk, UK. *Geochimica et Cosmochimica Acta* 128: 13-28.
Ellaby R. (1987) The Upper Palaeolithic and Mesolithic in Surrey. In: Bird J and Bird DG (eds) *The Archaeology of Surrey to 1540.* Guildford: Surrey Archaeological Society, 53-70.
Ellaby R. (2004) Food for thought: a late Mesolithic site at Charlwood, Surrey. In: Cotton J and Field D (eds) *Towards a New Stone Age: aspects of the Neolithic in South-east England.* London: Council for British Archaeology Research Report 137, 12-23.
Ellaby RL. (1983) Charlwood: Mesolithic Site. *Surrey Archaeological Bulletin* 182.
Ellis NV, Bowen DQ, Campbell S, et al. (1996) *An Introduction to the Geological Conservation Review*: JNCC.
English Heritage. (2012) *Designation. Scheduling Selection Guide. Sites of Early Human Activity*: English Heritage.
English Heritage. (2013) National Heritage Protection Plan Framework. English Heritage 1-28.
Erdtman G. (1960) The acetolysis method. A revised description. *Svensk Bot. Tidsk.* 54: 561-564.
Espa G, Benedetti R, De Meo A, et al. (2006) GIS based models and estimation methods for the probability of archaeological site location. *Journal of Cultural Heritage* 7: 147-155.
Evans C, Pollard J and Knight M. (1999) Life in the Woods: Tree-throws, 'Settlement' and Forest Cognition. *Oxford Journal of Archaeology* 18: 241-254.
Evans JA. (1861) Proceedings of the Society of Antiquaries. Thursday, January 19th, 1860. *Proceedings of the Society of Antiquaries of London (Second Series)* 1: 63-77.
Faegri K, Kaland PE and Krzywinski K. (1989) *Textbook of pollen analysis,* Chichester: John Wiley & Sons Ltd.
Farley M. (1978) Excavations at Low Farm, Fulmer, Bucks. 1: The Mesolithic Occupation. *Records of Buckinghamshire* 20: 601-616.
Farr L. (2013) Macrobotanical Analysis. In: Jones P (ed) *A Mesolithic 'Persistent Place' at North Park Farm, Bletchingley, Surrey.* Woking, Surrey: SpoilHeap, 85-92.
Farr LR. (2008) Enhancing our understanding of Mesolithic environments and resource exploitation in south-east England. A case study from Surrey. PhD Thesis. Royal Holloway, University of London.
Field A. (2013) *Discovering Statistics using IBM SPSS Statistics,* London: Sage Publications.
Field D. (1998) Round barrows and the harmonious landscape: placing Early Bronze Age burial monuments in south-east England. *Oxford Journal of Archaeology* 17: 309-326.
Finsinger W, Tinner W, van der Knaap WO, et al. (2006a) The expansion of hazel (Corylus avellana L.) in the southern Alps: a key for understanding its early Holocene history in Europe. *Quaternary Science Reviews* 25: 612-631.
Finsinger W, Tinner W, van der Knaap WO, et al. (2006b) The expansion of hazel (Corylus avellana L.) in the southern Alps: a key for understanding its early Holocene history in Europe? *Quaternary Science Reviews* 25: 612-631.

Fitter A. (1987) *Collins New Generation Guide Wild Flowers of Britain and Northern Europe,* London: William Collins Sons & Co. Ltd.
Freeman S, Bishop P, Bryant C, et al. (2007) The SUERC AMS laboratory after 3 years. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 259: 66-70.
Freeman S, Bishop P, Bryant C, et al. (2004) A new environmental sciences AMS laboratory in Scotland. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 223–224: 31-34.
Froom R. (1976) *Wawcott III: a stratified Mesolithic succession. BAR 27,* Oxford: British Archaeological Reports.
Froom R. (2005) *Late Glacial Long Blade Sites in the Kennet Valley. Excavations and Fieldwork at Avington VI, Wawcott XII and Crown Acres,* London The British Museum.
Froom R. (2012) *The Mesolithic of the Kennet Valley*: Roy Froom.
Gaffney VL, Thomson K and Fitch S. (2007) *Mapping Doggerland: the Mesolithic landscapes of the southern North Sea*: Archaeopress.
Gaillard MJ. (2007) Pollen Methods And Studies - Archaeological Applications. In: Elias SA (ed) *Encyclopedia of Quaternary Science.* Oxford: Elsevier, 2570-2595.
Gallois RW. (1965) *British Regional Geology The Wealden District*, London: Her Majesty's Stationary Office.
Gardiner JP. (1988) The composition and distribution of Neolithic surface flint assemblages in central southern England. *Department of Archaeology.* University of Reading.
Gardner RL. (2009) Modeling Archaeological Site Distribution in the Black Bottom of Illinois Using Geographic Information Systems and Logistic Regression. *Department of Geosciences.* Murray State University.
Garnett ER, Andrews JE, Preece RC, et al. (2004) Climatic change recorded by stable isotopes and trace elements in a British Holocene tufa. *Journal of Quaternary Science* 19: 251-262.
Garwood P. (2011) Early Prehistory. In: Booth P, Champion T, Foreman S, et al. (eds) *On Track, The Archaeology of High Speed 1 Section 1 in Kent.* England: Oxford Wessex Archaeology, 37-150.
Gearey B, Bermingham N, Chapman H, et al. (2010) *Peatlands and the Historic Environment*: IUCN UK Peatland Programme.
Ghilardi B and O'Connell M. (2013) Early Holocene vegetation and climate dynamics with particular reference to the 8.2 ka event: pollen and macrofossil evidence from a small lake in western Ireland. *Vegetation History and Archaeobotany* 22: 99-114.
Giaimo R, Matranga D and Campisi G. (2006) Odds Ratio Estimation in the Presence of Complete or Quasi-Complete Separation in Data. *Statistica Applicata* 18: 429-444.
Gibbard PL and Hall AR. (1982) Late Devensian river deposits in the Lower Colne valley, West London, England. *Proceedings of the Geologists' Association* 93: 291-299.
Gibin M, Longley P and Atkinson P. (2007) Kernel density estimation and percent volume contours in general practice catchment area analysis in urban areas. *the Proceedings of GISRUK.* Citeseer, 11-13.
Gibson J, Edwards T, Bursey G, et al. (1993) Estimating evaporation using stable isotopes: quantitative results and sensitivity analysis for. *Nordic Hydrology* 24: 79-94.
Giles J, Steven G and Emery M. (2011) Thursley National Nature Reserve Management Plan 1 April 2011 - 31 March 2016. Natural England.
Gillespie R, Gowlett JAJ, Hall ET, et al. (1985) Radiocarbon Dates from the Oxford AMS System: Archaeometry Datelist 2. *Archaeometry* 27: 237-246.
Gionfiantini R and Stichler W. (1995) Reference and Intercomparison Materials for Stable Isotopes of Light Elements. Vienna: International Atomic Energy Agency.
Girling M and Greig J. (1977) Palaeoecological investigations of a site at Hampstead Heath, London. *Nature* 268: 45-47.
Godwin H. (1940) Pollen Analysis and Forest History of England and Wales. *New Phytologist* 39: 370-400.
Godwin H. (1945) A Submerged Peat Bed in Portsmouth Harbour. Data for the Study of Post-Glacial History. IX. *New Phytologist* 44: 152-155.

Godwin H. (1949) The Spreading of the British Flora: Considered in Relation to Conditions of the Late-Glacial Period. *Journal of Ecology* 37: 140-147.
Godwin H. (1956) *The history of the British flora: a factual basis for phytogeography,* Cambridge: Cambridge University Press.
Godwin H. (1968) Studies of the Post-Glacial History of British Vegetation. XV. Organic Deposits of Old Buckenham Mere, Norfolk. *The New Phytologist* 67: 95-107.
Godwin H. (1975a) *History of the British Flora,* Cambridge: Cambridge University Press.
Godwin H. (1975b) History of the natural forests of Britain: establishment, dominance and destruction. *Philosophical Transactions of the Royal Society B: Biological Sciences* 271: 47-67.
Golledge NR. (2010) Glaciation of Scotland during the Younger Dryas stadial: a review. *Journal of Quaternary Science* 25: 550-566.
Goslar T, Bałaga K, Arnold M, et al. (1999) Climate-related variations in the composition of the Late Glacial and early Holocene sediments of Lake Perespilno (eastern Poland). *Quaternary Science Reviews* 18: 899-911.
Gott B. (1999) Cumbungi, Typha species: A staple Aboriginal food in southern Australia. *Australian Aboriginal Studies* 1999: 33.
Gowlett JAJ. (2016) The discovery of fire by humans: a long and convoluted process. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 371.
Gowlett JAJ, Hedges REM, Law IA, et al. (1987) Radiocarbon dates from the Oxford AMS System: Archaeometry datelist 5 (Thatcham). *Archaeometg.* 29: 27.
Grace JB and Wetzel RG. (1981) Habitat partitioning and competitive displacement in cattails (Typha): experimental field studies. *American Naturalist*: 463-474.
Graham D, Graham A, Branch NP, et al. (2014) Environmental sampling of a bell barrow on Horsell Common, Woking. *Surrey Archaeological Collections* 98: 125-140.
Graham D, Graham A and Nicolaysen P. (1999) Surface collection of worked flints from Thursley Common. *Surrey Archaeological Collections* 86: 163-169.
Graham D, Graham A and Wiltshire P. (2004) Investigation of a Bronze Age Mound on Thursley Common. *Surrey Archaeological Collections* 91: 151-166.
Grant MJ, Stevens CJ, Whitehouse NJ, et al. (2014) A palaeoenvironmental context for Terminal Upper Palaeolithic and Mesolithic activity in the Colne Valley: Offsite records contemporary with occupation at Three Ways Wharf, Uxbridge. *Environmental Archaeology* 19: 131-152.
Great Britain Board of Agriculture. (1809) *Agricultural Surveys: Surrey (1809)*.
Green CP, Williams K and Batchelor CR. (2011) Southwood Activity Centre, Elm Close, Tolworth (Undertaken for Phase 1 of the Hogsmill Community Archaeology Project): Environmental Archaeology Fieldwork Report. Quaternary Scientific (QUEST) Unpublished Report December 2011; Project Number 002/11.
Gregory RA, Murphy EM, Church MJ, et al. (2005) Archaeological evidence for the first Mesolithic occupation of the Western Isles of Scotland. *The Holocene* 15: 944-950.
Greig J. (1994) Pollen analysis of latrine fills from archaeological sites in Britain: results and future potential. *Ann. Assoc. Stratigr. Palynol.* 29 101-114.
Grimm EC. (1987) CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. *Computers & Geosciences* 13: 13-35.
Grimm EC. (2011) *TILIA 1.7.16.,* Springfield: Illinois state museum.
Groves JA. (2008) Late Quaternary vegetation history of the acidic lithologies of South East England. PhD Thesis. *Geography, Geology and Environment.* Kingston University.
Groves JA, Waller MP and Grant MJ. (2012) Long-term development of a cultural landscape: the origins and dynamics of lowland heathland in southern England. *Vegetation History and Archaeobotany* 21: 453-470.
Haapasaari M. (1988) The oligotrophic heath vegetation of northern Fennoscandia and its zonation. *Acta Bot. Fenn* 135: 1-219.
Hall A. (1978) Some new palaeobotanical records for the British Ipswichian interglacial. *New Phytologist* 81: 805-812.
Hall IR, Bianchi GG and Evans JR. (2004) Centennial to millennial scale Holocene climate-deep water linkage in the North Atlantic. *Quaternary Science Reviews* 23: 1529-1536.

Harding P. (2000) A Mesolithic site at Rock Common, Washington, West Sussex. *Sussex Archaeological Collections* 138: 29-48.
Harding P. (2006) The Late Mesolithic and Early Neolithic Flint Assesment at Sandway Road, Lenham, Kent. *CTRL Specialist Report Series.* Oxford Wessex Archaeology.
Hardy BL. (2010) Climatic variability and plant food distribution in Pleistocene Europe: Implications for Neanderthal diet and subsistence. *Quaternary Science Reviews* 29: 662-679.
Head K, Turney CSM, Pilcher JR, et al. (2007) Problems with identifying the '8200-year cold event' in terrestrial records of the Atlantic seaboard: a case study from Dooagh, Achill Island, Ireland. *Journal of Quaternary Science* 22: 65-75.
Healy F, Lobb SJ and Heaton M. (1992) Excavations of a Mesolithic site at Thatcham, Berkshire. *Proceedings of the Prehistoric Society* 58: 41-76.
Heathcote J. (2012) *Strategy for Water and Wetland Heritage*: English Heritage.
Heritage E. (1999) *EH Monument Type Thesaurus*. Available at: http://thesaurus.historicengland.org.uk/frequentuser.htm.
Hey G. (2010) Solent Thames Research Framework Resource Assessment Late Upper Palaeolithic and Mesolithic Period. Oxford Archaeology.
Hillman GC. (2015) 13 Late Palaeolithic plant foods from Wadi Kubbaniya in Upper Egypt: dietary, diversity, infant weaning, and seasonality in a riverine Environment. In: Harris DR and Hillman GC (eds) *Foraging and Farming: The Evolution of Plant Exploitation.* Abingdon, Oxon: Routledge.
Holliday TW. (1998) The Ecological Context of Trapping among Recent Hunter Gatherers: Implications for Subsistence in Terminal Pleistocene Europe. *Current Anthropology* 39: 711-719.
Hooper W. (1933) The pigmy flint industries of Surrey. *Surrey Archaeological Collections* 41: 50-78.
Hosmer DW and Lemeshow S. (2004) *Applied Logistic Regression*: Wiley.
Hubbard A. (1999) High-Resolution Modeling of the Advance of the Younger Dryas Ice Sheet and Its Climate in Scotland. *Quaternary Research* 52: 27-43.
Huggett RJ. (2007) *Fundamentals of Geomorphology,* Abingdon: Routledge.
Hughes PDM, Kenward HK, Hall AR, et al. (2000) A high-resolution record of mire development and climatic change spanning the Late-glacial–Holocene boundary at Church Moss, Davenham (Cheshire, England). *Journal of Quaternary Science* 15: 697-724.
Hunt TG and Birks HJB. (1982) Devensian Late-Glacial Vegetational History at Sea Mere, Norfolk. *Journal of Biogeography* 9: 517-538.
Huntley B. (1993) Rapid early Holocene migration and highabundance of hazel (*Corylus avellana* L.): alternative hypotheses. In: Chambers FM (ed) *Climate change and human impact on the landscape: studies in palaeoecology and environmental archaeology.* London: Chapman and Hall.
Huntley B and Birks HJB. (1983) *An Atlas of Past and Present Pollen Maps for Europe: 0-13000 Years Ago,* Cambridge: Cambridge University Press.
Hutchinson JN. (1980) Possible late Quaternary pingo remnants in central London. *Nature* 284: 253-255.
Huxtable HJ and Jacobi RM. (1982) Thermoluminescence dating of burned flints from a British Mesolithic Site: Longmoor Inclosure, East. *Archaeometry* 24: 164-169.
Hytteborn H, Maslov AA, Nazimova DI, et al. (2005) Boreal Forests of Eurasia. In: Andersson F (ed) *Ecosystems of The World 6 Coniferous Forests.* Amsterdam: Elsevier
Innes JB and Blackford JJ. (2003) The Ecology of Late Mesolithic Woodland Disturbances: Model Testing with Fungal Spore Assemblage Data. *Journal of Archaeological Science* 30: 185-194.
Innes JB, Blackford JJ and Simmons I. (2010) Woodland disturbance and possible land-use regimes during the Late Mesolithic in the English uplands: pollen, charcoal and non-pollen palynomorph evidence from Bluewath Beck, North York Moors, UK. *Vegetation History and Archaeobotany* 19: 439-452.
Innes JB, Blackford JJ and Simmons IG. (2004) Testing the integrity of fine spatial resolution palaeoecological records: microcharcoal data from near-duplicate peat profiles from the North York Moors, UK. *Palaeogeography, Palaeoclimatology, Palaeoecology* 214: 295-307.

Innes JB, Rutherford MM, O'Brien CE, et al. (2009) Late Devensian environments in the Vale of Mowbray, North Yorkshire, UK: evidence from palynology. *Proceedings of the Geologists' Association* 120: 199-208.
Isarin RFB. (1997) Permafrost Distribution and Temperatures in Europe During the Younger Dryas. *Permafrost and Periglacial Processes* 8: 313-333.
Isarin RFB and Bohncke SJP. (1999) Mean July Temperatures during the Younger Dryas in Northwestern and Central Europe as Inferred from Climate Indicator Plant Species. *Quaternary Research* 51: 158-173.
Isarin RFB, Renssen H and Vandenberghe J. (1998) The impact of the North Atlantic Ocean on the Younger Dryas climate in northwestern and central Europe. *Journal of Quaternary Science* 13: 447-453.
Jacobi R and Higham T. (2011) *The Latter Upper Palaeolithic recolonization of Britain: New results from radiocarbon dating,* Amsterdam: Elsevier.
Jacobi R and Tebbutt FSA. (1981) A Late Mesolithic Rock-Shelter Site at High Hurstwood, Sussex. *Sussex Archaeological Collections* 119: 1-36.
Jacobi RM. (1982) Later Hunters in Kent: Tasmania and the earliest Neolithic. In: Leach PE (ed) *Archaeology in Kent to AD 1500.* London: Council for British Archaeology 12-24.
Jacobi RM and Higham TFG. (2009) The early Lateglacial re-colonization of Britain: new radiocarbon evidence from Gough's Cave, southwest England. *Quaternary Science Reviews* 28: 1895-1913.
Jacobson GL and Bradshaw RHW. (1981) The selection of sites for paleovegetational studies. *Quaternary Research* 16: 80-96.
Jacques D and Phillips T. (2014) Mesolithic settlement near Stonehenge:excavations at Blick Mead, Vespasian's Camp, Amesbury. *Wiltshire Archaeological & Natural History Magazine* 107: 7-27.
Jarvis MG, Allen RH, Fordham FJ, et al. (1984) *Soils and their use in south-east England,* Cranfield: National Soil Resources Institute.
Jennings S and Smythe C. (2000) Six thousand years of history preserved in Farm Bog. In: Drakeford T and Sutcliffe U (eds) *Wimbledon Common and Putney Heath: a natural history* London: Wimbledon and Putney Commons Conservators, 28-39.
JNCC. (1977) Guidelines for selection of Earth Science SSSIs.
Jones P. (2013a) Archaeological Research Committee Annual Symposium 2013. *Surrey Archaeological Bulletin* 438: 11-16.
Jones P. (2013b) *A Mesolithic 'Persistent Place' at North Park Farm, Bletchingley Surrey,* Woking: Spoil Heap Publications.
Jones P. (2013c) *Upper Palaeolithic Sites in the Lower Courses of the Rivers Colne and Wey: Excavations at Church Lammas and Wey Manor Farm,* Surrey: SpoilHeap Publications.
Jones P and Cooper L. (2013) A Creswellian flint scatter at Wey Manor Farm, Addlestone. Surrey. In: Jones P (ed) *Upper Palaeolithic Sites in the Lower Courses of the Rivers Colne and Wey: Excavations at Church Lammas and Wey Manor Farm.* Surrey: SpoilHeap Publications, 9-54.
Jones P, Lewis JSC and Rackham J. (2013) Two Late Glacial hunting camps at Church Lammas, Staines. In: Jones P (ed) *Upper Palaeolithic Sites in the Lower Courses of the Rivers Colne and Wey: Excavations at Church Lammas and Wey Manor Farm.* Surrey: SpoilHeap Publications, 55-98.
Jowsey PC. (1966) An Improved Peat Sampler. *New Phytologist* 65: 245-248.
Keef PAM, Wymer JJ and Dimbleby GW. (1965) A Mesolithic Site on Iping Common, Sussex, England. *Proceedings of the Prehistoric Society (New Series)* 31: 85-92.
Keith-Lucas M. (2000) Pollen analysis of sediments from Moor Farm, Staines Moor, Surrey. *Surrey Archaeological Collections* 87: 85-93.
Kelly A, Charman DJ and Newnham RM. (2010) A Last Glacial Maximum pollen record from Bodmin Moor showing a possible cryptic northern refugium in southwest England. *Journal of Quaternary Science* 25: 296-308.
Kendon M, McCarthy M, Jevrejeva S, et al. (2016) *State of the UK climate 2015,* Exeter, UK: Met Office.

Kerney MP, Brown EH, Chandler TJ, et al. (1964) The Late-Glacial and Post-Glacial History of the Chalk Escarpment Near Brook, Kent. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 248: 135-204.

Kerney MP, Preece RC and Turner C. (1980) Molluscan and Plant Biostratigraphy of Some Late Devensian and Flandrian Deposits in Kent. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 291: 1-43.

Kinniburgh D, Gale I, Smedley P, et al. (1994) The effects of historic abstraction of groundwater from the London Basin aquifers on groundwater quality. *Applied Geochemistry* 9: 175-195.

Kitagawa H and van der Plicht J. (1998) A 40,000-year varve chronology from Lake Suigetsu, Japan; extension of the (super 14) C calibration curve. *Radiocarbon* 40: 505-515.

Kohler TA. (1988) Predictive locational modelling: history and current practice. In: Sebastian L and Judge WJ (eds) *Quantifying the Present, Predicting the Past.* Denver, US: Department of the Interior Bureau of Land Management, 19-59.

Kohler TA and Parker SC. (1986) Predictive Models for Archaeological Resource Location. *Advances in Archaeological Method and Theory* 9: 397-452.

Kolstrup E. (1980) Climate and statigraphy in northwestern Europe between 30,000 B.P., 13,000 B.P. with special reference to the Netherlands. *Meded. Rijks Geol. Dienst* 32 181-253.

Kuhnlein HV and Receveur O. (2007) Local Cultural Animal Food Contributes High Levels of Nutrients for Arctic Canadian Indigenous Adults and Children. *The Journal of Nutrition* 137: 1110-1114.

Kvamme KL. (1985) Determining relationships between the natural environment and prehistoric site locations: a hunter–gatherer example. In: Carr C (ed) *For Concordance in Archaeological Analysis: Bridging Data Structure, Quantitative Technique and Theory.* Kansas: Westport Publishers, 208-238.

Kvamme KL. (1992) A predictive site location model on the High Plains: An example with an independent test. *The Plains Anthropologist* 37: 19-40.

Kvamme KL. (2006) There and Back Again: Revisiting Archaeological Locational Modelling. In: Mehrer MW and Wescott KL (eds) *GIS and Archaeological Site Location Modelling.* New York: Taylor and Francis, 2-35.

Kvamme KL and Jochim MA. (1990) The Environmental Basis of Mesolithic Settlement. In: Bonsall C (ed) *The Mesolithic in Europe.* Edinburgh: John Donald Publishers Ltd, 1-12.

Lake MW, Woodman PE and Mithen SJ. (1998) Tailoring GIS Software for Archaeological Applications: An Example Concerning Viewshed Analysis. *Journal of Archaeological Science* 25: 27-38.

Landis JR and Koch GG. (1977) The measurement of observer agreement for categorical data. *biometrics*: 159-174.

Lang B, Bedford A, Brooks SJ, et al. (2010) Early-Holocene temperature variability inferred from chironomid assemblages at Hawes Water, northwest England. *The Holocene* 20: 943-954.

Leakey LSB. (1951) Preliminary excavations of a Mesolithic site at Abinger Common, Surrey. *Research Papers of the Surrey Archaeological Society* 3.

Leroi-Gourhan A. (1985) Pollen Analysis of Sediment Samples from Goughs Cave, Cheddar. *Proceedings of the University of Bristol Spelaeo. Society* 17: 141-144.

Lewis JSC. (1991) A late Glacial and early post-glacial site at Three Ways Wharf, Uxbridge, England: interim report. In: Barton N, Roberts AJ and Roe DA (eds) *The Late Glacial in North-West Europe.* . CBA Research Report, 246-255.

Lewis JSC and Rackham J. (2011) *Three Ways Wharf, Uxbridge: a Late glacial and Early Holocene hunter-gatherer site in the Colne valley,* London: Museum of London Archaeology.

Lewis JSC, Wiltshire PEJ and Macphail R. (1992) A Late Devensian/Early Flandrian site at Three Ways Wharf. In: Needham S and Macklin MG (eds) *Alluvial Archaeology in Britain.* Oxford: Oxbow Books, 249-260.

Lewis MD. (2010) Pleistocene hyaena coprolite palynology in Britain: implications for the environments of early humans. In: Ashton NM, Lewis SG and Stringer CB (eds) *The Ancient Human Occupation of Britain.* Oxford: Elsevier, 263-278.

Lewis SG, Maddy D and Scaife RG. (2001) The fluvial system response to abrupt climate change during the last cold stage: the Upper Pleistocene River Thames fluvial succession at Ashton Keynes, UK. *Global and Planetary Change* 28: 341-359.
Li Y, Zhou L and Cui H. (2008) Pollen indicators of human activity. *Chinese Science Bulletin* 53: 1281-1293.
Lillesand TM, Kiefer RW and Chipman JW. (2004) *Remote Sensing and Image Interpretation,* New Jersey: John Wiley & Sons.
Lock G and Harris T. (2006) Enhancing Predictive Archaeological Modelling: Integrating Location, Landscape and Culture. In: Mehrer MW and Wescott KL (eds) *GIS and Archaeological Site Location Modelling.* New York: Taylor and Francis, 36-55.
Long AJ, Scaife RG and Edwards RJ. (2000) Stratigraphic architecture, relative sea-level, and models of estuary development in southern England: new data from Southampton Water. *Geological Society, London, Special Publications* 175: 253-279.
Lotter AFaZ, H. (1989) Late-Glacial pollen analysis, oxygen-isotope record, and radiocarbon stratigraphy from Rotsee (Lucerne), Central Swiss Plateau. *Eclogae Geologicae Helvetiae* 82: 191-202.
Lowe J, Birks H, Brooks S, et al. (1999) The chronology of palaeoenvironmental changes during the Last Glacial-Holocene transition: towards an event stratigraphy for the British Isles. *Journal of the Geological Society* 156: 397-410.
Lowe JJ and Lowe S. (1989) Interpretation of the pollen stratigraphy of Late Devensian lateglacial and early Flandrian sediments at Llyn Gwernan, near Cader Idris, North Wales. *New Phytologist* 113: 391-408.
Lowe JJ and Turney CSM. (1997) Vedde Ash layer discovered in a small lake basin on the Scottish mainland. *Journal of the Geological Society* 154: 605-612.
Lowe JJ and Walker MJ. (1997) *Reconstructing Quaternary Environments,* Essex: Longman.
Lowe JJ and Walker MJ. (2015) *Reconstructing Quaternary Environments,* Abingdon: Routledge.
Lücke A, Schleser GH, Zolitschka B, et al. (2003) A Lateglacial and Holocene organic carbon isotope record of lacustrine palaeoproductivity and climatic change derived from varved lake sediments of Lake Holzmaar, Germany. *Quaternary Science Reviews* 22: 569-580.
Lunetta RS and Balogh ME. (1999) Application of multi-temporal Landsat 5 TM imagery for wetland identification. *Photogrammetric Engineering and Remote Sensing* 65: 1303-1310.
Macphail RI and Scaife RG. (1987) The geographical and environmental background. In: Bird J and Bird DG (eds) *The Archaeology of Surrey to 1540,*. Guildford: Surrey Archaeological Society, 31-51.
Magny M. (1993) Solar influences on Holocene climatic changes illustrated by correlations between past lake-level fluctuations and the atmospheric 14C record. *Quaternary Research* 40: 1-9.
Magny M. (2004) Holocene climate variability as reflected by mid-European lake-level fluctuations and its probable impact on prehistoric human settlements. *Quaternary International* 113: 65-79.
Manley G. (1959) The late-glacial climate of north-west England. *Liverpool and Manchester Geological Journal* 2: 188-215.
Manning SA. (1974) *The naturalist in south-east England: Kent, Surrey and Sussex*: David & Charles.
Maritime Archaeology Trust. (2012) *Maritime Archaeology Trust, HWTMA Investigations in 2012*. Available at: www.maritimearchaeologytrust.org/bouldnor2012.
Marshall JD, Lang B, Crowley SF, et al. (2007) Terrestrial impact of abrupt changes in the North Atlantic thermohaline circulation: Early Holocene, UK. *Geology* 35: 639-642.
Mason SLR. (2000) Fire and Mesolithic subsistence — managing oaks for acorns in northwest Europe? *Palaeogeography, Palaeoclimatology, Palaeoecology* 164: 139-150.
Mayewski PA, Rohling EE, Stager JC, et al. (2004) Holocene Climate Variability. *Quaternary Research* 62: 243-255.
Mayle FE, Lowe JJ and Sheldrick C. (1997) The Late Devensian Lateglacial palaeoenvironmental record from Whitrig Bog, SE Scotland. 1. Lithostratigraphy, geochemistry and palaeobotany. *Boreas* 26: 279-295.

McClymont EL, Pendall E and Nicholls J. (2010) Stable isotopes and organic geochemistry in peat: Tools to investigate past hydrology, temperature and biogeochemistry. *PAGES news* 18: 15-18.
McDougall DA. (2001) The geomorphological impact of Loch Lomond (Younger Dryas) Stadial plateau icefields in the central Lake District, northwest England. *Journal of Quaternary Science* 16: 531-543.
McMahon TC. (2007) Discerning Prehistoric Landscapes in Colorado and the Mesa Verde Region Using a Kernel Density Estimate (KDE) Method. *Digital Discovery. Exploring New Frontiers in Human Heritage, CAA 2006*: 151-166.
Mellars P and Dark P. (1998) *Star Carr in context,* Cambridge: McDonald Institute for Archaeological Research, University of Cambridge.
Mellars P and Reinhardt SC. (1978) Patterns of Mesolithic land-use in southern England: a geological perspective. In: Mellars P (ed) *The Early Postglacial Settlement of Northern Europe.* London: Duckworth, 243-293.
Mills W. (2012) Current research on the Late Glacial of Southern Britain. The Lawson collection and its technological representation in the Final Upper Palaeolithic. MPhil Dissertation. *Department of Archaeology.* University of Oxford.
Milne R and Brown TA. (1997) Carbon in the Vegetation and Soils of Great Britain. *Journal of Environmental Management* 49: 413-433.
Milner N and Mithen S. (2009) Hunter Gatherers of the Mesolithic. In: Hunter J and Ralston I (eds) *The Archaeology of Britain. An Introduction from the Upper Palaeolithic to the Industrial Revolution.* Second Edition ed. London: Routledge, 53-77.
Mitchell B. (1971) A Comparison of Chi-Square and Kolmogorov-Smirnov Tests. *Area* 3: 237-241.
Mitchell FJ. (2005) How open were European primeval forests? Hypothesis testing using palaeoecological data. *Journal of Ecology* 93: 168-177.
Mitchell FJG. (2006) WHERE DID IRELAND'S TREES COME FROM? *Biology and Environment: Proceedings of the Royal Irish Academy* 106B: 251-259.
Mithen S. (2000) *Hunter-gatherer landscape archaeology: The Southern Hebrides Mesolithic Project 1988-1998. Volume 1. Project development, palaeoenvironmental studies and archaeological fieldwork on Islay,* Cambridge: McDonald Institute for Archaeological Research.
Mithen S. (2003) *After the Ice, A global Human History 20,000-5000 BC,* London: Phoenix.
Mithen SJ. (1988) Modeling hunter-gatherer decision making: complementing optimal foraging theory. *Human Ecology* 17: 59-83.
Moellering H. (1993) MKS-ASPECTTM - A New Way of Rendering Cartographic Z Surfaces. *Proceedings - 16th International Cartographic Conference.* Cologne, Germany, 675 - 681.
Momber G, Scaife R and Nayling N. (2011a) Environmental Change in the cultural landscape across the valley. In: Momber G, Tomalin D, Scaife R, et al. (eds) *Mesolithic occupation at Bouldnor Cliff and the submerged prehistoric landscapes of the Solent.* York: Council for British Archaeology, 105-112.
Momber G, Tomalin D, Scaife R, et al. (2011b) Mesolithic Occupation at Bouldnor Cliff and the Submerged Prehistoric Landscapes of the Solent. *CBA Research Report 164.* York: CBA.
Money JH. (1960) Excavations at High Rocks, Tunbridge Wells, 1954-1956. *Sussex Archaeological Collections* 98: 173-222.
Moore P and Wilmott A. (1976) Prehistoric Forest Clearance and the Development of Peatlands in the Uplands and Lowlands of Britain. *Proc of the 5th International Peat Congress.* Poznan, Poland, 1-15.
Moore PD and Webb JA. (1978) *An illustrated Guide to Pollen Analysis,* London: Hodder and Stoughton.
Moore PD, Webb JA and Collinson ME. (1991) *Pollen Analysis,* Oxford: Blackwell Scientific Publications.
Morellón M, Valero-Garcés B, Moreno A, et al. (2008) Holocene palaeohydrology and climate variability in northeastern Spain: The sedimentary record of Lake Estanya (Pre-Pyrenean range). *Quaternary International* 181: 15-31.
Morrison A. (1980) *Early Man in Britain and Ireland*, London: Croom Helm.

Munsell AH. (1912) A Pigment Color System and Notation. *The American Journal of Psychology* 23: 236-244.
Munsell Color. (2000) *Munsell Soil Color Charts,* Grand Rapids, Michigan: Munsell Color X-Rite.
Munsterman D and Kerstholt S. (1996) Sodium polytungstate, a new non-toxic alternative to bromoform in heavy liquid separation. *Review of Palaeobotany and Palynology* 91: 417-422.
National Soil Resources Institute. (2015) *SoilscapesSoil Types Viewer*. Available at: http://www.landis.org.uk/soilscapes.
Nature Conservancy Council. (1989) Guidelines for selection of biological SSSIs.
Needham S. (1992) Holocene alluviation and interstratified settlement evidence in the Thames valley at Runnymede Bridge. In: Needham S and Macklin MG (eds) *Alluvial Archaeology in Britain.* Oxford: Oxbow Books, 249-260.
Needham SP. (2000) *Runnymede Bridge Research Excavations Volume 1. The Passage of the Thames Holocene Environment and Settlement at Runnymede*, London: The British Museum Press.
Nicholls M and Scaife R. (2008) Palaeoenvironmental Reconstruction from Sediments at West Quay Road, Southampton. *Journal of Wetland Archaeology* 8: 91-119.
O'Connell M, Huang CC and Eicher U. (1999) Multidisciplinary investigations, including stable-isotope studies, of thick Late-glacial sediments from Tory Hill, Co. Limerick, western Ireland. *Palaeogeography, Palaeoclimatology, Palaeoecology* 147: 169-208.
Orme LC, Reinhardt L, Jones RT, et al. (2016) Aeolian sediment reconstructions from the Scottish Outer Hebrides: Late Holocene storminess and the role of the North Atlantic Oscillation. *Quaternary Science Reviews* 132: 15-25.
Palmer SCF and Truscott A-M. (2003) Browsing by deer on naturally regenerating Scots pine (Pinus sylvestris L.) and its effects on sapling growth. *Forest Ecology and Management* 182: 31-47.
Parker AG. (2000a) Biotic response to Late Quaternary global change - the pollen record: a case study from the Upper Thames Valley, England. In: Culver SJ and Rawson PF (eds) *Biotic Response to Global Change: The Last 145 Million Years.* Cambridge: Cambridge University Press, 265-287.
Parker AG. (2000b) Biotic response to Late Quaternary global change – the pollen record: a case study from the Upper Thames Valley, England. In: Culver SJ and Rawson P (eds) *Biotic Response to Global Change: the Last 145 Million Years.* Cambridge: Cambridge University Press, 265-287.
Parker AG, Goudie AS, Anderson DE, et al. (2002) A review of the mid-Holocene elm decline in the British Isles. *Progress in Physical Geography* 26: 1-45.
Parker AG and Preston GW. (2014) Minchery Farm, Littlemore, Oxford - Geoarchaeology and Palaeoenvironments. Archaeology of East Oxford Report - Oxford University.
Parker AG and Robinson MA. (2003) Palaeoenvironmental investigations on the middle Thames at Dorney, UK. In: Howard AJ, Macklin MG and Passmore DG (eds) *Alluvial Archaeology in Europe.* Lisse: Swets and Zeitlinger.
Pearson RG, Dawson TP and Liu C. (2004) Modelling species distributions in Britain: a hierarchical integration of climate and land-cover data. *Ecography* 27: 285-298.
Peduzzi P, Concato J, Kemper E, et al. (1996) A simulation study of the number of events per variable in logistic regression analysis. *Journal of Clinical Epidemiology* 49: 1373-1379.
Peglar SM. (1993) The development of the cultural landscape around Diss Mere, Norfolk, UK, during the past 7000 years. *Review of Palaeobotany and Palynology* 76: 1-47.
Peglar SM, Fritz SC and Birks HJB. (1989) Vegetation and Land-Use History at Diss, Norfolk, U.K. *Journal of Ecology* 77: 203-222.
Pendall E, Markgraf V, White JWC, et al. (2001) Multiproxy Record of Late Pleistocene–Holocene Climate and Vegetation Changes from a Peat Bog in Patagonia. *Quaternary Research* 55: 168-178.
Peng CYJ, Lee KL and Ingersoll GM. (2002) An Introduction to Logistic Regression Analysis and Reporting. *The Journal of Educational Research* 96: 3-14.
Pennington W, Tutin T and Bertie D. (1977) The Late Devensian Flora and Vegetation of Britain [and Discussion]. *Philosophical Transactions of the Royal Society B: Biological Sciences* 280: 247-271.

Pennington W and Tutin TG. (1980) Modern Pollen Samples from West Greenland and the Interpretation of Pollen Data from the British Late-Glacial (Late Devensian). *New Phytologist* 84: 171-201.
Peterson EW, Cho CC and Finlayson ML. (2007) Fear of falling and associated activity curtailment among middle aged and older adults with multiple sclerosis. *Multiple Sclerosis* 13: 1168-1175.
Pettitt P. (2008) The British Upper Palaeolithic. In: Pollard J (ed) *Prehistoric Britain.* Oxford: Blackwell Publishing.
Pettitt P, Rockman M and Chenery S. (2012) The British Final Magdalenian: Society, settlement and raw material movements revealed through LA-ICP-MS trace element analysis of diagnostic artefacts. *Quaternary International* 272–273: 275-287.
Pettitt P and White M. (2012a) *The British Palaeolithic*, Abingdon, Oxon: Routledge.
Pettitt P and White M. (2012b) *The British Palaeolithic: Hominin Societies at the Edge of the Pleistocene World*, Abingdon, Oxon: Routledge.
Pilcher JR. (2005) Radiocarbon Dating and Environmental Radiocarbon Studies. In: Mackay A, Battarbee R, Birks J, et al. (eds) *Global Change in the Holocene.* London: Hodder Education, 63-74.
Pokorny J. (1986) *A Colour Guide to Familiar Trees, Leaves, Bark and Fruit,* London: Octopus Books.
Porta S, Latora V, Wang F, et al. (2009) Street centrality and densities of retail and services in Bologna, Italy. *Environment and Planning B: Planning and design* 36: 450-465.
Prasad S, Brauer A, Rein B, et al. (2006) Rapid climate change during the early Holocene in Western Europe and Greenland. *The Holocene* 16: 153-158.
Pratt S, Branch NP and Bates M. (2003) A249 Iwade to Queenborough improvement scheme, Kent: archaeological survey. Stage 4b: report on pre-evaluation fieldwork. Archaeoscape Report for Mott MacDonald.
Preece RC. (1994) Radiocarbon dates from the ‘Allerød soil’ in Kent. *Proceedings of the Geologists' Association* 105: 111-123.
Preece RC and Bridgland DR. (1998) *Late Quaternary environmental change in north-west Europe: excavations at Holywell Coombe, south-east England*: Chapman & Hall Ltd.
Preece RC and Bridgland DR. (1999) Holywell Coombe, Folkestone: A 13,000 year history of an English Chalkland Valley. *Quaternary Science Reviews* 18: 1075-1125.
Prentice C. (1988) Records of vegetation in time and space: the principles of pollen analysis. In: Huntley B and Webb T (eds) *Vegetation history*. Dordrecht: Springer Netherlands, 17-42.
Prentice IC. (1985) Pollen representation, source area, and basin size: Toward a unified theory of pollen analysis. *Quaternary Research* 23: 76-86.
Puhe J and Ulrich B. (2012) *Global Climate Change and Human Impacts on Forest Ecosystems: Postglacial Development, Present Situation and Future Trends in Central Europe*: Springer Science & Business Media.
Punt W, Marks A and Hoen PP. (2002) Myricaceae. *Review of Palaeobotany and Palynology* 123: 99-102.
Racine CH, Dennis JG and Patterson WA, III. (1985) Tundra Fire Regimes in the Noatak River Watershed, Alaska: 1956-83. *Arctic* 38: 194-200.
Radley J, Tallis J and Switsur V. (1974) The Excavation of Three ‘Narrow Blade’Mesolithic Sites in the Southern Pennines, England. *Proceedings of the Prehistoric Society.* Cambridge Univ Press, 1-19.
Radley JD. (2006) A Wealden guide I: the Weald Sub-basin. *Geology Today* 22: 109-118.
Ramsey CB. (2008) Deposition models for chronological records. *Quaternary Science Reviews* 27: 42-60.
Ramsey CB. (2009a) Bayesian analysis of radiocarbon dates. *Radiocarbon* 51: 337-360.
Ramsey CB. (2009b) Dealing with outliers and offsets in radiocarbon dating. *Radiocarbon* 51: 1023-1045.
Ramsey CB and Lee S. (2013) Recent and planned developments of the program OxCal. *Radiocarbon* 55: 720-730.
Rankine WF. (1936) A Mesolithic site in Farnham. *Surrey Archaeological Collections* 44: 22-46.

Rankine WF. (1949a) Mesolithic Chipping Floors in the Wind-Blown Deposits of West Surrey. *Surrey Archaeological Collections* 50: 1-8.
Rankine WF. (1949b) A Mesolithic survey of the West Surrey Greensand. *Surrey Archaeological Society Research Paper* 2.
Rankine WF. (1952) Mesolithic research in Surrey: with a tribute to Wilfrid Hooper LLD; FSA,. *Surrey Archaeological Collections* 52: 1-10.
Rankine WF. (1953) A Mesolithic Chipping Floor at The Warren, Oakhanger, Selborne, Hants. *Proceedings of the Prehistoric Society (New Series)* 18: 21-35.
Rankine WF. (1956) The Mesolithic of Southern England. *Research Papers of the Surrey Archaeological Society* 4.
Rankine WF. (1960) Appendix A. The Flints in: Excavations at High Rocks, Tunbridge Wells, 1954-1956. *Sussex Archaeological Collections* 98: 197-207.
Rankine WF, Rankine WM and Dimbleby GW. (1960) Further Excavations at a Mesolithic Site at Oakhanger, Selborne, Hants. *Proceedings of the Prehistoric Society (New Series)* 26: 246-262.
Rasmussen SO, Bigler M, Blockley SP, et al. (2014) A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy. *Quaternary Science Reviews* 106: 14-28.
Rawat Y and Everson C. (2012) Ecological status and uses of juniper species in the cold desert environment of the Lahaul valley, North-western Himalaya, India. *Journal of Mountain Science* 9: 676-686.
Raynaud S. (2012) Stable isotope analyses of keratin for human provenance: Implications for forensic science. *Departments of Archaeology and Chemistry.* University of Reading.
Razzhavin V. (2012) Dwarf Shrub Heath In: Nutall M (ed) *Encyclopedia of the Arctic.* New York: Routledge, 515-516.
Reille M. (1995) *Pollen et spores d'Europe et d'Afrique du Nord: supplement 1,* Marseille: Laboratoire de Botanique Historique et Palynologie
Reimer PJ, Bard E, Bayliss A, et al. (2013) IntCal13 and Marine13 radiocarbon age calibration curves 0-50,000 years cal BP. *Radiocarbon* 55: 1869-1887.
Renssen H, Goosse H and Fichefet T. (2007) Simulation of Holocene cooling events in a coupled climate model. *Quaternary Science Reviews* 26: 2019-2029.
Renssen H and Vandenberghe J. (2003) Investigation of the relationship between permafrost distribution in NW Europe and extensive winter sea-ice cover in the North Atlantic Ocean during the cold phases of the Last Glaciation. *Quaternary Science Reviews* 22: 209-223.
Reynier MJ. (1998) Early Mesolithic Settlement in England and Wales: Some Preliminary Observations. In: Ashton N, Healy F and Pettitt P (eds) *Stone Age Archaeology.* Oxford: Oxbow Monograph 102 Lithic Studies Society (Occasional Paper 6), 174-184.
Reynier MJ. (2002) Kettlebury 1-3: a Mesolithic 'Horsham' type stone assemblage from Hankley Common, Elstead. *Surrey Archaeological Collections* 89: 221-231.
Rhodes AN. (1998) A method for the preparation and quantification of microscopic charcoal from terrestrial and lacustrine sediment cores. *The Holocene* 8: 113-117.
Richards MP, Hedges REM, Jacobi R, et al. (2000) Gough's Cave and Sun Hole Cave human stable isotope values indicate a high animal protein diet in the British Upper Palaeolithic. *Journal of Archaeological Science* 27: 1-3.
Richards MP, Jacobi R, Cook J, et al. (2005) Isotope evidence for the intensive use of marine foods by Late Upper Palaeolithic humans. *Journal of Human Evolution* 49: 390-394.
Richardson DM. (2000) *Ecology and Biogeography of Pinus*: Cambridge University Press.
Richerson PJ, Boyd R and Bettinger RL. (2001) Was agriculture impossible during the Pleistocene but mandatory during the Holocene? A climate change hypothesis. *American Antiquity* 66: 387-411.
Roberts MR. (1993) *Excavations at Park Farm, Binfield, Berkshire, 1990,* Oxford: Oxford Archaeological Unit.
Roberts N. (2009) Holocene Climates. In: Gomitz V (ed) *Encyclopedia of Paleoclimatology and Ancient Environments.* Dordrecht, The Netherlands: Springer, 438-441.

Roebroeks W and Bakels CC. (2014) 'Forest Furniture' or 'Forest Managers'? On Neanderthal Presence in Last Interglacial Environments. In: Coward F, Hosfield R, Pope M, et al. (eds) *Settlement, Society and Cognition in Human Evolution.* Cambridge: Cambridge University Press, 174-188.

Rousseau D-D, Preece R and Limondin-Lozouet N. (1998) British late glacial and Holocene climatic history reconstructed from land snail assemblages. *Geology* 26: 651-654.

Rull V. (2009) Microrefugia. *Journal of Biogeography* 36: 481-484.

Rull V. (2010) On microrefugia and cryptic refugia. *Journal of Biogeography* 37: 1623-1625.

Sandford KS. (1965) Notes on the gravels of the Upper Thames Flood Plain between Lechlade and Dorchester. *Proceedings of the Geologists' Association* 76: 61-IN66.

Sayer D and Wienhold M. (2012) A GIS-investigation of four early Anglo-Saxon Cemeteries: Ripley’s K-function analysis of spatial groupings amongst graves. *Social Science Computer Review*: 0894439312453276.

Scaife R. (1980a) Late Devensian and Flandrian palaeoecological studies in the Isle of Wight. PhD thesis. Department of Geography, Kings College, University of London.

Scaife R. (1982) Late-Devensian and Early Flandrian vegetation changes in Southern England. In: Bell M and Limbrey S (eds) *Archaeological Aspects of Woodland Ecology.* Oxford: British Archaeological Reports, 57-74.

Scaife R. (1987) The Late-Devensian and Flandrian Vegetation of the Isle of Wight. In: Barber KE (ed) *Wessex and the Isle of Wight Field Guide.* Cambridge: Quaternary Research Association, 156-180.

Scaife R. (2000a) *Chapter 9 Palynology and Palaeoenvironment*, London: The British Museum Press.

Scaife R. (2000b) Pollen analysis at Farlington Marshes: A vegetation history of Langstone Harbour. In: Allen MJ and Gardiner J (eds) *Our changing coast: a survey of the intertidal archaeology of Langstone Harbour, Hampshire.* York: Council for British Archaeology, 171-175.

Scaife R. (2001) The prehistoric vegetation of Midhurst: a pollen study of the Common at New Pond. In: Magilton J and Thomas S (eds) *Midhurst. Chichester District Archaeology [series] 1.* Chichester: Chichester District Council, 95-102.

Scaife R. (2004) Denham, Bucks. (50692): A preliminary pollen analysis of the Early Holocene peat sequences. Wessex Archaeology Report.

Scaife R. (2015a) 2 - 8. Hampshire. The Southern Pollen Review. Heritage England.

Scaife R. (2015b) 2 - 9. The Isle of Wight. The Southern Pollen Review. Historic England.

Scaife R. (2015c) 2 - 10. The Solent. The Southern Pollen Review. Historic England.

Scaife R. (2015d) 2 - 16. Kent. The Southern Pollen Review. Historic England.

Scaife R. (2015e) 2 - 17. London. The Southern Pollen Review. Historic England.

Scaife RG. (1980b) Late-devensian and flandrian palaeoecological studies in the Isle of Wight. *Department of Geography.* Kings College London.

Scarre C. (2005) *The human past: world prehistory and the development of human societies*: Thames & Hudson.

Scott-Jackson JE. (2000) *Lower and Middle Palaeolithic artefacts from deposits mapped as Clay-with-flints. A new synthesis with significant implications for the earliest occupation of Britain,* Oxford: Oxbow Books.

Scott D, Welch D, Thurlow M, et al. (2000) Regeneration of Pinus sylvestris in a natural pinewood in NE Scotland following a reduction in grazing by Cervus elaphus. *Forest Ecology and Management* 130: 199-211.

Seagrief SC. (1959) Pollen Diagrams from Southern England: Wareham, Dorset and Nursling, Hampshire. *New Phytologist* 58: 316-325.

Seagrief SC and Godwin H. (1960) Pollen Diagrams from Southern England: Elstead, Surrey. *New Phytologist* 59: 84-91.

Seppä H, Schurgers G, Miller PA, et al. (2015) Trees tracking a warmer climate: The Holocene range shift of hazel (Corylus avellana) in northern Europe. *The Holocene* 25: 53-63.

Severinghaus JP, Sowers T, Brook EJ, et al. (1998) Timing of abrupt climate change at the end of the Younger Dryas interval from thermally fractionated gases in polar ice. *Nature* 391: 141-146.

Shennan I and Andrews JE. (2000) *Holocene Land–Ocean Interaction and Environmental Change around the North Sea,* Bath: Geological Society Publishing House.

Shennan I, Lambeck K, Flather R, et al. (2000) Modelling western North Sea palaeogeographies and tidal changes during the Holocene. In: Shennan I and Andrews JE (eds) *Holocene Land-Ocean Interaction and Environmental Change around the North Sea.* Bath: Geological Society Publishing House, 299-319.
Sheskin DJ. (2003) *Handbook of parametric and nonparametric statistical procedures*: crc Press.
Shotton FW, Blundell DJ and Williams RG. (1970) Birmingham University Radiocarbon Dates IV. *Radiocarbon* 12.
Shuman B, Webb T, Bartlein P, et al. (2002) The anatomy of a climatic oscillation: vegetation change in eastern North America during the Younger Dryas chronozone. *Quaternary Science Reviews* 21: 1777-1791.
Simmons I. (1994) Vegetation change during the Mesolithic in the British Isles: some amplifications. In: Chambers FM (ed) *Climate Change and Human Impact on the Landscape.* London: Chapman and Hall, 109-118.
Simmons IG and Innes JB. (1987) Mid-holocene adaptations and later Mesolithic forest disturbance in Northern England. *Journal of Archaeological Science* 14: 385-403.
Simmons IG and Innes JB. (1996a) Disturbance Phases in the Mid-Holocene Vegetation at North Gill, North York Moors: Form and Process. *Journal of Archaeological Science* 23: 183-191.
Simmons IG and Innes JB. (1996b) Prehistoric Charcoal in Peat Profiles at North Gill, North Yorkshire Moors, England. *Journal of Archaeological Science* 23: 193-197.
Simmons IG and Tooley MJ. (1981) *The Environment in British Prehistory,* London: Duckworth.
Sissons JB. (1980) The Loch Lomond Advance in the Lake District, Northern England. *Transactions of the Royal Society of Edinburgh:Earth Sciences* 71: 13-27.
Skempton AW and Worssam BC. (1976) The Quaternary History of the Lower Greensand Escarpment and Weald Clay Vale near Sevenoaks, Kent [and Discussion]. *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences* 283: 493-526.
Skene KR, Sprent JI, Raven JA, et al. (2000) Myrica gale L. *Journal of Ecology* 88: 1079-1094.
Slater C, Preston T and Weaver LT. (2001) Stable isotopes and the international system of units. *Rapid Commun Mass Spectrom* 15: 1270-1273.
Smart TL and Hoffman ES. (1988) Environmental interpretation of archaeological charcoal. In: Hastorf H and Popper V (eds) *Current Palaeoethnobotany.* Chicago: University of Chicago Press, 167-225.
Smith AG. (1970) The influence of Mesolithic and Neolithic man on British vegetation. In: Walker D and West RG (eds) *Studies in the Vegetational History of the British Isles.* Cambridge: Cambridge University Press, 81-96.
Smith AG. (1984) Newferry And The Boreal-Atlantic Transition. *New Phytologist* 98: 35-55.
Smith R. (1924) Stone Age Site Near Woking. *The Antiquaries Journal* 4: 415.
Smith R. (1925) Local Notes, Horsell Discovery of a Stone Age site. *Surrey Archaeological Collections* 36.
Smith VC, Staff RA, Blockley SPE, et al. (2013) Identification and correlation of visible tephras in the Lake Suigetsu SG06 sedimentary archive, Japan: chronostratigraphic markers for synchronising of east Asian/west Pacific palaeoclimatic records across the last 150 ka. *Quaternary Science Reviews* 67: 121-137.
Sommerville J and Tetlow EA. (2011) An analysis of the lithic collections from Rainbow Bar, Hampshire. *Lithics: the Journal of the Lithic Studies Society* 32: 6-16.
Stace C. (2010) *New flora of the British Isles,* Cambridge: Cambridge University Press.
Stapert D. (1986) Two findspots of the Hamburgian tradition in the Netherlands dating from the Early Dryas Stadial: stratigraphy. *Meded. Werkgr. Tert. Kwart. Geol.* 23: 21-41.
Stasney P. (2015) Examining the relationships between Holocene climate change, hydrology and human society in Ireland. *Department of Archaeology.* University of Reading.
Steinke RC, Ogden FL and Lai W. (2013) Evaluating TauDEM Delineated Stream Networks Against the National Hydrography Dataset. *AGU Fall Meeting Abstracts*.
Stewart JR and Lister AM. (2001) Cryptic northern refugia and the origins of the modern biota. *Trends in Ecology & Evolution* 16: 608-613.
Stockmarr J. (1971) Tablets with Spores used in Absolute Pollen Analysis. *Pollen et Spores* 13: 615-621.

Streif H. (2002) The Pleistocene and Holocene Development of the Southeastern North Sea Basin and Adjacent Coastal Areas. In: Wefer G, Berger WH, Behre KE, et al. (eds) *Climate Development and History of the North Atlantic Realm.* Berlin: Springer, 387-397.
Stuiver M and Polach HA. (1977) Discussion; reporting of C-14 data. *Radiocarbon* 19: 355-363.
Sugita S. (1994) Pollen Representation of Vegetation in Quaternary Sediments: Theory and Method in Patchy Vegetation. *Journal of Ecology* 82: 881-897.
Sutherland DG, Gordon JE, Smith DE, et al. (1993) *Chapter 13: Western Highland Boundary,* The Museum of London: Chapman and Hall.
Switsur V and Jacobi R. (1979) A radiocarbon chronology for the early postglacial stone industries of England and Wales. *Radiocarbon Dating*: 41-68.
Symonds M. (2014) London's Mesolithic moments. *Current Archaeology.* Chiswick, London: Current Publishing.
Tallantire PA. (1953) Studies in the Post-Glacial History of British Vegetation: XIII. Lopham Little Fen, A Late-Glacial Site in Central East Anglia. *Journal of Ecology* 41: 361-373.
Tallantire PA. (2002) The early-Holocene spread of hazel (Corylus avellana L.) in Europe north and west of the Alps: an ecological hypothesis. *The Holocene* 12: 81-96.
Taller A, Beyries S, Bolus M, et al. (2012) Are the Magdalenian Backed Pieces From Hohle Fels Just Projectiles or Part of a Multifunctional Tool Kit? *Mitteilungen der Gesellschaft für Urgeschichte* 21: 37.
Tarboton DG. CSDMS TauDEM Clinic “Hands On” Exercise. Logan: Utah State University.
Tarboton DG. (1997) A New Method for the Determination of Flow Directions and Contributing Areas in Grid Digital Elevation Models. *Water Resources Research* 33: 309-319.
Tarboton DG. (2004) TauDEM (Terrain Analysis Using Digital Elevation Models) Software. Logan: Utah State University.
Tarboton DG, Bras RL and Rodriguez-Iturbe I. (1991) On the Extraction of Channel Networks from Digital Elevation Data. *Hydrologic Processes* 5: 81-100.
Tarboton DG and Mohammed IN. (2013) TauDEM5.1 QUICK START GUIDE TO USING THE TAUDEM ARCGIS TOOLBOX. Logan: Utah State University.
Tauber H. (1965) *Differential pollen dispersion and the interpretation of pollen diagrams*: Danm Geol Unders IIR.
Taylor-Wilson R. (2002) *Excavations at Hunt's House, Guys Hospital, London Borough of Southwark* London: Pre-Construct Archaeology Limited.
Taylor DM, Griffiths HI, Pedley HM, et al. (1994) Radiocarbon-dated Holocene pollen and ostracod sequences from barrage tufa- dammed fluvial systems in the White Peak, Derbyshire, UK. *The Holocene* 4: 356-364.
The Museum of London. (2000) *The Archaeology of Greater London,* London: MoLAS.
Thomas C, Rackham J, Barham AJ, et al. (1996) Bramcote Green, Bermondsey: a Bronze Age Trackway and Palaeo-Environmental Sequence. *Proceedings of the Prehistoric Society* 62: 221-253.
Thorley A. (1981) Pollen Analytical Evidence Relating to the Vegetation History of the Chalk. *Journal of Biogeography* 8: 93-106.
Tolan-Smith C. (2008) Mesolithic Britain. In: Bailey G and Spikins P (eds) *Mesolithic Europe.* Cambridge: Cambridge University Press, 132-157.
Tooley MJ. (1986) Sea-Level changes and coastal morphology in North-west England. . In: Johnson RH (ed) *The geomorphology of North-West England.* Manchester: Manchester University Press.
Troels-Smith J. (1955) Karakterisering af lose jordater (characterisation of unconsolidated sediments). *Denmarks Geologiske Undersogelse* Series IV/3: 73.
Turner NJ, Łuczaj ŁJ, Migliorini P, et al. (2011) Edible and Tended Wild Plants, Traditional Ecological Knowledge and Agroecology. *Critical Reviews in Plant Sciences* 30: 198-225.
Turney C, Baillie M, Clemens S, et al. (2005) Testing solar forcing of pervasive Holocene climate cycles. *Journal of Quaternary Science* 20: 511-518.
Turney CM, Harkness DD and Lowe JJ. (2006) *Carbon isotope variations and chronology of the last glacial-interglacial transition (14-9 ka BP).*

Turney CSM, Coope GR, Harkness DD, et al. (2000) Implications for the Dating of Wisconsinan (Weichselian) Late-Glacial Events of Systematic Radiocarbon Age Differences between Terrestrial Plant Macrofossils from a Site in SW Ireland. *Quaternary Research* 53: 114-121.

Tzedakis PC, Emerson BC and Hewitt GM. (2013) Cryptic or mystic? Glacial tree refugia in northern Europe. *Trends in Ecology & Evolution* 28: 696-704.

van der Kaars S and De Deckker P. (2002) A Late Quaternary pollen record from deep-sea core Fr10/95, GC17 offshore Cape Range Peninsula, northwestern Western Australia. *Review of Palaeobotany and Palynology* 120: 17-39.

Van Geel B, Bohncke S and Dee H. (1980) A palaeoecological study of an upper Late Glacial and Holocene sequence from "De Borchert", The Netherlands. *Review of Palaeobotany and Palynology* 31: 367-448.

van Geel B, Heijnis H, Charman DJ, et al. (2014) Bog burst in the eastern Netherlands triggered by the 2.8 kyr BP climate event. *The Holocene*: 0959683614544066.

van Geel B and Middeldorp AA. (1988) Vegetational history of Carbury Bog (Co. Kildare, Ireland) during the last 850 years and a test of the temperature indicator value of 2H/1H measurements of peat samples in relation to historical sources and meteorological data. *New Phytologist* 109: 377-392.

Vanacker V, Govers G, Van Peer P, et al. (2001) Using Monte Carlo simulation for the environmental analysis of small archaeologic datasets, with the Mesolithic in Northeast Belgium as a case study. *Journal of Archaeological Science* 28: 661-669.

Vera FWM. (2000) *Grazing ecology and forest history,* Wallingford: CABI Publishing.

Verbruggen C. (1979) Vegetation and palaeoecological history of the Late Glacial period in Sandy Flanders (Belgium). *Acta Universitatis Oulensis, Series A, Geologica* 82: 231-234.

Verhagen P. (2007) *Case Studies in Archaeological Predictive Modelling*: Amsterdam University Press.

Viktorov SVe, Vostokova YA and Vyshivkin DD. (2013) *Short Guide to Geo-Botanical Surveying: International Series of Monographs on Pure and Applied Biology, Division: Botany*: Elsevier.

Vittinghoff E and McCulloch CE. (2007) Relaxing the Rule of Ten Events per Variable in Logistic and Cox Regression. *American Journal of Epidemiology* 165: 710-718.

von Grafenstein U, Erlenkeuser H, Müller J, et al. (1998) The cold event 8200 years ago documented in oxygen isotope records of precipitation in Europe and Greenland. *Climate Dynamics* 14: 73-81.

Walker M, Bohncke S, Coope G, et al. (1994) The Devensian/Weichselian Late-glacial in northwest Europe (Ireland, Britain, north Belgium, The Netherlands, northwest Germany). *Journal of Quaternary Science* 9: 109-118.

Walker M, Johnsen S, Rasmussen SO, et al. (2008) The global stratotype section and point (GSSP) for the base of the Holocene series/epoch (Quaternary system/period) in the NGRIP ice core. *Episodes* 31: 264-267.

Walker M, Lowe J, Blockley SP, et al. (2012) Lateglacial and early Holocene palaeoenvironmental 'events' in Sluggan Bog, Northern Ireland: comparisons with the Greenland NGRIP GICC05 event stratigraphy. *Quaternary Science Reviews* 36: 124-138.

Walker MJC. (1975) Late Glacial and Early Postglacial Environmental History of the Central Grampian Highlands, Scotland. *Journal of Biogeography* 2: 265-284.

Walker MJC. (2004) A Lateglacial pollen record from Hallsenna Moor, near Seascale, Cumbria, NW England, with evidence for arid conditions during the Loch Lomond (Younger Dryas) Stadial and early Holocene. *Proceedings of the Yorkshire Geological Society* 55: 33-42.

Walker MJC, Coope GR and Lowe JJ. (1993) The Devensian (Weichselian) Lateglacial palaeoenvironmental record from Gransmoor, East Yorkshire, England: A contribution to the 'North Atlantic seaboard programme' of IGCP-253, 'Termination of the Pleistocene'. *Quaternary Science Reviews* 12: 659-680.

Walker MJC, Coope GR, Sheldrick C, et al. (2003) Devensian Lateglacial environmental changes in Britain: a multi-proxy environmental record from Llanilid, South Wales, UK. *Quaternary Science Reviews* 22: 475-520.

Waller M and Kirby J. (2002) Late Pleistocene/Early Holocene Environmental Change in the Romney Marsh Region: New Evidence from Tilling Green, Rye. In: Long A, Hipkin S and Clarke H (eds) *Romney Marsh: Coastal and Landscape Change through the Ages.* OUSA Monograph.
Waller M and Long A. (2010) The Holocene Coastal Deposits of Sussex: a Re-evaluation. In: Waller M, Edwards E and Barber L (eds) *Romney Marsh: Persistence and Change in a Coastal Lowland.* Romney Marsh Research Trust, 1-21.
Waller MP. (1993) Flandrian vegetational history of south-eastern England. Pollen data from Panel Bridge, East Sussex. *New Phytologist* 124: 345-369.
Waller MP and Hamilton S. (2000) Vegetation history of the English chalklands: a mid-Holocene pollen sequence from the Caburn. *Journal of Quaternary Science* 15: 253-272.
Waller MP, Long AJ, Long D, et al. (1999) Patterns and processes in the development of coastal mire vegetation: Multi-site investigations from Walland Marsh, Southeast England. *Quaternary Science Reviews* 18: 1419-1444.
Waller MP and Marlow AD. (1994) Flandrian vegetational history of south-eastern England. Stratigraphy of the Brede valley and pollen data from Brede Bridge. *New Phytologist* 126: 369-392.
Wanner H, Solomina O, Grosjean M, et al. (2011) Structure and origin of Holocene cold events. *Quaternary Science Reviews* 30: 3109-3123.
Ward GK and Wilson SR. (1978) Procedures for Comparing and Combining Radiocarbon Age Determinations: A Critique. *Archaeometry* 20: 19-31.
Warren RE and Asch DL. (2000) A predictive model of archaeological site location in the Eastern Prairie Peninsula. In: Wescott KL and Brandon RJ (eds) *Practical Applications of GIS for Archaeologists.* . New York: Taylor and Francis, 5-32.
Watson E and Morgan AV. (1977) The Periglacial Environment of Great Britain During the Devensian. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 280: 183-198.
Webb MC, Wilson JR and Chong J. (2004) An Analysis of Quasi-complete Binary Data with Logistic Models: Applications to Alcohol Abuse Data. *Journal of Data Science* 2: 273-285.
Webster G. (2015) The archaeological and environmental aspects of Chobham Common.
Wein RW. (1976) Frequency and Characteristics of Arctic Tundra Fires. *Arctic* 29: 213-222.
Wescott KL and Kuiper JA. (2000) Using a GIS to Model Prehistoric Site Distributions in the Upper Chesapeake Bay. In: Wescott KL and Brandon RJ (eds) *Practical Applications of GIS for Archaeologists.* New York: Taylor and Francis, 62-77.
Wessex Archaeology. (1993) *The Southern Rivers Palaeolithic Project Report No. 2. 1992-1993. The South West and South of the Thames.* , Salisbury: Wessex Archaeology & English Heritage.
Wessex Archaeology. (1994) *The Sussex Raised Beaches and the Bristol Avon. The Southern Rivers Palaeolithic Project: Report No. 3, 1993-1994.* , Salisbury: Wessex Archaeology.
Wessex Archaeology. (2006) Units 300/305, 310/315/320/325 and 400. Riverside Way, Uxbridge, London Borough Of Hillingdon. Archaeological Evaluation Report, Wessex Archaeology.
Wessex Archaeology. (2008) *Springhead*. Available at: http://www.wessexarch.co.uk/projects/kent/ctrl/springhead/index.html.
Wessex Archaeology and Jacobi R. (2014) Palaeolithic and Mesolithic Lithic Artefact (PaMELA) database [data-set]. York: Archaeology Data Service.
West RG. (1988) A Commentary on Quaternary Cold Stage Floras in Britain. *Journal of Biogeography* 15: 523-528.
Wheatley D and Gillings M. (2000) Vision, Perception and GIS: developing enriched approaches to the study of archaeological visibility. In: Lock GR (ed) *Beyond the Map: Archaeology and Spatial Technologies.* Oxford: IOS Press, 1-27.
Wheatley D and Gillings M. (2002) *Spatial technology and archaeology: the archaeological applications of GIS*, London: Taylor and Francis.
Whitehouse NJ and Smith D. (2010) How fragmented was the British Holocene wildwood? Perspectives on the “Vera” grazing debate from the fossil beetle record. *Quaternary Science Reviews* 29: 539-553.
Whitehouse NJ and Smith DN. (2004) 'Islands' In Holocene Forests: Implications for Forest Openness, Landscape Clearance and 'Culture-Steppe' Species. *Environmental Archaeology* 9: 199-208.

Whittington G, Edwards KJ and Cundill PR. (1991) Late- and post-glacial vegetational change at Black Loch, Fife, eastern Scotland – a multiple core approach. *New Phytologist* 118: 147-166.
Whittle A. (1990) A Model for the Mesolithic-Neolithic Transition in the Upper Kennet Valley, North Wiltshire. *Proceedings of the Prehistoric Society* 56: 101-110.
Whittle A. (1999) The Neolithic Period, c.4000-2500/2200 BC: Changing the World. In: Hunter J and Ralston IBM (eds) *The Archaeology of Britain. An Introduction from the Upper Palaeolithic to the Industrial Revolution.* Second Edition ed. London: Routledge, 58-76.
Whittle A and Cummings V. (2007) Going Over: The Mesolithic-Neolithic Transition in North-West Europe. *Proceedings of the British Academy* 144.
Wicks K and Mithen S. (2014) The impact of the abrupt 8.2 ka cold event on the Mesolithic population of western Scotland: a Bayesian chronological analysis using 'activity events' as a population proxy. *Journal of Archaeological Science* 45: 240-269.
Wilkinson KN, Berzins V, Branch NP, et al. (1994) Great Rissington/Bourton Link Sewerage scheme: a study of the Late Devensian and early to middle Flandrian environments from material recorded during the watching brief. Thames Water Ltd/Cotswold Archaeological Trust.
Wilkinson KN, Scaife RG and Sidell EJ. (2000) Environmental and sea-level changes in London from 10 500 BP to the present: a case study from Silvertown. *Proceedings of the Geologists' Association* 111: 41-54.
Williams AS. (1972) Late Glacial-Postglacial Vegetational History of the Pretty Lake Region, Northeastern Indiana. *Hydrologic and biological studies of Pretty Lake, Indiana.* Washington: U.S. Government Printing Office.
Wiltshire PEJ. (1997) Kettlebury Hill Palynological Assesment. University College London.
Winser KD. (1987) Prehistoric flint sites at Sandy Meadow, Wotton. *Surrey Archaeological Collections* 78: 184-187.
Woodbridge J, Fyfe RM, Roberts N, et al. (2014) The impact of the Neolithic agricultural transition in Britain: a comparison of pollen-based land-cover and archaeological 14C date-inferred population change. *Journal of Archaeological Science* 51: 216-224.
Worboys MF and Duckham M. (2004) *GIS: A Computing Perspective, Second Edition*: Taylor & Francis.
Wymer JJ. (1962) Excavations at the Maglemosian Sites at Thatcham, Berkshire, England. *Proceedings of the Prehistoric Society* 28: 329-361.
Wymer JJ. (1982) The Palaeolithic Period in Kent. In: Leach PE (ed) *Archaeology in Kent to AD 1500.* London: Council for British Archaeology, 8-11.
Wymer JJ. (1996) The Palaeolithic and Mesolithic in Hampshire. In: Hinton DA and Hughes M (eds) *Archaeology in Hampshire: A framework for the future.* Hampshire: Hampshire County Council, 1-5.
Wymer JJ. (1999) *The Lower Palaeolithic Occupation of Britain Volumes 1 and 2,* Salisbury: Wessex Archaeology and English Heritage.
Wymer JJ and Bonsall C. (1977) *Gazetteer of Mesolithic sites in England and Wales with a gazetteer of Upper Palaeolithic sites in England and Wales,* London: CBA Research Report No 20.
Xie Z and Yan J. (2008) Kernel Density Estimation of traffic accidents in a network space. *Computers, Environment and Urban Systems* 32: 396-406.
Zhang L, Dawes WR and Walker GR. (2001) Response of mean annual evapotranspiration to vegetation changes at catchment scale. *Water Resources Research* 37: 701-708.

13. Appendices

13.1. Chi-squared Test Methodology

The methodology for the chi-square goodness-of-fit test is as follows:

1. Define the hypotheses:

   H_0: The observed frequency is the same as the expected frequency.
   H_1: The observed frequency is significantly different to the expected frequency.

2. Calculate the area of all of the categories of data (e.g. geological types).
3. Calculate how many Mesolithic records are present within each category.
4. Calculate the expected number of records per category:

Equation 13.1. Equation for the expected number of records per category.

$$\frac{Number\ of\ sites\ in\ total}{Total\ percentage\ of\ categories} \times \%\ area\ of\ category$$

Expected distribution is based on all frequencies being equal across the different categories (in a ratio to their size). The test therefore examines how the records should distribute if there expected frequency is met.

5. Calculate the chi-square statistic for each category:

Equation 13.2. Equation to calculate the chi-squared statistic.

$$\frac{(observed\ frequency - expected\ frequency)^2}{expected\ frequency}$$

6. Sum the chi-square statistic for all categories and compare the value to the critical values of the chi-square distribution using the appropriate degrees of freedom (df = categories -1) and significance level ($\alpha = 0.05$). If the chi-square statistic is less than the critical value then the null hypothesis (H_0) must be accepted.

13.2. The TAUDEM Method

The method for creating the total wetness index is detailed in Table 13.1. All analyses were undertaken in ArcGIS with the additional TAUDEM toolboxes.

Table 13.1 Development of the TWI(Tarboton);(Tarboton and Mohammed, 2013).

Step	ArcGIS Command
Import digital elevation model and convert the DEM to .tiff format.	*Conversion tools – to raster – raster to other formats (multiple) Raster – export raster – type .tiff*
Fill the pits within the dataset.	*TAUDEM Tools – basic grid analysis – pit fill (1 output - fel)*
Calculate the D-infinity flow direction for each cell. This calculates the direction of steepest descent and also the slope angles.	*TAUDEM Tools – basic grid analysis – D-infinity flow directions (2 outputs – ang and slp)*
Calculate the D-infinity specific contributing area. This calculates the number of other cells that would flow through a specific cell.	*TAUDEM Tools – basic grid analysis – D-infinity contributing area (1 output – sca)*
Calculate the slope over area ratio	*TAUDEM Tools – specialised grid analysis – slope over area ratio (1 output – sar)*
Calculate the TWI using the raster calculator	*Spatial Analyst – Map Algebra – Raster Calculator -ln(sar)*

Data tables relating to both the archaeological datasets and the environmental data can be found on the accompanying disk. The data included is as follows:

13.3. The HER Dataset – Surrey

13.4. The HER Dataset – Southeast

13.5. The PaMELA Dataset – Surrey

13.6. Langshot Bog Sedimentology Descriptions

13.7. Langshot Bog Organic Matter and Pyrite Data

13.8. Langshot Bog Isotopic Data

13.9. Langshot Bog Raw Pollen Data

13.10. Thursley Bog and Ockley Bog Transect Survey Data

13.11. Thursley Bog Sedimentology Descriptions

13.12. Thursley Bog Organic Matter Data

13.13. Ockley Bog Sedimentology Descriptions

13.14. Ockley Bog Organic Matter Data

13.15. Thursley Bog Raw Pollen Data

13.16. Ockley Bog Raw Pollen Data

13.17. Elstead Bog B Sedimentology Descriptions

13.18. Elstead Bog B Organic Matter Data

13.19. Elstead Bog B Raw Pollen Data

13.20. Significance and Threat Tests