British palaeoclimates and palaeoenvironments during the Hoxnian interglacial (Marine Isotope Stage 11).

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British palaeoclimates and palaeoenvironments during the Hoxnian interglacial (Marine Isotope Stage 11)

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Abstract

The Hoxnian interglacial can be correlated with Marine Isotope Stage 11 (MIS 11), which is one of the most significant interglacials in the Pleistocene. MIS 11 is widely believed to be an analogue for the current interglacial, making it a focus of particular interest in the palaeoclimatological community. Britain has numerous valuable terrestrial records for this period and with its location next to the Atlantic can play an important role in elucidating the climatic changes of this interval. However, in recent years relatively little work has been undertaken on the Hoxnian.

This thesis fills this important gap with new pollen data and the use of pre-existing pollen records to provide a fresh perspective on the palaeoclimate and palaeoenvironment of the period. In particular pollen based quantitative palaeoclimate reconstructions are performed: the first for Britain and one of very few anywhere for this time period.

The palaeoclimate reconstructions reveal important features of Middle Pleistocene climate, including the occurrence of significant seasonality, abrupt climate change and spatial heterogeneity. The reconstructions are related to other records from MIS 11 to build up a rich picture of the climate changes of this interval and the relationship between Britain and Europe and beyond.

In addition to the palaeoclimate reconstructions, new palaeofire and palaeoecological data are presented in order to construct a full and rounded narrative of Hoxnian palaeoenvironments. Finally, these various insights are combined in order to shed light on the significant archaeological record of this time, demonstrating the significant environmental obstacles that early hominids would have to have overcome in order to survive in Hoxnian Britain.

For my parents and Marion

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1 – Introduction

1.1 – Thesis overview

This project involves a novel and innovative analysis of British Middle Pleistocene sediments belonging to the Hoxnian interglacial. The Hoxnian contains some of the most extensive sequences of any interglacial in the British Isles, making it a rich and valuable archive for the exploration of past changes in climate and environment. Furthermore, the Hoxnian correlates with Marine Isotope Stage (MIS) 11 (Fig 1) (Bowen, 1999), which is widely recognised as a hugely important interval in the Quaternary record because of its status as a close analogue to the current interglacial.

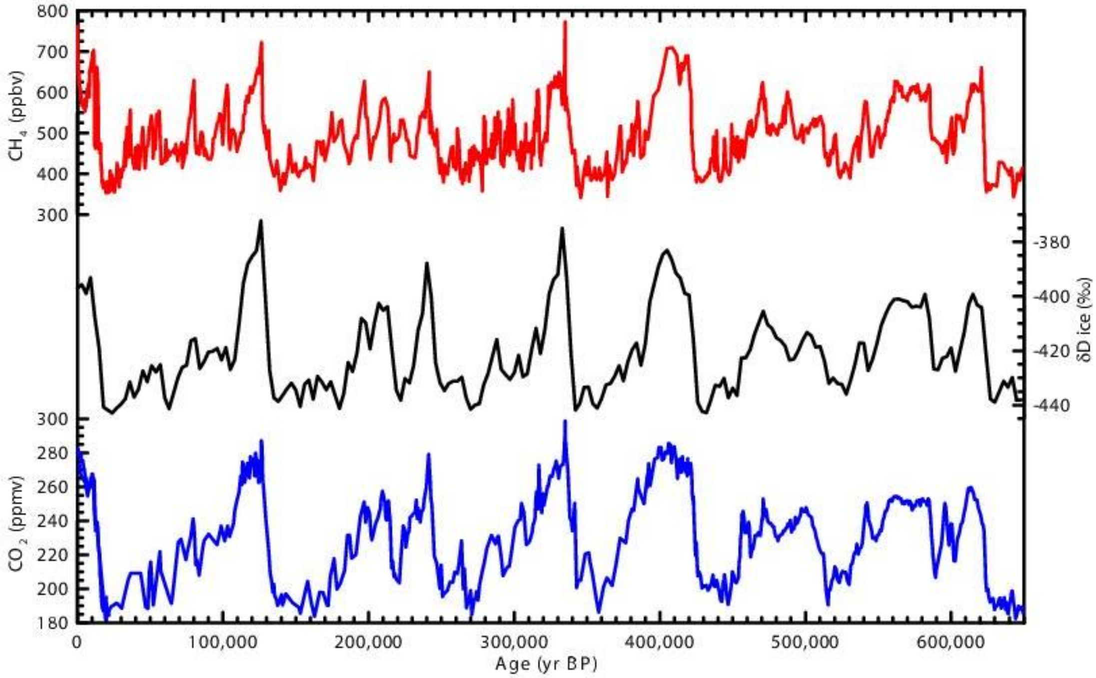


Fig 1: MIS 11, centred around 400 kyr BP, in its palaeoclimate context (EPICA, 2004)

The principal focus of this research is a quantitative palaeoclimate reconstruction for the Hoxnian. By employing pollen-based climate reconstructions for a number of lake sediment sequences, a detailed and robust perspective on the palaeotemperature and palaeoprecipitation trends of MIS 11 in north-western Europe is presented. This will be the first quantified reconstruction for the British Isles and one of the first undertaken in Europe as a whole.

A subsidiary component to this thesis concerns the establishment of a charcoal-derived fire history for the Hoxnian. Fire can represent a fundamental component of ecosystem functioning and yet fire history prior to the Holocene is generally poorly understood. Furthermore, the work is underpinned by the theoretical, empirical and experimental advancements that have occurred in palynology in recent decades. In concert with the palaeoclimate reconstructions, the end result will be a fresh perspective on the palaeoenvironment of the Hoxnian interglacial. These new insights will then be used to shed light on the fascinating archaeological record for this interval.

This is currently an exciting time for a return to British Middle Pleistocene sequences. Palynological analysis of this period was previously extremely common and played an important role in developing our understanding of this period and indeed in the advancement of palynology in general. In recent years, focus has drifted away from research into the Hoxnian. With the recognition of the significance of this interglacial and the extensive sequences available for study, there is a powerful opportunity for a fresh look at the Hoxnian.

It is an exciting time to be using pollen to investigate the Hoxnian. In recent years, palynology has been invigorated by fresh theoretical advancements, novel applications of the technique and the development of robust methods to infer past climate regimes. These developments have been directed primarily at the later Pleistocene and the Holocene and quantitative reconstructions also to the last interglacial. Applying them to the Middle Pleistocene represents an exciting opportunity and provides this research with a novel underlying basis. The approach taken here is unique when considering the British record, and rare in regions beyond Britain.

1.2 – Palaeoclimate reconstructions

For much of the 20th century, pollen analysis was widely employed as a tool to provide qualitative palaeoclimate information. This approached proved to be extremely valuable; in fact pollen was a crucial component in the establishment of many of the fundamental trends in palaeoclimate that researchers now recognise as standard (e.g. Lowe and Gray, 1980). On the basis of the vegetation inferred from pollen it is often possible to establish, with a reasonable degree of confidence, broad trends in climate. Many pollen diagrams contain sufficient information to enable shifts between wetter/drier and warmer/cooler to be reliably inferred.

These broad trends have provided and continue to provide extremely valuable information to Quaternary researchers. However there are many crucial questions and hypotheses that can only be investigated with the provision of reliable quantitative data. As a result, the methodologies that have been developed in recent years to quantify the climatic inferences drawn from this proxy are particularly valuable. Terrestrial palaeotemperature and palaeoprecipitation records can now be reliably constructed to provide a richer picture of past climate.

The latest IPCC report (IPCC, 2007), in particular the Palaeoclimate chapter, clearly emphasises the importance of Quaternary science. The IPCC notes that “an examination of how the climate system has responded in the past is useful in assessing how the same climate system might respond to the large anticipated forcing changes in the future” (Jansen *et al.*, 2007). Quantified palaeoclimate data has a hugely valuable role to play in this context. Broad qualitative conclusions, while they can still inform the science, become more important when transformed into absolute values which can compare to the measured and projected trends in temperature and precipitation that are so significant, as well as the climate model output that informs so much of the research in modern climate change science.

There is an additional incentive to quantification and more detailed palaeoclimate reconstructions in this particular instance. The interglacial under investigation is widely believed to be the best analogue for our current interglacial (Berger and Loutre, 2002). Understanding the climate changes of the Hoxnian will increase our understanding of natural climate variability and therefore could potentially inform the global warming debate. MIS 11 can be a gold standard for using palaeodata as a means of shedding light on important contemporary issues. Despite this, its promise has yet to be realised. The period has come under increasing investigation (for example, see Droxler *et al.*, 2003), but there remains a wealth of untapped information, particularly in the terrestrial realm. This project goes some way to filling this highly intriguing gap.

1.3 – Palaeolithic archaeology and palaeoclimate

Detailed palaeoclimate reconstructions offer the chance to provide important context to our understanding of human evolution and Palaeolithic archaeology. There are a diverse range of selective pressures which influenced our biological and cultural evolution, with climate and the environment believed to be highly significant (e.g. Stewart and Stringer, 2012).

The significance of climate in an archaeological sense is well illustrated in a series of papers in van Andel and Davies (2003). Indeed it is increasingly the case that archaeologists are seeking more detailed palaeoenvironmental reconstructions to place hominids into a more fully fleshed palaeolandscape. Carrion *et al.* (2011) provide a strong recent example for the western Palaearctic for the Early and early Middle Pleistocene, up to MIS 12. However precise climatic information is largely absent from this comprehensive review, demonstrating the gap in the literature that the current research is able to begin to fill.

From a British perspective, the recent Ancient Human Occupation of Britain (AHOB) project has been at the forefront of such attempts, combining thorough studies of palaeoenvironment with often pioneering archaeological discoveries. One such example stemming from the AHOB work is the discovery of very early human presence in Britain (Parfitt *et al.*, 2010).

The AHOB work made use of a wide range of palaeoenvironmental proxies and enabled significant behavioural conclusions to be drawn. This thesis aims to further develop and enhance this contribution through the presentation of quantified palaeoclimate data and a modern perspective on the climates faced by Hoxnian hominids. MIS 11 appears to represent an important period in the occupation of northerly regions of Europe. It is only through providing the environmental context for this change in the archaeological record that an accurate understanding of it can be built. The palaeoclimate reconstructions here and subsequent discussion of MIS 11 climate in North West Europe represent an important step in providing this context.

1.4 – Palaeofire reconstruction

The investigation of charcoal in sedimentary records provides a record of past fire events (Patterson *et al*., 1987). Such charcoal is widely available but its study has been relatively neglected, particularly when compared to pollen analysis. Iversen (1941) was amongst the first to appreciate its potential, but it is not until the past few decades that charcoal analysis has become widespread and theoretical issues developed. The flourishing development of this field comes particularly in response to the recognition that fire plays a key role in ecological dynamics, as a significant form of disturbance, influencing the composition, structure and distribution of vegetation (Bond and van Wilgren, 1996).

The understanding of fire as an important ecosystem component is no longer restricted to improving our appreciation of key ecological concepts. It is now vital to gain an appreciation of fire in the context of climate and climate change, as a result of anthropogenic global warming. Fire can be a major threat to human life and property, on a very wide scale, and under a changing climate, fire will be at the forefront of considerations of management of human societies (Parry *et al*., 2007). Efforts are already underway to model fire regimes under different future climate scenarios (e.g. Brown *et al.*, 2004 and Flannigan *et al.*, 2000) and there is evidence that wildfire activity has already altered in response to climate change (Westerling *et al.*, 2006).

In one of the earliest and most important papers looking at fire in the context of changing climate, Overpeck *et al.* (1990) note the importance of palaeodata. By understanding how fire regimes have responded to past changes in climate, Pleistocene researchers can help inform this vital debate. As the Past Global Changes (PAGES) project stress, long temporal records of vegetation disturbance and response are now acknowledged as a crucial element of ecosystem studies, and so the investigation of past fires is a key component of earth systems research (Overpeck *et al.*, 2003).

The importance of palaeofire studies is now clear and they are now common. However, despite this bloom of charcoal studies in recent years, they remain relatively temporally restricted, principally to the Holocene. The Pleistocene also offers rich possibilities for furthering the work already undertaken by palaeofire researchers. For example, the likelihood of non-analogue vegetation communities is greater in the Pleistocene. As a result of the complex migratory patterns, extinctions and other ecological processes that are likely to be a consequence of future warming, there are likely to be non-analogue communities in the 21st century. Therefore some of the most appropriate data for understanding the interactions between fire and ecosystems may not be found in the present or the Holocene, but the Pleistocene.

1.5 – Project aims

In summary, the aims of the project are:

- To provide a quantified temperature reconstruction for the Hoxnian interglacial and to place the period into its wider palaeoclimatic context in North West Europe and beyond.
- To reconstruct a fire history for the Hoxnian interglacial.
- To provide fresh perspective on pollen records for the Hoxnian interglacial, incorporating new theoretical advances.
- To provide new palaeoenvironmental data for archaeological investigations of the lower Palaeolithic.

2 – The Hoxnian and the Middle Pleistocene

This chapter will provide much of the crucial context for this study, covering the British Middle Pleistocene, the sites chosen for investigation and a general overview of Marine Isotope Stage 11.

2.1 - British Middle Pleistocene chronology

There are a considerable number of interglacial deposits, primarily in central and southern England, and a need to place them into a temporal framework. In the absence of geochronological techniques suitable for this, pollen analysis was used as a biostratigraphical tool. The basic premise underlying this approach is that separate interglacials, with differing climates, palaeogeographies and so on, should have differing patterns of vegetation development. These differing patterns would be characteristic of an interglacial and could therefore be used to define it.

Pollen biostratigraphy suggested that three interglacials had occurred in the Middle to Late Pleistocene, The Cromerian (pre-Anglian glaciation), Hoxnian and Ipswichian. This position was articulated in an influential paper by Mitchell *et al*. (1973) and gained credence from the fact that palynologists on the continent also argued for the presence of three interglacials, believed to be equivalent: the Cromerian, Holsteinian and Eemian.

The Hoxnian was originally thought to have a particular sequence of vegetation development, which marked it out on biostratigraphical grounds. As will be discussed below, this now appears to be incorrect, with pollen biostratigraphy conflating two separate interglacials into one. It is important to clarify at this stage that in this thesis “Hoxnian” will refer to a series of sites correlated with MIS 11 and not the formal stratigraphic unit, the Hoxnian.

The Mitchell *et al*. (1973) stratigraphy is now widely rejected, in favour of a more complex scheme that recognises the presence of many more interglacial periods preserved in the British record. This development was ultimately prompted by the construction of oxygen isotope curves and the revelation of multiple interglacial-glacial cycles during (and prior to) the Middle to Late Pleistocene (for example, Shackleton *et al*., 1990). Given that more than three global interglacials occurred during this period, it would be reasonable to expect that they a) would have affected the UK and b) would have left a record. The exact number of interglacials preserved remains a subject of debate, particularly for the pre Anglian (MIS 12) period, but nonetheless it became apparent that the basic three interglacial model would need considerable revision.

The current, post Anglian, stratigraphical consensus has been achieved through the application of biostratigraphical indicators such as mammals, the analysis of long fluvial terrace sequences, the application of amino acid geochronology and radiometric dating techniques. In particular, amino acid dating was instrumental in these developments, with Bowen *et al*. (1989) proposing four post Anglian interglacials, correlating with MIS 11, 9, 7 and 5e. One of the key conclusions from this research was that palynological approaches were conflating two distinct interglacials (MIS 11 and 9) into one.

The amino acid correlations of Bowen *et al.* have been shown to suffer from methodological problems (McCarroll, 2002). Despite this, the work was far-sighted in its attempts to overturn the reigning stratigraphical paradigm and also link local work into the bigger picture of regional and global climate changes. Furthermore, recent developments have rectified flaws in the amino acid approach (Penkman, 2005) and it is now a vital geochronological tool. The conflation of interglacials has also been confirmed by a variety of other indicators, such as mammalian biostratigraphy (Schreve, 2001a) and an analysis of pollen as a dating tool (Thomas, 2001).

The Hoxnian is now believed to correlate with MIS 11, with this scheme solidifying in recent years, particularly as geochronology is applied to a small, but increasing, number of deposits. For example, Grun and Schwarcz (2000) apply U-series and ESR dating to the type Hoxnian deposits at Hoxne and derive an age within MIS 11. The updated Amino

Acid methodology has been providing data in recent years which appears to confirm this (Preece and Penkman, 2005 and Preece *et al.*, 2007).

Most recently, Penkman *et al.* (2011) provided the most comprehensive and robust amino acid dataset for the British Isles yet. This dataset extends possibly as far back as MIS 17 (though this is uncertain) and includes a large selection of sites from the Hoxnian. Samples from both Stratum E and Stratum B at Hoxne were analysed as well as Marks Tey. In these instances an MIS 11 correlation was found, providing some of the strongest evidence yet presented for this correlation.

Preece *et al*. (2007) is a particularly comprehensive geochronological study, at the Beeches Pit site, applying U-series, thermoluminescence (TL), Amino Acid and OSL dating to the deposits and reaching an overall MIS 11 consensus. Scourse *et al*. (1999) also confirm the pattern from this growing body of geochronological work.

It must be noted that not every measure of age is always in exact agreement. Indeed, at Beeches Pit, the U-series, TL and AA are all in agreement, with the OSL dates being an outlier. Such disagreement is not unique to MIS 11 and has been reported for other interglacials (e.g. Green *et al*., 2006); this speaks for the need for caution in interpreting the results from geochronology. Furthermore a small number of authors do offer alternative stratigraphical schemes; Geyh and Muller (2005) present an intriguing critique of the Holsteinian - MIS 11 correlation in continental Europe and co-opt British sites into this differing framework. A major part of their case concerns the interpretation of U-series dates, arguing that the application of different age models can yield alternate ages. Whilst the technical aspects of their work should be met with caution (Preece *et al*., 2007), their thesis is a valuable reminder to proceed in a circumspect fashion and the need to constantly test stratigraphic models.

However, it is clear that Geyh and Muller (2005) have a limited understanding of the British Pleistocene and are guilty of a significant misreading of key literature. Their paper takes a palynological perspective and they look to Thomas's (2001) review of Pleistocene palynology to support their argument that pollen biostratigraphy is sufficiently precise (and accurate) to enable discrimination of closely spaced interglacials. This is despite the fact that Thomas (2001) clearly states that this is not possible. Geyh and Muller (2005) provide the only contemporary challenge to the Hoxnian - MIS 11 correlation and can be rejected (e.g. Scourse, 2007).

Whilst it is important to recognise that correlation is an imperfect science and that new information may bring to light important revisions, as seen with the overturning of the classic Mitchell *et al.* (1973) chronology, based on current knowledge, the Hoxnian - MIS 11 correlation appears extremely robust. The generally good agreement between different age controls at Beeches Pit underscores this and the recent work by Penkman *et al.* (2011) provides some of the most robust evidence yet for this correlation.

2.2 - The Hoxnian interglacial

2.2.1 – General vegetation development

The Hoxnian type site at Hoxne (West, 1956) does not contain a full interglacial sequence and so the picture must be supplemented from other sites, in particular the sequence from the Hoxnian parastratotype at Marks Tey (Turner, 1970). Vegetation development during the Hoxnian, has traditionally been subdivided into four broad pollen zones; Ho I (Late Glacial), Ho II (Early Temperate), Ho III (Late Temperate) and Ho IV (Early Glacial) (Turner and West, 1968). These pollen zones are then subsequently divided into various subzones.

In common with other interglacials, the sequence begins with the development of vegetation following the previous glacial period; boreal trees are present along with herbs and shrubs. Subsequently, mixed oak forest becomes the dominant vegetation type. Following this, there is the expansion of late-immigrating trees and a decline of the mixed oak forest. Finally, boreal forest returns, along with more open communities.

Hoxnian sites often preserve a feature that has become known as the Non Arboreal Pollen Phase. It appears towards the end of the Early Temperate stage, Ho II, and saw a decline in temperate tree taxa and a rise in non-tree taxa. The cause of this event has been much debated and will be discussed at length in this study. Additionally, it has been used as an important stratigraphic marker for the period.

There are a number of other features of this vegetation development that led to the correlation of Hoxnian sites. For example, the timing of arrival and expansion of certain species, such as *Quercus* and *Corylus,* which differ from those seen in a Last Interglacial (Ipswichian) context. The occurrence of *Azolla filiculoides* also indicates separation from the last interglacial as this species became extinct during the late Middle Pleistocene in Europe (Godwin, 1975).

Most Hoxnian sites tend only to consist of part of one or more pollen zones. Only Marks Tey is complete, with Quinton, Nechells, Barford and Athelington all containing substantial portions of the period (Thomas, 2001). Although the vegetation development is generally speaking consistent across Hoxnian sites, there are variations that can be ascribed to local vegetation changes. For example, at certain sites in Hertfordshire, Ho IIIa tends to be rather short (Boreham *et al*., 1999) and at some sites, the NAPP event is absent.

2.2.2 - The current status of Hoxnian palynology and research

Hoxnian palynology is currently not widely employed. Following the main phase of research into this period, the 1950s to 1980s, investigations into the Hoxnian have become generally less common, with a corresponding decline in the degree to which pollen is used to illuminate the palaeoenvironments of this interval. Indeed it is not just the Hoxnian which has become relatively neglected; studies of the British Middle Pleistocene in general are less frequent than they once were.

In recent years a small number of researchers (e.g. Roe, 2001; Roe *et al.*, 2009; Roe and Preece, 2011) have continued to investigate Middle Pleistocene terrestrial sequences in the UK. In these studies, where pollen has been employed it has been done so as a tool for fundamental palaeoenvironmental reconstruction and also to provide a certain degree of biostratigraphical control. The latter remains possible in a limited sense; for example, distinguishing the Hoxnian from pre-Anglian interglacials on the basis of palynology remains a legitimate exercise, if necessary. Researchers therefore still tend to look for the traditional Hoxnian biostratigraphic indicators. The work of Roe (see references above) has identified sites with a Hoxnian pollen signature but additional stratigraphic data has indicated that these localities belong to MIS 9. In particular, see Roe *et al.* (2009).

Since the work of West (1956) and Turner (1970) pollen analysis of Hoxnian deposits generally forms a subsection of a large paper describing and interpreting a particular set of sediments. Bridgland *et al*. (1999) provides a useful example of this; a pollen diagram is constructed and the authors infer an interglacial mixed oak woodland. Purported biostratigraphic indicators are noted and contribute to a discussion on the age of the deposit. A small number of papers are still published in which pollen is the main focus of investigation; often from sediments obtained in coring operations (e.g. Boreham *et al*., 1999). Nevertheless, research in recent years has not taken advantage of any of the theoretical developments in palynology that have occurred during this time.

There are signs, however, that research into the Hoxnian and the British Middle Pleistocene may have become reinvigorated, with a series of innovative new projects combining new data with syntheses of existing literature. One major recent investigation was conducted at Beeches Pit (Preece *et al.*, 2006; Preece *et al.*, 2007). This multiproxy study provided firm evidence of an MIS 11 age and a series of highly valuable archaeological insights, in particular suggestions of human fire use and links between palaeoenvironment and human behaviour.

Ashton *et al.* (2008) undertook new coring at Hoxne and presented additional geochronological data via amino acid stratigraphy. On the basis of this they propose correlations with other prominent records from this period and a specific correlation with the start of MIS11. This study represents one of the first attempts to place the Hoxnian into its detailed wider content, beyond simply arguing which Marine Isotope Stage it belongs to. Further details on this project will be provided in the discussion of Hoxne below and it forms an important component of the discussion section of this thesis.

Finally, Candy (2009) provided data from carbonate deposits to reconstruct broad temperature regimes, concluding that the Hoxnian (and by extension MIS 11) did not experience particularly unusually warm climate conditions in comparison to other Middle Pleistocene interglacials and the Holocene. Building on this work, Candy *et al.* (2010) undertook a synthesis of available proxy data and concluded that British terrestrial records for this period do not show a distinct transition in temperature regime between MIS 13 and MIS 11 as has been proposed based on a number of important global records. This could suggest a disconnect between climate forcing regimes in different regions and at different scales, an important finding that illustrates the valuable role that research into the Hoxnian can play.

It is these efforts to link the British Middle Pleistocene into the wider earth system that this research seeks to build upon.

2.2.3 - Hoxne

Hoxne is one of the most important Palaeolithic sites in the world as well as a valuable palaeoenvironmental archive. There is a long history of research at Hoxne, beginning with the discovery in the 1800s of stone tools by the antiquary, John Frere (Frere, 1800). Frere described the artefacts, now known to represent Lower Palaeolithic handaxes, as “weapons of war”, with local workers at the site referring to them as “fighting stones” (Prestwich, 1860). These findings prompted Frere to remark of a “very remote period indeed, even beyond that of the present world.” This was one of the earliest insights into the great age of humanity and our origins within deep time. It is therefore one of the most significant findings in scientific history and helped pave the way for the work of Lyell and Darwin. This was only the start of research at Hoxne, with a number of major programs of fieldwork having been undertaken since. A summary of the various stratigraphic interpretations of the site can be found in Figure 2.

There was periodic work undertaken in the mid 19th century, in particular by Joseph Prestwich who dug several trenches (Prestwich, 1860). He noted the presence of *Valvata* and *Bithynia* shells, in addition to large quantities of “vegetable matter” and from this concluded that the site contained a freshwater deposit, likely representing a slow stream or small marshy lake or mere. These deposits were seen to overlie ‘boulder clay’ and underlie the artefact bearing deposits. Prestwich (1860) provides the first example of palaeobotany at the site, with well-preserved wood from *Quercus*, *Taxus* and *Abies* being reported. Seeds were also present, but no description of them made. Prestwich (1860) also attempts a vague correlation, describing deposits at Mundesley, Copford, Lexden and others in the south of England as probably the same age. All were “formed before the country had assumed exactly its present form of surface, - before all its variety of hill and dale had been fashioned to their present shape.”

The first detailed investigation of the site is reported in Evans *et al*. (1896), which is largely based on work undertaken at the end of the 19th century by Clement Reid. The stratigraphy outlined by Evans *et al*. (1896) is ultimately in good agreement with the most recent interpretation of the site. On top of the ‘boulder clay’, they were able to recognise five beds; E at the base, to A. Bed A was found to contain the archaeology uncovered in these excavations, as well as fossils, including plant remains, molluscs and mammal bones. The authors were unable to use this assemblage to reach any climatic conclusions. Bed B was a “fine gravel” that seems to have contained little of interest at this time. However, one flake was observed and this was believed to be the horizon in which Frere discovered his artefacts.

Bed C, a deposit consisting of carbonaceous loam, sand and small clay pebbles, contained abundant floral remains. Arctic willow and arctic birch were commonly found and the authors concluded that the climate would have been similar to the “cold treeless regions of North America and Siberia.” Trees, with the possible exception of *Alnus*, were likely absent. A particularly noteworthy feature about Bed C is the possible evidence for reworking. Larger wood fragments were observed but were abraded, leading Evans. *et al.* (1896) to argue that they were derived from the underlying beds. They note that their arguments were primarily based on the quality of preservation and whilst they report that preservation of the arctic species was not always good, this material consists of leaves, moss and delicate seeds and they viewed these as too fragile to be derived. Intriguingly, the full floral list contains several plants that the authors believed unlikely to have lived alongside the arctic species, but did not appear to have been reworked. Evans *et al*. (1896) acknowledged that these could be problematic when reconstructing climate conditions and excluding them could represent circularity. It is therefore clear that care is required when evaluating the possible evidence for reworking.

The contact between Bed C and the underlying Bed D is abrupt, although Evans *et al*. (1896) note that this is somewhat masked by the presence of derived material from D, penetrating into C. The abundance of *Alnus* wood in the deposit, led to the conclusion that Bed D represented an alder-carr. Climatic conditions were believed to be temperate. Finally, Bed E was a green carbonaceous clay, often rather hard and consequently Reid found it difficult to extract fossil material. However, he was also able to characterise this deposit as temperate, with similar flora to Bed D.

The overall sequence of events outlined by Evans *et al.* (1896) was as follows. A river channel was cut into the ‘boulder clay’, which was elevated above present. Subsidence followed, turning the channel into a shallow freshwater lake, in which Bed E was deposited under a temperate climate. This lake became infilled, surrounded by a dense cover of alder, depositing Bed D. Lacustrine conditions re-appeared as a result of further subsidence or irregular infilling and Bed C was deposited, under cooler climate conditions. Finally Beds B and A were deposited by “floods”, although confusingly Evans *et al.* (1896) state that only parts of these deposits are actually fluvial.

West (1956) provided the next major analysis of the Hoxne site, providing a slightly altered stratigraphy as well as the first palynological investigation. The paper is lengthy and so a brief discussion must suffice here. West renamed Evans *et al.*'s (1896) Beds as Strata; his Strata E, D, C and B correspond with their Beds. In addition, he added a Stratum F and additional complexity in Bed A. West's comprehensive work also established the extent of this former lake basin, being roughly oval shaped and around 575 m along the long axis, at its maximum extent.

Stratum F consists of clay mud towards the centre of the basin and in ascending stratigraphic order, "drift mud, marl and clay-mud" at the edges. This stratigraphic change led West to conclude that Stratum F recorded rising lake levels. Distinguishing Stratum F was made clearer by the pollen analysis, which revealed it to be a cold climate, late-glacial deposit.

Generally speaking, the sedimentological interpretation of stratum E and D is similar to that of previous workers. West did reveal additional details; for example, he argues that the change in colour from Stratum F to Stratum E is probably primarily due to increasing organic content as climate warmed at the onset of the interglacial. He also provides greater clarity on the precise nature of the deposits. The overall lack of sorting, strongly suggests lacustrine conditions. However, he is able to point to evidence for a limited flow of water through the lake.

The sedimentological interpretation of Stratum C is also similar to that of Evans *et al.* (1896), albeit more fleshed out. West (1956) outlines evidence for changes in lake level, with oscillations between relatively high, though not as high as stratum E, and low. West notes the presence of solifluction deposits within Stratum C, at times of lower water level, from the occurrence of chalk pebbles and flints. He also argues that solifluction, in addition to erosion and reworking, removed stratum D and some of Stratum E from under Stratum C in the marginal parts of the lake during times of low lake level. This process resulted in the deposition of reworked clay, mud and pebbles from Stratum E and possibly layers of "drift mud" from Stratum B, within the main muddy stratified silt of the stratum.

Finally, West (1956) described the stratified clay, sand and gravel of Stratum B as being derived from solifluction from the sides of the basin, with some sorting in water, under periglacial conditions. Erosion and destruction of the lake basin then followed and the glacial deposits of Stratum A capped the sequence.

West's research also provided the first comprehensive palynological analysis of the site and indeed the period. More will be said, at various points in the thesis, about the palynology of the site. However, briefly, West's interpretation is that Stratum F was deposited during the Late Glacial, Ho I, and was characterised by open *Hippophaë* scrub. Stratum E was deposited during the Early Temperate Stage, Ho II, with four subzones. Ho IIa saw the formation of closed forest, dominated by birch, with the arrival of thermophilous trees. During Ho IIb, mixed-oak forest came to dominate the area and continued in Ho IIc. Lime and alder rose during this stage, which West (1956) interpreted as representing the thermal optimum of the period.

Ho IId again saw mixed oak forest, but with changes in composition such as the replacement of lime by elm. The Non Arboreal Pollen phase, a major period of deforestation, with high levels of non-tree pollen and the decline of elm, oak and hazel (with some replacement by birch and pine), occurred during Ho IId. Stratum D was deposited during the Late Temperate stage, Ho III, during which the mixed oak woodland declined, being replaced by pine and spruce. West (1956) interpreted Ho IId and Ho III as the beginning and continuation, respectively, of a climatic deterioration. Finally, Stratum C, was deposited under a cold climate regime, with tundra vegetation and some distant or scattered trees.

Following West (1956) the next major research carried out at the site was carried out by the University of Chicago, as part of a major archaeological excavation in the 1970s. In addition to the archaeology, new pollen data was collected, along with faunal remains and coleoptera. A geochronological investigation was performed and a new stratigraphic interpretation of the site developed. The data were finally collated in a large volume edited by Singer *et al*. (1993).

In some respects, this research can be regarded as being like the curate's egg. The archaeological excavations revealed valuable new data. However, in many respects the work as a whole is glossed over, particularly from a palynological and stratigraphic perspective, in favour of West (1956). Whereas West (1956) had built on previous interpretations, Gladfelter (1993) adopted a significantly different framework for much of the deposit. This new interpretation was not entirely wrong, but it did have the impact of introducing a degree of confusion into proceedings.

For the lacustrine portion of the sequence, Gladfelter (1993) still referred to the units as Stratum F, Stratum E and Stratum D. However, above the Stratum D unconformity, he avoided the use of the Stratum C, B and A divisions, in favour of a scheme of greater complexity, based on a numbering system, 1-9. In some respects, this was necessary as there are reasonable stratigraphic subdivisions that can be added to West's (1956) framework. However, the change to a numbering system was unhelpful.

Gladfelter (1993) interpreted Bed's 1 and 2 as representing fluctuating stream discharge into a small pond. These fluvial sediments buried artefacts from the Lower Industry. Bed 3 was deposited during the very final stages of lacustrine conditions. These sediments were probably truncated by a hiatus in sedimentation and are overlain by Bed 4, which includes Stratum C, and is interpreted as alluviation by a channel of substantial size, flowing east. This was deposited under a cool, although not cold, climate in the interpretation of Singer *et al*. (1993). In this work, Bed 4 is not directly equivalent to Stratum C; rather it is a lateral accretion deposit, containing channel lag deposits and Stratum C.

Beds 5 and 6 represent a large river system, with a laterally shifting channel. The Upper Industry was deposited during this time, a period interpreted as relatively temperate. There is then an unconformity, during which the floodplain stabilised and, probably, soil developed. Beds 7 and 8 are the result of alluviation during cold conditions. There is a final unconformity, in which the alluvial beds were truncated during a major period of incision. Finally, Bed 9 is weathered chalky boulder clay.

The stratigraphic context was finally clarified by Ashton *et al*. (2008) during the most recent excavations in the early part of the 21st century. Ashton *et al*. (2008) revert back to the basic scheme of West (1956), with appropriate subdivisions based on the subsequent research. Moreover, they clarify the Bed 4 – Stratum C relationship. This work exposed all the Strata at Hoxne, from A to G. This work is the first to attempt to place Hoxne into a modern research framework. Although Singer *et al.* (1993) did correlate with the marine record, Ashton *et al*. (2008) place the site into a much wider MIS 11 context.

The interpretation of the lower strata remains much the same as in previous research. Stratum G represents the chalky till of the Lowestoft Formation, widely correlated with MIS 12 (Bowen, 1999). Stratum F sees the warming of climate following the glacial period. Stratum E is the main lake deposits, indicative of temperate conditions. Stratum D suggests the drying of the lake basin under warm climate conditions.

Ashton *et al*. (2008), largely on the basis of beetle remains, argue that Stratum C was deposited under cold climate conditions. It represents a lacustrine environment. They also argue for a substantial hiatus between Stratum D and the deposition of Stratum C. Strata B1 and B2 are both fluvial deposits, with B1 being cut into B2. There is a rich vertebrate fauna from these deposits and the Lower Industry is associated with B1. The deposits of Stratum B2 interdigitate with the top of Stratum C, indicating increased channel activity in the basin and the general establishment of a fluvial environment. This appears, on the basis of the faunal remains, to have occurred under warmer climatic conditions, although not as temperate as during the deposition of the main body of lake deposits.

Stratum A2(iii) is a series of alluvial silts and may have been deposited under similar climatic conditions as B2, but the vertebrate remains are somewhat sparse and inconclusive. A2(ii), A2(i) and A1 are sands and gravels, with sedimentary structures indicating deposition in a cold climate regime.

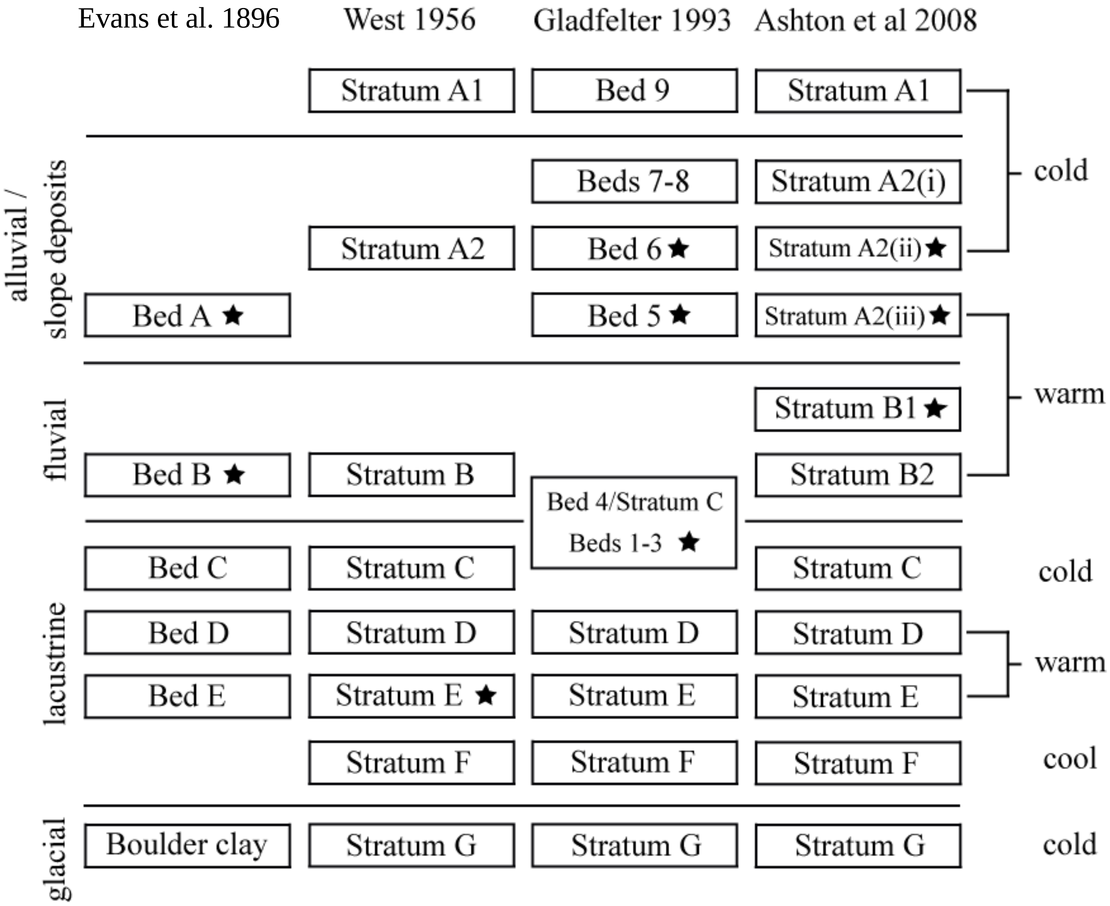


Fig 2: summary of stratigraphic interpretations of Hoxne, with an inferred climatic guide. Stars show where archaeology was believed to be found. Slightly adapted from Ashton *et al*. (2008)

In addition to the clarification of the site stratigraphy, Ashton *et al.*'s. (2008) major contribution concerns the correlation of the site with other deposits. Amino Acid dating places the site within MIS 11, consistent with the other body of geochronological data for the site and for the Hoxnian. Furthermore, there are hints of structure within the data; measurements taken from Stratum B2 indicate an age towards the end of MIS 11 (although an MIS 9 date cannot be ruled out entirely). Ashton *et al*. (2008) make the provocative argument that the strata below the Stratum D/Stratum C unconformity belong to an early substage of MIS 11, whereas Stratum C belongs to a separate cold substage and Stratum B a further later, warmer substage. Based on the SPECMAP chronology, these correlations could be, respectively, 11c, 11b and 11a (Ashton *et al*., 2008).

Ashton *et al.* (2008) note that their interpretation has implications for the correlation of other sites within the British Hoxnian. For example, rather than representing two substages of MIS 11 as suggested by Schreve (2001b), the gravels at Swanscombe likely only belong to the first substage, correlating with the strata below the major Hoxne unconformity. Such a controversy demonstrates that whilst the general attribution of Hoxnian sites to MIS 11 is well established, there remains a considerable amount of correlative work to be done within the period. This is an exciting and necessary challenge and Ashton *et al*. (2008) is a particularly significant step in this process. Not only do they place Hoxne in the context of the Marine Isotope Record, they also seek to link it to various other European MIS 11 sites and other offshore archives.

Ashton *et al*. (2008) are not the first authors to attempt correlations with continental Europe during the Pleistocene, but this modern updating is particularly welcome. It is now important to move beyond treating British sequences in isolation; they gain particular relevance when placed in a wider context. Terrestrial records for MIS 11 are not exactly rare, but nor are they hugely commonplace. Moreover, syntheses of the data are scarce and the kind of work performed by Ashton *et al*. (2008) not the norm. Britain has a reasonably rich record and can therefore play an important role in building up a more substantive picture of terrestrial environmental change during MIS 11. An additional discussion of these issues, as they relate to the findings of this research, will follow later in the thesis.

2.2.4 - Other Hoxnian sites

There are around 35 other sites with a “Hoxnian” pollen signature (Thomas, 2001), although in many cases it is difficult to reliably correlate them with MIS 11. Many of the sequences represent short fragments of the interglacial, where workers have uncovered a brief pollen sequence with an apparent affinity with the “Hoxnian”. The site at Grays (Gibbard, 1994) is one such example. These fragmentary records are essentially impossible to assign an age to on the basis of the pollen alone. Luckily, in a number of cases, they can be tied in with the Bridgland’s Thames Terrace lithostratigraphy (Bridgland, 2000) or the mammalian biostratigraphy established by Schreve (2001a). Clacton (Bridgland *et al.*, 1999) is one such example of a positive correlation. In other cases, such alternative stratigraphic tools can help to persuasively remove sites from the Hoxnian-MIS 11 equation; Cudmore Grove (Roe *et al.*, 2009) is an example. Roe *et al.* (2009) marshal a range of evidence to once again demonstrate the pollen based conflation of separate interglacials.

Lacustrine basins tend to provide the more complete records. Hoxne being one example, and Marks Tey (Turner, 1970) along with other sites such as Quinton (Horton, 1989) and Athelington (Coxon, 1985). These sequences developed in kettle holes and basins formed by melting ice from the Anglian glaciation. The Anglian glaciation is widely believed to correlate with MIS 12 (Bowen, 1999), although there are authors who have suggested that the Anglian tills may contain a MIS 10 component (Scourse *et al.*, 1999).

If the MIS 12 correlation of the Anglian is indeed accurate, then this gives a degree of confidence that these lacustrine sequences do indeed belong in MIS 11. In the case of Hoxne, this is not a particularly crucial element of the chronological evidence, but for sites such as Athelington, without geochronology, it remains highly important. Athelington (Coxon, 1985) is one of the more complete Hoxnian sequences, covering the second half of the interglacial as well as a portion of Ho II. Encouragingly, recent work at Athelington has uncovered biostratigraphic evidence that corroborates a Hoxnian age; the ostracod species *Ilyocypris quinculminata* is present in the deposit and is found no later than the Hoxnian in the British Isles (David Horne, pers. comm.).

We will now move on to consider the specific Hoxnian sites used in this thesis. Figure 3 presents a location map, which demonstrates a general focus upon East Anglia, but sites in the Midlands are also included. The reasons for the choice of sites will be covered in Chapter 5.

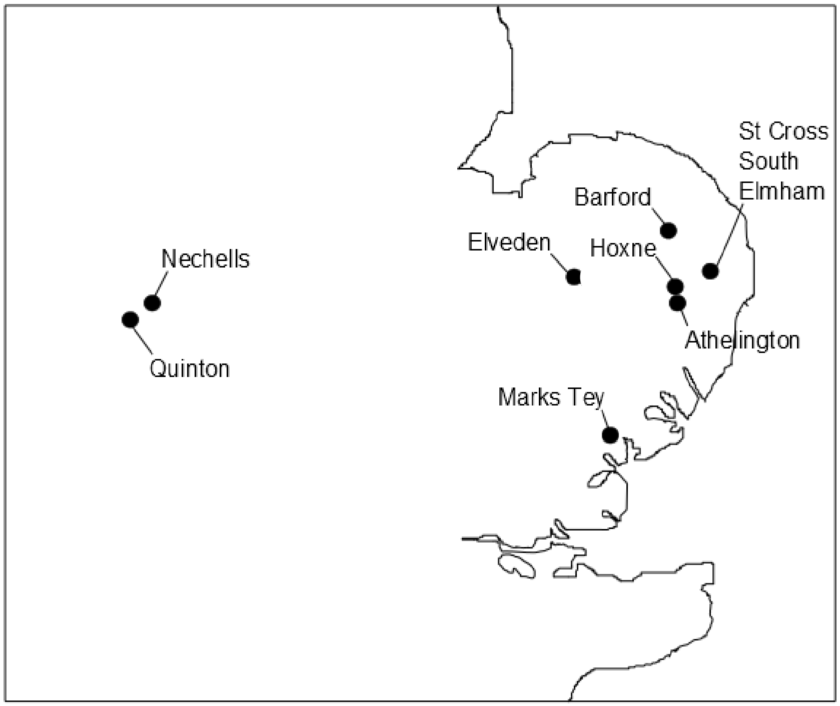


Fig 3: Map showing the location of sites used in this thesis.

Athelington

Athelington was investigated by Coxon (1985) and consists of interglacial lake sediments overlying Lowestoft Till. These deposits appear to occupy a basin consisting of shallow margins and then a rapid deepening. The interglacial sequence covered a significant portion of the Hoxnian, from Ho II to Ho IV.

Barford

Barford is located in central Norfolk and was described by Phillips (1976). Occupying a deep channel in the local chalk, Barford represents a lake deposit overlying boulder clay. Subsequent to the deposition of the interglacial deposits, a river eroded much of this material, leaving deposits on either side of the valley. The interglacial deposits are approximately 9 metres deep and are described as an organic clay mud.

The broad stratigraphy consists of boulder clay, overlain by interglacial organic muds, then a soft sandy clay with flint and chalk fragments interpreted as a solifluction deposit. Finally, the sequence is topped by gravel.

From a palynological perspective, the base of the deposit sees late glacial conditions, followed by Ho I. There is then a hiatus and zones Ho IIc to Ho IIIb. Only these latter zones are used in this thesis.

Elveden

Elveden is a site of considerable importance to Palaeolithic archaeology and represents a lake sequence overlying Anglian till. The pollen record is relatively short, covering Ho I to Ho IIa. This site is principally included to be able to provide a direct relation between archaeology and palaeoclimate.

Marks Tey

Marks Tey is one of the most significant British Pleistocene sites and the key record for the Hoxnian. The record from Marks Tey was presented by Turner (1970) and consists of a lake basin formed during the preceding glaciation. The basin is a narrow trough and during the subsequent course of infilling presents of record of the entire Hoxnian interglacial and some of the subsequent cold period. This was the first sequence to be so extensive and remains one of the few such examples in Britain during the Pleistocene. Even elsewhere in Northern Europe such coverage is relatively uncommon.

The palynological record constructed at Marks Tey now forms the basis for pollen zonation and the stratigraphic framework of the Hoxnian. There is also the possibility to use Marks Tey to provide some degree of chronological control during the Hoxnian. The sequence is finely laminated and Turner (1970) suggested that these represent varves. From this he tentatively suggested a length of the interglacial of between 30,000 and 50,000 years. However, Turner (1970) recognised that a significant amount of work remained to be undertaken on this putative varve chronology.

Nechells

Nechells is one of two sites located in the Midlands presented in this study. It was investigated by Kelly (1964) and sees, at the base of the sequence, a series of fluvioglacial sediments overlain by late glacial lake sediments predominantly consisting of laminated silts and clays. There is some suggestion that some of these laminae may be varved although this is not developed in any great depth.

The late glacial lake appears to have shrunk in size somewhat by the time of the interglacial lake deposits. Kelly (1964) suggests that the interglacial lake filled a hollow with dimensions of, at a minimum, 335m by 189 m. These deposits predominantly consist of silts and clays with some fine sand. The lake appears to have been replaced by marshy conditions. Finally the sequences is topped by further evidence of glacial activity.

The palynological record from Nechells is quite extensive. Kelly (1964) only provided local pollen zones and did not attempt to directly associate them with Hoxnian pollen zones, presumably because the full framework was not available until Turner (1970). The sequence covers more of the interglacial than is found at Hoxne, further explaining the lack of direct correlation with Hoxne (although Kelly (1964) did relate the pollen signal to sites of similar age). The interglacial sequence appears to cover a small portion of Ho I and extends into Ho IV.

Quinton

Quinton is the second of the sites located in the Midlands and represents a lacustrine sequence in a v-shaped hollow. The site was first investigated by Horton (1974) and also described in Horton (1989). The lake deposits largely consist of silts and clays with occasional peat and woody layers.

The pollen record from Quinton is one of the most extensive in the Hoxnian, indeed the

British Pleistocene in general. It covers both the late glacial of the preceding stage, the entirety of the Hoxnian and then some portion of the subsequent cold stage. In addition to the palynological analyses undertaken, Coope and Kenward (2007) present coleopteran data suggesting a potentially relatively brief period of extremely cold temperatures towards the end of the interglacial.

St Cross South Elmham

St Cross is a further lacustrine sequence in East Anglia, covering a significant portion of the early part of the interglacial.

2.3 – Marine Isotope Stage 11

2.3.1. – A general overview

Marine Isotope Stage 11 is one of the most intriguing interglacials of the Pleistocene, with recent work focusing on a number of key aspects from the significance of sea level records (Olsen and Hearty, 2009) to providing much needed terrestrial isotope records for the period (e.g. Mangili *et al.*, 2007). This research is interesting in its own right, however the fact that MIS 11 is considered a good analogue for the Holocene (Loutre, 2003) provides the context that elevates MIS 11 studies to a greater level of significance.

The SPECMAP timescale defines the stage boundaries of MIS 11 from 423 to 362 kyr BP (Imbrie *et al*., 1984). Ice core records have been slower to provide data for the Middle Pleistocene, with the Vostok core extending back to 420 kyr (Petit *et al.*, 1999) but containing chronological uncertainties at depth. However, the EPICA project recently extended the temporal scope of ice core archives, stretching back eight glacial cycles (EPICA community members, 2004).

From these various archives, MIS 11 emerges as a particularly long interglacial. The peak of interglacial warm conditions generally appears to have been maintained for around

30,000 years. This conclusion derives from a number of different studies, for example Oppo *et al.*, (1998), McManus *et al.* (2003), Raynaud *et al.* (2005) and Jouzel *et al.* (2007).

There does appear to be some slight degree of confusion surrounding terminology. For example, Dickson *et al.* (2010) cite various evidence by way of summary for a 30 kyr peak interglacial period, amongst them de Abreu *et al.* (2005). However, in this paper, peak conditions actually occur for 18 kyr, with "mild" conditions stretching for 27 kyr. So "peak interglacial" may include a range of different conditions over that 30 kyr period.

Dickson *et al.* (2010) in fact go on to make this point, noting that MIS 11 does appear to be an unusually long interglacial, but the exact length is partially dependent on the proxy being used. In their study, the very warmest interval lasted around 7000 years between 411 and 404 kyr BP. So, "peak interglacial" may not always mean the same thing and there may have been differing conditions during the main warm period. Nevertheless, this main warm period had a long duration.

The EPICA data underlines the significance of MIS 11. The last 500 kyr has been dominated by 100 kyr cyclicity, the period before 1 myr BP by 41 kyr cyclicity and the period in between a transitional phase between the two (EPICA community members, 2004). The transition towards the 100 kyr cycle, the so called Mid Pleistocene Revolution at around 900 kyr BP, was followed by a further distinctive climate event, the Mid-Brunhes Event (MBE) that took place around 430 kyr BP. This marks the transition between MIS 12 and MIS 11 (Termination 5) (EPICA community members, 2004) and appears to be present in a number of important global records such as EPICA (Luthi *et al.*, 2008) and the marine oxygen isotope record (Lisecki and Raymo, 2005).

It is from the MBE onwards that very pronounced oscillations between glacial and interglacial climates occur. In further work on the EPICA Dome C core, Jouzel *et al.* (2007) argue that peak temperatures in the warm interglacials (MIS 5.5, 7.5, 9.3, and 11.3) post the MBE were 2° to 4.5°C higher than the last millennium. In contrast, MIS 13, 15.1, 15.5 and 17 saw maximum temperatures 1° to 1.5°C colder, comparable to interstadials 7.1

and 7.3.

A recent synthesis of 37 ice, marine and terrestrial records by Lang and Wolff (2011) appears to confirm the basic MBE observation. They state that strong interglacials only occur during the last 450 ka (although weak ones, such as MIS 7, still happen) and strong glacials largely occur during this period, although MIS 16 is strong. Generally speaking a strong interglacial will follow a strong glacial, leading Lang and Wolff (2011) to make an important inference; that the strength of an interglacial is in large part determined by the strength of the preceding glacial and that as a consequence interglacial strength may not necessarily be particularly closely related to the immediate astronomical forcing. Interglacials are in some way influenced by a "memory" of the previous period and, although the underlying mechanism behind this remains unknown, Lang and Wolff (2011) point to the work of Parrenin and Paillard (2003) as a possible explanation, wherein interactions between ice volume and astronomical forcing control deglaciation. The implications for deglaciation are significant and this will be discussed later in this thesis.

As a consequence of being the first interglacial under the post MBE regime MIS 11 is described by the EPICA Community Members (2004) as "a key interglacial, both as viewed from the atmosphere in the EDC record and from the ocean in the δ^{18}O marine records." It is worth noting, however, this pre and post MBE contrast is not perfectly clear: Jouzel *et al*. (2007) observe during the most recent interglacials that the peak warmth can be found earlier, in contrast to MIS 17 to MIS 11 when maximum temperatures tended to occur towards the end of the warm period. This highlights the fact that a simplistic interpretation of the MBE may be inappropriate, a theme that will be discussed further in the review of MIS 11 terrestrial records below.

In terms of the general palaeoenvironment of the period, a common debate concerns how exceptional MIS 11 was when compared to other interglacial periods. As noted, Jouzel *et al*. (2007) reconstruct a relatively warm period, a position corroborated by a number of archives such as Lake Baikal (Prokopenko *et al*., 2001). In contrast, Hodell *et al*. (2000) reconstruct sea surface temperature in the south Atlantic and suggest that conditions were not particularly unusual. Of course, these varied results are not necessarily contradictory; the divergences may relate to local factors or to the differing responses in separate parts of the climate system. Nonetheless it illustrates the need for further research to build a consensus picture of the period.

Nowhere are diverging opinions better illustrated than over sea level; here there certainly are contradictory data. Marine isotopic data suggests that sea level during MIS 11 may be similar to today or possibly slightly higher, comparable to MIS 5e, at around +4-6 m (ven Hengstum *et al*., 2009). In contrast, an array of geologic data suggests substantially higher sea levels, at around +21 m (ven Hengstum *et al*., 2009). This was initially prompted by discoveries in Bermuda and the Bahamas (Hearty *et al.*, 1999) and there are ongoing efforts to reconcile the geologic data with the isotopic data. One possible resolution is that in places, the extreme highstand actually represents a tsunami deposit (McMurty *et al*., 2007) and other geologic interpretations suggest no highstand during this period, rather it occurred during MIS 9 (McMurty *et al*., 2010). But many workers stand by the geological data (ven Hengstum *et al*., 2009).

Recently, Bowen (2010) undertook a synthesis of available data and applied a correction factor to separate uplift from actual sea level changes. On the basis of this approach, Bowen concluded that sea level during MIS 11 was not substantially above present day levels, certainly not close to the 20+ m that have previously been suggested. This in turn implies that there is no need to invoke very high levels of melting of the Antarctic and Greenland Ice Sheets in order to account for very high sea level following the MIS 12 lowstand (around 140 m below present) (Bowen, 2010).

An important recent perspective on MIS 11 sea level was provided by Rohling *et al.* (2010) who, based on a continuous sea level history from the Red Sea stretching from MIS 13 to the Holocene, also suggested that there was no significant difference between the MIS 11 highstand and that of the Holocene. Moreover, Rohling *et al.* (2010) state that this record is of sufficiently high resolution that if any major short term excursions in sea level did occur, then they would be detected.

However, although recent papers appear to have been pointing towards a consensus in which sea levels were not exceptional and evidence to that effect can be explained by local geological peculiarities, this possible conclusion has been strongly challenged. Raymo and Mitrovica (2012) attempt to account for the high sea level observations recorded in Bermuda and the Bahamas by applying a subsidence correction associated with an unusually long interglacial. From this they revise the Bermuda and Bahaman levels down by 10 m, ultimately concluding that eustatic sea level was 6-13 m above present during the second half of MIS 11. Moreover, they argue that Bowen's (2010) data should actually be interpreted as implying a peak sea level 6-9 m above present. Their final and most important conclusion is that the prolonged length of warm conditions during MIS 11 led to the collapse of the Greenland and West Antarctic Ice Sheets.

Support for what is effectively an intermediate sea level, between the extremely high levels suggested by some geological interpretations and the similar to present inferred elsewhere, has recently come from Muhs *et al.* (2012). They provide data from Curacao in the Leeward Antilles Islands and reconstruct a probably +8.3 - +10 m sea level during MIS 11, although geochronological uncertainty warrants caution regarding this conclusion. Nevertheless, there is increasing evidence for somewhat higher sea levels during this interglacial, although a resolution with the Rohling *et al.* (2010) data is required.

2.3.2 – MIS 11 as an analogue for the present

The use of MIS 11 as an analogue for the present interglacial has become widely recognised and accepted. This position has been most regularly proposed and described in the work of Marie Loutre and Andre Berger. This review will first describe the basis for the proposed analogue.

Insolation changes at the top of the atmosphere can be calculated based on the orbital parameters of eccentricity, obliquity and precession (Berger, 1978). With the exception of high latitudes in winter, insolation is strongly influenced by precession. The precession parameter is modulated by eccentricity. If eccentricity is small, the amplitude of variation of precession and therefore insolation, is also small (Loutre, 2003). MIS 11 had very low values of eccentricity and hence relatively small variations in insolation. By way of illustration, over the duration of MIS 11, as defined by SPECMAP, the amplitude of insolation change at 65ºN in June is ~60 W m^{-2}. In contrast, during MIS 5, it is ~107 W m^{-2} (Loutre, 2003).

Insolation, from around 5 kyr BP, projected into the future, is characterised by its low amplitude of variation (Loutre and Berger, 2003). For example, between the present and 50 kyr in the future, the amplitude of long term June variations is a mere ~30 W m^{-2} and, taking a longer perspective, only ~65 W m^{-2} between now and 130 kyr in the future (Loutre, 2003). This characteristically small amplitude of the present and future makes MIS 11 provide the basis for constructing the MIS 11 – MIS 1 analogue.

Loutre and Berger (2000) used the insolation analogue to predict how long the present interglacial may last. Using a two dimensional climate model, forced with predicted insolation values and a range of CO_2 concentrations, they concluded that the earth is likely to experience a particularly prolonged warm period. Simulations with MIS 11 CO_2 concentrations were consistent with this. The interglacial will likely last for around 50 kyr from the present, with a glacial maximum around 100 kyr from now. It was only with low CO_2 values, that the model could generate an early entry into glaciation. Loutre (2003) summarises a series of modelling experiments by this group by noting the importance of the CO_2 – insolation phase relationship. Individually, neither can force early glaciation, only when both are in a downward phase that this occurs. Of course, modern CO_2 concentrations are far above "natural" interglacial values, further decreasing the possibility of an early entry into glaciation (Berger and Loutre, 2002).

In terms of insolation, this "behaviour" is rare over the past 3 million years. MIS 5 was once thought of as an appropriate comparison (e.g. Kukla *et al.*, 1997) but the amplitude of change is too great. There are other possible analogues that could be chosen; Berger and Loutre (2002) found five such examples and pointed out that there is a closer match between 1.56 and 1.50 myr BP.

Recent work has further developed the possible complicating factors associated with this now commonly cited argument. A number of recent papers have pointed to MIS 19 as actually representing the most appropriate analogue. Loutre and Berger (2000) noted the closer correspondence between insolation values in mid-June, but this has perhaps not been particularly widely appreciated until recently.

Further elaborating on this, Tzedakis (2010) observes that there is considerable similarity in the phasing between obliquity and precession during MIS 19 and MIS 1, in contrast to the MIS 11 – MIS 1. However, Pol *et al.* (2010) perform an alignment using EPICA data and report that the phasing is not precisely analogous, with a greater lag between obliquity and precession in the Holocene compared to MIS 19. In addition, there are also differences in the timing of the eccentricity maximum and the actual value of obliquity. Nevertheless Pol *et al.*, 2010) argue that it is a closer match, a position supported by Yin and Berger (2012).

Despite this issue, a general consensus appears to have developed that making comparisons between the present interglacial and MIS 11 is valid and necessary. Moreover, it is practical; there are many more MIS 11 records than there are MIS 19 and those that exist for this latter time period often have a number of associated problems. For example, sub millennial variability in the EPICA during MIS 19 has been erased due to strong isotopic diffusion processes in this part of the core (Pol *et al.*, 2010).

Nevertheless, the discussion above does stress the need for caution in making overly simplistic analogies. As Tzedakis (2010) points out, the choice of MIS 19 or MIS 11 has a not insignificant impact on the projected duration of the current interglacial. Moreover, even in making the MIS 11 analogue, there are a number of complicating factors. In particular, it is not necessarily immediately clear at which point you align the two records. Because MIS 11 was a particularly long interglacial; are there specific periods within this that are the most appropriate for drawing analogies? Indeed, Dickson *et al*. (2009) argue that the unusual length of MIS 11 makes the search for the best analogue difficult.

This issue is relevant when seeking to place the results here in their appropriate context and will be further explored in Chapter 12. However, in brief, the alignment between the two periods can be undertaken on the basis of precession (Loutre and Berger, 2000) or on the basis of obliquity (EPICA Community Members, 2004). Which one you choose has important implications, including for the results of this study.

2.3.3 – Sub-Milankovitch climate changes during MIS 11

Establishing palaeoclimate records from deep ice cores to supplement those obtained from the ocean has provided a valuable perspective on long term climate change. However, despite the considerable depth of time involved, efforts have also been underway to investigate higher frequency climate events. Given the ongoing concern surrounding global warming, understanding rapid climate change has been of considerable interest. From a palaeoclimate perspective, such endeavours were given particular momentum by the discovery of extremely rapid climate changes in the GRIP ice core (Dansgaard *et al*., 1993).

Whilst some of the extraordinarily rapid changes recorded in Greenland (e.g. Steffensen *et al*., 2008) are likely beyond the resolution obtainable for much of the Pleistocene and in many of the key records for this period, it is certainly possible to look at sub-Milankovitch climate changes. Recent research on the EPICA core has detected evidence for increased variability and possibly sub-millennial variance towards the end of MIS 11, at the onset of the final phase of cooling.

Relatively abrupt climate variability is particularly well recorded in ocean cores. North Atlantic data shows millennial scale variability to be a persistent feature during the past half a million years (Oppo *et al*., 1998). The cycles had a reasonably constant pacing, as noted during the last glacial cycle. Also consistent with the picture from the last glacial cycle and Holocene, the amplitude of variability is considerably greater during glacial periods, in particular during ice growth, than during interglacials. Oppo *et al*. (1998) focus on MIS 11 as a contrast to glacial periods, noting that the amplitude of sea surface temperature (SST) variability is between 0° to 1°C. Full glacial conditions saw fluctuations on the order of 3°C and periods of ice growth, 4° to 4.5°C. Despite the lower variability observed during MIS 11, it is clear that climate fluctuations did occur. This is further supported by evidence from terrestrial records, which will be discussed below.

2.3.4 – MIS 11 in the terrestrial realm

In the terrestrial sphere, much of the evidence for environmental change during MIS 11 comes from palynological analysis of lake sediments. In particular a number of long pollen records from Europe have proven to be extremely valuable, not only shedding light on MIS 11 but also provide a vital Pleistocene perspective. The Tenaghi Philippon core, from north eastern Greece is one of the longest, with strong chronological control initially stretching back to 450 kyr BP (Tzedakis *et al*., 2003) before eventually producing a chronology spanning the last 1.35 myr (Tzedakis *et al*., 2006). Correlation with marine records generally reveals a good correspondence in terms of orbital and suborbital variability.

However, this sequence is arguably just as important for the differences it reveals between terrestrial records and those obtained from marine and ice cores. In particular and in contrast to the EPICA record, no substantive change in vegetation is noted as a consequence of the MBE. Instead, a significant shift in vegetation is observed after MIS 16. Tzedakis *et al*. (2006) speculate that there was a major filling of available niche space, by species such as *Carpinus*, at this time. The severity of MIS 16, tectonically driven changes in hydrology, or some fundamental change interglacial climate regime are all offered as possible explanations.

From a further ecological perspective, it is intriguing to note that key global climate changes do not necessarily translate into significant effects on vegetation. Specifically, fluctuations in CO_2 between interglacials on the order of 30-40 ppmv do not seem to have had a noticeable impact on the extent of forest development in southern Europe (Tzedakis *et al*., 2006). This likely reflects the lack of significant moisture limitation in this region and may not hold elsewhere. Nonetheless this discussion stands as a stark warning not to make simplistic links between major trends in global environmental conditions and the ecology observed in pollen profiles.

These differences underscore the need to provide terrestrial records of Pleistocene climate and environmental change; the temptation is often to see the classic archives such as SPECMAP, as infallible data sets that can be liberally applied regardless of geographic location. However, in reality they represent a view of the past from a particular perspective.

As Tzedakis *et al*. (2006) note, the EPICA results concerning the MBE appears to record a fundamental global climate shift, yet the record from Tenaghi Philippon does not show a particularly strong signal at this time in terms of vegetation dynamics. Instead, MIS 16 appears to mark a fundamental shift in terms of vegetation composition. Moreover the obliquity cycle appears to persist into the period of generally recognised eccentricity dominance. Tzedakis *et al*. (2006) argue that this implies that climate mechanisms are in operation beyond those which typically operate at high latitudes on glacial-interglacial timescales.

This is an important observation, forcing us to be aware that an overreliance on many of the classic records may result in a particular narrative that fails to account for the full range of climate behaviour in space and time. This is further underscored by recent work in the British Isles, comparing records either side of the MBE (Candy *et al.*, 2010) which suggests no particular difference in palaeoclimates either side of this proposed transition. Again a decoupling in local records from global ones is observed, representing an important insight into the complexity of palaeoclimate and the need to provide good quality regional reconstructions for this time period.

The need for users of palaeo-archives to think critically about what they represent is ultimately the case with all records, with pollen data from lake basins no exception. Pollen records which, by their very nature, can only represent a limited spatial scale. It stands to reason that, whilst this scale may be sufficient to record broad trends, they will also be detecting regional (and often smaller) events. An understanding of climate change must not merely focus upon the big picture; the finer spatial resolution is equally as important, hence the need for particular focus on terrestrial archives. By the same reasoning, we must also recognize that the picture provided by the long pollen sequences, of for example Greece, may not apply directly to the UK. The overall pattern is likely one of overarching trends but also considerable spatial and temporal heterogeneity.

Having issued this note of caution, it is worth returning to the similarities between records. As pointed out, there is a correspondence with marine records at both orbital and suborbital timescales. This is particularly stressed in Tzedakis *et al.*'s (2003) reconstruction of the last 450 kyr, the time period encompassing MIS 11 and the majority of the research undertaken here. They note that there is "spatial coherence of climate variability between high latitudes and northeast Greece with an ocean-atmosphere linkage during the last 450 kyr". This points to the necessity of considering common controls for MIS 11/Hoxnian climate change and the importance of placing this work in such a wider context.

Long pollen records have also been instructive in illustrating the so called Stage 11 Problem (Droxler *et al.*, 2003), wherein the relatively moderate insolation forcing of MIS 11 was able to produce strong climatic responses. Tzedakis (2005), in a southern European summary, notes a large amplitude of forest expansion during this period, despite relatively moderate summer insolation. What was the amplification within the climate system? Although Lang and Wolff (2011) point the way to important inferences about interglacial strength, the Stage 11 Problem remains an unresolved question and again underscores the importance of MIS 11 in our understanding of climatic behaviour.

Generally speaking, detailed terrestrial records of climate change during MIS 11 are relatively scarce. One notable exception to this can be found in the Pianico palaeolake record from the Southern Alps (Mangili *et al.*, 2007). This archive confirms the occurrence of sub-Milankovitch climate oscillations, demonstrating that they are not simply a feature of deep ocean cores. Indeed, the varve sequence actually preserves evidence for centennial scale variability. Recently, additional evidence for relatively rapid climate changes has been provided from sequences in Germany (Koutsodendris *et al.*, 2010; Koutsodendris *et al.*, 2011; Koutsodendris *et al.*, 2012). This work is particularly significant and will be discussed at length in subsequent chapters.

This has been a brief review of the terrestrial evidence for MIS 11 climate. This issue will be dealt with in much greater depth in Chapter 12.

3 – Pollen and charcoal analysis

This chapter will review the fundamental principles of pollen analysis before moving on to discuss some of the key developments in palynology in recent years, including the use of pollen as a quantitative palaeoclimate proxy. Following this the theory and methodologies underlying charcoal analysis will be discussed.

3.1 – Palynological theory

3.1.1 – Fundamental principles

The underlying rationale of pollen analysis is as follows (adapted from Bennett and Willis, 2001):

1. Pollen and spores are produced in abundance by plants

2. Most of these fall to the ground

3. Pollen and spores are preserved in anaerobic environments e.g. lakes and bogs.

4. Pollen and spores in the atmosphere are subject to turbulent mixing; consequently there is a uniform pollen rain over a given area.

5. The proportion of a pollen type in pollen rain is dependent upon the abundance of its parent plant. Therefore the composition of pollen rain is a function of the composition of the vegetation and so a sample of the pollen rain is a snap-shot of vegetation at a particular point in space and time.

6. Pollen is identifiable to various taxonomic levels.

7. When a sample of pollen from sediment of a particular age is examined, the result is an index of vegetation surrounding the site of deposition at that point in space and time.

8. When pollen spectra are obtained from several samples through a sequence of sediment, they provide a picture of vegetation change through time.

9. When two or more series of pollen spectra are obtained from separate sediment sequences, it is possible to compare changes in vegetation through time at different places.

3.1.2 - Pollen in the environment

Prentice (1988) provides a useful introduction to pollen deposition. Large numbers of pollen grains are released during windier conditions in the day, into a turbulent airstream above the vegetation canopy. The content of this airstream varies, reflecting a local balance between gains and losses. Pollen is lost by deposition onto the canopy or through down-draughting and deposition at ground level in openings in the canopy. Such openings include sampling basins like lakes and bogs. Pollen trapped by the canopy eventually reaches the ground, either via rain or with falling plant parts, and represents the largest input to samples immediately below. Pollen deposited beyond the canopy, on the surface of water, joins the seston, which after some mixing becomes incorporated in the bottom sediment.

This simplified picture is complicated by a number of factors. Firstly, there is transport at low wind speeds in the trunk space, something likely to affect small basins in forested regions. However, this is probably not important in determining pollen source areas (for definition see below) because, for example, much of the pollen content of the trunk space is derived from above (Prentice, 1988). Secondly, large basins could receive a large pollen input from rain out. Pollen transported a long distance would be a particular factor here. However, again Prentice (1988) notes that this is not likely to be too much of a contributory factor, being responsible for only 10-20% of input to moderate sized basins.

An additional issue is the contribution a lake receives via fluvial transport of contemporary pollen from the surfaces and soils of the catchment and also from the erosion of older pollen from soils, peats and other material suspended in the drainage waters (Moore *et al.*, 1991). This inflow component could bias a pollen spectrum to the composition of pollen deposited on soil in the catchment. Vegetation around streams may provide a disproportionate contribution, with *Alnus* a good example of this. Relative to herbs and shrubs, tree pollen is released into the atmosphere in much greater quantities and low wind speeds in the trunk space reduce the dispersal effectiveness of pollen released near the ground. As a consequence, pollen records in forested areas contain relatively little pollen from shrubs and herbs, apart from those growing immediately around the lake. In open areas, non-arboreal pollen transport occurs in a similar fashion to that of tree pollen and the non-arboreal constituent of pollen spectra becomes much more significant. A crucial issue still remains however: the production of non-arboreal pollen is lower than forest pollen and so in open environments, pollen spectra can have a sizeable component of far-travelled tree pollen. In a qualitative sense, this can be countered as the tree pollen spectrum would be biased towards well dispersed types like *Pinus* and not heavier species like *Picea.*

Lake sediments, unlike peat, experience little downward movement of water and so downward transport of pollen is less likely. Conversely, mixing of surface sediment may occur through bioturbation and also through turbulence at the sediment-water interface. Another important sedimentary process is a bulk transport of material from shallower to deeper water, sediment focusing, as described by Davis and Ford (1982). This occurs because of preferential erosion of surface sediments at the margins of the lake. One effect this process can have is for cores taken in the deepest part of the lake to represent fringing vegetation more strongly than if purely atmospheric deposition were involved (Prentice, 1998). Further notable factors and sedimentation processes include: differential flotation characteristics of pollen types;

winds and currents; lake morphometry; basin topography and geology; and nutrient status (Davis *et al*., 1969; Moore *et al*., 1991).

Lateral and vertical mixing effects lead to a homogenising of lake sediments (Moore *et al.*, 1991). The downside of mixing is the loss of temporal resolution. The typically assumed upside is the ability to take a single core as being representative of the lake. Edwards (1983) investigated this assumption in a literature review of multiple core studies. He notes that there are cases where vegetation proximity can affect pollen representation in different parts of lake, but that uniformity, presumably as a result of re-deposition and smoothing, occurs. He concludes that a single core is likely to be generally satisfactory, although where detailed work is required, minor changes being considered or absolute pollen values used, then spatial variations in sedimentation may be important.

3.1.3 - R-values and pollen source area

Despite the widespread use of pollen records, palynologists in the 1980s and 1990s began to question whether or not their full potential was being utilised (Sugita, 1994). The relationship between the pollen produced by vegetation surrounding (at various spatial scales) a sedimentary deposit and the fossil pollen assemblage preserved is extremely complex. In order for palynology to move beyond simple reconstructions, it became apparent that new theoretical and empirical work was required.

The *R-value* (Davis, 1963) was an early theoretical development and is a correction factor applied to pollen percentages in order to calculate tree abundance. It is the ratio of pollen in a surface assemblage to the abundance of that taxon in the surrounding vegetation and represents an important early attempt to calibrate pollen with vegetation. It does, however, have its limitations: the value obtained is dependent upon the radius (catchment) from which the pollen is assumed to come (which may differ from one site to another); and it also depends upon the vegetation structure and local topography. The Fagerlind effect is a particular problem for the *R-value;* when using pollen percentages, at high values, small changes in proportions may be reflecting large alterations in the influx of pollen. These non-linearities are accounted for in the updated version of the *R-value*, the Extended *R-value* (ERV) (Parsons and Prentice, 1981; Prentice and Parsons, 1983).

Empirical research has demonstrated that there is a basic relationship between the size of sedimentary basins and pollen source area, with larger basins deriving pollen from larger areas than smaller basins (e.g. Jackson, 1994). Prentice (1985) provided a comprehensive and flexible (Sugita, 1994) quantification of pollen source area. The Prentice model estimates pollen deposition at a point in the centre of a basin; this is appropriate only where post depositional, horizontal movement of pollen is minimal, such as in a bog or fen. Sugita (1993) modified the Prentice model in order to estimate average pollen deposition per unit surface area (pollen loading) over the entire surface of a basin. This is more appropriate for deposition in a lake because mixing in water and focusing of sediment redistribute pollen originally deposited over the entire surface. Pollen landing everywhere on a lake surface is mixed before finally accumulating as sediment, a view supported by field studies (e.g. Davis, 1968), though with certain caveats to be discussed later.

The assumptions of the Sugita (1993) model are: 1) the sampling lake is a circular opening in the forest canopy; 2) the dominant agent of pollen transport is wind above the canopy; 3) pollen productivity is constant for each taxon; 4) spatial distribution of each taxon is expressed as a function of distance from a point at the centre of the lake - this means that the directions of pollen source do not influence pollen loading on the lake; and 5) arc-wise pollen deposition is expressed as a function of distance from a point source, derived from a diffusion model of small particles from a ground level source. The model is essentially one dimensional, whereas a lake is two-dimensional: Sugita (1998) acknowledges this potential limitation and demonstrates that it has little impact.

Trees close to the lake contribute more pollen than those further away, with the signal from trees near the lake being an order of magnitude greater than those from 200 m away and at least two orders of magnitude greater than from trees 1000 m from the lake

(Davis, 2000). Davis (2000) elegantly describes why basin size is such a significant variable. Trees adjacent to the lake input large amounts of pollen, a quantity roughly proportional to the length of the shore. In order to calculate pollen loading, this local contribution is divided by lake area. Loading per unit area of the lake surface from local trees therefore declines as lake size increases, because the ratio of perimeter to area grows smaller as lake radius increases. Conversely, loading from the regional vegetation remains constant per unit area because deposition from this source is nearly the same everywhere on the lake surface. The ratio of pollen loading from nearby vegetation to loading from regional vegetation decreases as lakes increase in size; lakes on the kilometre scale are dominated by regional pollen.

The Prentice model and Sugita's original modification assumes an even spatial distribution of plant abundance for a given taxon. However, in reality, vegetation tends to be patchy. Sugita (1994) developed the POLLSCAPE model to deal with pollen representation in heterogeneous vegetation. It simulates a forest landscape with patches of three species: large circular patches of species A and small circular patches of species B in a matrix of species C. A lake was situated randomly in a cell in the centre of the landscape; thirty lakes are simulated in the same landscape in a given experiment. Pollen loading was calculated using Sugita (1993). Sugita (1997) verifies the POLLSCAPE model by showing that it predicts well the pollen assemblages in surface sediments from a small lake in Alberta.

The POLLSCAPE modelling in Sugita (1994) suggests that the spatial scale represented by a particular pollen assemblage is affected by vegetation patterning. There are large site to site variations of pollen loading and pollen proportions for smaller lakes and smaller site to site variations for larger lakes (Sugita, 1994). When the size of the basin is larger than the vegetation patch, then the pollen assemblage in the basin reflects a homogenous vegetation structure. Where the basin is smaller than a vegetation patch, it is able to detect that patch and so for the reconstruction of heterogeneous vegetation, a series of small lakes are required. The model can predict, for any given landscape, the lake size needed to sense individual patches, thus making experimental design more effective.

3.1.4 - Relevant source area

An additional contribution from Sugita (1994) is a refinement to the pollen source area: the relevant source area. The original Sugita (1993) model predicts that 70% of relatively heavy pollen types (such as beech) originate within 1.2 km of the lake shore when the lake radius is 50 m, whereas it originates within 7 km when the lake radius is 750 m. For lighter pollen types (such as oak and pine), the pollen comes from a greater distance, with 70% from 10 km away with a lake radius of 50 m and within 40 km with a radius of 750 m. This provides a general area of vegetation from within which a given proportion of total pollen originates for lakes or bogs of different radii (Sugita, 1998).

Relevant source area is the area of vegetation that is reflected in lake to lake differences in pollen loading. It differs by specifying an appropriate spatial scale of vegetation represented by pollen. The POLLSCAPE simulation demonstrated that pollen from beyond a certain distance becomes nearly constant for all sites within a region. The area within this distance is the relevant source area, where differences in plant abundance are recorded as variance in pollen assemblages among sites, superimposed on a constant pollen background. It specifies the spatial scale at which site to site variability in the vegetation is 'relevant' to the pollen assemblages (Sugita, 1994, 1998) and is the smallest spatial scale of the landscape that can be reconstructed from a pollen assemblage. The relevant source area depends upon lake size, dispersal characteristics of pollen and patch size (Davis, 2000) and is distinctly smaller than the pollen source area Sugita (1994). Empirical testing of the relevant source area has been somewhat limited, though Calcote's (1995) work on small forest hollows is in excellent agreement with the model predictions.

A final issue to consider is the significance of source area for the comparison of pollen and charcoal. Relatively few studies have investigated this issue. Those studies that have, suggest that microscopic charcoal and pollen have comparable source areas (e.g. Tinner *et al*., 1999).

3.1.5 - Vegetation structure and recent modelling research

As the Prentice-Sugita model was formulated for a closed canopy forest, surrounding a basin, Sugita *et al*. (1999) investigate the effect of different vegetation structures (as distinct from patterning). They look at whether the POLLSCAPE simulation model is applicable to open, agricultural or semi-open forested landscapes (a range of 30-90% openness). The appropriateness of POLLSCAPE was tested by comparing predicted pollen assemblages with observed. Broadly speaking there were encouraging resemblances, suggesting that the model does not just function in fully wooded landscapes.

Interestingly, the relevant source area of pollen in both open (800 m) and semi-open (1000 m) landscapes was virtually the same for the simulated lake (3.14 ha). This remains the same irrespective of vegetation composition and patchiness and is much higher than in closed forests (75-100 m). The larger source area of more open environments is primarily caused by differences in the distribution of the vegetation patches in the landscape, with the presence of rare communities (more prevalent in the Swedish simulations) being a crucial factor, increasing the relevant source area. Rarity decreases the chance of having a particular vegetation patch nearby and so the predicted area required to achieve constant background pollen (a criterion for the relevant source area of pollen), becomes larger. This result again confirms that the 'spatial sensing properties' (Bunting *et al*., 2004) of pollen assemblages are affected by the patterning of vegetation within the landscape. It also suggests that a considerable amount of future research is required, in environments with different patterning, to see how widely applicable the Swedish landscape is.

Sugita *et al*. (1999) state plainly that 'quantifying the area of open land from pollen records is complex.' The main problem is that non-arboreal pollen percentages have a non-linear relationship with percentage cover of open land. This is the result of various factors, from degree of openness, spatial spread of patches, species composition and regional pollen production, which all affect the relationship between pollen and open land (Sugita *et al*., 1999). The traditional, simple use of non-arboreal pollen percentages to infer the area of open land around study sites is inappropriate.

Bunting *et al.* (2004) investigate the impact of varying taxon parameters and landscape patterning on relevant source area. The taxon parameters under investigation in this work include pollen fall speed and pollen productivity and the landscape features include patch size, rarity and diversity. One factor is varied whilst others remain constant. Isolating controlling variables is a particular benefit of the modelling approach.

Bunting *et al*. (2004) note that existing research (e.g. Jackson, 1994) suggests that increasing the fall speed of the lightest element in the assemblage should decrease the relevant source area of pollen for the assemblage. However, Bunting *et al*.'s. (2004) results suggest that pollen properties have little effect upon relevant source area. It is important that this result is verified, though provisionally speaking it would be encouraging given the limitations that often exist in pollen property databases. On the other hand, the size of landscape elements does have a marked impact upon the relevant source area of pollen. Indeed, Bunting *et al*. (2004) argue that the principal control on the relevant source area of a pollen assemblage may be the size of patches within the landscape: when basin size is constant, then the relevant source area of pollen is predominately an emergent property of vegetation patterning. They go on to suggest a number of empirical studies that provide evidence for the importance of vegetation patterning.

Palaeoenvironmental research has generally assumed constant basin size, and consequently a constant relevant source area of pollen. However, Bunting *et al*. (2004) demonstrate that changes in the vegetation itself can lead to changes in the relevant source area of pollen. This leads to interpretative difficulties; variations in the pollen record must be viewed with caution as they may be reflecting different landscape areas.

A range of software now exists, in recognition of the importance of modelling and simulation in pollen theory. The Mosaic (Middleton and Bunting, 2004) and OPENLAND3

(Elkof *et al.*, 2004) programs are both intended to simplify the usage of the POLLSCAPE model. Mosaic is especially user friendly, as it can be implemented without the use of GIS technology. HUMPOL (Bunting and Middleton, 2005) is an additional software tool that also makes modifications to certain elements of Sugita's original pollen dispersal models.

The assumptions underlying POLLSCAPE introduce an inherent inflexibility into simulations; HUMPOL seeks to remedy this situation. For example, the assumption of uniform landscape composition to a considerable distance beyond the area studied (i.e. background pollen is calculated from the composition of the vegetation within the landscape unit modelled) (Bunting and Middleton, 2005). This is appropriate for broad scale studies or for research in areas where assuming uniform topography, climate, soil, disturbance and consequently vegetation is appropriate. It is not appropriate in landscapes with strong regional variation in vegetation over distances of 10-100 km. In HUMPOL, the landscape is defined by a series of vegetation maps, with different extent and resolution, 'nested' together so that variation in vegetation composition at a range of scales can be incorporated into the simulation (Bunting and Middleton, 2005). Nesting enables pollen dispersal and deposition to be modelled in a large and variable landscape without having to make simplifying assumptions about background pollen rain.

Also being addressed is the one-dimensional nature of Sugita's model. In HUMPOL, the distribution of pollen sources in the landscape is dealt with in a two-dimensional rather than one-dimensional manner by using a cellular approach. This enables the simulation of variable windroses and also aspects of topography. As with Sugita (1997), the two dimensional approach appears to make little difference to the simulation output and this is also the case with the other modifications. The value of HUMPOL lies in its greater flexibility of data handling and the consequent ability to carry out more sophisticated 'thought experiments' concerning the controls on pollen dispersal and deposition.

Caseldine and Fyfe (2006) adopt an intriguing perspective, using some of this new software. They take a modelling approach to simulate hypothetical landscapes, hoping to better understand the nature of the Holocene elm decline. Modelling allows the testing of possible causal hypotheses and can help answer questions about vegetation structure and the spatial extent of change. They use two programs: Mosaic, described above, and POLFLOW, which is used to generate pollen assemblages at specific points within the landscape. Changes are made to the simulated landscape in order to evaluate the impact of altering vegetation structure and distribution on pollen deposition. This enables the estimation of the most likely character of former landscapes by comparing simulated and observed pollen assemblages. These are entirely hypothetical experiments in order to give an idea of the broad range in which natural or reconstructed landscapes should be structured in order to produce the sort of assemblages found in the fossil record.

This information can be used to help estimate the character and structure of vegetation communities thought to have existed within the 'real' landscape. GIS is used to create the 'real' landscape, with a series of units defined largely by hydrology, slope and parent material. It is combined with the theoretical vegetation structure generated in the hypothetical situation described above and inputted into POLFLOW. Again, the landscape can be varied in order to get closer agreement between observed and actual pollen assemblages. The simulated landscapes represent vegetation structures that represent plausible models of the past; they are good working hypotheses for inferring the likely scale and character of Early Neolithic landscape change (Caseldine and Fyfe, 2006).

The development and testing of hypotheses is an important element of robust scientific research. Caseldine and Fyfe (2006) demonstrate how a modelling approach can be used to generate hypotheses and Mitchell (2005) provides a fine example of how the recent theoretical developments in palynology can aid the development and testing of hypotheses. By having a greater understanding of the significance of a particular pollen assemblage from a lake and landscape of a certain kind, it is easier to design an experiment with falsification in mind. Mitchell (2005) aims to test the hypothesis that large herbivores maintained open landscapes in the primeval forests of Holocene Europe. Armed with the knowledge of spatial scale from Sugita's models he samples small hollows in order to gain a fine spatial resolution, effectively the local stand scale at which these processes would operate. From this it is demonstrated that open canopy forest was only maintained by human exploitation and so the herbivore hypothesis is falsified.

3.1.6 - Relevance for Hoxnian palynology

We can now offer a number of illustrative examples of how the latest developments in pollen theory may be applied to the Hoxnian and British Pleistocene research in general. Biostratigraphy is one area, with the ability to make large scale correlations dependent upon the detection of broad, regional, trends in vegetation development. If the source area for a pollen record can be determined, then greater confidence could be given to such trends.

Given the appropriate sampling strategy it may be possible to produce a more accurate picture of landscape structure. This would clearly have implications for a wide range of research issues and in particular could inform archaeological interpretations. Were, for example, the hominids of the Hoxnian faced with a rather patchy environment or was there a fairly homogenous vegetation distribution? Furthermore, an appreciation of structure is also significant as it could enable the testing of ecological theories, such as that pioneered by Mitchell (2005). Comparing the nature of the Hoxnian environment with that of the Holocene could provide an interesting perspective on modern day ecological processes and the degree to which humans have impacted upon this. Birks (1993 and 1996) makes a persuasive case for the relevance of palaeoecology to ecological and conservation issues.

Site selection strategy could be made more effective by coring at localities that are relevant to the particular research question in hand. These new theoretical developments are arguably at their most useful when used as a guide to focus research. Mitchell (2005) provides a powerful illustrative example of hypothesis testing (in this case the impact of herbivores on vegetation structure) using modern pollen theory to guide site selection. Such endeavours will of course be constrained by the limited range of appropriate Hoxnian sediments and the difficulties in interpreting the spatial characteristics of past basins.

3.2 - Palynological climate reconstructions

3.2.1 Why reconstruct qualitative palaeoclimates?

The use of pollen as a proxy for climate is a common element of palynology. This has predominately been undertaken in a qualitative manner; the herb and shrub dominated landscapes of the early post-glacial being used to infer cold climates for example. However, early attempts were made by Iversen (1944) to produce quantitative reconstructions of palaeoclimate.

Paralleling the theoretical developments of the 1980s that are described above, attempts were made to further develop quantitative links between pollen and climate. These efforts have continued apace as Quaternary scientists seek to provide a more precise and detailed (if not necessarily accurate) picture of past climate change. Most quantified reconstructions are for the Holocene, with an increasing number in the last interglacial. The discussion in chapter 2 concerning MIS 11 clearly illustrates the importance of this period and it should hopefully be apparent how quantitative climate reconstructions can be of considerable value to a period rich in stimulating palaeoclimatological questions. We can return to this subject here and provide a further illustration of the role that such reconstructions can offer.

Work in the Eemian demonstrates the considerable interest generated by detailed climate reconstruction; for example the debate concerning the stability of the Eemian, which was initially sparked by a pollen based temperature record (Field *et al.*, 1994). In this particular instance, the fact that a terrestrial record was at the very forefront of this debate, is testament to the significance of such studies. Furthermore, the pollen based nature of the reconstruction provides extra motivation in the context of this project. Conversely, the fact that the major findings of Field *et al*. (1994) are almost certainly incorrect (Litt *et al.*, 1996) is an extremely valuable cautionary tale.

There are specific questions of palaeoclimatological interest to be addressed. For example research in recent years has demonstrated the presence of climate gradients in Eemian Europe (e.g. Brewer *et al*., 2008). When a sufficient number of quantified reconstructions have been developed, it will be possible to establish whether or not this was the case during MIS 11. With quantified climate reconstructions, MIS 11 can begin to be placed into context with other interglacial periods. Terrestrial records can then begin to shed additional light on whether or not this was one of the warmest interglacials.

Another issue that could be addressed is a comparison between marine and terrestrial archives. There is some evidence (Candy, 2009) for a discrepancy between the picture of Middle Pleistocene climates provided by marine core records and those found in the terrestrial sphere. If this is confirmed, it is ultimately a question of scale and points to the possibility of localised forcing factors and a general picture of regional climatic variability. It will be exciting if we can move beyond broad brush palaeoclimate reconstructions and focus in on the finer details.

From many of these considerations comes the exciting possibility that high quality terrestrial records can actually begin to take the lead on engaging with pressing palaeoclimatological questions. Many of the key records for this period only provide qualitative temperature data. Although representing a different aspect of the climate system, conclusions derived from marine records, for example concerning peak interglacial warmth, often do not present precise quantified temperatures.

Answering the suggested presented above will allow the building up of a richer picture of how the MIS 11 climate system actually operated. This becomes particularly significant when we consider the question of the MIS 11-Holocene analogy. The understanding of natural variability in an earth system with a number of similarities to our own provides a valuable comparison when evaluating modern day climate change. How do the temperature changes being observed in the present day fit into the context of change derived from purely natural processes? Is rapid and high magnitude change possible within interglacials? Do “tipping points” exist within interglacials? It is only by quantifying climate changes of this period that these important issues can be adequately addressed. Finally, and importantly in this context, there remains the intriguing possibility of providing data for the evaluation of climate model output. This has not yet been performed but would clearly be an extremely valuable exercise.

It is also worth considering the prospects for the future of the Holocene. Whilst anthropogenic global warming is likely to alter the course of climate evolution in the short and medium term, will it prove sufficient to override the underlying natural trends of glacial-interglacial variability? There are arguments from some quarters (Ruddiman, 2003) that this has already occurred, earlier in the Holocene, although the general consensus has not yet fallen behind this interesting hypothesis. The weight of evidence seems to suggest that MIS 11 was fairly lengthy and if it is an appropriate analogue, then it may be that the current interglacial continues for a considerable period (Loutre and Berger, 2003). Whilst there is concern arising from global warming, in general terms the warmth of the current interglacial has been of benefit for human society (Fagan, 2003) and a slide into glacial conditions would be worrying. Constraining the timing and environmental changes of this could be an intriguing if somewhat speculative endeavour.

It is important to stress that the significance of quantitative reconstruction does not simply relate climatological questions surrounding MIS 11. From an archaeological perspective, it is rare for archaeologists to be furnished with detailed climatological data. Generally speaking, the landscapes of the Palaeolithic are discussed in qualitative, often relative, terms. It is not difficult to conceive both richer and more rigorous interpretations of archaeological data if it is possible to move beyond a description of an interglacial as “warm”, to one in which the development of climate is mapped out in detail. Already we see archaeologists concoct intriguing but somewhat speculative discussions placing hominids in their environments (e.g. White, 2000). Providing them with realistic palaeo-scenarios would clearly be of considerable benefit.

We do have a small number of examples where climate and environmental reconstructions have explicitly helped set the context for archaeological discussion. van Andel and

Tzedakis (1996) provide such a perspective for the period 150,000-25,000 kyr BP in Europe, and as useful as this is, it remains a reasonably broad sweep. This research fed into the Stage 3 Project (van Andel and Davies, 2003) and it is this work in particular that shows the benefit of applying high quality palaeoclimate data to archaeological questions, in this case issues such as Neanderthal thermal preferences and the substantive issue of what caused Neanderthal extinction.

3.2.2 Quantitative methodologies

Loosely speaking, approaches for the reconstruction of palaeoclimate using pollen data can be classified into two main categories; "numerical" methods and the mutual climatic range method (Klotz *et al*., 2004). "Numerical" approaches use mathematical formulae to relate the proportions of pollen in modem assemblages with present-day climatic parameters. Data is collected in as wide a range of environments as possible and the relationships established are assumed to be appropriate in the past and so quantitative palaeoclimates can be reconstructed. There are a number of different methodologies here, such as pollen climate response surfaces and modern analogue approaches.

Response surface analysis was used by Bartlein *et al*. (1986) as a method of translating the complex relationships of spatial abundance in pollen data into more simplified relationships with climate. Response surfaces express the relationship between the percentage of a pollen taxon and two or more climatic variables. They have become widely used, commonly as a tool in large scale spatial reconstruction, often for comparison with climate models; Bartlein *et al*. (1998) is one such example.

Guiot (1987) first adopted the modern analogue approach, wherein fossil pollen spectra are compared with present-day analogues. Around 10 closest modern samples for a given fossil sample are identified using statistical dissimilarity indices and the temperature is inferred by taking a weighted average of the closest modern samples (Seppa and Bennett, 2003). The modern analogue technique is now common but suffers from certain significant limitations. In particular, there may not be suitable modern analogues for past vegetation assemblages. This is a particular problem during glacial periods and has also proved troublesome in the Eemian interglacial; the *Carpinus* forests accompanied by *Ilex* cannot be found today for example (Klotz *et al*., 2004). Whilst solutions to the non-analogue problem do exist, they have extremely large statistical errors associated with them (Seppa and Bennett, 2003).

Iversen (1944) is an early example of the mutual climatic range method (MCR) approach. He used simple range overlaps in the following manner: if species A has a range of 1-10°C, species B has a range of 5-15°C and species C has a range 8-12°C, then the temperature would have lain within the overlap of these ranges (i.e. 8-10ºC). The mutual climatic range method, first developed by Atkinson *et al*. (1987), is effectively a more involved extension of this basic principle. It differs from the modern analogue approach, for example, by being based simply on presence/absence of a taxon and not relative proportions of plants. In this way, it is also effectively an indicator species approach.

By relying only on presence/absence, the MCR method does not suffer from non-analogue vegetation situations. Klotz *et al*. (2004) argue that MCR approaches suffer less from taphonomic effects than numerical ones, because changes in proportion are not significant. In this thesis, a variant of the MCR method, the Probability Density Function (*pdf*) approach (Kuhl *et al*., 2002), will be used. For palaeo communities that are temporally far removed from our own, it seems appropriate to focus on the method that is least likely to suffer from non-analogue problems. Furthermore, the *pdf* method enables the integration of pollen data with plant macrofossils. This has the advantage of reducing bias introduced into the reconstructions due to palynological taphonomic processes. Birks and Birks (2000) argue that macrofossils should be used in conjunction with pollen wherever possible.

There is important macrofossil data available for a number of Hoxnian sites. Cross comparison between pollen and macrofossil data offers the opportunity to clarify some long standing palaeoenvironmental conundrums, such as the temperature represented in the Stratum C deposits at Hoxne. Finally, the pdf method also produces precipitation output. This is a climatic variable rarely considered in palaeoclimate research and it offers considerable obvious potential for the interpretation of palaeofire data.

The *pdf* method was first outlined by Kuhl *et al*. (2002). It is a Bayseian probabilistic approach which derives climate data from the presence of individual taxa. A significant problem underlying previous usage of indicator species methodologies has been their use of limiting threshold values because typically only a minority of individuals define the limiting isotherms. The decreased probability of occurrence maps the distribution limits of plants better than threshold values. The *pdf* method uses probability density functions as transfer functions to describe the relationship between species and temperature. A given species-climate relation has its own *pdf* that is calculated from known European plant distributions and mapped climatological data covering that distribution. Multiple *pdfs* are combined to produce a most probable climate (with associated error bars).

A further and more detailed discussion of the conceptual issues surrounding pollen-climate reconstruction will follow, in Chapter 11.

3.3 – Pollen zonation

The zonation of pollen sequences is a common process, but is vulnerable to subjectivity. Numerical approaches, which are typically based on binary, optimal or clustering methods (Bennett, 1996), can help to circumvent this problem and have led to greater reliability in zonation (Seppa and Bennett, 2003). The most significant advancement in this area was made by Bennett (1996) who applied MacArthur's (1957) broken-stick model to pollen data.

The underlying principle entails comparing the reduction in variance with each additional zone, with the reduction obtained by zoning a randomized data set (Seppa and Bennett, 2003). Zonation proceeds so long as the reduction in variance for the number of zones produced by the broken stick model is higher than the reduction of variance from randomization. In this way, the pollen zonation is constructed on the basis of genuine structure in the data and not noise.

One of the key outcomes of Bennett's (1996) application of the broken stick model was the observation that the number of zones able to be recognized will generally increase with the number of samples. This is not a linear relationship and is dependent upon the inherent structure of the data. However, it is true to say that there may well be no satisfactory zonation possible if the number of samples is too low. It is also the case that zonation is more likely to emerge from noise if pollen counts are higher. In practical terms this may lead to a slight trade off; ideally a large number of samples, each with very high pollen counts will be employed. In reality a balance may have to be struck between the two.

3.4 – Charcoal analysis

3.4.1 - Charcoal in the environment

The most fundamental principle underlying charcoal analysis is that charcoal in a sedimentary sequence represents a fire event.

Patterson *et al.* (1987) provides an excellent review of the taphonomic processes surrounding charcoal deposition. The precision with which microscopic charcoal reflects the occurrence of fire is the result of taphonomy. Taphonomy is a function of transport, time taken to reach sediment following deposition, its fate within the depositional basin and finally the constancy of its position in the sediment (Patterson *et al.*, 1987).

Patterson *et al.* (1987) make the crucial point that taphonomic processes are potentially more problematic when dealing with charcoal than pollen. In palynology, the general aim is to reconstruct events that occur over some period of time, whereas charcoal studies may wish to reconstruct a specific fire event.

There are two primary agents of charcoal dispersal; wind and water. Fires produce a considerable quantity of airborne particulates and larger, heavier particles, and those with a high ratio of volume to surface area tend to move shorter distances. Important influences on aeolian transport are strong convective currents associated with fires and the speed and direction of wind and atmospheric washing by rain or snow. Runoff and erosion often both increase following a fire and water can transport a large amount of charcoal. Indeed, Patterson *et al*. (1987) report studies in which more charcoal is removed in water than in smoke and suggest that this might well apply to most lacustrine systems, except those that receive little surface runoff (e.g. kettle holes).

A considerable amount of charcoal is deposited soon after production, particularly with aeolian as opposed to fluvially derived charcoal. Transport time is likely to be shortest in areas of heavy precipitation, high relief, and where lakes receive runoff from spring snow-melt. Conversely, in areas that are dry as the result of prolonged drought, there could be significant delay in the transport process (Patterson *et al*., 1987).

Whitlock and Millspaugh (1996) provide a highly important taphonomic assessment of modern charcoal deposition in Yellowstone National Park, testing some of the basic assumptions surrounding this proxy. The use of charcoal analysis depends upon the premise that a charcoal peak (a stratigraphic interval with relatively abundant charcoal) represents a fire event. Specifically, Gardner and Whitlock (2001) define it as representing a primary contribution that is deposited through aerial fallout or other fire related processes shortly after the fire. Secondary charcoal introduced or reworked in the watershed or lake as a result of non-fire variables, such as surface run-off and sediment mixing, should be negligible so that spurious peaks are not formed. The results of Whitlock and Millspaugh (1996) do indeed indicate that a significant amount of charcoal is introduced to the sedimentary record following a fire. As compaction of sediment occurs it is probable that a peak in charcoal is formed, with its width being determined by the duration of secondary charcoal accumulation.

Secondary accumulation reduces the temporal precision of the charcoal peak. It is quite likely that this build-up of charcoal will continue for a number of years before the peak is completed. Following the Yellowstone fire, charcoal was still mobile within the system for four years and charcoal abundance in the sediment had not yet stabilized. Charcoal peaks correlating with known fires in the past, span 1-3 cm of the core, around 20 years of sediment accumulation (Millspaugh and Whitlock, 1995). Deep lakes were found to be less affected by the processes that re-deposit secondary charcoal.

Whitlock and Millspaugh (1996) conclude that the deepest part of the lake is the best location for collecting cores. This location may experience a lag in charcoal accumulation, but they show a steadier pattern of accumulation than the littoral or sublittoral zones. It is also possible that past fire events would be missed in shallow water if winds were particularly strong and cores taken on the upwind shore (Whitlock and Millspaugh, 1996).

Finally, Whitlock and Millspaugh (1996) also conducted an analysis of analytical error. They took multiple samples from different stations within one lake and their results implied that most differences were caused by true variations in the deposition of charcoal. This is particularly encouraging, suggesting that a charcoal peak does indeed represent the true abundance of charcoal at that sediment depth. Gardner and Whitlock (2001) and Clark *et al*. (1998) also examine the accumulation of charcoal in lakes following modern fires. Gardner and Whitlock (2001) confirm that there is a relationship between charcoal abundance (a peak) and a fire event. With regards to secondary charcoal accumulation, they report that differences in charcoal abundance between burned and unburned sites were detected two years after the fire. This is significantly shorter than in Yellowstone, possibly because of the nature of the vegetation, which can influence the fuel levels and amount of charcoal produced, or possibly because of the bathymetric characteristics of the lake (Gardner and Whitlock, 2001). Charcoal in shallow lakes is deposited evenly, in a relatively short period, whereas charcoal in larger lakes (such as in the Yellowstone study) could be initially concentrated closer to the shore, before being reworked to deeper sediments over time.

Both primary and secondary depositional processes could lead to important spatial variations in charcoal. This could impact upon interpretation, a particularly important consideration in cases where it is not possible to compare the charcoal record to known fire events. In this context, we must consider whether it is appropriate to sample a single core for charcoal analysis. Edwards and Whittington (2000) obtained multiple cores and, encouragingly, irrespective of the core used, the same qualitative reconstruction would have resulted though in quantitative terms there were differences.

Charcoal records have often been subdivided into two broad categories; a background signal and distinct charcoal peaks. The background component represents integrated contributions from across a landscape, being rather consistent within a region, varying among regions and responding to large scale factors such as climate change (Clark and Royall, 1996). Peaks are discrete punctuations that exceed the background level and may be a record of local fire, within the lake catchment. In an idealised taphonomic situation, coupled with a high resolution archive, each individual fire would produce its own peak. However, this is rarely the case, particularly in lakes, and the signals of multiple fires are likely to merge.

3.4.2 - Charcoal analysis theory

Developments in charcoal theory strongly concern the spatial representation of charcoal particles. Clark (1988a) used particle-motion physics to make the following points:

1. Charcoal particles smaller than 5-10μm in diameter are transported through the air for thousands of kilometres following a fire. Therefore to reconstruct local or even regional fire history, this size class is inappropriate.
2. Small charcoal particles will be transported away from the source of the fire, whereas large particles will be deposited locally. Fragments of greater than 50 μm are of greater value in detecting local fires than smaller size classes.

The presence of large charcoal particles should indicate a nearby source, however a number of issues remain. Clark and Patterson (1997) review diameter distributions in samples from North America and Siberia. They note that clear distinctions are not present in the distributions and no easily identifiable local/regional dichotomy exists. However, in theoretical terms, the absence of a clear distinction in diameter distributions does not rule out the use of particle size to infer spatial patterns from the archaeological record (Clark and Patterson, 1997). In particular, certain transport processes are likely to cause size distinctions. Limited wind dispersal beyond the burn edge, saltation and possible water transport will all emphasise a local signal (Clark and Patterson, 1997).

A final issue concerns the definition of microscopic and macroscopic charcoal. These are terms that are commonly referred to in the charcoal literature, but not especially well defined. In this discussion, the review by Whitlock and Larsen (2001) will provide the guidelines. Microscopic charcoal will refer to that found on pollen slides (<100µm) and macroscopic will refer to the larger particles that are observed when sieving and on thin sections.

As a consequence of the limited empirical basis, spatial interpretations from charcoal data must always be undertaken with caution. However, despite this, there are examples where data appears to support the basic theory. The Clark and Patterson (1997) review finds evidence in support of their claims regarding transport mechanisms. MacDonald *et al*. (1991) found no correspondence between known local fires and microscopic charcoal, but did observe a relationship between microscopic charcoal and known regional fires.

Whitlock and Millspaugh (1996) demonstrate a clear difference in charcoal particle size between relatively proximal and distal sites. Charcoal with a diameter of >125 µm were abundant in sites 7 km from the fire; beyond this, they declined sharply, thus verifying the prediction of decreasing abundance of larger sized particles, away from the fire. Gardner and Whitlock (2001) also provide support, observing that macroscopic charcoal can be used to reconstruct local fire events; a peak occurred when the watershed of the lake burned.

Clark *et al.* (1998) observe that in an experimental burn in Siberia, charcoal abundance rapidly declined past the edge of the burned area, again providing support for theory. Clark *et al.* (1998) argue that this decline in abundance is consistent with the considerable intensity and height of the convection column and may not apply to surface fires or less intense crown fires (Clark *et al.*, 1998). They go on to predict that burn intensity could reflect the source region for particles recovered in sediments; lower intensity burns being better than higher intensity for spatial representation of nearby fire events.

So, there is broad, if limited, support for Clark (1988a) with a few studies verifying his claims and adding extra detail. There appears to be little that can be used as an outright rejection of Clark (1988a), although the data of Pitkanen *et al.* (1999) is intriguing. In this work, the correspondence between fire-scar and charcoal data series suggests that an abundance of microscopic charcoal particles can indicate fires occurring at short distance from the lake (Pitkanen *et al.*, 1999). An experimental burn in the area provides support for this interpretation, with even the smallest size classes of microscopic charcoal found on pollen slides being deposited adjacent to the burning area. Pitkanen *et al.* (1999) believe that low fire intensities could explain their findings. A low convection column and a proportion of smoke moving along the surface would result in locally deposited microscopic charcoal.

The possible influence of fire intensity on the spatial significance of charcoal records has been briefly mentioned above and should not particularly come as a surprise. The possibility that charcoal size can be related to source area is essentially a function of the transport process and a key control on transport is fire intensity which affects plume buoyancy (Clark and Patterson, 1997). Pitkanen *et al.* (1999) go on to make the broad generalisation that such low intensity fires tend to characterise Fennoscandian forest sites, whereas those in the Boreal forest of North America tend to be of higher intensity.

The contribution made to spatial representation by the nature of the fire is an intriguing complication that requires investigation and clarification. Further modern day taphonomic studies that attempt to validate or falsify basic theory are urgently required, although due to the logistical challenges, there is unlikely to be a flood of studies appearing. As it stands, there is a need to be conservative in interpretation, but tentative conclusions about source from charcoal particle size can probably be reached.

3.4.3 - Charcoal theory and sampling methodology

It is important to place the theoretical developments surrounding charcoal analysis within the context of the practicalities of sampling. Sampling imposes certain limitations that may be significant in light of theory and so its impact must be discussed.

The production of pollen slides is both chemically and mechanically rigorous so that organic and inorganic matter can be successfully removed from the sample (Rhodes, 1998). Pollen grains are immune to such procedures because of their sporopollenin rich exines, whereas charcoal particles are less robust, being mechanically fragile and vulnerable to chemical degradation. The steps taken in the production of pollen slides can reduce the total area and number of charcoal particles by physical or chemical removal (Tinner and Hu, 2003). Furthermore, sieving and decanting during pollen preparation can eliminate large particles and alter charcoal size distribution, potentially leading to bias. Irrespective of this, pollen slides tend to record smaller particles and theoretically should be better indicators of regional fire (Clark, 1988a).

The alternative technique that arguably shows most promise is the use of petrographic thin sections. In contrast to pollen slides, during the preparation of thin sections (Clark 1988b) charcoal particles remain undisturbed and are able to record larger particles. As a consequence, Clark (1988b) recommends their use for the reconstruction of local fires. In addition to thin section analysis, sieving can be undertaken in order to select only large charcoal particles, for the investigation of 'local' fire history (Carcaillet *et al*., 2001).

3.4.4 - Charcoal measurement

There have been a variety of mechanisms employed to quantify charcoal under the light microscope. These include the counting of numbers of charcoal particles or the measuring of their area by means of point counts, classification according to size and also shape (Patterson *et al.*, 1987; Tolonen, 1986). Waddington (1969) was the first to introduce the measurement of charcoal particles in area size classes; this is now one of the most widely used procedures for counting charred particles (Tolonen, 1986).

Area determinations are undertaken in order to estimate the quantity of charcoal. The use of area has traditionally been believed to be preferable to simple number counts because in the latter, all pieces contribute equally to the final sum (Patterson *et al.*, 1987). In addition, by measuring area, different size classes can be created, although the number of size classes used varies amongst authors. Tolonen (1986) published an influential guide to basic charcoal analysis and stated that it is unnecessary to use more than two or three classes. If only the total particle area is required and not numbers of particles or any size distinction, then the rapid point count method (Clark, 1982), can be employed.

For overall estimates of quantity, Patterson *et al.* (1987) question the need to measure area, on the basis that total charcoal area has been seen to be highly correlated with the number of charcoal particles in pollen slides (Tinner and Hu, 2003). Tinner and Hu (2003) test this statistical relationship, finding that charcoal number concentrations can be used to predict charcoal area concentrations (Tinner and Hu, 2003). They conclude that the time consuming process of charcoal area measurement on pollen slides does not need to be undertaken. This is a rather definitive statement, where caution would probably be more appropriate. The review of charcoal analysis here has demonstrated that variability exists, primarily because no one fire is the same, and so blanket statements are difficult to make.

Tinner and Hu (2003) do recognise this point, using their predictive equation in other circumstances. For the vegetation types analysed (shrub tundra, boreal and temperate forests) the equation can be widely applied, assuming that the same pollen slide preparation techniques have been used. This is an encouraging result, but nonetheless, further replication is required and it is premature to place too much emphasis on this finding when we bear in mind the variability of fire dynamics. This may particularly be the case in time periods beyond the Holocene, when vegetation composition may have been non-analogous.

3.4.5 – Fire in the landscape

Our understanding of the actual dynamics occurring during a fire event remains somewhat limited, not unsurprisingly given the danger that a fire poses. Nonetheless, some generalities can be made and are well summarised in Moore (2000), primarily referring to forest fire. Briefly, there are three broad fire categories; 'ground fire' in which only the upper soil layer and litter burn; 'surface fire' in which only vegetation at or near to ground burns; 'crown fire' which spreads through the crown of trees. Strictly speaking, these definitions do not cover the full range of forest fire regimes. There are seven further categories, but such a level of detail is unnecessary here. Finally, it is important to recognise the inherent variability in fire regimes; no two fires are the same.

The controls of fire are: condition and availability; climate and weather; temperature; humidity; precipitation; and topography (Moore, 2000). Natural fires are usually free-burning, spreading through ignition points and lines (Moore, 2000). The 'head' of the fire moves at the greatest rate, the 'tail' the slowest and the 'flanks' have varying speeds. If a fire is moving slowly then it tends to be more circular in shape. Speed of movement is strongly influenced by wind, generally acting to increase the rate of spread, although it can slow the spread of a surface fire along its windward edge (Moore, 2000).

Slope has similar effects to wind on spreading rate. Topography is also important because landscape structure influences the response to fire. It affects the resource base and colonisation through the availability of species, their composition, population and migration (Moore, 2000); the greater the heterogeneity, the more variable the response.

Early views of ecology, particularly those of Clements (1916), saw ecosystems as being dominated by orderly, predictable succession. From this perspective, disturbances, such as fire, were external perturbations that interrupted succession. As the Gleasonian perspective (Gleason, 1917) gradually came to be adopted, disturbance could be more comfortably adopted into our understanding of ecosystem dynamics. The significance of disturbance has now become a dominant part of ecological thought, particularly as a result of research in the 1970s, such as the intermediate disturbance hypothesis of Connell (1978).

In some respects, fire can effectively be viewed as a herbivore: it consumes large amounts of plant material in irregular amounts of varying intensity and season (Bond and van Wilgen, 1996). Plant growth, survival and fecundity are influenced by fire, as are the dynamics of seeds and seedlings. However, as Bond and van Wilgen (1996) note, fire can have greater impacts than other forms of disturbance such as herbivory. For example, it is one of the few processes that can regularly kill mature plants and so, because openings provide a platform for vegetation, it plays a major role in structuring communities. Fire operates at a variety of scales, from the individual (e.g. germination, establishment of seedlings, mortality) to species and communities (e.g. invasion, extinction, succession, diversity changes) (Tinner *et al*., 2005). It is this wide ranging impact that makes it so significant.

Pollen and charcoal records are now beginning to contribute to this picture. On millennial timescales, Millspaugh *et al*. (2000) suggest that there is a link between varying fire frequency and climate. For example, when summer insolation decreased, climate became cooler and wetter and fire incidence decreased. This was the case irrespective of vegetation changes. Tinner *et al*. (1999) show that fire has played a major role in vegetation development in Switzerland over the past 7000 years. For example, fire reduced forest diversity, an interesting observation that has relevance for our understanding of the relationship between disturbance and diversity. Further examples of the influence of fire on vegetation communities can be found in a wide range of papers, including Carrion *et al*. (2003), Larocque *et al*. (2003) and Lytle (2005). On a global scale, Power *et al.* (2008) reconstruct changes in fire regime since the Last Glacial Maximum and note a broad global coherence, but with regional subtleties. When we consider the likelihood of global climate changes, this is a significant result. Further to this, Marlon *et al.* (2009) demonstrate that there can be substantial increases in fire activity as a result of rapid climate change, in this case the Younger Dryas.

Tinner *et al*. (1999) illustrates the relevance of palaeo-studies for appreciating modern ecological processes. They show that an increase in fire regime during the late Holocene in Switzerland shifted the mixed oak forest into a fire resistant alder-oak forest. Clark and Royall (1996) provide a further illustration of this in their reconstruction of northeastern North American fire regimes over the past 2000 years. They note that there was no evidence for fire in eastern North American mixed oak forest suggesting that fire plays a less important role in oak recruitment than previously believed in this ecosystem. In the UK, evidence of fire in temperate deciduous woodlands would be a highly significant finding. In his hugely influential book, Rackham (1986) argued that British woodlands do not burn. Demonstrating fire in these ecosystems in the past would be of considerable interest.

The Past Global Changes (PAGES) project is a major international project that seeks to understand the past in order to better predict the future. In the PAGES summary of terrestrial biospheric dynamics (Overpeck *et al.*, 2003), the crucial role that fire can play is recognised. It is therefore clear that palaeofire studies are highly significant. As no such studies have taken place in the Hoxnian and are rare in Pleistocene studies, the research here will fill a considerable gap. Moreover, it will fit well with the pollen based reconstruction of climate.

4 - Hominids in the Hoxnian

The final section of this thesis will discuss how the palaeoclimate data presented informs our understanding of archaeology of this period. There is a long history of research tying environment and climate with hominid activities and behaviour. External environmental factors are on an equal footing with social factors in illuminating the archaeological record at this time. To provide the background context for later discussions, the following sections outline the basic features of Hoxnian archaeology.

4.1 – The basics of Hoxnian archaeology

The Lower Palaeolithic archaeology of the Hoxnian period is dominated by the Clactonian industry and its relationship with the Acheulian industry. The Clactonian was first recorded at Clacton-on-Sea in Essex and the earliest definition was provided by Breuil (1932) who specified that it was based on flakes and cores and with symmetrically and bifacially flaked handaxes absent. The cores were worked in a rather *ad-hoc* manner to produce large flakes. The resulting cores were a variety of shapes and sizes, with differing degrees of reduction, whereas the flakes were either unretouched or made into crude, minimally retouched, scrapers. In some cases, the cores were slightly and partially bifacially worked into tools, but with no suggestion that a regular and symmetrical handaxe was the goal (Wenban-Smith, 1998).

The Acheulian industry is primarily characterised by abundant well-made symmetrical handaxes. Flake tools were a more minor, albeit still integral, component, and were presumed to be made on debitage from handaxe manufacture, although some unstandardised core and flake technology was also practised (Wenban-Smith, 1998).

In this original view, the Clactonian is technologically distinct from the Acheulian, and is often regarded as a typologically and technologically primitive industry displaying inferior technique and skill (White, 2000). Also, significantly, the Clactonian and

Acheulian did not just appear to be technologically distinct, but also separated in time. The Clactonian appeared to only be found in cold climate deposits, whereas the Acheulian was associated with interglacials.

These technologies were viewed in cultural terms: the parallel development of two industries used by culturally separate human groups. One group used a bifacially dominated technology and favoured warmer climes, whereas the other used exclusively core and flake technology in colder conditions (Wenban-Smith, 1998). The Clactonian has no close affinities with the Acheulian; rather it is ultimately related to the chopper technologies of Asia (White, 2000). It arrived in Britain from Asia, via central Europe, whereas populations from southern Europe introduced the Acheulian.

The important temporal distinction between the Acheulian and Clactonian was reinforced over subsequent decades of research, albeit with Clactonian artefacts being found early in the interglacial. The particular pattern suggested to Wymer (1974) that the Clactonian first appeared in the late Anglian or Earliest Hoxnian. The group manufacturing this industry settled in Britain during the pre- and early temperate periods (Ho I-IIb), being replaced by the Acheulian peoples just before the late temperate (Ho IIc). Wymer (1974) hypothesised that there may have been overlap and possibly even competition between the populations, though he later retreated from this position because of a re-assignation of the Acheulian material at Hoxne to the late temperate (Ho IIIb) (Wymer, 1983).

The cultural explanation very much held sway at the time of Wymer's publication. However, there were dissenting voices, in part motivated by theoretical developments in archaeology, of which Ohel (1979) was the first. Ohel (1979) argued that the Clactonian and Acheulian were actually different stages in the same sequence of reduction, taking place in different parts of the landscape. The Clactonian represented the early roughing out of handaxes and the Acheulian being the later stages of development and the finished tools.

McNabb and Ashton (1992) have also proposed a non-cultural explanation, based both on an analysis of the technology itself and also intriguing new stratigraphic evidence. From the technological perspective, they argue that the Clactonian and Acheulian are actually the two end members of a single continuum. The Clactonian is not a distinct entity in itself, rather the non-handaxe end of this continuum and part of a suite of core working techniques (McNabb and Ashton, 1992).

McNabb and Ashton (1992) have been able to unite the Clactonian and Acheulian by arguing that the two technologies overlap. There are typically Clactonian core and flake elements in many Acheulian industries and crucially, they argue, there are handaxes in Clactonian assemblages.

Ashton and McNabb (1994) believe that the definition of a handaxe is too constrained; they should instead be viewed as a continuum ranging between 'classic' and `nonclassic.' The latter refers to objects which have some shaping of the biface edge, but do not imply the deliberate imposition of a preconceived template. These nonclassic forms are found regularly in Acheulian assemblages but, even though they primarily form the basis for stating that handaxes occur in the Clactonian, they are scarce in Clactonian contexts. Ashton and McNabb (1994) also recognise the presence of a tiny number of classic bifaces in Clactonian material.

These arguments have been accepted in some quarters (e.g. Gamble, 1999) but attacked by others, particularly by Wenban-Smith (1998) who questions the provenance of these artefacts. According to Wenban-Smith (1998) only two of the handaxes were recovered from controlled excavations, at Little Thurrock and Barnham.

The material from Barnham poses the greatest challenge to the distinctiveness of the Clactonian. Ashton *et al*. (1994) recovered handaxe manufacturing scatters as well as an assemblage with a traditional Clactonian composition. Ashton *et al.* (1994) further claim that, although they were found some distance apart, they both come from the same horizon and geological context. The key question from Barnham is how strict the contemporaneity is between the Clactonian and Acheulian material. This is a difficult question to answer; Wenban-Smith (1998) suggests that they could in fact be separated by a considerable length of time, thousands of years, but this explanation smacks of rationalisation in the face of a challenge to a favoured hypothesis.

One of the most recent contributions to the debate comes from Lycett and von Cramon-Taubadel (2008). They make use of observations by Henrich (2004) that population declines in Australian aboriginals over recent millennia seem to have led to a loss of cultural elements due to imperfect copying. This is particularly the case where the skill level involved in a task is high. In a small population, it is more likely that chance events will determine whether cultural traditions can be transmitted. Based on this, Lycett and von Cramon-Taubadel (2008) argue that the Clactonian can largely be explained by demographic processes; it developed when populations fell below a threshold below which the more complex technologies of the Acheulian could not be maintained. They argue that this can explain the occasional occurrence of Acheulian material in Clactonian contexts. It is an intriguing argument and may help move the debate forward.

Ultimately, it is difficult to reach definitive conclusions about the status of the Clactonian. A conservative approach is appropriate; starting from the assumption that the Clactonian is valid (though some might argue that this isn't a conservative starting point), the challenge is to demonstrate this not to be the case. We must consider whether a small number of, mainly non-classic, items are adequate to falsify the Clactonian. In strictly Popperian terms, one handaxe would be sufficient but when considering that the concept of non-classic is controversial and that there are legitimate doubts about provenance, it is not yet reasonable to do away with the Clactonian. Furthermore, Barnham aside, the temporal distinction between handaxe and non-handaxe assemblages remains compelling evidence for discriminating between the Clactonian and Acheulian remains. The technological reformulations of McNabb and Ashton do not fully account for this observation, indeed they are in danger, as White (2000) notes, of explaining away the Clactonian, not explaining it.

4.2 – Human vegetation interactions

Mellars (1976) was one of the earliest models linking human activity with the palaeoenvironment and still remains an important template. In this model, manipulation of the environment is undertaken in order to increase faunal and floral resources. When an opening in the forest canopy occurs, there is an increased input of light to the ground, encouraging the growth of grasses, herbs and successional shrub species (Innes and Blackford, 2003).

Compared with an undisturbed forest, post-fire vegetation contains an increased plant resource base for humans. Vegetation regrowth also attracts animals and has greater nutritional value, thus encouraging expansion of game populations. Such effects are observed in modern times for elk, pig and particularly deer, amongst other animals (Innes and Blackford, 2003). These increased numbers are easier to hunt because they are more visible and cannot hide. Open ground also facilitates the movement of humans, an important aspect of hunting.

When a disturbance in the vegetation, associated with charcoal (microscopic), is observed and is in agreement with the basic changes predicted by resource management models, then human interference is inferred. Simmons and Innes (1996), describe this approach:

> "Disturbance of woodland vegetation is inferred from a combination of changes in pollen taxa and frequencies together with the presence of charcoal in organic profiles. Diminution in the quantities of forest trees such as *Quercus*, *Tilia* and *Ulmus* is accompanied by rises in species such as *Pinus sylvestris* and *Fraxinus excelsior* and genera like *Betula*. In the case of non-tree pollen, rises are usually detected in grasses and *Calluna*. Many herb types are also found either sporadically or as continuous curves."

This line of reasoning tends to be supported by considering the timing and frequency of such events, with empirical data on the relative paucity of lightning caused fire being seen as particularly important. This approach has received broad support within the archaeological and palaeoecological communities, though it should be recognised that the difficulties in directly establishing human interference are considerable, and much of the evidence used is 'unavoidably circumstantial' (Innes and Blackford, 2003).

The basic line of inference remains an important interpretive model. However, recently a number of workers have argued this approach is excessively simplistic. For example, opportunistic behaviour may well have been common; taking advantage of a naturally generated clearing rather than making the initial wholesale changes (Brown, 1997).

Moore (2000) also provides an alternative perspective on the basic model, in particular, drawing attention to the importance of sampling strategy and the need to identify a regional signal. Moore (2000) also argues that less emphasis should be placed on a peak in the charcoal record, with an increase followed by continuity in charcoal levels being more significant.

Ashton *et al.* (2006) argue that researchers in the Pleistocene ought to be looking for these sorts of signals. In view of recent developments demonstrating human control of fire during the Hoxnian (Preece *et al.*, 2006) it would be particularly interesting to see if this control extended to managing the landscape through fire. In light of the continual developments that indicate greater cognitive sophistication than previously thought (see below), this would be an intriguing additional dimension to this.

4.3 – Behavioural implications of Lower Palaeolithic archaeology

This section will discuss the implications of Lower Palaeolithic archaeology for the lifestyle, behaviour and cognition of ancient hominid populations.

4.3.1 - Archaeology and physical anthropology

The expensive tissue hypothesis (Aiello and Wheeler, 1995) provides a broad perspective. Aiello and Wheeler argue that the brain and the gut are both 'expensive tissues' and compete in their metabolic requirements, with gut size acting to constrain brain mass. Gut size itself is negatively correlated with diet quality and so for brain size to increase, high quality, easy to digest food is required. A shift to such a diet, with increasingly large amounts of animal products, was essential in the evolution of larger brain size.

Was meat derived through scavenging or was some portion obtained through active hunting? Roebroeks (2001) notes that the increase in brain size that occurred around 500 ka BP, just before the time period in question here, would have put both females and juveniles under increased energetic stress. It is around this time that greater co-operation between caring females and high quality food (fat rich game) is predicted by the grandmothering hypothesis (O'Connell *et al*., 1999). Furthermore, it is also around this time that the evidence for hunting of large mammals becomes a little clearer, as predicted by the expensive tissue hypothesis (Gamble, 1999). Aiello (1998) suggests that this may be the first sign of specialised division of labour between the sexes. Assuming this is accurate, these strategies suggest relatively sophisticated forms of social behaviour and organisation.

The strongest evidence for hunting during this period comes from the discovery of a throwing spear at Schöningen, Germany (Thieme, 1997). There is also evidence from the Hoxnian site at Clacton for a similar implement (Oakley *et al.*, 1977). As Dennell (1997) notes, both skill and time were required to produce the Schöningen spear. In his words, this indicates 'considerable depth of planning, sophistication of design, and patience in carving the wood.' The origin of spears has recently been pushed further back in the Palaeolithic, to approximately 500 kyr BP. Wilkins *et al.* (2012) report evidence for hafting of stone points to spears in South Africa.

Spears would have provided an efficient method with which to obtain animal meat in order to meet the energetic requirements of being a large-brained hominid. The kind of dietary change that occurred around this time would have necessitated a shift in the range behaviour of hominids, from a primate to a carnivore pattern (Gamble, 1999). The emergence of larger territories during this period finds support from raw material transport data, with distances of 28 km being regularly observed, compared to around 14 km previously (Gamble, 1999).

Humans are in many physiological respects, poorly suited to hunting, lacking strong olfactory and auditory capacities and limited speed (Roebroeks, 2001). As a consequence, both modern hunters and the hominids of the Hoxnian would have to use their superior intelligence. Knowledge of animal behaviour must have played a key role in the successful hunting of large mammals as would a general appreciation of the environment. Furthermore, Roebroeks (2001) points out, hunting likely required a strong evolutionary stimulus on cooperation and information sharing, particularly between different age groups. Education was required in order for a Pleistocene hunter to be effective; this required a complex form of interaction in order to transmit information and a move away from 'here and now' thinking.

Another broad perspective can be found in the social brain hypothesis (e.g. Dunbar, 1998). Dunbar finds a positive correlation between a range of indices of social complexity and neocortex volume in extant primates. An important aspect of the social brain hypothesis is that social group size is ultimately constrained by relative neocortex size (Dunbar, 2003). For the hominids that inhabited the Hoxnian landscape, group size would not have been significantly lower than that of modern humans, being around 120 persons (Dunbar, 2003). Such a group size exerts considerable pressure on social structure; to bind a social group requires sophisticated forms of communication such as language (Aiello and Dunbar, 1993). The large group sizes of around 500 ka BP seem unlikely to have been sustained without some form of language.

4.3.2 - Stone tools

The broad view of stone tool technology classifies technological change into a series of modes (Foley and Lahr, 2003). In the broad scheme of things, Mode 2 largely concerns us here (although the Clactonian is strictly defined as a Mode 1 technology) and covers the production of bifaces and bifacially worked handaxes. There is greater emphasis in Mode 2, compared to previously, on symmetry and regular form and it represents a major (albeit probably gradual) cognitive shift (Foley and Lahr, 2003). Greater planning and greater goal directed behaviour is implied by these tools and higher conceptual and cognitive abilities in general (Ambrose, 2001).

At the smaller scale, Hallos (2005) investigates the temporal aspect of Acheulian tool production from a number of European sites, including Elveden and Beeches Pit. Hallos' (2005) analysis of refitting sequences demonstrates that spatial and temporal fragmentation existed in knapping routines. In addition, the interruption of a reduction sequence was not random, being repeated throughout an assemblage, therefore indicating a consistent pattern of behaviour. These observations suggest that Hoxnian hominids had the ability to think ahead, with goals in mind.

A considerable amount of work inferring mental capabilities from stone tools has been performed by Thomas Wynn. Wynn (2002) concerns the significance of symmetry; bifaces, as opposed to Mode 1 tools fashioned for immediate use, would have actually existed in the mind of the user as a tool. By the Hoxnian, there had been further developments in biface symmetry, namely the development congruency, 3-D symmetries and broken symmetry (see Wynn, 2002) around 500 kyr BP. This suggests a significant advancement in appreciation of space, a development that unites archaic *Homo sapiens,* to a certain degree, with modern humans and our ability to navigate and map.

A note of caution must also be introduced: inferring any aspect of behaviour from the biased, incomplete, record left behind by hominids is a speculative endeavour. Coventry and Clibbens (2002) argue that the significance of symmetry requires further justification and caution that extrapolating from behaviour to cognitive ability needs to be undertaken with care.

Whilst alternative, non-cognitive, hypotheses must continually be considered and whilst the specific details may remain somewhat murky, it does seem reasonable to accept Wynn's (2002) argument that around 500 kyr BP, significant cognitive changes occurred. Certainly, major archaeological changes did occur at this time (Gamble, 1999). If alternative factors were responsible, then why are they not found at any particular time when tools were manufactured?

4.3.3 - Clactonian and Acheulian models

Raw materials are an important factor in the British record of this period (White, 1998). In terms of handaxes, White (1995) shows that pointed forms correlate with flint from river gravels, which is generally of poor flaking quality. More ovate forms are likely to have only been possible when a source of large flint nodules was available and ovate bifaces are indeed typically found in such contexts.

Despite this, there is a particularly unsatisfactory element when raw materials are tied too closely to tool development. There is strong evidence that raw material transfers were being carried out by hominids during this period of the Palaeolithic (Feblot-Augustins, 1997). It is difficult to believe that hominids, who were clearly capable of transporting material around the landscape, were unable to make a handaxe simply because they were not located directly next to an inviting outcrop of flint.

Wenban-Smith (1998) also considers raw materials as a significant variable, arguing that the Clactonian is an *ad hoc* technology that is appropriate for hominids in a flint rich landscape. This would be the case, he argues, in the early stages of the interglacial, when the landscape was covered in coarse fluviatile and outwash gravels as a consequence of the Anglian glaciation. On the other hand, when the landscape became more vegetated and the glacial gravels silted over, the *ad hoc* strategies would have been insufficient. There became the need for a more varied technology with a portable handaxe element that could be used in anticipation of future use. In other words, a drift in cultural practices (as opposed to two distinct cultures) occurred from the early Clactonian to the later Acheulian period.

Wenban-Smith's (1998) hypothesis appears to be somewhat simplistic, producing a neat dichotomy in environmental conditions that is unlikely to have been the case. It is unlikely that there would not have been times and localities during the warmer part of the interglacial when raw materials were relatively freely available. White (2000) argues along similar lines, noting that there should reasonably be spatial not just temporal variations in the Clactonian-Acheulian pattern, with both being found throughout the interglacial, according to the availability of raw materials. The briefest survey of Hoxnian sites reveals this not to be the case. It is interesting, however, to note the overlap between the technologies at Barnham; perhaps this could be interpreted as evidence of a cultural transition.

Mithen (1994) argues that hominids in open environments will congregate in larger groups because of the increased risk posed by predators and also because of wider distribution of food. Strong bonds will result from interactions with predators and the interpersonal problems that develop in large groups. As a consequence, the transmission of information through social interaction is particularly strong, enabling the supposedly more complex technology of the Acheulian to be produced. Conversely, in forested environments, with less chance of encounters with predators and the smaller patches of food, hominids will form smaller social groupings. The stresses imposed by living in a large group are reduced and so social learning is decreased. It then becomes more difficult to manufacture 'complex' tools and the Clactonian is the result.

McNabb and Ashton (1995) attack this hypothesis, noting that it is simply not the case that Acheulian artefacts are exclusively associated with open environments and Clactonian with forested. This picture has only been strengthened with recent mammalian environmental reconstructions (e.g. Schreve, 2001a). Mithen (1995) makes only a cursory attempt at refuting this point. However, White (2000) makes the case that not everything from Mithen (1994) must be discarded; arguing that handaxes in the Acheulian do show fundamental differences in socially maintained knapping repertoires.

In the Ashton and McNabb (1994) model handaxes are viewed as problem-solving devices. If a particular problem required their usage then they will be present at a particular site, thus arguably indicating a degree of mental flexibility. Clactonian sites, rather than representing an entirely separate technology, are simply those localities where handaxes were not deemed necessary by the hominids. However, White (2000) notes the rather odd fact that, in this view, similar riverine environments would have been used for considerable periods of time, for different tasks, some using handaxes, others not.

Ashton (1998) updates this model with a significant role for raw materials, producing the static resource model. The stone tools left at a site would reflect the nature of the resources; valuable static resources would lead to repeated visits and actions in a single location, whereas more mobile resources (e.g. animals) would lead to a series of discards representing few or single events.

Ashton (1998) argues that at Barnham, raw material as a static resource provides a good explanation for the overall pattern of lithic distribution, although mobile resources become more important further away from the raw material source. However, White (2000) observes that the model functions well at Barnham and Elveden, but is less comfortable at a variety of other locations. It seems as though we are still searching for a full understanding of the archaeology of the Hoxnian interglacial.

5 – Methods and Materials

The central component of this research consists of a pollen based temperature reconstruction for the Hoxnian, based on newly sampled cores and data derived from the published literature (see appendix). Furthermore, charcoal analysis is applied to new Hoxnian cores in order to generate a fire history. Finally, pollen modelling techniques are employed in order to provide a fresh ecological perspective on palaeoecological data. The methodology describes the site selection criteria, the techniques employed to derive pollen and charcoal data from the newly sampled cores, the approach taken to extract data from publications and the palaeoclimate and palaeoecological modelling approaches taken.

5.1 – Site Selection Criteria

Clearly the principle consideration with regard to site selection for this study must be the likelihood of a Hoxnian/MIS 11 age. As discussed in Section 2.1 it is easy to select sites with a Hoxnian pollen signature, but this does not necessary mean that they correlate with MIS 11. It is now widely recognized that some sites that have been assigned to the Hoxnian on the basis of pollen actually correlate with interglacials other than MIS 11 (e.g. Scourse *et al.,* 1999).

Establishing this MIS 11 age and developing chronologies in general in terrestrial Middle Pleistocene research comes up against the inevitable constraints imposed by limited age control and imperfect dating methodologies. Very few sites are dated by absolute methods and so there is a heavy reliance on relative dating techniques, many of which have been the subject of considerable controversy and historical revisions as new evidence has come to light. Confidence in site selection on age grounds can never be as secure as for younger periods. Nevertheless it is possible to sensibly assign ages to sites during this period, providing a sound basis for conducting research into the Hoxnian and Marine Isotope Stage 11.

In two cases, Hoxne (Grun and Schwarz, 2000) and Marks Tey (Rowe *et al.*, 1999), there are reliable absolute age estimates to go alongside relative dating approaches. In the other five cases, the age can be established less definitively. Thomas (2001) outlines two lines of evidence that suggests the sites presented here that are not absolutely dated can be assigned to MIS 11. Firstly, interglacial sequences of the type presented here typically lie in basins associated with glaciation. Assuming no major stratigraphic gap exists, it therefore follows that the interglacial sequence will represent the MIS after the one to which the glacial sediments are assigned. The major swathes of glacial sediments in East Anglia are assigned to the Anglian, which is generally believed to correlate with MIS 12 (Bridgland, 1994), therefore the sites from this region used here correlate with MIS 11. Sites in the Midlands are less clearly associated with an Anglian/MIS 12 glaciation and so the above logic cannot be applied.

Secondly, the Non Arboreal Pollen Phase (NAPP – see section 2.2.1) is thought to be unique and therefore enables sites where it is recorded to be assigned to the same interglacial. This enables sites outside East Anglia, such as those in the Midlands, to be correlated with those in East Anglia that are more confidently associated with MIS 11, on the basis of NAPP presence. This approach is potentially open to charges of circularity, though it is a fairly common form of stratigraphic reasoning. Moreover, the fact that the NAPP appears in a similar part of the pollen sequence at each site (and the similarity in sequence is established by other features of the pollen diagram, rather than the placement of the NAPP) is strongly suggestive of shared age. It would be an unusual coincidence if the same feature appeared at the same point in different interglacials, although this is possible if there was a commonality in external forcing of such events in multiple time periods. Nevertheless we must find some basis on which to proceed and this is a reasonable one.

It should be noted that there has recently been considerable debate surrounding the age of East Anglian glacial sediments that have previously been correlated with MIS 12. An alternative to the traditional model has been developed that invokes glaciation during Marine Isotope Stages 16, 12, 10 and 6 (Hamblin *et al.*, 2005). There are a number of lines of evidence and arguments used in support of this. Crucial to this was the discovery of erratics, heavy minerals and till balls all of glacial derivation at the Leet Hill site (Lee *et al*., 2004). Leet Hill lies beneath Anglian sediments (Lowestoft Till) and so a pre MIS 12 age for these deposits and the Happisburgh glaciation in particular was suggested. Ages have been assigned based on correlation with a river terrace model, assuming major terrace formation every 100 kyr (Lee *et al.*, 2004).

This debate remains ongoing, although recent dating evidence is weighted towards the traditional model, as summarised by Preece and Parfitt (2012), who present a strong defence of the correlation of East Anglian glacial sediments with MIS 12. This provides us with confidence that the reasoning above regarding interglacial sediment age is reasonable. It is also important to be aware that the alternate glacial stratigraphy presented by Hamblin *et al* (2005) still correlates the Lowestoft Till with MIS 12. The East Anglian lacustrine sites analysed in this thesis that are not independently dated are all underlain by Lowestoft Till. Therefore we have additional confidence that they are MIS 11 age.

In summary, sites are chosen on the basis of (1) association with the immediately-preceding Anglian glaciation and (2) NAPP presence. There are sites with a Hoxnian pollen signature that are not so intimately associated with Anglian age sediments, for example channel fills such as at Tillingham (Roe, 2001). However, unless there is independent and reliable dating, they cannot be accepted. Indeed recent work has demonstrated that a channel with a Hoxnian pollen signature in Essex correlates with MIS 9 (Roe and Preece, 2011). A site in East Anglia associated with the Anglian and without the NAPP would be considered, although the NAPP is preferable. Outside East Anglia, the NAPP must be recorded. The strong emphasis on the presence of the NAPP is also justifiable in a wider sense because of the clear and distinctive nature of this disturbance. Investigating the event therefore potentially has considerable scientific merit, beyond its use as a biostratigraphic tool.

Other considerations are relevant to site selection, such as temporal completeness, geographic coverage and replication. In the former case, there are numerous sites with a Hoxnian pollen signal. A full list can be found in Thomas (2001), which illustrates that the vast majority of sequences are either short or fragmentary. The aim of the present study is to reconstruct the major climatic trends of this period, therefore only sites with substantial temporal coverage are appropriate. Or, more precisely, only sites that span a significant number of pollen zones have been selected. The sites and their associated pollen zones are:

- Athelington – Ho II to Ho IV
- Barford – GI to Ho III
- Hoxne – Gl to Ho III
- Marks Tey – Gl to Gl (spans entirety of Hoxnian)
- Nechells – Gl to Ho IV
- Quinton – Gl to Ho IV
- St Cross South Elmham – Ho I to Ho II

The above descriptions are illustrative only; for example not all of Ho I is recorded at St Cross South Elmham. In addition, Elveden is chosen for the potential to compare to the archaeological record. The following map shows again the location of these sites:

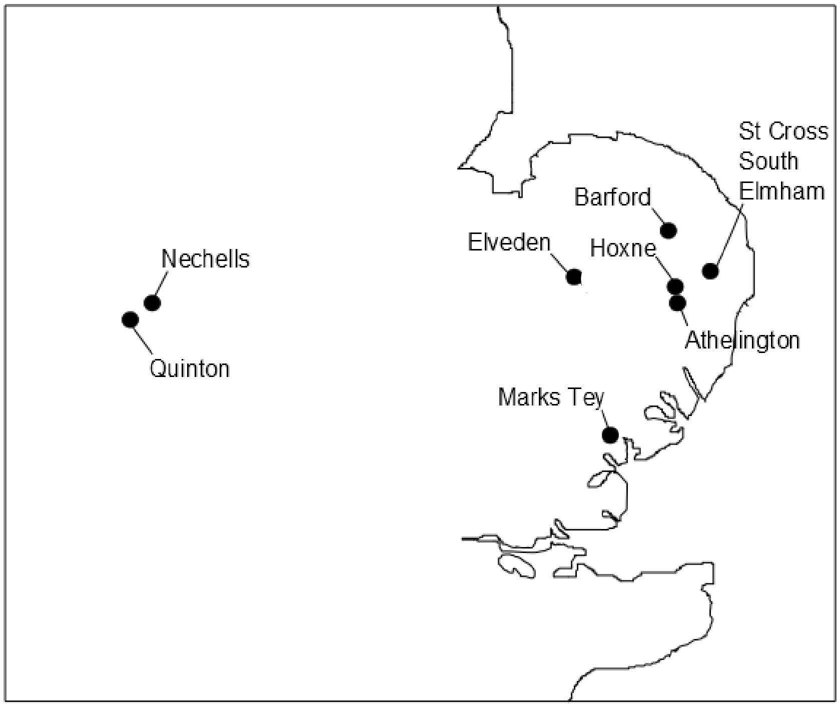


Fig 4: Map showing the location of sites used in this investigation.

The shortest of the above sequences is St Cross South Elmham, which bears comparison in terms of coverage of pollen zones (if not necessarily time) with other localities such as Shoeburyness and the Nar Valley. Indeed it is at the lower end in terms of pollen zones spanned, and much lower would render it inadmissible for the purposes of this study. However, crucially, and in comparison with the similar sites mentioned previously, it contains the Non Arboreal Pollen phase. Quendon was a candidate for inclusion and indeed has a slightly greater pollen zone span than St Cross South Elmham. However, it lacks the NAPP and on balance was rejected as it is not of sufficient length to outweigh the lack of NAPP.

In the case of geographic coverage, there are severe restrictions posed by taphonomic processes. Hoxnian deposits representing a significantly long interval are largely deposited in former lake basins outside the margins of subsequent ice advances. There is a particular concentration in East Anglia, which is the most taphonomically favourable region due to the long term processes of subsidence that it has been experiencing. Preservation has also been possible in the Midlands (which may enable an investigation of east-west gradients), however ultimately we are left with relatively restricted geographic coverage. Nevertheless, a regional picture is being presented: this has the advantage of lessening the possibility of peculiar local signals and promoting the likelihood that genuine signals, of wider significance are being reconstructed

Were this research to have been conducted in previous decades, it would have been possible to extend this gradient and geographic coverage by incorporating Gortian sites in Ireland. However, recent research is much more equivocal over the age of sites assigned to the Gortian period. The sites have a Hoxnian/Holsteinian pollen signature, but absolute ages fail to correlate them with MIS 11. Dowling *et al.* (1998) provide amino acid dates suggestive of an MIS 7 age, whereas U-series dating indicates MIS 5e. The authors ultimately argue that some Gortian deposits may represent MIS 7, whereas others can be correlated with MIS 9 and MIS 11. However, there is sufficient uncertainty to mean that these sites cannot be used.

Finally, although this does not strictly speaking cover why specific sites were chosen, it is important to discuss the number of sites selected. Seven were chosen in order to maximize the chances for replication and ultimately place any conclusions on a firmer basis. In any palaeo study there will inevitably be tension between the ideal basis for testing a hypothesis and the quality of the data available. There are, simply put, only a limited number sites of sufficient length available for study. In order to replicate results, minimising the likelihood that a particular observation simply results from chance, or from local site processes, the maximum number of relatively lengthy sequences were chosen

5.2. Site background, sediment sampling and core description

This section provides details on the sampling undertaken at Hoxne and Athelington and the sediments recovered from coring. Although it is difficult to precisely map out the dimensions of vanished palaeo lakes, in some cases, particularly at Hoxne, we have a reasonable idea of the size and shape of the basin. The recommended strategy is for coring to be undertaken as close to the deepest part of the lake as possible (e.g. Whitlock and Millspaugh, 1996) and this was possible in the case of Hoxne. In the case of Athelington, the basin dimensions are much more uncertain. It is probable that more marginal deposits were cored.

5.2.1 – Hoxne

A considerable number of investigations have been carried out at Hoxne over the past two centuries, with the former brick pit ultimately becoming the type site for the Hoxnian interglacial (grid reference TM 176767). Being the type site makes in highly appropriate as one of the cores from which primary data was analysed for palaeoclimate reconstructions.

A more detailed overview of the site is provided in section 2.2.3, briefly however, previous research has established the following broad sedimentary sequence, with the names of units following West (1956):

- Stratum G – a thick (up to 7.5 m) chalk rich boulder clay representing glacial till, in places overlain by a sandier deposit likely formed by solifluction in the cold climate that followed the disappearance of the local glaciers
- Stratum F – a relatively thin deposit that varies depending on the location in which it is found, but represents lacustrine deposition under cold climate, late-glacial type conditions. In more central parts of the lake, it is observed as a clay deposit, slightly sandy in places, with a layer of chalk pebbles and some irregular lamination. In more marginal localities it appears a unit that is fairly organic (twigs and then above this abundant seeds) rich towards the base, overlain by a shelly clay-mud.
- Stratum E – a thick clay deposit, almost entirely homogenous and unvarying, representing deposition in reasonably deep water, under interglacial conditions
- Stratum D – a relatively thin, extremely organic rich deposit with small quantities of clay and silt. Represents the formation of peat as the lake dried out, still under interglacial conditions
- Stratum C – a deposit of intermediate thickness (up to 3m) consisting of a sandy-silt

at the base, with a considerable amount of organic matter, fining up into a laminated silt. The latter sediments also contain reworked material from Stratum E in the form of small balls (up to 1 cm) of clay.

- Stratum B – a deposit of intermediate thickness (up to 2m) composed of stratified clay, sand and gravel. Layers of sorted chalk pebbles also recorded. Some debate as to the formation of this unit, with West (1956) arguing for solifluction but Ashton et al (2008) favouring a fluvial origin.
- Stratum A – generally subdivided into two units:
    - Aii – a varied deposit, consisting, of three distinct sediments; sand and clay, sand or a sandy gravel. West (1956) argued that the latter likely represents a glacial till, whereas the former two types of sediment he viewed as somewhat more enigmatic but also deposited in a cold climate. Ashton et al (2008) describe this unit as representing alluvial deposition
    - Ai – thin (c 60cm) and consisting of fine sand seemingly deposited in a periglacial climate

As discussed, this represents a relatively basic overview of the sedimentary sequence and the main units present. Ashton et al (2008) present the latest and more nuanced perspective (see 2.2.3).

The core analysed in this thesis was collected during excavations between 2000 and 2003 undertaken by Simon Lewis, Nick Ashton and Simon Parfitt, as part of the AHOB Project. The following figure shows the location of the most recent work alongside the extensive investigations carried out in the 1970s and earlier. The core used in this investigation is BH 02/1.

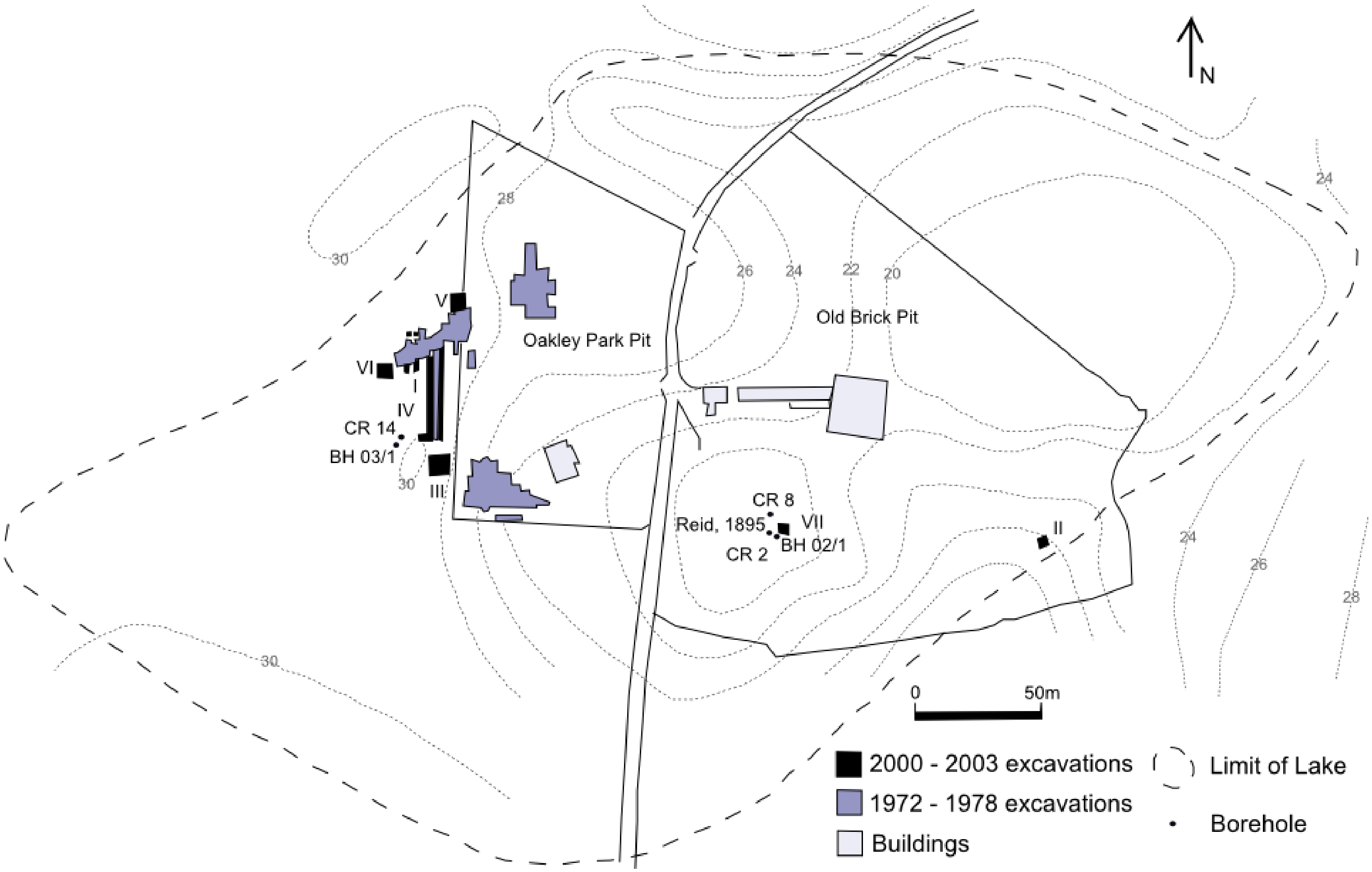


Fig 5: Site diagram for Hoxne (drawn from Ashton *et al.*, 2008)

The following photograph shows the drilling underway and presents a general impression of the modern state of the site.

Fig 6: coring underway at Hoxne

The following table provides a description of the sedimentary units observed within the core at Hoxne. They closely reflect those already described at the site by previous workers.

Depth	Description
0-130 cm	A laminated, dark olive grey (occasionally dark olive brown) deposit, composed principally of silt. A small number of discrete layers (up to 0.8cm) of fine sand are recorded periodically, particularly towards the top of the unit. The thickest of these fine sand layers also contains small, woody organic fragments. There are regular occurrences of organic material, particularly between 40 and 80 cm. Some of the organic material is substantial in size, with one

	wood fragment 2cm in length. There is also a discrete organic layer at 30cm. The sequence becomes slightly finer towards the top and calcium carbonate was present throughout. Lies unconformably on the unit below. Correlates with Stratum C.
130-200 cm	A black layer, highly organic rich throughout. Towards the base of the unit, the sediment is composed almost entirely of organic material (often quite loosely compacted together), some of it relatively large (up to 1.5 cm). The non-organic content increases slightly towards the top and consists of clay-silt, still with very abundant organic material. Calcium carbonate present where non-organic sediments occur. Correlates with Stratum D
250-830 cm	An entirely homogenous very dark greyish brown clay. No primary structure or stratification observed. Sediment has become brecciated and blocky during post deposition. Correlates with Stratum E

Table 1: description of the sediments in Hoxne borehole BH 02/1

The initial pollen sampling resolution of the Hoxne core was approximately every 16 cm so that the presence of charcoal and the overall nature of the pollen stratigraphy could be determined relatively rapidly. Higher resolution sampling followed the coarse initial scan, with the core being sampled closer to 8 cm resolution. This sampling strategy ultimately is comparable to that undertaken in fire and vegetation studies on Holocene samples. The sampling interval was not precisely fixed due to the discontinuous nature of the core; the coring process produced short, 10cm gaps between each individual section. Additionally, it proved difficult to sample parts of the heavily organic rich unit due to the often loose nature of this material. In Stratum C, care was taken to avoid sampling reworked clay balls, but no such material was observed in this study. A sediment log for the Hoxne core can be seen in Figure 7

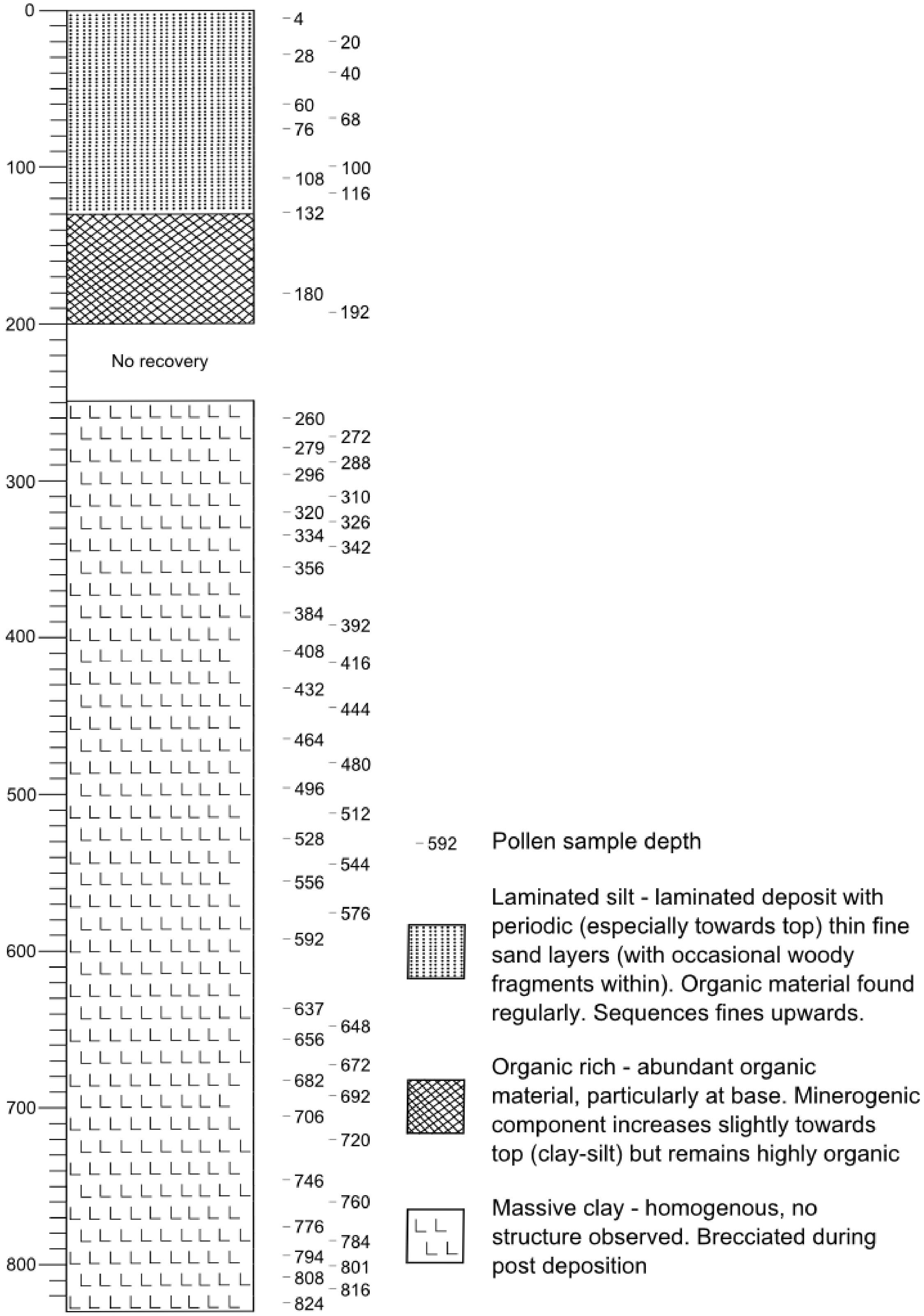


Fig 7 – sediment log for the Hoxne core BH 02/1

5.2.2 – Athelington

Athelington is another former Brick Pit, containing a Hoxnian interglacial lacustrine sequence (grid reference TM 222710). It was chosen as the second site for primary data collection because of its close geographic proximity to the type site at Hoxne, couple with the likelihood of recovering a greater portion of the interglacial. In addition, the site, currently a grass field, is readily accessible and relatively practical to sample, in contrast to a location such as Marks Tey, which would require a major logistical effort.

Previous research at Athelington by Coxon (1985) established the presence of a lake basin lying on Anglian age Lowestoft Till. The lake was a low energy environment (and became even lower, signified by increasing clay content) with sand lenses representing occasional higher energy inputs. Towards the latter stages of the interglacial, during Ho III, the lake appears to have become shallower or possibly even dried out at times before eventually reverting back to a deeper low energy lake environment by the end of the interglacial. Despite drilling a number of boreholes, Coxon (1985) was unable to precisely and accurately map the spatial extent of the palaeolake.

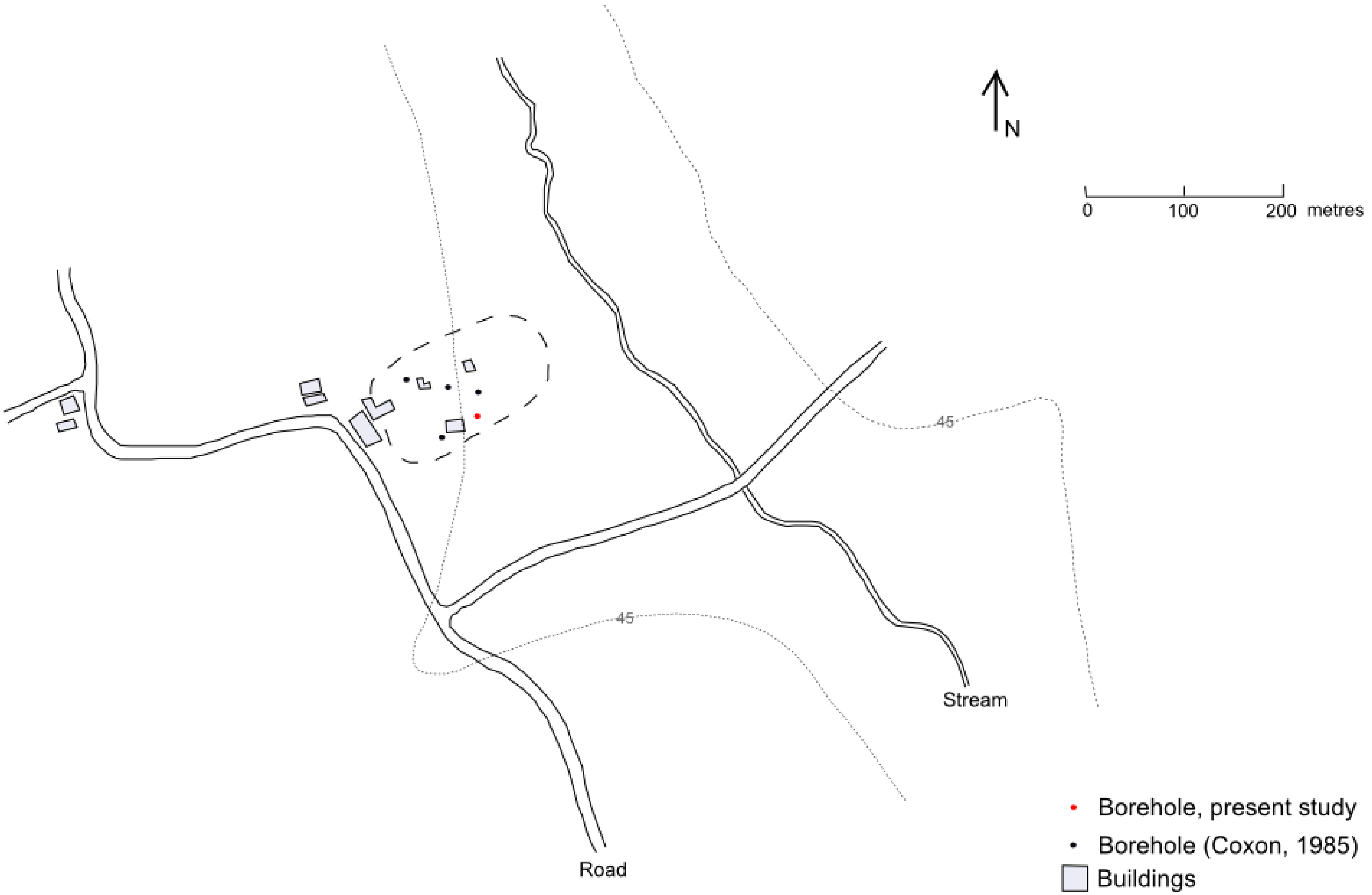


Fig 8: Site diagram for Athelington (adapted from Coxon, 1985)

Sampling at Athelington proceeded somewhat differently to that at Hoxne. The location of the coring site was partly constrained by the permission given regarding drilling location and the likelihood of sediment recovery based on existing information on the geometry of the basin (Coxon (1985). Boreholes were drilled for this research project using COBRA-driven window sampling system. A number of boreholes were begun but had to be abandoned due to the heavily waterlogged nature of the sediment. The final borehole (see red borehole in Fig 8) successfully recovered 4 m of sediment which was suitable for sampling, from 440 cm down.

No actual cores were taken and curated; rather, samples were collected in sample bags in the field, every 4 cm within a given length of core, although such a regular interval was not always possible. However, as preservation of pollen in the Athelington material is not always optimal, the final pollen sampling resolution proved to be lower than the 4cm sampling regime followed in the field. The following table provides a description of the sedimentary units observed within the core from Athelington (Table 2). A sediment log can be observed in Figure 9.

Depth	Description
440-540 cm	A massive greyish brown silt unit. Contains occasional flint nodules, randomly distributed
540-650 cm	A massive greyish brown silt unit. Contains abundant quantities of chalk, distributed at random throughout.
650-700 cm	A black, highly organic rich, peat like unit. Contains a number of large (up to 1.5cm) woody fragments in amongst the generally organic nature of the sediment.
700-730 cm	A massive dark olive grey silt unit. Contains abundant quantities of flint, distributed at random throughout.
730-840 cm	A massive, very dark greyish brown clay. Occasional discrete, small pockets of organic rich material (woody fragments), distributed reasonably evenly throughout the unit although increasing somewhat in frequency towards the top.

Table 2: description of the sediments in the Athelington borehole

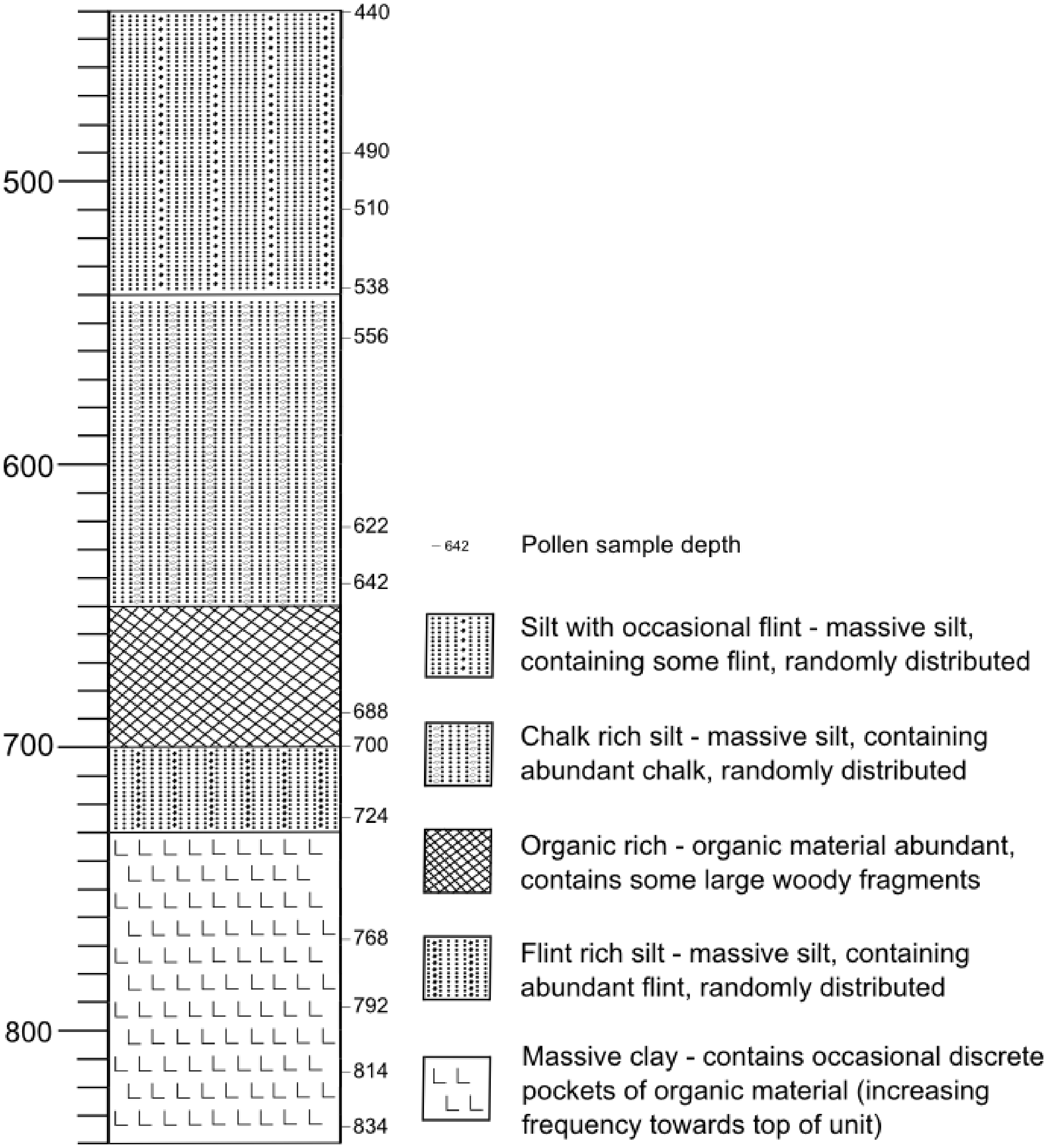


Fig 9 – sediment log for the Athelington core

5.3 – Charcoal sampling

5.3.1 – Charcoal identification

Most analysts tend to be conservative when identifying charcoal, restricting themselves to black, completely opaque, angular fragments (Clark 1988b). This convention was adopted here. This helps to sidestep some of the difficulties in charcoal identification. Ambiguity results from turbulence resulting in local oxygen deficits and incomplete combustion, leading to a gradation in fragments from unburned to black ash (Clark 1988b).

5.3.2 – Microscopic charcoal

Pollen slides were used for microscopic charcoal analysis. The use of pollen slides confers certain advantages, particularly on the practical side because no additional sample preparation is required and counting is straightforward. Furthermore, pollen slides enable the direct comparison of pollen and charcoal and therefore enable a much easier and reliable evaluation of the impact of fire on the vegetation. For this reason we can reject alternative methods such as thin section analysis and the pollen slide non-destructive method of Rhodes (1998).

There are two possible forms of measurement available for charcoal measurement on pollen slides; the point count method and charcoal area size classes. Point counting was adopted in this thesis. Point counting, as applied to micro-charcoal, was first developed by Clark (1982). It applies algorithms to estimate with the total area of charcoal on the slide and is not subject to the vagaries of the preparation process. Moreover, it is quick and efficient, typically taking less than thirty minutes per slide.

Point count techniques are widely used in microscopy to estimate the area of a particular inclusion on a plane. For the mathematical details, refer to Clark (1982), however simply put, by applying a number of points to a plane surface, the ratio of the number of points intercepting a particular phase within that surface to the total number of points is a measure of the areal density of that phase. Areal density is the ratio of the area of the phase to the area of the plane. The area of the phase can then be estimated from the total area of the plane surface.

In practical terms, charcoal represents the phase and the microscope the plane surface. The total area of charcoal can therefore be determined mathematically. A grid, in the form of an eyepiece reticle, was used in conjunction with the microscope and transects were taken across the slide. Clark (1982) recommends more than one transect is undertaken; two was the standard used here. Charcoal in a field of view was noted; when a point on the reticle falls on charcoal, this was recorded, as was the number of fields of view on a given slide and the total number of points applied (irrespective of whether they intersect with any charcoal). This data provides the requisite information to calculate the area of charcoal (Clark, 1982), which can then be expressed in terms of the volume of the sample, which is standardised (see pollen methods below).

Charcoal area size classes were rejected because of the potentially serious limitations inherent to this approach. For example, Rhodes (1998) points to the inherent destructive nature of the pollen preparation process and argues that this will introduce bias into area classes through the breakup of charcoal particles. This argument has essentially never been addressed by proponents of the size class technique and lessens confidence in the approach.

An additional concern regarding size classing is the actual value of the data obtained (assuming the size classes are not artefacts). It must be questioned whether there is sufficient theoretical or empirical evidence to support clear links between the separate size categories and distance from the fire. A limited amount of empirical research has been undertaken in this regard and the results are suggestive of some validity (Blackford, 2000). However this is not sufficient to justify significant confidence in the approach, particularly considering that this research concerns heathland areas and may not be applicable to large lake systems with their inherently complex taphonomic processes. Taking these points into account, it is appropriate to employ point counting, a method that avoids such limitations.

5.3.3 - Macroscopic charcoal

Macroscopic charcoal was analysed from sieved residues and sampling took place, where possible at continuous 1 cm intervals in recognition of the fact that high resolution analysis provides the best indication of the frequency and concentration of charcoal. However, such a high resolution approach was only possible for the top of the Hoxne core. Individual spot samples were taken elsewhere. The methodology is as follows.

1) Core samples of 1cm thickness taken, each with a volume of 2.5 cm^3.

2) Sample dispersed in 5-10ml KOH solution and left overnight.

3) Supernatant liquid poured off and discarded after the sediment had settled.

4) Material re-suspended in very dilute Sodium Hypochlorite (4-6%) solution and left overnight. This bleaches the organics excluding the charcoal.

5) Sample mixed well and wet sieved through a 250 µm sieve.

6) The solution was poured into a petri dish with graph paper underneath and placed under a microscope. The angular black (opaque) particles were counted. If there were few, all were counted; if there were many, counts were made on a proportion of randomly selected squares on the graph paper and the total charcoal fragments per sample were calculated from this.

5.4 – Pollen analysis

The rationale behind the use of pollen slides and their relationship to charcoal analysis was described above. Therefore what follows is a description of the analytical technique used. The basic steps in pollen analysis are well described in a number of sources, with probably the most commonly used example being Moore *et al.* (1991). Broadly speaking this was the methodology adopted here. Nonetheless most pollen analysts have their own particular deviations from this standard and so it is appropriate to spell out the approach.

Prior to sampling, all equipment was washed thoroughly with distilled water and the surface of the core was scraped off in order to remove modern contamination. The samples were then, where possible, taken from the centre of the core.

The Hoxne core is brecciated in places and this necessitates certain compromises when sampling. In order to maximise stratigraphic confidence, samples were taken from the large, coherent, blocks that exist in the breccia; these are unlikely to have moved vertically through the profile. If no such block exists then the nearest one, at 4 cm intervals, either side of the desired sampling point was used. Finally, because all cores are separated into distinct sections with gaps in between, sampling must take account of this. Because of the possibility of contamination at the top of a core section, samples were not taken from the very top or bottom; the nearest 4 cm was again used. Because of the gaps, a rigid sampling frequency was not possible.

After the extraction of the sample, the following steps were taken:

1 cm^3 of sample added to 15 ml centrifuge, along with a *Lycopodium* tablet.

1. *Removal of calcium*

   10 ml of 10% HC1 added to the sample and mixed. Once effervescence stopped, tube was placed in a water bath at 70°C and stirred until effervescence again stopped. Acetone was squirted in if the tube threatened to froth over. The sample was then centrifuged (3000 r.p.m. for 4 minutes) and the supernatant decanted. If the sediment was highly calcareous then this step was be repeated, two or three

times if necessary. Finally, the sample was washed with distilled water, centrifuged and decanted.

The water bath temperature and centrifugation time and speed was applied throughout pollen preparation. Furthermore, at every stage, the sample and chemical was thoroughly mixed before being centrifuged.

2. *Removal of humic acid*

   10 ml of 10 % KOH was added and the sample was placed in a water bath for 5 minutes and stirred occasionally.

3. *Removal of organics*

   The sample was strained and washed through a fine mesh screen (170-180um) into a 50 ml centrifuge tube. The residue on the sieve was washed thoroughly with distilled water to ensure the maximum amount of pollen passed through. The sample itself was then centrifuged and decanted and then washed and centrifuged at least 5 times with distilled water until no trace of brown colour remained in the supernatant. At this point, the sample was transferred back to the 15 ml centrifuge tubes.

4. *Removal of silicates*

   10 ml of 10% HCL was added. The next step depended upon whether mineral matter was present in the sample. If not, then the procedure moved to step 5 following addition of HCL. The necessity of HF digestion in a given section of core was determined by trial and error during initial sampling.

   If mineral matter was present, then the sample was treated (in an appropriate fume cupboard) with 10 ml of 40% HF. It was then placed in a water bath for 20 minutes, being stirred occasionally. Upon removal from the water bath, methanol was added to reduce the specific gravity and the sample then centrifuged and decanted (into a sodium carbonate neutralising solution). Next, 10% HCL was added to the sample, filling the tube half way, which was then placed in the water bath for 20 minutes (and stirred occasionally). Upon removal, the sample was again centrifuged and the colour of the supernatant noted. If it was yellow (or green) then the procedure was repeated with fresh HF. Otherwise, following decanting, preparation continued with 10 ml of distilled water being added and then centrifuged and decanted.

5. *Removal of water*

This step was necessary prior to acetolysis because the acetolysis mixture reacts very violently with water. 10 ml of Glacial Acetic Acid was added to the sample, centrifuged and decanted. This step was then repeated.

6. *Removal of cellulose*

Erdtman's Acetolysis Solution was used during this step and was produced by mixing 9 ml of Acetic Anhydride and 1 ml of concentrated sulphuric acid. This solution was then added to the sample which was then placed in a water bath for 3 minutes, being stirred halfway through. The sample was removed from the water bath, Acetic Acid added, centrifuged and decanted. A further 10 ml of Acetic Acid was added and centrifuged and decanted.

7. *Mounting*

10 ml of Tertiary Butyl Alcohol (TBA) was added, centrifuged and decanted. Subsequently, a minimum amount of TBA was introduced and the sample washed into a separate, labelled, vial. This vial was left in a fume cupboard, lightly sealed with cotton wool and left until the TBA evaporated. Care was be taken to ensure that the sample did not dry out excessively. Finally, silicon oil (200 cs viscosity) was added in an amount equal to the remaining sediment. The sample could then be placed onto a slide using a toothpick, with a cover slide then placed over the top. The slides were then housed in standard pollen analysis storage sleeves.

5.5 – Data collection from published material

To supplement the palynological analysis described in the previous sections and provide data for palaeoclimate reconstruction it was necessary to extract data from previously published pollen diagrams. Attempts were made to contact surviving authors for raw pollen data, however these attempts were unsuccessful.

Diagrams found in the following sources were used (see pages 441-450 in appendix):

- Barford
    - Phillips (1976)
    - Figure 26
- Marks Tey
    - Turner (1970)
    - Figures 7, 8, 13 and 14
- Nechells
    - Kelly (1964)
    - Figure 11 (page 560) and Figure 12 (page 561)
- Quinton
    - Coope and Kenward (2007)
    - Figure 2
- St Cross South Elmham
    - Coxon (1984)
    - Figure 61

The palaeoclimate reconstruction methodology employed is based on the presence or absence of taxa. Therefore it is not strictly necessary to be able to establish the precise quantities being plotted on a given pollen diagram. Simply recording whether or not a particular pollen type was recorded is sufficient. Nevertheless, to provide additional confidence in the robustness of this process, a series of trials were performed, where attempts were made to establish the detail of a number of pollen diagrams and reconstruct the exact pollen percentages recorded.

Marks Tey was chosen as the first such example due to its importance as a data set for the British Pleistocene. Turner (1970) presents a number of pollen diagrams from Marks Tey There is no single sequence that covers the entire interglacial and so Turner (1970) achieved complete coverage through a composite of separate cores.

The most comprehensive temporal span comes from the borehole Marks Tey 1A, for which the pollen diagram is recorded in Figures 7 and 8 of Turner (1970). 1A begins in a cold period assigned to the end of the previous glacial and then continues uninterrupted to some way into Ho IIIb. It was therefore a simple choice to select this sequence for analysis.

Marks Tey 1B records only Ho III and the post interglacial cold sediments and can therefore be rejected. Marks Tey II contains Ho III, Ho IV and the glacial, however Ho IV is lower resolution due to brecciation and a has limited coverage of Ho IVb and is therefore sub-optimal for use in palaeoclimate reconstructions. The most suitable borehole to complete the top of the Marks Tey composite sequence is Marks Tey III, which spans at a reasonable resolution Ho IIIb to the glacial period, with a more detailed coverage of Ho IV. Marks Tey III, recorded in Figures 13 and 14 of Turner (1970), therefore joins Marks Tey 1A as the sequences used for palaeoclimate modelling.

Values were extracted from the Marks Tey by eye, with lines being drawn vertical up the diagram, corresponding to pollen percentages. These provide additional guidance to promote accuracy of readings. At each sample depth, a horizontal reading is performed and the percentage of a given pollen type is recorded. Note that the diagrams for each borehole span two figures, tree pollen and non-tree pollen. The same procedure was employed for both.

It is recognized that this is a somewhat crude approach. Nevertheless it appears to have been a robust process. A general test for the reliability of the data reading process is the closeness to which each sample depth sums to 100%. In a number of cases 100% was successfully achieved and in the vast majority of cases the sum is just a few percent either side.

Marks Tey is one of the easier diagrams to extract information from. The percentage indicators are clearly defined and the diagrams are large making for easy viewing. At the opposite end of the spectrum is the diagram used for Quinton. This diagram covers only a relatively small portion of a page making it more difficult to accurately read the diagram. For much of the core, around the central portion, the percentages come close to 100. Although there is greater variance than shown in the readings from Marks Tey, the values are reasonably and encouragingly accurate. However, at the top and bottom of the core readings do not come close to 100. There is no obvious value around which they centre, although 50 may be the closest approximation. There is no clear explanation as to why the percentages do not add up to 100 in these sections. We must treat the results obtained from these portions of the core with greater added scepticism.

There is a common trend in the Nechells data to be substantially above 100%, particularly for the upper portions of the core. Along with Quinton this is the only site in which data has been extracted from diagrams to be significantly above the expected sum. St Cross and Barford both sum to much closer to 100%, in line with Marks Tey. Ultimately, because we are concerned with presence or absence, this crude testing is not crucial. If a pollen type is recorded then we can assume that it was present and so it is not essential that a value of 100% is derived. There is arguably greater concern if numbers significantly lower than 100% are obtained, possibly suggestive of missing data.

5.6 – Pollen based climate reconstruction

5.6.1 – Fundamentals of the pdf *method*

The probability density function (*pdf*) methodology of Norbert Kuhl was applied to the pollen data to produce quantified temperature reconstructions (Kuhl *et al.*, 2002). The relationship between a given taxon and climate is based on the CRU climate data set (New *et al.*, 2000) and plant species distribution maps (Meusel and Jager, 1992). The latter are digitised and georeferenced (Scholzel *et al.*, 2002) to match the climate data.

The method uses taxon-climate relations that are described by taxon-specific likelihood functions (*pdfs*). These quantify the relationship between climate and a taxon's distribution. An individual *pdf* is reconstructed for a given taxon and the combination of co-occurring taxa represents the most probable reconstructed climate.

The likelihood function is $f_{\vec{X}|Y}(\vec{x}|y=1,C)$, where $y_k=1$ denotes the presence of the species Y_k and C represents the influence of non-climatic variables. If a given taxon is strongly influenced by such factors then it is removed from the reconstruction. $\vec{X}$ is a climate state vector, consisting of three dimensions; mean January temperature (T_{Jan}), mean July temperature (T_{Jul}) and the annual sum of precipitation (P_{ann}). The reconstruction is the posterior probability density for $\vec{X}$ given by the following Bayes theorem:

$$f_{\vec{X}|Y_1..Y_{n_k}}(\vec{x}|y_1=1,...,y_{n_k}=1,C)\alpha\pi_{\vec{X}}(\vec{x}).\prod_{k=1}^{n_k}\frac{f_{\vec{X}|Y_K}(\vec{x}|1,C)}{m_{\vec{X}}(\vec{x})}$$

where $m_{\vec{X}}(\vec{x})$ is the marginal climate distribution and $\pi_{\vec{X}}(\vec{x})$ is the uninformative climate prior distribution.

The precipitation values are skewed and this leads to the problem of multivariate non-normal distribution functions when estimating the taxon specific likelihood functions. Standard statistical procedures do not account for this and a non-Gaussian approach is necessary. Univariate probability distributions are common, but finding a multivariate analogue is difficult. This problem is solved here by projecting $\vec{X}$ to a multivariate standard normal distribution through the use of copulas (Scholzel and Friederichs, 2008). The following figure provides a visualisation of the methodology:

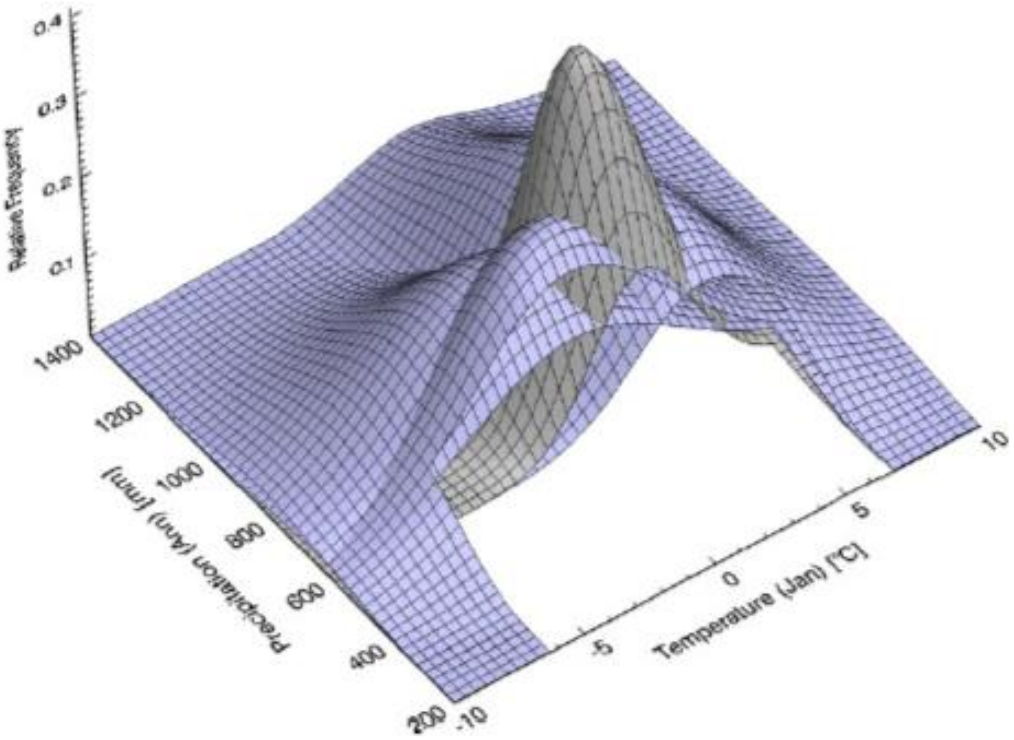


Fig 10: From Kuhl *et al* (2007) a visualisation of the *pdf* methodology. Features the likelihoods of *Carpinus betulus*, *Taxus baccata* and *Picea abies* combining to produce the grey posterior.

The above is an abbreviated version of the complete methodology. For further details, see first Kuhl *et al* (2002) and then Neumann *et al* (2007) and Scholzel (2006) which describe subsequent modifications of the method.

5.6.2 – Model input

The *pdf* fundamentally works on a presence/absence basis. However there are features of the input that need to be made clear and so this section of the methodology will provide a complete outline of the underlying input behind the palaeoclimate reconstructions presented in this thesis. In essence, two forms of reconstruction take place in this thesis. Firstly, reconstructions that form the basis of sensitivity testing to explore the robustness of the methodology and results. Secondly reconstructions to provide the data used to investigate the palaeoclimate of the Hoxnian. The secondary one being sensitivity testing to explore the robustness of the reconstructions and explore some of the important subtleties inherent to the *pdf* methodology.

With regards to the palaeoclimate reconstruction methodology, there are two key issues that must be covered first:

1) There is not a fully comprehensive list of taxa that can be inputted into the model
2) The input is principally composed of species, whereas it is often not possible to identify pollen down to species level

With regards to the range of taxa available for input, all of the trees and shrubs that will be encountered in a typically northern European pollen study are present. Incompleteness arises in the representation of herbs. It is unsurprising that only selected herbs are available for input; there are thousands of such species that could potentially be incorporated into the *pdf* methodology and it would be entirely unreasonable to do so. It is possible to pick herbs to represent particular taxonomic groupings (see below), however not all such groupings are represented (Compositae for example). It is therefore important to note that not all pollen that is recorded is able to be used in the palaeoclimate reconstructions and in some cases an assumed representative has to be chosen.

The necessity to assume a particular representative is an example of the second point outlined above. With herbs, for example, there may be many different types of species that are found within the taxonomic level represented by a particular pollen grain and only a small number of options for input in the model related to that taxonomic level (for example there are thousands of species within Fabaceae and only a handful of possible model inputs).

The approach taken here is twofold:

- To present reconstructions that solely consist of the more taxonomically assured trees, shrubs and herbs. These reconstructions will then be used as the basis for palaeoclimate interpretation
- To perform sensitivity tests to explore the implications of taxonomic precision and species choice

Input for final reconstructions

Even in the case of trees and shrubs, where taxonomic issues are more straightforward, there are choices that have to be made. Although there are much fewer species associated with a particular tree or shrub taxonomic grouping, there will typically be a number of them. For example, the model allows the following species of oak to be used in a reconstruction:

- *Quercus cerris*
- *Quercus coccifera*
- *Quercus ilex*
- *Quercus petraea*
- *Quercus pubescens*
- *Quercus robur*
- *Quercus suber*

In addition, for selected genera (primarily tree), there is the option to input an aggregate, which is composed of the combined distribution areas of all the species available for those genera. Ideally, wherever possible, a species is used rather than an aggregate as a species will be more climatically precise. However, there are cases where there is sufficient uncertainty to warrant the use of aggregates. In this regard, the work here is heavily guided by Harry Godwin's History of the British Flora (1975). This is the most authoritative guide to the composition of Britain's Pleistocene flora. It contains an extensive description of all pollen types recorded and which species they most likely represent (where possible). Clearly this work is a number of decades old now, however it remains authoritative and the main conclusions are unlikely to have changed, particularly in light of the general slowdown in Pleistocene palynology in recent years.

Oak is one species for which an aggregate was chosen. It is probable, assuming present species distributions extend into the past, that the species of oak represented by the pollen recorded in the Hoxnian was either *Quercus robur* or *Quercus petraea*. However, Godwin (1975) notes that while there are slight morphological differences between the two grains, it is extremely difficult to separate them. Therefore we are not able to choose between these two species and must opt for the aggregate. This is somewhat frustrating as the inability to choose one of just two species then translates into an aggregate composed of seven species. Nevertheless this is the most justifiable approach to take. Aggregates were also used, based on the reasoning described here, for birch (assumed to be tree birch), elm, lime, alder, maple, willow and elder.

By way of contrast, Pine is treated differently. Once again there are a number of species that it is possible to input:

- *Pinus cembra*
- *Pinus mugo*
- *Pinus nigra*
- *Pinus pinea*
- *Pinus sylvestris*

From present species distributions we would expect *Pinus sylvestris* to be represented by British pollen. Godwin (1975) also states the high probability that this is indeed the case, although he does acknowledge the slim possibility of other species. Nevertheless the balance of probability strongly favours *Pinus sylvestris* and so this was chosen for input.

There are a number of cases for trees and shrubs where there is no aggregate available; the choice has to be made between the available species. Typically this is not a particularly difficult selection. For example, fir is represented by *Abies alba*, *Abies borisii-regis*, *Abies* *bornmulleriana*, *Abies cephalonica* and *Abies nordmanniana*. The only native fir in the UK is *Abies alba* and of this list only the latter two are now present through introduction. Godwin (1975) states that all Pleistocene *Abies* finds are *Abies alba* adding to the reliability of this species choice. Other tree and shrubs represented in this way are *Carpinus betulus*, *Fagus sylvatica* and *Fraxinus excelsior*.

A number of other trees and shrubs are inputted as species where these are the only species available for input to represent these genera. They are *Taxus baccata*, *Corylus avellana*, *Juniperus communis*, *Hippophaë rhamnoides*, *Hedera helix*, *Empetrum nigrum*, *Viscum album* and *Ilex aquifolium*. In each of these cases it is highly likely that they accurately reflect the actual species being recorded by Hoxnian pollen. They are the native species found in the UK presently and the only possibilities discussed by Godwin (1975).

It is these taxa, for which we have the most confidence, along with the aggregates that form the basis of the final reconstructions. In addition, they are supplemented by a small number of herbs for which we are similarly assured. For example it is possible to identify *Plantago* down to species level (such as *Plantago lanceolata*), likewise *Calluna vulgaris*. In addition, there is an aggregate for *Filipendula*.

Input for sensitivity tests

The following sensitivity tests are undertaken:

- The influence of aggregation
- The influence of adding assumed herbs
- The influence of applying thresholds

As discussed above, the final reconstructions use a mixture of aggregates and tree and shrub species (and a small number of herbs). To further explore the influence of aggregation, a comparison was performed between a scenario in which all possible aggregates are used and one in which aggregates were replaced by assumed species. This is just for trees and shrubs (and the herbs we are confident were present). So, for example the aggregate approach uses a *Quercus* aggregate, whereas the assumed separate species uses *Quercus robur*. There are actually two species of oak that could be used, the other being *Quercus pubescens* and this is the case for other species. Therefore two assumed species scenarios were performed when a decision could not be made about which to choose:

- *Betula pendula*, *Quercus robur* and *Filipendula ulmaria* (described in results as pen rob ul)
- *Betula pubescens*, *Quercus pubescens* and *Filipendula vulgaris* (described in results as pub pub vu)

Other assumed tree and shrub species were kept constant in these two scenarios. They were *Ulmus glabra*, *Acer campestre*, *Tilia cordata*, *Alnus glutinosa*, *Sambucus nigra* and *Salix caprea.*

For the herbs to be used in sensitivity tests, assumed representatives of different herb types are chosen. Often there will be many thousands of species within the taxonomic level identified by pollen and many of these species currently grow in Britain. Therefore it is unlikely that the species chosen actually reflects the species producing the Hoxnian pollen. Nevertheless, the species chosen are ones that are presently found in East Anglia and the Midlands, adding as much realism as possible into the sensitivity testing.

Taxonomic group	**Species chosen/aggregate**
Abies	*Abies alba*
Acer	*Acer campestre*
Alnus	*Alnus glutinosa*
Betula	Aggregate
Carpinus	*Carpinus betulus*
Corylus	*Corylus avellana*
Empetrum	*Empetrum nigrum*
Fagus	*Fagus sylvatica*

Fraxinus	*Fraxinus excelsior*
Hedera helix	*Hedera helix*
Hippophaë	*Hippophaë rhamnoides*
Ilex	*Ilex aquifolium*
Juniperus	*Juniperus communis*
Picea	*Picea abies*
Pinus	*Pinus sylvestris*
Quercus	Aggregate
Salix	*Salix caprea*
Sambucus	*Sambucus nigra*
Taxus	*Taxus baccata*
Tilia	*Tilia cordata*
Ulmus	*Ulmus glabra*

Table 3: preferred trees and shrubs used in model runs

Adding in herbs is primarily undertaken as an exercise in testing the sensitivity of the model. Does, for example, the addition of a greater number vegetation types constrain the model or produce smaller error bars, regardless of whether this end result is actually more accurate? Nevertheless, to maximise the chance of obtaining reliable results from the addition of herbs, species are chosen which are widely present in the British Isles today.

The herb species selected can be seen in the following table:

Taxonomic group	**Representative species**
Asteraceae	*Hypochaeris radicata*
Caryophyllaceae	*Moehringa trinervia* (i)
	Stellaria holostea (ii)
Chenopodiaceae	*Chenopodium polyspermum*
Cyperaceae	*Cladium mariscus*
Fabaceae	*Sarothamnus scoparius*
Lamiaceae	*Lycopus europaeus* (i)
	Teucrium scorodonia (ii)

Plantago	*Plantago lanceolata*
Potentilla	*Potentilla anserine*
Ranunculaceae	*Ranunculus flammula*
Rosaceae	*Rubus caesius* (i)
	Crataegus monogyna (ii)
Rubiaceae	*Galium palustre*
Rumex	*Rumex acetosa*
Thalictrum	*Thalictrum palustre*

Table 4: species used to represent particular taxonomic groupings. i and ii refer to model run sets. Two alternative herb model runs are performed, one with set i herbs and another with set ii.

The following table provides an example of both the final reconstruction and the herb sensitivity testing for the main sequence at Hoxne.

Pollen recorded	**Final reconstruction**	**Trees, shrubs, herbs i**	**Trees, shrubs, herbs ii**
Betula	*Betula aggregate*	*Betula aggregate*	*Betula aggregate*
Pinus	*Pinus sylvestris*	*Pinus sylvestris*	*Pinus sylvestris*
Ulmus	*Ulmus aggregate*	*Ulmus aggregate*	*Ulmus aggregate*
Quercus	*Quercus aggregate*	*Quercus aggregate*	*Quercus aggregate*
Tilia	*Tilia aggregate*	*Tilia aggregate*	*Tilia aggregate*
Alnus	*Alnus aggregate*	*Alnus aggregate*	*Alnus aggregate*
Fagus	*Fagus sylvatica*	*Fagus sylvatica*	*Fagus sylvatica*
Carpinus	*Carpinus betulus*	*Carpinus betulus*	*Carpinus betulus*
Fraxinus	*Fraxinus excelsior*	*Fraxinus excelsior*	*Fraxinus excelsior*
Acer	*Acer aggregate*	*Acer aggregate*	*Acer aggregate*
Abies	*Abies alba*	*Abies alba*	*Abies alba*
Picea	*Picea abies*	*Picea abies*	*Picea abies*
Taxus	*Taxus baccata*	*Taxus baccata*	*Taxus baccata*
Sambucus	*Sambucus aggregate*	*Sambucus aggregate*	*Sambucus aggregate*
Corylus	*Corylus avellana*	*Corylus avellana*	*Corylus avellana*

Salix	*Salix aggregate*	*Salix aggregate*	*Salix aggregate*
Hippophaë	*Hippophaë rhamnoides*	*Hippophaë rhamnoides*	*Hippophaë rhamnoides*
Hedera helix	*Hedera helix*	*Hedera helix*	*Hedera helix*
Ilex	*Ilex aquifolium*	*Ilex aquifolium*	*Ilex aquifolium*
Type X	-	-	-
Poaceae	-	-	-
Cyperaceae	-	*Cladium mariscus*	*Cladium mariscus*
Empetrum	*Empetrum nigrum*	*Empetrum nigrum*	*Empetrum nigrum*
Ericaceae	-	-	-
Artemisia	-	-	-
Cirsium	-	-	-
Compositae	-	-	-
Brassicaceae	-	-	-
Caryophyllaceae	-	*Moehringa trinervia*	*Stellaria holostea*
Chenopodiaceae	-	*Chenopodium polyspermum*	*Chenopodium polyspermum*
Filipendula	*Filipendula aggregate*	*Filipendula aggregate*	*Filipendula aggregate*
Lamiaceae	-	*Lycopus europaeus*	*Teucrium scorodonia*
Fabaceae	-	*Sarothamnus scoparius*	*Sarothamnus scoparius*
Geranium	-	-	-
Plantago	-	*Plantago lanceolata*	*Plantago lanceolata*
Potentilla	-	*Potentilla anserina*	*Potentilla anserine*
Ranunculaceae	-	*Ranunculus flammula*	*Ranunculus flammula*
Rosaceae	-	*Rubus caesius*	*Crataegus monogyna*
Rubiaceae	-	*Galium palustre*	*Galium palustre*
Rumex	-	*Rumex acetosa*	*Rumex acetosa*
Scabiosa	-	-	-
Thalictrum	-	*Thalictrum minus*	*Thalictrum minus*
Valeriana	-	-	-
Apiaceae	-	-	-
Mentha type	-	-	-
Taraxacum	-	-	-

Geum	-	-	-
Alisma	-	-	-

Table 5: basic inputs for model run for lower portion of Hoxne core

Table 5 provides a clear illustration of the fact that there is an imperfect alignment between the data used in the model and the pollen data recorded. Assumptions have been made regarding the representation of the pollen sampled and then inputted into the palaeoclimate reconstruction. Moreover there are a number of pollen types recorded which cannot be constrained at all in the model. It is important to provide complete clarity regarding the underlying basis of the palaeoclimate modelling approach, so that the results can be judged accordingly. It is an exciting and ultimately robust methodology. Nevertheless, as with all models, it is an imperfect representation of reality.

The third form of sensitivity testing concerns the use of thresholds. Although this is a presence/absence approach, it might be argued that there are valid reasons for requiring a minimum number of pollen grains to be recorded before accepting presence, long distance transport for example. Because much of the data here are taken from published material, there is not sufficient precision to be able to reliably impose thresholds. However, we can explore this issue through Hoxne, where of course thresholds can be applied, and Marks Tey which is likely to be the most robust data set taken from existing pollen diagrams.

Three thresholds are applied to the data, specifically for wind-blown taxa only. Applying thresholds to taxa that are insect propagated is unnecessary as typically these will not disperse far and therefore accurately record presence at a site. Two simple thresholds of 1 and 4% were adopted and an additional one used by Norbert Kuhl in his own reconstructions. This is based on the empirical cumulative distribution function devised by Neumann *et al.* (2007) and varies slightly by site. The values used here are those appropriate for Hoxne and extended to Marks Tey (Kuhl, pers comm.). The table below shows the species to which thresholds are applied and shows the percentages for the Kuhl approach (for some taxa no threshold is used here by Kuhl):

Taxa	**Percentage**
Betula	2.0
Pinus	-
Abies	0.05
Picea	1
Ulmus	1.5
Quercus	3.0
Tilia	0.5
Fraxinus	0.5
Alnus	3.0
Acer	0.05
Carpinus	-
Pteocarya	-
Taxus	-
Corylus	4.0
Salix	-
Juniperus	-

Table 6: thresholds based on Kuhl threshold approach

Finally, on the basis of results from thresholds, it was decided to run experiments showing the influence of a particular taxa on the reconstruction. Specifically, experiments were performed with and without *Picea*.

All input for the various reconstructions and sensitivity test scenarios can be found in the Appendix.

5.7 - Pollen Zonation

Pollen zonation was primarily undertaken by applying the broken stick modelling of Bennett (1996) and took place using the psimpoll program, developed by Keith Bennett. All pollen data input and analysis took place within psimpoll. As recommended by Bennett (1996) zonation is undertaken using optimal splitting by information content, with a broken stick model applied. For comparative purposes, constrained cluster analysis by sum-of-squares (CONISS) was also used. This enabled the exploration of the impact of differing zonation techniques on the data set. If the two produce similar results, this gives added confidence that the zones have a sound statistical basis.

5.8 – Pollen modelling

The HUMPOL (Middleton and Bunting, 2004) suite of software was used to perform a series of modelling experiments based on the pollen data recovered from Hoxne. HUMPOL incorporates various programs, the two key ones being MOSAIC and POLFLOW. MOSAIC was used to generate hypothetical landscapes, consisting of vegetation types and/or communities, depositional centres and vegetation structure. These landscapes were then inputted into POLFLOW, along with the relevant pollen data for the vegetation in question. The POLFLOW program outputs pollen loadings for a given sampling location. An example of simple landscape construction within MOSAIC can be found in Fig 11.

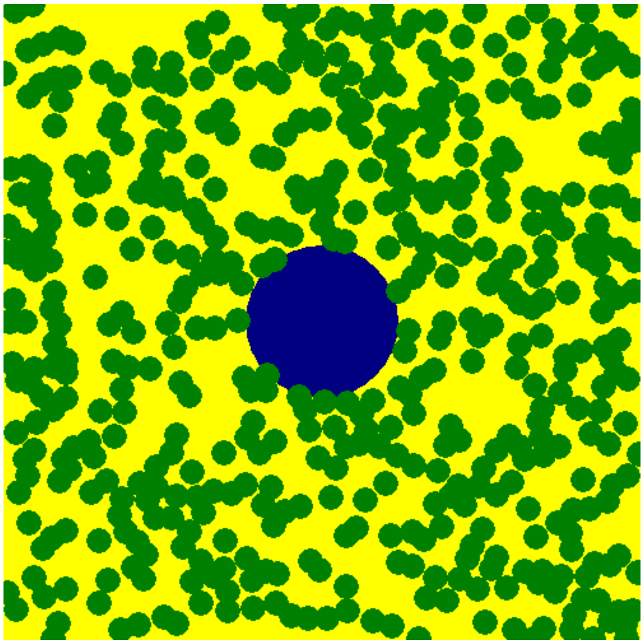


Fig 11: Example of a hypothetical landscape, constructed within MOSAIC. At the centre is a lake, which will be “sampled” within POLFLOW. Surrounding the lake, in yellow is a matrix of a given vegetation type(s). Embedded within this matrix, in green, are communities of a given vegetation type(s). The green communities cover approximately 50% of the matrix.

The example shown above can be used to illustrate in detail how the modelling process took place. The design of an experiment was undertaken in two simultaneous formats; the landscape generated in MOSAIC must be consistent with the pollen data inputted into POLFLOW. So, if the MOSAIC landscape consisted of two communities, yellow and green, then POLFLOW had to reflect this.

MOSAIC simulates the proportions of these two communities, in this case roughly 50% green and 50% yellow, whilst the composition of the communities was specified by the data inputted into POLFLOW. In this example, the POLFLOW input must specify the existence of two communities as per MOSAIC, in addition to the actual make up of the communities themselves. For example, green may be designated as solely consisting of birch pollen, whereas the yellow matrix is a combination of half alder and half pine. An additional word of clarification: the term “matrix” is the technical one adopted by users of HUMPOL. This may be slightly misleading; the green points in the landscape do not produce pollen consisting of green and yellow pollen, rather they provide green only to the sampling point.

The landscapes constructed within MOSAIC consist of grid cells, typically 500 by 500. The size, in metres, of these grid cells must be specified. This enables the spatial scale of the landscape to be varied. An example of the same community structure, but a larger scale, is shown in Fig 12:

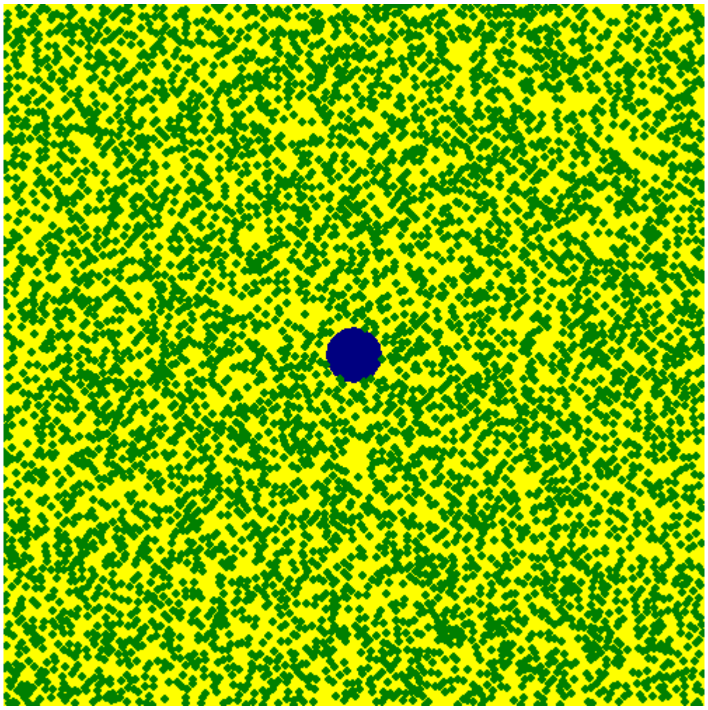
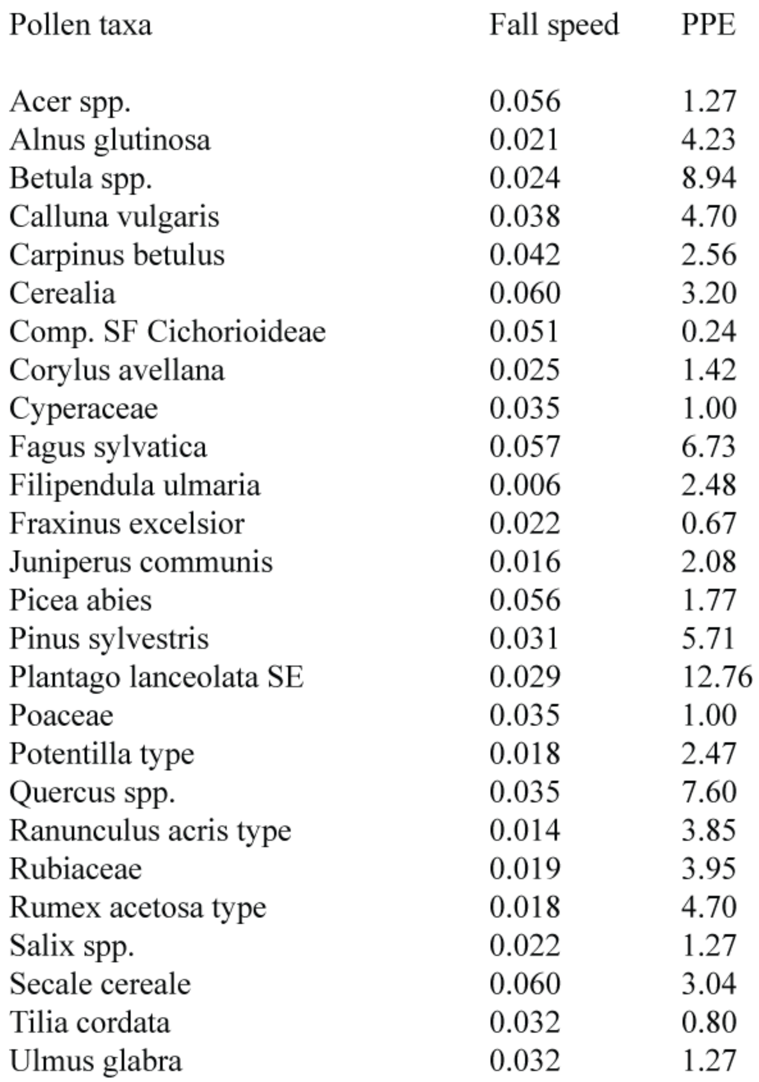


Fig 12: a hypothetical landscape constructed within MOSAIC, as in Fig 11 but on a larger spatial scale.

The grid cells in MOSAIC are plotted as coordinates, eastings and northings. Within POLFLOW, the sampling location was defined by eastings and northings and if you wish a particular locality to be sampled, then the precise coordinates must be inputted. In this study, a lake was generated within the landscape to reflect the Hoxne basin and the centre of this lake was designated as the sampling point. No pollen is generated from the area denoted as representing the lake.

In this worked example, we have birch (green), pine and alder (yellow) as the pollen types in question. POLFLOW requires both fall speed and pollen productivity estimates for each type inputted. This data is derived from Brostrom *et al.* (2004) and Sugita *et al.* (1999) and the full list is shown below:



Pollen taxa	Fall speed	PPE
Acer spp.	0.056	1.27
Alnus glutinosa	0.021	4.23
Betula spp.	0.024	8.94
Calluna vulgaris	0.038	4.70
Carpinus betulus	0.042	2.56
Cerealia	0.060	3.20
Comp. SF Cichorioideae	0.051	0.24
Corylus avellana	0.025	1.42
Cyperaceae	0.035	1.00
Fagus sylvatica	0.057	6.73
Filipendula ulmaria	0.006	2.48
Fraxinus excelsior	0.022	0.67
Juniperus communis	0.016	2.08
Picea abies	0.056	1.77
Pinus sylvestris	0.031	5.71
Plantago lanceolata SE	0.029	12.76
Poaceae	0.035	1.00
Potentilla type	0.018	2.47
Quercus spp.	0.035	7.60
Ranunculus acris type	0.014	3.85
Rubiaceae	0.019	3.95
Rumex acetosa type	0.018	4.70
Salix spp.	0.022	1.27
Secale cereale	0.060	3.04
Tilia cordata	0.032	0.80
Ulmus glabra	0.032	1.27

Table 7: Pollen productivity estimates and fall speeds for various European pollen taxa.

As can be noted from Table 7, there are only a relatively restricted number of pollen taxa for which PPE's and fall speeds have been estimated. This, by necessity, forces a considerable simplification upon the modelling experiment. It simply is not possible to incorporate every pollen type sampled into the models and so the ecosystems simulated were stripped down reflections of their real life counterparts. This is particularly acute where non-arboreal pollen is concerned, whereas trees and to a lesser extent shrubs, are much better covered. Note also the total absence of aquatic taxa available.

With the hypothetical landscape loaded and the details of the pollen types inputted, POLFLOW then simulates pollen loading at the sampling point specified. The model used in this simulation can be varied, but the default option was the Prentice dispersal model (Prentice, 1985) to generate pollen assemblages. For a closer approximation of reality, the model would ideally incorporate a “real” lake and follow the Sugita model (Sugita, 1993) model for lake deposition. However, MOSAIC is not actually simulating a lake, it is merely mapping out an area from which pollen is not produced.

There are various possible experiments that can be performed using the HUMPOL suite. In this case, the approach taken was to compare modelled landscapes and the pollen deposition simulated within them with the observed pollen deposition within the Hoxne core at various time slices. The modelling proceeded by a basic form of sensitivity testing, investigating key parameters of interest, in order to gain an appreciation for the structure and composition of the ecosystem at various points in time during the Hoxnian. The aim was not to produce a modelled landscape that produces pollen which precisely matches the data as this will simply not be possible given the limited taxa available for input. Furthermore, models, particularly relatively basic ones such as this, are simplifications of reality and are best used as an exploration tool to elucidate the fundamentals of the ecosystem in question.

Key questions to be explored concern whether, when taking into account variations in pollen productivity, the pollen diagram accurately reflects the composition of the ecosystem. So, for example, if a time slice of the pollen diagram suggests an ecosystem composition of 25% birch, 25% hazel, 25% alder and 25% oak does inputting these proportions into the model produce pollen loadings and proportions comparable to the data? If not, then the ecosystem may have looked different to that inferred from a plain reading of the pollen spectra. A second important question concerns the nature of a landscape structure likely to have generated the pollen data in the core. There may also be overlap between these questions, with community composition and structure interacting to generate the most plausible outcome.

Fig 13 provides some illustrations of how the modelling process is used here to investigate these questions. A full list of the models performed will not be described in this chapter because the process itself will dictate the nature of the enquiry. See Chapter 8 for a full treatment of the modelling and output.

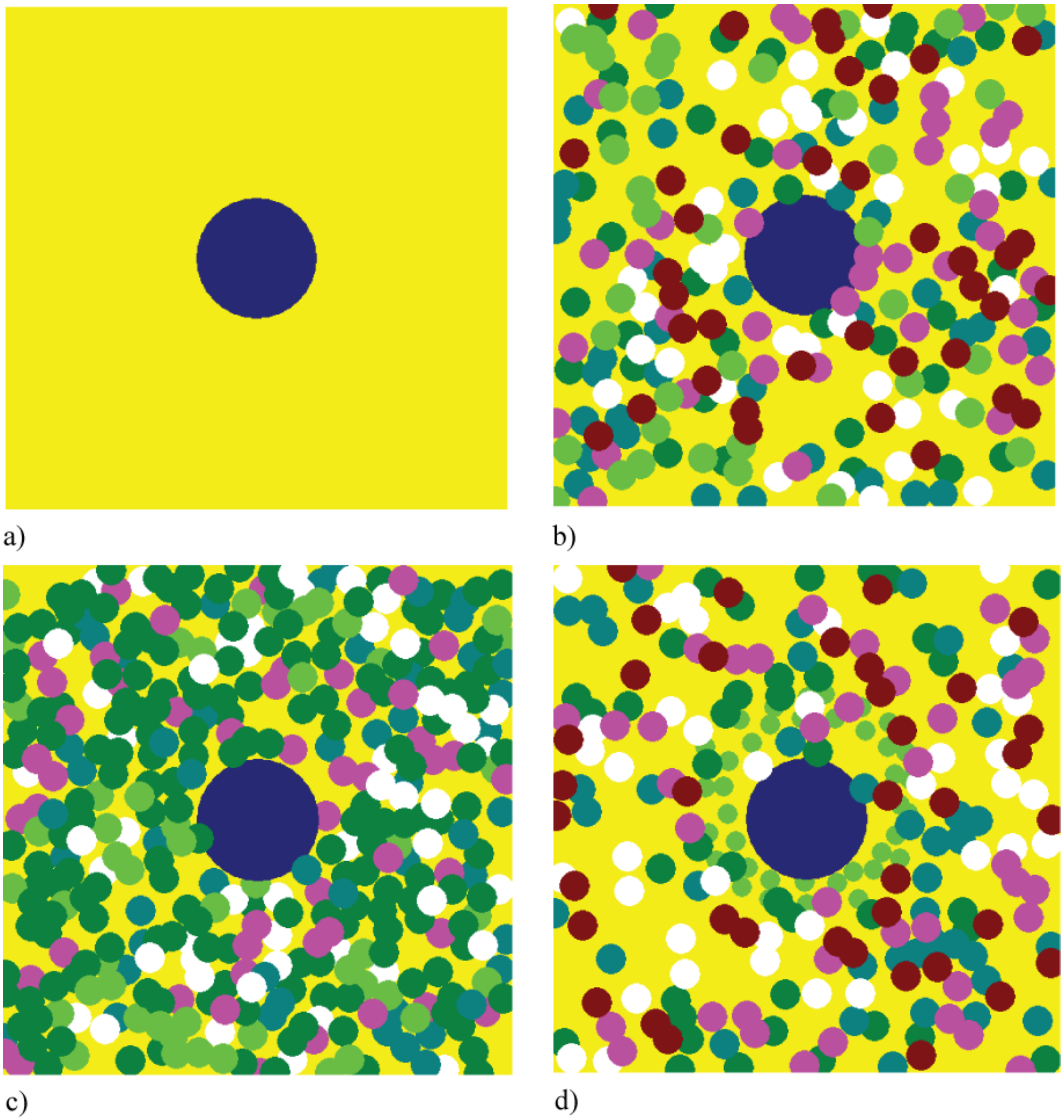


Fig 13: an illustration of the modelling process. a) represents structurally simple landscape consisting of a matrix community, (in this case consisting of seven species though this cannot be graphically shown). b) represents a matrix community, with six others existing as patches in the landscape. c) represents a matrix community, with five other communities present as patches and one of these communities (dark green) present in greater amounts than the others. d) represents a matrix community with six other communities present, one of which (lightest green) is preferentially clustered around the lake.

6 – Pollen results

This chapter will present the results from the various pollen analyses conducted during this thesis.

6.1 – Pollen stratigraphy from Hoxne

The Hoxne pollen diagrams are presented in Figs 14-18. Five pollen zones were constructed for the data from the main portion of the core, with Stratum C being treated separately.

6.1.1 – Main sequence

Local Pollen zone H1 (824-750 cm)

Pollen zone H1 is overwhelmingly dominated by *Betula*, although it is already declining from the onset of the zone and the base of the core. Other significant components of the flora during this interval are relatively static, with the exception of *Quercus* which begins to increase and reaches a peak towards the end of the zone. *Pinus* and *Ulmus* are present, although the latter is limited and declines. *Tilia* appears towards the end of the zone and *Fraxinus* is present in small quantities.

The shrub flora during H1 is scarce, with only *Corylus* being observed in significant numbers. *Hedera* was present as was small amounts *Hippopha*ë. Herbs are one of the most substantive components of the pollen diagram. The herb flora contains a comparable level of diversity to the herb flora in most other zones of the diagram. It is dominated at this time, as in most others, by Poaceae and Cyperaceae. Other notable components include the presence of Asteraceae, Caryophyllaceae, Apiaceae and the large family Ranunculaceae. *Valeriana*, *Filipendula*, *Artemisia* and *Empetrum* are also observed.

Aquatic plants are present during H1, although they are only a minor component of the pollen spectra and lacking diversity: *Myriophyllum*, *Sparganium* are observed. Ferns are somewhat more common during H1 although also lacking diversity, with Filicales being dominant, a regular feature of the spores throughout the entire pollen diagram. The other spore recorded was *Ophioglossum*.

Local Pollen zone H2 (750-680 cm)

Betula remains a significant component of the flora, although it continues to steadily during this zone, reaching low numbers by the end. *Quercus* declines slightly, though remains significant. The dominant feature of H2 is the appearance of *Alnus* in large quantities. *Tilia* is also present, though it declines. *Ulmus* and *Taxus* (towards the end) are also present and *Pinus* is a continual feature throughout zone H2.

As with H1, shrubs are relatively scarce, although *Corylus* starts to increase by the end. *Hedera* remains present in small quantities. Herbs continue to be significant with Poaceae and Cyperaceae remaining the main contributors to the herb sum, but sedges decline somewhat from H1. *Empetrum* is found fairly consistently in H2 and Asteraceae, Ranunculaceae and *Thalictrum*, *Cirsium* and Apiaceae. *Scabiosa*, Rubiaceae, Fabaceae, *Filipendula*, Caryophyllaceae, Chenopodiaceae and *Artemisia* are all found.

The aquatic portion of the pollen spectra is similar to that of H1, being limited in numbers and diversity, containing only small quantities of *Myriophyllum*, *Sparganium* and *Typha latifolia*. Again, ferns are somewhat more prevalent, largely due to the notable presence of Filicales. *Polypodium* is the only other spore found during pollen zone H2.

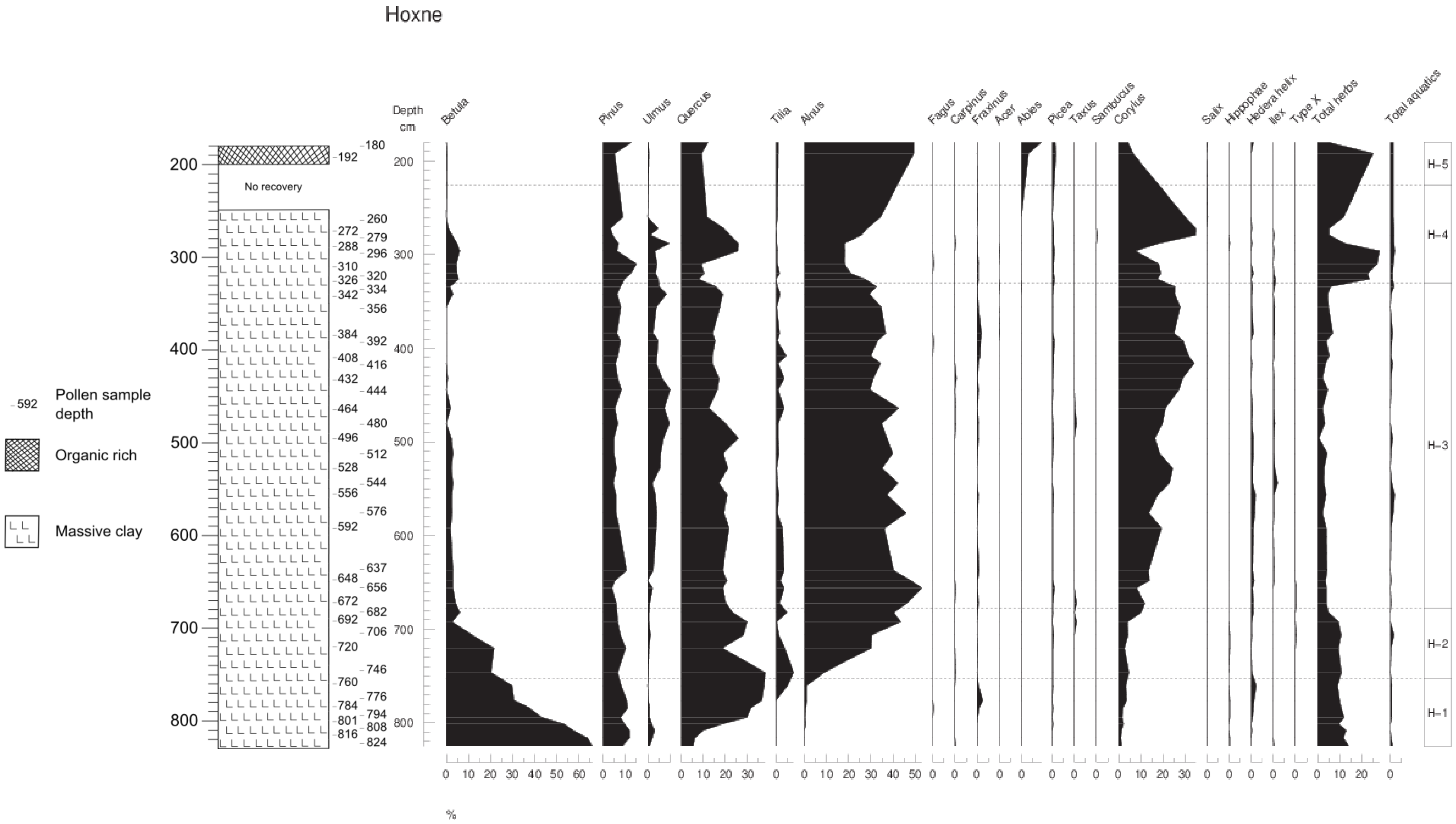


Fig 14: summary pollen diagram from the main Hoxne sequence, zoned using a broken stick model and optimal splitting by information content.

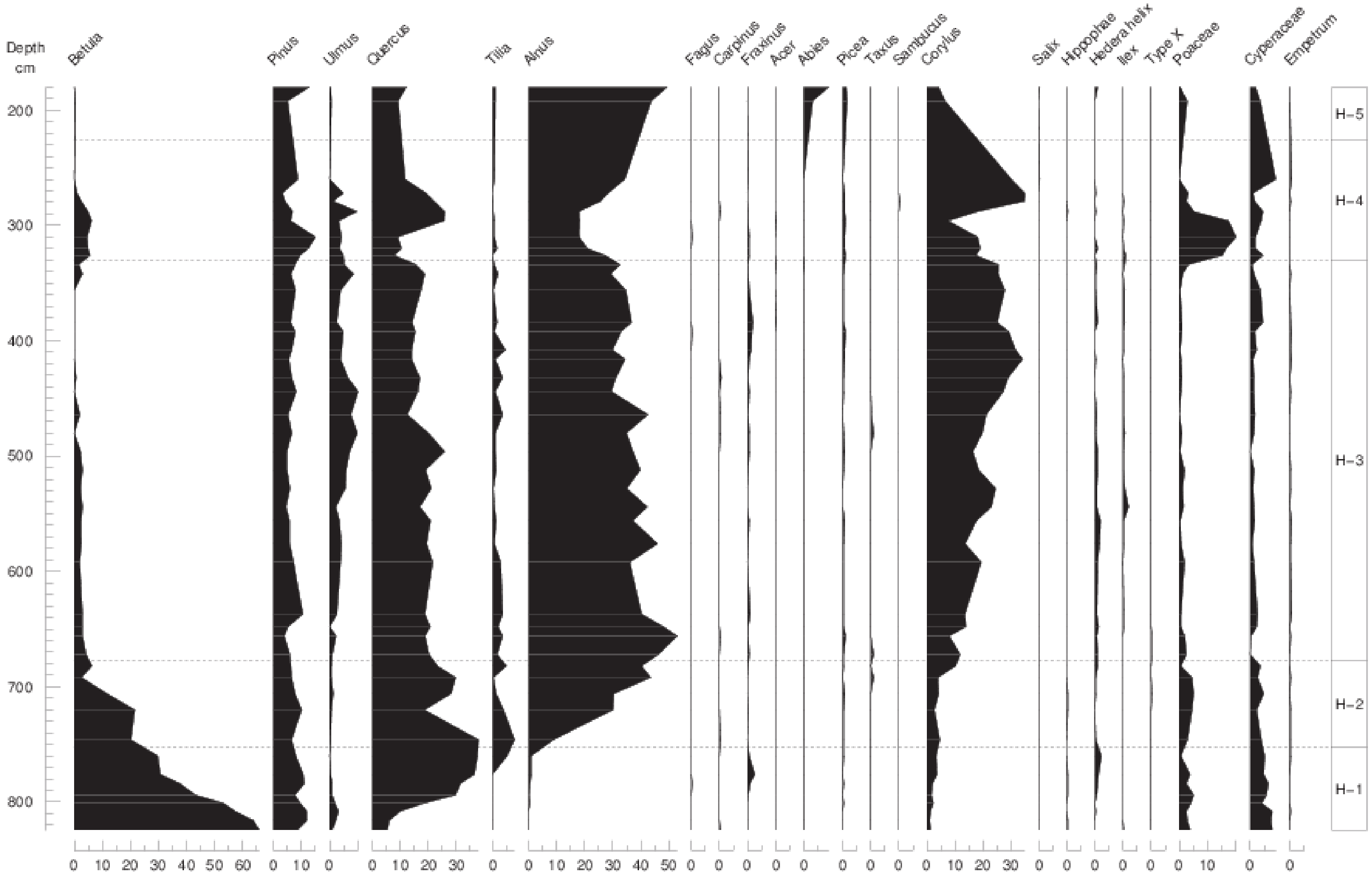


Fig 15: pollen diagram from the main Hoxne sequence, zoned using a broken stick model and optimal splitting by information content (Part 1).

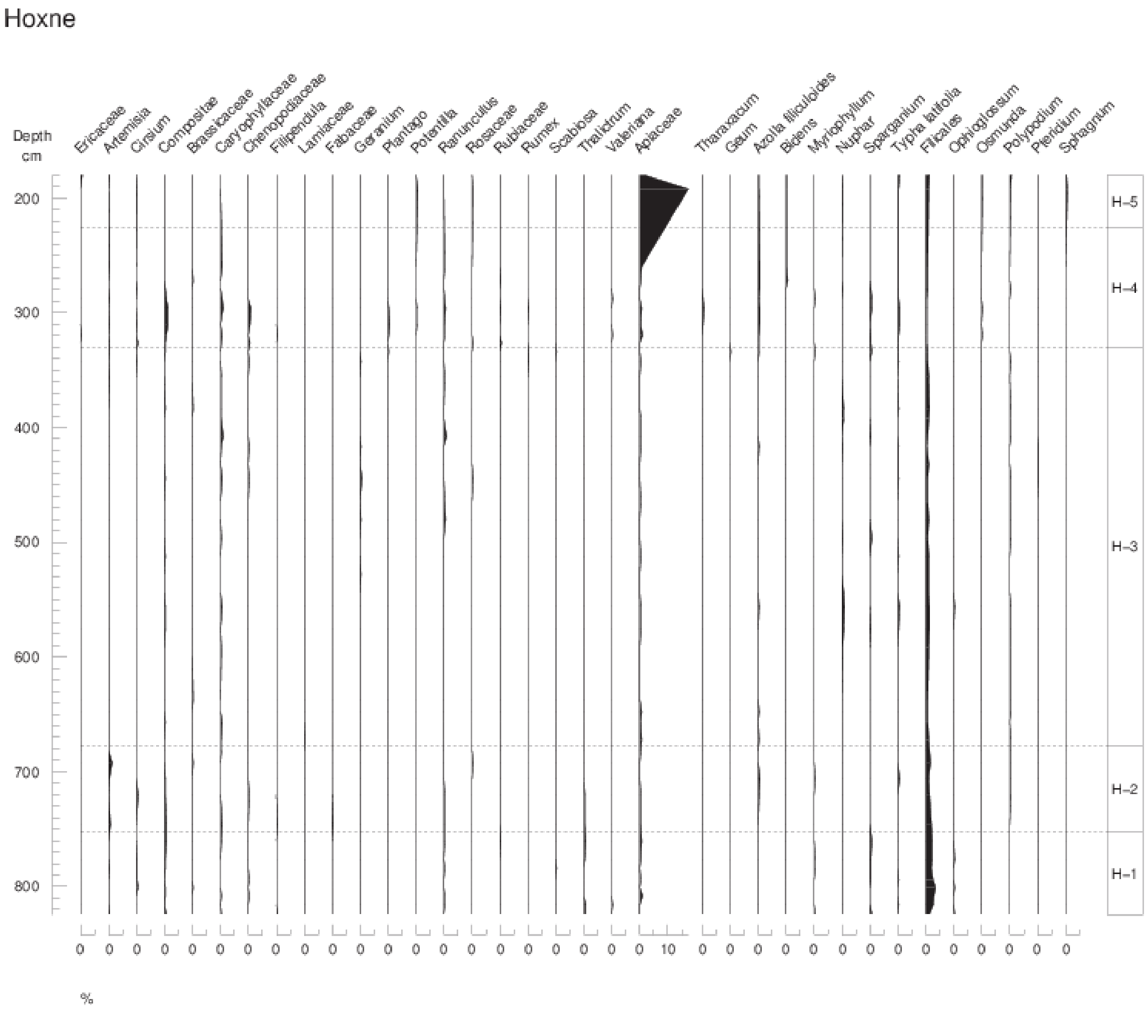


Fig 16: pollen diagram from the main Hoxne sequence, zoned using a broken stick model and optimal splitting by information content (Part 2).

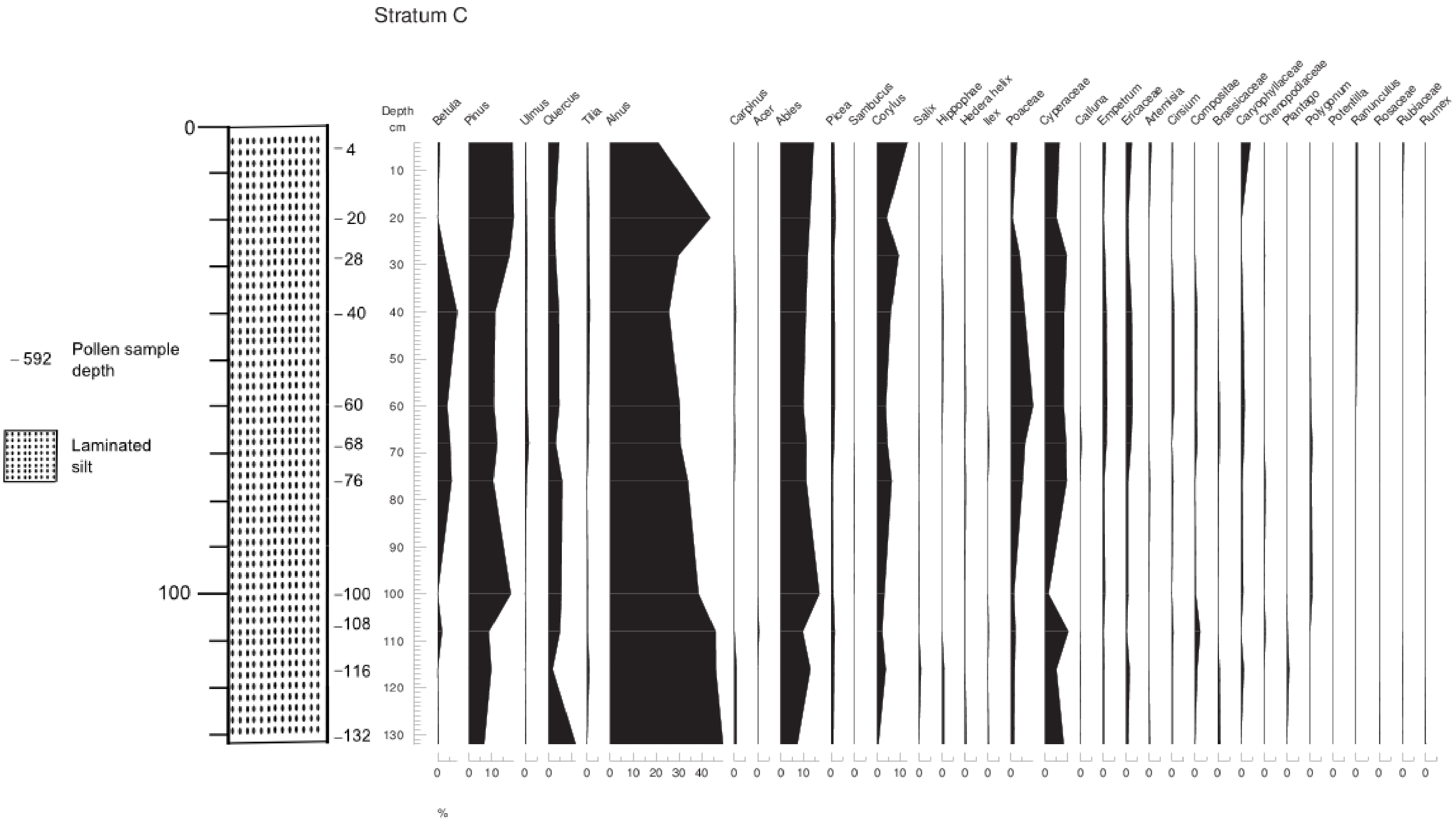


Fig 17: pollen diagram from Stratum C (Part 1).

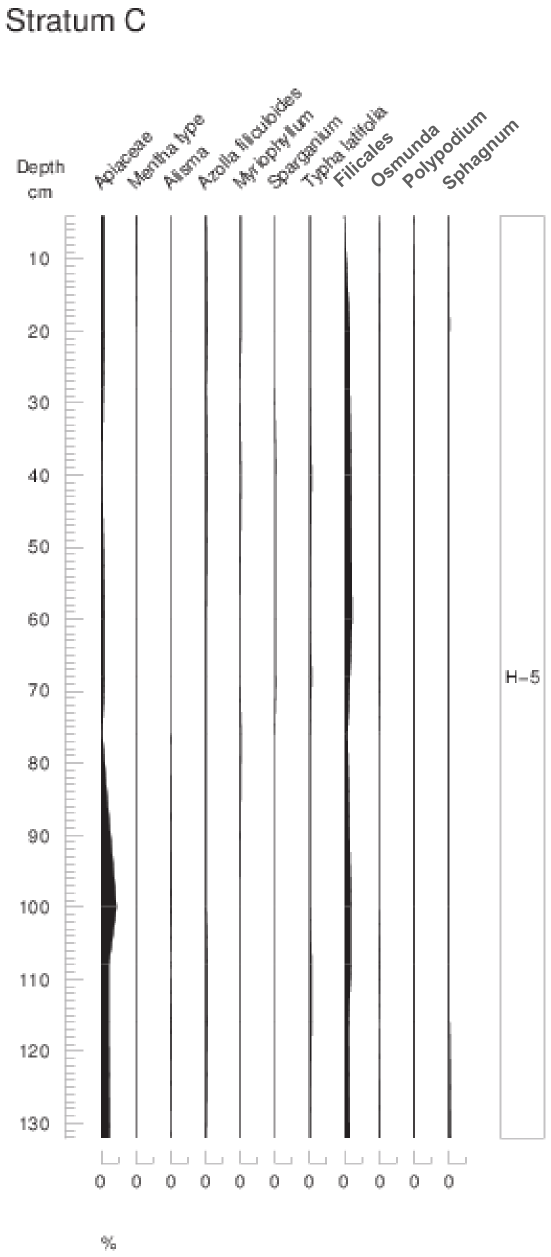


Fig 18: pollen diagram from Stratum C (Part 2).

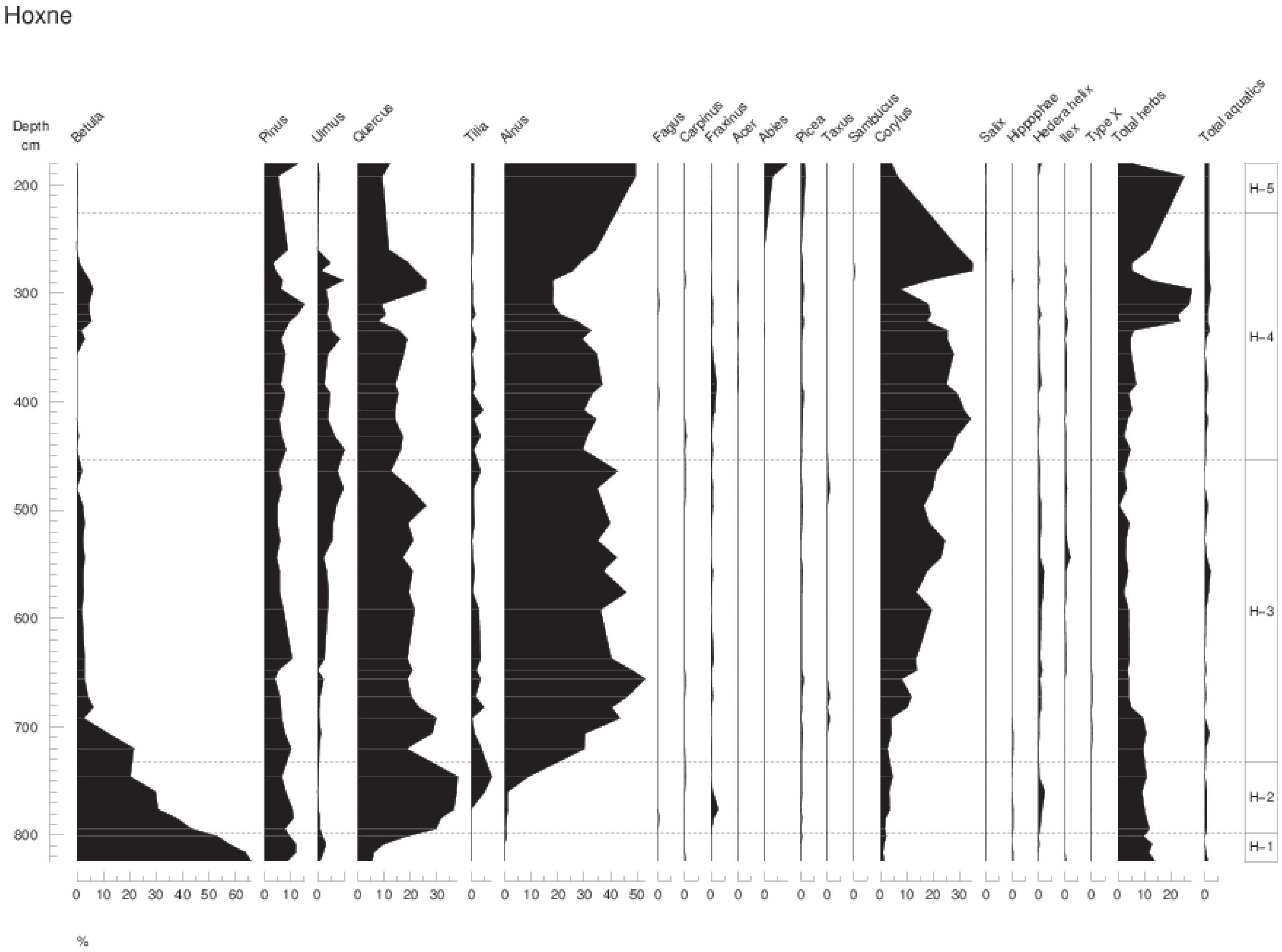


Fig 19: summary pollen diagram from the main Hoxne sequence, zoned using a broken stick model and CONISS.

Local Pollen zone H3 (680-330 cm)

H3 is the dominant pollen zone in this diagram. It sees significant contributions from *Pinus, Ulmus, Quercus* and *Alnus,* with *Tilia* also present. *Betula* declines to minimal levels during this period. *Fraxinus* is also noticeable as is *Picea* and periodic appearances of *Taxus*. *Fagus* makes one of its rare appearances during H3, albeit briefly and in small quantities.

There is a marked rise of *Corylus* at this time, *Hedera* is a significant feature of the shrub component and *Ilex* is consistently recorded. The herb component of the flora sees a step change down from its previous level, to a new level that will persist for the rest of the diagram (with the exception of the major, short, rise towards the end). This is largely the result of a significant drop in the quantity of Poaceae and Cyperaceae. Caryophyllaceae, Ranunculaceae and Apiaceae are the three most consistently recorded other components of the herb flora.

Aquatics remain relatively infrequent and consist of *Azolla filiculoides*, *Bidens*, *Sparganium* and *Typha latifolia*, although none of these are continuously present. Spores are slightly more prevalent than aquatics, mainly due to the regular presence of Filicales. *Polypodium* is also found frequently and *Ophioglossum* is recorded as well.

Local Pollen zone H4 (330-220 cm)

Pollen zone H4 is dominated by the sudden rise of herbs, to become the dominant component of the pollen diagram. The response of tree taxa is equally dramatic, with some significant declines, but also some other tree taxa rising in prominence. This event was, however, a transient one; by the end of the zone, there has been a recovery of trees and a decline in the herb fraction.

Concentrating specifically on the period of herb dominance, *Quercus*, *Alnus* and *Corylus* are all observed to decline to substantially lower values; approximately half their previous value. In contrast, *Betula* and *Pinus* both increase, though not as substantially as *Quercus*, *Corylus* and *Alnus* fall away. Other components of the tree and shrub element of the pollen spectra remain relatively constant; *Ulmus*, *Tilia*, *Fraxinus*, *Picea*, *Hedera* and *Ilex*. None are found in large numbers at this time. *Hippophaë* makes a brief re-appearance in the pollen diagram towards the end of the herb dominated interval.

The large herb spike during H4 is overwhelmingly dominated by Poaceae. In contrast to previous periods where herbs have largely consisted of Poaceae and Cyperaceae, in this instance Cyperaceae are not particularly significant. They have risen relative to H4, but do not exceed quantities found in H1 and H2. It is Poaceae that is driving the herb component of the pollen diagram at this time. That said, there are also a wide variety of other herbs present; they are at their most diverse and abundant during this event. Particularly notable examples include Asteraceae, *Cirsium*, Caryophyllaceae, Chenopodiaceae, *Plantago*, *Ranunculus*, Rubiaceae, *Taraxacum* and Apiaceae. Also present are *Filipendula*, *Potentilla*, Rosaceae, *Rumex* and *Valeriana*, Interestingly, there are also herbs that, along with the aforementioned tree species, decline at this time. For example, *Empetrum* was relatively frequent prior to and after this event, but absent during it.

There are no particularly significant changes in either aquatics or spores observed during the high herb phase. As is common in the pollen diagram, *Typha latifolia* is a part of the aquatic sum and is joined by *Sparganium* and *Azolla*. Filicales makes up the spore component, with *Osmunda* also recorded.

The high herb phase spans only around 40 cm of the core. There was a sudden shift into it and a similarly sudden reversion back to a tree dominated pollen spectra. *Quercus*, *Alnus* and *Corylus* all increase and *Betula* and *Pinus* fade away.

It should be noted that there was a gap in recovery of 50 cm, from 250 to 200 cm, at the end of this zone, overlapping into the next and this explains the distinctive smooth shape of the curve at this point.

Local Pollen zone H5 (220-180 cm)

The final pollen zone is dominated by *Alnus* and has significant components of *Pinus* and *Quercus*. *Tilia* remains present. One of the most distinctive features of this period is the appearance in relatively significant amounts of *Abies* and *Picea*, for the first time in the diagram.

Shrubs are infrequent at this point with *Corylus* remaining present but declining and only a fleeting occurrence of *Hedera*. From the herb spectra, Poaceae is significant as is Cyperaceae and there is an unusual spike of Apiaceae. Other noteworthy herbs include *Potentilla* and Rosaceae but generally herbs are not especially diverse. In terms of aquatics, *Azolla* and *Bidens* are present and once again Filicales dominates spores, *Osmunda*, *Polypodium* and *Sphagnum* all recorded.

Zonation of the Hoxne data using CONISS instead of optimal splitting for information content was also undertaken and the results can be seen in Fig 19. The pollen zones reconstructed are the same as in both cases.

6.1.2 – Stratum C

Stratum C has traditionally not been zoned and that convention will follow here. The pollen diagram is generally fairly consistent through this period, with few hugely significant changes, although there are subtle variations to be mentioned. The tree flora is largely composed of *Alnus*, with significant contributions from *Abies*, *Pinus* and *Quercus*. *Quercus* declines midway through Stratum C, whereas *Pinus* increases around this time. *Betula* also makes a more substantive appearance towards the end of the period and *Corylus* also gradually starts to rise. There is a continual low level contribution from *Picea* and *Salix*, *Carpinus* and *Sambucus* are recorded on occasion, in very low numbers. *Hippopha*ë, *Hedera* and *Ilex* were counted, also in very low quantities.

The herb component of the pollen sum during Stratum C is very high; indeed, it is frequently comparable to the values reached during the high herb phase of H5 and is generally higher than at any other point in the main Hoxne pollen sequence. Cyperaceae is the most abundant constituent of the pollen sum, closely followed by Poaceae which gradually rises in prevalence as Stratum C progresses. A number of other herb taxa maintain an almost continuous presence, such as *Empetrum*, Ericaceae, *Cirsium*, Caryophyllaceae and, in particular, Apiaceae. The latter has a particularly noteworthy presence, especially early on in the period when it is recorded in very large numbers. Other herbs recorded reasonably frequently include, *Artemisia*, Asteraceae, Crucifereae and *Thalictrum*. Finally, the presence of *Mentha*, *Rumex*, Rosaceae, *Potentilla*, Ranunculaceae, *Polygonum*, *Plantago*, Chenopodiaceae and *Calluna* was also noted.

Aquatics are recorded during Stratum C, though not particularly frequently; *Azolla* and *Typha latifolia* are the most common. Spores are relatively more prevalent during this period than in the rest of the Hoxne core, mainly due to the reasonably large quantities of Filicales observed.

6.2 – Pollen stratigraphy from Athelington

The choice of number of pollen zones is complicated in this instance by the fact that the biostratigraphy of the pollen sequence recovered differs from that of Coxon (1985). Coxon (1985) identified six zones, that he correlated with Marks Tey; Ho IIc1, Ho IIc2, Ho IIc3, Ho IIIa, Ho IIIb and Ho IV. Coxon's Ho IV has high levels of *Betula* and low levels of *Abies*. The sequence established here does not see any fall in *Abies* and so it seems unlikely that this zone was uncovered during the coring as part of this research. In contrast, the base of Coxon's (1985) core began in mixed oak forest, whereas here an early stage of the interglacial, with high levels of *Betula* and *Pinus* seems to have been recovered. There is also the issue of a relative lack of resolution, due to coring restrictions, in the data. As will be discussed, the resolution was not sufficient to detect the Non Arboreal Pollen phase, known to be present at the site. Therefore, with a shorter sequence at the top, a longer sequence at the base and a lower resolution, comparing the number of zones established by Coxon (1985) is made difficult.

The decision is made to reconstruct five zones; this seems the most appropriate comparative number. The base of the record sees a dominance *Betula* and *Pinus*, then the rise of *Quercus*. By comparison with the stratotype at Hoxne, this is assumed to represent two zones, Ho IIa and Ho IIb. It is reasonable to include these zones in the analysis. The simplest step would be to then add the additional five zones from Coxon's original work (not including Ho IV, which is clearly absent), to make seven in total; Ho IIc1, Ho IIc2, Ho IIc3, Ho IIIa, Ho IIIb, plus Ho IIa and Ho IIb from the Hoxne comparison. However, Ho IIc1 is very limited in Coxon's diagram and Ho IIc2 is dominated by the NAPP. Furthermore, Coxon (1985) discusses the fact that dividing Ho IIc into three subzones was not initially undertaken by Turner (1970). Taking these factors into account, Ho IIc is combined into one zone, with Ho IIIa and Ho IIIb treated separately. To summarise, the zonation is split into five based on Ho IIa and Ho IIb from Hoxne and Ho IIc, Ho IIIa and Ho IIIb from Athelington.

Local Pollen zone A1 (780-830 cm)

The pollen spectrum during this period is dominated by *Betula* and *Pinus*. There are few other trees or shrubs that make a substantive contribution. *Fraxinus* and *Corylus* are both found in very low numbers, along with isolated occurrences of *Acer*. Herbs make quite a considerable contribution to the sum particularly grasses and also sedge. Asteraceae are quite common as are Ranunculaceae, *Thalictrum* and Apiaceae. *Rumex* are recorded as are Chenopodiaceae. No aquatics or spores were recorded at this time.

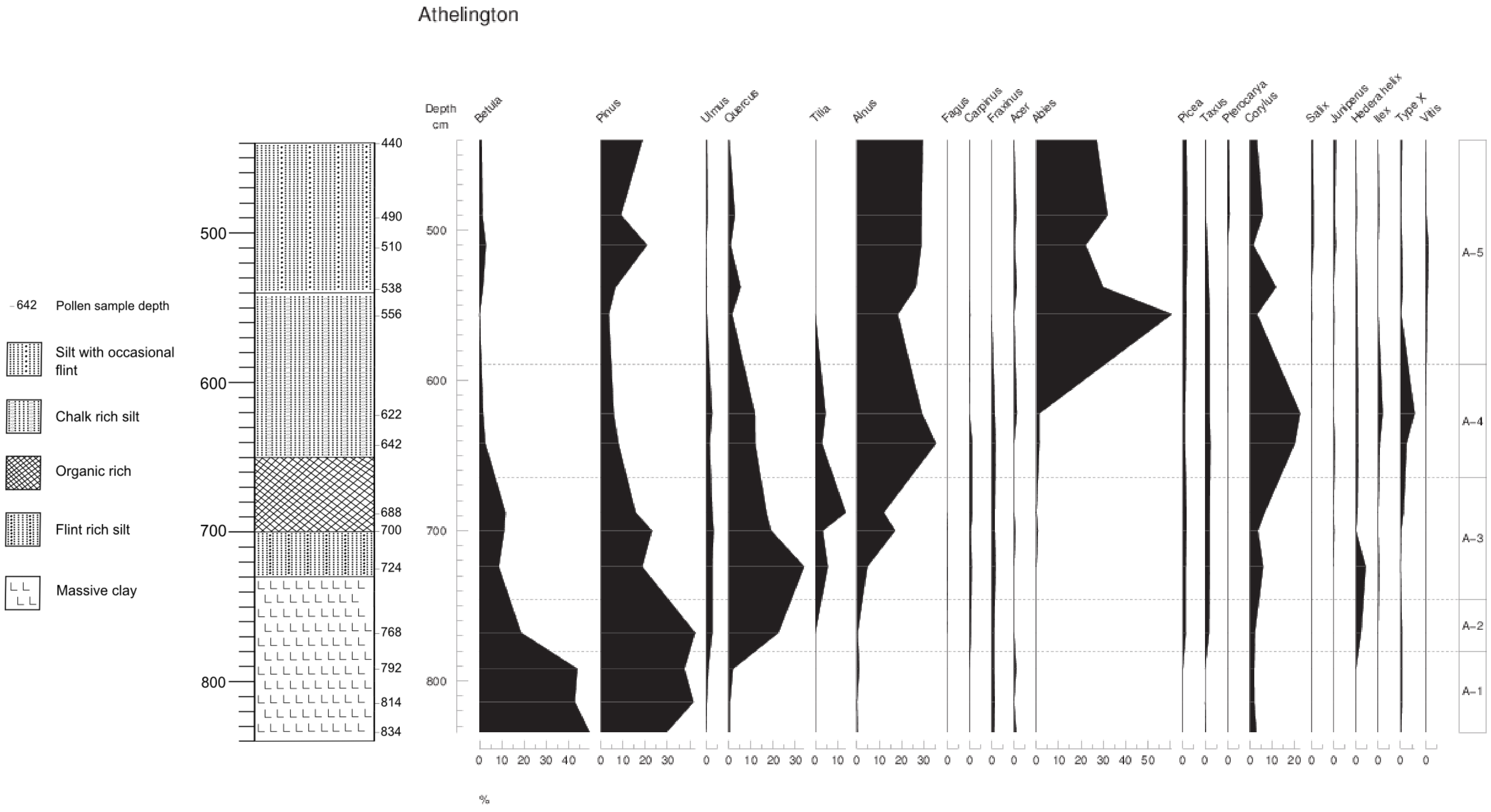


Fig 20: pollen diagram from Athelington, zoned using a broken stick model and optimal splitting by information content (Part 1).

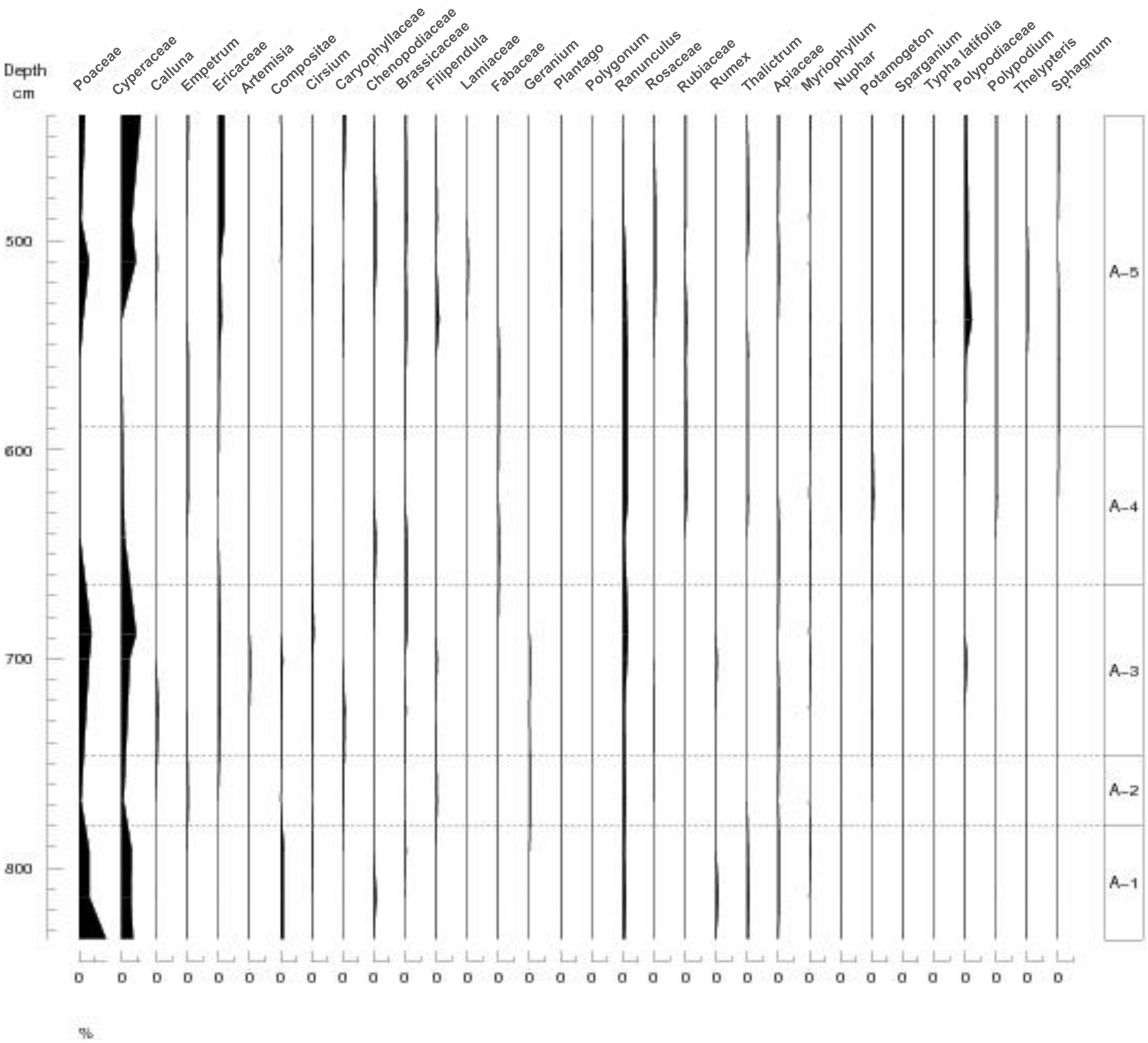


Fig 21: pollen diagram from Athelington, zoned using a broken stick model and optimal splitting by information content (Part 2).

Local Pollen zone A2 (745-780 cm)

This short pollen zone is dominated by *Pinus*. *Betula* is beginning to decline in the pollen diagram, *Pinus* peaks during this phase and then declines and *Quercus* begins a substantial increase. Midway through A2, *Tilia* and *Alnus* also begin to rise, although they remain limited in number. A number of other trees are present in low quantities; *Ulmus*, *Fraxinus*, *Taxus*, *Picea* and *Carpinus*. *Corylus* is the predominant shrub at this time and is joined by *Hedera*. Herbs remain reasonably present, though they initially suffer a dip in the first half of the zone. Poaceae and Cyperaceae are the main constituents, along with Ranunculaceae and Caryophyllaceae. *Cirsium*, *Calluna* and Ericaceae are some of the other taxa recorded. Once again, aquatics and spores are virtually absent.

Local Pollen zone A3 (665-745 cm)

The main feature of pollen zone A3 is the decline of previously dominant tree types and their replacement by other trees and shrubs. *Betula* and *Pinus* continue the decline witnessed in A2, with *Quercus* initially rising to its peak within the pollen diagram before also falling away. *Tilia* and *Alnus* continue to rise in the pollen spectrum, accompanied by *Corylus*. *Hedera* also rises during A3, reaching a peak midway through the zone. As in A2, there is a low level presence of *Ulmus*, *Carpinus*, *Fraxinus*, *Picea* and *Taxus*. Towards the end of the zone, the extinct taxon Type X begins the start of a significant increase in the pollen diagram. Herbs are reasonably common during A3; as usual, Poaceae and Cyperaceae make up the bulk of the herb sum, with Ranunculaceae again prevalent. Ericaceae, *Cirsium* are found, along with occurrences of *Geranium* and Asteraceae. Aquatics and spores are limited.

Local Pollen zone A4 (590-665 cm)

Pollen zone A4 is dominated by *Alnus* and *Corylus*, both of which peak midway through the zone. *Quercus* remains a reasonably significant component, though it continues to decline, as does *Pinus*, *Tilia* and *Betula*, the latter fading away to very low numbers. Type X is reasonably prevalent at this time, peaking in the pollen diagram, and *Abies* begins to increase significantly towards the end. Once again, there are a number of trees and shrubs present in low numbers; *Ulmus*, *Carpinus*, *Fraxinus*, *Acer*, *Picea*, *Taxus*, *Juniperus*, *Hedera* and *Ilex*. Herbs are at their most infrequent during this period, with limited quantities of Poaceae, Cyperaceae, Chenopodiaceae and Ranunculaceae being recorded. Aquatics, mainly *Potamogeton*, are slightly more common, but spores are still rare.

6.2.5 – Local Pollen zone A5 (440-590 cm)

This final pollen zone spans the longest section of core. *Abies* peaks in very high quantities during A5, before falling away somewhat, though remaining a substantial component of the pollen sum. *Alnus* remains significant, whilst *Pinus* begins to rise during this period. *Tilia* disappears early on in A5, whilst *Quercus* and *Corylus* both decline to low levels. *Pterocarya* is a new arrival to the pollen diagram, as are *Salix* and *Vitis*, but they are low in abundance. This is also the case with *Betula*, *Acer*, *Picea*, *Taxus*, *Juniperus* and *Hedera*. Type X also fades away during this time.

The herb sum increase during A5, to similar levels as A1. Poaceae and, in particular, Cyperaceae are the predominant elements of this sum. Other notable components include Ranunculaceae, Ericaceae, Brassicaceae, Rubiaceae and Rosaceae. *Mentha*, *Plantago*, *Filipendula* and Caryophyllaceae are also recorded. Aquatics are present in small quantities and consist of *Typha latifolia*, *Sparganium* and *Potamogeton*. Spores see a minor peak at this time, due to the presence of Polypodiaceae. *Sphagnum* and *Thelypteris* are also noted.

7 – Charcoal results

The quantified charcoal data will be reported by site and by size category. Microscopic charcoal values were so low that there is little point in producing graphs; just the raw data will be provided. Only in Stratum C was it possible to carry out continuous sampling for charcoal and hence construct a curve. In the main Hoxne core and the Athelington core, sampling was undertaken at the levels from which pollen was sampled.

7.1 – Hoxne

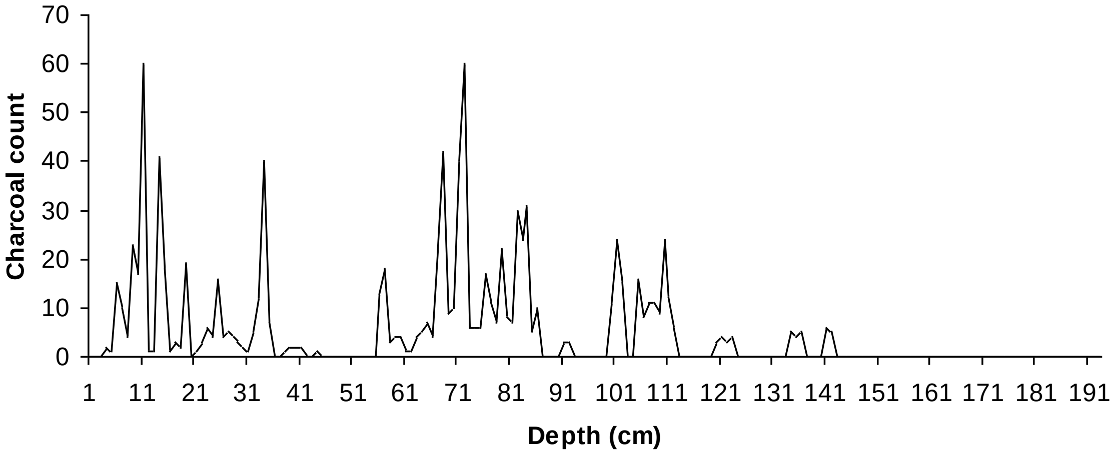


Fig 22: macroscopic (<250µm) charcoal from Stratum C at Hoxne

Depth (cm)	Charcoal area (cm^2/cm^3)
4	0.000
20	0.000
28	0.000
40	0.014
60	0.013
68	0.002
76	0.011
100	0.000
108	0.003
116	0.000
132	0.000

180	0.000
192	0.000

Table 8: Microscopic charcoal area from Stratum C.

Depth (cm)	Charcoal area (cm^2/cm^3)	Macroscopic charcoal count
260	0.000	0
272	0.000	0
279	0.000	0
288	0.000	0
296	0.000	0
310	0.000	0
320	0.000	0
326	0.011	0
334	0.000	0
342	0.000	0
356	0.000	2
384	0.000	0
392	0.008	0
408	0.000	0
416	0.000	0
432	0.000	0
444	0.003	0
464	0.000	0
480	0.000	0
496	0.000	0
512	0.000	0
528	0.000	0
544	0.000	0
556	0.000	0
576	0.007	0
592	0.000	0
637	0.000	0
648	0.000	2
656	0.000	0
672	0.000	0
682	0.000	0
692	0.000	0
706	0.000	0

720	0.010	0
746	0.000	0
760	0.000	3
776	0.000	0
784	0.000	0
794	0.009	0
801	0.014	0
808	0.000	0
816	0.016	0
824	0.000	0

Table 9**:** Microscopic charcoal area from the main Hoxne core and macroscopic charcoal counts (<250μm).

The results show very low levels of charcoal in both cores and in both micro and macroscopic charcoal. Clearly fire activity was very low during the Hoxnian period, though there may be some minor exceptions during Stratum C.

7.2 - Athelington

Depth (cm)	Charcoal area (cm^2/cm^3)	Macroscopic charcoal count
440	0.000	0
490	0.000	0
510	0.009	0
538	0.000	0
556	0.000	0
622	0.010	0
642	0.000	0
688	0.000	4
700	0.000	0
724	0.000	0
768	0.000	6
792	0.000	0
814	0.013	0
834	0.011	0

Table 10: Microscopic charcoal area from the Athelington core and macroscopic charcoal counts (<250μm).

As with the Hoxne core, the results show very limited amounts of charcoal. The implications of these results will be discussed further in Chapter 9.

8 – Pollen models

This chapter presents the results of the various pollen modelling experiments undertaken.

8.1 – Spatial scale

A number of model experiments were run in order to test for the effects of spatial scale on the pollen assemblage. The question these runs investigated was; would an experiment with pollen sourced from a relatively small area around the lake produce a pollen assemblage markedly different from experiments incorporating a larger spatial scale. This can be illustrated with a community representing the Hoxnian forest pollen zone H2. A simple matrix of birch, pine, oak, hazel, grass and sedge makes up the pollen spectra, with percentage values roughly corresponding to those found within the pollen data, and three spatial scales, 5 km^2, 15 km^2 and 50 km^2 were used. The results can be seen in Table 11.

Species	**Landscape %**	**Pollen yield sampled**			**Pollen yield %**		
		5 km^2	15 km^2	50 km^2	5 km^2	15 km^2	50 km^2
Birch	34	0.1973	0.3259	0.4533	50.64	51.67	52.78
Pine	12	0.0374	0.0600	0.0808	9.59	9.51	9.41
Oak	40	0.1465	0.2313	0.3064	37.61	36.67	35.68
Hazel	4	0.0036	0.0059	0.0082	0.93	0.94	0.96
Grass	5	0.0024	0.0038	0.0050	0.62	0.60	0.59
Sedge	5	0.0024	0.0038	0.0050	0.62	0.60	0.59

Table 11: the effect of spatial scale on simulated pollen assemblages from Hoxne pollen zone H2. The landscape consists of six taxa, in percentages approximating those found in the actual pollen data. Pollen yields at a sampling point in the centre of the landscape are simulated and converted into percentages. A simple matrix is used.

The data in Table 11 clearly demonstrate that spatial scale has an impact on the simulated pollen assemblages. All pollen types increase their loading (pollen yield) in the larger landscapes, for the simple reason that larger landscapes have more vegetation in them. However, there is not an order of magnitude of difference in loading between the 5 km^2 and 50 km^2 landscapes.

Despite the clear differences in pollen loading between the three simulations, there is actually very little difference in the percentage output. The proportions of pollen taxa are similar in all three cases. This indicates that, whilst landscape size impacts upon the amount of pollen actually deposited, it has no effect on how the ecosystem is represented in the pollen data. In turn, this implies that generally speaking there will be a general consistency in the ecosystem on a variety of scales; it would appear similar close to the lake at Hoxne as well as at distances further away. However, this may not always be the case depending on special cases of landscape structure.

This pattern is found consistently. It is not solely in the simple landscape case described above, it also happens with more complex structured landscapes. This can be illustrated again with an ecosystem representing pollen zone H2. Fig 23 shows the considerable difference between the two simulations and Tables 11 and 12 show the output.

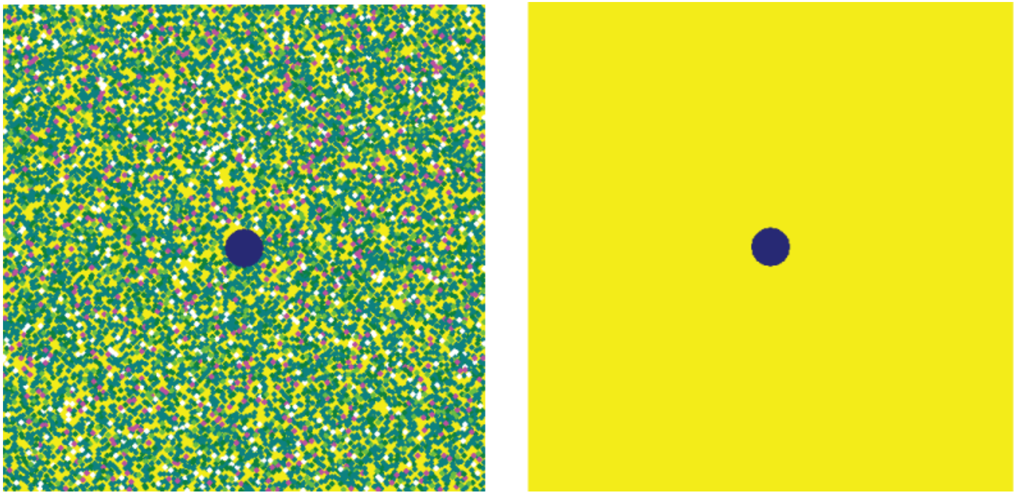


Fig 23: comparison of the two landscape structures used to generate the data in Table 11 and Table 12. In the simulation on the left, pine, oak, hazel, grass and sedge all exist in patches, embedded in a birch matrix. In the simulation on the right, all species are within the matrix.

Species	**Landscape %**	**Pollen yield sampled**			**Pollen yield %**		
		5 km^2	15 km^2	50 km^2	5 km^2	15 km^2	50 km^2
Birch	31	0.1752	0.3141	0.4002	46.99	50.73	49.11

Pine	11	0.0358	0.0578	0.0617	9.61	9.34	7.57
Oak	41	0.1516	0.2323	0.3280	40.67	37.52	40.25
Hazel	5	0.0041	0.0065	0.0114	1.11	1.06	1.40
Grass	6	0.0033	0.0042	0.0056	0.88	0.68	0.68
Sedge	6	0.0028	0.0041	0.0080	0.75	0.67	0.98

Table 12 the effect of spatial scale on simulated pollen assemblages from Hoxne pollen zone H2. The landscape consists of six taxa, in percentages approximating those found in the actual pollen data. Pollen yields at a sampling point in the centre of the landscape are simulated and converted into percentages. A patchy landscape was simulated.

Once again, Table 12 shows that varying spatial scale has little impact on the ecosystem represented in sampled pollen. There is slightly more variability in this instance, but not sufficient to alter this basic conclusion.

8.2 – Does pollen data accurately reflect ecosystem composition?

Tables 11 and 12 not only present evidence regarding spatial scale, they also make an important point regarding the representation of an ecosystem in the pollen sampled. Note birch in Table 12: it makes up 31% of the landscape, but around 49% of the sampled pollen. So there is clearly not a straightforward one to one relationship between the amount of a given taxa in the landscape and the amount preserved in a core. Moreover, an additional complication arises; not only is there not a one to one relationship, the proportion of different taxa is not accurately represented in the sample. In this instance, birch is less frequent in the environment than oak, but more common in the pollen diagram. This is the result of the greater pollen productivity (PPE) of birch than pollen and ultimately means that there is a bias within the pollen diagram. It is not, interpreted in terms of simple quantities of pollen recorded, an accurate reflection of ecosystem composition.

This issue becomes particularly acute where taxa with particularly low PPE’s are concerned; hazel and grass being an example. This can be demonstrated with reference to the high herb phase during Hoxne pollen zone H5. Table 13 shows the results of a simplified version of the ecosystem composition at this time. There are very few herb taxa for which PPE data is available, so they are all subsumed under grass. The simulation was run with the percentages of taxa in the landscape taken from those found in the pollen data. If such a landscape produces simulated values that match closely with this input, then it is probable that the pollen data accurately reflects ecosystem composition.

Species	Landscape %	Pollen yield sampled	Pollen yield %
Birch	5	0.04792053	14.69
Pine	16	0.07995460	24.52
Oak	10	0.05782428	17.73
Elm	5	0.00537341	1.65
Alder	18	0.08699563	26.68
Hazel	18	0.02672908	8.20
Grass	28	0.02130368	6.53

Table 13: simulating the landscape of the high herb phase during pollen zone H5. Based on a simple landscape, 15 km^2, with all species in a matrix (see for an example)

Table 13 shows, again, that there is no simple relationship between sampled pollen and the actual ecosystem surrounding a lake. The landscape percentages inputted into the model were designed to approximate those found in the actual pollen data. Yet the model output cannot replicate this; a landscape consisting of 5% birch, for example, does not produce 5% birch in a modelled sample. This strongly indicates that the 5% birch in the real sample is not indicative of 5% birch in the real landscape.

The starkest example of this problem can be found with grass. The model output shown in Table 13 demonstrates that a large percentage of grass in the landscape produces only a modest amount of grass in a sample. Despite being the largest component of the modelled ecosystem, it is the second smallest component of the pollen sum derived from a core. It therefore becomes clear that to produce a grass signal that makes up 28% of a pollen sum, as in the high herb phase of H5, requires grass to constitute substantially more than 28% of an ecosystem.

This finding is also replicated in the attempt to model the birch and oak dominated forest of pollen zone H2. In this case, grass is a much smaller component of the observed pollen sum, around 5%. Modelling such a value produces a modelled sample of less than 1%. Therefore, if the real, observed sample of grass is 5%, it must have been more prevalent than this in the actual ecosystem at this time. As grassland effectively represents open environments, the results of the modelling experiment suggest that Hoxnian ecosystems must have often been considerably more open than a simple interpretation of the pollen diagrams would suggest.

Species	**Landscape %**	**Pollen yield sampled**	**Pollen yield %**
Birch	1.6875	0.01627613	10.06
Pine	5.75	0.02666519	18.48
Oak	3.375	0.01823044	11.27
Elm	1.6875	0.00156392	0.97
Alder	6.25	0.03048923	18.85
Hazel	6.25	0.00936637	5.79
Grass	75	0.05918759	36.58

Table 14: simulating the landscape of the high herb phase during pollen zone H5. Based on a landscape of grass patches in a matrix 15 km^2

How much more grass in the landscape was there? Table 14 describes the results a model experiment to address this issue. In this instance, grass was modelled as the overwhelmingly dominant component of the landscape, at 75%. At such a high amount, it does indeed become the main constituent of the modelled pollen sum, at close to 37%. However, this is only around 10% higher than the quantities of grass observed, approximately 28%, in the real pollen data. So, whilst grass during the high herb phase of H5 probably did not make up 75% of the landscape, it would have been comfortably the dominant component, probably close to half. This period must therefore have been very open.

8.3 – The influence of landscape structure

A further issue investigated was the impact of landscape structure on pollen assemblages. An example of two contrasting landscape structures for the high herb phase was simulated. Fig 24 shows a landscape in which tree and shrub patches exist within a matrix of grass. Moreover, alder is preferentially concentrated around the lake basin, a plausible ecological scenario given the preference of alder for damp habitats. The alternate landscape structure, is the simple matrix, shown in Fig 23, and the results can be seen in Table 15.

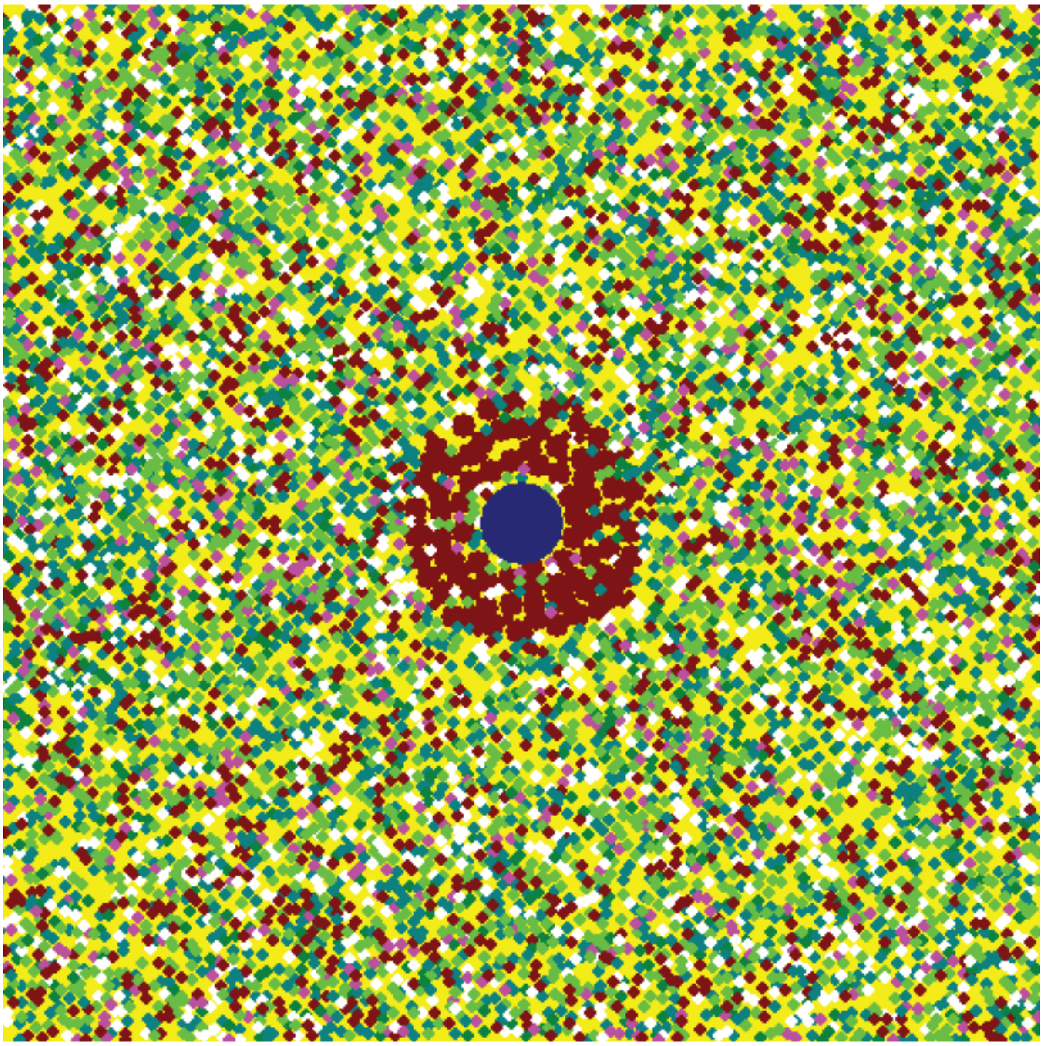


Fig 24: a complex landscape structure, with trees and shrubs embedded within a grass matrix. The brown dots concentrated around the lake represent alder.

Species	**Landscape %**	**Pollen yield sampled**		**Pollen yield %**	
		simple	Complex	simple	complex
Birch	5.5	0.05271259	0.03170367	16.61	9.23
Pine	15.1	0.07545715	0.05348308	23.78	15.58
Oak	10.6	0.06129374	0.04593226	19.31	13.38
Elm	5	0.00537341	0.00435047	1.69	1.27
Alder	15	0.07249636	0.16937102	22.84	49.33

Hazel	17.8	0.02643209	0.02007538	8.33	5.85
Grass	31	0.02358622	0.01844407	7.43	5.37

Table 15: comparing two difference landscape structures during the high herb phase of pollen zone H5. The simple landscape is all the taxa in a matrix, the complex landscape consists of patches of taxa within a grass matrix, with alder concentrated around the lake.

Table 15 shows a marked difference that landscape structure can have on simulated pollen assemblages. In this case, the difference between the simple and complex landscapes is driven by the concentration of alder around the lake. When alder simply exists as a general component of a matrix, it makes up 23% of the pollen sample. In contrast, when it surrounds the lake and dominates the ecosystem at this point, it produces nearly 50% of the sample. Clearly, concentrating alder round the Hoxne lake can produce elevated alder concentrations in the actual pollen data.

The impact of large amounts of alder is a depression of the percentages of other taxa, although interestingly their proportions do not alter. This suggests that the other aspect of the changed landscape structure between the two scenarios, patchiness, is not having a particularly great impact. This can be further investigated in a simple comparison of a patchy landscape versus a matrix one. In essence, this was performed in the construction of Tables 11 and 12, but for clarity here is a summary taking the 15 km^2 case.

Species	**Pollen yield sampled**		**Pollen yield %**	
	Simple	Patchy	Simple	patchy
Birch	0.3259	0.3141	51.67	50.73
Pine	0.0600	0.0578	9.51	9.34
Oak	0.2313	0.2323	36.67	37.52
Hazel	0.0059	0.0065	0.94	1.06
Grass	0.0038	0.0042	0.60	0.68
Sedge	0.0038	0.0041	0.60	0.67

Table 16: a comparison of a simple and a patchy landscape.

The data in Table 16 clearly show that there is little difference between a patchy landscape and one which species are grouped together, with no separation into separate communities within the landscape. This is quite a fundamental ecological difference and it is interesting to note that his appears to have no impact on the reconstructed pollen assemblage.

9 – The ecology and fire history of the Hoxnian

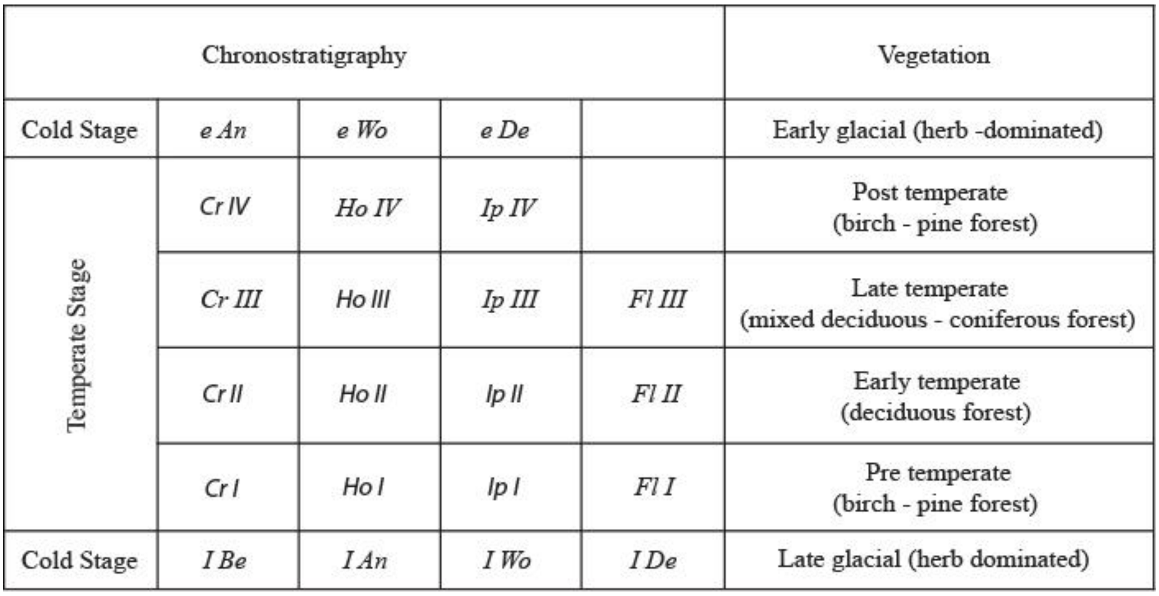
This chapter will combine the results presented in the previous three chapters to present a new perspective on the ecology and fire history of the Hoxnian.

9.1 – Pollen zonation

Zonation is a tool of stratigraphy and stratigraphy is ultimately employed to provide geologists with more practical ways to handle large amounts of data, in addition to enabling the testing of particular hypotheses (for example, relating to the timing of events). The geological column is the most obvious example of zonation of geologic data. The relative lack of data for much of this record can make zonation and correlation rather difficult. For the more recent past, we are faced with different complications that result from the fact that there is actually rather a lot of data. In most respects the more detailed data provided by Quaternary sequences are a positive, allowing us to reconstruct past events in much greater depth. However, in doing so, we are particularly confronted by issues of time transgression and dating control. Both these issues can be found at any point in geologic history, but they are acute during the Quaternary, because the questions we wish to answer are more temporally complex.

Given the large volume of data that geologists have to deal with, it is reasonable to employ zonation. It can be fairly justified on these reasons alone. It is particularly useful in the initial stages of understanding a given time period, linking records and building up a coherent picture of environmental change. Zones such as the Atlantic and Sub-Boreal were very helpful, preliminary divisions of the Holocene. Pollen zonation becomes less useful as more advanced forms of dating come along; radiocarbon and tephra have, to some degree, negated the importance of zonation within the late Quaternary. It remains useful to divide up individual sites but as a method of correlation it is much less practical. Indeed, the advent of secure radiocarbon dating helped to demonstrate that earlier conceptions of zonation were overly simplistic (Bennett, 1988). Unfortunately, such dating tools are not available for much of the Pleistocene. Zonation still remains massively important.

Hoxnian pollen zonation has a particularly significant status within the British Pleistocene. Such was the seeming regularity and clarity of pollen zones within Pleistocene deposits, earlier workers mistakenly conflated what we now know to be separate interglacials, as seen in the Marine Isotope Record, into one interglacial. The subdivision of Pleistocene interglacials into characteristic zones became a particularly powerful scheme. This scheme was largely developed by West (1968) and Turner and West (1968) and is summarised in Fig 25.



Chronostratigraphy					Vegetation
Cold Stage	*e An*	*e Wo*	*e De*		Early glacial (herb -dominated)
Temperate Stage	*Cr IV*	*Ho IV*	*Ip IV*		Post temperate (birch - pine forest)
	Cr III	*Ho III*	*Ip III*	*Fl III*	Late temperate (mixed deciduous - coniferous forest)
	Cr II	*Ho II*	*Ip II*	*Fl II*	Early temperate (deciduous forest)
	Cr I	*Ho I*	*Ip I*	*Fl I*	Pre temperate (birch - pine forest)
Cold Stage	*l Be*	*l An*	*l Wo*	*l De*	Late glacial (herb dominated)

Fig 25: a British pollen biostratigraphical framework

This paradigm influenced thinking regarding Pleistocene stratigraphy (and the questions that are ultimately built on the foundations of stratigraphy, such as how did the climate oscillations of the past actually proceed) for many decades. Indeed the paradigm persisted for a considerable period after the discovery, via marine records, of the complexity and structure within the Pleistocene. It was, arguably, not until the publication of amino acid stratigraphies and tentative geochronology in the 1980s (e.g. Bowen *et al*., 1989) that attitudes within the British Pleistocene community began to change.

The pollen zonation at Hoxne conducted by West (1956) was one of the first to give rise to the format reported in Fig 25. It was hugely influential and it is therefore of considerable interest to see whether there was indeed a firm basis for the scheme, despite the fact that the overall paradigm that it helped support is no longer tenable.

Furthermore, whilst this aspect of such an investigation is largely dominated by historical curiosity, there is also a practical element. Pollen biostratigraphy may not be able to distinguish closely spaced interglacials, however beyond the reach of geochronological tools with small error bars, it remains one of the only tools available to subdivide periods of time within a given period. It is therefore extremely useful and whilst it is undoubtedly an imperfect technique, it is unlikely to be fatally flawed in the application here.

One of the main problems to beset pollen zonation is the issue of time transgression; one of the first illustrations for the Quaternary came from Smith and Pilcher (1973) who showed that Godwin's Holocene pollen zones from the British Isles are diachronous. A particularly elegantly illustration of this issue was provided by Bennett (1988) who confirmed the significance of time transgression and also demonstrated that pollen zones can be (though are not always) limited in space. However, time transgression may only a problem depending on the research question in hand; if you are interested in events on very short timescales it is indeed troublesome. Conversely, if broad temporal questions are your focus, then its impact will be minimal.

Furthermore, time transgression and issues of space are unlikely to greatly affect this and other studies of the British Pleistocene. Due to the nature of sediment preservation in the UK, many of the deposits in question are restricted to a small geographic area. This is certainly the case in this study, which deals primarily with East Anglia. Bennett, (1988) was focusing on larger areas than is the case here, making comparisons between regions not within them.

His comparisons take the form of transects across and up the country. For example, the southerly transect begins in East Anglia, with the next site, Cross Mere, being a considerable distance away on the Welsh border, in Shropshire. This is a scale largely beyond that under consideration here and even in this case there are occasions during the Holocene when the vegetation at the two sites have similar vegetation that correlates in time. Therefore it seems unlikely that within the region in question, these issues are likely to be particularly problematic. Indeed, Bennett (1988) provides support for this by noting the similarities between the two sites he studies within East Anglia; Saham Mere and Sea Mere. Neither of these sites are particularly far apart but they are a comparable distance to Hoxne and Athelington, for example. Marks Tey to Hoxne is further, but even this can be comfortably considered as within the region. Obviously two sites from the midlands are included in this thesis and the chances of time transgression are slightly greater in this instance, but potentially not significantly so. Given the need to make assumptions to provide an appropriate framework, this is deemed acceptable.

A further consideration arises from that fact that Bennett (1988) takes no account of the issues of basin size and spatial representativeness of a given site. Many of the sites Bennett (1988) considers are small in scale and so are reflecting local and not regional vegetation patterns, where there may be different dynamics in terms of time transgression.

Given the continued value of pollen zonation within MIS 11 and given the iconic status of Hoxne, an assessment of the pollen zones is an important task. Are they valid, do they have any statistical significance? Zonation within the British Pleistocene has not typically been conducted using numerical and statistical techniques. As a recent example, Boreham *et al.* (1999) investigated the site at Tye Green and constructed a pollen based stratigraphy solely on the basis of "eyeballing" the pollen diagram. This is the same technique as used originally by West (1956) at Hoxne; looking, ultimately subjectively, for what are deemed to be significant changes in pollen assemblages and constructing pollen zones at those points.

This method is not subject to mathematical rigour; there is no way to demonstrate that these zones are significant in a statistical sense. Boreham *et al.* (1999) determined the existence of six local pollen zones that they then argue correspond to Hoxnian substages Ho I, Ho II, Ho IIIa, Ho IIIb, Ho IVa and Ho IVb. That Boreham *et al.* (1999) were able to suggest these subdivisions at their site is suggestive of some degree of significance of the zones, but to some extent this is an unsatisfying approach. Moreover, whilst seeking to correlate with a stratotype is a perfectly valid and necessary exercise, there may be a danger in conditioning when constructing the zones at an individual site, based on the expectations set out by the stratotype.

It is important at this point to again recognise that pollen zones are ultimately arbitrary constructs imposed on the data. The key is to minimise the arbitrariness. As discussed above, in using numerical techniques we are assessing significance, but this is only statistical significance. As pollen zones do not exist in reality, there will always be a degree of subjectivity introduced, simply because you are creating them in the first place. This does not appear to be something that is always acknowledged in the literature, with workers simply saying that they apply Bennett's (1996) methodology to determine the number of statistically significant zones. In reality the process involves the added step of specifying the number of zones required.

Running the psimpoll program that enables the application of the Broken Stick method provides a series of menu options. The first thing to set is the number of pollen zones required; the Broken Stick methodology then analyses the data and produces a statistically significant output based on your desired number. One could request 2 or 20 zones and the program will find 2 or 20 zones that are statistically meaningful. These zones have rigour, but there is ultimately a subjective basis. In this study, therefore, it was reasonable to use the Broken Stick method to test the zones constructed by previous workers, in particular the number of divisions in the Hoxne pollen diagram suggested by West (1956). This is preferable to constructing an entirely new stratigraphy; the one outlined by West (1956) is familiar to all workers in the period and so confirmation of this is preferable to the adoption of a new scheme.

There is some degree of agreement between West's zones and the five zones established upon the application of statistical techniques, which is encouraging. The scheme presented here is not identical, although it is likely the result of the model zoning around the NAPP, which West did not do. However, beyond this there is a final zone at the top of the sequence (like Ho III a) and zones towards the lower portions corresponding to the shift between boreal and more temperate forest. Therefore the fundamental features appear to correspond.

What is doubly encouraging is the agreement between two distinct methods; the Broken Stick and CONISS (Grimm, 1987). CONISS was applied because it is a well established technique, widely used (although less so since the advent of the Broken Stick) and therefore worthy of investigation. Moreover, it is computationally easy to run CONISS within psimpoll and so little additional time was taken up by this further analysis.

9.2 – Hoxnian ecology and vegetation openness

9.2.1 – Observations regarding Hoxnian ecology

The pollen modelling highlights the importance of PPEs, with the patterns observed being strongly controlled by the PPE's of the various taxa concerned. Those with low PPE's are likely to be underrepresented in a pollen sample when compared to their prevalence in a landscape, whereas those with high PPE's are likely to be overrepresented. Grass and many herbs would have played greater roles in an ecosystem, as would a number of tree and shrubs, such as elm, lime and hazel. In contrast, taxa with high PPE's such as alder, oak and, in particular, birch may have been less substantive than previously believed.

These insights affect our appreciation of the ecology of the period although ultimately they do not force a radical shift in understanding. We are still ultimately dealing with temperate deciduous woodlands. The ecology may have at times closely resembled modern woodlands, particularly early on in the record when birch and oak dominate, with a lesser contribution from pine. This is a fairly typical combination in many parts of Britain, although usually on acid soils which probably were not present here.

Generally speaking, the more complex the ecosystem represented in the pollen spectra, the more difficult it is to disentangle the taphonomic biases inherent in the pollen signal and reach a conclusion as to exactly how the woodland would have looked. We can however look for particularly unusual ecosystem types based on the presence of unexpected taxa and the likelihood of a non-analogue situation. In this regard, the pollen spectra do not reveal any unexpected combinations of taxa, but we cannot really say if the proportions of taxa and the ultimate make up of the communities were similar to today.

If Stratum C belongs in a later substage of MIS 11, it may represent something of an ecological transition period, with the presence of typical interglacial trees, being joined by dwarf species and a wider array of herbs (although there is the potential for a reworked component, which will be discussed in Chapter 11). The fact that fir, a typically boreal species, is present at this time supports this argument. If we avoid thinking simply in binary terms, cold and warm, arctic flora and temperate, and recognise that ecology is characterised by gradations and the absence of easily defined groupings, then Stratum C may appear to be less perplexing. Viewing the period through a Gleasonian rather than Clementsian ecological lens is much more reasonable.

Thinking generally about the relationship between vegetation and climate change, we can particularly reflect on the abrupt climate event that has been reconstructed (see Section 12.5). This event suggests that ecosystems can respond significantly to climate change, corroborating similar conclusions from the late glacial and Holocene (e.g. Williams *et al.*, 2002). This is particularly significant considering the likelihood of future climate change, with an added significance from the potentially analogous nature of the time period studied here. There already appears to be evidence for global ecological responses to climate change (Walther *et al.*, 2002) and a number of studies have looked at possible vegetation responses to climate change over the next century. For example, Higgins and Scheiter (2012) predict significant regime shifts in major ecosystems, although these are likely to occur asynchronously.

Thuiller *et al*. (2005), project that more than half of European species could be vulnerable of threatened by 2080 and even modest scenarios of climate change pose a serious extinction risk. However, the majority of these losses would be concentrated in the Mediterranean region and in areas bordering Siberia. Regions closest to the Atlantic are least sensitive, something that the results presented here may support. Despite the severity of the abrupt climate event, the ecosystem largely recovered afterwards. This suggests a degree of resilience to perturbation with this ecological system. However, presumably if this climatic change had persisted and become a distinct trend, then there would have been a significant ecosystem reorganisation as a result. Furthermore, the overall Hoxnian record is one of varying species over time that reflects climatic change. These changes were on the scale of those predicted over the coming centuries (i.e. a few degrees). Therefore, if vegetation is relatively tightly coupled to climate as seems to be the case here and in other palaeo studies (e.g. Williams *et al*. 2002), then we might expect changes to British woodlands in the future.

Finally, it is also worth mentioning that the pollen results obtained here match well with the previous studies undertaken at these sites by West (1956) and Coxon (1985). The same taxa were largely recorded and the overall stratigraphy produced much the same, with the exception of extra recovery of the interglacial and loss at the top at Athelington. At Hoxne, the only pollen type not recorded in this study but found by West (1956) is *Scabiosa* (which he found only two cases of). In contrast, this study has determined the presence of *Mentha*, which West did not. At Athelington, Coxon recorded *Urtica*, which was not uncovered in the present analysis. These results represent a deeply encouraging taphonomic test; it is rare for more than one core to be taken for a lake basin. It is always assumed that this core is representative of the pollen deposited, but this assumption is hardly ever tested. The data presented here suggests that this is indeed a fair assumption.

9.2.2 – Landscape structure and openness

The pollen models presented here are an exciting new perspective on Pleistocene palaeoecology. However they are also somewhat frustrating because they offer a first step, but it is unlikely that further developments will be possible. The next stage of the modelling process would be to incorporate real world landscape information. For example Caseldine and Fyfe (2006) construct a “real” landscape based on GIS data for a given area incorporating soil type, slope relief and aspect, drainage, underlying geology and so forth. In the relatively recent past, this approach is perfectly possible, albeit with some underlying assumptions. However in a period as distant as the Hoxnian, it is simply not possible to reconstruct the environment with that level of detail. It would be a case of “garbage in, garbage out”.

Adding this additional level of detail enables a considerable degree of constraint on the models. This is necessary where landscape structure is concerned in order to avoid the problem of equifinality; a range of different landscape types producing the same pollen signal, thus making it impossible to discriminate between the scenario that actually produced the signal and those that were capable of doing so but did not. The absence of this constraint in the study here effectively means that a full investigation of landscape structure is impossible. However, there are some basic insights we can reach and crucial ones at that. The key one is landscape openness.

The degree of openness within an ecosystem is a fundamental ecological question, with particular modern relevance. Palaeoecology has a massively important role as it guides policy makers in their choice of management strategy. There are essentially two competing hypotheses; the first is Vera (2000) who argues for a "wood-pasture" model in which the landscape of Europe prior to human disturbance was a mosaic of trees and open meadows. This mosaic was maintained by the grazing activities of large herbivores, which can potentially have a hugely significant impact on vegetation structure (Johnson, 2009) (although it is worth pointing out that other processes are capable of creating openness). The competing hypothesis favours a "high forest" model, in which there is a largely closed woodland canopy in the pre-disturbance period (Mitchell, 2005). It should be noted that proponents of this view do allow for some degree of openness. Also, a more intermediary position is advocated by Bradshaw *et al.* (2003) who argue that closed woodland predominated but stress the existence of open patches. The Vera hypothesis quickly gained support amongst management strategists, with Natural England developing an approach in which grazing by large herbivores is a central component for the preservation and promotion of "natural" British landscapes (Kirby, 2004).

We cannot say precisely how much open area there was likely to have been during the Hoxnian. The modelling results indicate that there was more than a simple inspection of a pollen diagram would reveal, likely considerably more. However there are other factors that influence openness, such as the patterning of landscape structure (Sugita, *et al.*, 1999). In the results presented here, landscape structure seems to be a relatively minor player, in contrast to other modelling results (Bunting *et al.*, 2004). This perhaps suggests a need for further investigation of this issue within modelling studies, or it might be that an insufficient variation in landscape type was undertaken in this study.

Irrespective of these concerns, the fact that there are other possible controls on openness that have not been elucidated here demonstrates the need for caution and to avoid over interpreting the precise values. Nevertheless, it is clear from the model output that Hoxnian forests would have contained open space, particularly early on in the interglacial when non-arboreal pollen was higher and especially during the NAPP, when the landscape must have been very open indeed. During zone H4, when non-arboreal pollen was very low there was probably relatively little open ground, although still more substantive than the percentages suggest.

There is also some corroborating evidence for this view from the composition of the pollen diagrams, in particular the persistence of hazel. In modern forests, hazel is typically only present for around 100 years (Huntley, 1993) because its short stature means that is easily outcompeted for light by taller growing species. The fact that it seems to thrive for much of the time (and remember that with a low PPE it was probably present in greater abundance than suggested by the pollen diagrams) may indicate the canopy was rather open in places.

The debate surrounding the structure of the Holocene seems to be gradually resolving itself to a compromise position. Initial results (e.g. Mitchell, 2005) suggested a refutation of the Vera hypothesis. However, recent modelling work (Soepboer and Lotter, 2009) and pollen sampling (Fyfe, 2007) has suggested that whilst the general picture would have been closed forest, there were nevertheless significant open patches within this. Independent evidence has tended to corroborate this; for example, based on beetle taphonomy, Whitehouse and Smith (2010) argue for the importance of local openness.

Hoxne reflects quite a large spatial area; ideally a network of large and small sites would be built in order to better characterise exactly how openness was structured within the landscape. Was it a case of large swathes of open space, or were the open areas relatively small patches in a closed forest that would be best detected by pollen sites that sample a restricted area, At this stage, we cannot say much beyond the fact that at times openness was present. Moreover, we may never be able to move much beyond this given the inherently limited number of sites.

What factors would have been responsible for maintaining openness? Herbivores do remain a plausible mechanism. Mitchell (2005) points to similarities in Holocene pollen assemblages between Ireland, where large mammals are almost absent, and mainland Europe which had a much richer assemblage, as evidence that large mammals must have had a relatively limited impact on vegetation. However, as Svenning (2002) points out, even in Europe the large mammal assemblage was relatively denuded when compared to previous interglacials. This is also the case for the Hoxnian, in which not only were typical Holocene fauna such as auroch and deer present, but also extremely large animals such as *Palaeoloxodon antiquus,* the extinct straight tusked elephant (known to be present at Hoxne during Ho II- Stuart *et al.*, 1993) and *Stephanorhinus kirchbergensis*.

9.3 – Fire during the Hoxnian

The results presented in Chapter 7 demonstrate that fire was not an important component of ecosystem dynamics and that hominids were not using fire on a management scale. In some respects, negative results are disappointing; however they do still provide us with information. Given that fire can be such a crucial process, widening the investigation of fire histories into the Pleistocene was a worthwhile endeavour and has enabled us to establish that little of significance occurred, during the Hoxnian at least.

The general perspective of recent British woodlands is that they are extremely resistant to burning. In his seminal book "The History of the Countryside", Rackham (1986) describes them as burning like "wet asbestos" and refers to the major drought of 1976 in which, despite regular human firing of stubble, woodlands simply did not burn. The results presented here would confirm this. Despite the Rackham view, there are ecologists (e.g. Brown, 1997) who argue that it is possible for lightning to start fires in our woods. The test of this hypothesis here, in a wildwood uninfluenced by human activity, suggests that it is false. This serves to solidify our ecological understanding of fire behaviour in Britain.

It is worth noting that a limited amount of charcoal has been found. Of minor note is the fact that microscopic charcoal is found in very small quantities towards the base of the Hoxne core. There is clearly no large scale fire activity occurring at this time; by way of comparison, Lavoie and Richard (2000) report values of around 4 cm^2/cm^3 for substantive fires in Canada, which are significantly in excess of the values reported here. Moreover, it is possible that this microscopic charcoal is transported some distance, perhaps from the continent. However, it is an interesting coincidence that this occurs at a time with relatively high levels of pine. As Rackham (1986) notes, this is the one tree in the UK that is susceptible to fire. Also this is a period with slightly higher levels of non-arboreal pollen suggesting grassland areas, which are more likely to burn.

Further adding to the potential significance of grassland are the charcoal results from Stratum C. The greatest amount of macroscopic charcoal is recorded from this deposit and there appear to be minor peaks suggestive of fire activity. Again there is no indication of a particularly substantial burn; by way of comparison, Walsh *et al*. (2008) report counts of around 400 (in smaller sample volumes) for forest fires in North America. However, the fact that it is macroscopic charcoal demonstrates that local burning must have occurred; material of this size is not transported any great distance. It is noteworthy that Stratum C has relatively high levels of non-arboreal pollen and therefore open grassland. It could be that this type of ecosystem was slightly vulnerable to small scale grassland fires. An additional hypothesis is that hominid hearths were responsible, with these minor peaks the result of small campfires set by Hoxnian hominids. This hypothesis will require testing from other sites of this age, with known hominid activity.

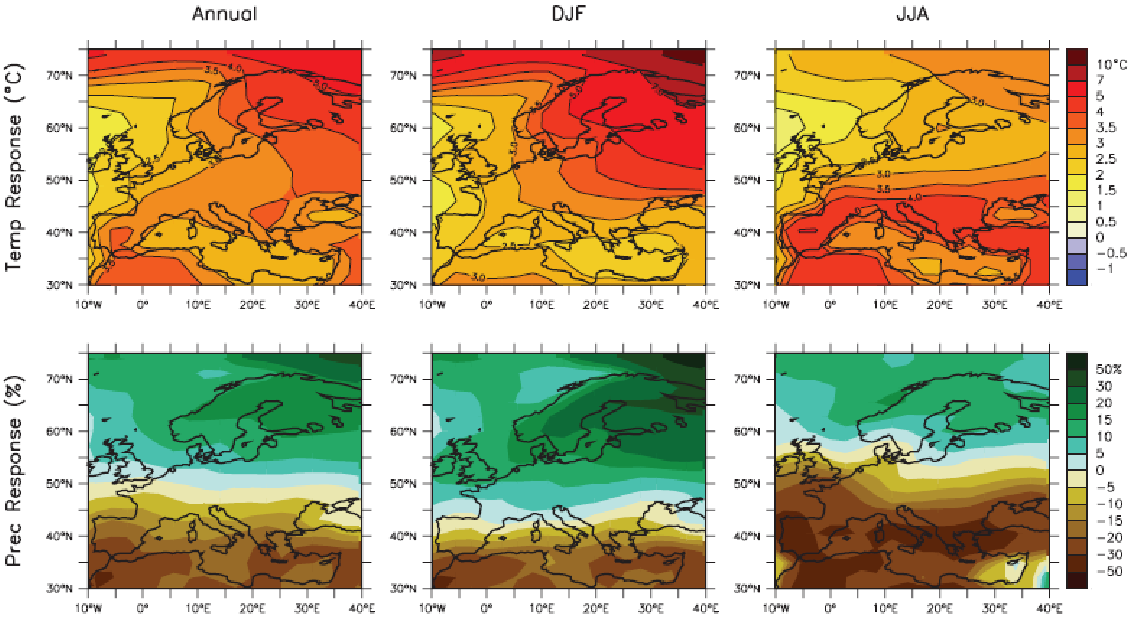


Fig 26: Top row: Annual mean, DJF and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Middle row: same as top, but for fractional change in precipitation. From Christensen *et al*. (2007).

The sampling undertaken here was for woodland which, in being basically temperate deciduous, is similar to our own. We can use this to emphasise the role, or lack thereof, of fire in structuring British woodland ecosystems. However, there is one key variable that is different between the two time periods; climate. Future fire activity is a crucial component of IPPC projections of climate change impact (Parry *et al.*, 2007). Can we use the results here to shed light on possible changes in fire behaviour over the coming century?

Fig 26 shows temperature change in Europe between 1980 to 1999 and 2080-2099 and is taken from the IPPC model ensembles (Christensen *et al.*, 2007). Summer temperatures are predicted to be 2ºC higher than the present in summer, which is comparable to the reconstructions presented here. Annual rainfall shows a slight increase in the future, although the crucial summer period is drier. We do not have seasonal precipitation reconstructions for the Hoxnian, but there is the suggestion of somewhat drier conditions overall. Therefore we can consider the possibility that the slightly warmer summers and slightly drier Hoxnian is an analogue for future summers. In which case, we might not expect climate change to have a particularly significant impact on future woodland fire. This is a pleasing conclusion, given the myriad of other issues posed by climate change for wooded ecosystems (e.g. Wamelink *et al*., 2009).

10 – Palaeoclimate reconstruction results

This chapter will present the results of the sensitivity testing undertaken to explore some of the fundamental controls on the reconstructions. These scenarios will then be followed by the final reconstructions for each of the sites chosen in this thesis, a description of the main features of each reconstruction and finally a summary table presenting an overview of the data.

The following figure is presented to illustrate the main features of the reconstruction diagrams:

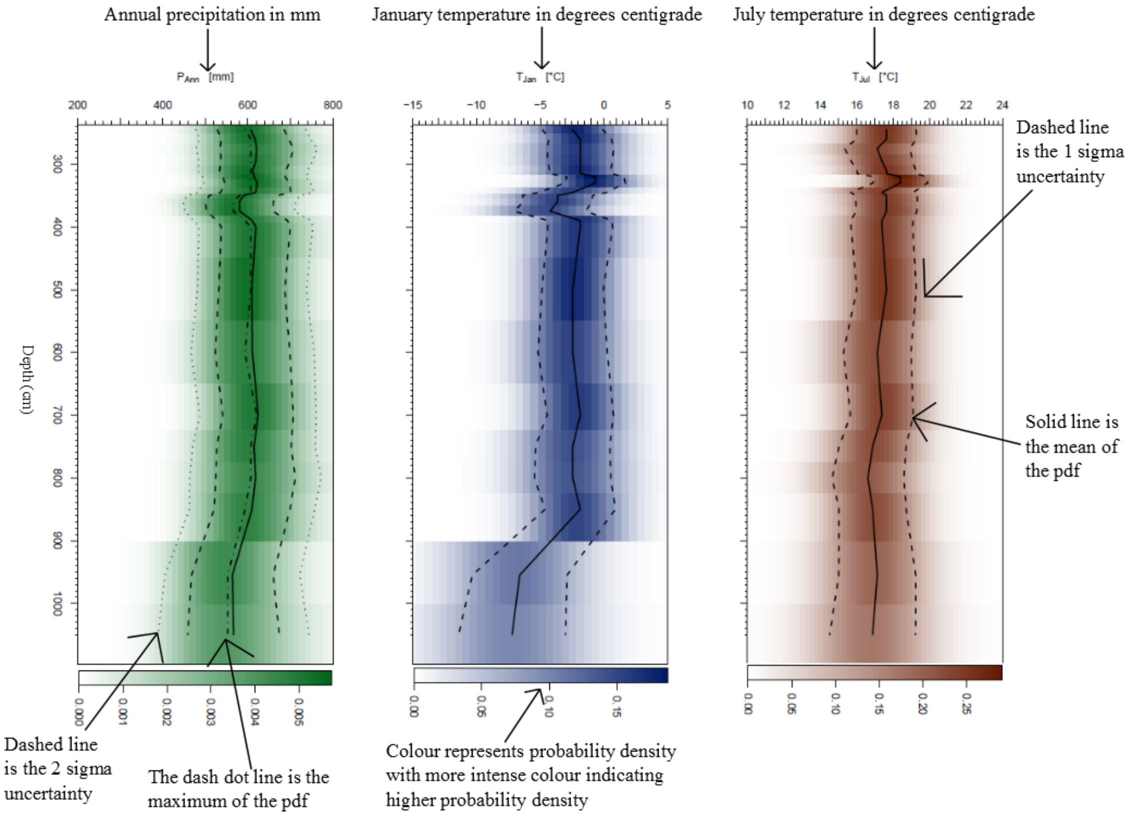


Fig 27: Describing the main features of the palaeoclimate reconstruction diagrams

The output from the *pdf* method is standardised, by default, to a particular size. This means that each reconstruction appears the same, regardless of the actual depth of sediment involved at a given site. Therefore in this chapter, caution must be taken when comparing diagrams at this stage as they are not on a common framework. This work will be undertaken in Chapter 12.

10.1 – Sensitivity testing

A series of sensitivity tests were performed in order to explore the limitations of the *pdf* methodology adopted here. These scenarios cover the following:

- The influence of taxonomic resolution
- The influence of species diversity
- The influence of thresholds applied to presence/absence data
- The influence of an individual species

10.1.1 - taxonomic resolution

This section describes the effect on reconstructed climates as a result of using aggregate species versus using individual species. For the details of this form of sensitivity testing see chapter 5. To recap, the palaeoclimate model enables the input of species and, for selected taxa, an aggregate based on the combined distribution areas of the species within that taxa. For example, *Ulmus* can be inputted either as *Ulmus glabra*, *Ulmus carpinifolia*, *Ulmus laevis* or an aggregation of the three.

The aggregate approach is the most conservative, based on the fact that it is often not possible to identify pollen down to species level. To input as species requires simplifying assumptions that may not be easy to justify. For this reason, where they are available, aggregates have been preferred in this study. However, the aggregates are potentially less precise, because they are composed of the ranges of a number of species, not just one.

These comparisons are purely to investigate the functioning of the model. Therefore the following diagrams are simply presented as Site 1 and Site 2. For these two sites, three different model runs were performed, using just trees and shrubs (and herbs where there is an appropriate selection):

- Aggregate species where possible
- Separate species 1 (*Betula pendula*, *Quercus robur*, *Filipendula ulmaria*)
- Separate species 2 (*Betula pubescens*, *Quercus pubescens*, *Filipendula vulgaris*)

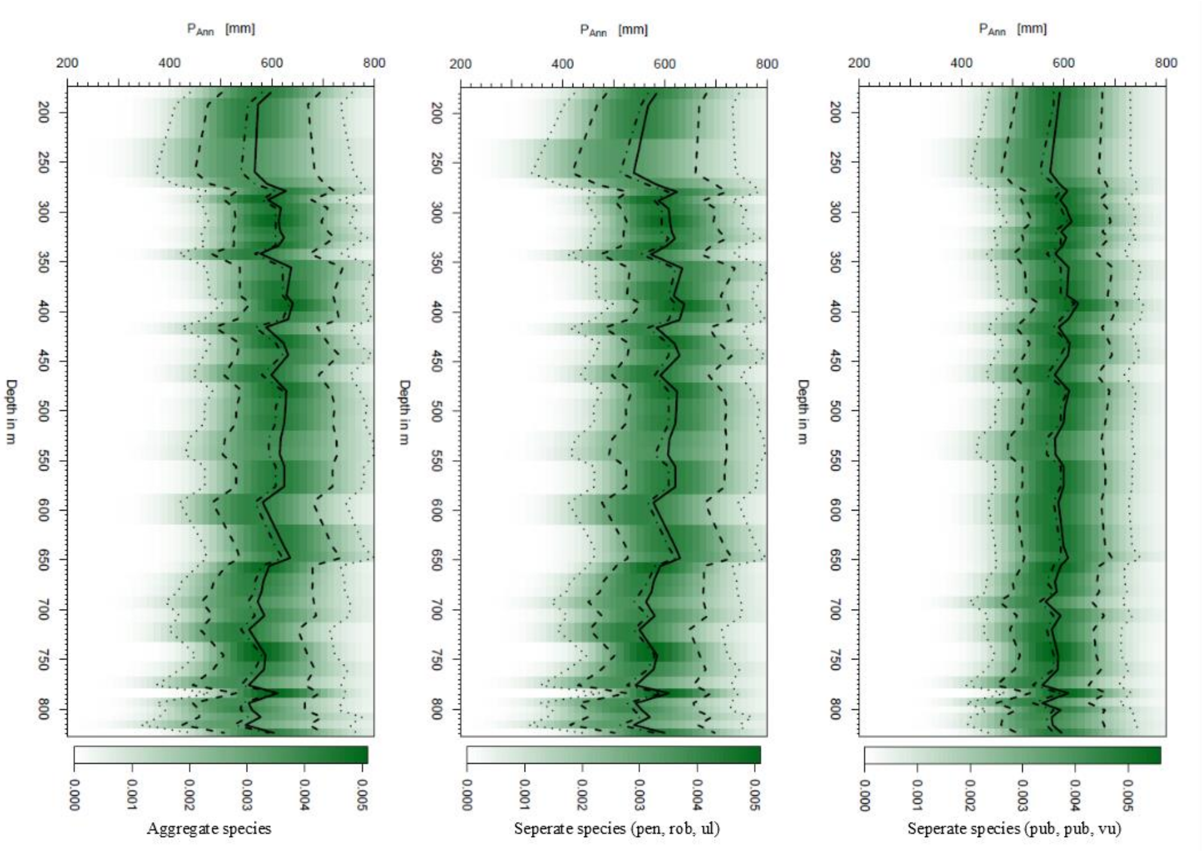


Fig 28: Reconstructed precipitation for “Site 1”. Intensity of colour refers to the probability density of reconstructed climate. The mean of the pdf (solid line), 1 sigma uncertainty (dashed), 2 sigma (dotted) and the maximum of the pdf (dash dot) are given. Figure compares the impact of the inclusion of aggregated species to represent a taxa compared to individual species chosen to represent a taxa.

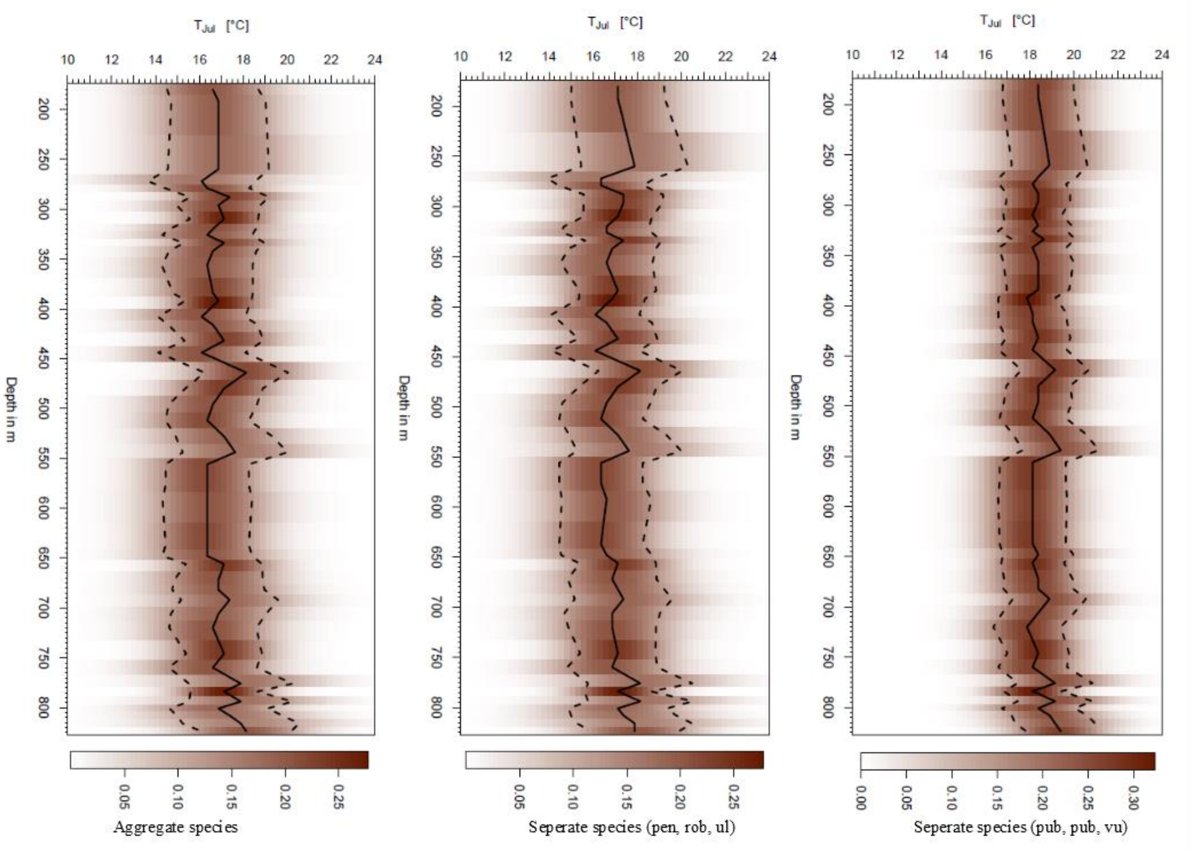


Fig 29: Reconstructed July mean temperatures for "Site 1". Intensity of colour refers to the probability density of reconstructed climate. The mean of the pdf (solid line) and 1 sigma uncertainty (dashed) are given. Figure compares the impact of the inclusion of aggregated species to represent a taxa compared to individual species chosen to represent a taxa.

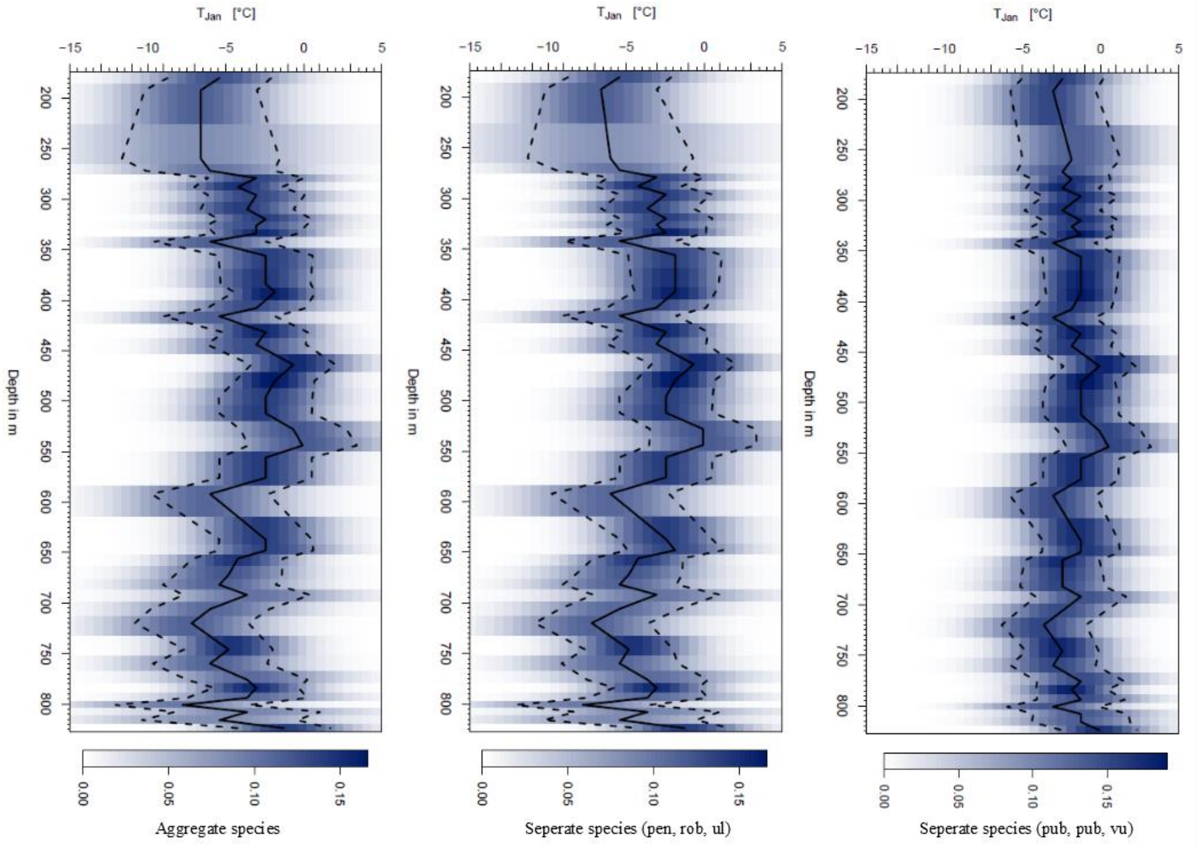


Fig 30: Reconstructed January mean temperatures for “Site 1”. Intensity of colour refers to the probability density of reconstructed climate. The mean of the pdf (solid line) and 1 sigma uncertainty (dashed) are given. Figure compares the impact of the inclusion of aggregated species to represent a taxa compared to individual species chosen to represent a taxa.

For Site 1 there is relatively little difference between the three different model runs. The same broad trends are recorded in each of the simulations for each of the climate variables; summer temperature, winter temperature and precipitation. The only appreciable difference can be found in the model runs featuring *Betula pubescens*, *Quercus pubescens*, *Filipendula vulgaris*. In this instance, although the climate curves follow the same patterns, the magnitude of variability is lower.

This observation can be clearly illustrated in the third of the figures, Fig 30, representing winter temperature. The aggregate species and separate species (*Betula pendula*, *Quercus robur*, *Filipendula ulmaria*) models show a sharp initial two-stage drop in temperature at the base of the sequence, down from -2ºC to -8ºC, a fall of around 6ºC. In contrast, the second separate species run starts at a slightly higher temperature -1ºC and falls to just -3.5ºC.

This higher temperature in the *Betula pubescens*, *Quercus pubescens*, *Filipendula vulgaris* run compared to the other two is a feature that is repeated on a number of occasions in the rest of the winter temperature reconstructions and is also observed in summer temperatures. Summer temperature generally appears to be less variable than winter and just over 1ºC warmer in the third model.

In the winter reconstructions, the temperature in the *Betula pubescens*, *Quercus pubescens*, *Filipendula vulgaris* reconstruction is often significantly higher. Interestingly there is greater convergence in temperature when the first two reconstructions have higher probability densities. For example, at the top of the sequence, colour intensity is relatively low, though greater for the pub, pub, vu reconstruction. In this result, temperature is a little over -3ºC, compared to around -6.5 ºC for the other two reconstructions. In contrast, where probability density is higher in the aggregate and pen, rob, ul reconstructions at just over 460 cm, the difference is much smaller, -0.5ºC compared to around -1.5ºC. This possibly suggests a bias to reconstruct lower temperatures where the output is less certain.

For precipitation, the reconstructed values are similar between the three model runs. The pub, pub, vul experiment does not have significantly higher or lower rainfall totals. However it does have a flatter, less variable curve, as discussed above.

The *Betula pubescens*, *Quercus pubescens*, *Filipendula vulgaris* reconstruction generally has slightly more intense colours, representing a greater probability density. This is worth noting, although it is potentially misleading to read too much into this comparison. One may have a very “probable” reconstruction, but if the input is not based on sound principles (e.g. species are selected for which the taxonomic precision is not available) then the ultimate reconstruction may be less reliable than a less “probable” one with a more robust input. The strength of the probability density is most instructive within the diagram, investigating the probability of different time periods within a sequence. It is an indicator of internal reliability, contingent on the initial starting parameters. Comparison of colour intensity between model runs was informative, however, in illuminating a possible cold bias in cases of low probability density.

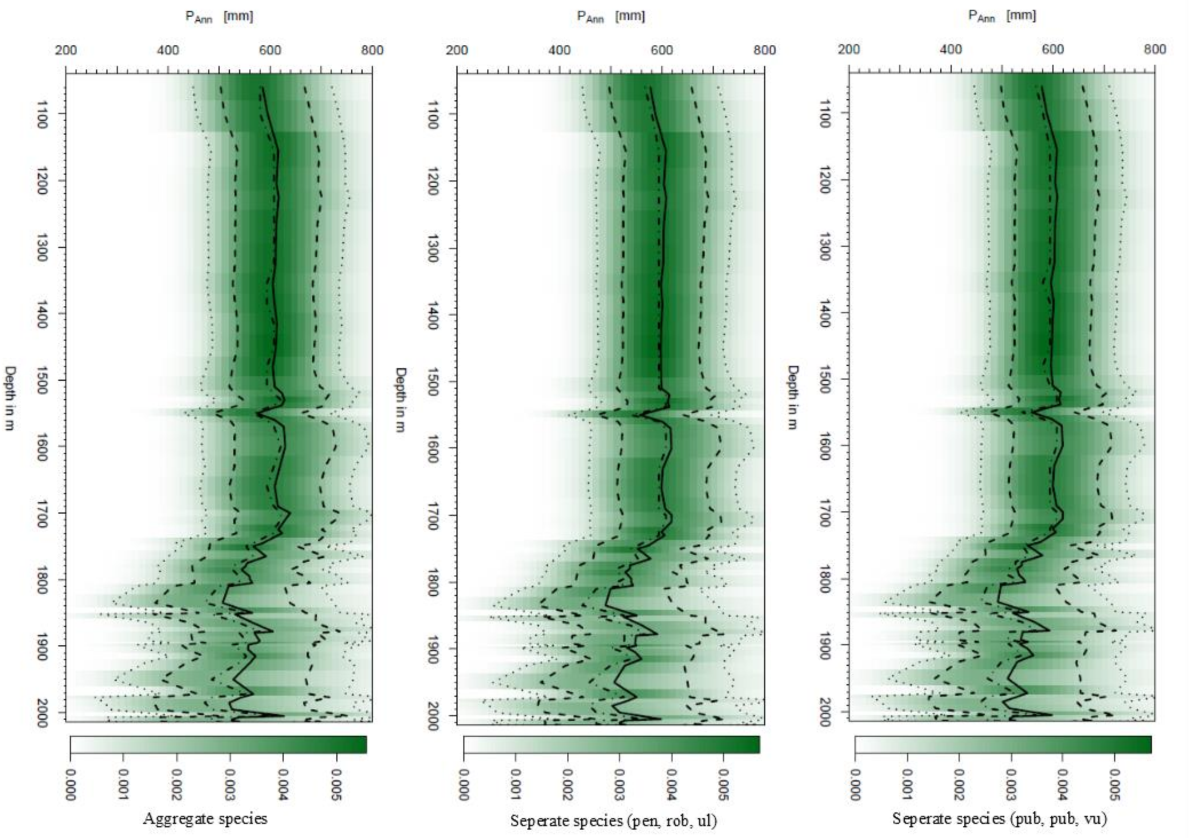


Fig 31: Reconstructed precipitation for "Site 2". Intensity of colour refers to the probability density of reconstructed climate. The mean of the pdf (solid line), 1 sigma uncertainty (dashed), 2 sigma (dotted) and the maximum of the pdf (dash dot) are given. The figure compares the impact of the inclusion of aggregated species to represent a taxa compared to individual species chosen to represent a taxa.

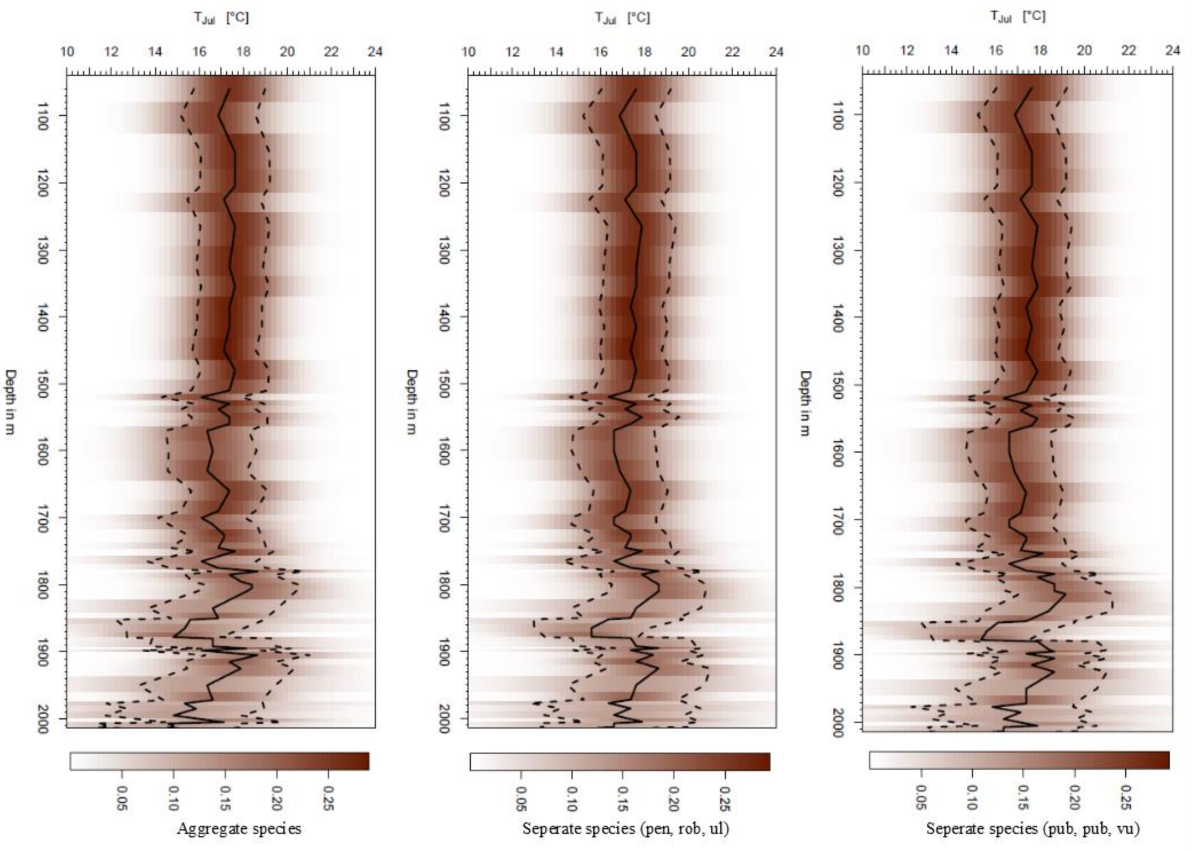


Fig 32: Reconstructed July mean temperatures for “Site 2”. Intensity of colour refers to the probability density of reconstructed climate. The mean of the pdf (solid line) and 1 sigma uncertainty (dashed) are given. The figure compares the impact of the inclusion of aggregated species to represent a taxa compared to individual species chosen to represent a taxa.

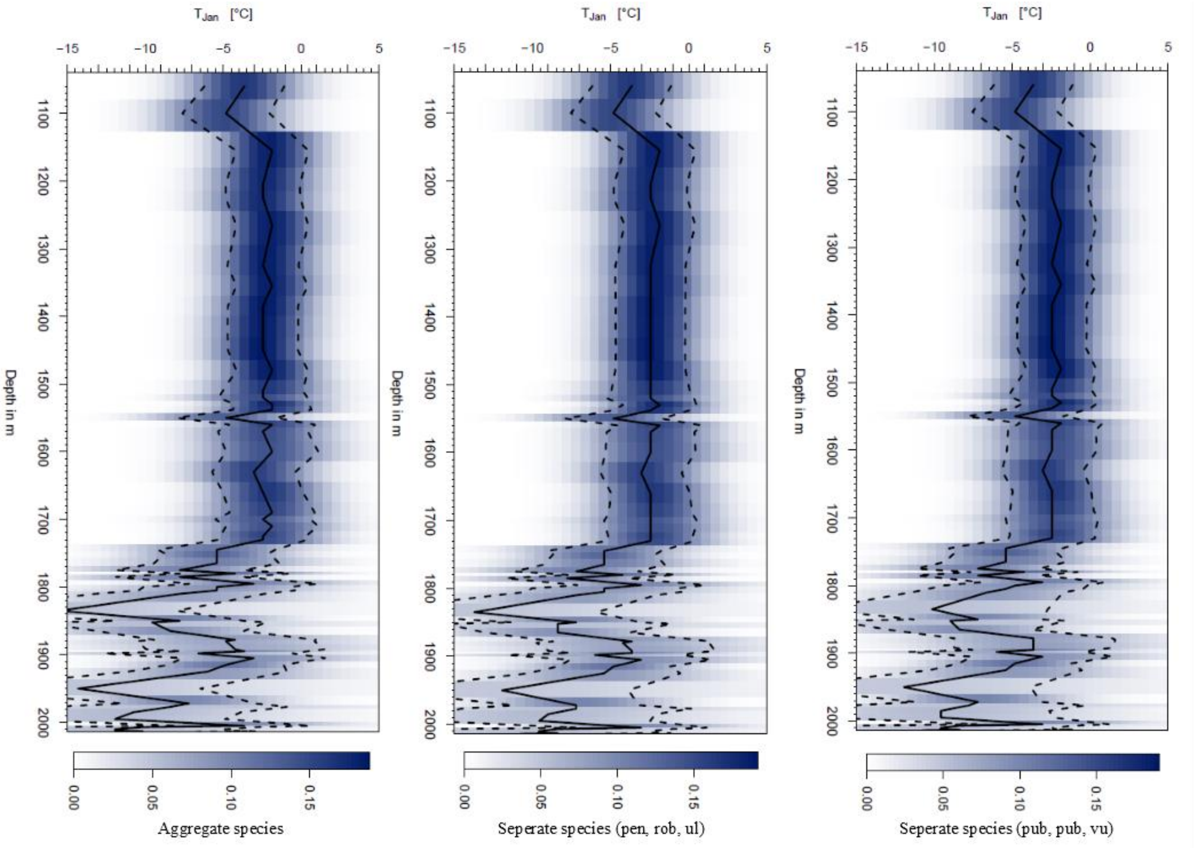


Fig 33: Reconstructed January mean temperatures for "Site 2". Intensity of colour refers to the probability density of reconstructed climate. The mean of the pdf (solid line) and 1 sigma uncertainty (dashed) are given. The figure compares the impact of the inclusion of aggregated species to represent a taxa compared to individual species chosen to represent a taxa.

Site 2 shows similar features to those observed above for Site 1. Again there is relatively little difference observed between the three reconstructions. The most notable feature, particularly distinctive in winter, is that the runs with *Betula pubescens*, *Quercus pubescens*, *Filipendula vulgaris* show similar levels of variability but a lower magnitude than the other two. This result demonstrates that the choice of species can influence important aspects of the reconstruction.

10.1.2 –species diversity

The results that follow show the impact of widening the scope of species used, albeit using species assumed to represent a particular group of herbs. Where only trees, shrubs and selected herbs for which there is confident assignation (e.g. *Calluna*) this is referred to in the figures below as trees and shrubs. There are then two runs including assumed herbs, a species 1 set and a species 2 set. See Chapter 5 for definitions of these. Results for two sites, Barford and Hoxne are presented to illustrate this particular aspect of sensitivity testing.

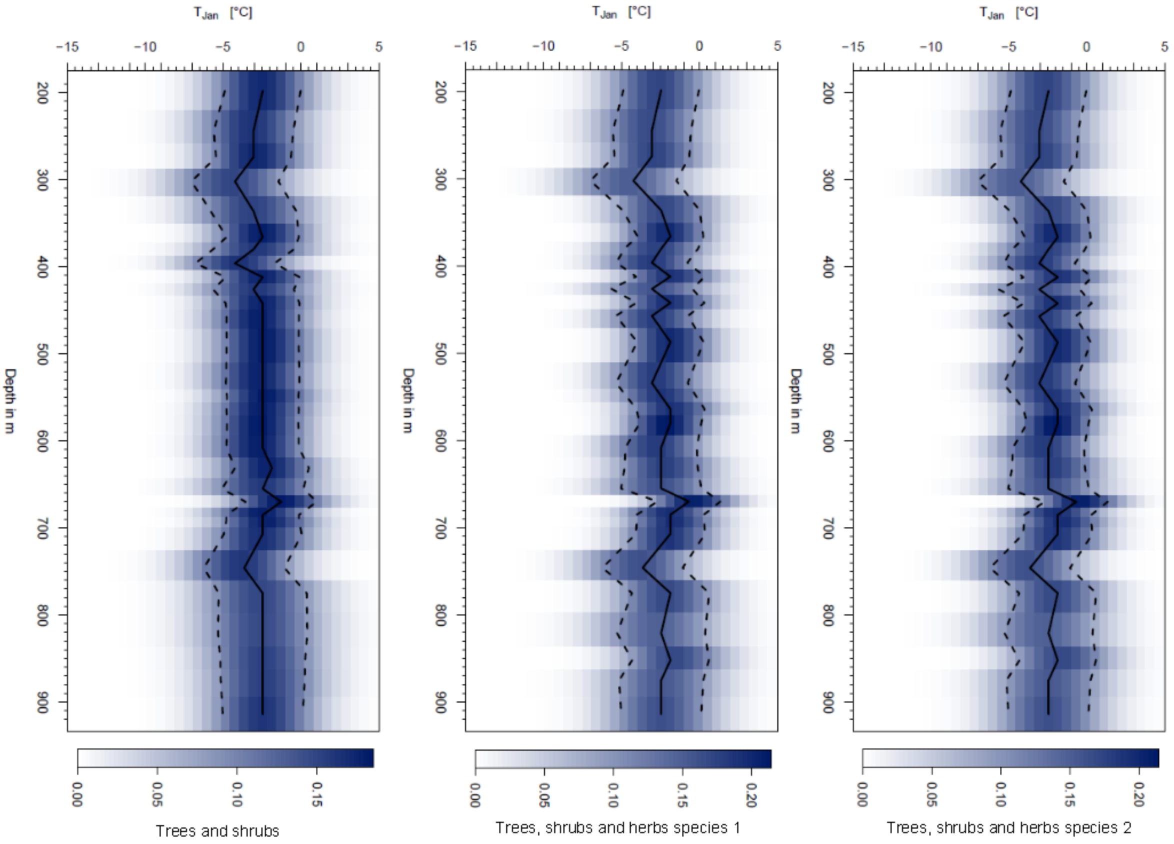


Fig 34: Reconstructed January mean temperatures for Barford. Intensity of colour refers to the probability density of reconstructed climate. The mean of the pdf (solid line) and 1 sigma uncertainty (dashed) are given. The figure explores the impact of including a more diverse range of species through the choice of assumed species to represent particular herb taxa.

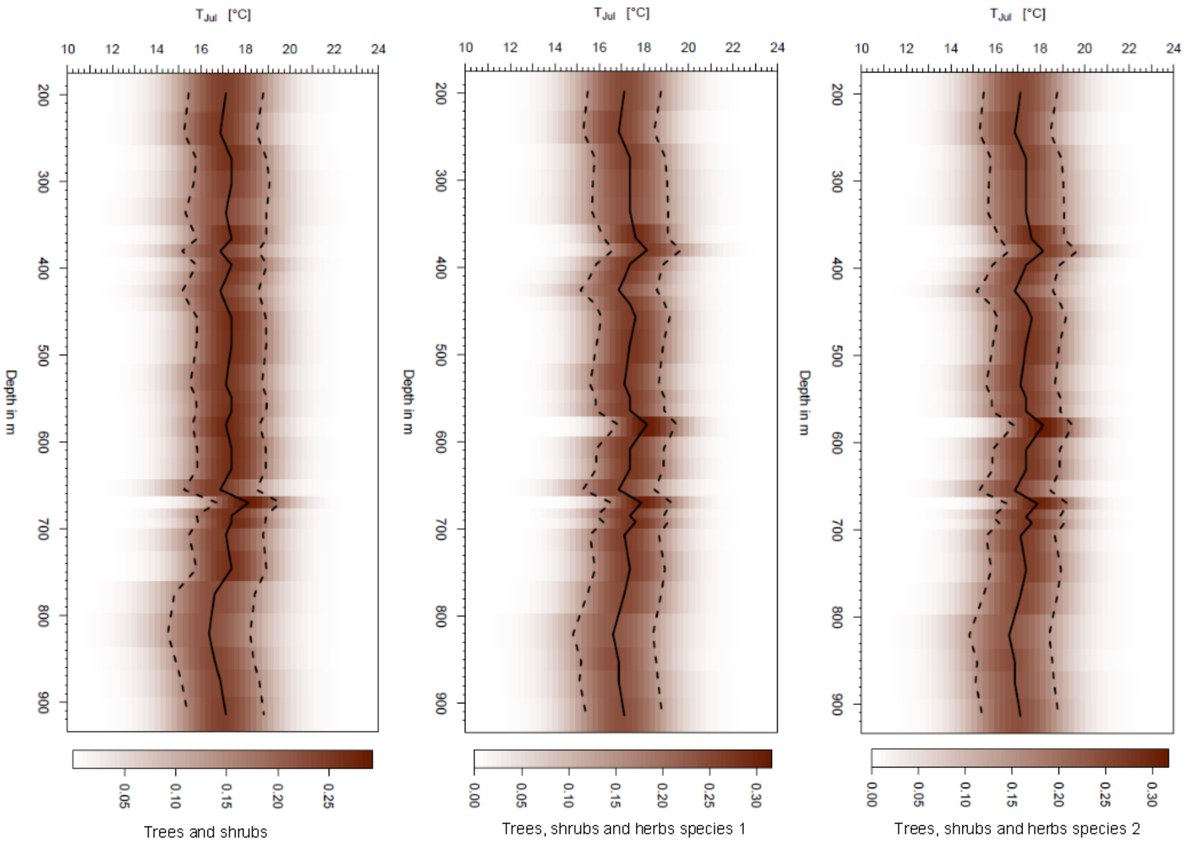


Fig 35: Reconstructed July mean temperatures for Barford. Intensity of colour refers to the probability density of reconstructed climate. The mean of the pdf (solid line) and 1 sigma uncertainty (dashed) are given. The figure explores the impact of including a more diverse range of species through the choice of assumed species to represent particular herb taxa.

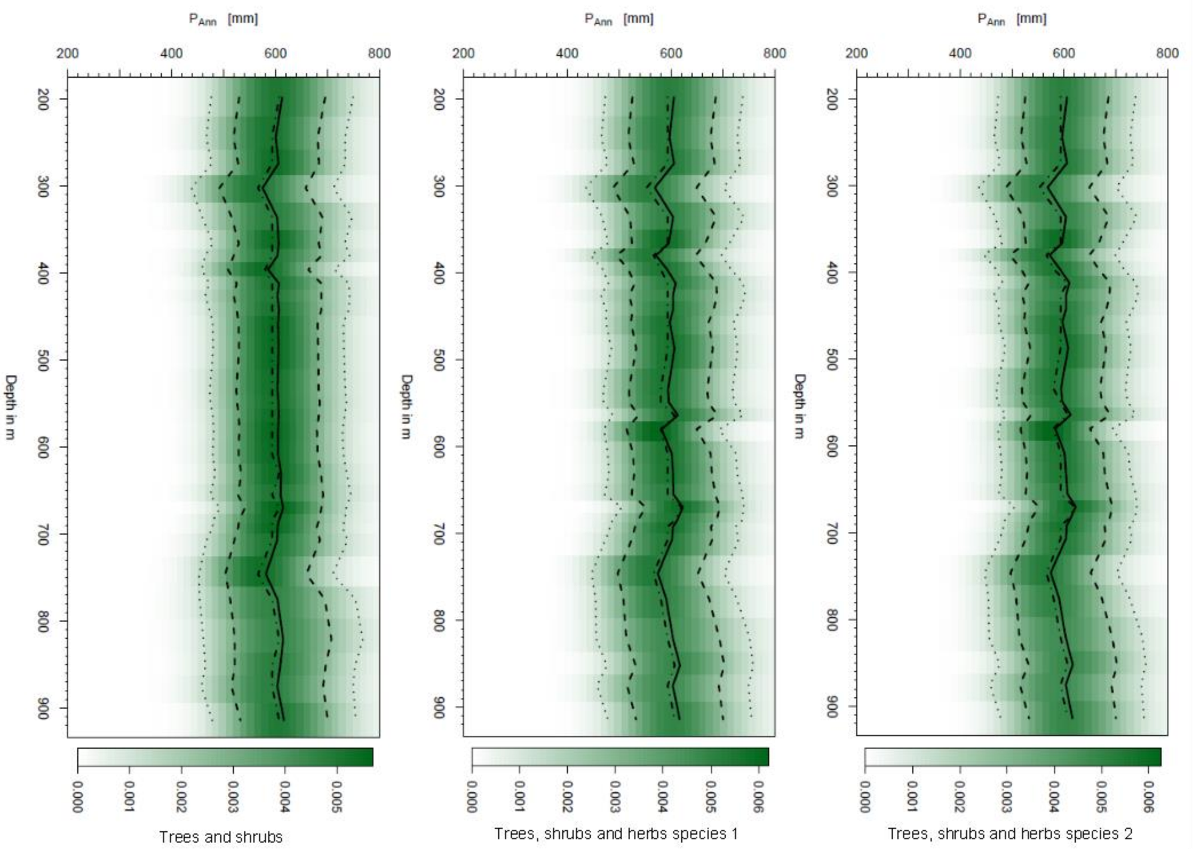


Fig 36: Reconstructed precipitation for Barford Intensity of colour refers to the probability density of reconstructed climate. The mean of the pdf (solid line), 1 sigma uncertainty (dashed), 2 sigma (dotted) and the maximum of the pdf (dash dot) are given. The figure explores the impact of including a more diverse range of species through the choice of assumed species to represent particular herb taxa.

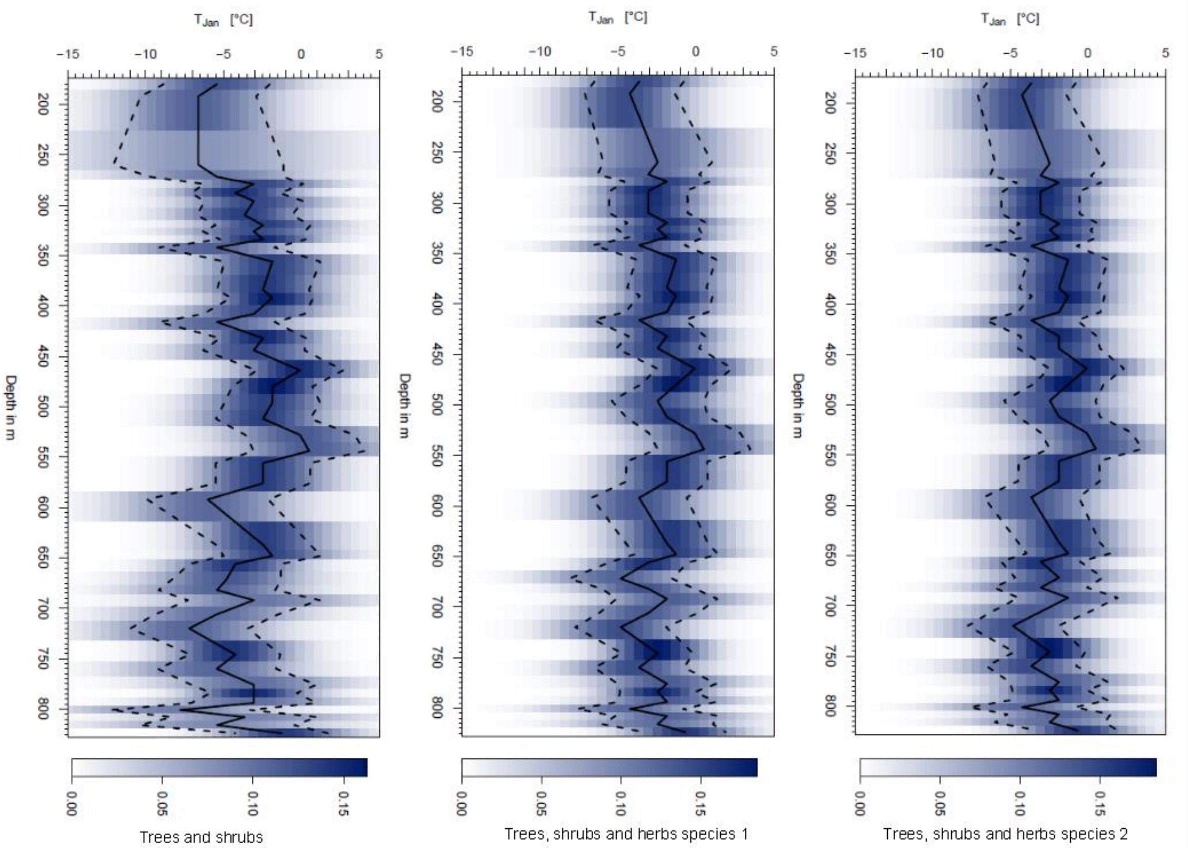


Fig 37: Reconstructed January mean temperatures for Hoxne (main sequence). Intensity of colour refers to the probability density of reconstructed climate. The mean of the pdf (solid line) and 1 sigma uncertainty (dashed) are given. The figure explores the impact of including a more diverse range of species through the choice of assumed species to represent particular herb taxa.

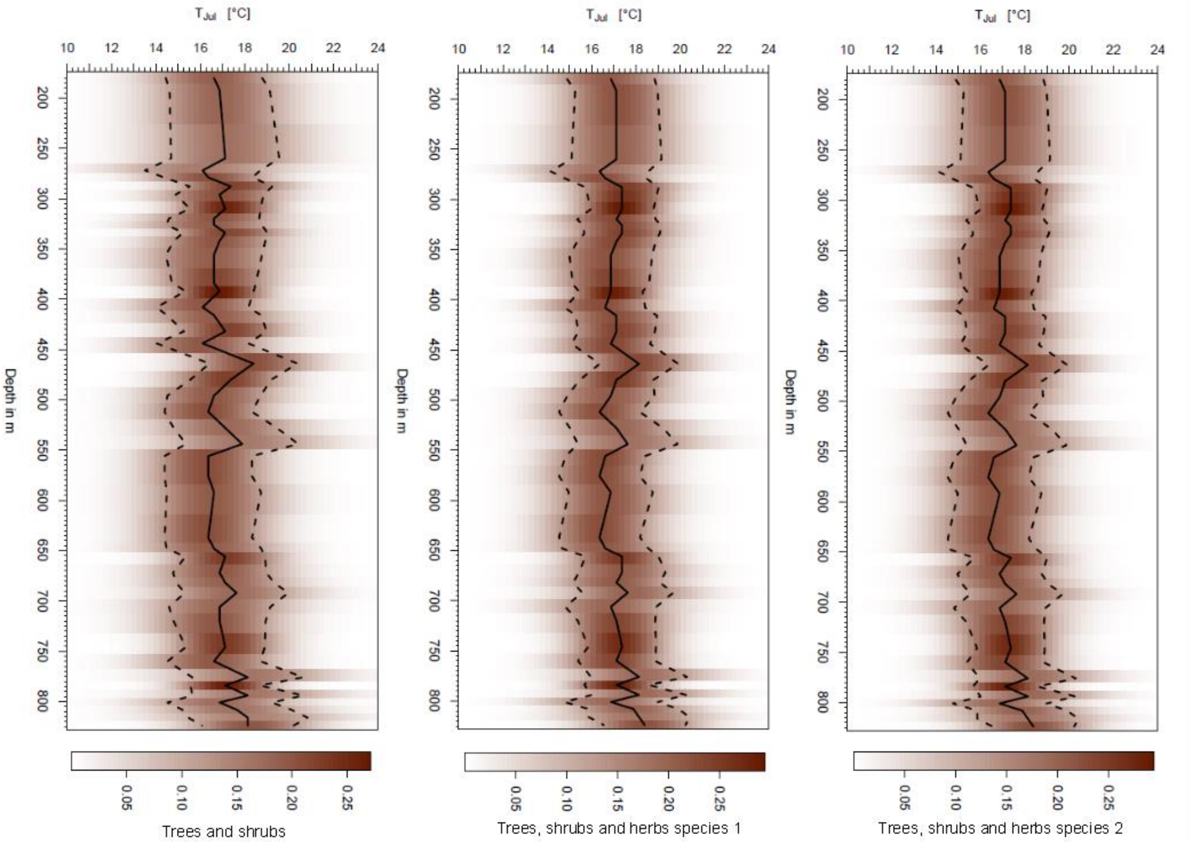


Fig 38: Reconstructed July mean temperatures for Hoxne (main sequence). Intensity of colour refers to the probability density of reconstructed climate. The mean of the pdf (solid line) and 1 sigma uncertainty (dashed) are given. The explores the impact of including a more diverse range of species through the choice of assumed species to represent particular herb taxa.

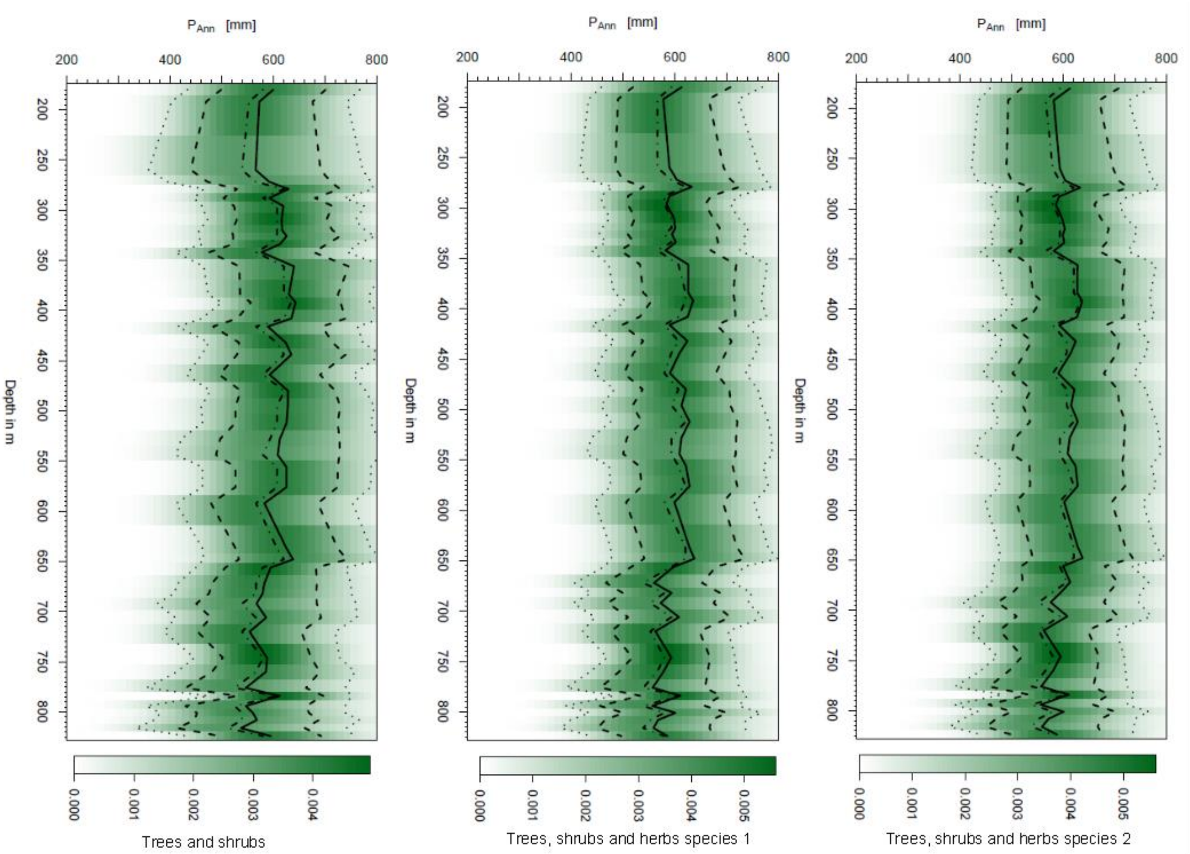


Fig 39: Reconstructed precipitation for Barford Intensity of colour refers to the probability density of reconstructed climate. The mean of the pdf (solid line), 1 sigma uncertainty (dashed), 2 sigma (dotted) and the maximum of the pdf (dash dot) are given. The figure explores the impact of including a more diverse range of species through the choice of assumed species to represent particular herb taxa.

There is relatively little difference observed as a result of the addition of selected species to represent herbs. This is to some degree encouraging; if the addition of herbs, even ones we cannot truly be sure of the presence of, led to wildly different results, this could lessen our confidence in the use of trees and shrubs only to reconstruct climate.

The most noteworthy difference is that the addition of herbs dampens the magnitude of some of the climate oscillations. This may imply that some of the magnitude of variability is the result of a relatively small constraint on temperature as a result of fewer species being used in the trees and shrubs reconstruction.

10.1.3 – applying thresholds

The impact of imposing thresholds on the data is explored in the following set of figures. This was undertaken based on actual percentage data derived from Hoxne and inferred percentage data taken from Turner (1970) for Marks Tey. The following diagrams present comparisons for summer and winter temperature and precipitation and show the final reconstruction shown in the figures above, a 1% threshold, a 4% threshold and a threshold applied by Norbert Kuhl in earlier modelling work.

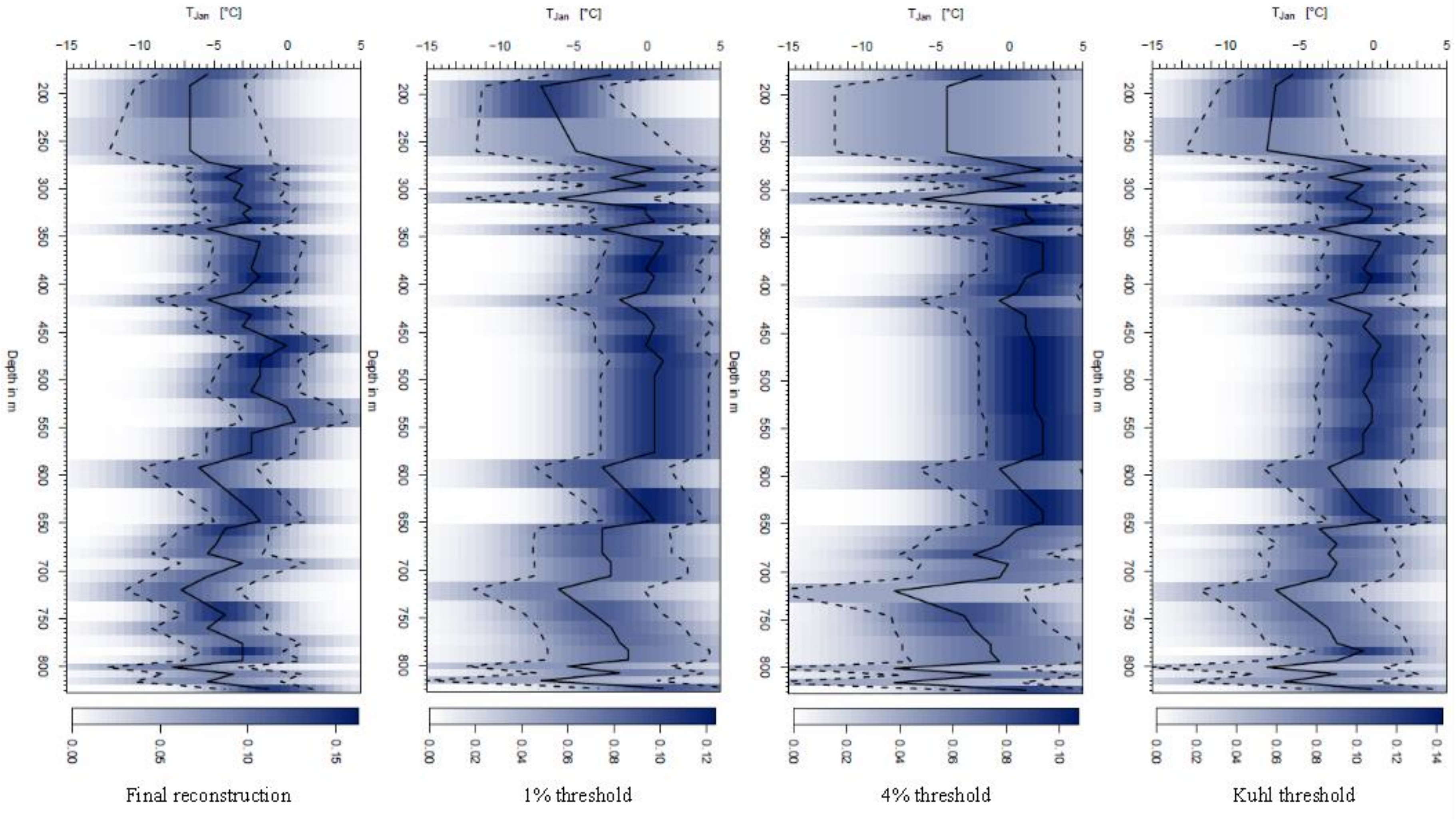


Fig 40: Comparison of final Hoxne winter reconstruction with models where thresholds have been applied to pollen data

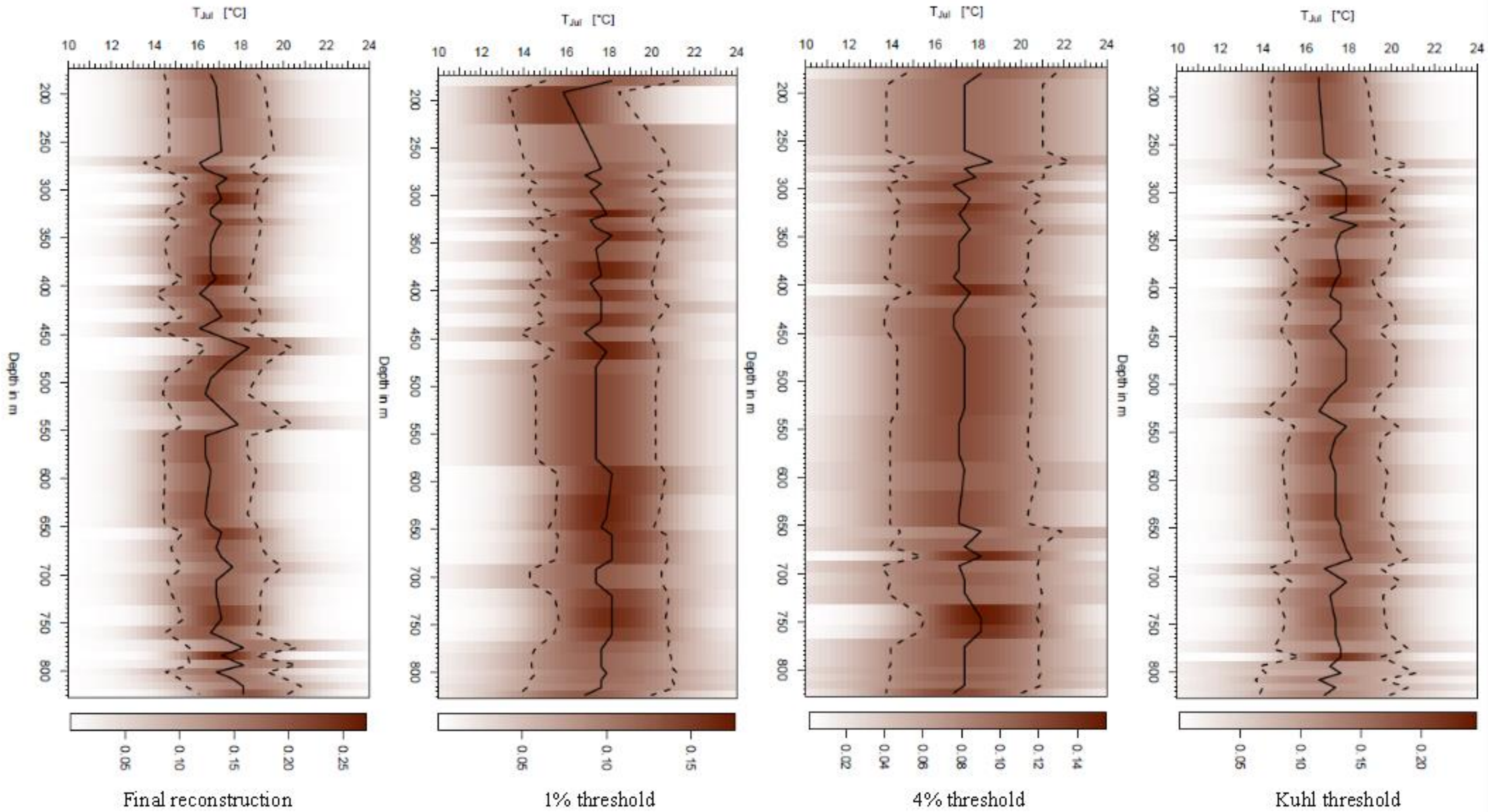
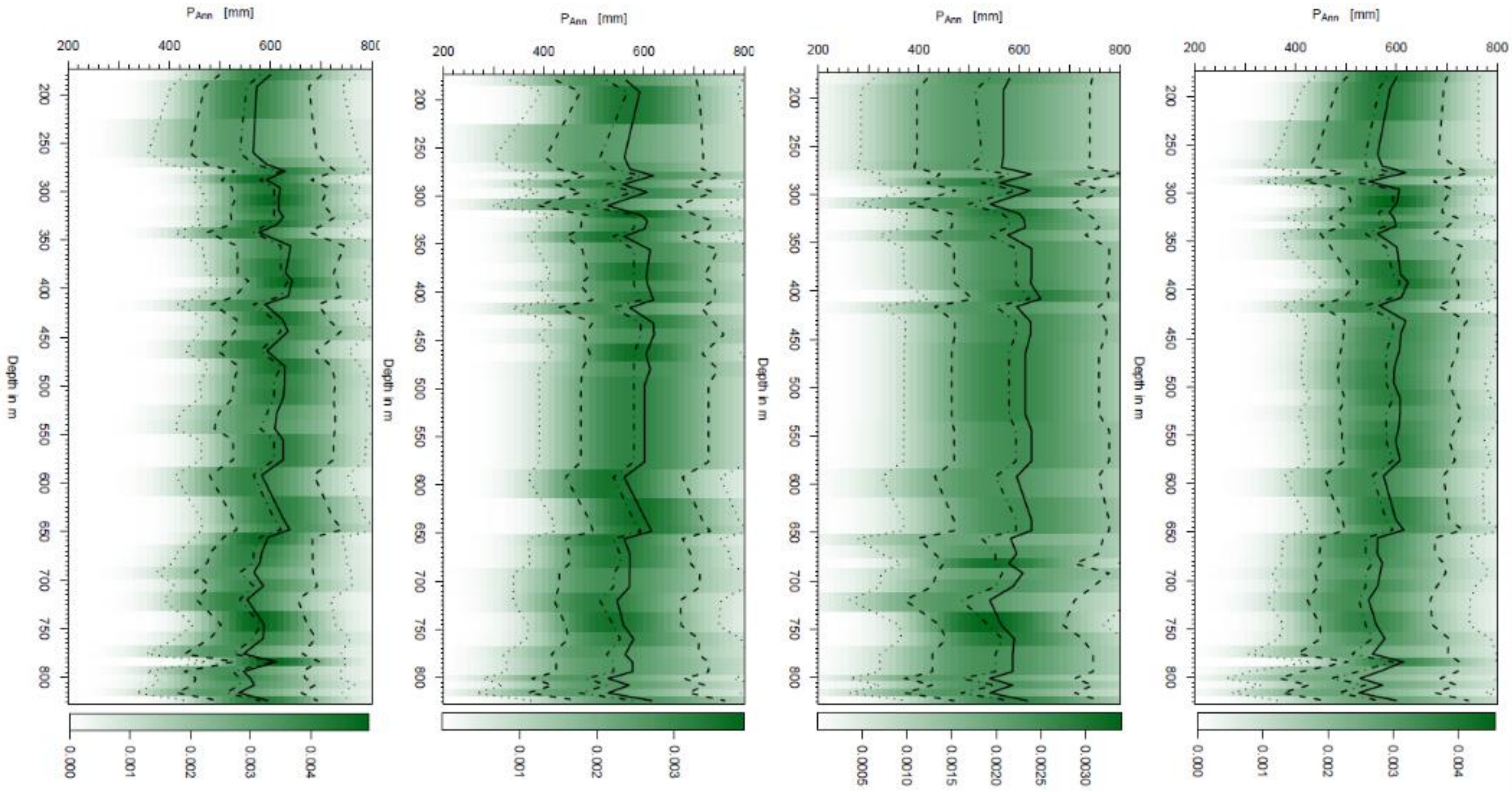


Fig 41: Comparison of final Hoxne summer reconstruction with models where thresholds have been applied to pollen data



Final reconstruction 1% threshold 4% threshold Kuhl threshold

Fig 42: Comparison of final Hoxne precipitation reconstruction with models where thresholds have been applied to pollen data

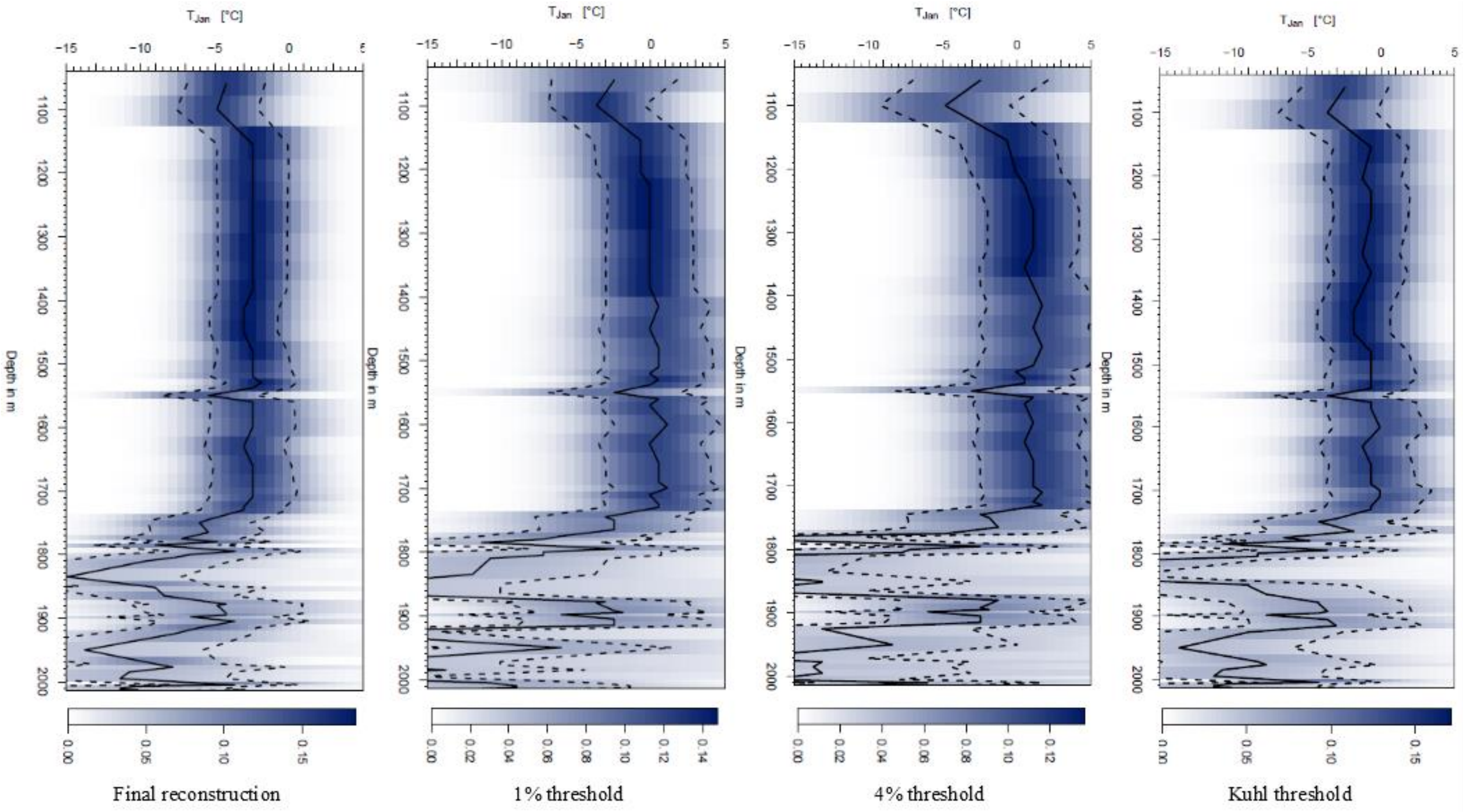
For the Hoxne pollen data it is clear that the imposition of thresholds has an impact on the reconstructed climate parameters. Fundamentally, the trends remain largely similar, which is encouraging. For example, the basic observation for winter temperatures at Hoxne of an initially cold start, before rising to a peak and then declining can be observed in all four of the model results presented in Fig 40. This implies that there is a strong signal that underlies the reconstructions and that is robust to changing input parameters.

The general influence of thresholds here appears to be to reduce variability somewhat. This can be best illustrated in the winter reconstruction, which is generally the most variable of the three modelled parameters. Note, for example, the distinct smoothing between 350 and 550 cm in the 1% and 4% thresholds compared to the final reconstruction. Even the Kuhl threshold, which is on the whole less severe than the other two, smoothes this section of the core out somewhat.

Typically, the thresholds remove fluctuations in temperature, while preserving the same basic trend. However, there is one notable instance where the 1 and 4% thresholds appear to add variance. At just over 300 cm, a major spike in temperature is observed in these reconstructions that is not present in the final reconstruction or the Kuhl model.

Summer temperature and precipitation also show a reduction in variability. These results ultimately imply that some variability is the result of changes in pollen that is present in a core in small amounts, at least at Hoxne. The significance of this and whether or not it reflects real changes in climate will be discussed in Chapter 11.

One additional important observation is that the reconstructions using thresholds have somewhat warmer temperatures during the central part of the core. For example between 450 and 550 cm, temperatures in the winter threshold reconstructions are around 0ºC, compared to approximately -2ºC in the final reconstruction. Summer temperatures are only slightly warmer, but the same phenomenon is observed. This suggests that a species or a number of species present in low numbers play a significant role in driving down temperatures.



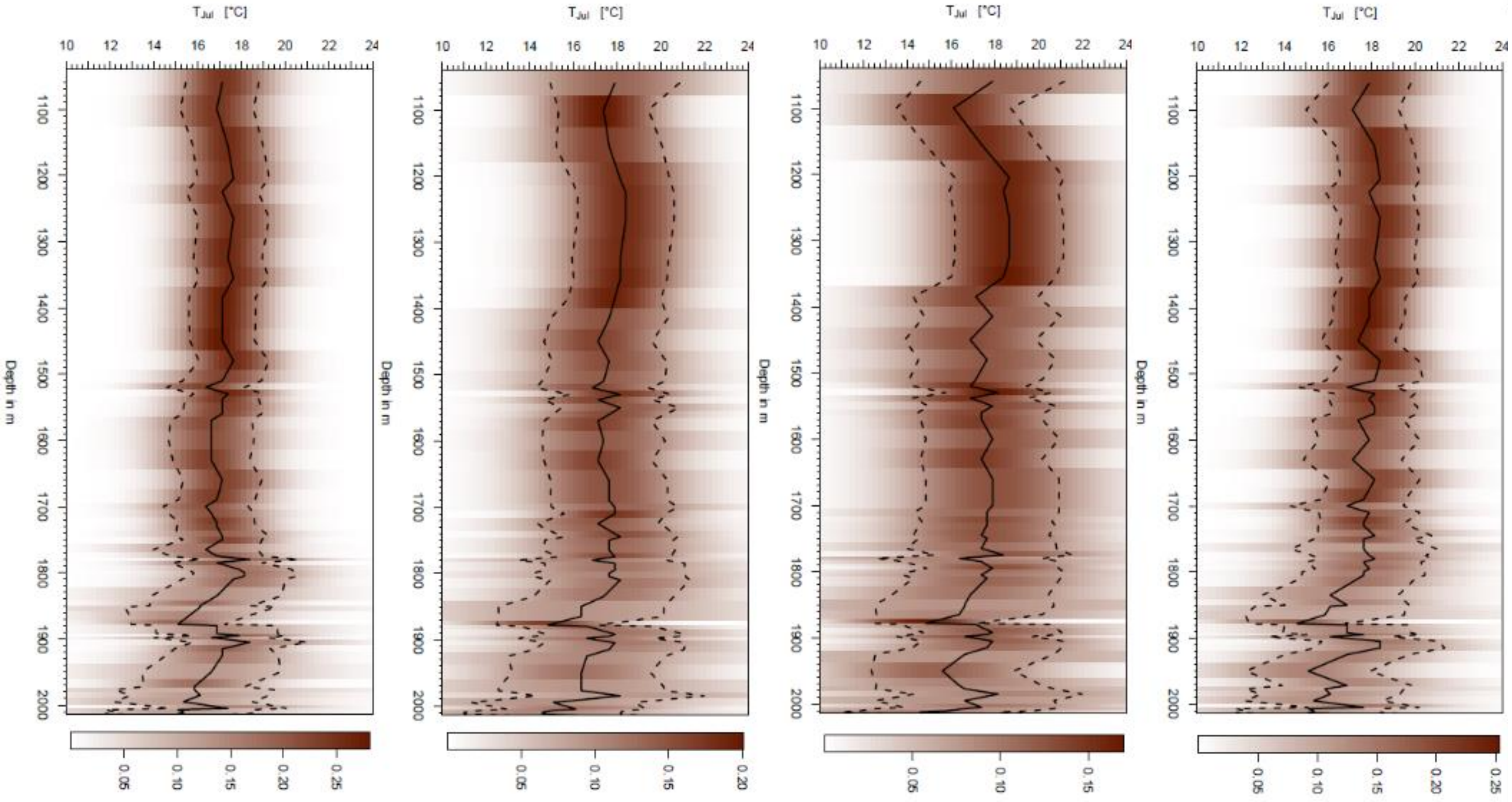
Final reconstruction

1% threshold

4% threshold

Kuhl threshold

Fig 43: Comparison of final Marks Tey (1A) winter reconstruction with models where thresholds have been applied to pollen data



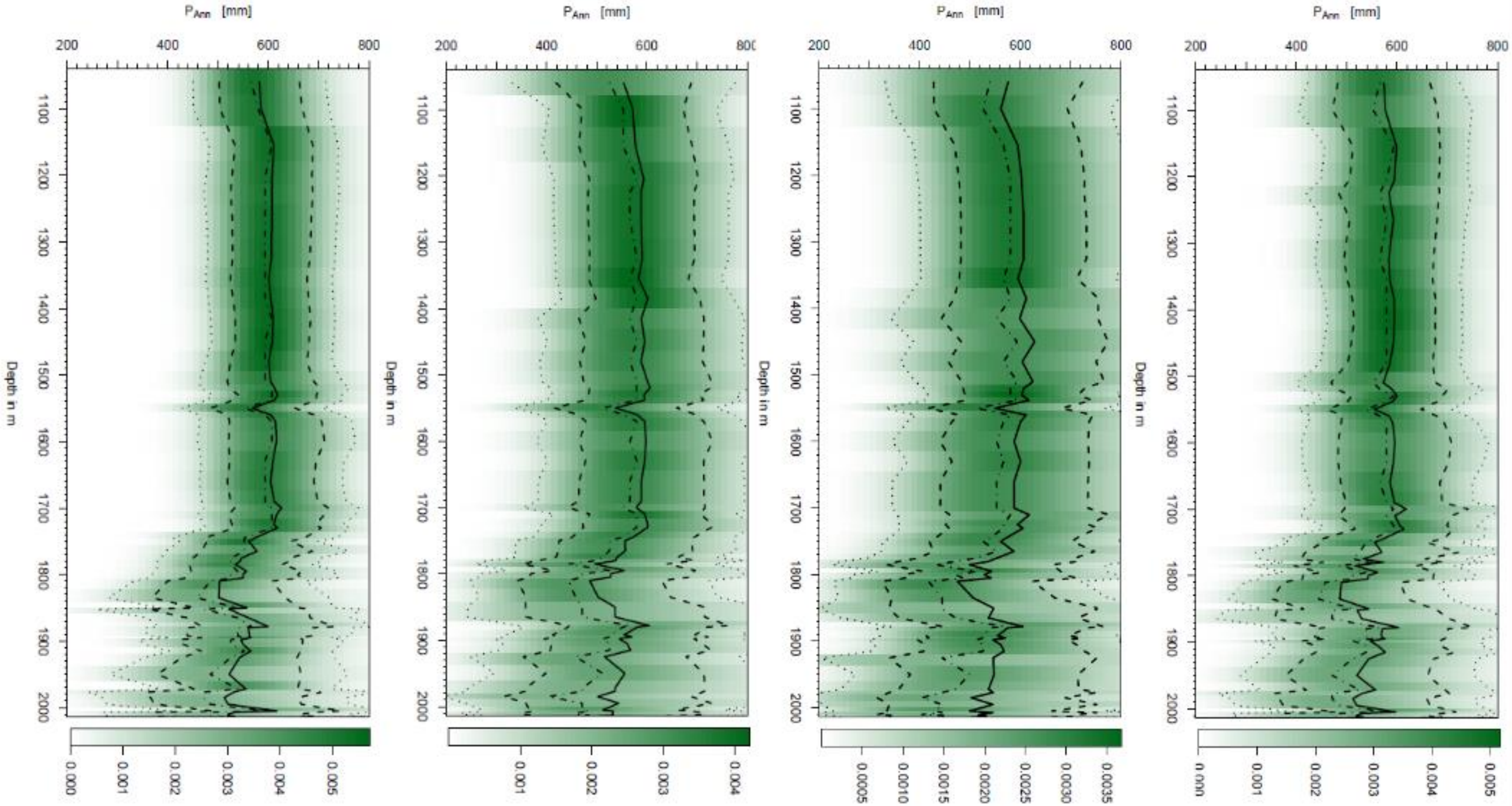
Final reconstruction

1% threshold

4% threshold

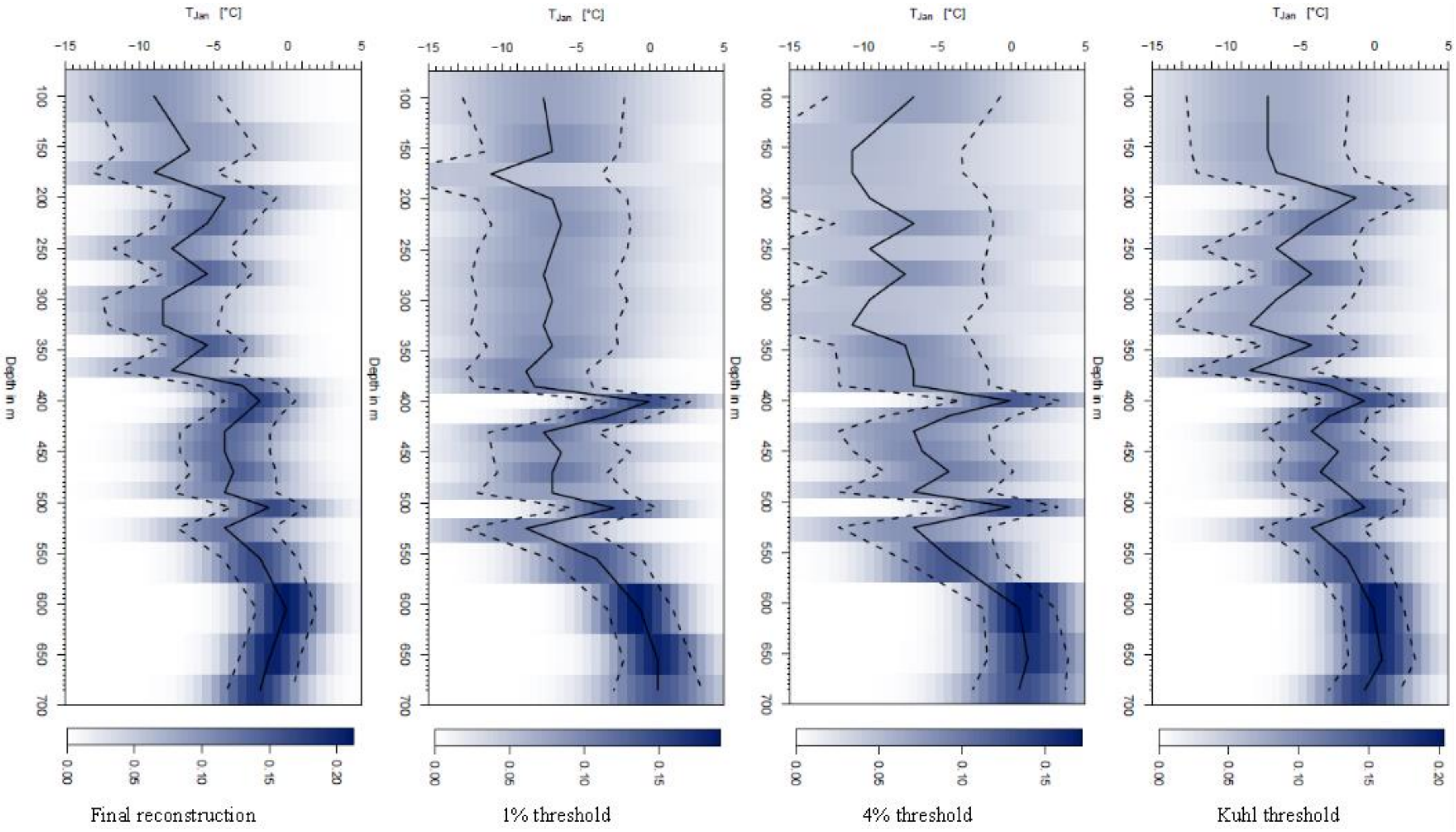
Kuhl threshold

Fig 44:Comparison of final Marks Tey (1A) summer reconstruction with models where thresholds have been applied to pollen data



Final reconstruction   1% threshold   4% threshold   Kuhl threshold

Fig 45:Comparison of final Marks Tey (1A) precipitation reconstruction with models where thresholds have been applied to pollen data



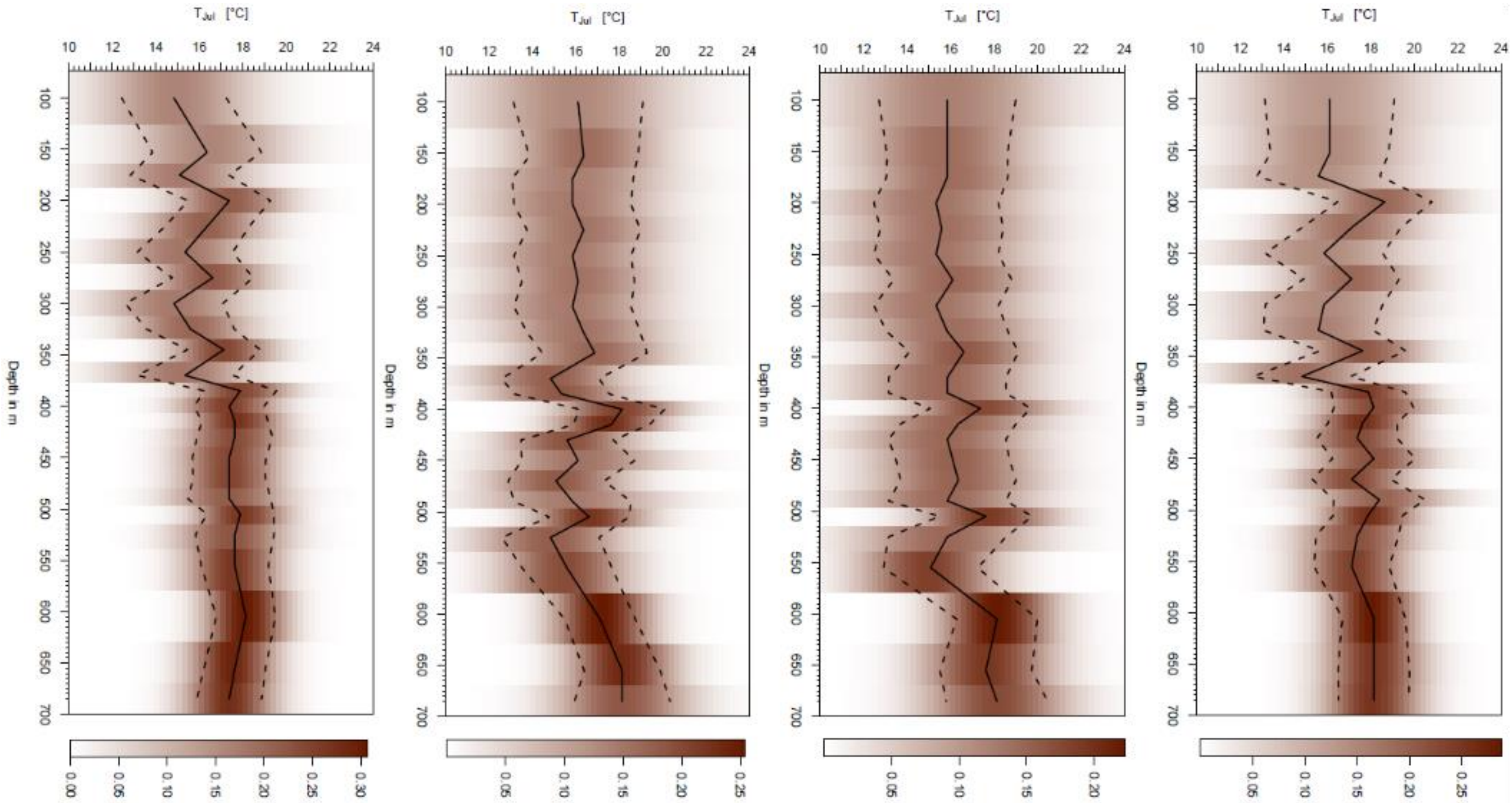
Final reconstruction

1% threshold

4% threshold

Kuhl threshold

Fig 46:Comparison of final Marks Tey (III) winter reconstruction with models where thresholds have been applied to pollen data



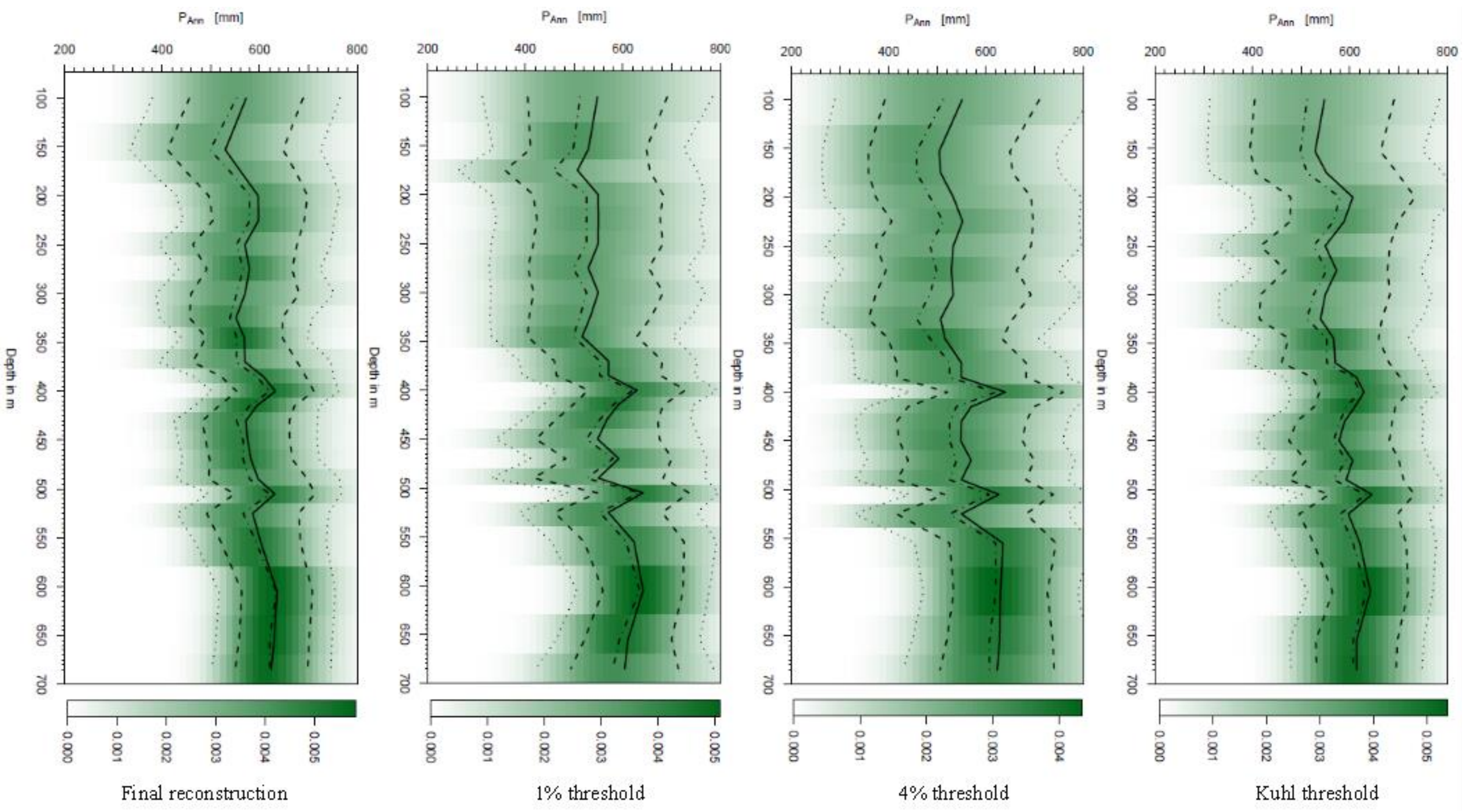
Final reconstruction

1% threshold

4% threshold

Kuhl threshold

Fig 47:Comparison of final Marks Tey (III) summer reconstruction with models where thresholds have been applied to pollen data



Final reconstruction

1% threshold

4% threshold

Kuhl threshold

Fig 48:Comparison of final Marks Tey (III) precipitation reconstruction with models where thresholds have been applied to pollen data

The threshold experiments at Marks Tey present a somewhat more complicated picture, although there are similarities with the results reported above for Hoxne. Generally speaking it is clear that the same underlying trends are observed in all of three climate parameters being reconstructed. This was also the case at Hoxne, providing further support for a significant signal climate signal being recovered.

Dealing first with the record from the borehole recording the lower part of the sequence at Marks Tey, we see a broad pattern of very cold, highly variable winter temperatures followed by a relatively stable record for the rest of the sequence, before a final oscillation at the top. There is, compared to Hoxne, relatively little difference between these four reconstructions. The amount of variability remains similar, although its magnitude is actually increased at the base of the sequence, when a threshold is applied. In this instance, this may be due to a decreased number of species, reducing the constraint on the reconstruction.

We can therefore see two possible impacts of the threshold. Firstly a decreased amount of variance from the absence of species occurring in small amounts, but an increase in magnitude of a given change due to a lessening on the number of species contributing to the reconstruction of a climate state.

The thresholds do not have a particularly significant impact on summer temperature, although there is a warming phase towards the top of the record that appears, particularly with the 4% threshold.

The top part of the Marks Tey record provides a reiteration of many of the points made above, suggesting that there is a consistent influence from the presence of a threshold. Once again, winter temperatures provide the best illustration of this with clear similarities in the overall trend, but a decreased amount of variance where there are thresholds. This is particularly noticeable towards the top of the record. However, some of the temperature changes are greater in the presence of a threshold.

10.1.4 – individual species influence

Given the discussion above regarding thresholds it is clear that the inclusion of species that are present in low numbers can have an influence on the reconstructed temperatures. This is unexpected; clearly changing the composition of input is likely to have an impact on the end result. However, some species will have a greater impact than others because of the particular climate parameters associated with them and it may be the case that in practice little noticeable difference occurs as a result of their inclusion or exclusion.

The differences in absolute temperature observed at Hoxne and Marks Tey in the previous section provide a good basis for exploring the inclusion or exclusion of a particular species. This experiment is undertaken on the input for the final reconstruction. At Hoxne, given the consistently observed higher temperature in the presence of a threshold, it seems probable that only species that are consistently present would be responsible, rather than species that intermittently occur throughout the record. In this instance, the only species that qualifies is *Picea*. The following figures show the difference the climate reconstructions for a *Picea* in vs *Picea* out input.

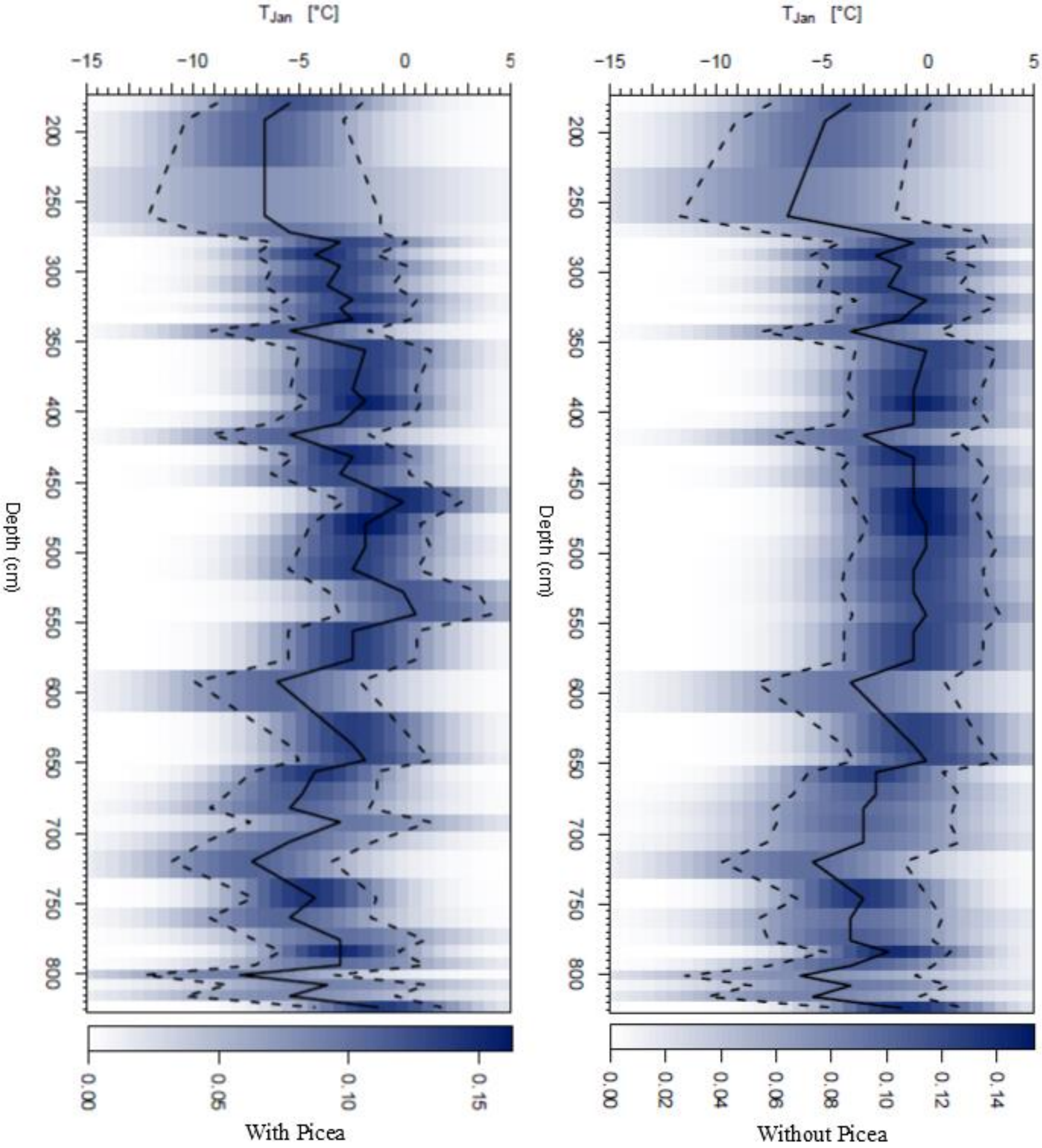


Fig 49: Comparing winter temperatures for the main sequence at Hoxne between *Picea* present and *Picea* absent experiments.

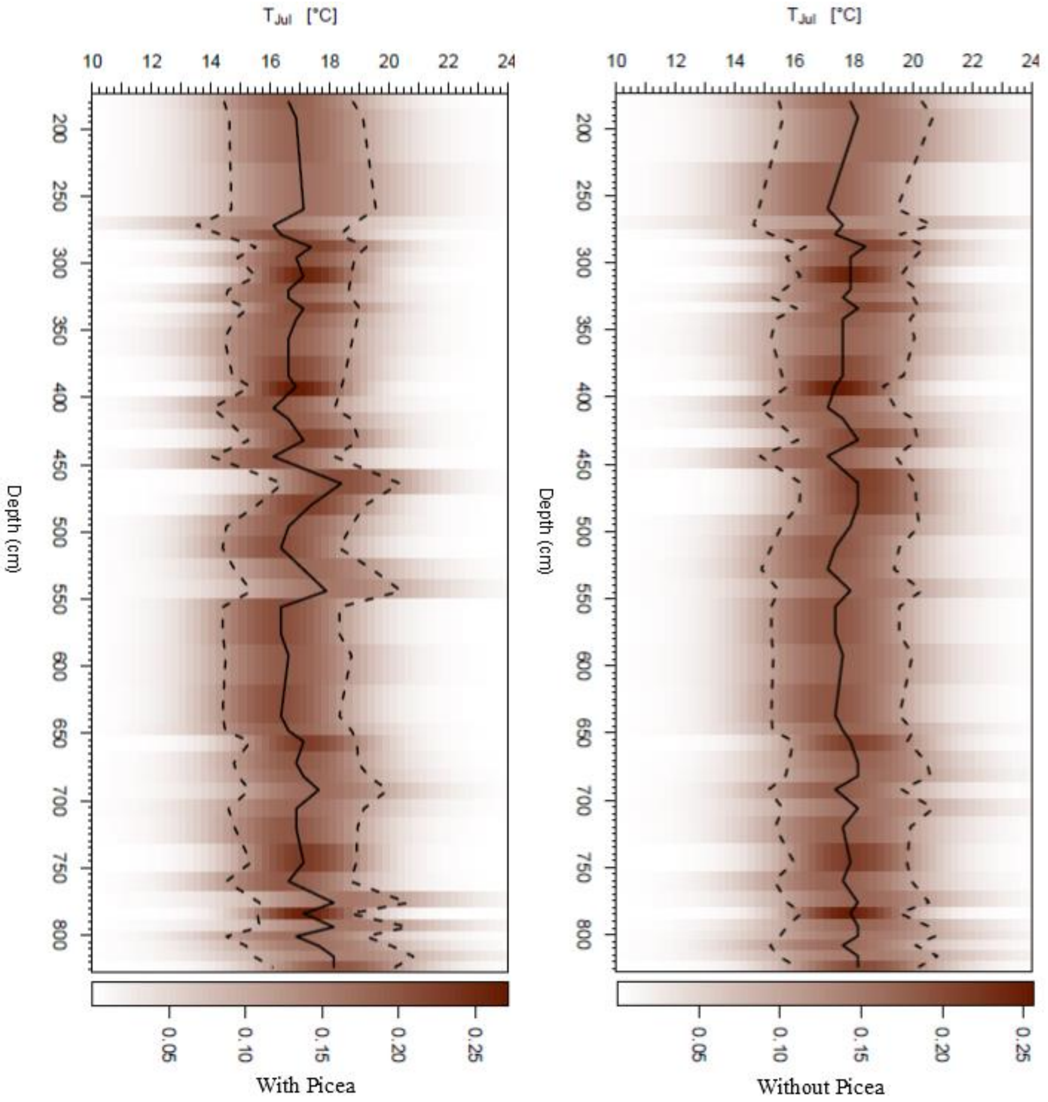


Fig 50: Comparing summer temperatures for the main sequence at Hoxne between *Picea* present and *Picea* absent experiments.

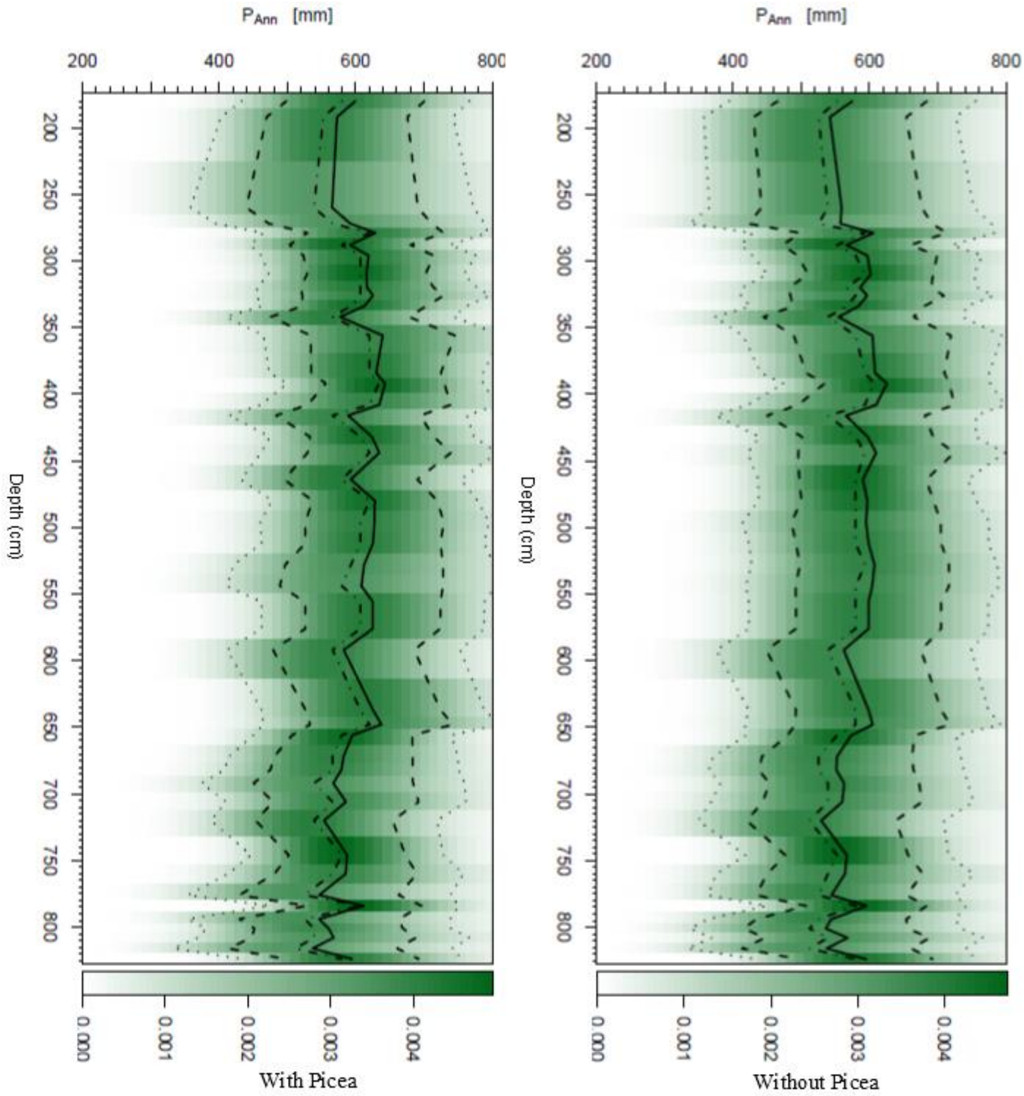


Fig 51: Comparing precipitation for the main sequence at Hoxne between *Picea* present and *Picea* absent experiments.

The inclusion of *Picea* has a noticeable impact on the reconstruction for Hoxne. In particular, it appears to lower temperatures during both summer and winter. For example, typical summer temperatures with *Picea* present are typically around 17ºC or slightly below, whereas with this species present a value close to 17ºC is observed. During the mid-part of the sequence in winter, a typical temperature when *Picea* is included would be around -4 ºC, with it absent closer to -1 ºC. Removal of *Picea* appears to have little impact on precipitation.

Note also that removing *Picea* also appears to have an impact on the magnitude of variability observed, particularly in winter. In the central portion of the core, for example, the strength of the oscillations recorded are much smaller. It may also be the case that the amount of variability is lessened. This would be somewhat unexpected as *Picea* is experimented with here due to its consistent presence; it would seem more likely that removing something with a more patchy occurrence would have this impact. However, the two curves do track each other quite closely and it is difficult to tell if there is actually less variance or if the magnitude has just been damped down sufficiently to give this impression.

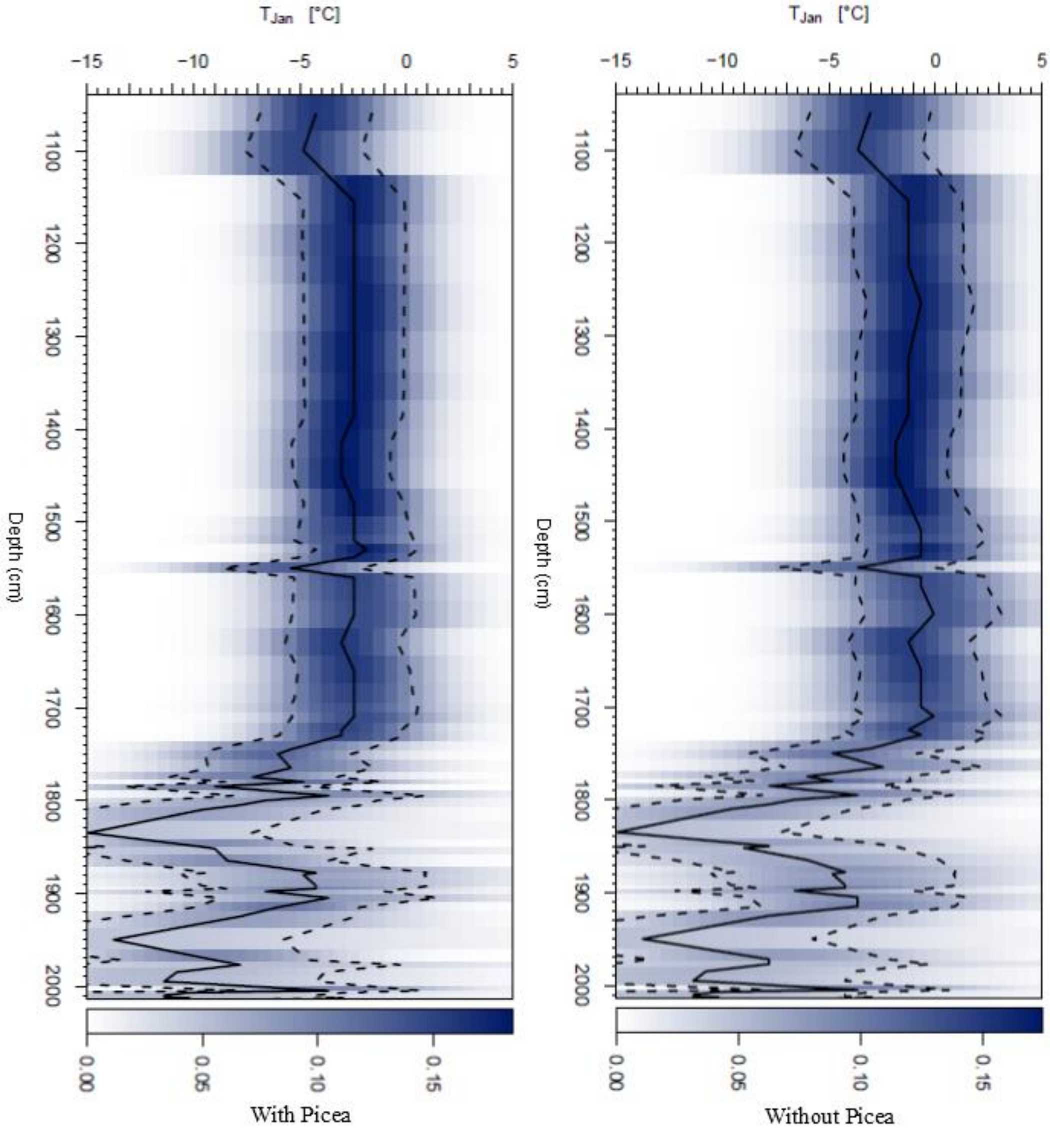
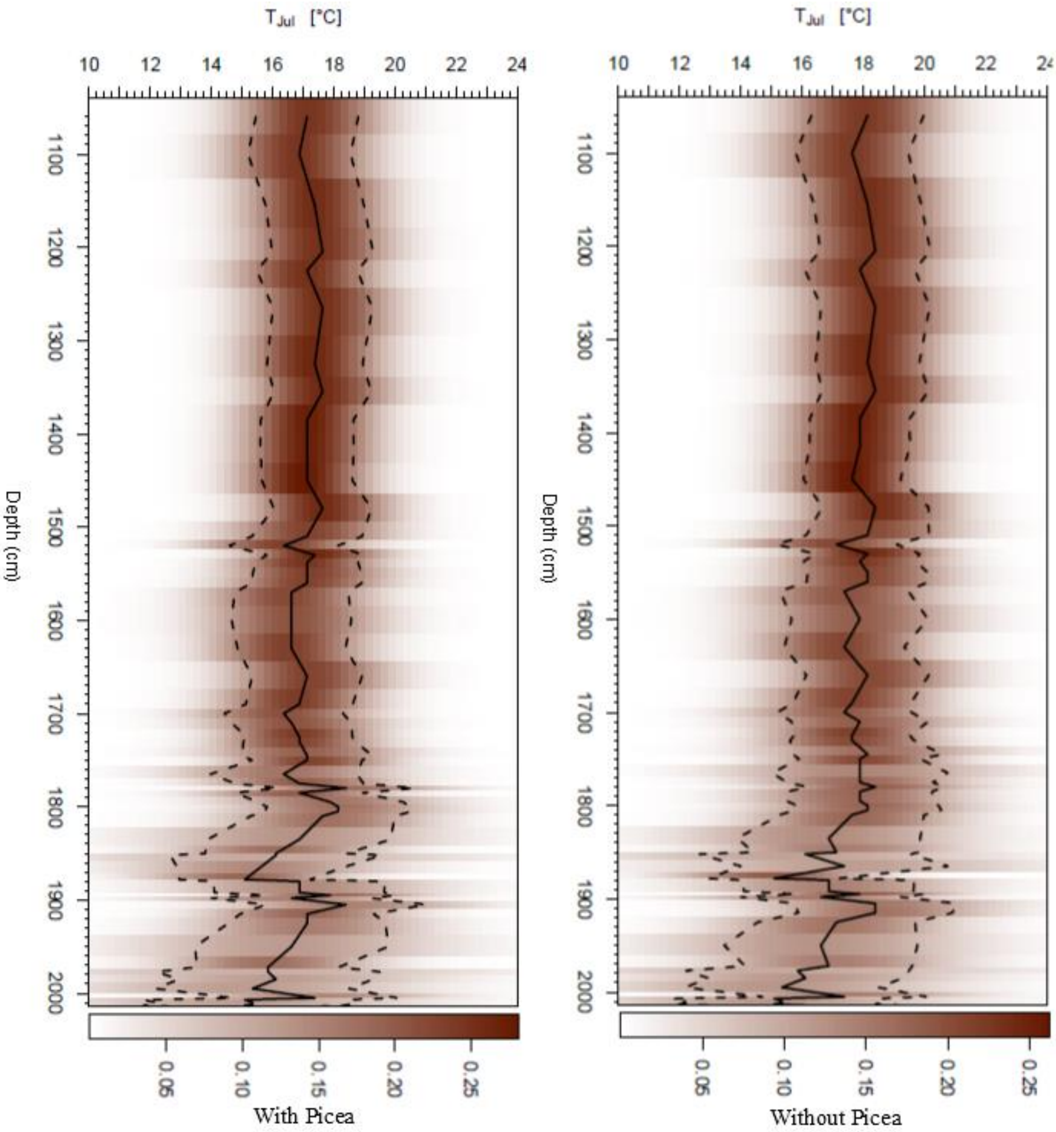


Fig 52: Comparing winter temperatures for the lower sequence at Marks Tey between *Picea* present and *Picea* absent experiments.



With Picea

Without Picea

Fig 53: Comparing summer temperatures for the lower sequence at Marks Tey between *Picea* present and *Picea* absent experiments.

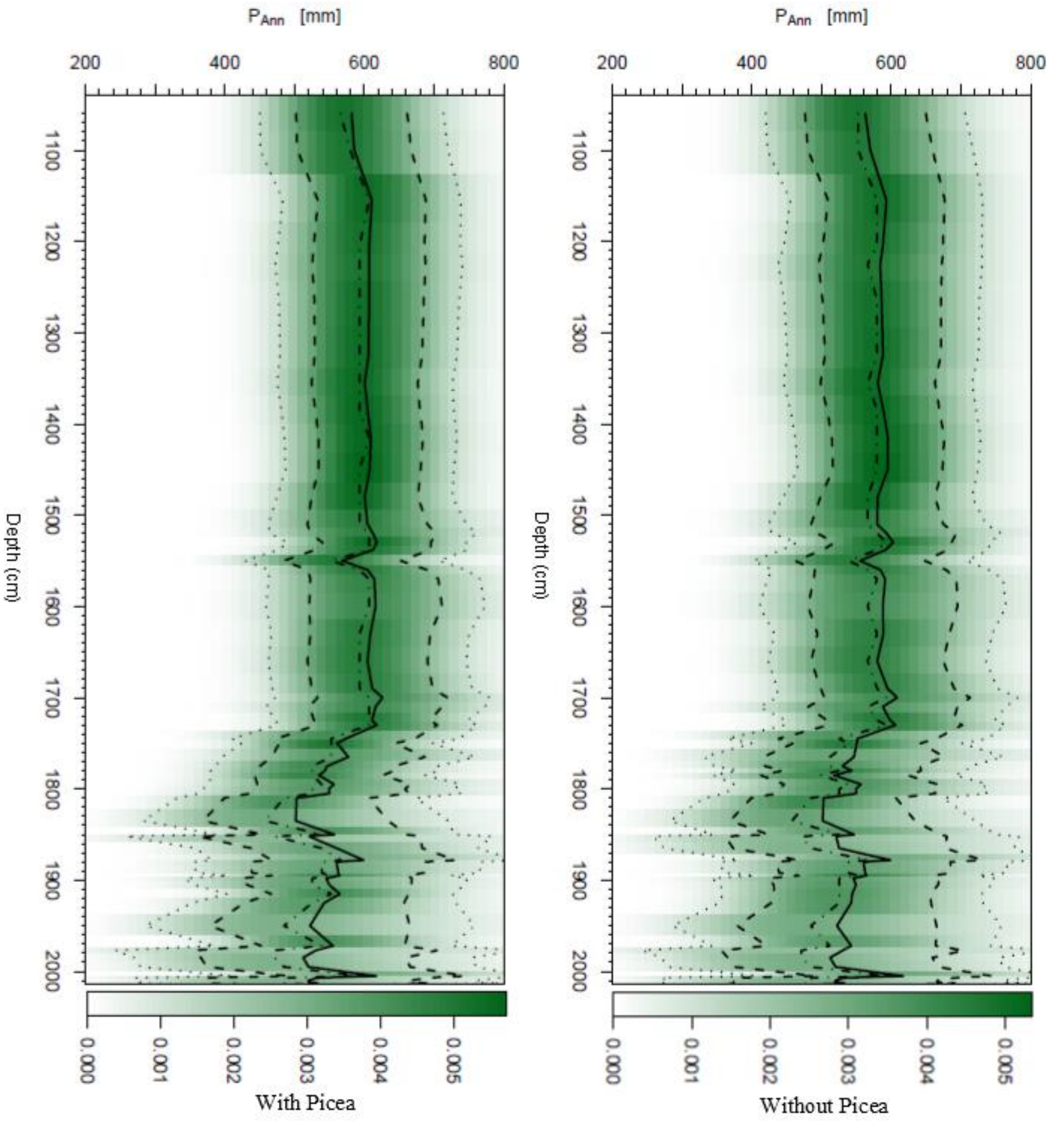


Fig 54: Comparing precipitation for the lower sequence at Marks Tey between *Picea* present and *Picea* absent experiments.

At Marks Tey, the important observation recorded at Hoxne, that of warmer temperatures in the absence of *Picea*, is replicated. However, the impact of its removal during winter appears to be less. This demonstrates that there will not always be a simple, linear relationship between the presence of a particular taxa and temperature. The reconstruction is the result of the interaction between numerous different taxa.

10.2 - Palaeoclimate reconstructions for Hoxnian sites

The following section presents the results of the reconstructions for each of the sites studied in this thesis. The input underlying each reconstruction can be viewed in the appendix.

10.2.1 – Marks Tey

Borehole 1A

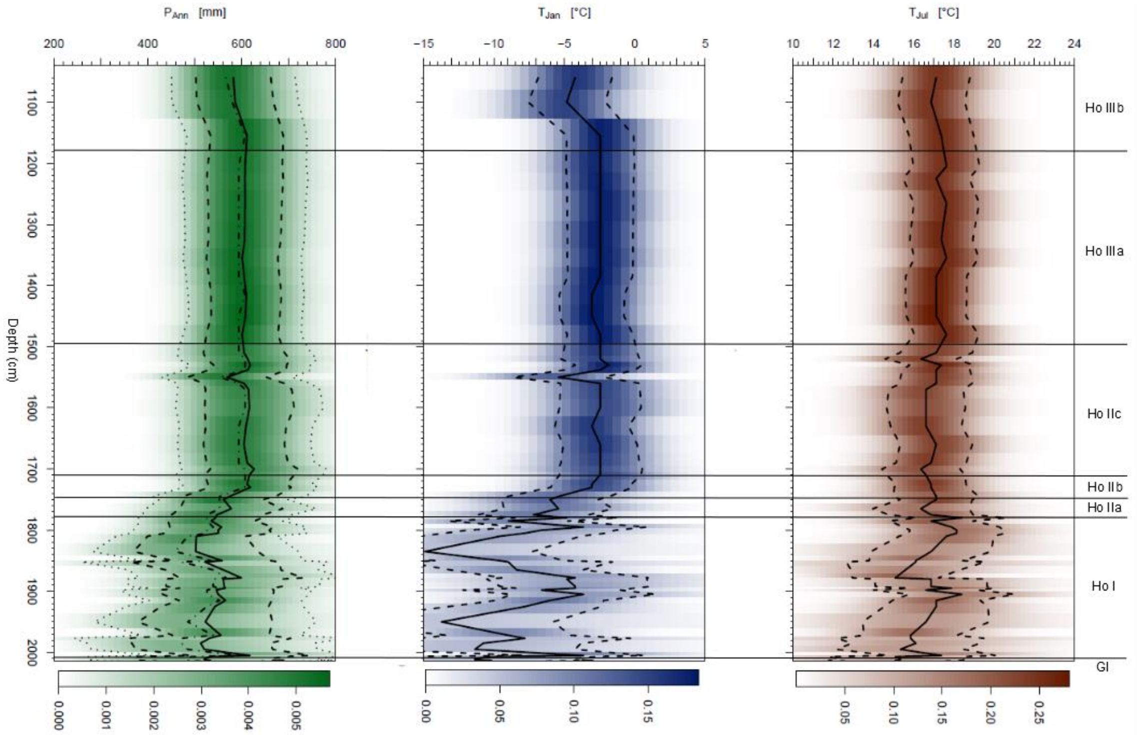


Fig 55: Reconstructed January and July mean temperatures, and annual precipitation for Marks Tey (borehole 1A). Intensity of colours refers to the probability density of reconstructed climate, the mean (solid line) and 1 sigma (dashed). Precipitation also shows 2 sigma (dotted) and the maximum of the pdf (dash dot).

January temperature at Marks Tey (borehole 1A)

A very clear division occurs in the record of winter temperature for the lower part of the Marks Tey sequence. During Ho I, temperatures are often extremely low and also highly variable, with two main periods of cooling interrupted by a short warm interval. Temperatures reach as low as -15ºC at one point. Following the second of the major cold spikes, there is then a general warming (albeit an interrupted one) until the end of Ho IIb. At this point the record then becomes largely smooth, consistently around -2.5ºC.

At the end of Ho IIc, there is a very distinct cooling spike of over 2ºC. In amidst an otherwise consistently stable record, this event stands out clearly. It appears to be short lived and a return to previous conditions soon occurs and they continue right up until the end of Ho IIIa. During Ho IIIb a cooling of around 2ºC can be observed and is followed at the very end of the record by rising temperatures.

July temperature at Marks Tey (borehole 1A)

Ho I sees a gradual warming trend, interrupted by a cooling episode towards the end of the period. Temperatures start off relatively low, around 16ºC but reach 17ºC by the start of Ho IIa, where they remain for the rest of the sequence, into Ho IIIb. Again, this period is marked by consistent temperatures in the reconstruction. As with winter temperatures, there is also a cooling event at the end of Ho IIc, although it occurs slightly later and has a smaller magnitude, around 0.5ºC. There is the suggestion of a decline in temperature during Ho IIIb, though it is brought to an end by the possible beginnings of a subsequent rise.

Precipitation at Marks Tey (borehole 1A)

The precipitation record is similar to summer and winter temperature. In this instance an early, drier precipitation regime in Ho I, gives way to wetter conditions for the rest of the period. Ho I sees precipitation at around 550 mm during Ho I and then a consistent trend of 600 mm. The early period of high variance is relatively minor compared to the temperature records, particularly the winter curve. There is also a distinct and abrupt decrease in precipitation at the end of Ho II, mirroring the sharp fall in winter temperature. During Ho IIIb there is the suggestion of declining precipitation, although this appears to have ended at the very top of the core.

The lowest probability density for all of the three reconstructions occurs during Ho I, which is also the most variable. The rest of the sequence, for all three climate metrics, sees high probability densities, indeed some of the most consistently so for any reconstruction at any site.

Borehole III

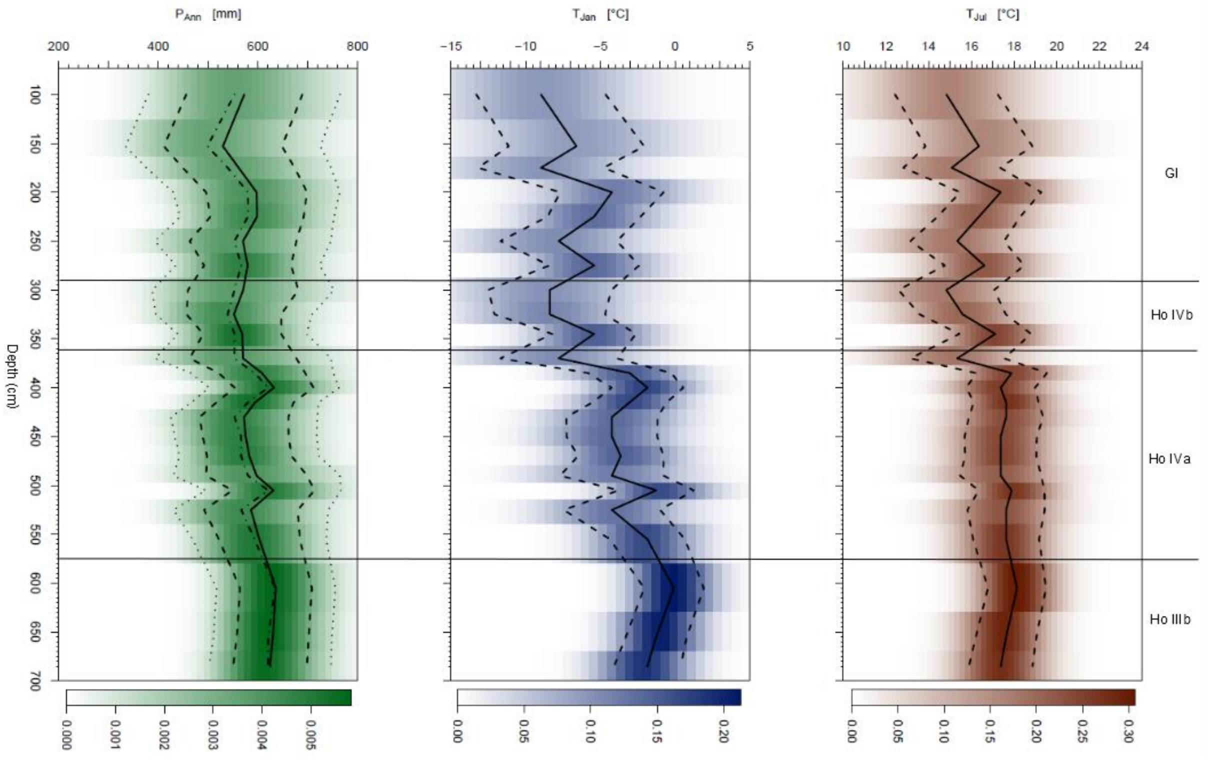


Fig 56: Reconstructed January and July mean temperatures, and annual precipitation for Marks Tey (borehole III). Intensity of colours refers to the probability density of reconstructed climate, the mean (solid line) and 1 sigma (dashed). Precipitation also shows 2 sigma (dotted) and the maximum of the pdf (dash dot).

An important general point to note is the consistency between the Ho IIIb reconstruction for the top part of the Marks Tey sequence and the lower part, reported on above. In particular, the summer and winter records record initially rising temperatures, replicating and continuing the trend observed in these climate metrics at during Ho IIIb in the lower sequence.

January temperature at Marks Tey (borehole III)

Winter temperature rises steadily until the end of Ho IIIb to around -1ºC, which represents one of the high points of winter temperature in the entirety of the Marks Tey record. From this point onwards there is a consistent cooling trend through to the end of the interglacial sequence and into the subsequent cold period beyond. This trend is a somewhat unstable one, particularly in the later pollen zones, but is nevertheless consistent. By the end of the sequence recorded at Marks Tey, winter temperature is extremely low, close to -10ºC.

July temperature at Marks Tey (borehole III)

Summer temperatures are consistently close to 17ºC until the end of Ho IVa. From that point, the start of Ho IVb, there is a continued decline in temperature, again an unstable one, through into the start of the cold period. By the end of the record, summer temperatures are at their coldest, 14ºC, in the entire Marks Tey sequence and one of the coldest recorded at any site at any stage in this study.

Precipitation at Marks Tey (borehole III)

Precipitation is largely similar to June and July temperature, showing, overall, a decline over time. Initially, precipitation values are around 600 mm and fall to approximately 520 mm, although this trend is perturbed slightly by a final increase at the top of the sequence.

10.2.2 – Hoxne

Main sequence

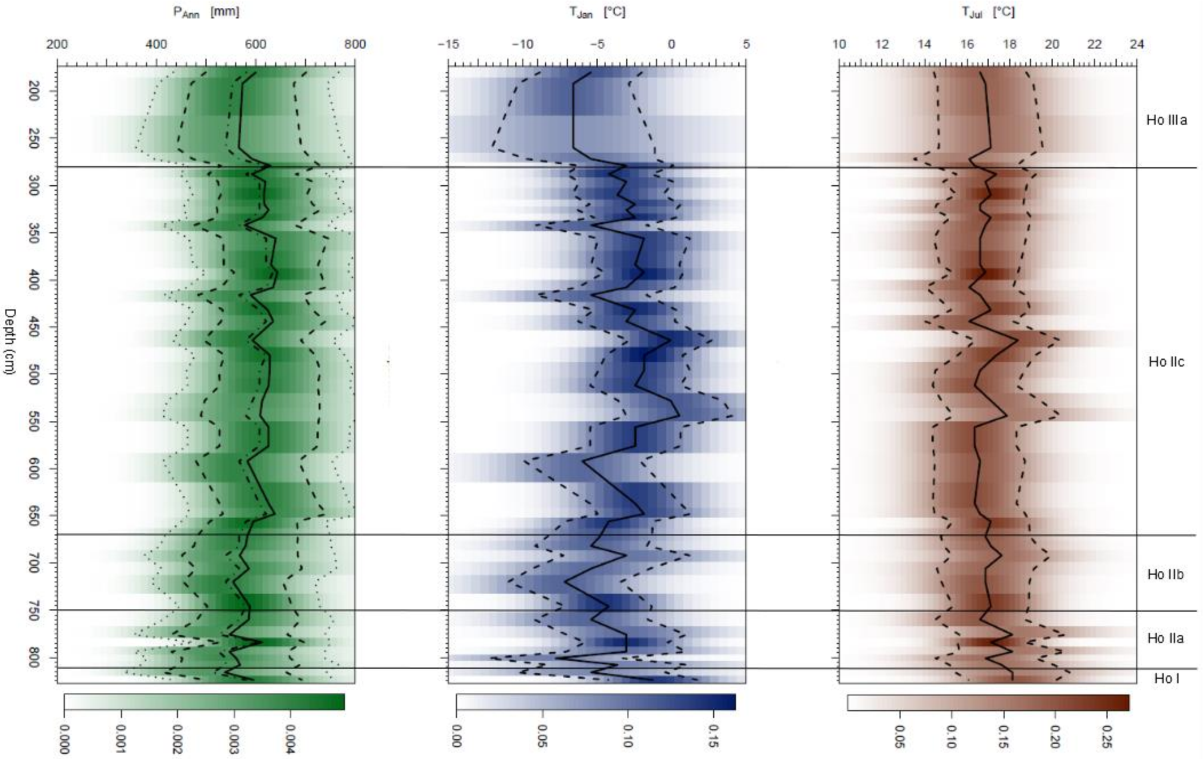


Fig 57: Reconstructed January and July mean temperatures, and annual precipitation for the main sequence at Hoxne. Intensity of colours refers to the probability density of reconstructed climate, the mean (solid line) and 1 sigma (dashed). Precipitation also shows 2 sigma (dotted) and the maximum of the pdf (dash dot).

<u>January temperature at Hoxne</u>

There is a great deal of variability in winter temperatures at Hoxne. It seems unlikely that this always reflects genuine climatic changes. This variability makes it difficult to establish broad trends, but some major features do become clear. There is a tri-partite temperature regime, with Ho I to early Ho IIc featuring variation around a general temperature of approximately -5ºC. There is a suggestion of a consistent lowering in temperature initially, during Ho I. Following this early unstable cooler phase, temperatures then appear to peak midway through Ho IIc at approximately -2.5ºC before a gradual decline back towards -5ºC by the end of this pollen zone. Finally, Ho IIIa is less variable and slightly colder at just below -6ºC.

July temperature at Hoxne

July temperatures are somewhat more stable than during winter. In addition, in contrast to winter temperatures, although variability exists, there are no major longer term trends. Temperature persists around 17ºC or just below, with oscillations from this value.

Precipitation at Hoxne

Precipitation levels are generally around 620 mm throughout the record. Variability exists and often aligns with that seen in the winter temperature record, albeit with a smaller magnitude of change. During Ho IIIa, there is a suggestion of lowered precipitation, just below 550 mm.

For all three reconstructions, the probability density is quite high. Ho IIIa features the lowest probability density.

Stratum C

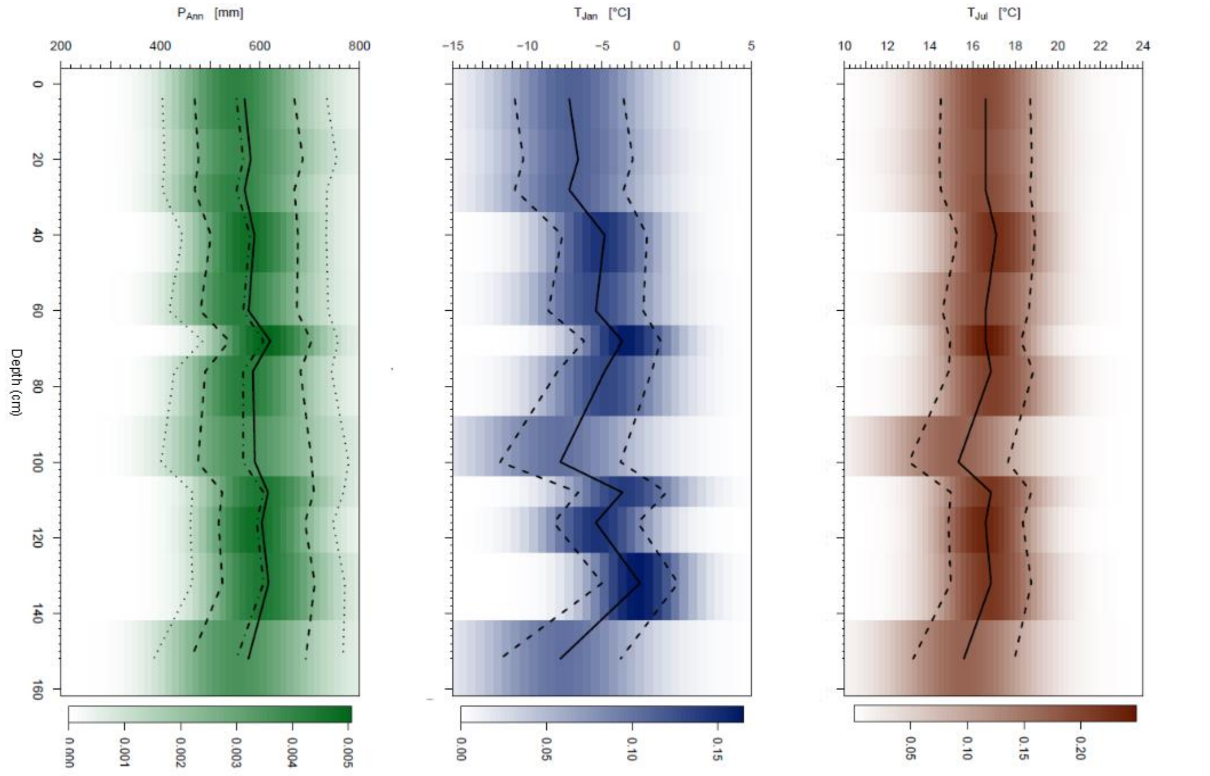


Fig 58: Reconstructed January and July mean temperatures, and annual precipitation for Stratum C at Hoxne. Intensity of colours refers to the probability density of reconstructed climate, the mean (solid line) and 1 sigma (dashed). Precipitation also shows 2 sigma (dotted) and the maximum of the pdf (dash dot).

January temperature during Stratum C at Hoxne

Stratum C is a relatively short sequence. January temperature reach a peak early on at approximately -4ºC and the general trend is, overall, downwards to a minimum at the end of -7ºC. This trend is interrupted by a sharp, saw toothed cooling spike, where temperature falls by approximately 3ºC before rising again.

July temperature during Stratum C at Hoxne

July temperature is largely smooth throughout Stratum C, with one cooling at the same point as the one recorded in the January record. Other than this, temperatures remain at around 16.5ºC throughout.

Precipitation during Stratum C at Hoxne

Precipitation during Stratum C is consistent, being just below 600 mm throughout the sequence.

10.2.3 – Athelington

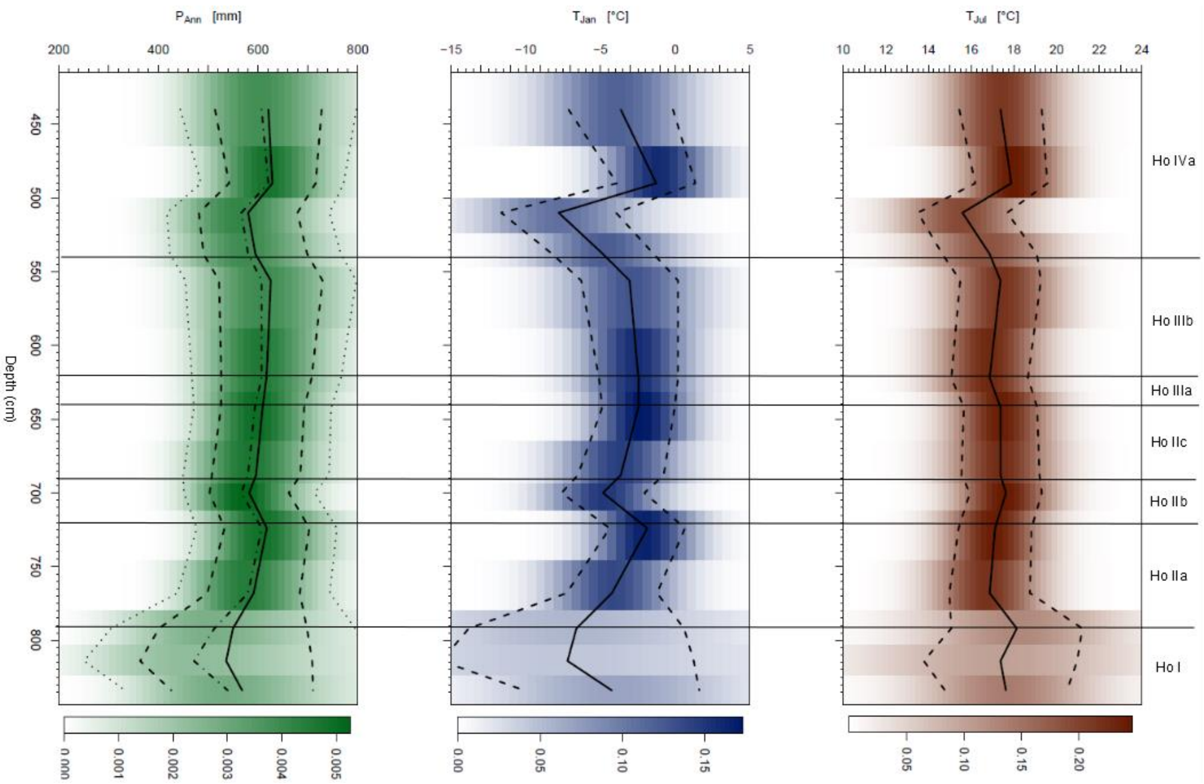


Fig 59: Reconstructed January and July mean temperatures, and annual precipitation for Athelington. Intensity of colours refers to the probability density of reconstructed climate, the mean (solid line) and 1 sigma (dashed). Precipitation also shows 2 sigma (dotted) and the maximum of the pdf (dash dot).

January temperature at Athelington

January temperature during Ho I is very low, around -7ºC. This period features the lowest probability density. There then follows a steady trend towards warmer conditions, through Ho IIa reaching a peak of -1ºC at the onset of Ho IIb. A small decline follows during Ho IIb before a gradual rise to a peak of around -3ºC during Ho

IIIa and subsequent consistency around this point. This continued until a distinct decline at the end of the period, culminating in the lowest temperature recorded at Athelington, -8ºC, early in Ho IVa. A return to warmer temperatures of around -2ºC occurs, before another decline, this time of around 2ºC, follows, concluding the winter temperature record.

July temperature at Athelington

As with January temperature, the initial stages of the summer temperature reconstruction has relatively low probability density. The trends observed during summer largely reflect those described above for winter, with the exception of an early warmer peak on the boundary of Ho I and Ho IIa and no distinct decline during Ho IIb. Generally speaking summer temperatures are less variable than during winter, typically around 17ºC. The warmest temperature occurs, briefly, during Ho IVa, just below 18ºC.

Annual precipitation at Athelington

Precipitation again starts with lowered probability density, at the base of the sequence. There is a very slight decrease in precipitation during Ho I, the trend is then upwards until the end of Ho IIa, where a value of 620 mm is reconstructed. There is then a 30 mm decline during Ho IIb before another steady rise to 630 mm by the end of Ho IIIb. Another decrease in precipitation of around 30 mm is recorded at the start of Ho IVa before returning to 630 mm and stabilising at this point until the top of the sequence.

The decline in precipitation during Ho IV occurs at the same time as drops in summer and winter temperature. The decline Ho IIb is mirrored in winter temperature but not summer, with a similar pattern occurring during Ho I. In all three reconstructions, the majority of the sequence is relatively lacking in variance.

10.2.4 – Barford

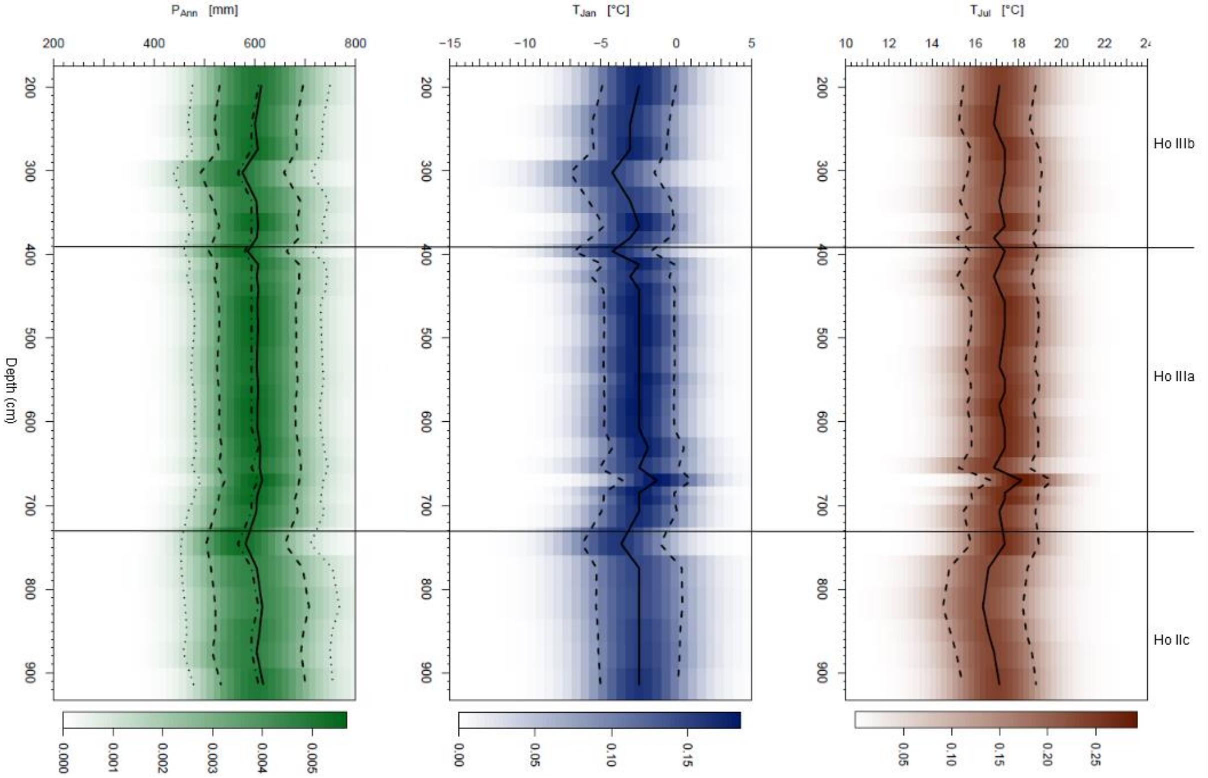


Fig 60: Reconstructed January and July mean temperatures, and annual precipitation for Barford. Intensity of colours refers to the probability density of reconstructed climate, the mean (solid line) and 1 sigma (dashed). Precipitation also shows 2 sigma (dotted) and the maximum of the pdf (dash dot).

January temperature at Barford

January temperature at Barford is consistently around -3ºC, with a number of small deviations from this temperature. A small decrease in temperature of around 1ºC can be observed at the end of Ho IIc. Relatively early on in Ho IIIa there is a small and presumably short lived temperature rise of around 0.5ºC. The transition from Ho IIIa to Ho IIIb seems a temporary decline in temperature of around 1.5ºC, which is repeated more gradually during Ho IIIb.

July temperature at Barford

Summer temperatures at Barford are consistently around 17ºC and generally stable. A short lived temperature rise early in Ho IIIa of just less than 1ºC occurs at the same time as a rise in winter temperature. There is also a more extended fall, of around 0.5ºC, and then rise in temperature at the base of the sequence, during Ho IIc. Winter temperatures are stable during this time.

Precipitation at Barford

Precipitation is also stable in this record, with 500 mm being recorded throughout the sequence. In terms of variation from this, precipitation tracks winter temperatures, showing small changes (approximately 20 mm) at the same time as deviations in this metric.

Probability densities are lower towards the base of the sequence, in Ho IIc, for all three reconstructions.

10.2.5 – Nechells

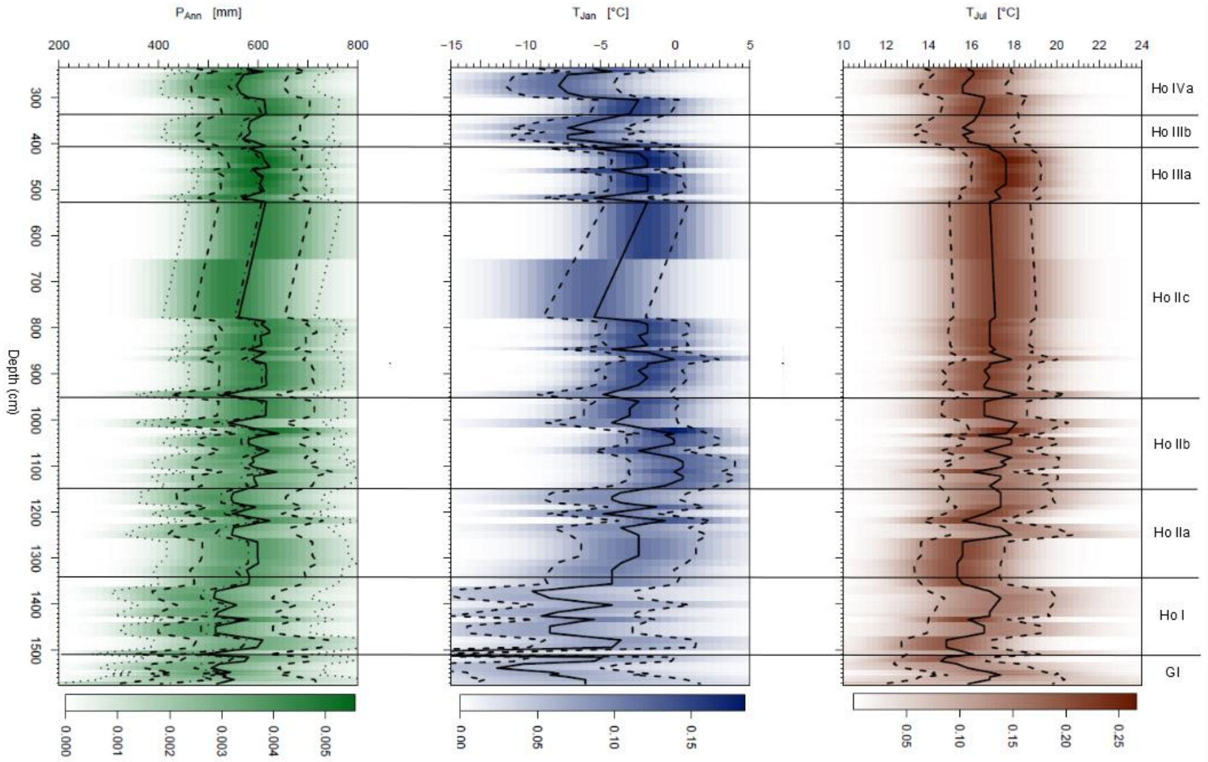


Fig 61: Reconstructed January and July mean temperatures, and annual precipitation for Nechells. Intensity of colours refers to the probability density of reconstructed climate, the mean (solid line) and 1 sigma (dashed). Precipitation also shows 2 sigma (dotted) and the maximum of the pdf (dash dot).

<u>January temperature at Nechells</u>

January temperature is quite variable, although a pattern can be observed despite this. The base of the sequence, during the cold conditions preceding the Hoxnian interglacial, sees very low temperatures, down to around -12ºC at one stage, although untangling a single clear temperature average from this period is difficult. Following these initial extremely low temperatures, there is a continuing increase, punctuated by a number of declines, until a peak for the Nechells record is reached at the beginning of Ho IIb. Ho I remains very cold, between -6 and - 9ºC. Ho IIa is slightly less variable and begins at approximately -5ºC.

The temperature peak in Ho IIb is around 0ºC. Roughly halfway through this pollen zone there is a distinct fall in temperature, which appears to mark a change to a new winter temperature regime that continues until the end of Ho IIIa. Although there is a considerable degree of variability, this period can be seen to have temperatures somewhere around -3ºC.

There is the suggestion that Ho IIIb marks the start of a period of declining temperature, although this is not entirely clear.

July temperature at Nechells

July temperatures are similarly variable as January, although as is common in these reconstructions, the magnitude is lower. Temperatures rise from between 14ºC and 15ºC at the very start of the interglacial to 17ºC during Ho IIb, where they remain fairly consistently until the end of Ho IIIb. There is also the suggestion of a warmer interval at the end of Ho IIIb. Finally, there appears to be a temperature decline towards -16ºC at the end of the sequence, during Ho IVa.

Both temperature records at Nechells therefore broadly indicate a temperature curve over much of the interglacial from colder to warmer and ultimately back to colder conditions, as might be expected.

Precipitation at Nechells

Precipitation is once again similar, with an initial rise from low values around 520 mm before reaching a level close to 600 mm during Ho IIb that then persists. There is a less clear signal of decline at the end of the record.

10.2.6 – Quinton

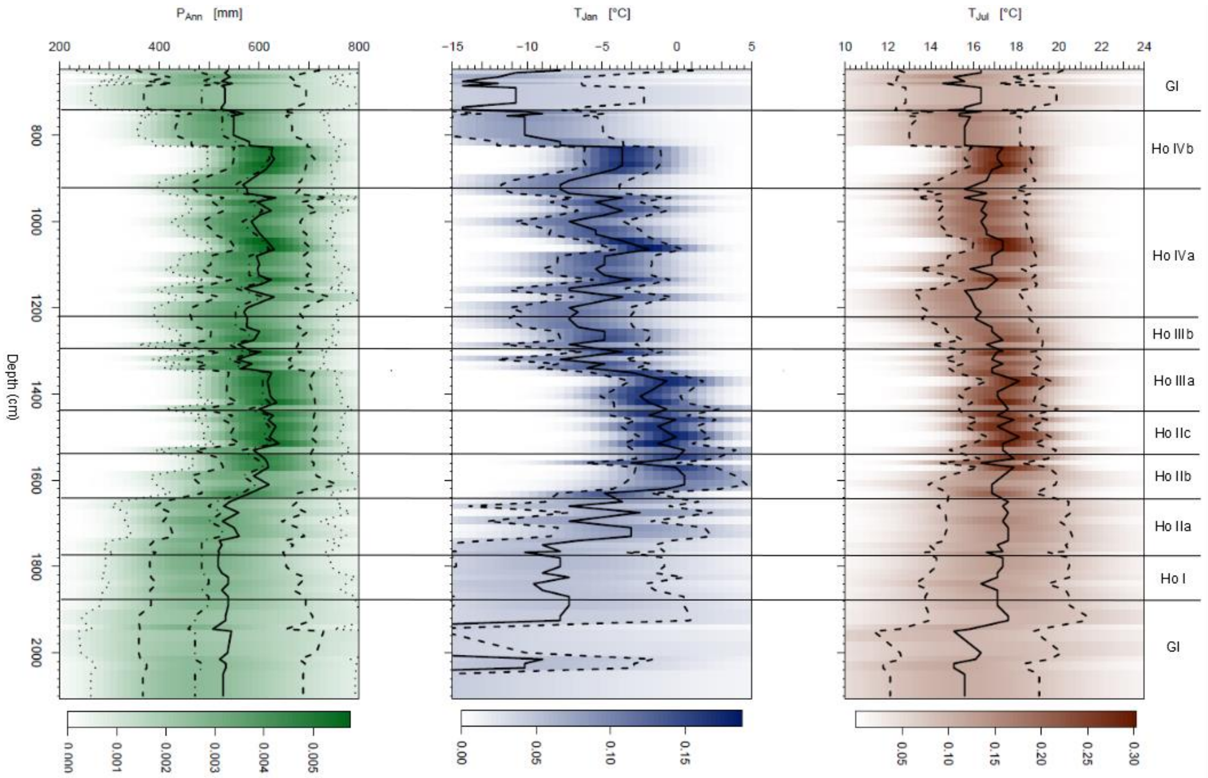


Fig 62: Reconstructed January and July mean temperatures, and annual precipitation for Quinton. Intensity of colours refers to the probability density of reconstructed climate, the mean (solid line) and 1 sigma (dashed). Precipitation also shows 2 sigma (dotted) and the maximum of the pdf (dash dot).

January temperature at Quinton

January temperature at Quinton in the early part of the record is extremely low, although marked by large error bars and low probability density. During the cold period prior to the interglacial and indeed during Ho I, winter temperature is at least -10ºC. From the start of Ho IIa, climate ameliorates until Ho IIb. At this stage the temperature is around 0ºC, possibly slightly below. This is maintained (although there is the suggestion of a decline) until Ho IIIa, where there is a step change to a new temperature regime. This new regime is characterised, despite variability, by a temperature of approximately -5ºC and continues until midway through Ho IVb. From this point onwards, the climate deteriorates significantly, with very low temperatures being reconstructed, potentially as low as -15ºC. However there is, as with the start of the record, significant uncertainty associated with these values.

July temperature at Quinton

July temperature is largely similar to January temperature in terms of the overall pattern. Initially, during a period with low probability density, the climate is cool during summer months at approximately 14ºC. Temperatures then rise up to Ho IIa, where 17ºC becomes the typical summer temperature. There is some suggestion that, as with winter temperature, there is a decline during Ho IIa. However, this is checked during Ho IV, where conditions warm, back to 17ºC. Finally, during the latter stages of Ho IVb, there is a distinct transition to a colder climate, with temperatures between 15 and 16ºC.

Precipitation at Quinton

The precipitation reconstruction follows a similar pattern to winter and summer temperature. Relatively dry conditions persist through the first three pollen zones before reaching a high of 620 mm during zones Ho IIb to Ho IIIa. The end of the latter zone has a distinct shift to lower precipitation, in common with the temperature records, around 570 mm. Similar to temperature, there does appear to be something of a rising trend from this point, until 620 mm during Ho IVb. Finally, there is a fall in precipitation at the end of the interglacial, into the subsequent cold stage. Precipitation ends at a value close to 540 mm.

10.2.7 – St Cross-South Elmham

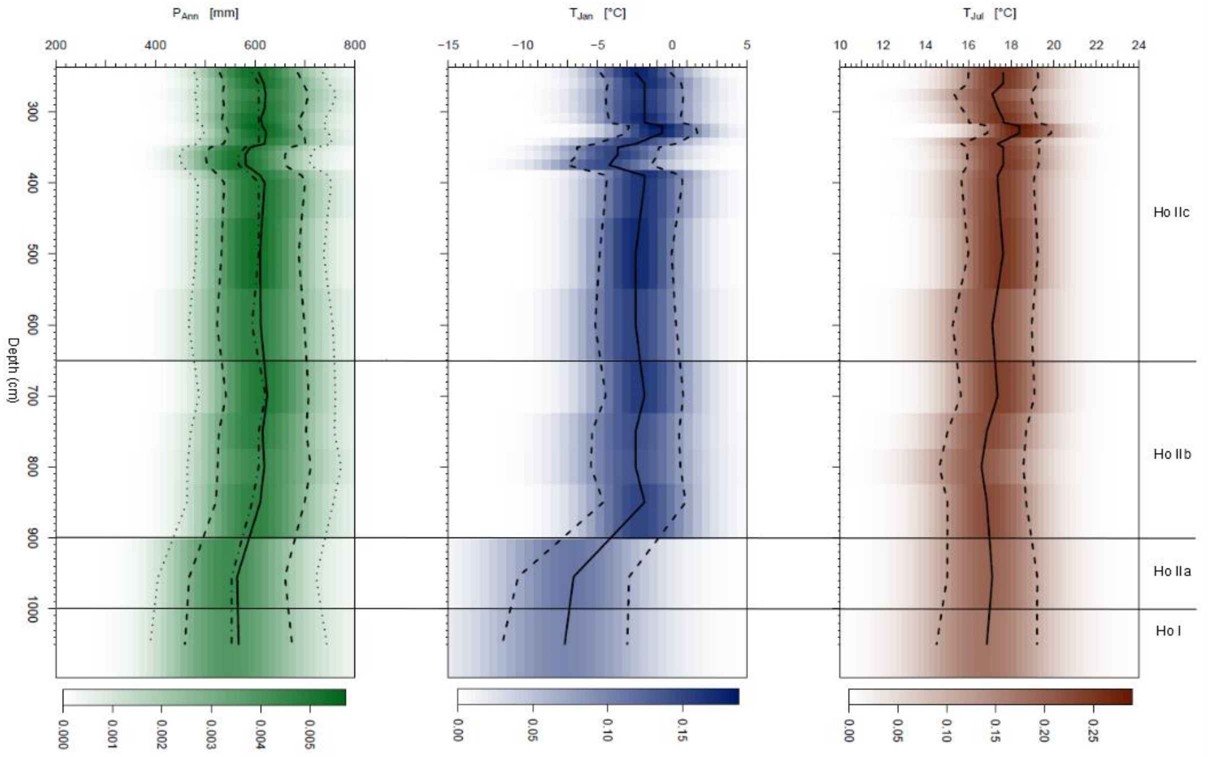


Fig 63: Reconstructed January and July mean temperatures, and annual precipitation for St Cross South Elmham. Intensity of colours refers to the probability density of reconstructed climate, the mean (solid line) and 1 sigma (dashed). Precipitation also shows 2 sigma (dotted) and the maximum of the pdf (dash dot).

<u>January temperature at St Cross South Elmham</u>

During Ho I, January temperature is low, at approximately -7ºC and then rises steadily to reach -2.5ºC during the early stages of Ho IIb. The temperature then remains steady for the rest of the sequence, with the exception of a very clear decrease in temperature during Ho IIc. In this episode, temperature falls by close to 2ºC before returning back to more typical values soon afterwards.

<u>July temperature at St Cross South Elmham</u>

Summer temperature at this site sees little in the way of variability. It may be the case that Ho IIc was warmer than preceding pollen zones.

Annual precipitation at St Cross South Elmham

Precipitation is lowest during Ho I at approximately 560 cm, before rising during Ho IIa and reaching a consistent level of 600 mm part way through Ho IIb. This level is interrupted by an abrupt fall in precipitation during the latter stages of Ho IIc, coincident with the fall in winter temperature.

10.2.8 – Elveden

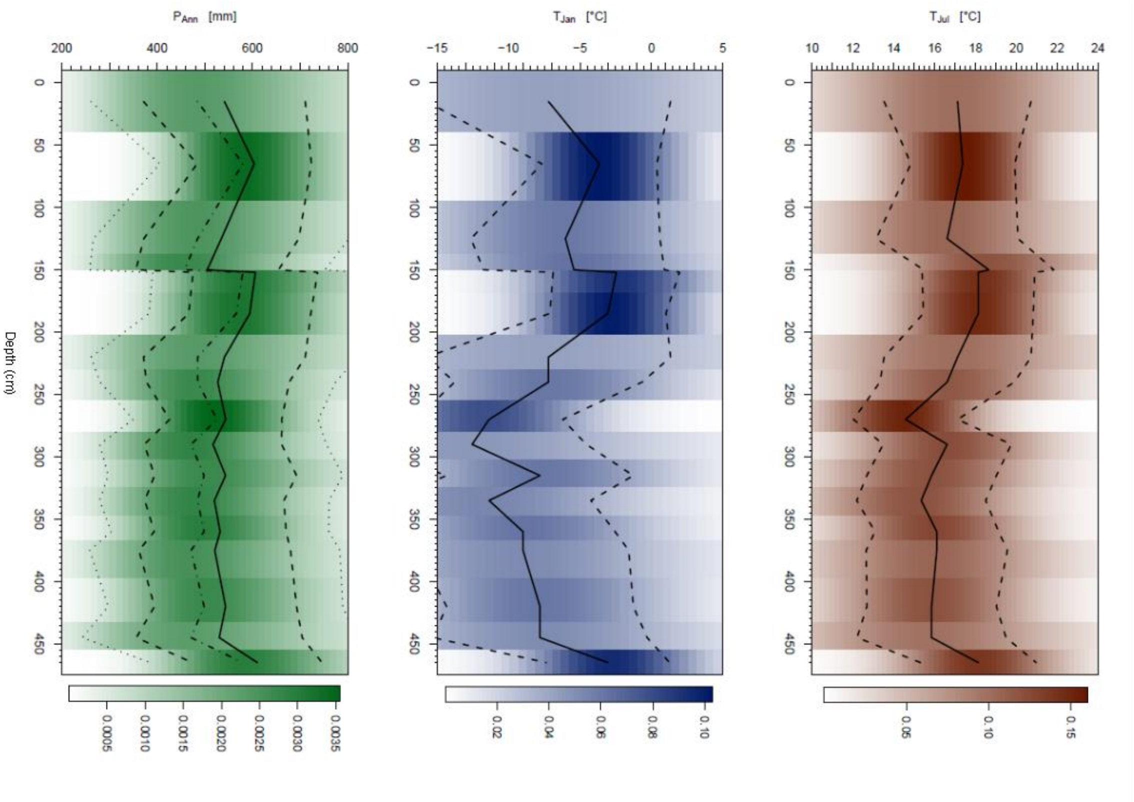


Fig 64: Reconstructed January and July mean temperatures, and annual precipitation for Elveden. Intensity of colours refers to the probability density of reconstructed climate, the mean (solid line) and 1 sigma (dashed). Precipitation also shows 2 sigma (dotted) and the maximum of the pdf (dash dot).

Finally, the brief record from Elveden, from the early period of the interglacial (HO I into Ho IIa) shows a general pattern of warming. The base of the sequence is distinctly colder in both summer and winter, winter in particular. Generally winter temperatures are cold, reaching down to -10ºC and never getting above -5ºC. Summer eventually reaches temperatures of around 17ºC and precipitation is consistently below 600 mm. Conditions were therefore generally cool in summer, cold in winter and relatively dry for much of the interval recorded at Elveden.

10.3 – Palaeoclimate results summary table

The following table presents a written summary of the results presented above, enabling the comparison of the climatic conditions at different sites during different pollen zones. It can be difficult to produce a representative temperature for a particular time period. Moreover there may be periods where variability is particularly high, meaning that not every shift in climate can be captured in a summary. Any trends that are clear and emerge from this variability are recorded and changes in low variances curves, such as Athelington, are more likely to be noted in the table than those at a much more variable locality like Quinton.

Pollen Zone		Athelington	Barford	Hoxne	Marks Tey	Nechells	Quinton	St Cross	Summary
Glacial	Winter temp	-	-	-	-12	-6 at least, down to -12	-8 at least, likely lower but uncertain	-	Between -6 and -12, likely closer to -12
	Summer temp	-	-	-	15	Varies between 17 and 14	15.5 rising to 17	-	Between 15 and 17
	Precipitation	-	-	-	510	520	520	-	Between 510 and 520
Ho I	Winter temp	-5 falling to -7.5, rising to -7	-	-1.5 falling to -6	Oscillates between -5 and down to -15	Varies between -4 and -10	-8	-7	Significant range, possibly closer to -7
	Summer temp	17.5 rising to 18	-	17.75	15 rising to 17. Oscillates down to 15.	Varies between 15 and 17	17	17, possible rise	Between 15 and 17, likely closer to 17
	Precipitation	580 falling to 540, rising to 560	-	560	Variable, around 540	Varies between 520 and 580	520	580	Between 520 and 580, likely closer to 580
Ho IIa	Winter temp	-7 rising to -2	-	Variable, between -4 & -8. No clear trend	-7 rising to -6	-4 rising to -2.5	-8 rising to -4.5. Variable.	-7, rise to -4.5	Likely rise from -7 to between -4.5 and -2
	Summer temp	18 falling to 16.5, rising to 17	-	Varies 18 to 16.5	16.5	15 rising to 17	17 rising to 17.25	17	Likely between 17 and 18

Pollen Zone		Athelington	Barford	Hoxne	Marks Tey	Nechells	Quinton	St Cross	Summary
	Precipitation	560 rising to 620	-	580, rising to 600, variable	540 rising to 560	580	520 rising to 540	580 rising to 600	Likely rise from 560/580 to 600
Ho IIb	Winter temp	-2 falling to -5, rising to -4.5	-	Variable, between -4 to -8. No clear trend.	-6 rising to -2.5	-2 rising to 0, abrupt fall to -3	-4.5 rising to 0	-4.5 rising to -2	Between -4.5 and -2.
	Summer temp	17 rising to 17.5, falling to 17	-	17	16.5	Varies around 17	17.25 rising to 17.5	17	Around 17
	Precipitation	620 falling to 580, rising to 600	-	580	560 rising to 600	600	540 rising to 600	600 rising to 620	Around 600, possible rising trend
Ho IIc	Winter temp	-4.5 rising to -3	-2.5, fall at end to -3, rise to -2.4	Variable, suggestion of trend from -5 to -2.5 falling to -4	-2.5. Zone ended by abrupt oscillation to -6	Variable around -3	0 falling to -1. Variable	-2. Abrupt fall to -5 at end of zone, rise to -1 then return to -2	Likely somewhere between -4 and -1
	Summer temp	17	17, fall to 16, recover to 17	16.5, variability up to 18	16.5	17	17.5	17	Around 17
	Precipitation	600 rising to 610	500	Variable, suggestion of rise from 590 to 620	600, oscillation at end to 560	600	600	620. Abrupt fall to 580 at end	Around 600
Ho IIIa	Winter temp	-3	-2.5	-4 falling to -6.5	-2.5	Variable around -3	-1 falling to -5	-	Wide range, between -

Pollen Zone		Athelington	Barford	Hoxne	Marks Tey	Nechells	Quinton	St Cross	Summary
									6.5 and -1
	Summer temp	17 falling to 16.75	17	17, fall to 16, then 17	17	Rises to 17.5, falls to 17	17.5 falling to 17	-	Around 17, suggestion of falling temp
	Precipitation	610 rising to 620	500	620 fall to 570	600	600	600, abrupt fall to 570	-	Around 600, possible fall
Ho IIIb	Winter temp	-3 falling to -5	-2.5 fall to -4, rising to -2.5	-	-2.5, falling to -5, rising to 0. Final fall to -1.5	-3 fall to -5, rise to -3	Variable, around -5	-	Likely between -5 and -2.5
	Summer temp	16.75 rising to 17.25, late fall to 16.75	17	-	17 rising to 18, falling to 17.75	17 falls to 16	17 falling to 16	-	Around 17, possible fall
	Precipitation	620 rising to 630, falling to 600	500	-	600, falling to 580, rise to 620, fall to 600	600	570	-	Variable around 600
Ho IVa	Winter temp	-5 falling to -8, rise to -1.5, falling to -4	-	-	Variable. -1.5 falling to -7	-3 fall to -8, finishes -5	Highly variable, around -5/-6	-	Likely between -3 and -5
	Summer temp	16.75 falling to 15.5, rising to 17.75, falling to 17.25	-	-	17.75, fall at end to 16	16 falling to 15.5	Variable around 16	-	Between 16 and 17
	Precipitation	600 falling to 580, rising to 620, then falls	-	-	600 falling to 560	600	Variable around 570	-	Falling from 600 to 560/570

Pollen Zone		Athelington	Barford	Hoxne	Marks Tey	Nechells	Quinton	St Cross	Summary
		slightly							
Ho IVb	Winter temp	-	-	-	Variably, around -7	-	-7, rising to -4, abrupt fall to -10	-	Around -7
	Summer temp	-	-	-	16 falling to 15.5	-	16 rising to 17, abrupt fall to 15.5	-	Likely between 16 and 15
	Precipitation	-	-	-	560	-	570, rising to 620, abrupt fall to 550	-	Around 560/570
Glacial	Winter temp	-	-	-	-7 falling to -9	-	Around -10	-	Becoming close to -10
	Summer temp	-	-	-	15.5 falling to 14.75	-	15.5	-	Around 15
	Precipitation	-	-	-	560	-	540	-	Around 54-/560

Table 17 : summarising Hoxnian interglacial climates from the sites reconstructed in the present thesis

11 – Critical discussion of palaeoclimate reconstructions

This chapter will provide critical discussion of proxy palaeoclimate reconstructions, both methods in general and the specific results presented in this thesis. This chapter will begin with a discussion of important conceptual issues.

11.1 – Conceptual issues in proxy palaeoclimate reconstruction

11.1.1 – The uniformitarian assumption in climate reconstruction

One of the fundamental underlying principles in palaeoclimate research is one that underlies many geological endeavours but is not always subjected to appropriate critical scrutiny; the uniformitarian assumption. The reconstruction of palaeoclimate here and in other studies simply would not be possible without assuming that the relationship between modern day vegetation (or indeed any proxy) distribution and climate also applies in the past. However, is this assumption valid?

Workers in this field are clearly aware of the assumption and regularly make it explicit in their papers, however it is less common for its validity to be explored. In a wider sense, the tenability of the uniformitarian framework has been much discussed; in a practical sense, the occurrence of processes not operating today is now widely acknowledged, with the Channelled Scablands being a classic example (Baker, 2009), and in a philosophical sense, the concept has been much discussed (e.g. Gould, 1987).

Modern geology in general takes a mature approach to the uniformitarian concept, but there are areas where it is has tended to go unexplored. Palaeoclimate reconstructions are one such example, most probably because making the assumption ultimately leads to some very valuable techniques and workers and naturally eager to exploit them. Furthermore, it is actually an extremely difficult concept to test. Happily, this situation is now changing with the advent of ancient DNA reconstruction, making it possible to get more direct insights into the biology of fossil flora.

The recovery of ancient DNA is now a relatively widely used approach (Willerslev and Cooper, 2005), but its application to plants has been limited. Furthermore, the relevance of ancient DNA for the fundamentals of palaeoclimate reconstruction has barely been explored. Indeed, in describing the method adopted in this thesis, Kuhl *et al.* (2002) is one of the rare examples.

Kuhl *et al.* (2002) notes that Suyama *et al*. (1996), in one of the pioneering examples of ancient plant DNA sampling, report few DNA changes in *Abies* during the past 150,000 years. This engenders confidence in the uniformitarian assumption and is indeed encouraging. However, it would be more satisfying to have further examples and since 2002, this has slowly become possible. Over a shorter timescale, the past 10,000 years, Bennett and Parducci (2006) report finding genetic continuity between Scots pine samples from Sweden.

Kuhl *et al.* (2002) qualifies the uniformitarian argument by not simply stating that the climate tolerances of vegetation should be the same, but also that no evolution should have taken place. This is unreasonable, as only evolution related to climate is the relevant factor, and some degree of evolutionary change is likely to have occurred (evolution being defined as change in gene frequencies in a population over time). In small populations in particular, genetic drift is likely to have been operating over the Pleistocene.

However, changing climatic tolerances is likely to be an adaptive phenomenon and so drift is not something to be unduly concerned about. Seeking the occurrence of climate adaptation by vegetation during the Pleistocene comes with limitations, related to wider debates within evolutionary biology. Whilst many researchers look for signals of positive Darwinian selection (i.e. adaptation), it is becoming increasingly clear that many of the statistical methods used are flawed (e.g. Nozawa *et al*., 2009).

A further complication in this debate is the consideration of methodological limitations to ancient DNA sampling. The danger of modern DNA contamination is the main logistical challenge posed in ancient DNA research. The Neanderthal mitochondrial and upcoming nuclear genomes have had to be rigorously processed and have been subject to questions regarding contamination (e.g. Wall and Kim, 2007). This issue is recognised by those working on ancient plant DNA (e.g. Gugerli *et al.*, 2005) and there are no specific examples where contamination has been detected. However, given the problems reported in other areas of ancient DNA research, it is appropriate to be conservative at this stage.

Kuhl and Gobet (2010) consider an additional theoretical perspective, pointing to the work of Willis and Niklas (2004). These authors note a generally complex floristic response to Quaternary environmental changes. However, as a general rule, evolution does not appear to have occurred; rather extinction has been the predominant response, which does not particularly appear to concern us here (Type X excepted). On a basic level, a pattern of expansion and contraction out of glacial refugia was the typical behaviour of plant populations. The core areas remained relatively stable, not promoting genetic change (Kuhl and Gobet, 2010).

From a methodological standpoint there are reasons to believe that any evolution that may have occurred should not pose a particular problem for the reliability of the reconstructions. Kuhl and Gobet (2010) note that in contrast to traditional indicator species approaches, the *pdf* methodology is not particularly susceptible to the influence of climatic limits of species. This is because the complete distribution area forms the basis of the pdf, rather than focusing on the climatic limit of a taxa. This means that even if evolution has taken place, shifts in the climatic niche should not be unduly felt.

Are there other ways that we can test the uniformitarian assumption? Davis *et al.* (2005) provide one possible perspective and are some of the relatively few authors who consider the implications of Pleistocene evolution for the inferences (not just regarding climate) made by palaeoecologists. Davis *et al.* (2005) draw their data from Prentice *et al.* (1991), which incorporated a prediction of fossil pollen distribution in eastern North America, from climate model output, using modern pollen – climate transfer functions.

Encouragingly, and in a fine example of hypothesis testing, the predictions matched the data well at various intervals of time over the last 24,000 years. This provides confidence that the relationship between pollen and climate hasn’t changed over this time period. However, there was a qualifier to this; the predicted distribution of *Picea* was less than that observed, possibly suggesting a wider tolerance for the genus in the past. Davis *et al*. (2005) argue that this is due to the wide distribution of an extinct species of spruce, *Picea critchfieldii* in these particular palaeo records. Aside from Type X, which is not incorporated in the reconstructions presented here, there are no known extinct species in the British Pleistocene record, so this particular problem is sidestepped. However, it does serve a cautionary purpose.

An additional test can be performed by comparing the output from a given reconstruction with one performed by an independent technique. If changing climatic tolerances were a problem, it is unlikely that independent methods would produce consistent results. The Krakenes project is one such example, where various different proxies (such as pollen and chironomids) produced a largely coherent pattern of temperature change during the late glacial (Birks *et al*., 2000). However, the late glacial, may not be of sufficient time depth for major evolutionary events to have occurred.

Further back into the Pleistocene, research in the Eemian provides another independent test of a pollen based technique. Boettger *et al*. (2000) provide stable isotope data from German sites which demonstrates a relatively stable climate during the Eemian. Subsequently, the method employed in this thesis was applied to the same site to provide a similar result (Kuhl and Litt, 2003). There is no way of using the stable isotope data to independently verify the precise temperatures reconstructed by Kuhl and Litt (2003), but the agreement over trends is extremely encouraging. The use of multiproxy studies will be further discussed below.

Ultimately, it is not possible to conduct an in depth assessment of the validity of the uniformitarian perspective; the data is not yet available. It is certainly likely that the evolutionary history of flora during the Pleistocene is more dynamic than perhaps some palaeo-workers have appreciated. However, there are encouraging signs that the assumption can be applied and given the widespread use of it within the Quaternary community (not just pollen), it seems appropriate to adopt it in this study.

11.1.2 Fundamental ecological considerations

A further conceptual issue to which we can ascertain greater certainty surrounds the fundamental ecological principles that underlie the reconstruction method of choice. In ecological thinking, there has been considerable historical debate regarding the basic nature of community structure. The debate can be divided into two opposing models, both developed by early 20th century American ecologists; Henry Gleason and Frederic Clements. Clements (1916) essentially viewed communities as superorganisms, with the individual components being tightly integrated. Conversely, Gleason (1917) saw communities as composed of species behaving individualistically, being grouped together at a given time because of the particular constraints of the environment. Ultimately the Gleasonian perspective became favoured, a fact recognised in undergraduate level ecology text books (e.g. Morin 1999). It therefore makes basic ecological sense to avoid community based palaeoenvironmental reconstructions, in favour of an individualistic, presence absence, approach, as adopted here.

An additional factor in favour of the presence/absence approach also derives from fundamental ecological principles, or rather the somewhat perplexing lack of them. Despite reference to the adoption of a generally Gleasonian perspective, it is also true to say that ecology has struggled to find general, overarching, rules and principles. A classic example of this is the intermediate disturbance hypothesis (Connell, 1978), which predicts the highest levels of community diversity in response to intermediate levels of abiotic disturbance. It is an extremely elegant and appealing theory and is successful in a number of respects; however, there are many exceptions and complications to this proposed rule (e.g. Bongers *et al*., 2009) and, whilst still useful, is unsatisfactorily oversimplified (e.g. Sheil and Burslem, 2003).

The problems inherent in ecological generalisation make it appropriate that a more parsimonious reconstruction method is adopted. This minimises the risk of error being introduced by inappropriate theoretical principles. A presence or absence based technique is simpler and therefore better suited to navigating through the maze of ecological fuzziness. Ultimately the basis of proxy based reconstructions is a biological and ecological one. It is therefore essential that the method chosen conforms to key principles and recognises the complexities of ecology as a science.

The results of the pollen modelling performed in this research also make a strong case for the use of a presence – absence methodology. The experiments demonstrated that there is no clear and simple relationship between the percentages and proportions of pollen preserved in a sample and the percentages and proportions in the ecosystem surrounding the sampling point. Presence – absence sidesteps these important issues and avoids many of the biases that are inherent in pollen diagrams as a result of the vagaries of pollen production.

It is worth stressing at this stage that the community based approaches are cannot be simply dismissed. Indeed to do so would be to do without a significant contribution to Quaternary Sciences. It is not just pollen based proxy methods that have this basis, a number of other valuable sources of data do too; many palaeoceanography studies rely on this approach for example (e.g. Imbrie and Kipp, 1971).

11.1.3 – Site selection

An underappreciated aspect of quantitative palaeoclimate reconstruction concerns site selection and sampling issues. Here we can use the pollen theory described in Chapter 3 to help illuminate a fundamental but often overlooked aspect of proxy reconstructions. We are therefore bringing together two of the most important new developments in palynology in recent years.

In proxy reconstruction, considerable discussion of the complex statistical basis of the various methodologies has taken place. However, recent advances in our understanding of the taphonomic processes associated with pollen deposition have not been incorporated into these discussions. The underlying pollen signal is fundamental to the reconstructions, therefore it is important that these developments are used where appropriate.

One of the most crucial aspects of this is the spatial representation of the site in question. An individual locality will preserve evidence of a given climate regime, but will also be subject to local microclimatic factors when what is really desired is the reconstruction of regional climate and the significant trends. Focusing on a site that records a local vegetation signal will mean that the vegetation – climate relationship may be dominated by local climate and short term noise, in addition to the complexities of local ecological processes and so may not produce a meaningful reconstruction. One possible solution is to sample many such sites over a given area and then extract the overall trends. However this may be time consuming and resource heavy, although potentially workable for the Holocene where there is a large existing data set. Even then, there will be uncertainty introduced by the correlation of separate sites. For pre-Holocene periods, when there is a limited availability of localities, the aggregation of multiple records is rarely possible. Therefore sites have to be chosen on the basis of their ability to reconstruct broad regional patterns of vegetation, which will produce a much stronger relationship with climate.

In his recent simulation studies, Sugita (2007) performed three sensitivity analyses to elucidate the impact of basin size, at the following radii; 20 m (0.13 ha), 390 m (48 ha) and 750 m (177 ha). 48 hectares and above is defined as a “large lake”. “Large lakes” are those that reflect regional vegetation composition and Hoxne likely comes close to this size. It is important to recognise that Hoxnian basins are not as well constrained physically as those in the Holocene. At Hoxne, using stratigraphic evidence from boreholes and also taking into consideration the topography of the site, West (1956) was able to provide a reconstruction of the lake. For around 30% of the lake edge, its margin can be placed with a reasonable degree of confidence and for the rest, the position remains more uncertain. The degree of error in the latter case is likely to be on the metres scale; anything more than this would be inconsistent with the general topography (Hoxne is a kettle hole) and the areas that can be reconstructed with confidence. So the degree of uncertainty is likely to be relatively small.

Taking another site by way of example, Athelington is much more difficult to judge than Hoxne. Coxon (1985) published a small reconstruction of the extent of the lake basin, with an approximate diameter of 200 metres. This would put it below the “large lake” threshold, although still substantially above the 0.13 ha size, which records local vegetation only. However, there is actually little basis for constraining the basin in this way. Coxon (1985) drilled only a limited number of boreholes and this data was insufficient for a full basin reconstruction.

Athelington is an old brick pit and the suspicion is that Coxon (1985) was guided by the dimensions of the pit working than any real assessment of the scale of the basin. This means that there is considerable uncertainty surrounding the extent of the Athelington lake basin. The boreholes and screw augurs put down by Coxon (1985) do hint at a minimum size of at least 100 m diameter, again larger than the 0.13 ha minimum of Sugita (2007). It may be that the lake was somewhat larger than this but anything beyond these minimum dimensions is speculation. In correlation with the deposits at Marks Tey, Coxon (1985) notes a number of similarities between the vegetation records. Encouragingly, this suggests that, despite the uncertainties introduced, there is the record of a regional vegetation cover preserved in the Athelington deposits.

It is also worth noting that the theoretical studies that constrain the representativeness of basin size do allow for a certain degree of uncertainty. Nielsen and Sugita (2005) evaluate the impact of various parameters on RSAP, with basin size being kept ‘constant.’ In this case, constant actually refers to lakes with radii varying from 106 m to 293 m, a range that easily envelops the uncertainty in reconstructing Hoxnian basins. Such a range is an acceptable site selection strategy to “minimize the effect of basin size on pollen source area” (Nielsen and Sugita, 2005).

In Sugita’s (2007) recent sensitivity studies, there is very little difference in the results between 48 and 177 hectare lakes, in contrast with the sharp differences between 0.13 hectares and 48. It is clear that at a certain point, increasingly larger basins add little regional representativeness, but it is not entirely clear where this point is. There is a considerable size range between 0.13 ha and 48 ha and it seems plausible somewhat smaller lakes than 48 ha may be similarly representative of the large scale, possibly introducing an additional allowance of uncertainty. Further tests are required to more precisely define a “large lake”. Sugita (2007) recognises that this definition of a “large lake” may be somewhat impractical and suggests that, if a 48 ha lake is unavailable, then palynologists need to select larger sized lakes where possible and, if available, add additional lakes.

11.1.4 – Bayesian vs. frequentist methodologies

An important aspect for discussion concerns the statistical framework underlying the quantitative reconstruction. The methodology developed by Kuhl *et al.* (2002) can be described as Bayesian, an approach which is increasingly being used in palaeo-disciplines. The adoption of Bayesian frameworks is not entirely recent; Van Deusen and Reams (1996) applied Bayesian procedures to palaeoclimate reconstructions based on tree ring data. However, it has become much more common in the past decade. Much of this increased application was spurred by developments in archaeology and chronology construction, in particular by Buck and colleagues (Buck *et al*., 1991), and it is now a key component in the development of calibration curves (Reimer *et al*., 2004) in addition to the production of individual site chronologies (Blockley *et al*., 2004).

A large part of the attraction for chronologists is the ability of Bayesian methodologies to rigorously deal with uncertainty. It is this property that also makes it appropriate for use in palaeoclimate reconstruction, though there are still relatively few cases where it has been used. The Bayesian approach is not restricted to any particular modelling strategy; it spans the divide between approaches such as indicator species or modern analogue. For example, Haslett *et al*. (2006) apply it to a modern analogue technique. Haslett *et al*. (2006) are particularly concerned with the issue of uncertainty, noting that one of the most significant concern underlying proxy based reconstructions is the reliable and realistic modelling of the uncertainty with which a particular climate variable is reconstructed. In the Bayesian paradigm, uncertainty is explicitly modelled (Toivonen *et al*., 2001).

Toivonen *et al*. (2001) discuss how this uncertainty tends to be introduced into reconstructions in three ways. Firstly, nature is inherently stochastic. When researchers have performed the calibrations between proxy data and the reconstruction variable of interested, they have done this stochastically, to reflect nature’s stochasticity. This is not unreasonable, but it does introduce uncertainty. Secondly, the data itself is subject to all of the biases and problems that arises during data collection. This means that the data itself is fundamentally stochastic. Thirdly, and somewhat philosophically, all statistical constructs can ever do is produce a working model of reality. Our understanding of nature is always provisional and therefore our models are only ever works in progress at best. This imperfect reflection of reality will always introduce uncertainty. Despite all of this, Haslett *et al*. (2006) point out that no methodologies based on frequentist statistics actually model uncertainty. A Bayesian approach is well suited to this task and to the development of palaeoclimate records in which uncertainty is clarified.

The rigorous treatment of uncertainty has clear importance, both in the restricted sense that the user is aware of the limitations of their own data set but also in the wider applications of such data. Using data gathered from MIS11 to place the modern climate debate into context is one of the possibilities with quantified proxy data; clearly this will be more substantive if uncertainty is well understood. One of the most important modern usages of palaeoclimate data is the testing of climate model output (e.g. Kageyama *et al*., 2006). This is not simply a matter of eyeballing the respective sets of data; a rigorously mathematical comparison ought to be performed. Again, this will have greater value if the uncertainty is properly appreciated. Interestingly, climate model users are now also adopting Bayesian methodologies in their simulations (Annan and Hargreaves, 2006).

Korhola *et al*. (2002) provide further discussion on the advantages of the Bayesian approach. They cite, for example, the fact that ecological information can be incorporated into the models in mathematically consistent and elegant ways. However, it is the issue of uncertainty that is crucial and important to draw attention to. Korhola *et al*. (2002) have further information on the relative merits of the frequentist vs. Bayesian approaches.

As Kuhl and Gobet (2010) note, the *pdf* method explicitly calculates uncertainty. In this instance uncertainty in the reconstructed climate depends on the climatic distribution of the taxa present. Different taxa fill different climate spaces and some more or less narrowly than others. If the reconstruction features taxa with broad ranges then the climate reconstruction will have a larger uncertainty (Kuhl and Gobet, 2010). This is incorporated as a fundamental part of the reconstruction.

11.1.5 – Multiproxy studies as a test of proxy reliability

Huntley (2012) provides a critical look at a number of aspects of proxy palaeoclimate reconstruction. Huntley’s paper is particularly exciting because it illuminates certain factors that may be important but are rarely considered. Many of the typical critical looks at proxy reconstructions provide valuable looks at the statistical methodologies employed (e.g. Telford and Birks, 2005). However, Huntley provides a critical look from a biological perspective and is one of the most significant discussions of reconstruction methods in recent years. This makes it appropriate to use as a base for a wider discussion about the use of multiproxy studies as an important sense check on the information provided by quantitative palaeoclimate approaches.

The value of Huntley’s (2012) approach is that it reminds us that despite the statistical methods that may be applied to proxy data, ultimately the reconstructions will only be as good as the underlying biological data and assumptions. Many biological factors are considered by researchers in this area. For example, Willis *et al.* (1997) considered whether there is in fact a greater role for soil formation in observed vegetation development, potentially making it of similar importance to climatic forcing. They were able to conclude that in fact, over longer time periods, climate drives vegetation change which then drives soil development. This is the kind of crucial biological testing of our assumptions that is necessary but, as Huntley (2012) points out, is sometimes neglected.

Huntley raises a series of very important points and anyone engaged in palaeoclimate reconstructions on the basis of proxy evidence is obliged to take them extremely seriously. Moreover, other criticisms levelled by authors such as Telford and Birks (2005) are important reminders to continually view proxy reconstructions with a critical perspective.

There is a sense that some of Huntley’s points, while useful, are not fully developed into a coherent statement regarding the ultimate impact on a reconstruction. In some cases, a point is raised for consideration but this is not always followed through into concrete examples about what this may mean in terms of the end result. Does this issue lead to greater uncertainty or fundamental conceptual flaws for example? In other words, what is the impact in practice not theory?

This issue can be illustrated through Huntley's (2012) interesting distinction between microclimate and macroclimate and whether or not a proxy responds more strongly to one or the other. Microclimate is defined as "the climate near the ground and being characterised by spatial patterns at scales of 10^{-6} to 10^{-0} km." Huntley observes that many species respond strongly to microclimatic variables, with microclimate playing an important role in determining distribution for a number of species (Suggitt *et al.*, 2011).

In particular, beetles are likely to experience microclimate rather than meso or macroclimate. This issue is unlikely to affect the reconstructions provided here; other than low growing arctic species, vegetation does not respond strongly to microclimate (Huntley, 2012). Nevertheless, we can use this as an illustrative example of the impact of some of the issues Huntley raises on the final conclusions that may be derived from proxy palaeoclimate reconstructions. Beetles may experience microclimatic conditions, but how does this translate into the end result?

This is not to say that there are not methodological issues that apply to the MCR reconstructions. For example, Bray *et al.* (2006) argue that beetles are unlikely to be normally distributed in climate space, an important assumption underlying the original methodology (Atkinson *et al.*, 1987). Addressing these sorts of fundamental statistical issues is crucial to developing more robust quantitative interpretations of past climate.

It will also be argued here that the use of multiproxy studies provides an important test that demonstrates that palaeoclimate reconstructions are, by and large, successful. The discussion above, concerning uniformitarian assumptions has already mentioned the Krakenes project (Birks *et al.*, 2000) and the Eemian comparison between pollen and stable isotopes (Kuhl and Litt, 2003). A recent study (Axford *et al.*, 2011) set out to specifically test the coherence between a range of proxies, from different archives in the Arctic. There was strong correlation between them and an accurate reflection of regional climate.

Ammann *et al.* (2000) present a summary of Late Glacial sequences in Switzerland, at a number of sites, principally Gerzensee and Leysin, covering multiple proxies. There is strong coherence between them, even though they reflect different aspects of the climate system, and, excitingly, this agreement persists through rapid climate change. More recent work at Gerzensee (Lotter *et al.*, 2012) has continued the theme of proxy agreement, although there are some differences between pollen and chironomids, reflecting the need to always recognise that proxies respond in their own unique ways to forcing and may have different sensitivities. The Krakenes project (Birks *et al.*, 2000) is another strong example of multiproxy coherence.

Huntley (2012) briefly covers multiproxy studies and raises the point that the different proxies should ultimately be comparing appropriate variables. Given the frequent coherence between proxies that is observed, it would have been useful for Huntley (2012) to have provided the greater context that multiproxy studies afford and used that as a basis for assessing the actual impact of the issues that he raises. He does mention a small number of instances where disagreement was observed (e.g. Walker *et al.*, 1993), which is a somewhat partial presentation of the overall pattern.

We can also compare the same proxy but different methodologies. Such a comparison was undertaken by Kuhl *et al.* (2010) for a Holocene sequence in Germany between the *pdf* method and a modern analogue approach. Good agreement between the two approaches was observed. It should, however, be noted that in Kuhl and Litt (2003) a similar comparison was made, showing disagreement stemming from non-analogue vegetation during the Eemian, which provides strong support for the methodology adopted here.

A particularly significant recent comparison between proxies was undertaken by Helama *et al.* (2010) comparing reconstructions over the last millennium in Fennoscandia from both pollen and tree rings. Typically, pollen is thought of as being best suited to the reconstruction of low frequency variability, whereas tree rings pick up high frequency variance while there is uncertainty at low frequencies. However, Helama *et al.* (2010) not only show that both records are in good agreement, a significant result on its own, they also demonstrate that pollen is able to replicate high frequency variability. This is a hugely encouraging finding and provides us with confidence that pollen based climate reconstructions are able to accurately detect short term and abrupt changes in climate.

Ultimately, while Huntley (2012) raises some hugely important points and will undoubtedly help assist in the continued development of improved proxy reconstruction, to some extent there is a sense that the bigger picture is being missed. In certain respects, this is reminiscent of recent extremely controversial debates surrounding climate variability during the last millennium. Mann *et al.* (1998) provided a tree ring based reconstruction of temperature for the past 600 years that showed abnormally high temperatures in recent decades.

The Mann *et al.* (1998) conclusions and methodologies came under sustained attack and flaws in the work have been identified (e.g. von Storch and Zorita, 2004). However, the IPCC (2007) presented a synthesis of available reconstructions, using a range of proxies, not just tree rings, stating that "on the evidence of the previous and four new reconstructions that reach back more than 1 kyr, it is likely that the 20th century was the warmest in at least the past 1.3 kyr."

Particularly encouraging is the agreement that can be found with glacial records, a proxy that has no common underlying control other than climate. Oerlemans (2005) related changes in glacier length to climate and from this was able to derive a temperature reconstruction from a large number of glaciers, widely distributed across the planet. The fact that an almost entirely unrelated proxy, representing a wholly different part of the earth system, reaches similar conclusions is strong evidence that the fundamental conclusion reached is robust.

This is not to give the impression that all critiques of palaeoreconstruction are ultimately unimportant. This is certainly not the case; in particular, the work of Telford and Birks has been offered a number of significant constructive statistical critiques (e.g. Telford and Birks, 2005) and recommendations (e.g. Telford and Birks, 2011). However, ultimately the broad degree of coherence observed is hugely encouraging.

That said, the move from coherence where the bigger picture is concerned to testing precise hypotheses, reconstructing individual events or truly understanding the exact nature of variability, may be complicated. These are relevant issues for the reconstructions presented here and can once again be illustrated by the Mann *et al.* (1998) controversy. As demonstrated above, the fundamental conclusion reached by these authors appears to have been borne out. However, subsequent studies have demonstrated greater variability than was initially reconstructed. For example, Esper *et al.* (2002) reconstructed a warmer Mediaeval Warm Period than Mann *et al.* (1998) and then Moberg *et al.* (2005) showed generally greater variance, even arguing that it is only recent decades that appear to be unusual, not the whole of the 20th century.

Both of these points, greater variability and yet unusual recent warmth, can be illustrated in the following two figures. Fig 65 shows the original reconstruction (Mann *et al.*, 1998) and Fig 66 is a compilation of reconstructions as of 2008 (Mann *et al.*, 2008). The recent compilation shows that temperature fluctuated more significantly than was initially suggested, but that a “Hockey Stick” shape still remains despite this.

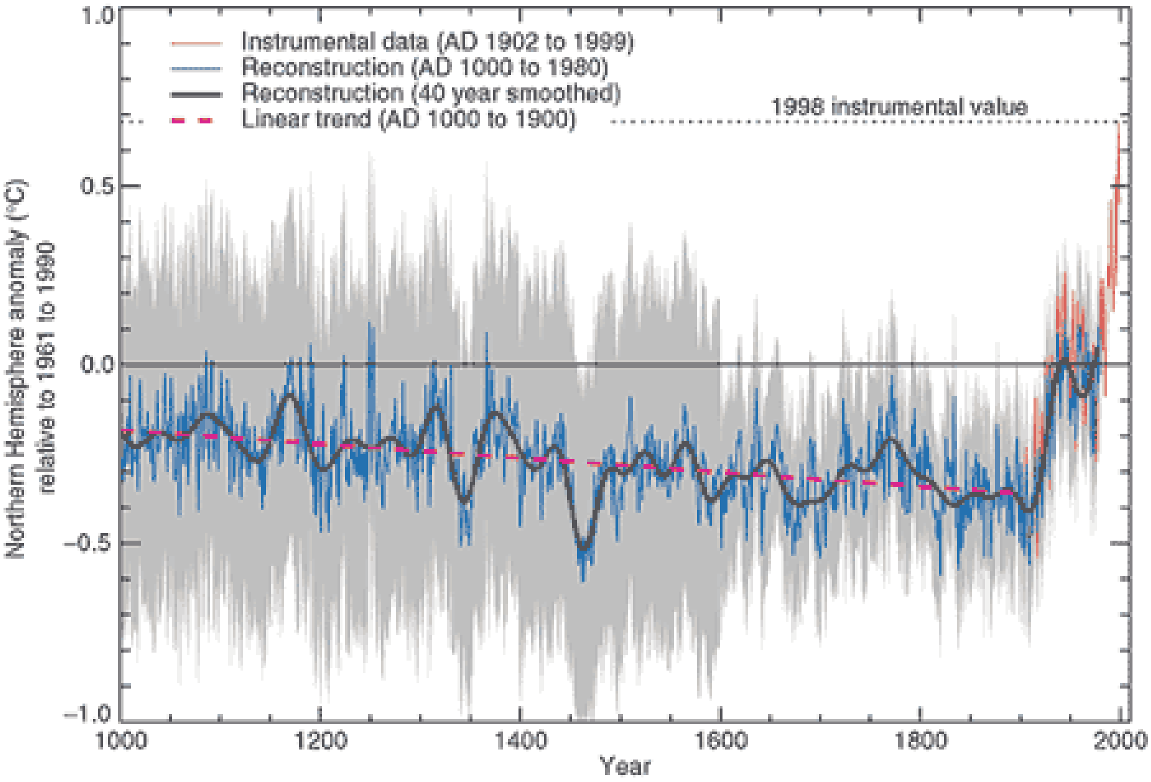


Fig 65: The original tree ring derived “hockey stick” from Mann *et al.* (1998)

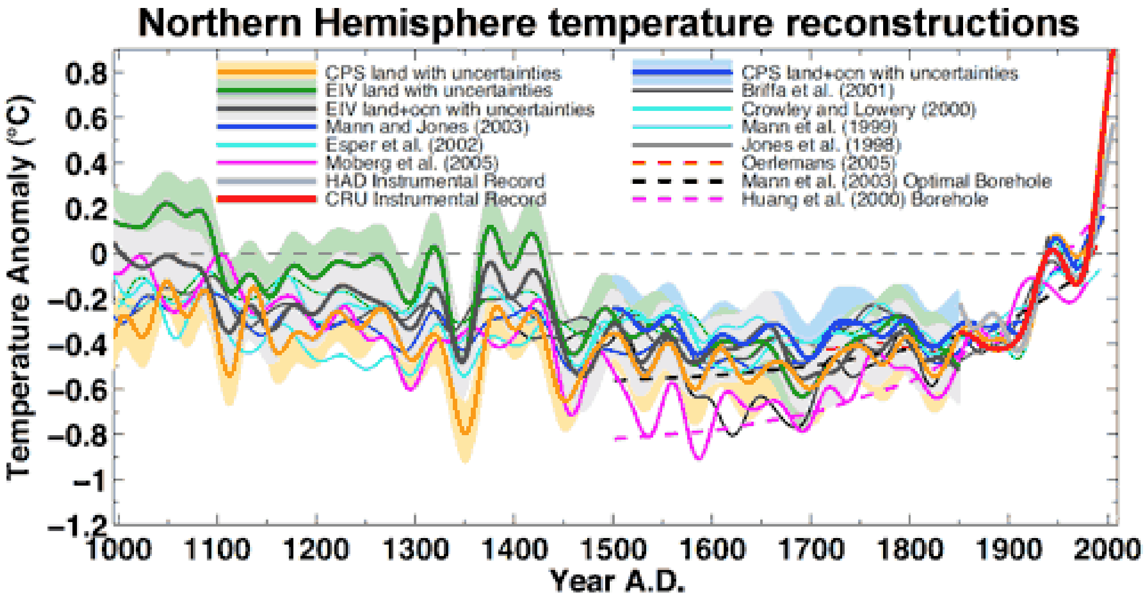


Fig 66: Northern hemisphere temperature reconstructions from a variety of proxies (Mann *et al.*, 2008).

Our understanding of variability in recent centuries is continually developing (e.g. Esper *et al.*, 2012) and we must always be aware of the uncertainty associated with biological proxies and the statistical methods used to transform them into a reflection of past climate. Nevertheless, the "Hockey Stick" debate provides a good example of how, despite all the associated complications, it does appear to be possible to use proxies to produce robust and reliable reconstructions of palaeoclimate.

11.2 – Evaluating the Hoxnian reconstructions

The following sections will provide a critical discussion of the results obtained in this thesis.

11.2.1 – Establishing the presence of a robust climate signal

The palaeoclimate reconstructions were subjected to a series of sensitivity tests. This testing process evaluated the impact of taxonomic precision, the use of a greater number of species, the imposition of thresholds and the impact a particular species may have on the final result. These are some of the crucial boundary conditions associated with the reconstructions and therefore experimenting with them is a powerful way to explore the limitations of this approach.

Generally speaking, the results of the sensitivity testing described in the previous chapter demonstrate that the reconstructions presented in this thesis are robust. There are differences that result from differing inputs, some important, which will be discussed below. However, fundamentally, the trends in palaeoclimate remain the same regardless of the approach taken. This gives us confidence that a meaningful and significant climate signal is being extracted from Hoxnian pollen data.

Additional confidence that the reconstructions are robust derives from the strong overall degree of similarity between them. This can be illustrated in Figs 67 to 69. Ultimately there is generally a small envelope in which reconstructed climate lies. This is particularly the case for summer temperature and precipitation and whilst there is greater divergence in winter there is nevertheless generally a coherent signal.

Figures 67-69 use the timescale derived from Marks Tey as an approximation for the chronology of this period. This will be discussed in further detail below. Two versions of the following diagrams will be presented. Ultimately they act as summaries of the data and will firstly be shown in an envelope to demonstrate the degree of coherence. Later they will be presented without, in order to aid interpretation of the climate signal they contain.

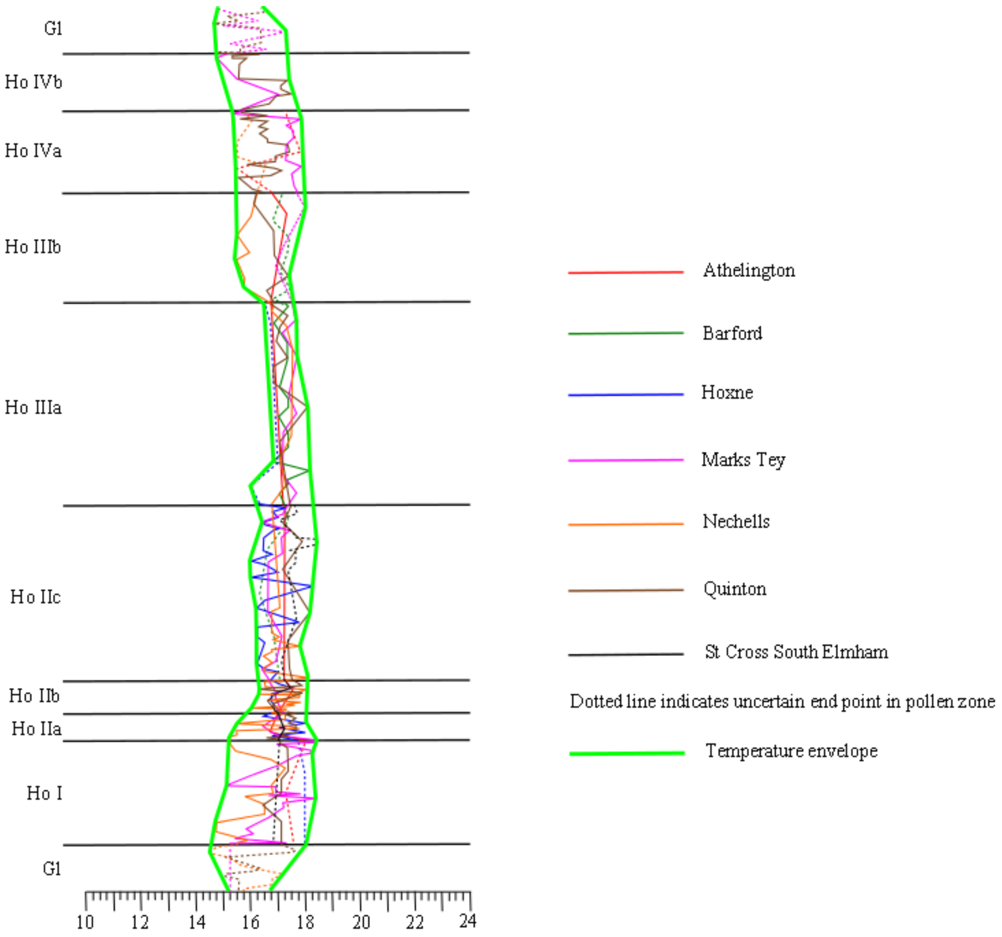


Fig 67: Range of reconstructed summer temperature during the Hoxnian. Dotted lines used to indicate an uncertain end point within a pollen zone, though the decision was taken for consistency to have records span the entirety of the zone in which they start and finish.

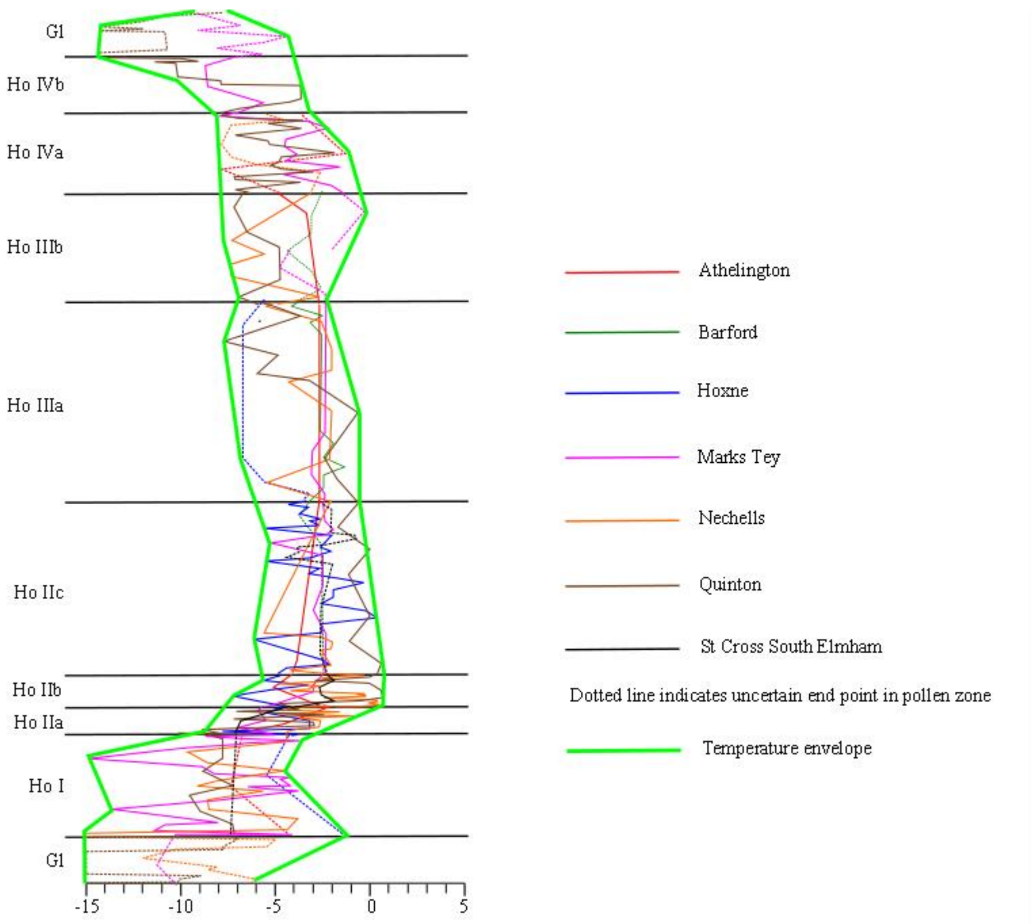


Fig 68: Range of reconstructed winter temperature during the Hoxnian. Dotted lines used to indicate an uncertain end point within a pollen zone, though the decision was taken for consistency to have records span the entirety of the zone in which they start and finish.

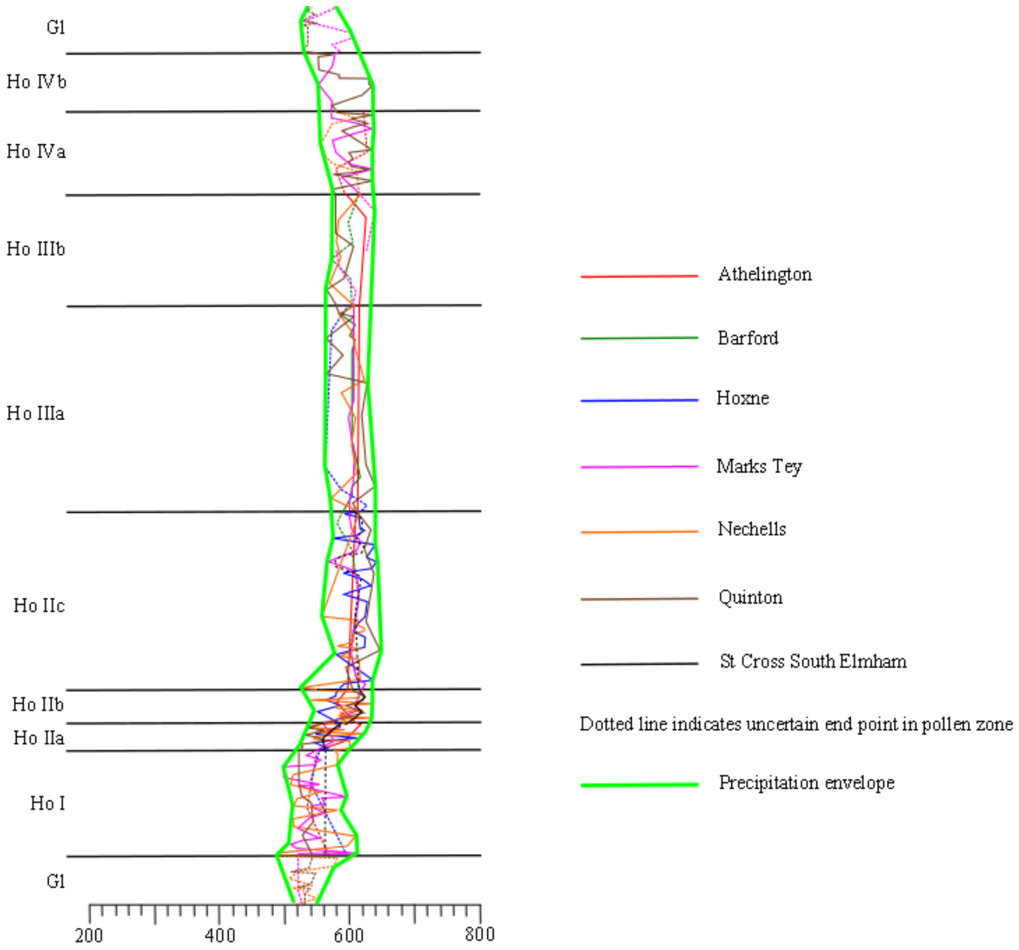


Fig 69: Range of reconstructed winter precipitation during the Hoxnian. Dotted lines used to indicate an uncertain end point within a pollen zone, though the decision was taken for consistency to have records span the entirety of the zone in which they start and finish.

The range of winter temperature is greater than that of summer and precipitation. Nevertheless it is clear that broadly speaking there is a consistent signal being replicated. This is highly encouraging and suggests that the reconstructions have integrity.

Returning back to the subject of uncertainty, the pdf method is also beneficial because not only does it present classic error bars, it also offers probability density. This gives an additional perspective to the interpretation of the reconstructions. Generally speaking, throughout the reconstructions, probability density is quite high although it is interesting to note a general trend whereby the beginning and end (i.e. colder phases) of the interglacial have lower values.

Quinton is a good example of this and it suggests a heightened degree of uncertainty in reconstructed climate during colder phases. This may relate to lower floristic diversity, as will be discussed below. Greater uncertainty through lower probability density under cold climates is also mirrored by the widening of error bars that is observed at this times. This adds an additional note of caution. Generally speaking, however, the error bars around the mean are relatively tight enabling us to be more certain regarding the integrity of observed trends.

11.2.2 – Comparison with other Hoxnian proxies

Ultimately it would be preferable to be able to compare to detailed records provided by other proxies, however the record provided by such proxies is currently patchy and therefore there will be a strong reliance on pollen based reconstructions. Nevertheless there are some alternatives that are available.

Coope (2010) presents a summary of coleopteran temperature inferences for British interglacials. In broad qualitative terms, Coope (2010) describes MIS 11 climate as being "not much different from today." A quantitative summary for the period is also presented, with July temperature during the "thermal maximum" (likely equivalent to Ho II) lying between 15 and 19˚C and January temperature between -10 and 6˚C. The results presented here are consistent with this, although it is questionable how informative such a large range for winter temperature really is.

Unpublished Chironomid estimates are available for Hoxne. These were undertaken by Steve Brooks according to the methods in Brooks and Birks (2003). For Stratum E two samples were taken and summer temperatures of 17.54 to 21.12˚C and 17.81 to 20.51˚C were recorded. This corresponds with Ho IIc temperatures and is slightly higher than the mean of the *pdf* at most sites for this time period (including Hoxne), which is around 17˚C.

The 1sd error overlaps with the lower part of the chironomid range and so the two results are not necessarily inconsistent. In addition, Horne (pers comm.) rounds these ranges down at the lower end and up at the top. Moreover, this represents just two samples and therefore it would not be advisable to place too greater emphasis on this comparison. Nevertheless, there is the suggestion from Stratum E that this proxy may reconstruct slightly higher summer temperatures than indicated by pollen.

In contrast, for Stratum C, summer temperatures recorded in pollen are not substantially lower than they are during the Hoxnian, being just over 16˚C. However, Chironomids indicate cool summers, with three samples recording, respectively, 12.5 to 14.76˚, 13.91 to 16.11˚C and 12.24 to 14.48˚C. Only the top range of one sample comes close to the pollen estimates. In this instance, there appears to be a stronger suggestion of a difference between the two proxies.

Ideally more chironomid work will be undertaken to provide a richer proxy data set. Despite the above observations, at this stage there is not sufficient evidence to make strong conclusions from this line of evidence, either about temperature or to provide illuminating context for pollen. This thesis has presented curves which ultimately represent hundreds of pollen based climate reconstructions. The small handful of other estimates need to be significantly expanded before particularly meaningful comparisons are possible.

The possibility that pollen reconstructions from Stratum C are not sufficiently cold is further supported by comparison with beetle data. Ashton *et al.* (2008) suggest temperature of 10ºC or below in summer and -15ºC in winter.

One possible explanation for the discrepancy in Stratum C reconstructions is the proposed occurrence of reworking. Reworking is believed to occur from the underlying Stratum D, which is represented in the diagrams presented here as Ho IIIa. The evidence has been based strongly on a supposed mismatch between the presence of thermophilous plants alongside macrofossil evidence for cold climate species. The latter are delicate and unlikely to survive reworking and therefore represent the in situ, representative flora and the warmer species must be reworked.

This argument is somewhat crude (for example, not taking into account species ranges or non-analogue situations) and is arguably a little circular. Nevertheless, it is quite commonly accepted. Few samples were taken from Ho IIIa, but the temperatures are arguably consistent with those observed in Stratum C, with winter below -5˚C and summer just above 16˚C. This lends support to the presence of a reworked component.

Reconstructions from other cold periods presented in this study demonstrate that the method is capable of returning very low temperatures, particularly during winter. Therefore if there was a cold signal during Stratum C, it does seem strange that it is not strongly expressed in the pollen record.

Care was taken to avoid any small clay balls suggested by West 1956 to contain reworked materials, although it is possible that there is a wider reworking phenomena at place. Despite this, it would seem unlikely that each sample taken contained reworked material. If climate was significantly colder during Stratum C and this was able to be reflected in pollen (as seems likely), we might expect to see pronounced oscillations between a Ho IIIa temperature and much colder temperatures. We must be aware that the reconstructions from Stratum C are influenced by taphonomic biases, but cannot be sure that this is the case.

To further investigate this, a reconstruction based on macrofossils was undertaken. One of the great strengths of Kuhl's *pdf* approach is the ability to use macrofossils to supplement the palynological data (Aarnes *et al.*, 2012). The use of plant macrofossils alongside pollen has been strongly recommended by Birks and Birks (2000), not just for palaeoclimate reconstructions but for a wide variety of palaeo questions.

In the present study it is unfortunate that plant macrofossil data is not available at the same resolution as pollen and therefore has not been used. However, given the rich macrofossil list for Stratum C, it is worth considering. The analysis was performed based on samples collected by Reid (Evans *et al.*, 1896) which he interpreted as being either in-situ or reworked (largely based on excluding thermophilous species). Reworked species according to Reid were excluded from this analysis.

An important caveat is that this effectively represents a single bulk sample for the whole period and therefore any changing temperatures or other nuances will be lost. Differing temperature regimes could well be merged into one. Bearing these cautionary words in mind, a summer temperature of just below 18ºC and a winter temperature of -7ºC is reconstructed. This is clearly a distinct mismatch with the evidence from chironomids and coleoptera and may imply that very cold temperatures, particularly during summer are not always being captured. In this specific instance it may be because some of the species that represent cold climate regimes, such as *Salix myrsinites* and *Salix polaris* are not available for inclusion in the model.

However, before the entire weight of criticism falls on the *pdf* method it should be noted that there are disagreements amongst other Stratum C proxies. Horne (pers comm.) has used the MOTR method to reconstruct a range of 14 to 19ºC during summer and -7 to +1ºC in winter, which is more consistent with the pollen evidence.

Comparisons with beetles for the rest of the Hoxne sequence reveal a more coherent picture. During Ho IIIa (Stratum E), Ashton *et al.* (2008) report July temperatures of 15 to 19ºC and Horne (pers comm.) 16 to 19ºC and -10 to +6ºC for winter. This is consistent with the reconstructions presented here. The MOTR ostracod method also shows agreement with pollen, albeit across a wide range. Three samples from Stratum E have been analysed using this technique (Horne, pers comm.). The results for summer are, respectively, 11 to 21ºC, 12 to 25ºC and 12 to 21ºC. During winter they are, respectively, -10 to +3ºC, -8 to +13ºC and -10 to +3ºC.

In summary the picture is largely one of agreement at Hoxne and for the small number of other localities where there are quantitative reconstructions. However, there is some confusion regarding Stratum C that still needs to be resolved.

11.2.3 – Pollen zonation as an appropriate framework

It is vitally important that there is a framework on which to compare the sites used in this thesis. Ideally this framework would be provided by radiometric dating and other forms of relatively precise and accurate chronological tools. Unfortunately this is not possible due to the temporal position of the period in question. One possible caveat to this statement could potentially be found through the use of tephrachronology. This form of chronological control enables sites, often over considerable distances, to be correlated very precisely (Lowe, 2011). It is widely used during the Holocene and Late Glacial in particular and is now being extended to into MIS 3 and even earlier (e.g. Bourne *et al.*, 2010). It would prove very beneficial, given the clear importance of earlier interglacials, for there to be a concerted effort to develop a tephrastratigraphy for these periods. The value of this is confirmed by the use of tephra to link the Bouchet and Praclaux records (Tzedakis *et al.*, 1997).

Nevertheless, until tephra is widely employed during MIS 11 and in the absence of radiometric dates, we are forced to rely on pollen zonation to provide a structure on which to make comparisons and to divide the interglacial into meaningful subsections of time. It could also be possible to break the Hoxnian down according to climatic rather than pollen zones and correlate on this basis. In effect this would be a form of tuning, which is common in Quaternary research. However this has the potential to introduce circularity and is therefore inappropriate.

Using pollen zones to guide palaeoclimatic research in past interglacials is in fact not uncommon. This work is consistent with, for example, Kaspar *et al.* (2005) who synthesise a large number of Eemian pollen records, across a wide area of west, central and eastern Europe. These records then form the basis of a data-model comparison for this time period. The sites linked on the basis of pollen zones in Kaspar *et al.* (2005) are extremely widespread, much larger than in this thesis.

11.2.4 – The influence of sampling strategy on the reconstructions and presence/absence approaches in general

What, if any, role does sampling play when it comes to the trends and major features of the reconstructions presented here? We can in part investigate this question by assessing the sampling resolution at each of the sites presented, as below (depth/number of samples):

- Athelington = 28 cm
- Barford = 25 cm
- Hoxne

  - Main sequence = 14 cm
  - Stratum C = 12 cm
- Marks Tey
  - Lower sequence = 16 cm
  - Top sequence = 24 cm
- Nechells = 13 cm
- Quinton = 12.5 cm
- St Cross = 37 cm

Clearly there is a considerable range of sampling resolutions, with St Cross being sampled at low resolution and Stratum C at much higher resolution. Does this in any way relate to the observed reconstructions.

Fig 70-72 present the reconstructions on a common, Marks Tey pollen zone based, timeframe. From this we can compare the characteristics of each curve. There does appear, broadly speaking, to be a relationship between the degree of variability observed in a record and the sampling resolution. Compare, for example, St Cross to Quinton.

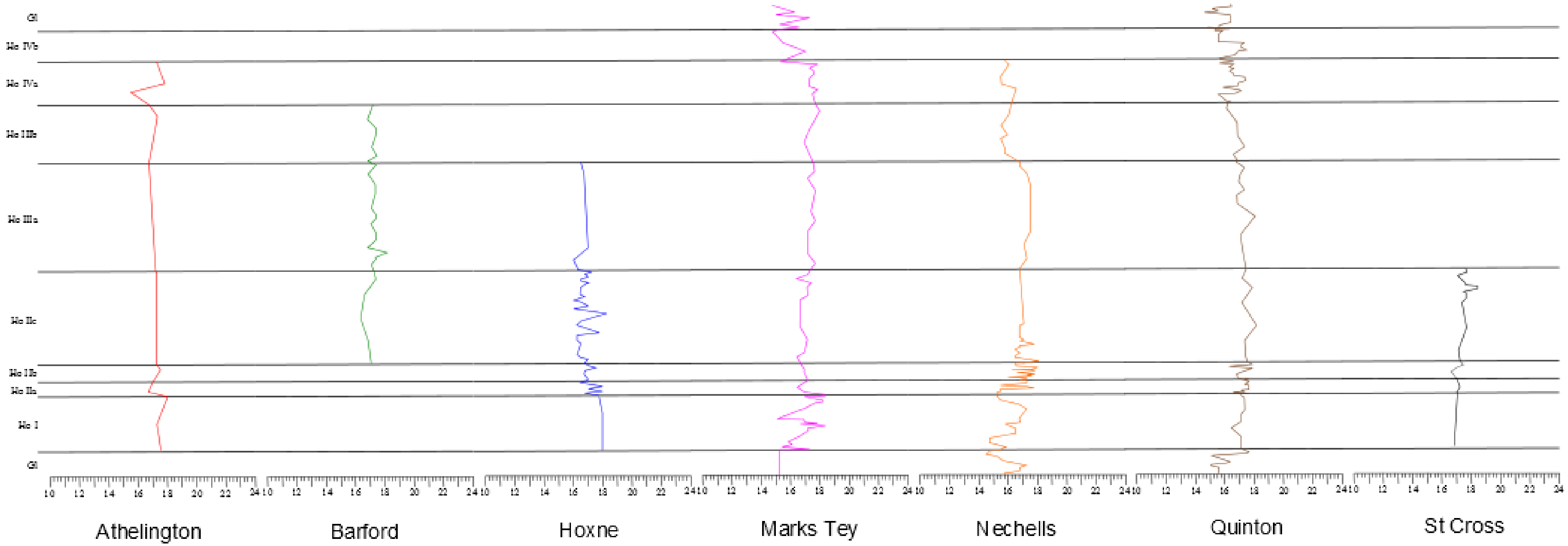


Fig 70: The summer reconstructions on a common timescale derived from Marks Tey

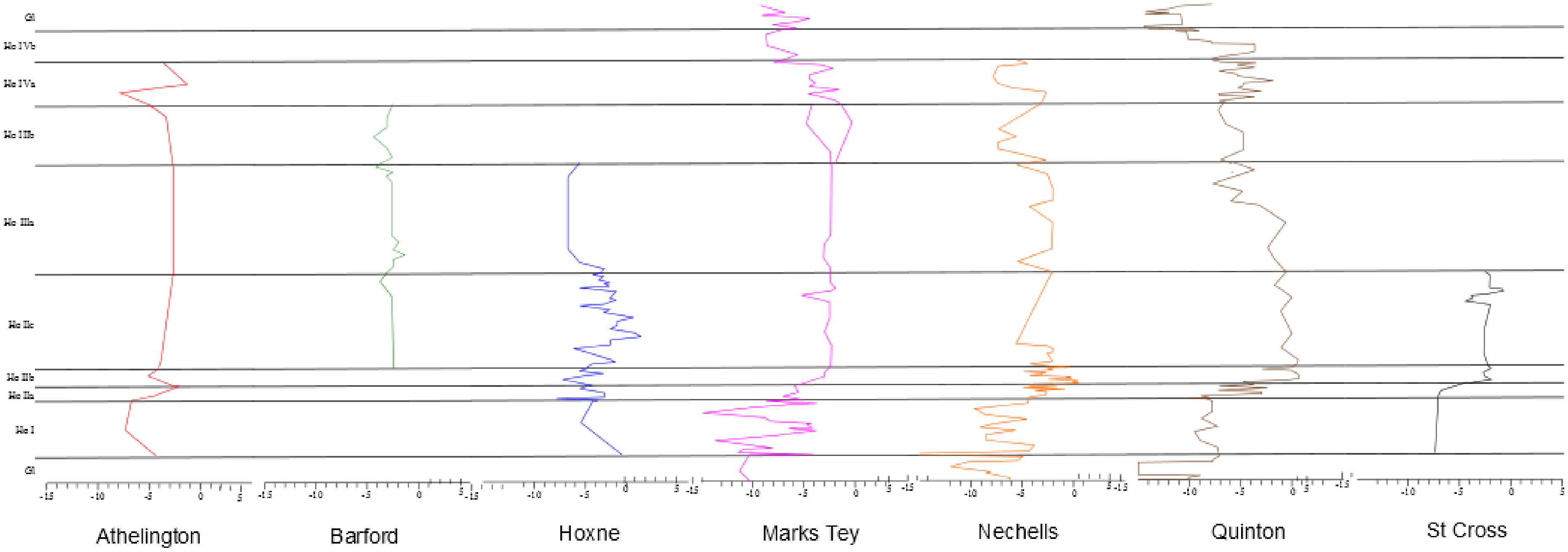


Fig 71: The winter reconstructions on a common timescale derived from Marks Tey

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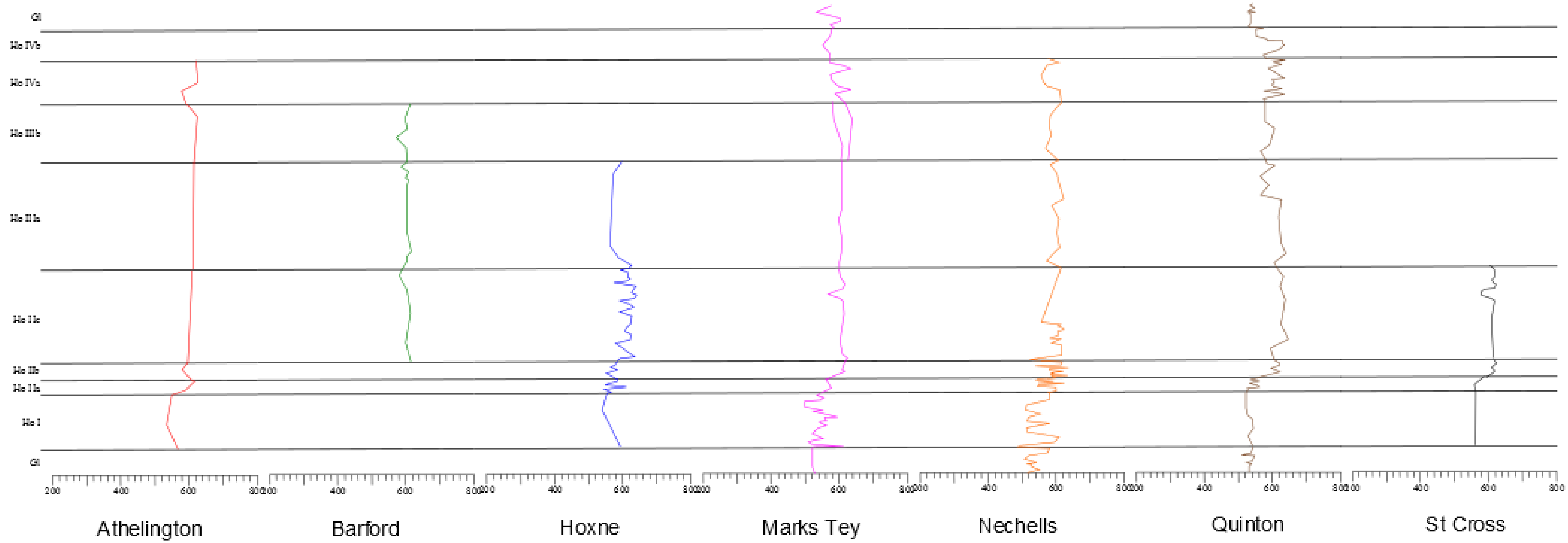


Fig 72: The precipitation reconstructions on a common timescale derived from Marks Tey

How is variance related to sampling? Broadly speaking the reconstructions reveal clear and consistent trends. Nevertheless, the observed curves are obviously dependent on the pollen inputted, which for various reasons, even when there is an overall consistent ecology being recorded, can vary. As a consequence, these fluctuations could then translate to the climate reconstruction and are more likely to be detected the higher the sampling resolution. At the fine sampling resolution scale, subtle changes in pollen spectra occur from sample to sample, up and down the core, and this will by default be detected by the pdf method.

It should, however, be stated that there is no simple and straightforward relationship between sample resolution and variability. For example, sampling resolution at Marks Tey is relatively high and yet for much of the reconstruction, through Ho IIc for example, there is a small degree of variability. Some of the most heavily sampled parts of the sequence (the 16 cm listed above is an average) lie in Ho IIa and IIb, both of which are relatively smooth portions of the curve.

Broadly speaking, the *pdf* method is likely to be less heavily influenced by changes in pollen diagrams that do not particularly represent a significant wider ecological/climatological signal. Presence or absence approaches avoid the need to rely on changes in percentage (and assemblage) which a long history of palynological research has demonstrated to be subject to numerous complicating factors.

In their recent authoritative review of probabilistic pollen – climate reconstruction methods, Ohlwein and Wahl (2012) observe that there is no simple, direct functional and/or mechanistic relationship between pollen and climate and pollen production is related to numerous factors. A more parsimonious approach is appropriate in the face of this complexity and so presence/absence is generally likely to be a more reliable methodology at a fundamental level. Ohlwein and Wahl (2012) observe that presence/absence largely sidesteps the complications of non-analogue situations and is less sensitive to plant competition and other non-climatic influences.

The influence of far travelled, non-representative pollen is a confounding variable that all reconstruction methods are vulnerable to (though percentage approaches perhaps less so). However, presence/absence can also be influenced by an opposite problem, that of missing relatively rare (due to low dispersal levels) but climatically significant taxa such as *Hedera*. One way to minimise this problem is to have very large sample sizes. Kuhl and Gobet (2010) recommend counts of 1000. The counts in the pollen diagrams used here are somewhat variable. Below is the average pollen count for each of the sites:

- Athelington = 300
- Barford = 500
- Hoxne = 300
- Marks Tey
    - Lower sequence = 297
    - Upper sequence = 270
- Nechells = 250 (tree pollen)
- Quinton = 242
- St Cross = 613

Compared to the recommendation of Kuhl and Gobet (2010) these are relatively small counts (though they are generally close to the typically recommended level of 300). We must therefore accept the possibility that some rarer taxa have not been captured and incorporated into the reconstructions. One possible implication of this is that at the start and end of the interglacial, when floristic diversity is lower, the reconstructions are more vulnerable to artificial variability. This is because with fewer taxa to constrain the reconstruction, any changes in the pollen spectra will potentially be magnified. Nevertheless the general coherence observed between sites is good evidence that a significant and robust signal is being recorded.

One way to deal with some of these issues is to impose thresholds on the data. For example, large sample size will increase the likelihood of capturing climatically insignificant far travelled material. Therefore in the case of large pollen counts thresholds may be particularly useful.

The use of thresholds generally is a recommendation of Ohlwein and Wahl (2012). However, they do recognise the difficulties of undertaking this in a completely objective way. Moreover, it can potentially exclude valuable climatic information and so should not be seen as a panacea for the issues associated with presence/absence methodologies.

Straightforward thresholds of the type adopted here (i.e. not the Kuhl threshold) were used by Latalowa and van der Knaap (2006) who adopted thresholds at 0, 1, 2, 5 and 10%. Their paper is specifically looking at the Holocene record of spruce and they observe that crucial dynamics are missed at thresholds above 1%. This makes it clear that while the imposition of thresholds may have some benefit, they can potentially also work against the accuracy of a reconstruction.

In this study the addition of thresholds has a noticeable influence on the reconstructions, although it does not alter any broad trends or major conclusions. This influence was further refined to being largely the result of small amounts of spruce pollen. However, this is not necessarily the same as saying that incorporating these low levels is necessarily more or less accurate. Broadly speaking, the use of large basin sizes should provide a regional picture. However, far travelled, non-representative pollen (which a threshold could mitigate against) can still occur in this scenario.

It would be interesting to use the insights gained from modern pollen theory to be more discerning about site selection, for example selecting from large lakes and small hollows. This would ultimately provide a better way to discriminate between local and regional signals. In this, however, we are very much at the mercy of taphonomy. Any future attempts to apply this methodology to British Holocene sequences should, however, attempt this approach. Typically site selection for palaeoclimate research in the UK does not make the most of such approaches.

It is difficult to judge exactly where to draw a threshold and if it ultimately provides a more realistic insight into the actual floristic composition of a site. The use of pollen productivity and fall speed would go some way to filling this gap and was initially considered here. However, there remains a considerable amount of basic data collection required before this can become feasible. Current data is incomplete and only available for a relatively narrow range of taxa (see section 5.8 for a current listing).

A discussion of thresholds brings us on to the robustness of selecting data from published diagrams. In general terms there is no particular reason to believe that this is not a reasonable approach to take. With the caveats discussed above about presence/absence in mind, if we see a pollen type recorded on a diagram it is a valid assumption to take that this species was observed by the original analyst. Therefore this provides a sound basis for palaeoclimate reconstruction. Moreover, it potentially opens up an exciting array of possibilities for future research in the Middle Pleistocene, where original data may no longer be available. Nevertheless, we should be aware that at some sites, such as Quinton there were peculiarities observed during data collection, particularly at the start and end of records and this should add a note of caution to their interpretation.

12 – The palaeoclimate of the Hoxnian interglacial

This final chapter will establish the climatic trends of the Hoxnian and compare this to the observed climate at this time in North West Europe and beyond. We will first deal with the issue of chronology within MIS 11 in Britain.

12.1 – Establishing a chronology for the Hoxnian

Many of the most interesting research questions in Quaternary science are underpinned by the need for a reliable chronology, both precise and accurate. The field differs from many other geological disciplines by the large number of deposits for a given time period and the large number of these that have a high temporal resolution. Moreover, there are often dating techniques available to unlock these inherent sedimentological advantages. Frequently, the ability to test hypotheses regarding events occurring on relatively short time scales has considerable wider relevance, abrupt climate change for example, and this puts Quaternary geologists in a unique position. High quality chronologies are therefore highly valuable and their absence is significant. Unfortunately, no such chronology exists for the Hoxnian, however it is possible to make estimates that at least go some way to enabling us to investigate the climate and environmental changes of the period in detail.

Where sites are annually laminated, there is the chance to develop excitingly precise and accurate timescales. To some extent, this may be possible at Marks Tey (Turner, 1970). A portion of the interglacial Marks Tey record is finely laminated, with light and dark couplets. The light layers consist almost entirely of diatoms and the darker layers are composed of organic debris and diatoms. Turner (1970) argues that there is a rhythmic cycle to the deposit of these laminae and that the couplets represent annually deposited varves.

There are certainly examples in numerous lake settings of diatom based varves; the German lake Holzmaar (Prasad *et al.*, 2006) for instance. With the Marks Tey couplets, there is some uncertainty; in places Turner (1970) did not investigate them in any great detail. Moreover, they cannot always be counted clearly. Nonetheless, there is evidence of annual deposition at Marks Tey that can be used build an idea of chronology. Turner estimates the presence of 5000-10,000 lamination pairs from the start of the interglacial to the end of Ho IIb. More precisely, he estimates that Ho IIc lasted around 2700 years and the earliest part of Ho III another 2000 years. The total length of the interglacial, based on these varve counts and an approximate sedimentation rate, was between 30 and 50,000 years according to Turner (1970).

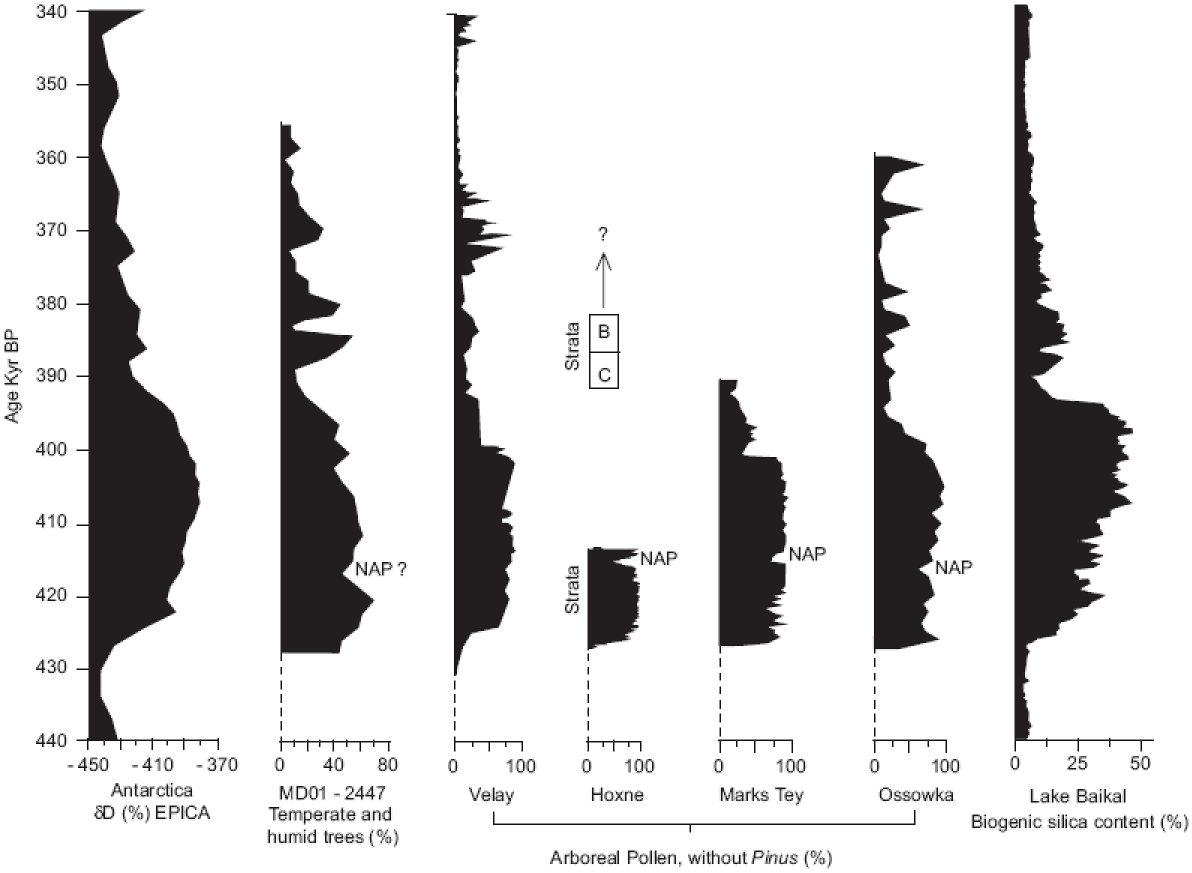


Fig 73: a correlation of Hoxne and Marks Tey with European terrestrial and marine records and the EPICA ice core. From Ashton *et al.* (2008).

Can we further refine our understanding of chronology during the Hoxnian? Correlation with dated sequences on the continent offers such an opportunity. Ashton *et al.* (2008) correlated Hoxne and Marks Tey with the Velay long pollen record (Reille and de Beaulieu, 1995) and the offshore pollen record of core MD01-2447 (Desprat *et al.*, 2005). The correlation is reasonable and is based on three tie points; the sudden increase of arboreal pollen at the beginning of the interglacial (the start of MIS 11c), following the MIS 12 glaciation; the Non Arboreal Pollen phase; the sudden decline of arboreal pollen at the end of the interglacial. This correlation fixes Hoxne and Marks

Tey in time; the Hoxnian begins at around 425 kyr BP and ends approximately 25,000 years later at 400 kyr BP. Interestingly, this is roughly comparable with the lower end estimate of Turner (1970). Given that much of Turner's estimate was based on assumptions regarding sedimentation rate, it is an encouraging comparison.

Further encouragement comes from a comparison of the better chronologically resolved (probably) portions of his estimate. If there are between 5 and 10,000 couplets from the start of the interglacial to the end of Ho IIb and Ho IIc lasted 2700 years, that places the end of Ho IIc between 7700 and 12,700 years into the interglacial. The NAPP is found towards the end of Ho IIc and must therefore be somewhere close to this range. Based on Ashton *et al.*'s (2008) correlative work, the NAPP can be estimated to have occurred at around 415 kyr BP, 10,000 years into the interglacial. This is comparable to the estimate derived from the Marks Tey data.

An alternative approach for the correlation of a European terrestrial MIS 11 sequence with wider records was taken by Koutsodendris *et al.* (2012). This work is undertaken on laminated lake sediments at the Dethlingen site in Germany, which has an assigned Holsteinian age. The Holsteinian is typically correlated with MIS 11, although this correlation is more controversial in Europe than the correlation in Britain of the Hoxnian with MIS 11. In particular, the geochronological questions raised by Geyh and Muller (2005) (see section 2.1 of the literature review) become more pertinent. However, as Koutsodendris *et al.* (2012) point out, the correlation between the Velay record (de Beaulieu *et al.*, 2001) and a marine record off north west Iberia (Desprat *et al.*, 2005) is strong evidence that the Holsteinian represents MIS 11 in continental Europe.

The laminated sediments at Dethlingen are established as varves to form a floating chronology that is then tied in with two other varved sites very close by; Hetendorf (Meyer, 1974) and Munster-Breloh (Muller, 1974). Taken together this chronological estimation suggest an interglacial with a duration of approximately 15,000 +/- 1500 years (Koutsodendris *et al.*, 2011).

Koutsodendris and colleagues argue that the Holsteinian should not be correlated with the beginning of MIS 11, rather it relates to the second half of MIS 11c, in other words covering the period between 415 to 397 kyr. This is a distinctly different approach to that advocated by Ashton *et al.* (2008) and we must evaluate these two competing hypotheses.

Fundamentally, the arguments of Koutsodendris *et al.* (2010; 2012) rest on the duration of the interglacial established through varve counting (both by these authors and Meyer and Muller). The methodologies used to establish the annual nature of these laminations and subsequent counting (Koutsodendris *et al.*, 2011) are robust and it seems reasonable to believe that this represents an accurate length for the interglacial in Germany. From these varve counts, they attempt to adopt a stratigraphic framework that best suits a Holsteinian lasting this long. This is a reasonable approach, although it arguably imposes constraints that then lead to the necessity to provide somewhat convoluted climatic explanations. This will be discussed further below.

MIS 11c has a duration of approximately 28 kyr in total, which the Holsteinian cannot span the entirety of. If it correlates with the beginning of MIS 11c then, with a duration of around 15 kyr it will have ended somewhere shortly after 410 kyr BP. Koutsodendris and colleagues do not find this to be a satisfactory chronology. They point to the broad observation from EPICA data that peak warmth during MIS 11c appears to occur towards the end of this period (Jouzel *et al.*, 2007). The Holsteinian ending midway through MIS 11c would be inconsistent with this they argue.

Further support for this line of reasoning derives from a number of records in which a delayed climatic optimum during MIS 11 is observed.

A terrestrial interglacial that does not begin until sometime into the interglacial, as traditionally defined by marine and ice core records, requires a strong explanation. Koutsodendris and colleagues recognise this potential problem.

Firstly they argue that the onset of terrestrial and marine interglacials is in fact asynchronous. This may be the case, but they do not provide particularly convincing support for this. Or, more specifically, there is not strong evidence for an asynchrony lasting for around 10,000 years, which would be required in their stratigraphic model. They point to the MD01-2443 core as evidence, specifically Tzedakis *et al.* (2004), which in this particular work stretches back to MIS 9. However, this paper does not suggest a sufficiently strong asynchronous signal to justify their claims. For example, Tzedakis *et al.* (2004) point to the generally good agreement between the temperate tree curve and the record of atmospheric methane from Vostok, both in terms of the pattern of change and also the timing. The following figure is taken from Tzedakis *et al.* (2004) and does not display particularly strong marine – terrestrial asynchrony:

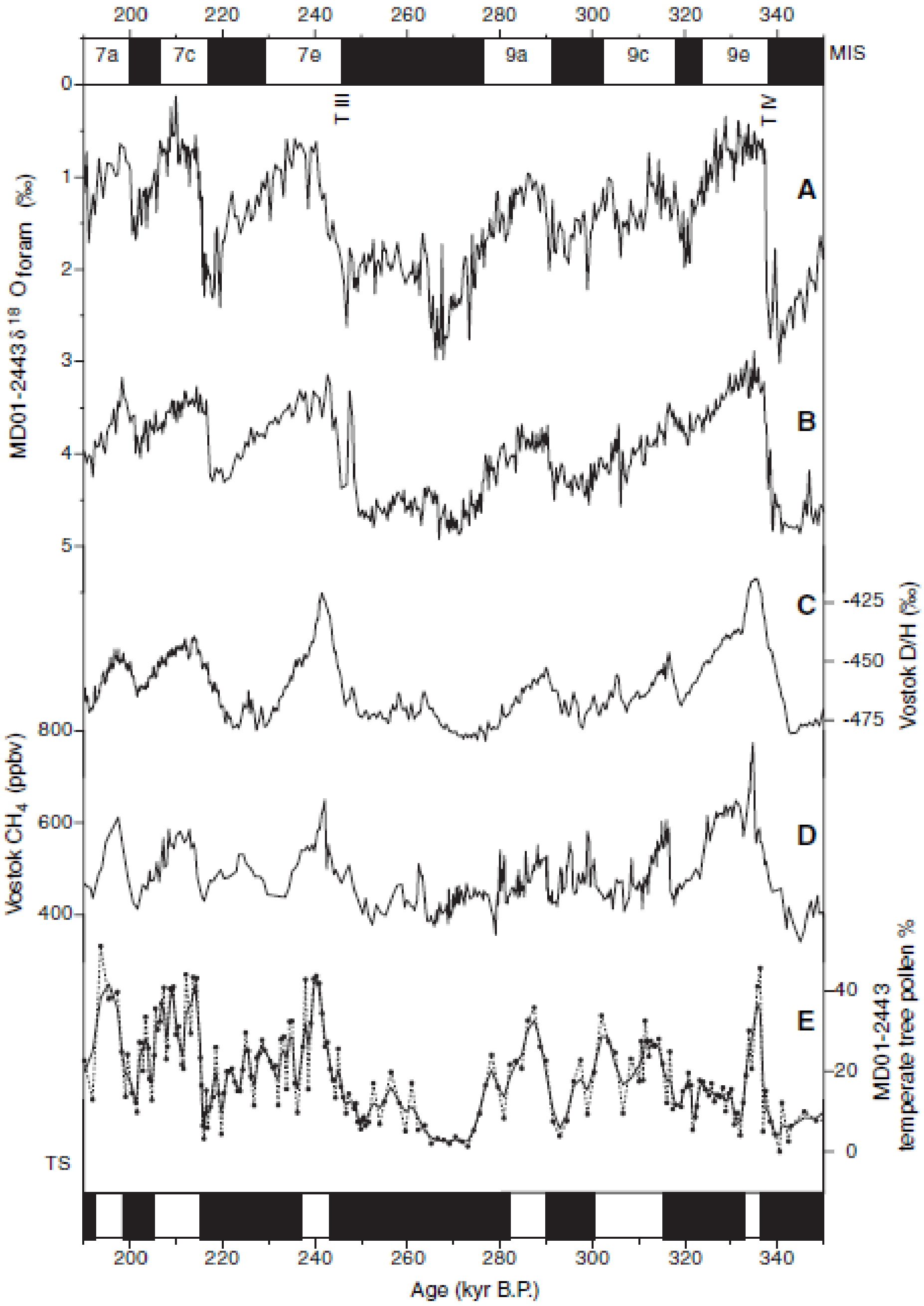


Fig 74: various middle Pleistocene records synchronised on a common timescale by Tzedakis *et al.* (2004).

The MD01-2443 record during MIS 11 also closely matches the atmospheric methane record (Tzedakis *et al.*, 2009b), for example both showing a distinctive asymmetrical "M" shaped structure during the period from 424 to 395 kyr BP.

The second question that arises is if there was a delayed onset of terrestrial interglacial conditions, what conditions prevailed before this and why did a delay occur? With regards to the former, Koutsodendris argue that the sequence at Schoningen (Urban, 2007), which displays boreal forest conditions in the late Elsterian (the so called Esbeck Interstadial) represents the pioneer Holsteinian forest.

Regardless of the potentially slightly confused stratigraphic nomenclature, it must be asked why extensive evidence for this phase is not widely found elsewhere. For example, given that Hoxnian sequences often formed in kettle holes, why is a 10 kyr boreal phase not widely observed. It is clear that lengthy sequences spanning a late glacial can be recorded in such archives, as they are abundantly from the last deglaciation in Britain (e.g. Lowe, 1978).

In terms of the delayed onset, Koutsodendris *et al.* (2012) argue that this can be partly explained as a result of the distance from refugia, combined with initially slow to develop temperate forest in Southern Europe. In the case of the former, clearly there is a lag/migration time, but this does not necessarily have to be particularly lengthy as the development of full interglacial conditions during the Holocene shows. Moreover, the argument that a weakly developed temperate forest to the south is not especially convincing. They refer to the summary diagram for MD01-2443 presented in Tzedakis (2010), which is presented below:

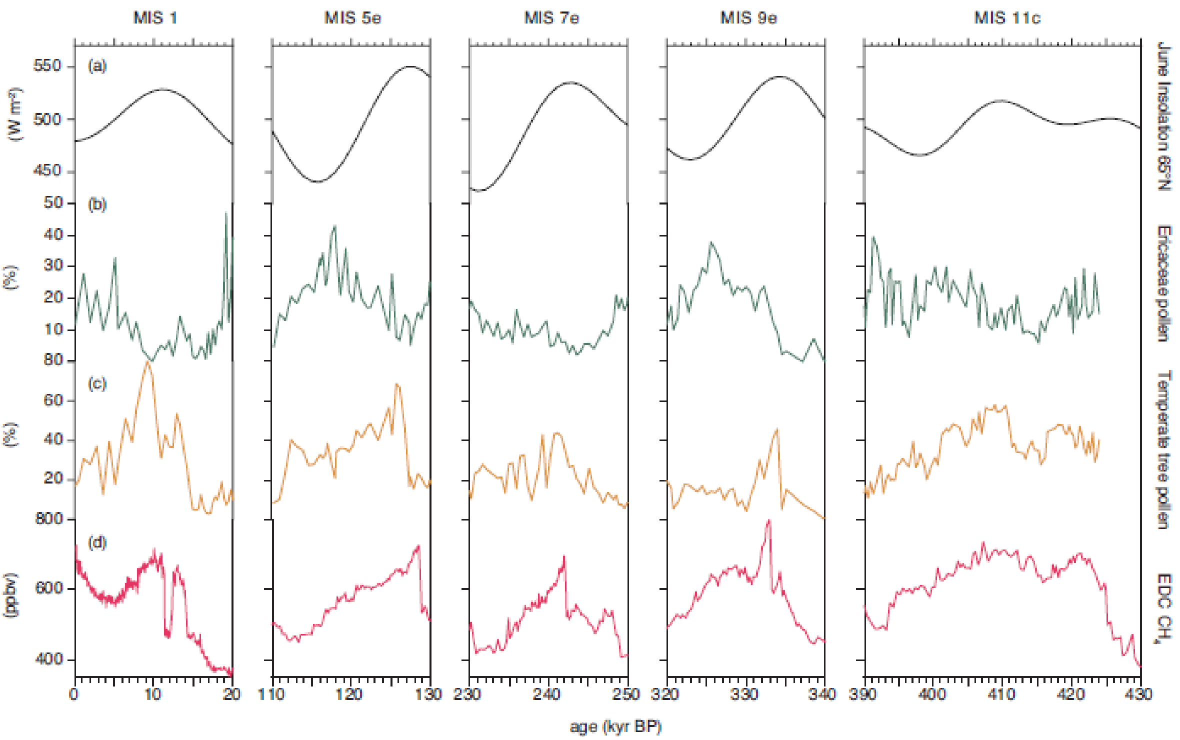


Fig 75: summarising the MD201-443 palaeoclimate record (Tzedakis, 2010)

From this figure it is clear that the maximal extent of temperate forest was not reached until some time during MIS 11c, approximately 410 kyr BP. However, before this, temperate trees were clearly present and at significantly higher percentages of the pollen sum than during glacial periods. Moreover, these levels are comparable to the maxima in MIS 9 and MIS 7. There is no ecological basis to believe that a percentage of around 40% compared to 60% is likely to prevent migration from the refugia, which is essentially the argument put forward by Koutsodendris *et al.* (2012) with regards to the significance of refugia. There must be a climatic explanation, which is provided and will be discussed shortly. Finally, although Koutsodendris *et al.* (2012) feel that the supposed delay in reaching a southern temperate tree maxima is significant, they do not make note of the fact that such a maxima is reached early on in the MD01-2447 core off Iberia, around 421 kyr BP.

Ultimately, the Koutsodendris argument requires the existence (and prolonged maintenance of) a substantial temperature gradient across Europe. Despite an attempt to argue for the significance of an arguably weaker temperate phase early on in Southern Europe, they do acknowledge that southerly regions saw the spread of interglacial forests soon after Termination 5. This is shown clearly in the MD01-2447 core, which is located off Northwestern Iberia. Whilst representing “southern” Europe, this is getting close to the more northerly reaches of Europe. Moreover, the MD01-2443 core from further south has close similarities with the Velay record from the Massif Central in France (Tzedakis *et al.*, 2009b). Here we are edging further north, making the existence of a radically different climate regime further north more improbable.

The above discussion hopefully makes it clear that there are a number of problems with regards to the correlation of the Holsteinian with the latter part of MIS 11c. However, it is important to remember that the initial reason for attempting this correlation was the duration established through varve counting. This is robust, does not easily relate to the lengthy period observed in numerous other records and therefore must be explained. Moreover, a correlation with the second part of MIS 11c, despite the complications, is more reasonable than if it correlates with the onset of this period and then ends during the middle, when temperatures elsewhere remain at full interglacial levels.

If we assume that the Hoxnian lasted for approximately 30 kyr and commenced roughly at the start of MIS 11c, could there have been the existence of an east-west gradient as well as north-south one. Koutsodendris *et al.* (2012) do argue that conditions in western Europe were likely warmer at certain times, due to the close proximity to the Atlantic. Moreover, there were similar gradients during other interglacials (e.g. Kaspar *et al.*, 2005). However, it seems somewhat improbable that trees would migrate from southerly refugia to Britain, bypassing more central regions along the way (though this should not be strictly ruled out).

It must also be remembered that the longer duration of the Hoxnian is largely based on correlation, albeit a parsimonious and entirely reasonable one. It does not have the strong chronological control afforded by varve counting in the German sequences. So we are left with a somewhat unsatisfactory picture.

It is tempting to settle for a somewhat convoluted correlation because of the strength of the varve counting. However it should also be noted that there are other sequences in Germany that have a varve chronology. One such example is Bilshausen, where annual layer counting has established an interglacial duration of around 26,000 years (Kuhl and Gobet, 2010 and references therein). The correlation of Bilshausen with MIS 11 is somewhat uncertain, with an alternative correlation with MIS 13 possible.

Kuhl and Gobet (2010) ultimately favour placing Bilshausen within MIS 11, although acknowledging the plausibility of MIS 13. This introduces an extra component of uncertainty and strongly suggests we should not rely solely on the varve chronology from Dethlingen. Here the approach taken by Ashton *et al.* (2008) is ultimately preferred. Given the complexities inherent in attempting to gain a chronological framework during the Middle Pleistocene, a parsimonious approach is preferable. The Ashton *et al.* (2008) framework is straightforward, simple and is not required to provide convoluted explanations by way of support. Fig 73 essentially shows the position taken here, but a specific diagram will be presented below (Fig 79).

12.2 – The climatic changes of the Hoxnian

The following figures present a combined illustration of Hoxnian climate:

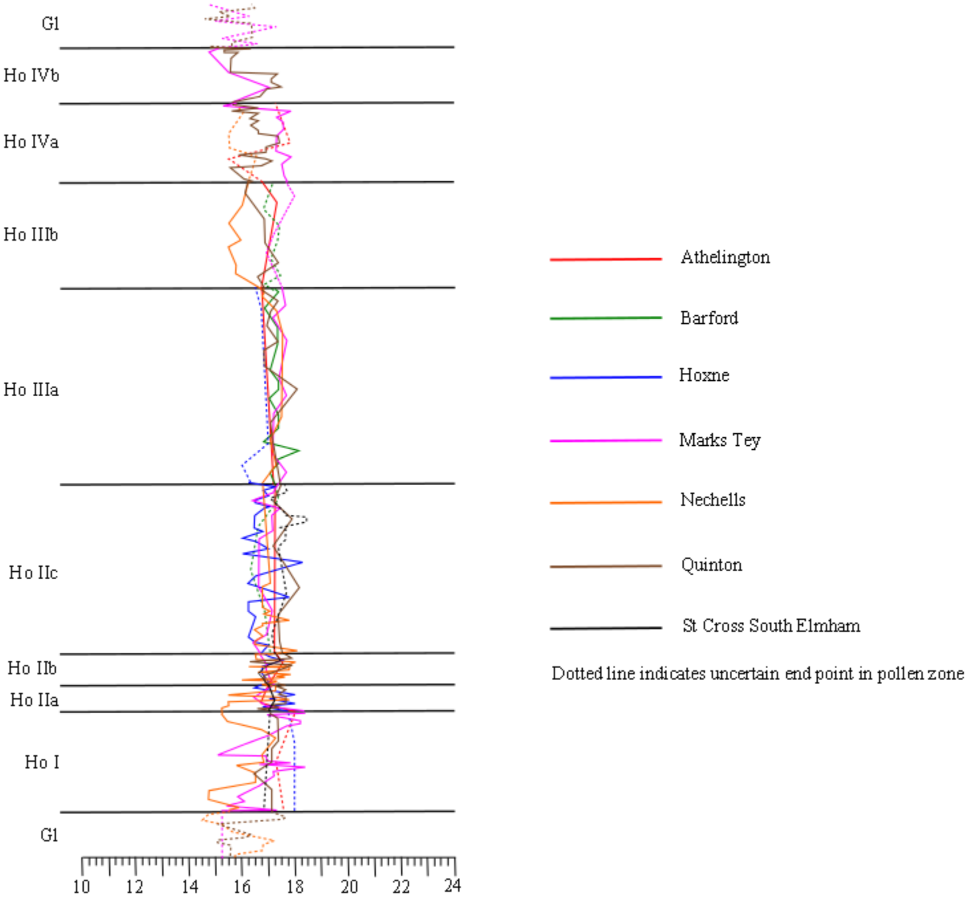


Fig 76: combined summer temperature reconstructions on the Marks Tey approximated timescale

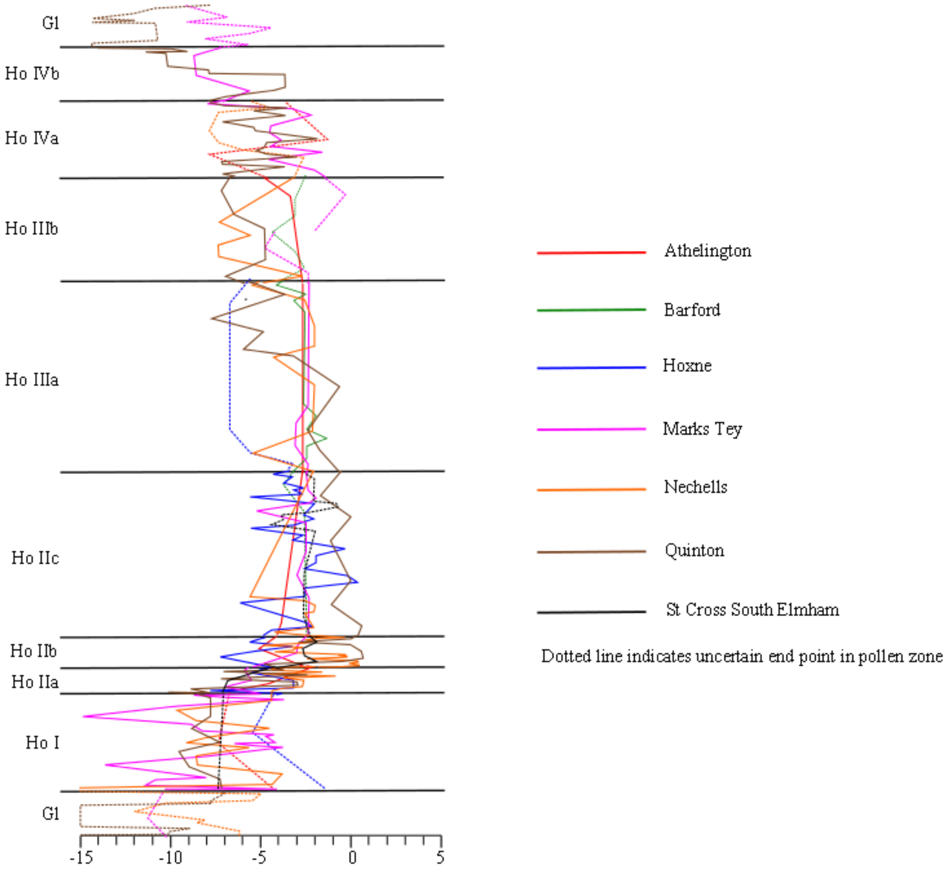


Fig 77: combined winter temperature reconstructions on the Marks Tey approximated timescale

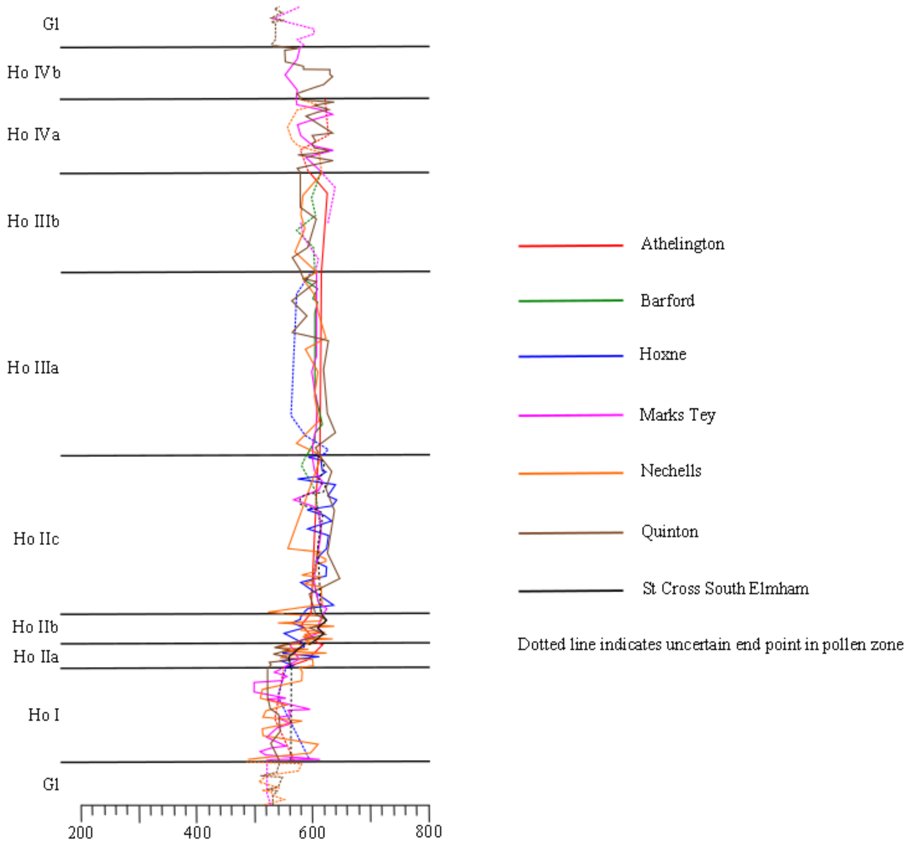


Fig 78: combined precipitation reconstructions on the Marks Tey approximated timescale

12.2.1 – Climate preceding the Hoxnian interglacial

A small number of the sites included in this study contain evidence for the prevailing climate of the end of the cold period prior to the Hoxnian interglacial. The reconstructions from Marks Tey, Nechells and Quinton are all characterised by relatively low probability density and in the case of Quinton, considerable uncertainty, with very large error bars. Moreover, there is extremely high variability during this period at all sites, with extreme variations in temperature, particularly during winter. Precipitation, however, is relatively stable.

Despite the elevated uncertainty associated with the reconstructed climate of this period, it is nevertheless possible to make some important generalisations. It is clear that temperature during this period was low, seemingly colder than at any point during the Hoxnian. Any precise temperature or precipitation value taken to be representative of this time must be viewed with caution, particularly winter temperature. This is further compounded by the fact that reconstructed temperatures at Quinton are consistently lower than at other sites. However, during January, a value somewhere around -10^{o} is possible. During summer, temperatures may have been around 15^{o} and annual precipitation somewhere in the region of 550 mm.

The lack of chronology makes it difficult to establish how long a period of time the pre-interglacial sediments in this study represents. There is very little of this period preserved at Marks Tey, but there appears to be more at the other two sites. It is difficult to further explore the climate of this period in the absence of any sort of chronology.

12.2.2 – Climate during pollen zone Ho I

Ho I is recorded at a considerable number of sites, enabling us to speak more confidently about the prevailing climate of this pollen zone, in comparison with the preceding time period. Ho I can be observed at Athelington, Hoxne, Marks Tey, Quinton, Nechells and St Cross.

Ho I may represent the first part of the interglacial, but the clear conclusion from the palaeoclimate reconstruction is that this interval was cold and relatively dry. There is good agreement across all sites for this basic observation. There is a wide range of winter temperatures observed, although a general clustering around -7ºC possibly suggests this as a representative temperature. Overall there does not appear to be any particular trend in winter temperature at this time, though subsequent sections will consider the evidence for abrupt climate change.

In summer, temperatures are slightly cooler than in much of the rest of the interglacial, though not extremely so. There is some disagreement amongst the records, but a temperature a little below 17ºC may be likely. There is a suggestion of a rising temperature trend from some sites, Marks Tey and Nechells in particular, though this is not especially clear. Regardless of this, summer temperatures appear to peak sometime during or at the end of Ho I, relatively early on in the interglacial.

With regards to precipitation, levels are at one of their lowest points within the interglacial, similarly low as the cold periods that bookend the Hoxnian. There is good agreement among the sites investigated and a general consensus of precipitation levels somewhere around 500 mm, although St Cross is a little higher.

12.2.3 – Climate during pollen zone Ho II

Ho II is the most consistently recorded of all pollen zones in this study. During the early stages of Ho II, there appears to be an amelioration of winter temperatures. Based on the Marks Tey timescale (5000-10000 years from the start of the interglacial until the end of Ho IIc) this presumably took place relatively gradually, perhaps over a thousand years or so. There is some degree of divergence amongst the reconstructions, but this rise in temperature appears likely to have been of the order of a number of degrees, possibly around 3 to 4ºC.

Winter temperature then appears to have plateaued during Ho IIc. There is a range of values and a degree of variance from the Hoxne record at the lower end that makes it hard to select a lower bound. However, temperatures were likely between 0 and -5ºC.

There is a greater clustering approximately in the middle of this range, so winter conditions were perhaps around -2 to -3ºC.`

Summer temperature does not show the same trend as winter, having seemingly reached a plateau at the start of Ho II. There is greater agreement amongst the reconstructions at this point and they point to a temperature through this period of around 17ºC or possibly slightly above.

Precipitation also displays the rising trend during Ho IIa and Ho IIb, observed in winter temperature. This was perhaps on the order of around 60 to 80 mm, from the lower 500 mm region to around 600 mm. During Ho IIc a consistent value around 600 mm is recorded.

12.2.4 – Climate during pollen zone Ho III

Ho III is reasonably well represented in the reconstructions. During Ho IIIa, the Hoxne reconstruction presents significantly lower temperatures than the other sites and likely only covered a small portion of this pollen zone. Excluding Hoxne provides a more coherent picture and suggests a general continuance of temperatures during Ho IIc, somewhere possibly around -2 to -3ºC.

Generally speaking, temperatures during Ho IIIa appear to be quite consistent, although the records begin to diverge towards the end, particularly at Quinton where a deterioration in climate is suggested. On the basis of the sites as a whole, this deterioration cannot be supported. By the time of Ho IIIb, however, there is a possible suggestion that a decline in temperature has occurred. The lower sequence from Marks Tey, Nechells and Quinton are all clearly at lower temperatures than during Ho IIIa, closer to -5ºC.

Summer temperatures appear to remain fairly consistent at around 17ºC, continuing the trend from Ho II. Towards the end there is increasing divergence. This pattern is also found in precipitation where a consistent level of approximately 600 mm is maintained (the short part of Ho IIIa at Hoxne notwithstanding).

12.2.5 – Climate during pollen zone Ho IV and the post Hoxnian

Winter temperatures during Ho IVa seem to largely continue from where they left off in Ho IIIb. However, during Ho IVb there is evidence of a further deterioration in climate, albeit from just two records, Marks Tey and Quinton. Nevertheless, there does appear to be good agreement between these two sites that temperatures cooled further. There is some divergence regarding that precise nature of this change, though we are perhaps looking at temperatures closer to -8ºC.

There is some suggestion that this temperature decline was also felt during summer. Ho IVa temperatures continue at around 17ºC, albeit with a greater range than previously. Then there appears to be a fall of a degree to 16ºC. This seems to occur later at Quinton than Marks Tey, but both records ultimately converge on this value during Ho IVb. There is also an indication that precipitation is declining by Ho IVb too, down to approximately 550 mm.

Summer temperature and precipitation then both continue at similar levels into the cold period beyond the Hoxnian. It is less clear what happens to winter temperatures. It is possible that the climate took another downward turn to values of -10ºC and beyond. However there data is relatively sparse by this point and not in particularly strong agreement.

12.3 – British and European Climate during MIS 11

12.3.1 – Broad comparisons and the big climate picture

Although there are relatively few quantified temperature reconstructions elsewhere, there are a number of other records available for comparison. One quantified record comes from Bilshausen, Germany (Kuhl and Gobet, 2010) although it remains uncertain whether this has an MIS 11 or MIS 13 age, as discussed above. MIS 11 seems more probable on balance and the record shows a number of similarities with the Hoxnian reconstructions presented here.

In particular, there is close agreement that winter temperatures were significantly colder than the present day. At no point during the Bilshausen record do conditions rise above 0˚C and are generally significantly below it. The temperatures themselves are comparable during the early stages of the interglacial, with conditions somewhere between -5 and - 10˚C. There is also a broad similarity in the shape of the summer and winter curves, with cooler conditions at the beginning and end of the interglacial. Moreover, apart from a period towards the top of the sequence, temperatures are similar, close to around 17˚C.

Two general perspectives on the palaeoclimate of this period are presented by Kukla (2003) and Rousseau (2003). Kukla (2003) argues for generally similar temperatures to the present day (albeit with local pockets of increased temperature), whereas the other, Rousseau (2003), argues that MIS 11 was warmer and wetter. The results presented here are more in line with the former perspective.

In terms of precipitation, this study is relatively novel and there is little basis for comparison (other than to the present day, which will be done below). The overall trend is for slightly drier conditions at either end of the interglacial, with relatively wetter conditions prevailing for the rest of the period.

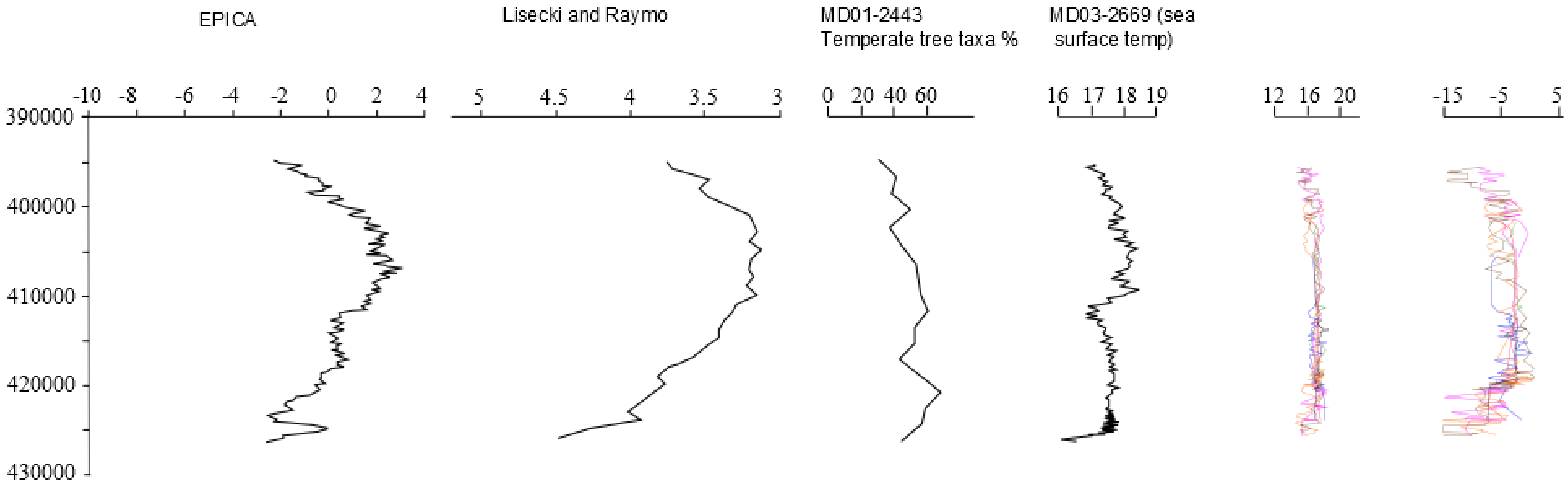


Fig 79: A comparison of the summer and winter reconstructions with wider records. The EPICA data (ºC) comes from Jouzel *et al*. Lisecki and Raymo is a δ18O record from a marine core. The other two records come from the Atlantic; MD01-2443 (Tzedakis, 2010) and MD03-2669 (Rodrigues *et al.*, 2011).

12.3.2 – Seasonality, peak warmth and regional climate differences

Returning to the Bilshausen comparison, it is important to note that there are a number of interesting differences between the two records. The rise in winter and summer temperature appears to occur somewhat later in the interglacial at Bilshausen. There is a suggestion of an initial early shift to slightly warmer winter conditions, around 3000 years into the interglacial. This could potentially coincide with the end of Ho I. However, the main shift to a warmer regime occurs after 10,000 years. Regardless of whether Ho II ends after 5000 or 10,000 years as suggested by Turner (1970), this is significantly later than during the Hoxnian when the warmest conditions are reached by the onset of Ho IIc. The warmest conditions at Bilshausen occur towards the end of the interglacial, in contrast to the Hoxnian. Moreover, the warmest winter temperatures are never as high at Bilshausen as they were in Britain.

This pattern of warmth later in the interglacial is also observed at Dethlingen, although Dethlingen reaches warmer temperatures. The difference between Dethlingen and Bilshausen is strange given their close proximity, although this could simply be the result of a model differences between sites as is observed in this study. However, there does appear to be a consistent difference in temperature between sites, with Dethlingen warmer. Along with the differing chronology between the two sites, this points to significant unresolved issues in the Middle Pleistocene of Germany.

These comparisons raise two interesting issues; firstly that the timing of peak warmth is different across Europe and secondly that there was increased seasonality during the Hoxnian/Holsteinian.

Dealing initially with the question of seasonality, in general, we might not expect this observation because of the nature of orbital forcing during MIS 11. Precession helps control seasonality by altering the earth to sun distance during each season. If the northern hemisphere summer is at perihelion, summers in this part of the globe are hot and winters cold. Precession is modulated by eccentricity; when eccentricity is low, the strength of precession’s seasonal effect is damped. MIS 11 is a period of low eccentricity; therefore seasonality should be relatively low, just taking into account the basics of orbital forcing.

If seasonality is indeed high during the Hoxnian, this could suggest that Britain at this time was somewhat decoupled from very wide scale climatic forcing. Instead, more local changes in atmospheric circulation may have been responsible. East Anglia is presently one of the more continentally influenced climates in the British Isles; this greater sensitivity means that it may not be hugely surprising that continentality in this region was at times higher in the past. Mayes and Sutton (1997) note the modern day importance of easterly airstreams of continental character in the study area. It may be that this regional climatic influence was enhanced during the Hoxnian.

Kuhl and Gobet (2010) also record generally increased seasonality during the Holsteinian in Germany. Koutsodendris *et al.* (2010) also note elevated seasonality, although they present a changing pattern to this, with the earliest stages of the interglacial being more seasonal. This pattern has been noted at other localities; for example, at Lac du Bourget in France (Pross *et al.*, 2000) and Lake Ossowka in Poland (Nitychoruk *et al.*, 2005). With rising winter temperatures during the early stages of the Hoxnian, this signal also appears in Britain, although peak temperatures are reached earlier.

Despite these nuances, the overall impression is of greater seasonality. In contrast, much further to the east, the picture from Lake Baikal suggests lower seasonality during MIS 11 (Prokopenko *et al.*, 2010). We are therefore gradually building up a richer picture of the regional nature of climate during this period.

Kuhl and Gobet (2010) ascribe increased seasonality to the possible absence of a marine connection between the North Sea and the Atlantic, via the English Channel. This follows the suggestion of Pross and Klotz (2002) who argued that sea level changes in the North Sea exert a powerful impact on regional climate. Higher relative sea level means a more maritime climate, whereas a reduction comes through its lowering, leading to more a continental climate, with extremes of temperature.

In this instance, clearly the North Sea was not at a low level. However, Kuhl and Gobet (2010) argue that the absence of inflow of a major source of warm water would have had a similar (albeit less significant) effect; colder winters and increased seasonality. Clearly, this argument is only important if the major breach of the channel had not occurred by this stage.

It is now known that two episodes of catastrophic flooding from large glacial lakes, as a result of the breaching of rock dams in the southern North Sea, carved the channel (Gupta *et al.,* 2007). The exact timing of these events is a matter of considerable debate. Traditionally there have been suggestions that the initial breach occurred at some point during MIS 12 (Gibbard, 1995). However, recent work by Hijma *et al.* (2012) has suggested that a connection remained between Britain and the continent until MIS 5e. If this is indeed the case, then there may well have a role for the North Sea in explaining the observed temperatures. This is particularly the case as there would have been a greater land area (through the "land bridge" to Europe) thus enhancing impact of a cooler North Sea.

A complementary explanation may lie in the behaviour of the North Atlantic Oscillation (NAO), which is one of the most important determinants of winter temperature in this region. During a positive phase of the NAO, west to east atmospheric flow brings warm moist air to Europe, resulting in relatively warm winters. By contrast, during a negative phase, Europe experiences much colder winters, as recorded today and in recent decades (Sirocko *et al.*, 2012).

Recent evidence appears to demonstrate the existence of a distinctly negative phase of the NAO during MIS 11c. Kandiano *et al.* (2012) observe cold sea surface temperatures in the Nordic seas at the same time as warmer conditions in middle latitudes and the subtropics. This translates into steeper meridional sea surface temperature gradients, which is indicative of a negative NAO.

Kandiano *et al.* (2012) also note support for this observation in pollen records from Southern Europe. During a negative NAO, storm tracks shift southwards bringing wetter conditions to this region. Kandiano *et al.* (2012) point to a number of records (e.g. Desprat *et al.*, 2005) in support of pollen evidence for moister conditions.

Therefore, there does appear to be a body of evidence supporting the negative NAO hypothesis and this could well provide at least part of the explanation for the observed seasonality behaviour during the Hoxnian.

On shorter timescales, negative NAO has been associated with periods of cold winter conditions. Shindell *et al.* (2001) argue that the low solar irradiance at the time of the Maunder Minimum forced a shift to a negative NAO, cooling the Northern Hemisphere, particularly in winter. In this instance we are dealing with the decadal timescale, so we cannot necessarily translate this observation onto the multi millennial level. Nevertheless, the Kandiano *et al.* (2012) results suggest a persistence of this behaviour. MIS 11 was a period of weak insolation maxima (driven by precession), perhaps this played a role.

Differences in the timing of peak warmth perhaps point to the existence of an east-west climate gradient, a point that will be further supported in the discussion below regarding abrupt climate change. Britain's position close to the North Atlantic may have helped, both in terms of providing access to initially warmer climate regimes and generally promoting slightly more clement conditions in winter.

In general it is not particularly surprising that warm peak warmth is observed in some records relatively early in the interglacial. Although numerous records see maxima of temperature being reached during the latter stages of MIS 11c (e.g. Jouzel *et al.*, 2007) it is not as though prior to this, during the interglacial, temperatures were cold. For example, Rodrigues *et al.* (2011), in a core off the Iberian margin, record the maximum SSTs during the second half of MIS 11c. However, during the first half, SSTs were close to a degree above modern values.

Elsewhere, Voelker *et al.* (2010) provide SST reconstructions from mid-Atlantic localities. In contrast to the typical picture of late MIS 11c maximum warmth, they show two periods with similarly high SSTs, separated by a cooling at around 415 kyr BP. The first of these two warm periods began at 425 kyr BP. This underscores the point made by Hodell *et al.* (2000) that there is a need to interpret length of interglacial observations carefully, because they can be heavily dependent on the sampling strategy adopted. Regardless, the results of Voelker *et al.* (2010) further emphasise that it is not unexpected to observe warm conditions during the early stages of MIS 11c.

As Britain is strongly influenced by Atlantic climate, it is therefore reasonable that warmer conditions occurred earlier here than they did in more central regions of Europe and that a significant temperature gradient was in operation. This emphasises the importance of terrestrial data from close to the Atlantic margin and the need to construct a picture of climate based on a wide geographic coverage.

The decline in SSTs observed by Voelker *et al.* (2010) is replicated in other records elsewhere. Dickson *et al.* (2009) note that proxy records in regions sensitive to subtle changes in climate (for example at atmospheric or oceanic frontal boundaries) appear to show changes which indicate a shift towards incipient glacial conditions at 415 kyr BP. This coincides with the mid MIS 11 insolation minimum and is also detected in pollen records in southern Europe (Tzedakis *et al.*, 2009b). Since the publication of Dickson *et al.* (2009), further support for their contention can be found in Rodrigues *et al.* (2011) where SST reconstructions also show a slight decline around this time.

This possible shift towards glacial inception does not appear to be recorded during the Hoxnian. If there were significant changes in Atlantic temperature, it might be expected that this would detected in Britain. However, it should be noted that changes in SST were relatively subtle; the decline at this time in the Iberian core of Rodrigues *et al.* (2011) is on the order of 0.5˚C. Voelker *et al.* (2010) is slightly higher, around 1˚C. Nevertheless both are relatively small and perhaps such changes in SST were not significant enough to translate into a terrestrial temperature change in western Europe.

An alternative suggestion is that more northerly regions generally did not experience this climate change. There is a possible hint from core M23414 (Kandiano and Bauch 2007) of a cooling at this time, but it is not particularly clear. Moreover, at Site 980 (McManus *et al.*, 1999) there is no sign of any cooling. As this was a relatively transient event, it may be that these sites simply did not capture it at the resolution sampled. Nevertheless, it is interesting that these more northerly localities, on a similar latitude to the sites here, do not express this shift towards glacial inception. A similar signal is observed at Bilshausen (Kuhl and Gobet, 2010). The Hoxnian may be coherent with this regional picture.

12.3.3 – General trends in Hoxnian climate

Next we can move on to discuss the overall pattern of climate change during the Hoxnian. In terms of timing we have to be cautious because the age of the sequences are derived from correlation. Fig 79 shows a comparison with other records, including MD01-2447 (Desprat *et al.*, 2005), which is used to provide chronological control for the Hoxnian. Furthermore, the chronology for Desprat *et al.* (2005) is derived from orbital tuning as is the Lisiecki and Raymo (2005) record. Therefore this record is not wholly independent either.

Jouzel *et al.* (2007) is dated independently however and this does provide an independent basis for timing. Moreover, regardless of these issues, the trends reconstructed here stand on their own and therefore there is considerable value to these wider comparisons. It is particularly interesting to note the strong similarities in the shape of the EPICA and Lisecki and Raymo (2005) curves compared to the reconstructions presented here. They suggest that despite some of the regional differences and subtleties discussed above, that the Hoxnian ultimately experienced palaeoclimate trends similar to those occurring globally. In essence we have initially rising temperatures, warmth, followed by a deterioration in climate towards the end.

Are there noteworthy features of climate change within this overall trend? In addition to abrupt climate events, other interglacials have seen significant millennial scale variability. One of the most noteworthy examples are the cyclical changes in climate on a 1500 year time scale established by Bond and colleagues from North Atlantic sediment cores (Bond *et al.*, 1997) and ascribed to solar forcing (Bond *et al.*, 2001).

It should be stated that searching such features, in a period of limited chronological control, will be particularly difficult. Indeed, even during the Holocene there is ongoing debate, not just about the causes of such events but even their very existence. Recent research suggests that the cyclicity reported by Bond may in fact simply be a statistical artefact (Obrochta *et al.*, 2012).

Despite these complexities, might we expect to observe millennial scale variability during the Holocene? Pollen in general is capable of recording climate changes of such frequency; for example, Roucoux *et al.* (2001) show a strong relationship between Iberian pollen changes and North Atlantic climate variability during MIS 5a -3. Furthermore, the *pdf* method used here has reconstructed millennial scale climate variability in the Holocene, in response to solar forcing (Kuhl and Moschen, 2012).

In contrast, the search for cyclicity of a Bond type has proved somewhat more difficult using pollen analysis, with evidence often being somewhat cryptic even when a proposed linkage is suggested (e.g. Pelachs *et al.*, 2011). However, some pollen records appear to show a clearer link, in the Mediterranean for example (Dormoy *et al.*, 2009) and the south east of America (Grimm *et al.*, 2006). We might therefore expect that millennial scale climate changes could be recorded in the Hoxnian if they occurred, although teasing out statistically significant cyclical behaviour would be much more challenging.

Beyond the temperatures rising and falling at the beginning and end of the interglacial and the evidence for abrupt change, there do not appear to be any significant other climate changes occurring during the Hoxnian. For much of the interglacial temperatures appear to track relatively closely to a stable mean value. Is this picture reflected in other records from this period? The German sequences at Dethlingen and Bilshausen both appear to show a similar picture, although interestingly the laminated sediments (not the pollen) at Dethlingen appear to show evidence of sub-decadal and decadal cyclicity linked to solar cycles (Koutsodendris *et al.*, 2011).

This seems to be a reflection of a broader pattern observed elsewhere. Analysing the EPICA core and performing a comparison between MIS 11 and the Holocene, Pol *et al.* (2011) observe lower variability during MIS 11. Furthermore, the variability that does occur is predominately found during the cooling phase, after a relatively stable warm plateau. In the North Atlantic, a similar picture emerges with McManus *et al.* (1999) finding that MIS 11 is the longest interval in the entirety of their record (the last 0.5

Myr) without millennial scale changes in SST. We therefore see Hoxnian records reflecting a wider phenomena of MIS 11 climate.

The Hoxnian record appears to generally be quite seasonal with warm summer temperatures and in the Atlantic ocean warm conditions are generally recorded. In some ways, this might be rather surprising. The broad persistence of warm climates over an extended period appears to have led to a substantial reduction in the size of the Greenland Ice Sheet (Raymo and Mitrovica, 2012). Although there is some uncertainty, climate model experiments show that significant melting of the GIS leads to a reduction of AMOC strength and as a result cooling in the North Atlantic (e.g. Stouffer *et al.*, 2006).

What might explain this possible paradox? A similar situation appears to have arisen during the last interglacial, where Sanchez-Goni *et al.* (2012) record the period of greatest warmth in Europe coinciding with maximum GIS melt and a weaker AMOC. Sanchez-Goni *et al.* (2012) undertake model experiments which suggest that Greenland melting affected deep convection close by and reduced AMOC significantly, but this did not translate to a perturbation of overturning in the Nordic Sea and as a result heat transport to Europe remained unaffected. Perhaps similar behaviour occurred during MIS 11.

Turning our attention to the end of the interglacial, Muller and Pross (2007) argue that the insolation minima at 397 kyr BP, terminated full terrestrial interglacial conditions in Europe, based on the decline of thermophilous indicators in various pollen records. Chronologically, they base this argument on tuning to points independent of the precise interval under consideration thus, they argue, enabling them to provide a reasonably objective comparison between records indicating glacial inception and the insolation minima at this time. They also note that the independently dated Devil’s Hole record supports this position (Winograd *et al.*, 1997)

The records presented here provide support for this hypothesis in as much as they demonstrate cooling climatic conditions around this time. Muller and Pross (2007) observe that warm conditions persisted at this time in North Atlantic records of SST. Muller and Pross (2007) suggest that sea level was dropping by this time, indicating ice sheet build up, a position strongly supported by Rohling *et al.* (2010). They go on to argue that these relatively warm oceanic conditions provide a ready supply of moisture to feed the burgeoning continental ice sheets.

Once again we see the regional complexity of climate change, which appears to be a persistent feature emerging from this (and other) discussions. The Eemian has also demonstrated such complexities (e.g. Brewer *et al.*, 2008) and it is encouraging to see MIS 11 climates progress in this way. There are also suggestions from other less intensively studied interglacials such as MIS 7 for a similar picture (e.g. Preusser *et al.*, 2005).

Finally, it is interesting to note that Desprat *et al.* (2005) argue that insolation forcing alone cannot account for the observed shift towards glacial conditions. Instead, a crucial role must have been played by vegetation. Their works draws on an analogy with MIS 5e, for which climate model experiments have been formed and show a crucial positive feedback mechanism from changing vegetation patterns. Although not mentioned by Desprat *et al.* (2005) their work echoes earlier climate model suggestions from Gallimore and Kutzbach (1996).

The arrival of boreal type vegetation towards the end of the Hoxnian is a reflection of a southerly shift in the tree line. Further north the taiga is replaced by snow covered tundra, with a higher albedo, therefore providing positive feedback, further cooling climate. The cooling climate at the end of the interglacial appears, at least in part, to be being driven by the fundamental reorganisation of ecosystems in Europe and beyond. This important finding complements the extensive work being undertaken showing vegetation playing a crucial interactive role in the climate system during the present day and the Holocene (e.g. Foley *et al.*, 2003).

It would be interesting to further explore vegetation-climate feedbacks during this time period. This is prompted by recent GCM modelling research (Herold *et al.*, 2012) which suggests a greater coverage of temperate forest in the Northern Hemisphere during MIS 11 compared to 19, 9, 5 and the Holocene (except the present day). There are interesting hints at the possible impact of this. For example, in the eastern United States, temperate forests have a warming effect on summer temperature (Bonan, 2008).

However, the current state of knowledge about the radiative forcing effects of such forests is surprisingly poor (Bonan, 2008). Any further investigations into this area will have to wait until progress is made in understanding the relationship between temperate forests and climate.

12.4 – Comparison to other interglacial periods

12.4.1 – The present day

The UK Met Office provides spatially averaged climate data at two scales, UK-wide and regional. The regional data is more spatially granular whereas the UK-wide picture is coarser. Because the records generally represent larger spatial scale climates, it is therefore more appropriate to use the slightly wider perspective from the UK data. This set of averages offers three different averaging periods, 1961-1990. 1971-2000 and 1981-2010. This presents an interesting challenge as the selection of averaging period makes a significant difference to the climate observed, as a result of the continuing warming trend.

For example, July temperature in East Anglia has progressed from 15-16ºC in places and 16 to 17ºC in others in 1961-1990, to predominantly 16-17ºC for 1971-2000 to a roughly even amount of 16-17ºC and >17ºC for 1981-2010. January temperatures are relatively similar in the first two averaging periods, but again there has been a warming shift by the time of the most recent period.

Clearly this observation poses a challenge for selection the appropriate modern base level for comparison. Ultimately we are most interested here in the behaviour of "natural" systems. The signal of temperature rise is principally anthropogenic, both globally (Santer *et al.*, 2013 and in England (Karoly and Stott, 2006). In terms of understanding the behaviour of the climate system, a comparison with the earliest period is most appropriate, when the signature of human influence remained minimal. However, it is also instructive to place modern temperatures, with their anthropogenic component, into natural context. Therefore we will perform a comparison with the 1981-2010 averages as well.

	January temperature (ºC)		July temperature (ºC)	
	1961-1990	1981-2010	1961-1990	1981-2010
Athelington	3-4	3-4	16-17	>17
Barford	3-4	3-4	15-16	16-17
Hoxne	3-4	3-4	16-17	>17
Marks Tey	3-4	4-5	16-17	>17
Nechells	3-4	4-5	15-16	16-17
Quinton	3-4	4-5	15-16	16-17
St Cross	3-4	3-4	16-17	>17

Table 18: Modern temperature at the selected sites.

We can clearly see a general shift over this period to a temperature range approximately a degree higher. Even at sites where this has not been observed fit within an overall regional picture in which temperatures are increasing.

It is clear that the Hoxnian generally saw significantly colder winters and probably slightly warmer summers than the modern day, prior to the recent human-derived warming. July temperatures do not appear to have been significantly hotter, but a degree or so higher is a reasonable conclusion. The weight of evidence is indicative of a more seasonal, more continental climate regime, as discussed previously, and strongly suggests a notably different system operating during the Hoxnian, compared to the present. This suggests the need for caution when making overly simplistic comparisons aimed at using palaeorecords to inform current understanding of 20th and 21st century climate changes.

Despite this cautionary note, it is interesting to observe that at the current date, it is only through the addition of anthropogenic forcing that temperatures rise to the point where they are comparable in summer to those recorded in the Hoxnian. There have been periods during the Holocene with comparable summer warmth to the Hoxnian (see below) but under current climatic conditions, human activities are necessary to bring about similar July temperatures.

In terms of rainfall, all of the sites for the period 1961-1990 have rainfall of at least 600 to 700 mm and generally higher, between 700 and 800 and in the Midlands potentially even 8000-1000 mm according to the Met Office data. This is interesting and strongly suggests that the Hoxnian was in fact drier than the present day. Unfortunately a lack of other comparative data for the period restricts much further discussion. This may, however, point to a more continental climate regime during this period, further strengthening observations regarding seasonality.

One note of caution in this regard. The most probable precipitation regime is reconstructed and is quite likely reliable. However, there are relatively few data points in the modern vegetation – climate relationships in areas of high rainfall. This could mean that in palaeo times with high levels of rainfall, such as, potentially, an interglacial, there may be an underestimate of precipitation (Kuhl, pers. comm.).

11.4.2 – The Holocene

The most appropriate basis for comparison during the Holocene is the extensive compilation of pollen based climate data for the Holocene, compiled by Davis *et al.* (2003). Davis *et al.* (2003) divide the continent into six regions, with Britain in the central west. An interesting aspect of this reconstruction is that it shows winter temperature changing more substantially than summer, consistent with the evidence presented here.

Temperatures rise during the Holocene until around 6000 kyr BP. During the Hoxnian, this rise occurs until the start of Ho II in summer and the start of Ho IIc in winter. The Marks Tey sequence suggests the end of Ho IIc at 5000-10,000 years into the interglacial, with Ho IIc appearing to last 2700 years. Therefore within the bounds of chronological uncertainty, this initial temperature rise is approximately consistent with the picture from the Holocene.

The Holocene climatic optimum saw temperatures warmer than the present day and then broadly speaking, across the northern hemisphere, a subsequent decline. In contrast, the Hoxnian sees temperatures being consistently maintained for a considerable period of time after reaching a peak. Dickson *et al.* (2009) argue that that a reinvigoration of meridional overturning circulation occurred in the second half of MIS 11c. This may help to explain why the early peak warmth in Britain was maintained, whereas during the Holocene there was a decline from this initial high. However, as we do not know the full progression of temperatures in the current interglacial, we must be cautious in reaching these sorts of conclusions.

Winter temperatures during the Holocene were significantly higher than the Hoxnian. Summer temperatures may have been slightly below. This further enhances the case for enhanced seasonality during the Hoxnian. The differences observed between the two time periods underscore the fact that although there is a significant orbital analogy, important differences remain. Clearly observed climate is more than simply a reflection of orbital forcing.

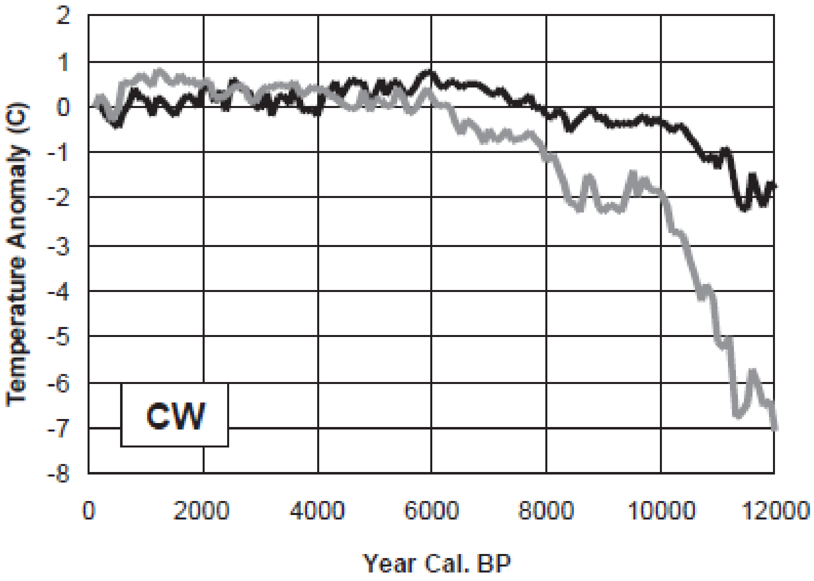


Fig 80: reconstructed summer (darker line) and winter temperatures for the study region during the Holocene (Davis *et al.*, 2003)

12.4.3 – MIS 5e and other interglacials

Moving on to the Eemian, which is the penultimate interglacial in Europe, correlated with Marine Isotope Stage 5e. The Eemian has been the subject of a considerable amount of work in recent years and, in contrast with MIS 11, there are a large number of quantified temperature records and also a range of modelling studies. This means there is a rich data set available for comparison. Ultimately it is hoped that studies of MIS 11 progress to the point where there is a similar richness.

In Britain, last interglacial sequences are referred to as Ipswichian. In common with Hoxnian investigations, studies of this period have become relatively uncommon. From the British perspective, Coope (2010) presents beetle data for which he argues that a consistent weight of evidence suggests summer temperatures of at least 20ºC and winter temperatures of 0ºC. In their review of four Ipswichian sites, Candy *et al.* (2010) also argue for a similar picture. Warmer summer temperatures than the present are also indicated in pollen based temperature reconstructions undertaken by Kaspar *et al.* (2005). Kaspar *et al.* (2005) also reconstruct cooler temperatures in winter than currently, although not to the same extent as the Hoxnian.

Brewer *et al.* (2008) also provide quantitative reconstructions based on pollen, albeit for mainland Europe and not the British Isles. They reconstruct an Eemian with an early peak, followed by a small decline in temperature and finally ended by a sharp decline in temperature and precipitation. The sharp final decline, particularly in temperature, is recorded in the Hoxnian and this suggests that a relatively sudden end to interglacials may be a persistent feature.

Interestingly, there are indications that the end of MIS 5e in Europe was marked by an "aridity pulse" lasting approximately 468 years (Sirocko *et al.*, 2005). Data from the Eifel region documents a decline of thermophilous trees as well as dust storms, aridity and fire. Sirocko *et al.* (2005) ascribe this event to a sudden shift southwards of the North Atlantic current.

There is no particularly strong evidence for aridity and fire during the equivalent phase of the Hoxnian. Moreover, there has been a failure to replicate the aridity pulse in Eemian central Europe (Binka *et al.*, 2011), although this may be due to the greater distance from the Atlantic. However, there are suggestions of stepped declines in temperature at the end of the Hoxnian. There are not many reconstructions by this point and there is no temporal control and these may just reflect the general decline in temperature referred to above (sharp but not abrupt, on a centennial scale). Nevertheless it is an intriguing possibility that related behaviour was occurring at this time.

The results of Kaspar *et al.* (2005) suggest that MIS 5e in Britain also saw enhanced seasonality, along with the Hoxnian. It would be interesting to see how this compares to Marine Isotope Stages 7 and 9. Perhaps strong interglacials also see more extreme ranges of climate, in contrast to weak ones such as MIS 7. This would be an interesting hypothesis to test.

There is some preliminary evidence for warm conditions during MIS 9 in Britain. Fluvial deposits on the River Lea in London suggest conditions that were warmer than during MIS 7 and the Holocene (Green *et al.*, 2006). However this is based on data from a single site and needs further work, potentially including quantitative palaeoclimate reconstructions of the type performed here.

A comparison between multiple interglacial periods was undertaken by Candy *et al.* (2010) based numerous British interglacial records, before and after the MBE. Their fundamental conclusion is that there is no particularly significant transition in Britain across this boundary. Moreover, they argue that this case expands more widely into the North Atlantic region, citing the SST record of Ruddiman *et al.* (1986) which shows similarly between pre and post MBE interglacials.

The data presented here is fully consistent with the hypothesis presented by Candy *et al.* (2012). The temperatures presented for the Hoxnian do not show particularly unusual levels of warmth compared to the indicators for pre MIS 12 interglacials in Britain. For MIS 19-13, Candy *et al.* (2010) suggest a typical Tmax of between 16 and 17˚C to low 20˚C and a typical Tmin of 6˚C or below to 4 or 5˚C. In addition the suggestion that more northerly Atlantic regions did not experience a mid-MIS 11c cooling adds an additional dimension to Candy *et al.*’s (2010) suggestion of a decoupling to of climate in the North Atlantic.

This picture is complicated, however, by recent analyses of herpetofauna at Gran Dolina, Spain (Blain *et al.*, 2012). Other than Candy *et al.* (2010) this is the only attempt to explicitly compare terrestrial climates on either side of the MBE. In contrast to Candy *et al.* (2010), Blain *et al.* (2012) observe a distinct difference between pre and post MBE interglacials. The latter are both warmer and drier than the former.

The Blain *et al.* (2012) findings again indicate the complexity of regional climate during the Pleistocene and could possible refine the Candy *et al.* (2010) hypothesis. Their suggestion of North Atlantic climate decoupling may be restricted to northerly areas rather than areas such as Spain, which are broadly in the North Atlantic. However, as discussed in Chapter 2, Tzedakis *et al.* (2006) record the most significant shift in southern European vegetation occurring during MIS 16.

Taking a broad perspective, we can turn to the model simulations of Yin and Berger (2010). Their models suggest warmer interglacials post the MBE event, primarily as the result of increased global mean temperatures during northern hemisphere winters. The big picture presented by Yin and Berger (2010) appears to be contradicted at the relatively local scale by the results here and more generally by Candy *et al.* (2010). However, it is interesting to observe some of the nuances of their results, which are expressed in terms of a temperature difference between pre and post MBE interglacials.

During winter and summer, looking specifically at Britain and the wider eastern north Atlantic region there is actually no difference expressed between the interglacials either side of the MBE during winter. This region stands out very sharply in contrast to other areas in the northern Hemisphere in not showing any significant change during this season. It would not be appropriate to place too much emphasis on results obtained for the fine spatial detail in a Global Climate Model. However, this regional feature is quite extensive and presumably reasonably robust.

Candy *et al.* (2010) point to the similarities in sea surface temperatures in the Atlantic during the pre and post MBE. Interglacials MIS 19-13 are not particularly cooler then MIS 11-1. It seems reasonable to suggest that conditions in the Atlantic Ocean may be responsible for the regional picture. Generally warm conditions in the ocean promote similarly warm conditions on land, in the interglacials either side of the MBE. The Atlantic may be playing a dominant role in regional climate, mitigating against the primarily insolation driven changes of the MBE dichotomy.

Alonso-Garcia *et al.* (2011) present data suggesting that interglacials saw a shift northwards of the Arctic front after MIS 21. This may have been an important contributory factor in enabling the Atlantic to contribute to warm interglacials even before the MBE. It would be interesting to observe terrestrial temperatures prior to MIS 21, but unfortunately the record at this time is highly fragmentary.

We should recall that Blain *et al.* (2012) present a different perspective to the results in this thesis. In addition, a cautionary note must be added regarding oceanic temperatures. Although Candy *et al.* (2010) point to Ruddiman *et al.* (1986) and McManus *et al.* (1999) as showing comparable SSTs in pre and post interglacials, there is evidence to contradict this. Lawrence *et al.* (2009) present SST from the north Atlantic. Although they principally focus on the Pliocene, their record stretches until the present day. MIS 19 to MIS 13 are all consistently cooler than MIS 11 to MIS 1, although 19-15 are only slightly warmer than 1 and 7.

More records need to be analysed before we can truly build up a picture of European climate across this interval, in addition to a complete picture of sea surface temperature. It is clear that a significant amount of work remains before we can understand the European terrestrial response to the apparent broad scale change in the climate system during the MBE recorded by data and models.

12.5 – Abrupt climate change during the Hoxnian

Despite the assorted uncertainties in these reconstructions, it does appear as though there is evidence of instability in climate recorded. In particular the enigmatic NAPP phase will be proposed as representing a distinct climate cooling event. Furthermore, the possibility of other climate fluctuations will also be discussed.

12.5.1 – Establishing the existence of abrupt climate changes during the Hoxnian

The most appropriate way to investigate this issue is through hypothesis testing. As Alley and Agustdottir (2005) note, once the reality of abrupt events in the Quaternary record became clear, a natural tendency to "anomaly hunt" became apparent. The benefit of searching for related anomalies is that a richer and more detailed picture of a particular event develops. The downside is that there may be a tendency to conflate different signals or, worse, to see a signal when one is not there.

One possible way to help avoid some of these pitfalls is to develop a hypothesis regarding a particular event that can then be tested. Shuman (2012) notes that this is not a straightforward task, arguing that making specific predictions deriving from a particular process driven hypothesis can be difficult given the inherent limitations of the discipline. Ultimately this relates to the long running debate concerning the possibility and problems with hypothesis in the geological sciences (for example, Vermeesch, 2009).

However, despite such complications, producing a hypothesis is a reasonable way to proceed. Starting from basic principles:

1. Abrupt climate change is a pervasive feature during the Quaternary and during periods of deglaciation in particular (Alley, 2007. It is therefore quite probable that such events took place during the Middle Pleistocene and we might expect to find evidence for this.

2. If abrupt climate change did occur, vegetation is capable of recording it. This indeed appears to be the case. Tinner and Lotter (2001) demonstrated that the response of pollen and vegetation ecosystems to the 8.2 ka event was rapid, as did Veski *et al*. (2004). The general fact that a number of pollen records seem to show this climatic cooling further supports this.

   There is further evidence that vegetation and pollen is capable of responding to and reflecting abrupt climate change during the Younger Dryas. The studies at Krakenes and Gerzensee during the Younger Dryas (Birks and Ammann, 2000) provide an excellent example of this. Williams *et al*. (2002), based on a compilation of pollen records from North America and Europe during the Late Glacial, demonstrate that vegetation consistently responds on timescales less than 200 years and frequently less than 100 years.

3. If abrupt climate change did occur there will be a regional signal. The event will be detectable in records not only from the UK but also from the continent. This will to some extent be constrained by the smaller number of appropriate studies undertaken. Nevertheless we will expect to see the event recorded in more than one record from more than one locality.

   Williams *et al*. (2002) demonstrated a rapid vegetation response, but also a geographically widespread one. Pollen sequences on both side of the Atlantic were responding to a common forcing. As Williams *et al*. (2002) note, this combination indicates a tight coupling, at times, between vegetation and the atmosphere. This is further demonstrated by Gajewski *et al*. (2006), who show a synchronicity in major vegetation transitions during the Holocene both within North America and Europe and between the continents. They further show that there are correlations with environmental changes recorded in Greenland and North Atlantic sediments. These major vegetation changes were therefore likely responding to major atmospheric circulation changes. We therefore see pollen recording major changes and over a wide area.

4. Given the known behaviour of previous abrupt climate changes, a cooling, synchronous within the limitations of the chronological controls available, will be observed. This will be accompanied by a change in moisture regime, likely to drier conditions, although this cannot strictly be predicted in light of the complex regional changes in precipitation during the 8.2 ka event observed by Magny and Begeot (2004).

We will now consider the evidence for abrupt climate change on a site by site basis. The lack of chronological control makes it difficult to assess what time scale an oscillation in a curve spans. It is probable that the tighter the deviation, the more abrupt, but we cannot be certain. This will constrain the following exercise, but we can nevertheless make reasonable investigations into this subject.

Athelington

There is no particularly strong evidence of substantial short term climate change in the Athelington record.

Barford

The Barford record is relatively stable and no particularly clear abrupt signals are apparent. Possible exceptions are a cooling observed in winter temperatures towards the end of Ho IIc and also one during Ho IIIb.

Hoxne

The Hoxne record contains a considerable amount of variability making it difficult to pick out significant events. Ho IIc in particular sees a lot of variance. Of these changes, the one at the end, recorded in winter, spans the narrowest portion of the pollen zone and is therefore presumably the most abrupt.

Marks Tey

The lower sequence at Marks Tey shows three particularly notable events, two of which occur during Ho I. There is then a relative period of stability which is interrupted by a distinct cooling at the end of Ho IIc. These features are displayed in all three climate metrics; summer temperature, winter temperature and precipitation.

The top part of the sequence displays a general trend of climate deterioration. There is a significant amount of variability within this part of the record. The most consistent feature appears to be a cooling recorded in both summer and winter at the end of Ho IVa and precipitation decline.

Nechells

Nechells is a hugely variable record and it is difficult to discern coherent signals of abrupt change beyond those presumably introduced by noise. Perhaps the clearest changes are those recorded in the early part of the record, particularly in winter temperature.

Quinton

As with Nechells, high variability introduces complications into the study of abrupt events. The sharpest changes are those recorded in winter temperature, particularly at the top of the sequence. Precipitation shows few noticeable changes and summer is also relatively stable.

St Cross

St Cross shows one of the clearest examples of abrupt climate change amongst all of the records. It displays a very distinct cooling during winter and a coeval decline in precipitation before recovering to previous levels.

12.5.2 – The Non Arboreal Pollen Phase as an 8.2 ka type event

The NAPP is hypothesised here to be the result of freshwater forcing in the North Atlantic, similar to the 8.2 ka event observed during the Holocene (Alley and Agustdottir, 2005). The following discussion will be divided into a search for related abrupt climate changes in Europe, a description of the 8.2 ka event and a discussion of the mechanism forcing it, followed by an investigation of the similarities between the abrupt MIS 11 change and the 8.2 ka event. Because an analogy is being drawn, it is important to provide a detailed exploration of this major early Holocene climate event.

Records of an NAPP in Britain and Europe

The most consistently observed abrupt climate event is that which is found towards the end of Ho IIc. This corresponds to the Non Arboreal Pollen phase at each of the sites where this cooling is record. Being observed clearly in more than one reconstruction gives us confidence that a significant signal exists, however we must ask why it is not so clearly present in all those reconstructions that span this period.

The most straightforward case is that of Athelington where sampling resolution was low and so the NAPP was not recovered. At Quinton there was no clear NAPP in the diagram used for the reconstruction and therefore it is unsurprising not to find it. Thomas (2001) reports its presence and undertook pollen sampling herself. Unfortunately her pollen data were not available for use in this thesis.

The NAPP associated cooling at Hoxne does not appear particularly clearly in the reconstruction, but it is present. Interestingly it emerges more distinctly in the reconstruction performed with thresholds. It is also not overly prominent at Barford, but does appear to be present. It is particularly clear at Marks Tey and St Cross and this is a sufficient basis to provide support for the abrupt climate change hypothesis described above. Moreover, the chronology from Marks Tey (Turner 1970) suggests an event lasting around 350 years, which can reasonably classify as rapid climate change.

It should be noted that in proxy palaeoclimate reconstructions, there is a tendency for a bias towards the mean (Birks, 1998) and actually an underestimation of climatic change (Birks, 2003). This can result from a wide variety of methodological concerns, in this instance the pdfs being represented by normal distributions and the combination of numerous taxa has this effect (Kuhl and Gobet, 2010). The practical implication of this issue is that fine scale climate changes may not always be detected and variability not captured. The fact that there is good agreement from a number of sites, despite this limitation, is good evidence that a robust signal is being recorded.

To provide additional support we must look further afield for similar events. Kukla (2003) points to a number of other European localities where an NAPP type signature is recorded. Most significantly are localities in Germany: the pollen diagram from Munster Breloh (Muller 1974) contains an abrupt event, a decline in temperate taxa known as the older regressive phase. Most recently, Koutsodendris *et al.* (2012) at the nearby site of Dethlingen has presented compelling evidence for a similar abrupt shift in vegetation and climate.

Koutsodendris *et al.* (2012) refer to their event as the Older Holsteinian Oscillation (OHO). In basic terms it is characterised by a short term decline of temperate trees and an increase in boreal taxa, specifically birch and pine. The varve chronology they have constructed enables them to provide a duration for the OHO, suggesting a length 220 years. The decline in temperate trees (from 27 to 4.5% of the total spectra) occurred in just 90 years.

In addition to changes in vegetation, Koutsodendris *et al.* (2012) record changes in the diatom assemblage during the OHO. For example, an increase in *Fragilaria* spp. is indicative of a prolonged period of ice cover. In addition, the increase of the spring bloomer *S. medius* suggests changes in lake stratification that reflect a cooling climate. Ultimately, Koutsodendris *et al.* (2012) argue that their evidence demonstrates not only an abrupt shift to colder climate but also more significant cooling during winter. This is wholly consistent with the evidence presented in this thesis and offers powerful support to the rapid climate change hypothesis outlined above.

Is it possible to relate the OHO to the NAPP? Koutsodendris *et al.* (2012) assume that they correlate though they do not actually provide a basis for this. An assumed correlation is not entirely unreasonable; the nature of both events is similar and both were clearly highly significant occurrences. Therefore it makes a degree of logical sense that they represent the same event at the same time. However it is important to attempt to provide a more objective basis for this.

The lack of strong chronological control in the Hoxnian makes this task difficult. Turner (1970) estimates that Ho IIc lasted 2700 years and the NAPP occurred towards the end of this period. Taking a very crude perspective, Ho IIc covers two metres at this site, therefore each cm represents 13.5 years. The NAPP begins 1.4 metres from the base of this zone and so began 1890 years into Ho IIc.

Turner (1970) also estimates the presence of between 5000 and 10,000 laminae couplets until the top of Ho IIb. Taking the lower end of this estimate we have the onset of the NAPP at 6890 years into the interglacial. Broadly speaking this agrees reasonably well with Koutsodendris *et al.* (2012) who establish a starting age of 6000 +/- 500 years into the interglacial. Clearly there is a huge degree of uncertainty associated with the reasoning presented here. However there is sufficient coherence to, at the very least, not falsify the abrupt climate change hypothesis and, fairly reasonably, lend it some support.

Ashton *et al*. (2008) draw attention to other possible NAPP phases in European cores, again suggestive of a wider event. Obviously, the correlation ties them together and so this cannot be used as independent evidence where timing is concerned. However, other localities can provide such evidence and there is an extensive list provided in Koutsodendris *et al.* (2012). These localities cluster in central and northern Europe, suggesting that this event may not have propagated especially widely.

What was the 8.2 ka event?

With the occurrence of an abrupt climate event established as a plausible working hypothesis, we must now turn to the cause of this. In arguing for an 8.2 ka type event, we are building on the preliminary suggestion voiced by Kukla (2003) who speculated about a rapid climate change, “occurring in response to a major glacier surge into the northern North Atlantic.”

The 8.2 ka event was first clearly resolved in Greenland ice cores; Johnsen *et al*. (1992) simply refer to it as a δ^{18}O minimum, occurring at 8210 +/ 30 yr BP. Subsequently, numerous ice core analyses of the event were published, and have been collated by Alley *et al.* (1997) and Alley and Agustdottir (2005). The latter summarise the picture from Greenland as having involved “a notable cooling; drop in snow accumulation rate; rise in wind-blown dust, sea salt and forest-fire smoke; and drop in methane.”

The temperature fall in Greenland was significant and has been estimated by a number of authors; Alley *et al*. (1997) suggest 6ºC, Leuenberger *et al*. (1999) reconstruct 7.4ºC with Kobashi *et al*. (2007) somewhat smaller at 3.3ºC. The timing of the event in Greenland has been most precisely clarified by Thomas *et al*. (2007), who show a 160.5 year period with depressed δ^{18}O values, and a central spike lasting for 69 years. They also suggest that atmospheric circulation was little changed. Kobashi *et al*. (2007) report a similar duration of 150 years with a particularly cold period of around 60 years.

Away from Greenland, Alley and Agustdottir (2005) review the evidence from North America and argue that it appears most strongly in proxy records from the eastern part of this region. In this review we are more interested in the European picture and so an extensive discussion of the North American evidence is not necessary. Nonetheless, it does seem to reveal itself in a number of records, pollen profiles included. For example, Shuman *et al*. (2002) infer a century long cooling from pollen records in Massachusetts.

In European proxy records, there is a reasonable degree of clarity regarding the 8.2 ka event. One of the first British papers to make the link with the event in Greenland was Rousseau *et al*. (1998) who reported a cooling of around 1ºC based on land snail assemblages. Garnett *et al*. (2004) performed isotopic measurements on ostracod shells, with the δ^{18}O record showing a cooling. Mg/Ca data also suggests that the event was dry (Garnett *et al.*, 2004). This observation of drier conditions was also picked out by Baldini *et al*. (2002) based on shifts in strontium and phosphorus in an Irish speleothem. The dry climate event in this record lasts for 37 years. Marshall *et al*. (2007) used a chironomid based palaeotemperature reconstruction to demonstrate a cooling of 1.6ºC at Hawes Water in north-west England.

The 8.2 ka event is resolved in a number of European pollen records. Tinner and Lotter (2001) documented evidence from two lakes in Switzerland and Germany, Soppensee and Schleinsee. At both these sites, the most distinctive feature is a sudden collapse of hazel (30% to 13% at Soppensee and 40% to 16% at Schleinsee). This is accompanied by a rise in pine, birch and lime, as well as the invasion of beech and fir. The chronology at these sites is reasonably precise; the fall in hazel appears to have occurred in less than 20 years, demonstrating a very rapid response of the ecosystem to abrupt climate change.

Seppa *et al.* (2009) performed and compiled a pollen based temperature reconstruction for 36 sites in Fennoscandia. The 8.2 ka event appears in many of these records, particularly at sites close to the range limits of thermophilous taxa. The records with higher resolution show an annual cooling of 1ºC, followed by an abrupt warming of 2ºC in around 50 years (Veski *et al*., 2004). A cooling of a degree or so appears to be a common feature of pollen records and indeed European proxy records in general (Alley and Agustdottir, 2005). An exception comes from sites in France, where falls of between 2 and 2.5ºC are reconstructed (Magny and Begeot, 2004).

Magny and Begeot (2004) and Magny *et al*. (2003) also draw attention to regional changes in precipitation during the 8.2 ka event. This period is generally seen as being cold and dry in Europe, however there is evidence from a central belt of the continent that conditions became wetter. Magny and Begeot (2004) argue for a tripartite subdivision, with southerly and northerly regions being drier and a central belt between 50ºN and 43ºN, seeing increased precipitation. They also suggest such an occurrence for other periods of cooling, suggesting that it is a robust palaeoclimatic feature. Magny *et al*. (2001) argued for a key role for the Atlantic Westerly Jet, with a southerly position enhancing cyclonic activity and increasing precipitation over mid latitudes.

It is important to consider the role of seasonality in the 8.2 ka event. Alley and Agustdottir (2005) argue that cooling was significantly greater during winter then summer. They note that most proxies tend to be biased towards the reconstruction of summer temperatures. As a result, the magnitude of winter cooling will be downplayed.

Although the 8.2 ka event seems to be a robust feature of North Atlantic proxy records, there are considerable complications. Rohling and Palike (2005) conducted a review of the proxy evidence during this period and conclude that in addition to the major anomaly at 8.2 kyr BP, there is also a broader climate deterioration between 8.6 and 8 kyr BP. In some records, the temporal resolution may be insufficient to be able to reliably discriminate between the two. For example, Rousseau *et al.* (1998) report their cooling as having occurred between 8500 and 8000 cal yr BP. This more gradual event has different underlying forcings and is spatially widespread, being found both in the North Atlantic and further afield. Rohling and Palike (2005) suggest that the sharp event may be restricted to the North Atlantic.

Other authors concur with this suggestion; Thomas *et al*. (2007) say that the evidence is weak that sites further away are displaying the same abrupt signal. Thomas *et al*. (2007) also highlight the fact that this conclusion can potentially lead to confusion if events are not robustly defined. They state that the term “8.2 ka event” ought to be reserved for signals of a timing and duration that they report; i.e. around 160 years, 8200 years ago. The Rohling and Palike (2005) review also highlights the dangers of pattern seeking.

What caused the 8.2 ka event?

The 8.2 ka event is generally believed to be caused by an injection of freshwater into the north Atlantic, causing slowdown of the thermohaline circulation (THC). The hypothesis that switches in the THC is responsible for abrupt climate change was first fleshed out by Broecker *et al*. (1985) and the research field is summarised by Alley (2007). Deep outflow of cold North Atlantic Deep Water, due to density driven sinking in high latitude seas, is balanced by a warm northwards surface flow that transports heat into the North Atlantic and serves to moderate climate. A freshwater injection can serve to depress the density differences that promote sinking, thus slowing down or shutting off the circulation and depriving the North Atlantic of the heat brought from southerly latitudes. Although there are many details still to be established, there is a consensus that this mechanism has indeed operated and has led to rapid climate fluctuations (though see Wunsch, 2003).

Most modelling of freshwater forcing has focused on the Younger Dryas or treats the subject in general terms, and has persuasively demonstrated that perturbations in the THC can occur as a result of this mechanism (e.g. Rahmstorf, 1995). However, there have been some research efforts devoted specifically to the 8.2 ka event. In their major review, Alley and Agustdottir (2005) were only able to point to a handful of studies. Moreover, though consistent with the hypothesis, there have been limitations associated with some of the research undertaken. For example, Renssen *et al.* (2002) use an inappropriately large volume of flood water (Clarke *et al.*, 2009).

In recent years, there has been an increase in the research devoted to this particular anomaly. In particular, LeGrande *et al*. (2006) and LeGrande and Schmidt (2008) demonstrate not only that freshwater forcing can impact upon the THC, but that the specific proxy responses observed can generally be replicated with a reasonable degree of consistency. The complexities of the event have also been fleshed out by Wiersma et al (2011) who observe a delayed response, potentially on the decadal scale, between forcing and temperature change.

A significant general observation regarding the freshwater forcing hypothesis is that it leads to greater cooling in winter. The cooler climate results in greater production of sea ice, which acts as a positive feedback to further driver down winter temperatures (Alley and Agustdottir, 2005). Denton *et al.* (2005) also argue for the significance of seasonality during abrupt climate change and a dominance of winter cooling.

An additional consequence of thermohaline circulation slowdown (or shutdown) is a shift in North Atlantic wind circulation from a meridional (southwest to northeast) to a zonal (west to east) pattern. Interestingly, Seager and Battisti (2007) argue that a complete understanding of the observed climate changes associated with these abrupt events must include a central role for these variations in wind regime. The shift to zonal conditions would cause extensive cooling of Europe.

Clearly, there also has to be evidence for a large injection of freshwater coincident with the 8.2 ka event. This does indeed appear to be the case, with the largest pulse of the last deglaciation occurring at this time (Barber *et al*., 1999), as a result of the catastrophic drainage of glacial Lakes Agassiz and Ojibway. Further complementing this picture is the evidence for cooling and freshening in the North Atlantic at this time as well as a reduction in deep flow speed (Ellison *et al*., 2006). Kleiven *et al*. (2008) also record changes in flow speed around 8.2 kyr BP, demonstrating a significant reduction in lower North Atlantic Deep Water in the northwest Atlantic.

Some potential inconsistencies remain; though progress is being made (e.g. Ellison *et al.* 2006), there has traditionally been equivocal and sparse evidence for changes in the North Atlantic meridional overturning circulation (MOC) (Keigwin and Boyle, 2000) for example. However, as research in this area progresses new findings generally tend to support the hypothesis. Most recently, Hoffman *et al.* (2012) present evidence for freshwater discharge into the Labrador Sea, where it has the chance to significantly perturb deepwater formation. This is a particularly significant piece in what remains of the 8.2 ka forcing puzzle.

An 8.2 ka type event during MIS 11

The reconstructions offered here, combined with the evidence from Europe are strongly suggestive of an abrupt climatic event during MIS 11. The most likely analogy is to be found with the 8.2 ka event. It is particularly encouraging to see the strength of the winter signal in the records here and also that presented by Koutsodendris *et al.* (2012). This is consistent with a freshwater forced slowdown on North Atlantic thermohaline circulation and the significance of seasonality as described by Alley and Agustdottir (2005) and Denton *et al.* (2005).

The fall in precipitation is also consistent with an 8.2 ka type event. The spatial variability of precipitation changes during the 8.2 ka event was mentioned above. Magny and Begeot (2004) divide the European continent into three geographical moisture regimes associated with the position of the Atlantic Westerly Jet, with Britain in the northerly dry region. This seems to be a persistent feature of late Pleistocene cooling events and appears to have been replicated in the Hoxnian as well.

In terms of the change in climate, the two records with the clearest signal, Marks Tey and St Cross both show around a 2 to 2.5ºC cooling. Hoxne is closer to a 3ºC drop in temperature and Barford only around 1ºC. Generally speaking this is a good degree of agreement, further bolstering the case for a coherent signal. A cooling of this magnitude is a little higher than the typical average based on pollen records for the 8.2 ka event (Alley and Agustdottir, 2005), although it is comparable to French records (Magny and Begeot, 2004).

Koutsodendris *et al.* (2012) suggested that the temperature decrease would be lower in Britain than in Central Europe. An east-west temperature gradient, possibly as a result of weakened westerlies (bringing warm air to Central Europe) and/or a stronger influence of the Siberian high (bringing cold air to Central Europe) may have been in existence. This suggestion has been corroborated by the work here; the fall of around 2ºC is lower than that reconstructed in Germany, a little over 4ºC, using the same methodology as here Koutsodendris *et al.* (2012).

Note that not all Hoxnian sites display evidence of the NAPP and as a result the climate cooling reported here. As a general point, this is not necessarily a particular concern because a site simply may not detect the event. For example, Head *et al*. (2007) fail to detect the 8.2 ka event in a pollen record from western Ireland. They argue that the event was of insufficient magnitude or duration to be detected. An alternative, or perhaps supplementary, explanation is that the site is a small basin and so reflects local processes. Local ecological processes may dominate over the wider picture, particularly as the ecosystem was already rather open and herbaceous. Irrespective of the reason, the Head *et al*. (2007) result demonstrates that even with an event as well established as that at 8.2 ka, there may not be a signal preserved.

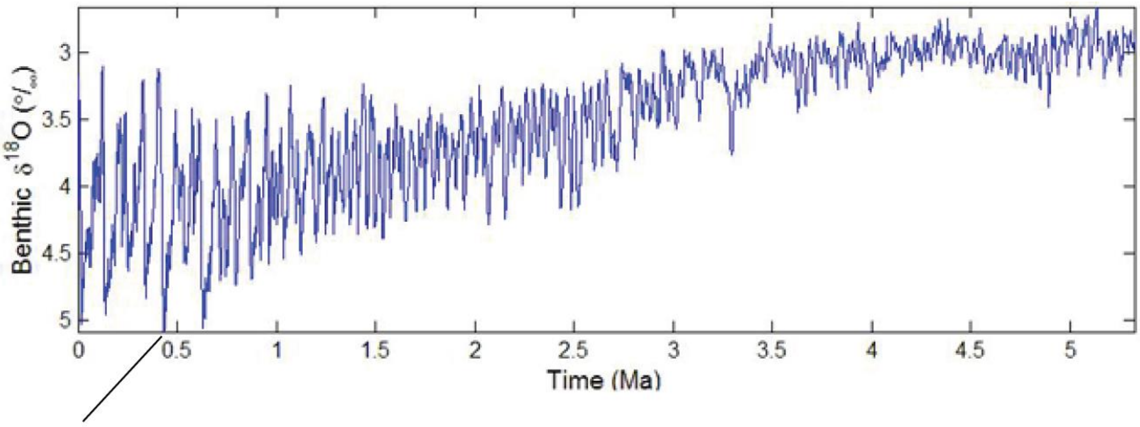
In the Hoxnian, the lack of a signal from some of the localities studied here is discussed above. Beyond this, there are Hoxnian sites where no NAPP is recorded. Typically these are fluvial localities. Thomas (2001) notes the importance of sedimentary processes in the preservation of the NAPP, arguing that fluvial sites generally have a lower resolution when compared to lake sites, hence the lack of the NAPP in any terrace record.

Finally, what about the possibility of overprinting of distinct events, as discussed by Rohling and Palike (2005). This seems unlikely to be the case here; according to the chronology from Marks Tey, the NAPP was indeed abrupt, around 350 years from the decline of trees to their recovery. Such a short term feature is indeed indicative of very rapid climate change, although it is a century or so longer than high precision records for the 8.2 ka event and a little longer than suggested by Koutsodendris *et al.* (2010). This mismatch could well be the result of the less robust varve analysis undertaken by Turner (1970) compared to these authors. Nevertheless it appears clear that the event was of shorter duration than a more gradual climatic deterioration of the type identified by Rohling and Palike (2005).

An 8.2 ka type forcing mechanism during MIS 11

What evidence is there for an appropriate forcing mechanism at this time? Given that progress is still being made (e.g. Ellison *et al.*, 2006) in reconstructing the trigger for the 8.2 ka event, clearly there is going to be substantially more uncertainty during MIS 11. However, we can look for evidence generally consistent with the hypothesis. One important aspect to consider will be how to explain the fact that the 8.2 ka type event of the Hoxnian occurred significantly further into the interglacial than the 8.2 ka event itself.

Clearly, the most basic requirement is the presence of a northern Hemisphere ice sheet during the preceding glacial period, MIS 12. The Laurentide Ice Sheet will have been in place by this point; indeed it appears to have reached its full extent as early as 2.4 myr ago (Balco *et al.*, 2005). Major ice sheet build up during glacial periods would therefore have been common throughout the Pleistocene and it seems to have reached an apogee during MIS 12, which was the coldest and most severe glaciation of all. For example, in the 5.5 myr long benthic stack of Lisiecki and Raymo (2005), MIS 12 has the heaviest δ^{18}O values throughout the entire time period, with the exception of MIS 16 which reaches a comparable low (Fig 81). It consequently seems probable that MIS 12 will have set the scene for significant ice sheet – ocean interactions during MIS 11.



MIS 12

Fig 81: The LRO4 stack (Lisiecki and Raymo, 2005). Taken from www.lorraine-lisiecki.com/stack.html

Not only was there a particularly intense glacial during MIS 12, the transition from this appears to have been prolonged. In general terms, Lang and Wolff (2011), in discussing the relationship between glacial and interglacial strength (strong glacial followed by strong interglacials) reference the conceptual model proposed by Parrenin and Paillard (2003).

It has generally been considered strange that a period of relatively weak insolation forcing could produce an interglacial as strong as MIS 11. Parrenin and Paillard (2003) propose terminations as a result of a threshold occurring both in terms of ice sheet volume and astronomical forcing. If forcing is weak, then terminations need a stronger glacial maximum (Lang and Wolff, 2011). In contrast to terminations, glacial inception solely occurs through astronomical forcing, leading to a longer period of deglaciation when forcing is weak (Lang and Wolff, 2011) as it was during the time period in question. Parrenin and Paillard (2003) also observe that the necessity for the build-up of large ice sheets to produce a strong interglacial may lead to large freshwater discharges into the North Atlantic.

So this broad conceptual framework suggests a lengthy deglaciation and the potential for the injection of significant volumes of freshwater into a critical region. This provides important general support for the abrupt climate change proposition. Moving into more specific detail, Koutsodendris *et al.* (2012) make an important observation regarding the sea level reconstruction presented by Rohling *et al.* (2010). In their reconstruction, sea level comparable to today is not reached until approximately 404 kyr BP, around 20 kyr into the interglacial. This strongly implies the persistence of large volumes of ice until well into the interglacial, possibly as a result of peak warmth being delayed until the second half of MIS 11c (Jouzel *et al.*, 2007).

In the high northern Atlantic full interglacial conditions are documented as lasting for only 10 kyr, between 398 and 408 kyr BP (Bauch *et al.*, 2000). Deglaciation at this locality lasted for a considerable period of time, from 430 to 410 kyr BP, further supporting the persistence of ice and a lengthy deglaciation. Kandiano and Bauch (2007) studying core M23414, which lies close to the same latitude as these study sites, in the North Atlantic, note that meltwater processes continued until 411 kyr BP. Moreover, significant ice rafted debris (IRD) deposition was ongoing up until this time. This is a very strong indicator that ice sheets were continuing to interact with the oceans, well beyond the likely point at which the NAPP occurs (possibly 414 kyr BP at the latest).

At Site 980 (McManus *et al.*, 1999), again to the west of the British Isles, there is extensive IRD deposition across the MIS 12/MIS 11 transition and into MIS 11c. There is a particularly major spike at approximately 418 kyr BP, which could potentially coincide with the NAPP. There is a further event at approximately 410 kyr BP. Despite M23414 and Site 980 being relatively closely located, there is a 4000 year difference in the length of full interglacial conditions between the two sites. This points to a certain degree of uncertainty and re-emphasises the difficulty in attempting, based on current data, to link any events with great certainty. But we do see evidence consistent with the forcing necessary for an 8.2 ka type event.

Knies *et al*. (2007) present a study of Arctic freshwater forcing on the thermohaline circulation during the Pleistocene (Knies *et al*., 2007). The authors note a “spectacular” freshwater pulse during the MIS 12/MIS 11 transition that they ascribe to the melting of icebergs and the disintegration of large ice sheets. This pulse appears to have led to the destabilization of thermohaline circulation in the north Atlantic (Knies *et al.*, 2007). The event appears to occur probably slightly earlier than the proposed date of the NAPP, around 420 kyr BP. But with a sampling resolution of 2-3000 years there is temporal uncertainty. Finally, Matrat *et al.* (2007) analysing cores from the Iberian margin show fluctuations in NADW production occurring until approximately 410 kyr BP, with one major event around 413 kyr BP.

Interestingly, recent simulations by Gregoire *et al.* (2012) suggest that meltwater pulses may have resulted from specific ice dynamical behaviour, specifically the separation of particular parts of the North American ice sheet. Meltwater Pulse 1A was likely driven by the separation of the Laurentide and Cordilleran Ice Sheets and the 8.2 ka event by the separation of the Labrador and Baffin ice domes (Gregoire *et al.*, 2012). More substantial volumes of ice may have prolonged these separations, hence the later occurrence in MIS 11c of a freshwater related cooling.

Another important forcing mechanism may have been large volumes of iceberg discharge from the decaying Laurentide Ice Sheet, supplementing the more conventionally recognised freshwater drivers (Wiersma and Jongma, 2010). Again, persistence of ice long into the interglacial provides the opportunity for this particular factor to have an impact.

It is difficult to identify specific freshwater forcing events that correlate with the NAPP. Despite the considerable number of marine records spanning this period, there is a significantly lower temporal resolution compared to the Holocene. Significant advancements in this respect must be made before any correlation can be made with confidence. Hopefully such efforts will be made as they have recently been for the last interglacial. Nicholl *et al.* (2012) present evidence for a Laurentide outburst flood event during the early part of MIS 5e. This flood passed through the Hudson Strait and into the Labrador Sea. They suggest that such events were likely pervasive features of the early part of Late Quaternary interglacials.

An interesting speculation is that with a lengthy deglacial period and the loss of larger volumes of Northern Hemisphere ice, the North Atlantic may have been more vulnerable to the injection of freshwater. Perhaps this could explain why a greater decline in temperature is recorded in the pollen based reconstructions presented here, compared to Holocene pollen records.

12.5.3 – Other abrupt climate change during the Hoxnian

There is, in some records, a considerable degree of variability. The most coherent of which seems to occur during Ho I where at Marks Tey, Nechells and Quinton there appears to be at least two falls in winter temperature that occur roughly simultaneously. At Athelington and Hoxne, where the entirety of this zone is not recorded, there also appears to be a decline in temperature. Taken together, we have some evidence for additional abrupt climate events.

It should also be noted that compared to Holocene records that use the *pdf* method (e.g. Kuhl and Gobet, 2010), the Hoxnian/Holsteinian shows significantly more variance. The *pdf* method therefore does not automatically produce highly variable reconstructions. This broad comparison potentially suggests that there is significance to at least some of the fluctuations observed.

During the decay of the Laurentide Ice Sheet, there were numerous meltwater pulses in early Holocene (Teller and Leverington, 2004). Given the apparent strength of explanatory power of the meltwater forcing hypothesis, it might be reasonable to expect some of these other events to have led to short lived climatic deteriorations. A growing body of research is beginning to suggest that there is indeed another such anomaly, centred at around 9200 yr BP.

Fleitmann *et al*. (2008) synthesise the evidence for a 9200 ka event. Their review is particularly convincing evidence for a notable anomaly because of their rigorous statistical approach. It is not simply an eyeballing of various curves. They identify ten records with convincing evidence, the strongest being in Greenland ice cores (e.g. Vinther *et al*., 2006). From a European perspective, it is encouraging that the event is reproduced in the classic Ammersee lake record (von Grafenstein *et al*., 1999). There is also evidence from a British lake deposit (Marshall *et al*., 2007).

Most recently, a 9.2 ka event was reconstructed by Boch *et al*. (2009) in an Austrian stalagmite. Interestingly, they note that in contrast to the asymmetrical 8.2 ka event in their record, the 9.2 ka event is symmetrical in temporal structure. This, they argue, could indicate a difference in the forcing mechanism involved in the two events. It would be unreasonable to use a single record to reach such a conclusion, but it is a useful caution that there remains much to learn about this anomaly. This need for caution is emphasised by the fact that the duration of the 9.2 ka event depends on the definition of start and end point used (Boch *et al.*, 2009). Rasmussen *et al.* (2006) suggest a duration of 40-100 years, whereas Fleitmann *et al.* (2008) suggest 150-200 years.

Despite these complications there is intriguing evidence for another meltwater forced cooling event in the early Holocene and evidence continues to build. Work in North America has been particularly important in this regard, with Axford *et al.* (2011) providing chironomid evidence for a 9.2 ka event (and an 8.2) and Gavin *et al.* (2011) and Hou *et al.* (2012) further corroborating this.

These last two papers are intriguing because not only do they display signals at around 9.2 ka, they also suggest that short lived coolings may have been a pervasive feature of the early Holocene. Gavin *et al.* (2011) report multiproxy analysis from western Canada demonstrating an additional event at 10.2 ka. Hou *et al.* (2012) is even more intriguing; isotopic records reveal abrupt cooling events at 10.6, 10.2 and 9.5 ka. The authors attribute these events to weakened meridional overturning circulation as a result of freshwater injections into the North Atlantic.

12.5.4 – Alternative mechanisms

It is important to consider alternative hypotheses for the NAPP cooling. This is particularly the case given that there are, as yet, no freshwater events that can be directly tied in with the anomaly. Indeed, given the difficulties of correlating records during this period and the frequent lack of resolution, it may actually never be possible to make the link with total confidence. This uncertainty makes it essential that other forcing mechanisms are considered.

One such alternative mechanism is solar forcing. Total solar irradiation (TSI) can not only cause cooling on centennial timescales (e.g. Shindell *et al.*, 2001), it can also have significant impacts on ocean circulation. In model experiments, Goosse *et al*. (2002) demonstrate that the reduction in radiative forcing that occurs as a result of a decreased TSI can trigger a local, temporary shutdown of deep water convection in the Nordic Sea. They note that the possibility of this happening is low, but an appropriate forcing can act as a trigger. The strong evidence for freshwater forcing having caused the 8.2 ka event (e.g. Ellison *et al*., 2006) argues against a solar driver. Furthermore, given the absence of appropriate proxy records for TSI during MIS 11, this hypothesis is essentially impossible to test. Nonetheless, it must be borne in mind as a possible influence.

Finally, when considering alternative hypotheses, we must turn to the discussion of the NAPP in Turner (1970). Turner rejected a climatic forcing for the NAPP event, a view that has been echoed since (e.g. Ashton *et al*., 2008). However, this rejection was based on rather weak reasoning, the only evidence being that the decline of forest relative to grassland was not sufficiently great. What would constitute a sufficient decline is not specified. There is no particular reason to believe that the observed changes in herb taxa in relation to tree taxa could not reflect a climatic shift. Moreover, the results of the pollen modelling presented here effectively nullify Turner's (1970) line of reasoning anyway as it is clear that grassland did indeed constitute a large part of the ecosystem at this time. Furthermore, the kinds of pollen shift observed during the NAPP event are very similar in composition to the climatically driven pollen assemblage changes observed in many pollen records during the 8.2 ka event.

Turner (1970) tentatively suggests major regional fire as a cause for the NAPP. Indeed, this observation was an initial motivating factor behind this research. However, a fire-driven trigger can be ruled out; the data presented in this thesis demonstrates no major fire peak at this time in the Hoxne sequence, either in microscopic or macroscopic charcoal. We can also help to dismiss this line of reasoning from first principles. Given that the NAPP is recorded over a very wide area (Marks Tey to Quinton in the Midlands), a huge fire would presumably have been the cause. This is unlikely given the general propensity for British woodlands to be fire resistant. Although there is a danger of circularity in this reasoning, the fact that there are no major fires recorded elsewhere in the sequence, in similar ecosystems, does indeed support the idea that it is difficult to fire a wooded landscape in Britain. The alternative, that a series of local fires all occurred at the same time, is unlikely, given the rarity of lightning struck natural fires and, again, the difficulties of burning a British wood. This is compounded by the fact that there is no significant precipitation decline at this time, which could facilitate conditions in which fires may start. The observation of an NAPP style phase also recorded on the continent, adds weight to the above remarks.

Turner (1970) argues that the persistence of alder is evidence for a fire driving the NAPP phase. Alder, which tends to grow in damp conditions, would be relatively invulnerable to fire activity. However, this line of evidence is negated by the data from Hoxne, which shows a very distinct fall in alder during the NAPP. An additional discrepancy is the increase in pine at this time. Of all the species that might burn, pine is one. Following the fire episode, it could colonise the disturbed area and hence increase; however it would be expected to initially decline. Turner (1970) does record the presence of "abundant" microscopic charcoal at this time, though without quantification it is hard to say what this actually signifies. However, it may be that the opening of the ecosystem as a result of the climatic cooling led to some localised fire occurrences; grassland is significantly easier to burn than woodland.

12.6 – MIS 11 as an analogue for the present interglacial

In general terms, MIS 11 is a good analogue for the present interglacial, although, as discussed in section 2.3.2 there is ongoing debate as to whether there are superior analogues. Nevertheless, despite this debate, there are strong similarities between the two periods. As Loutre (2003) points out, the period from 423 to 362 kyr BP is characterised by the low amplitude of insolation change, a feature shared with recent millennia and the foreseeable future. However, the actual nature of the analogue is somewhat more complex. MIS 11 was a long period of time and there are periods within it that are better suited for comparison than others. Indeed, it is precisely the fact that MIS 11 was of a long duration that the details of the analogue are somewhat vexed (Dickson *et al.*, 2009).

The debate concerning the appropriate basis for comparing the two interglacials has typically been split into two camps, those who favour an alignment based on the obliquity record and those who favour an alignment based on minima in precession. The ultimate impact of these two approaches is to shift the period of Holocene overlap backwards or forwards during MIS 11 (Fig 74). The obliquity perspective places the analogue at the start of MIS 11, following the termination of the previous interglacial. This was the approach taken by the EPICA community members (2004) and Broecker and Stocker (2006). Dickson *et al*. (2009) also align the Holocene with the start of MIS 11, although their approach is based on sea surface temperature and δ^{18}O records.

Conversely, the precession based comparison places the overlap substantially later, between 405 and 360 kyr, and was adopted by Loutre and Berger (2003). Ruddiman (2005) also aligns on the basis of precession, with the analogue beginning at a similar point as Loutre and Berger (2003). This does not appear to be a debate that is likely to be resolved at any point soon. Indeed choosing between the two competing approaches is extremely difficult. In their recent review of MIS 1 analogues, Tzedakis *et al.* (2012) note the ongoing controversy in this respect and the general lack of resolution, although Tzedakis (2010) suggests that methane trends and palynological records from southern Europe favour the precession model. Fig 82 shows the two schemes.

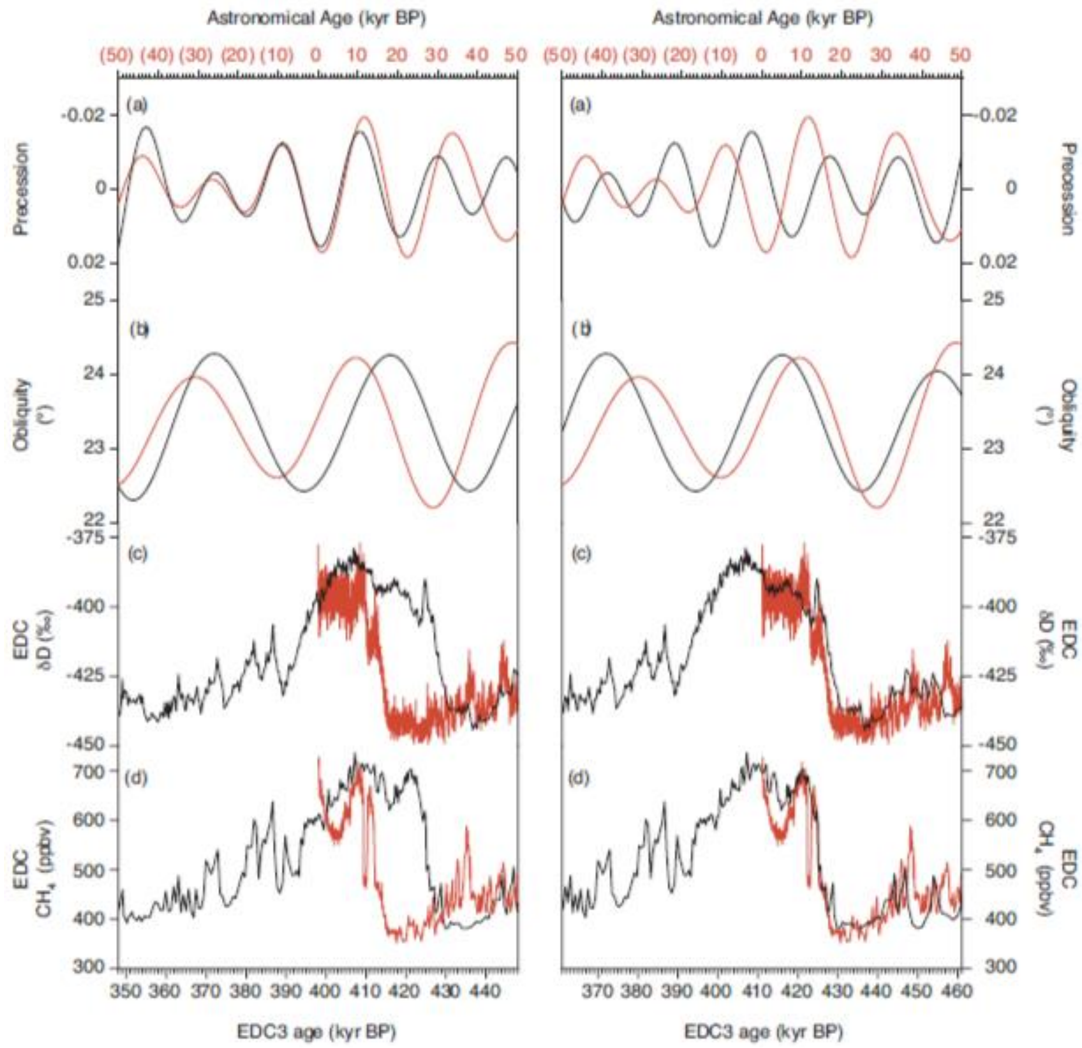


Fig 82 comparing analogues based on precession (left) and obliquity (right). Red colour indicates Holocene record, black is MIS 11.

In this study, the Hoxnian correlates with the start of MIS 11. If we are to compare the two periods, we have to assume an analogue related to obliquity. Note that if we had adopted the chronology proposed by Koutsodenris *et al.* (2012), with a shorter Hoxnian, spanning the second half of MIS 11c, we might expect the Holocene soon to be reaching the end of its natural length and a distinct decline in temperatures (in the absence of anthropogenic forcing, both modern and prehistoric – Ruddiman (2003)) will occur in the relatively near future.

The obliquity scenario implies a much longer duration for the Holocene. Although, as was outlined above, there are a number of differences between the two periods we might broadly expect temperatures to remain relatively stable overall, as occurred in the

Hoxnian. It should also be noted that determining length solely on the basis of astronomical alignment is a somewhat reductive approach. Crucifix (2011) argues this point convincingly, also stretching to saying that statements about trends in greenhouse gases such as methane (e.g. Ruddiman, 2003) as an indicator of interglacial length are simplistic.

Even if there were a perfect insolation analogue (and there is not) then there is no guarantee that interglacials will behave in the same way during both periods (Crucifix, 2011). Even though the MIS 1 – MIS 11 comparison is imperfect, there are insolation similarities and yet many of the observed climate trends are clearly different, as demonstrated in this study. Crucifix (2011) argues that this point will also extend to the timing of glacial inception and that small disturbances within the climate system may act to cause a delay to inception, potentially by many thousands of years.

The significance disturbance as an important component of the climate system brings us on to the occurrence of an abrupt cooling event during the Hoxnian. This is noteworthy, particularly as it occurs quite some time into the interglacial. This suggests that terrestrial climates during remain vulnerable to perturbation throughout an interglacial and can respond dramatically when faced with a significant forcing event.

Despite that fact that we are now many thousands of years into the Holocene, it may be the case that rapid climate change remains an inherent possibility within the system. Such a suggestion must be qualified by noting the differing ice sheet-ocean interactions between the two periods, with these interactions persisting for a considerable period following the MIS 12/MIS 11 transition. During the Holocene, which followed a much less severe glaciation, inputs of IRD and meltwater pulses ceased relatively early on.

Nevertheless, given the spectre of future climate change, this issue remains a concern. The Greenland and Antarctic Ice Sheets are both beginning to show convincing evidence for rapid thinning (e.g. Pritchard *et al.*, 2009) and recent work has confirmed loss of mass in both cases (Shepherd *et al.*, 2012). Furthermore there is a wealth of data demonstrating that thresholds and hysteresis behaviour exists within the climate system (Maslin *et al.*, 2001). A final consideration is that if the NAPP event was forced by solar activity, rather than a freshwater pulse, then similar triggers may still be in prospect. Either way the data presented here suggests that the possibility of abrupt climate change and a terrestrial response in the future should not be completely dismissed.

.13 – Hoxnian archaeology in the light of new findings in palaeoclimate, palaeoecology and fire

The results presented in this thesis have significant implications for the understanding of Palaeolithic archaeology. These implications will be discussed below.

13.1 – Archaeological implications of the palaeoclimate reconstructions

It is clear from the reconstructions presented here that adaptation to cold climate conditions must have occurred in order for hominids to survive in these environments. The significance of this has to be prefaced by the apparent fact that the first stages of this adaptive process must have occurred prior to the Hoxnian, as made clear by the archaeological record found at Happisburgh (Parfitt *et al.*, 2010). This site is hugely important for two reasons; firstly it extends the chronology of human occupation back to 800 kyr BP. Secondly, it demonstrates that humans were present in northern Europe in boreal conditions.

Useful context for this discussion can be found in a brief explanation of the "short chronology" framework for the Palaeolithic occupation of Europe proposed by Roebroeks and van Kolfschoten (1994). In this model, Europe was not populated by hominids until 500,000 years ago. The strict interpretation of this hypothesis was falsified almost immediately by discoveries made in the Iberian peninsula. The Spanish site of Atapuerca revealed, just a year after the publication of the short chronology, the presence of humans 780,000 years ago (Carbonell *et al.*, 1995). Subsequent discoveries in the area have elaborated considerably upon this picture, with remains at Atapuerca having been found that date to around 1.2 myr ago (Carbonell *et al.*, 2008). Discoveries in the Guadix-Baza Basin also demonstrate a much earlier occupation of Europe, around 1 myr ago (Oms, *et al.* 2000).

Spanish sites provide a good example of the importance of favourable environmental conditions during the very earliest occupation of Europe. Agusti *et al.* (2009) use Mutual Climatic Range temperature data for herpetofauna to demonstrate that occupation at sites such as Atapuerca took place during warm climatic conditions. They argue that colonisation west from sites in the Caucuses, dated much earlier than anywhere in western Europe (Gabunia *et al.*, 2000), was hindered by a cold climate regime. Almost as soon as the climate is observed to warm at the Spanish sites, they became occupied.

Dennell and Roebroeks (1996) revised the short chronology by essentially positing a geographical separation in Europe, with the north of the Alps not being colonised until 500,000 years ago. They argued that a "quantum leap" in behaviour would have been required to take hominids beyond 35 degrees latitude. However, the discoveries at Pakefield in East Anglia, demonstrating human presence in Britain at around 700,000 years ago (Parfitt *et al.*, 2005) showed that even the revised model is flawed.

However, there remain some important components to the short chronology. Roebroeks (2006) argued that the ecological aspects of the short chronology remain valid. Occupation at Pakefield took place under Mediterranean climatic conditions; as the authors conclude, these pioneers were able to spread northwards in familiar climatic conditions, using their existing adaptations. Though the site is northerly, it remains Mediterranean in aspect. This was falsified by the boreal discoveries at Pakefield. However, there still appears to be considerable significance attached to the 500,000 kyr date.

The short chronology always posited a step change around 500,000 years ago and this appears to remain the case, with occupation in northern Europe only becoming common after this point. Britain provides a case in point; Ashton and Lewis (2001) demonstrate that British Palaeolithic populations peaked between MIS 13 and MIS 10, before declining around MIS8. Gamble (2009) has characterized this migration into Britain as one of two major population expansions, the other occurring around 30,000 years ago.

Despite the evidence that now exists for occupation in cold climates, this does not appear have been to be commonplace. This is perhaps to be expected given that the evidence for habitual fire use prior to 400 kyr BP appears to be weak (Roebroeks and

Villa, 2011). Prior to the regular use of fire, it seems that occupation of northerly latitudes during cold climates was relatively rare. In the absence of this significant development, it may have been that occupation was only possible under particular circumstances.

Ashton and Lewis (2012) argue that sites such as Happisburgh offered a very specific suite of resources that enabled a tenuous hold in this difficult environment. In this case a river valley affording a wide range of feeding opportunities, close to the possibilities offered by the nearby coastal and marine environment. Ultimately therefore we still appear looking at a significant shift in human activity prior to or around the time of the Hoxnian.

This raises the question of whether there was anything particularly unique about the Hoxnian to which adaptations were required. As Candy *et al.* (2010) point out, interglacials in Britain do not appear to have been distinctly different either side of the MBE. The primary perspective of Candy *et al.* (2010) concerns the warmth of interglacials, whilst the most relevant season here is likely to be the cold of winter.

Candy *et al.* (2010) provide a summary of Tmin based on beetle data for MIS 19-13 sites. As is typical for such estimates, the range is quite large, making it difficult to compare with the more precise estimates presented here. In turn this poses a challenge to establishing whether or not cold climates during the Hoxnian were particularly unique. The typical range is from around -8 to +4ºC, which encompasses the winter temperatures presented here.

If the Hoxnian did represent a unique challenge then there must have been a correspondingly rapid adaptation, be it physical or cultural. Dennell *et al.* (2011) argue that population sizes at this time were low; this does not provide a strong genetic basis for rapid adaptation and small numbers are unlikely to provide the social melting pot required for cultural responses to extreme climates. It therefore seems quite probable that the ability to cope with the environments of the Hoxnian developed over a significant period of time, and the observed rise in occupation of North West Europe represents the culmination of this process.

There was almost certainly no one single event of overwhelming importance that opened up the British Isles to regular occupation. Moreover, it was not solely the extremes of temperature that had to be dealt with. For example, Kappelman *et al.* (2008) demonstrate the importance of lower ultra violet radiation at higher latitudes as a climatic variable influencing hominid populations.

From an evolutionary perspective, *Homo sapiens* and *Homo neanderthalensis* mtDNA diverged some time before MIS 11, at 660 kyr BP +/- 140 kyr, as determined from the sequencing of the Neanderthal mitochondrial genome (Green *et al.*, 2008). The exact nature of the evolutionary split, for example the role and/or status of *Homo heidelbergensis*, is beyond the scope of this thesis. However, it is worth stressing that genetic divergence is not equivalent to population and phenotypic divergence. British archaeological data can shed important light on these additional processes, with one model stressing population divergence some time between 500 and 400 kyr BP based on the presence of very clear Neanderthal features in the Swanscombe skull which dates to the Hoxnian (Stringer and Hublin, 1999). Therefore, at least in one respect, the Hoxnian may have been a particularly important period.

In terms of specific cold adaptations, there is evidence that Neanderthal physiology (Steegman *et al.*, 2002) and postcranial morphology (Holliday, 1997) evolved at least in part, as an adaptation to the cold. There are also cold adapted features recorded in the Boxgrove tibia, dating to MIS 13 (Trinkaus *et al.*, 1999). This again demonstrates the likelihood the this was an ongoing process, rather than a step change around the time of the Hoxnian.

From a social perspective, one of the main developments in archaeology over the past few decades is the gradual appreciation of the cognitive sophistication of our hominid ancestors. For example, it has recently been demonstrated that *Homo erectus* as early as 750 kyr BP was differentiating personal activities, such as knapping, eating, food preparation, in a “home” type space (Alperson-Afil, 2009). Therefore we must also look to explanations beyond the physical for the ability of hominids to cope in Hoxnian climates.

One possibly crucial social adaptation was the control of fire, particularly for cooking.

Wrangham *et al.* (1999) were some of the first authors to explicitly link the importance of cooking to human evolution and Wrangham has continued to develop this theme in a range of research papers. Cooking will have had a variety of impacts; one of the most crucial ones where the adaptation to cold environments is concerned is a more efficient use of energy during food consumption. Cooking breaks down collagen, making cooked meat easier to digest than raw meat; this has been demonstrated to provide a distinct energy benefit (Boback *et al.*, 2007).

The impact of cooking on hominid social structure would also have been considerable, a point on which a number of authors have speculated. One of the more convincing such examples comes from Foley and Gamble (2009). They argue that bonding between individual males and females would have been enhanced, ultimately leading to strong families ties, that exist within an overall community structure. Presumably this kind of nested structure provides a greater resilience within a given population, because of the existence of more than one level of support structure. It is this kind of social change that will have enabled hominids to continue to function in the environment of a northerly location during MIS 11. Finally, at a more prosaic level, fire also simple helps people to keep warm. The presence of fire during the Hoxnian, coupled with the cold winters of the period, helps to flesh out an important social adaptation during the lower Palaeolithic.

Another key aspect likely enabling the colonisation of northerly latitudes was the significant increase in encephalisation that occurred within *Homo* around 600 kyr BP (Rightmire, 2004). This actually occurred after the first clear evidence of fire usage, at around 800 kyr BP (Goren-Inbar *et al.*, 2004), demonstrating that no one single event or one single behaviour led to the ability to colonise Hoxnian landscapes. This encephalisation increase led to a significant increase in cognitive sophistication, the signs of which can be found in the archaeological record. Sections 4.3.1 and 4.3.2 contain a number of examples of this sophistication and discuss the impact that increased brain size would have had on social structures.

The climate results presented here strengthen the importance of these developments in hominid physical and behavioural evolution. For example, Hallos (2005) suggests that planning ability was a component of the behaviour repertoire of Hoxnian hominids.

This would certainly be an advantage given the significant summer-winter shifts in temperature that would have occurred. Being able to plan for a period of fairly hostile weather conditions would have been hugely beneficial. Indeed, given that summer and winter conditions would have been quite different, an inherent behavioural flexibility, as suggested by Hallos (2005) and in the Ashton and McNabb (1994) activity facies model, would have been vital. For example, during northern winters, fat levels in prey tend to decline; modern hunter gatherers therefore focus on the acquisition of fat during these months and tend to ignore the harvesting of protein (Speth, 1987).

The increased size of social groups due to larger brain size (Hill and Dunbar, 2003) would also presumably have been an advantage. With larger groups come more individuals that a population can rely on in times of need and generally more effective cooperation in subsistence tasks (Gamble, 2009). Also, a larger population is likely to have more members with helpful individual skills and experience. Finally, a larger group is buffered to a greater extent against the loss of members and will generally have a higher genetic fitness. The climate reconstructions presented here demonstrate that this whole suite of sophisticated behaviours would have been necessary for survival and may indeed have helped fix their presence in human societies.

Of course, no matter how well able to cope with a given environment a group of hominids may be, there will be environmental and ecological tolerances beyond which they are unable to function. It is therefore interesting to speculate on the impact of the NAPP abrupt cooling event on hominid populations. It is particularly noteworthy that the majority of sites for which there is dating evidence suggest occupation during Ho II (McNabb, 2007), which would be prior to this severe climatic change. Perhaps this deterioration in climate, which was also marked by a distinct change in the local environment, led to local extinction?

It should be stated that there are sites of occupation in the later stages of the Hoxnian such as the middle gravels at Swanscombe. However, Schreve (2001b) places these deposits in later substages during MIS 11 (not something with which Ashton *et al.*, (2008) agree, as discussed previously) so it may be evidence for later occupation is equivocal. If access across the channel was restricted, then local populations may have been forced to extinction. Even if this were not the case, Hublin and Roebroeks (2009) argue that the available weight of evidence suggests that Neanderthal populations in northern Europe did not generally ebb and flow latitudinally in response to climate change. They simply went locally extinct.

If hominids are definitely present during later parts of the interglacial then this also provides us with important insights; the general prevalence of sites during the early Hoxnian suggests that the NAPP event may have had some notable impact on populations. But if some persisted, then it demonstrates that Neanderthal groups were actually remarkably resilient in the face of environmental change. Such a conclusion would contradict suggestions that Neanderthals lacked robustness at the micropopulation scale due to insufficient behavioural flexibility (Stiner and Kuhn, 2006). In fact the general presence of Neanderthals in a climate regime with significant seasonal shifts argues against this point. This is particularly the case if we accept the demographic arguments made by Lycett and von Cramon-Taubadel (2008); Clactonian groups would have been relatively small and so it becomes more remarkable that they were present in this environment.

Finally, persistence through the NAPP phase could even possibly contradict explanations for their ultimate extinction that tie in the instability of climate during MIS 3 (van Andel and Davies, 2003), although admittedly climate was much more changeable at that time. We might also speculate that an increase in population size as represented by Acheulian groups (Lycett and von Cramon-Taubadel, 2008) helped facilitate survival through the NAPP cooling.

An important additional consideration is the palaeogeography of the time, specifically the opening of the English Channel. As discussed previously, there is an ongoing debate concerning the timing of this event, now known to be the result of two episodes of catastrophic flooding from large glacial lakes, as a result of the breaching of rock dams in the southern North Sea (Gupta et al., 2007).

There is evidence for the initial breach having occurred at some point during MIS 12 (Gibbard, 1995). If this initial episode of flooding totally cut Britain off from mainland Europe then hominids living in the East Anglian region will have been subjected to the full force of seasonal shifts in climate. In contrast, Hijma *et al.* (2012) argue that it probably was not until the Eemian that a connection between the English Channel and the North Sea was established. If this is the case, then an escape route to more clement conditions further south will have existed. The distinction between the two is quite significant in terms of implications for hominid behaviour.

13.2 - Archaeological implications of Hoxnian ecological data

What kinds of landscape did hominids occupy during the Hoxnian? It is commonly believed that a diverse range of environments were inhabited, from river basins of various sizes, the high ground of the Downs, the extensive till plains that would have been common following the Anglian glaciation and various lacustrine habitats. This view is notably summarised and expressed by Wymer (1999) and echoed elsewhere, most recently by McNabb (2007).

Ashton *et al.* (2006) question this consensus, arguing that the only two environmental contexts that can be rigorously investigated are lakes and rivers. Material on the higher ground is present in abundance, but its stratigraphic and chronological provenance is almost always impossible to determine. Estuarine and coastal environments would also almost certainly have been exploited, but unfortunately the evidence for occupation is scanty. It is only at lake sites and rivers that there is sufficient detail for comprehensive analysis (Ashton *et al.*, 2006). Exploring these two locales, Ashton *et al.* (2006) conclude that it is only at the river sites where there is strong evidence for occupation; the evidence from lake sites is equivocal.

Why would hominids have favoured river valleys during the Hoxnian? Ashton *et al.* (2006) propose that rivers provided easily navigable corridors through the landscape, providing important practical and cultural links. Moreover they were easily visible, whereas lake sites would often have been smaller and less recognisable. In addition, Ashton *et al.* (2006) argue for a distinction in landscape structure between lakes and rivers. The former would have been in relatively dense forest, with the latter much more open, due in part to presence of large herbivores. The denser regions of forest would have been more difficult to penetrate, discouraging hominid presence in these areas.

In the open river valleys, the greater quantities of herbaceous vegetation would support larger populations of herbivores available for hunting. Furthermore, landscape diversity would be greater, with patches of grassland, woodland and floodplain environments. This would provide a relatively increased amount of habitats and resources available for exploitation (Ashton *et al.*, 2006).

The absence of hominids (or absence of evidence for hominids) from around Hoxnian lake sites and their preferential usage of rivers does seem to be a valid pattern. Furthermore, the explanation put forth by Ashton *et al.* (2006) is a plausible one based on the available data. However, can the inferences drawn regarding landscape structure in this research add any further clarification to this model? The answer is clearly yes; for some of the period there would have been an important component of openness within the Hoxnian forest. River corridors would not necessarily always be much easier to pass through than forests. Moreover, it is also worth considering that modern hunter gatherers are perfectly capable of operating in forested environments. Openness would not always have been hugely common, but there would have been enough at times to complicate this aspect of the Ashton *et al.* (2006) explanation.

Openness also finally falsifies the Mithen (1994) model, wherein the dense forests during an interglacial result in the fracturing of larger social groups, into smaller populations with decreased social learning. The structure of the landscape would have been unlikely to facilitate such a process.

So what can explain the preference for river sites over lake sites? It is important to recognise that there is no simple dichotomy, with occupation only potentially occurring at these localities. Forests could have been occupied, but the opportunity for fossil preservation is extremely limited here. Nevertheless, the absence from lakes does seem to be significant. Without the ability to expand the modelling effort, it is difficult to come up with an entirely realistic picture of the environment around a lake such as Hoxne. However, it seems ecologically reasonable for a division of the landscape into patches of trees, open ground and wetland. In which case, rivers may not have the advantage in terms of habitat diversity as suggested by Ashton *et al.* (2006). The most probable explanation is the greater availability of lithic resources, which is one of the other components suggested by Ashton *et al.* (2006).

We can also speculate on the significant of a river versus a lake as an actual feature. Lakes, even if relatively large, occupy a single location within a landscape, whereas rivers are much more pervasive, appearing almost as veins that cross through space. It may be that rivers have a greater inherent attraction to a hominid than a lake environment. Gamble (1999), emphasises the importance of tracks in a landscape to hominid populations. Modern hunter gatherers traverse their landscape non-randomly; they do not simply wander here and there, they follow well defined tracks that have developed over many generations. Rivers make an obvious "track" and would therefore be a magnet to the residents of this period.

An additional ecological influence comes from a consideration of the food resources available to the hominids of the period. Generally speaking, Neanderthals are seen as top carnivores, receiving the majority of their proteins from meat eating. This conclusion is largely based on isotopic analyses of later bone material (e.g. Richards et al., (2000)), as well as taphonomic analysis of bone assemblages (Gaudzinski and Roebroeks, 2000). However, a number of authors have also pointed to the importance of plant resources in human evolution, in particular the use of plant underground storage organs (USOs). For example, Laden and Wrangham (2005) argue that the use of USOs was a crucial factor in the early evolution of Australopithecines.

With regards to the more recent period of hominid history, Hardy (2010) puts forward the intriguing hypothesis that actually meat would have been an insufficient supply of necessary macronutrients and that plant resources, particularly USOs, would have been crucial. This may be especially the case in the Hoxnian; USOs provide a concentrated source of carbohydrates and energy and at their most productive in late Autumn/Winter. Given the prevailing climate, it seems eminently possible that they played an important role. Hardy (2010) points to a number of key species, amongst which are *Typha* and *Polygonum*, both of which are recorded at the Hoxne and Athelington sites.

13.3 – Archaeological implications of the fire record

The absence of large scale management of forests for hunting during this period appears to be a clear conclusion derived from the fire data. Whilst it is dangerous to reach conclusions on the basis of absence of evidence, we can at least speculate on what this absence can tell us about Hoxnian hominids. The first and most obvious conclusion is that despite the evidence for cognitive sophistication and despite the evidence for the ability to plan, this kind of behaviour was a step too far. At a time when archaeology is gradually expanding the behavioural repertoire of ancient hominids, this is an important check on such a trend.

Burning to manage requires the appreciation that fire will cause woodland to burn and that this will cause it to open out. Furthermore, the ecological effects of this opening will be to attract prey, increasing the possibility of greater resource yields. Such a model is actually non-trivial and one that Hoxnian hominids were apparently incapable of conceiving. This is despite that fact that they were lighting fires in hearths; evidently they could not scale up and appreciate that this small event could lead to a larger event. The local could not be translated into the wider scale. It may be that they were unable to appreciate that the landscape and ecosystem consists of multiple interacting components and that cause leads to a layered effect. In their minds, the landscape is two-dimensional rather than three. There is evidence for a reasonable degree of intentionality at this time (Dunbar, 2003) but clearly it was not sufficient.

Of course, they were not assisted in making this cognitive leap by the inherently unfavourable conditions for burning within British forests. We might conceive of a scenario in which a large scale natural fire promotes hunting opportunities and the hominids subsequently mimic this. However, this does not seem to have occurred. It would be therefore interesting to test the woodland management hypothesis for this time period elsewhere in Europe where fires start naturally much more readily. It may be that in these localities, hominids did develop the ability to use fire to control woodland. However, a recent paper investigating the model for Upper Palaeolithic and late Neanderthal populations in western Europe has demonstrated no control of fire regimes between 70 and 10 kyr BP (Daniau *et al.*, 2010).

Incidentally, the data presented here actually provides a test of sorts for the Mesolithic burning hypothesis. A number of authors (e.g. Brown, 1997) working on this time period have drawn attention to the possibility of natural fires replicating a human signal. However, we have shown here that the difficulty of burning British woodlands, as suggested by Rackham (1986), is indeed inherent. This supports an inference that humans must be responsible.

14 – Conclusions

This section will present an overall perspective on the results and suggest directions for future research. The significant novel findings of this thesis relate to the palaeoclimate reconstructions presented for the Hoxnian. A number of methodological issues have been explored and the results found to be robust. From this, a narrative of palaeoclimate change in Britain and Europe during MIS 11 has been developed.

At a broad scale, MIS 11 appears to have begun relatively cold and dry before progressing through a period of warmer temperatures before a decline into the subsequent glacial. This is in general agreement with the picture presented in a number of significant global records such as EPICA.

Winter temperatures were significantly colder than the present and summer temperatures perhaps slightly warmer. This is convincing evidence for a more seasonal climate regime. This heightened seasonality also appears to be recorded on the continent. In this respect and others, there is good agreement with Holsteinian records. However there is also significant spatial variability observed, for example with regards to the timing of peak warmth.

There does not appear to be much evidence of millennial type variability during this period, however there is evidence for abrupt centennial scale climate change. In particular, the previously enigmatic NAPP is proposed as an analogue to the 8.2 ka event, forced by freshwater discharge into the North Atlantic. Other abrupt climate changes early on in the interglacial may have occurred.

These palaeoclimate reconstructions are used to provide a context for the archaeology of the period. It is revealed that hominids of MIS 11 in Europe would have had to survive during periods of significant cold and also periods of climate instability. This implies a significant degree of resourcefulness and cognitive ability. Substantial behavioural and cultural adaptations must have occurred sometime around or just prior to the Hoxnian, enabling northerly regions of Europe to become more regularly colonised.

The fire record of the Hoxnian is sparse, though there is some evidence for fire activity. From a palaeoecological perspective, modelling reveals some of the taphonomic biases in pollen samples and implies a certain degree of openness in the landscape. It also helps inform our understanding of the palaeoclimate results through an appreciation of basin size.

Future work should continue to make use of advance in pollen theory, particularly as the development of more extensive data sets with which to input into models will make them even more widely applicable. As a guide to research they are invaluable and also help reveal significant aspects of palaeoecology. A full scale modelling study for the Hoxnian would be very welcome.

From a palaeoclimatological perspective, a widening to other periods during the British Pleistocene would be very welcome. Quantitative records offer a unique opportunity to study past climates in detail and with rigour. Hand in hand with a widening application in Britain should be the encouragement of European workers to apply quantitative methods to the Pleistocene. This research has shown that many fascinating insights can be gained from this period, with many more exciting questions and challenges to come.

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Appendices

The appendices contain all relevant materials for the palaeoclimate reconstructions, including the original pollen data from this study, the inferred percentages from published diagrams, and the published diagrams themselves. Following this is the input itself to the *pdf* method, including the final reconstructions and all sensitivity tests.

Abbreviations (presented in a typical order in the data):

Be = betula aggregate
Bepu = Betula pubescens
Bepe = Betula pendula
Pisy = Pinus sylvestris
Pinn = Pinus aggregate
Ul = Ulmus aggregate
Ulgl = Ulmus glabra
Qud = Quercus aggregate
Quro = Quercus robur
Qupu = Quercus pubescens
Ti = Tilia aggregate
Tico = Tilia cordata
Al = Alnus aggregate
Algl = Alnus glutinosa
Fasy = Fagus sylvatica
Cabe = Carpinus betulus
Frex = Fraxinus excelsior
Ac = Acer aggregate
Acca = Acer campestre
Abal = Abies alba
Piab = Picea abies
Taba = Taxus baccata
Sam = Sambucus aggregate
Sani = Sambucus nigra
Coav = Corylus avellana
San = Salix aggregate

Sacca = Salix campestre
Hirh = Hippophaë rhamnoides
Juco = Juniperus communis
Ilaq = Ilex aquifolium
Emni = Empetrum nigrum
Fi = Filipendula aggregate
Fiul – Filipendula ulmaria
Cavu = Calluna vulgaris
Vial = Viburnum alba
Eueu – Euronymous europea
Arma = Armeria maritima
Plme – Plantago media
Plla – Plantago lanceolata
Poav – Polygonum aviculare
Ruac – Rumex acetosa
Thmi – Thalictrum minor
Urdi – Urtica dioica
Cllma – Cladium mariscus
Chpo – Chenopodum polyspermum
Motr - Moehringia trinervia
Lyeu - Lycopus europaeus
Rafl - Ranunculus flammula
Ruca – Rubus caesius
Gapa – Galium palustre
Viop – Viburnum opulus
Vila – Viburnum lantana
Sasc - Sarothamnus scoparius
Stho - Stellaria holostea
Crmo - Crataegus monogyna
Tesc - Teucrium scorodonia

Pollen counts from Hoxne and Athelington

Hoxne (main sequence) pollen counts

Depth (cm)	Betula	Pinus	Ulmus	Quercus	Tilia	Alnus	Fagus	Carpinus	Fraxinus	Acer	Abies
180	0	40	1	38	3	154	0	0	0	0	28
192	1	16	2	29	3	136	0	0	0	0	10
260	0	27	0	36	2	105	0	0	1	0	0
272	3	10	15	59	0	87	0	0	0	0	0
279	8	13	4	68	1	79	0	0	0	0	0
288	15	21	30	79	1	55	0	1	1	0	0
296	19	19	10	79	2	56	0	0	1	1	0
310	14	46	13	28	2	55	1	0	2	0	0
320	15	38	11	32	5	64	0	0	2	0	0
326	17	29	15	24	0	83	0	0	2	0	0
334	5	24	16	48	2	100	0	0	1	1	1
342	9	19	26	57	6	89	0	0	1	0	0
356	0	24	12	53	1	105	0	0	2	0	0
384	0	19	8	44	5	113	0	0	6	1	0
392	0	24	15	47	2	101	1	0	5	0	0
408	0	20	13	43	14	91	0	0	4	0	0
416	0	17	12	43	3	105	0	0	2	0	0
432	2	20	20	52	11	95	0	2	1	0	0
444	0	25	31	50	3	90	0	0	2	0	0
464	6	16	23	38	11	129	0	1	1	0	0
480	0	20	30	61	3	106	0	1	2	0	0
496	7	15	22	79	3	114	0	0	2	0	0
512	9	15	18	58	4	121	0	0	1	0	0
528	7	18	17	64	1	106	0	0	0	0	0
544	9	14	7	52	2	129	0	0	0	0	0
556	8	18	11	65	4	116	0	0	2	0	0
576	8	18	13	60	2	142	0	0	1	0	0
592	6	22	12	66	9	110	0	0	0	0	0
637	9	32	8	57	11	122	0	0	3	0	0
648	9	16	0	63	6	146	0	0	1	0	0
656	9	12	7	57	11	160	0	1	1	0	0
672	13	18	3	62	5	141	0	0	2	0	0
682	19	19	2	71	15	123	0	0	1	0	0
692	8	20	2	91	1	133	0	0	0	0	0
706	36	24	4	87	4	94	0	0	0	0	0
720	66	31	2	57	12	92	0	0	1	0	0
746	62	20	1	116	24	27	0	1	0	0	0
760	92	25	0	116	16	3	0	0	2	0	0
776	95	33	1	113	0	3	0	0	8	0	0
784	116	34	3	97	0	2	1	0	3	0	0
794	134	24	3	92	0	1	0	0	1	0	0
801	166	30	6	58	0	2	0	0	0	0	0
808	177	37	10	31	0	0	0	0	0	0	0
816	197	37	7	19	0	0	0	0	0	0	0
824	203	27	3	17	0	0	0	1	0	0	0

Hoxne (main sequence) pollen counts

Depth (cm)	Picea	Taxus	Sambucus	Corylus	Salix	Hippophae	Hedera helix	Ilex	Type X
180	4	0	0	13	1	0	3	0	0
192	5	0	0	20	0	0	0	0	0
260	0	0	0	92	1	0	0	0	0
272	2	0	0	107	0	0	1	0	0
279	2	0	1	107	0	0	0	1	0
288	2	0	0	55	0	1	1	0	0
296	3	0	0	23	0	0	0	1	0
310	2	0	0	55	0	0	0	0	0
320	2	0	0	58	0	0	3	1	0
326	3	0	0	53	0	0	0	3	0
334	2	0	0	78	0	0	2	2	0
342	1	0	0	77	0	0	1	0	0
356	1	0	0	84	0	0	1	2	0
384	1	0	0	77	0	0	3	2	0
392	3	0	0	89	0	0	0	1	0
408	2	0	0	96	0	0	0	1	0
416	2	0	0	104	0	0	1	0	0
432	1	0	0	88	0	0	0	1	0
444	1	0	0	83	0	0	0	1	0
464	0	1	0	64	0	0	2	1	0
480	1	3	0	60	0	0	1	2	0
496	2	0	0	50	0	0	3	1	0
512	1	0	0	56	0	0	3	1	0
528	0	0	0	74	0	0	2	2	0
544	0	0	0	70	0	0	2	6	0
556	2	0	0	55	0	0	6	1	0
576	1	0	0	42	0	0	5	1	0
592	1	0	0	59	0	0	3	0	0
637	1	0	0	41	0	0	2	1	0
648	1	0	0	42	0	0	4	1	0
656	3	0	0	24	0	0	2	0	1
672	1	3	0	36	0	0	3	0	1
682	1	0	0	31	0	0	3	0	0
692	0	3	0	12	0	0	1	0	0
706	2	0	0	13	0	1	1	0	1
720	1	0	0	8	0	1	0	0	0
746	1	0	0	14	0	0	1	0	0
760	1	0	0	10	0	0	7	0	0
776	0	0	0	11	0	1	4	0	0
784	1	0	0	6	0	1	3	0	0
794	0	0	0	5	0	1	2	0	0
801	1	0	0	7	0	0	0	0	0
808	0	0	0	4	0	0	1	0	0
816	0	0	0	3	0	1	0	0	0
824	0	0	0	4	0	1	0	1	0

Hoxne (main sequence) pollen counts

Depth (cm)	Poaceae	Cyperaceae	Empetrum	Ericaceae	Artemisia	Cirsium	Compositae
180	1	6	0	2	1	0	0
192	9	11	0	0	0	1	0
260	0	28	2	0	1	0	0
272	10	3	0	0	0	0	0
279	8	5	1	0	0	1	1
288	16	14	0	0	1	0	2
296	54	12	0	0	0	0	4
310	62	6	0	0	1	1	4
320	51	6	0	1	0	0	2
326	47	14	0	0	1	2	1
334	10	2	0	0	1	0	1
342	4	4	1	0	0	1	0
356	1	11	0	0	1	0	0
384	3	14	1	0	0	0	1
392	3	5	2	0	0	0	0
408	1	7	1	0	0	0	0
416	2	3	2	0	0	0	0
432	3	4	0	0	0	0	0
444	2	4	1	0	0	0	1
464	0	5	0	0	0	0	0
480	3	4	0	0	0	0	0
496	1	0	0	0	0	0	0
512	6	4	1	0	0	0	1
528	4	3	1	0	0	0	0
544	5	4	0	0	0	0	0
556	1	5	2	0	0	0	1
576	2	2	1	0	0	0	1
592	6	4	1	0	0	0	0
637	2	8	2	0	0	0	0
648	2	7	0	0	0	0	0
656	6	1	1	0	0	0	1
672	8	0	0	0	0	0	0
682	2	11	0	0	0	0	0
692	14	8	1	0	4	0	0
706	16	15	0	0	1	0	1
720	14	7	1	0	0	2	1
746	9	12	1	0	2	0	2
760	2	16	1	0	0	0	2
776	12	15	0	0	0	1	1
784	8	20	0	0	1	1	1
794	16	18	0	0	0	1	0
801	13	13	0	0	0	2	1
808	8	24	1	0	0	0	1
816	9	23	0	0	0	0	0
824	12	24	0	0	1	0	2

Hoxne (main sequence) pollen counts

Depth (cm)	Brassicaceae	Caryophyllaceae	Chenopodiaceae	Filipendula	Lamiaceae	Fabaceae
180	0	0	0	0	0	0
192	0	0	0	0	0	0
260	0	2	0	0	0	0
272	1	0	0	0	0	0
279	0	0	0	0	0	0
288	0	2	0	0	0	0
296	0	3	3	0	0	0
310	0	0	2	0	0	0
320	0	2	0	1	0	0
326	0	1	2	0	0	0
334	0	0	0	0	0	0
342	0	0	1	0	0	0
356	0	1	0	0	0	0
384	1	1	0	0	0	0
392	0	1	0	0	0	0
408	0	3	0	0	0	0
416	0	1	1	0	0	0
432	0	0	0	0	0	0
444	0	2	1	0	0	0
464	0	0	0	0	0	0
480	0	0	0	0	0	0
496	0	1	0	0	0	0
512	0	0	0	0	0	0
528	0	0	0	0	0	0
544	0	0	0	0	0	0
556	0	2	0	0	0	0
576	0	0	0	0	0	0
592	0	1	0	0	0	0
637	1	0	0	0	0	0
648	0	0	0	0	0	0
656	0	2	0	0	0	0
672	0	1	0	0	1	0
682	0	1	0	0	0	0
692	1	0	0	0	0	0
706	0	0	0	0	0	0
720	0	0	1	0	0	0
746	0	2	0	1	0	1
760	0	1	0	0	0	0
776	0	0	0	0	0	0
784	0	0	0	0	0	0
794	0	0	1	0	0	0
801	1	0	0	0	0	0
808	0	1	1	0	0	0
816	0	0	0	0	0	0
824	0	1	0	1	0	0

Hoxne (main sequence) pollen counts

Depth (cm)	Geranium	Plantago	Potentilla	Ranunculus	Rosaceae	Rubiaceae	Rumex	Scabiosa
180	0	0	0	0	0	0	0	0
192	0	0	2	0	1	0	0	0
260	0	0	0	1	0	0	0	0
272	0	0	0	0	0	1	0	0
279	0	0	0	0	0	0	0	0
288	0	0	0	1	0	0	0	0
296	0	1	1	2	0	1	1	0
310	0	2	1	1	0	0	0	0
320	0	1	0	1	0	0	0	0
326	0	0	0	0	1	2	0	0
334	0	1	0	0	0	0	1	1
342	1	0	0	0	0	0	1	0
356	0	0	0	1	0	0	0	0
384	0	0	0	0	0	0	0	0
392	0	0	0	0	0	0	0	0
408	0	0	0	3	0	0	0	0
416	1	0	0	0	0	0	0	0
432	0	0	0	0	0	0	0	0
444	2	0	0	0	1	0	0	0
464	0	0	0	1	0	0	0	0
480	1	0	0	2	0	0	0	0
496	0	0	0	0	0	0	0	0
512	0	0	0	0	0	0	0	0
528	1	0	0	0	0	0	0	0
544	0	0	0	0	0	0	0	0
556	0	0	0	0	0	0	0	0
576	0	0	0	0	0	0	0	0
592	0	0	0	0	0	0	0	0
637	0	0	0	0	0	0	0	0
648	0	0	0	0	0	0	0	0
656	0	0	0	0	0	0	0	0
672	0	0	0	0	0	0	0	0
682	0	0	0	0	0	0	0	0
692	0	0	0	0	1	0	0	0
706	0	0	0	0	0	0	0	0
720	0	0	0	1	0	0	0	0
746	0	0	0	1	0	0	0	0
760	0	0	0	1	0	1	0	0
776	0	0	0	0	0	0	0	0
784	0	0	0	1	0	0	0	1
794	0	0	0	0	0	0	0	0
801	0	0	0	0	0	0	0	0
808	0	0	0	1	0	0	0	0
816	0	0	0	1	0	0	0	0
824	0	0	0	0	0	0	0	0

Hoxne (main sequence) pollen counts

Depth (cm)	Thalictrum	Valeriana	Apiaceae	Tharaxacum	Geum	Azolla filiculoides	Bidens
180	0	0	5	0	0	1	1
192	0	0	54	0	0	1	1
260	0	0	2	0	0	2	1
272	0	0	1	0	0	2	2
279	0	0	0	0	0	2	0
288	0	1	0	1	0	1	0
296	0	0	2	2	0	2	0
310	0	0	1	1	0	2	0
320	0	1	3	0	0	1	0
326	0	0	0	0	0	1	0
334	0	0	0	0	1	1	0
342	0	0	1	0	0	0	0
356	0	0	0	0	0	0	0
384	0	0	0	0	0	0	0
392	0	0	1	0	0	0	0
408	0	0	1	0	0	0	0
416	0	0	1	0	0	1	0
432	0	0	0	0	0	0	0
444	0	0	0	0	0	0	0
464	0	0	1	0	0	0	0
480	0	0	0	0	0	0	0
496	0	0	0	0	0	0	0
512	0	0	1	0	0	0	0
528	0	0	0	0	0	0	0
544	0	0	0	0	0	0	0
556	0	0	1	0	0	1	0
576	0	0	1	0	0	0	0
592	0	0	0	0	0	0	0
637	0	0	0	0	0	0	0
648	0	0	2	0	0	1	0
656	0	0	1	0	0	0	0
672	0	0	2	0	0	1	0
682	0	0	1	0	0	0	0
692	0	0	0	0	0	0	0
706	0	0	0	0	0	2	0
720	1	0	1	0	0	1	0
746	1	0	1	0	0	0	0
760	2	0	2	0	0	0	0
776	1	0	1	0	0	0	0
784	0	0	0	0	0	0	0
794	0	0	1	0	0	0	0
801	0	0	0	0	0	0	0
808	0	0	3	0	0	0	0
816	2	1	0	0	0	0	0
824	2	0	0	0	0	0	0

Hoxne (main sequence) pollen counts

Depth (cm)	Myriophyllum	Nuphar	Sparganium	Typha latifolia	Filicales	Ophioglossum	Osmunda
180	0	0	0	2	4	0	1
192	0	1	0	1	3	0	1
260	0	0	0	1	2	0	0
272	0	0	0	1	2	0	0
279	0	1	1	1	2	0	0
288	1	0	2	1	1	0	0
296	0	0	2	2	1	0	1
310	0	0	0	2	1	0	0
320	0	0	1	1	1	0	1
326	0	0	1	1	1	0	0
334	1	0	2	1	2	0	0
342	0	0	0	1	2	0	0
356	0	0	0	0	3	0	0
384	0	2	0	1	4	0	0
392	0	2	0	0	3	0	0
408	0	0	1	0	2	0	0
416	0	1	0	1	1	0	0
432	0	0	0	1	3	0	0
444	0	0	0	1	2	0	0
464	0	0	0	0	2	0	0
480	0	0	0	0	3	0	0
496	0	1	2	0	2	0	0
512	0	0	0	1	3	0	0
528	0	0	0	0	3	0	0
544	0	2	0	0	3	0	0
556	0	3	0	2	4	1	0
576	0	2	1	1	4	0	0
592	0	1	0	0	3	0	0
637	0	0	0	0	2	0	0
648	0	0	0	0	2	0	0
656	0	0	0	0	2	0	0
672	0	0	0	0	3	0	0
682	0	0	0	0	4	0	0
692	0	0	0	0	5	0	0
706	1	0	0	2	3	0	0
720	0	0	0	0	4	0	0
746	0	0	0	0	6	0	0
760	0	0	2	0	7	0	0
776	1	0	1	0	7	1	0
784	1	0	1	0	6	0	0
794	0	0	1	1	8	0	0
801	0	0	0	0	11	1	0
808	0	0	0	0	9	0	0
816	0	0	0	1	8	0	0
824	1	0	2	0	4	1	0

Hoxne (main sequence) pollen counts

Depth (cm)	Polypodium	Pteridium	Sphagnum
180	2	0	1
192	1	0	2
260	0	0	0
272	0	0	0
279	1	0	0
288	0	0	0
296	0	0	0
310	0	0	0
320	0	0	0
326	0	0	0
334	0	0	0
342	1	0	0
356	0	0	0
384	1	0	0
392	1	0	0
408	1	0	0
416	0	1	0
432	0	1	0
444	1	1	0
464	1	0	0
480	1	0	0
496	1	0	0
512	0	0	0
528	0	0	0
544	0	0	0
556	1	0	0
576	1	0	0
592	1	0	0
637	1	0	0
648	1	0	0
656	0	0	0
672	1	0	0
682	1	0	0
692	1	0	0
706	1	0	0
720	1	0	0
746	0	0	0
760	0	0	0
776	0	0	0
784	0	0	0
794	0	0	0
801	0	0	0
808	0	0	0
816	0	0	0
824	0	0	0

Hoxne (Stratum C) pollen counts

Depth (cm)	Betula	Pinus	Ulmus	Quercus	Tilia	Alnus
4	3	59	1	15	1	65
20	0	61	2	9	3	136
28	10	55	3	10	3	92
40	27	36	2	15	4	81
60	13	34	3	15	2	94
68	17	38	5	10	2	94
76	19	33	2	19	0	105
100	0	57	0	18	1	120
108	6	27	1	16	1	142
116	0	31	0	6	3	144
132	1	21	1	37	0	153
152	3	32	0	6	0	86

Depth (cm)	Carpinus	Acer	Abies	Picea	Sambucus	Corylus
4	0	0	45	4	0	41
20	0	0	40	6	0	13
28	0	0	37	4	0	29
40	2	0	35	5	0	19
60	0	0	31	5	0	12
68	1	0	35	4	0	14
76	0	0	35	2	1	20
100	0	0	53	3	0	10
108	0	2	30	5	0	7
116	3	0	41	4	0	12
132	3	0	23	3	0	2
152	0	0	32	6	0	14

Depth (cm)	Salix	Hippophae	Hedera helix	Ilex	Poaceae
4	0	0	0	0	8
20	0	0	0	0	2
28	0	0	0	0	12
40	0	2	0	0	19
60	0	1	1	0	30
68	1	0	0	2	19
76	0	0	1	0	16
100	1	0	0	0	4
108	0	0	0	1	6
116	3	3	0	0	5
132	0	3	2	1	4
152	0	0	0	0	15

Depth (cm)	Cyperaceae	Calluna	Empetrum	Ericaceae
4	20	0	4	8
20	16	0	1	3
28	30	0	3	4
40	27	0	5	8
60	26	0	6	9
68	29	2	5	7
76	30	0	2	3
100	5	0	3	3
108	32	0	1	1
116	16	1	2	5
132	26	0	2	3
152	4	0	1	2

Depth (cm)	Artemisia	Cirsium	Compositae	Brassicaceae
4	3	1	0	0
20	0	0	0	0
28	0	0	0	0
40	0	3	3	0
60	0	3	2	2
68	0	0	3	2
76	1	2	0	1
100	0	0	1	0
108	0	2	7	0
116	0	1	3	2
132	1	1	0	3
152	1	1	0	0

Hoxne (Stratum C) pollen counts

Depth (cm)	Caryophyllaceae	Chenopodiaceae	Plantago	Polygonum
4	13	0	0	0
20	1	0	0	0
28	1	1	0	0
40	3	0	0	0
60	5	0	0	1
68	4	0	0	3
76	2	2	0	2
100	3	0	0	3
108	0	2	1	0
116	4	0	3	0
132	0	0	0	0
152	0	0	0	0

Depth (cm)	Ranunculus	Rosaceae	Rubiaceae	Rumex
4	2	0	2	0
20	2	0	0	0
28	2	0	0	0
40	2	0	0	1
60	0	0	0	0
68	0	0	0	0
76	0	0	0	0
100	0	0	0	0
108	0	0	0	0
116	0	0	1	0
132	0	1	0	1
152	0	1	0	1

Depth (cm)	Thalictrum	Apiaceae	Mentha type	Alisma
4	1	3	1	0
20	2	3	0	0
28	2	2	0	0
40	0	1	0	0
60	2	3	0	0
68	0	3	0	0
76	1	1	0	0
100	1	14	0	1
108	3	7	0	0
116	0	7	0	1
132	0	8	0	0
152	0	2	0	0

Depth (cm)	Azolla filiculoides	Myriophyllum	Sparganium	Typha latifolia
4	1	1	0	1
20	2	1	0	1
28	1	0	0	1
40	2	1	1	2
60	1	0	1	1
68	1	0	1	2
76	1	1	0	1
100	1	0	0	1
108	2	0	0	2
116	2	0	0	2
132	1	0	0	1
152	2	0	0	2

Depth (cm)	Filicales	Osmunda	Polypodium	Sphagnum
4	5	1	1	1
20	5	1	1	1
28	6	1	1	1
40	7	1	1	1
60	5	1	1	1
68	3	0	1	1
76	6	0	1	1
100	6	1	1	1
108	4	0	1	1
116	5	1	1	2
132	5	1	2	2
152	5	1	1	1

Athelington pollen counts

Depth (cm)	Betula	Pinus	Ulmus	Quercus	Tilia
440	3	58	1	1	0
490	4	28	2	9	0
510	9	64	0	3	0
538	5	21	1	17	0
556	0	11	1	5	0
622	5	18	8	36	14
642	8	24	5	36	9
688	35	47	8	51	41
700	34	70	10	58	10
724	26	56	8	102	17
768	56	127	8	67	0
792	132	113	3	6	0
814	128	125	1	2	0
834	148	89	0	2	0

Depth (cm)	Alnus	Fagus	Carpinus	Fraxinus	Acer
440	91	0	0	0	0
490	89	0	0	0	3
510	89	0	0	0	1
538	83	0	0	0	4
556	56	0	1	0	0
622	89	0	0	4	4
642	107	0	4	5	0
688	36	0	4	4	0
700	52	1	2	4	2
724	14	1	3	5	0
768	1	0	2	3	0
792	3	0	0	3	3
814	0	0	0	4	0
834	1	0	0	3	3

Depth (cm)	Abies	Picea	Taxus	Pterocarya	Corylus
440	83	5	1	2	10
490	98	6	1	3	18
510	68	6	3	0	5
538	94	5	5	0	37
556	185	5	6	1	10
622	4	3	6	0	69
642	4	3	7	0	61
688	0	5	6	0	20
700	2	5	6	0	11
724	0	4	6	0	18
768	0	4	5	0	7
792	0	0	0	0	6
814	0	0	0	0	6
834	0	0	1	0	9

Depth (cm)	Salix	Juniperus	Hedera helix	Ilex	Type X
440	2	3	0	0	2
490	3	2	1	1	1
510	3	3	0	0	2
538	0	0	2	0	3
556	1	1	2	0	1
622	0	0	3	6	19
642	0	2	3	2	8
688	0	0	2	0	4
700	0	1	0	0	1
724	0	0	13	1	0
768	0	0	7	0	2
792	0	0	0	0	2
814	0	0	0	0	2
834	0	0	0	0	1

Depth (cm)	Vitis	Poaceae	Cyperaceae	Calluna	Empetrum
440	0	6	19	0	1
490	1	2	10	0	0
510	4	10	14	1	0
538	3	4	0	0	0
556	2	1	0	0	1
622	0	1	2	0	1
642	0	1	3	0	0
688	0	12	14	0	0
700	0	10	8	0	0
724	0	7	6	2	0
768	0	2	2	0	1
792	0	10	10	0	0
814	0	10	9	0	0
834	0	26	11	0	0

Athelington pollen counts

Depth (cm)	Ericaceae	Artemisia	Compositae	Cirsium	Caryophyllaceae
440	6	0	0	0	3
490	6	0	1	0	0
510	2	0	0	1	0
538	3	0	0	0	1
556	1	0	0	0	0
622	0	0	0	0	0
642	0	0	0	0	0
688	2	0	0	2	0
700	2	1	2	1	0
724	2	0	1	1	2
768	0	0	0	0	1
792	0	0	3	1	0
814	0	0	3	0	0
834	0	0	3	0	0

Depth (cm)	Chenopodiaceae	Brassicaceae	Filipendula	Lamiaceae	Fabaceae
440	0	1	0	0	0
490	2	2	1	0	0
510	2	1	0	1	0
538	0	2	3	0	0
556	0	1	0	0	1
622	0	0	0	0	0
642	2	2	0	0	1
688	0	2	0	0	0
700	0	0	1	0	0
724	0	1	0	0	0
768	0	0	1	0	0
792	0	1	0	0	0
814	2	0	0	0	0
834	0	0	0	0	0

Depth (cm)	Geranium	Plantago	Polygonum	Ranunculus	Rosaceae
440	0	0	0	0	0
490	0	0	0	1	2
510	0	1	1	3	2
538	0	0	0	4	1
556	0	0	0	5	0
622	0	0	0	5	0
642	0	0	0	2	0
688	0	0	0	5	0
700	1	0	0	4	0
724	0	0	0	2	1
768	1	0	0	3	0
792	0	0	0	2	0
814	0	0	0	3	0
834	0	0	0	2	0

Depth (cm)	Rubiaceae	Rumex	Thalictrum	Apiaceae	Myriophyllum
440	1	0	0	1	1
490	1	0	2	0	0
510	0	0	0	1	0
538	2	0	0	0	1
556	1	0	1	0	1
622	2	0	1	0	0
642	0	0	0	1	1
688	0	0	0	0	0
700	0	1	0	0	1
724	0	0	0	1	0
768	0	0	0	0	0
792	0	0	1	1	1
814	0	2	2	1	0
834	0	0	1	0	0

Depth (cm)	Nuphar	Potamogeton	Sparginium	Typha latifolia	Polypodiaceae
440	0	1	1	1	2
490	0	1	1	1	3
510	0	1	1	1	3
538	0	1	1	1	7
556	1	0	0	0	1
622	1	2	1	0	0
642	0	1	0	0	0
688	0	0	0	0	0
700	0	1	0	0	2
724	0	1	0	0	0
768	0	0	0	0	0
792	0	0	0	0	0
814	0	0	0	0	0
834	0	0	0	0	0

Athelington pollen counts

Depth (cm)	Polypodium	Thelypteris	Sphagnum
440	1	0	1
490	1	0	0
510	1	1	0
538	1	1	1
556	1	0	1
622	1	0	0
642	0	0	0
688	0	0	0
700	0	0	0
724	0	0	0
768	0	0	0
792	0	0	0
814	0	0	0
834	0	0	0

Percentage pollen data from previously published diagrams

Barford percentages from published pollen diagrams

Depth (cm)	Betula	Pinus	Ulmus	Quercus	Tilia	Alnus	Carpinus	Fraxinus	Acer	Abies
198	3	14	1	2	1	16	1	0	0	47
244	5	13	3	6	1	15	0	1	1	15
274	6	10	1	5	1	20	1	1	1	20
302	4	7	2	8	1	20	0	1	1	10
336	2	7	3	5	1	27	0	2	1	9
366	4	7	2	5	1	26	1	1	1	9
380	3	5	2	9	1	25	0	1	1	10
396	2	6	2	4	1	29	4	1	1	5
412	5	8	2	5	1	27	3	2	0	5
426	4	6	2	8	1	22	0	2	1	5
442	3	6	2	4	1	30	5	2	0	5
457	4	6	2	4	<1	31	4	2	1	3
487	5	5	2	9	1	24	3	2	1	4
534	4	7	1	9	1	23	5	1	0	2
549	3	9	2	8	1	26	1	2	0	3
564	3	7	2	9	1	33	1	3	1	1
580	6	9	2	11	1	21	1	3	1	1
608	5	6	1	11	1	20	1	2	1	1
631	5	11	3	11	1	17	1	2	1	0
655	5	10	2	13	1	21	0	2	1	0
670	4	8	1	13	1	23	1	2	1	0
685	5	10	1	16	1	21	1	1	1	1
692	6	9	3	17	1	22	1	2	1	0
707	6	7	3	15	1	22	0	1	1	1
746	2	21	1	17	2	26	1	1	0	0
775	16	17	1	6	2	26	0	2	0	0
821	5	11	3	10	3	28	0	1	0	0
852	5	7	5	16	2	29	0	3	0	0
875	5	11	4	16	2	30	0	5	0	0
914	7	11	3	22	5	35	1	4	0	0
944	30	54	1	4	0	1	0	0	0	0
975	51	20	1	3	1	5	0	0	0	0
1032	2	5	0	1	0	0	0	0	0	0

Barford percentages from published pollen diagrams

Depth (cm)	Pterocarya	Picea	Taxus	Corylus	Salix	Hedera	Ilex	Type X	Rhamnus frangula
198	0	2	3	6	0	1	<1	1	0
244	0	2	5	21	1	0	1	2	0
274	0	1	5	20	0	0	1	3	1
302	0	2	3	30	1	1	0	3	0
336	0	1	5	26	0	0	1	5	0
366	0	2	6	23	0	1	1	2	0
380	0	3	3	27	0	<1	1	5	0
396	0	4	4	25	0	1	0	5	0
412	0	2	3	25	0	1	1	4	0
426	0	4	5	30	0	1	1	5	0
442	0	3	4	23	1	1	1	5	0
457	0	2	4	28	0	0	1	5	0
487	0	2	6	23	0	1	2	5	1
534	0	5	2	26	1	1	5.04	5	0
549	0	4	3	27	0	1	1	3	1
564	0	3	3	24	0	<1	<1	3	0
580	0	4	4	24	1	1	1	2	0
608	0	7	4	29	1	0	1	4	0
631	0	8	3	26	1	1	1	5	0
655	0	6	2	27	0	<1	1	5	0
670	0.2	5	1	27	0	1	1	5	0
685	0	5	1	24	1	1	1	6	0
692	0	6	1	22	1	1	1	4	0
707	0	4	1	24	1	1	1	3	0
746	0	5	1	8	0	1	0	3	0
775	0	3	1	7	0	<1	1	0	0
821	0	4	5	21	0	1	1	4	0
852	0	2	11	8	1	1	1	4	0
875	0	1	4	10	1	1	1	5	0
914	0	1	0	5	0	1	1	2	0
944	0	0	1	0	0	0	0	0	0
975	0	0	0	1	0	<1	0	1	0
1032	0	0	0	0	1	0	0	0	0

Barford percentages from published pollen diagrams

Depth (cm)	Rhamnus cathartica	Hippophae	Vitis	Juniperus	Empetrum	Calluna	Ericales
198	0	0	0	0	1	0	0
244	0	0	0	0	2	1	<1
274	0	0	0	0	1	0	1
302	0	0	0	0	1	0	1
336	0	0	0	0	0	0	0
366	0	0	0	0	1	0	0
380	0	0	0.2	0	2	0	0
396	0	0	0	0	2	0	0
412	0	0	0	0	2	0	0
426	0	0	0	0	2	0	0
442	0	0	0	0	2	0	0
457	0	0	0	0	1	0	1
487	0	0	0	0	0	1	0
534	0	0	0	0.2	2	0	0
549	0	0	0	0	2	0	0
564	0	0	0	0	2	0	1
580	0	0	0.2	0	2	1	0
608	0	0	0	0	2	0	0
631	0	0	0	0	<1	0	1
655	0	0	0	0	1	1	0
670	0	0	0	0	1	0	0
685	0	0	0	0	1	0	0
692	<1	0	0	0	1	0	0
707	0	0	0	0	1	0	1
746	1	0	0	0	1	1	0
775	1	0	0	0	1	0	1
821	0	0	0	0	1	0	0
852	0	0	0	0.2	1	0	1
875	1	0	0	0	1	0	0
914	0	0	0	0	1	0	0
944	0	0	0	0	0	0	0
975	0	1	0	0	0	0	0
1032	0	86	0	0	0	0	0

Barford percentages from published pollen diagrams

Depth (cm)	Gramineae	Cyperaceae	Artemisia	Caryophyllaceae	Chenopodiaceae
198	1	0	0	0	0
244	2	0	0	0	0
274	1	0	<1	0	0
302	2	0	0	0	0
336	1	1	0	0	0
366	1	1	0	1	1
380	1	0	0	0	0
396	2	1	0	0	0
412	2	0	0	<1	0
426	1	0	0	0	0
442	0	1	1	0	0
457	0	0	0	0	0
487	1	1	1	1	0
534	2	0	0	0	0
549	1	0	0	0	0
564	1	0	0	0	0
580	1	<1	1	1	1
608	1	0	1	0	0
631	1	0	0	0	1
655	1	0	0	1	0
670	2	1	0	0	0
685	1	1	0	0	0
692	1	1	0	0	0
707	1	1	0	1	0
746	6	0	1	0	0
775	10	1	0	0	0
821	1	0	0	0	1
852	1	1	0	0	0
875	1	0	0	0	0
914	1	0	1	0	0
944	3	1	0	0	0
975	5	7	0	0	0
1032	1	0	0	0	0

Barford percentages from published pollen diagrams

Depth (cm)	**Compositae (tub)**	**Compositae (lig)**	**Cruciferae**	**Leguminosae**	**Plantago**
198	0	0	0	0	0
244	0	0	1	0	0
274	0	0	<1	0	0
302	0	0	0	0	0
336	1	0	0	0	0
366	0	0	1	0	0
380	0	0	0	0	0
396	0	0	1	0	0
412	0	0	0	1	0
426	0	0	<1	0	0
442	0	0	0	0	0
457	0	0	1	0	0
487	0	0	0	0	0
534	0	0	0	0	0
549	1	1	0	0	0
564	0	0	1	1	0
580	0	0	0	0	0
608	0	0	0	0	0
631	0	0	0	0	0
655	0	0	0	0	0
670	1	0	0	<1	0
685	0	0	0	0	0
692	0	0	0	0	0
707	1	0	0	0	0
746	0	0	0	0	<1
775	0	1	1	0	1
821	0	0	0	0	0
852	0	0	0	0	0
875	1	0	0	0	0
914	0	0	0	0	0
944	1	1	0	0	0
975	1	1	0	0	0
1032	1	2	0	0	0

Barford percentages from published pollen diagrams

Depth (cm)	Ranunculaceae	Rosaceae	Rubiaceae	Thalictrum	Umbelliferae	Valeriana
198	0	0	0	0	0	0
244	1	0	0	0	1	0
274	0	0	0	0	0	0
302	0	0	1	0	1	0
336	0	0	0	1	1	0
366	0	0	0	1	1	0
380	1	1	0	0	0	0
396	<1	0	0	0	0	0
412	0	0	0	0	0	0
426	0	0	0	0	0	0
442	0	0	0	0	0	0
457	0	0	0	0	0	0
487	0	0	0	0	0	0
534	1	0	1	0	0	0
549	2	<1	0	0	0	0
564	0	0	0	0	0	0
580	1	0	0	0	0	0
608	1	0	0	0	0	0
631	0	0	0	0	0	0
655	0	0	0	0	0	0
670	0	0	0	0	1	0
685	0	0	0	0	0	0
692	0	1	0	0	0	0
707	1	0	0	0	0	1
746	0	0	0	0	1	0
775	0	0	0	0	1	0
821	0	0	0	0	0	0
852	0	0	0	0	1	0
875	0	0	0	0	0	0
914	0	0	0	0	1	0
944	1	0	0	1	1	0
975	0	0	0	1	1	0
1032	0	0	0	0	1	0

Barford percentages from published pollen diagrams

Depth (cm)	**Filipendula**	**Hypericum**	**Urtica**	**Labiatae**	**Centaurea nigra**	**Rumex**	**Trifolium**
198	0.2	0	0	0	0	0	0
244	0	0	0	0	0	0	0
274	0	0	0	0	0	0	0
302	0	0	0	0	0	0	0
336	0	0	0	0	0	0	0
366	0	0	0	0	0	0	0
380	0	0	0	0	0	0	0
396	0	0	0	0	0	0	0
412	0	0	0	0	0	0	0
426	0	0	0	0	0	0	0
442	0	0	0.2	0	0	0	0
457	0	0.2	0.2	0	0	0	0
487	0	0	0	0	0	0	0
534	0	0	0	0	0	0	0
549	0	0	0	0	0	0	0
564	0	0	0	0.2	0	0	0
580	0	0	0	0	0	0	0
608	0	0	0	0	0	0	0
631	0	0	0	0	0	0	0
655	0	0	0	0	0	0	0
670	0	0	0	0	0	0	0
685	0	0	0	0	0	0	0
692	0	0	0	0	0	0	0
707	0	0	0	0	0.2	0	0
746	0	0	0	0	0	0	0
775	0	0	0.2	0.2	0	0.2	0.2
821	0	0	0	0	0	0	0
852	0	0	0	0	0	0	0
875	0	0	0	0	0	0	0
914	0	0	0	0	0	0	0
944	0	0	0	0	0	0	0
975	0	0	0	0	0	0	0
1032	0	0	0	0	0	0	0

Marks Tey (borehole 1A) percentages from published pollen diagrams

Depth (cm)	Betula	Pinus	Abies	Picea	Ulmus	Quercus	Tilia	Fraxinus	Alnus	Acer	Carpinus
1060	3	9	40	<1	1	6	0	1	30	1	1
1100	4	14	23	1	1	3	<1	0	22	0	2
1155	2	7	15	1	3	7	1	0	25	1	1
1205	3	4	5	<1	1	8	1	1	28	<1	8
1225	5	2	3	1	1	4	<1	1	34	0	10
1265	3	4	4	1	1	7	1	1	20	1	14
1325	3	4	1	1	2	8	<1	1	22	<1	5
1355	2	3	1	1	2	9	1	1	12	<1	6
1385	3	3	<1	1	1	12	1	1	15	1	3
1415	4	4	1	1	3	11	1	1	21	1	1
1450	3	2	1	1	2	10	<1	1	19	1	1
1480	3	4	<1	1	1	15	1	1	15	1	1
1510	4	5	<1	1	4	19	<1	1	14	<1	0
1520	9	8	0	1	6	22	<1	1	13	0	0
1530	9	6	0	1	5	20	<1	1	18	0	<1
1538	6	7	0	1	4	18	1	1	16	0	<1
1550	10	6	0	<1	3	13	1	1	25	1	0
1560	3	7	0	1	2	8	1	1	21	1	0
1570	3	4	0	1	6	8	1	1	21	0	0
1600	1	3	0	1	6	8	1	1	16	0	0
1630	2	3	<1	1	7	12	<1	1	11	0	0
1660	2	3	<1	<1	13	11	1	1	19	<1	0
1690	3	2	0	1	22	10	1	1	14	<1	0
1700	2	1	0	1	8	13	<1	0	28	0	0
1710	2	3	0	1	4	20	2	1	30	0	0
1725	5	4	0	1	1	21	1	5	34	<1	0
1730	7	3	0	1	2	29	1	<1	39	1	0
1745	12	5	0	<1	1	41	2	<1	15	0	0
1750	17	5	0	<1	1	50	<1	1	4	<1	0
1765	23	7	0	<1	3	49	0	<1	3	0	0
1775	44	8	0	1	3	25	0	1	2	0	0
1780	65	10	<1	0	1	1	1	0	2	1	0
1785	60	12	0	<1	1	4	0	0	1	<1	0
1795	56	10	0	0	6	10	0	1	0	<1	0
1800	66	8	0	0	6	8	<1	0	0	<1	0
1805	73	10	0	0	4	5	<1	0	0	<1	0
1810	58	18	0	0	1	3	0	0	1	<1	0
1835	62	10	0	0	0	3	0	0	0	0	0
1850	76	2	0	1	0	<1	0	0	0	<1	0
1852	85	2	0	0	0	0	0	0	0	0	0
1865	80	5	0	<1	<1	1	0	0	0	0	0
1878	80	9	0	0	<1	1	0	0	0	0	0
1880	66	11	0	0	1	4	0	0	0	0	0
1892	56	8	0	0	8	20	0	0	1	0	0
1895	64	8	0	0	11	9	<1	0	1	<1	0
1898	68	7	0	0	9	8	0	0	1	0	0
1905	78	6	0	0	1	7	0	0	0	<1	0
1915	59	19	0	<1	1	1	0	0	<1	<1	0
1925	76	2	0	0	0	1	0	0	<1	<1	0
1950	72	8	0	0	0	2	0	0	0	0	0
1972	74	9	0	<1	1	0	0	0	<1	<1	0
1977	85	2	0	0	0	0	0	0	0	0	0
1985	79	1	0	0	0	0	0	0	0	0	0
1995	70	1	0	0	0	0	0	0	0	0	0
2005	59	6	0	0	0	0	0	0	0	0	1
2007	64	2	0	0	0	0	0	0	0	0	0
2010	62	1	0	0	0	0	0	0	0	0	0
2012	48	1	0	0	0	0	0	0	0	0	0
2013	30	3	0	0	0	0	0	0	0	0	0
2014	28	3	0	1	0	0	0	0	0	0	0

Marks Tey (borehole 1A) percentages from published pollen diagrams

Depth (cm)	Taxus	Corylus	Salix	Hippophae	Juniperus	Hedera	Ilex	Viscum	Vitis	Euonymus
1060	2	1	0	0	1	<1	0	0	<1	0
1100	6	13	0	0	0	0	0	0	0	0
1155	12	15	0	0	0	1	<1	0	1	0
1205	10	22	0	0	0	0	<1	0	0	0
1225	10	20	0	0	0	<1	<1	0	0	0
1265	8	30	0	0	0	<1	<1	0	0	0
1325	5	39	0	0	0	1	1	0	0	0
1355	11	41	0	0	0	<1	1	0	0	0
1385	5	41	0	0	0	1	1	0	0	0
1415	5	36	1	0	0	<1	1	0	0	0
1450	2	47	1	0	0	<1	1	0	0	0
1480	2	44	0	0	0	1	1	0	0	0
1510	1	42	0	0	0	1	1	0	0	0
1520	1	23	0	0	0	1	<1	0	0	0
1530	3	18	1	0	0	1	1	<1	0	0
1538	3	20	0	0	0	1	<1	0	0	0
1550	3	18	1	0	0	<1	0	0	0	0
1560	2	20	0	0	0	<1	1	0	0	0
1570	12	30	0	0	0	1	1	0	0	0
1600	10	46	0	0	0	1	<1	0	0	0
1630	11	40	1	0	0	1	1	0	0	0
1660	11	31	0	0	0	1	1	0	0	0
1690	22	18	0	0	0	<1	1	0	0	0
1700	23	18	1	0	0	1	1	0	0	0
1710	4	23	0	0	0	1	1	0	0	0
1725	1	11	<1	0	1	2	<1	0	0	0
1730	0	10	<1	0	0	1	<1	0	0	0
1745	0	10	0	0	0	1	0	0	0	0
1750	0	5	1	0	1	1	0	0	0	0
1765	0	2	0	0	0	1	0	0	0	0
1775	0	2	2	0	1	0	0	0	0	<1
1780	0	2	0	1	0	0	0	0	0	0
1785	0	<1	1	0	4	0	0	0	0	0
1795	0	1	1	0	0	1	0	0	0	0
1800	0	1	1	0	0	0	0	0	0	0
1805	0	0	1	0	0	0	0	0	0	0
1810	0	0	1	0	1	0	0	0	0	0
1835	0	0	1	0	4	0	0	0	0	0
1850	0	0	1	<1	1	0	0	0	0	0
1852	0	0	0	<1	<1	0	0	0	0	0
1865	0	0	0	<1	0	0	0	0	0	0
1878	0	0	1	0	0	0	0	0	0	0
1880	0	0	2	0	1	<1	0	0	0	0
1892	0	0	1	0	0	<1	0	0	0	0
1895	0	<1	1	0	1	<1	0	0	0	0
1898	0	1	1	0	0	0	0	0	0	0
1905	0	0	0	0	1	<1	0	0	0	0
1915	0	1	0	0	0	<1	0	0	0	0
1925	0	0	1	<1	2	0	0	0	0	0
1950	0	0	1	0	1	0	0	0	0	0
1972	0	0	<1	<1	0	0	0	0	0	0
1977	0	0	0	1	0	0	0	0	0	0
1985	0	0	<1	<1	0	0	0	0	0	0
1995	0	0	3	1	1	0	0	0	0	0
2005	0	0	4	2	0	0	0	0	0	0
2007	0	0	2	2	0	0	0	0	0	0
2010	0	0	4		1	0	0	0	0	0
2012	0	0	5		1	0	0	0	0	0
2013	0	0	5		0	0	0	0	0	0
2014	0	0	5		5	0	0	0	0	0

Marks Tey (borehole 1A) percentages from published pollen diagrams

Depth (cm)	Viburnum	Type X	Gramineae	Cyperaceae	Armeria	Artemisia	Calluna
1060	0	0	1	1	0	0	0
1100	0	<1	3	0	0	0	1
1155	0	1	1	1	0	0	<1
1205	0	1	1	1	0	0	0
1225	0	1	1	1	0	0	0
1265	0	2		<1	0	0	0
1325	0	3	1	0	0	0	0
1355	0	3	1	0	0	0	0
1385	0	5	1	1	0	<1	1
1415	0	2	1	1	0	0	0
1450	0	3	1	0	0	<1	1
1480	0	2	1	1	0	0	0
1510	0	3	1	0	0	0	0
1520	0	2	6	0	0	0	1
1530	0	1	8	1	0	0	0
1538	1	1	11	0	0	0	1
1550	<1	1	10	1	0	0	0
1560	0	1	23	1	0	0	0
1570	0	1	1	1	0	0	1
1600	0	1	1	0	0	0	0
1630	0	2	1	0	0	0	<1
1660	0	1	1	1	0	0	0
1690	0	2	0	0	0	<1	0
1700	0	1	0	1	0	0	0
1710	<1	2	1	1	0	0	0
1725	0	5	1	1	0	0	0
1730	0	1	<1	<1	0	0	0
1745	0	1	5	1	0	<1	0
1750	1	0	4	1	0	0	0
1765	1	0	5	0	0	0	0
1775	0	0	5	1	0	0	0
1780	0	0	13	1	0	0	0
1785	0	0	10	1	0	1	0
1795	0	0	9	<1	0	0	0
1800	0	0	5	1	0	0	0
1805	0	0	4	0	0	0	0
1810	0	0	8	2	0	0	0
1835	0	0	12	3	0	0	0
1850	0	0	11	1	0	0	0
1852	0	0	8	2	0	<1	0
1865	0	0	8	1	0	0	0
1878	0	0	4	1	<1	0	0
1880	0	0	8	2	0	0	0
1892	0	0	3	0	0	0	0
1895	0	0	2	0	0	0	0
1898	0	0	1	1	0	0	<1
1905	0	0	3	<1	0	0	0
1915	0	0	8	1	0	0	0
1925	0	0	13	1	0	0	0
1950	0	0	10	2	0	0	<1
1972	0	0	7	1	0	0	0
1977	0	0	7	1	0	0	0
1985	0	0	14	1	0	0	0
1995	0	0	17	5	0	0	0
2005	0	0	18	2	0	1	0
2007	0	0	18	8	0	0	0
2010	0	0	18	3	0	0	0
2012	0	0	26	10	0	0	0
2013	0	0	24	5	0	0	0
2014	0	0	22	10	0	0	0

Marks Tey (borehole 1A) percentages from published pollen diagrams

Depth (cm)	Chenopodiaceae	Centaurea (nigra)	Empetrum	Erica cf terminalis	Ericaceae
1060	0	0	1	0	0
1100	0	0	2	0	3
1155	0	0	0	0	<1
1205	0	0	0	0	<1
1225	0	<1	1	0	1
1265	0	0	0	0	1
1325	0	0	<1	0	1
1355	0	0	0	0	1
1385	<1	0	<1	0	<1
1415	<1	0	1	0	<1
1450	0	0	1	0	1
1480	0	0	0	0	1
1510	<1	0	0	0	1
1520	0	0	1	1	0
1530	0	0	0	0	<1
1538	0	0	0	<1	1
1550	0	0	0	0	1
1560	0	1	0	0	1
1570	<1	0	0	0	1
1600	0	0	0	0	<1
1630	<1	0	0	0	1
1660	0	0	0	0	1
1690	0	0	<1	0	<1
1700	<1	0	0	0	<1
1710	0	0	0	0	1
1725	<1	0	0	0	<1
1730	0	0	0	0	<1
1745	<1	0	0	0	<1
1750	0	0	0	0	1
1765	0	0	0	0	1
1775	1	0	0	0	<1
1780	0	0	0	0	0
1785	0	<1	0	0	<1
1795	0	0	0	0	0
1800	0	0	0	0	0
1805	0	0	0	0	0
1810	1	<1	0	0	0
1835	<1	0	0	0	1
1850	<1	0	0	0	0
1852	0	<1	0	0	0
1865	<1	0	0	0	0
1878	<1	0	0	0	0
1880	0	0	0	0	0
1892	0	0	0	0	0
1895	0	0	0	0	0
1898	<1	0	0	0	0
1905	0	0	0	0	0
1915	<1	0	0	0	<1
1925	<1	0	0	0	0
1950	0	0	0	0	0
1972	<1	0	0	0	1
1977	<1	0	0	0	0
1985	<1	0	0	0	0
1995	0	0	0	0	0
2005	<1	0	0	0	0
2007	1	0	0	0	0
2010	3	0	0	0	0
2012	0	0	0	0	<1
2013	0	0	0	0	<1
2014	0	0	0	0	0

Marks Tey (borehole 1A) percentages from published pollen diagrams

Depth (cm)	Gentianaceae	Helianthemum	Plantago coronopus	Plantago maritima
1060	0	0	0	0
1100	0	0	0	0
1155	<1	0	0	0
1205	0	0	0	0
1225	0	0	0	0
1265	0	0	0	0
1325	0	0	0	0
1355	0	0	0	0
1385	0	0	0	0
1415	0	0	0	0
1450	0	0	0	0
1480	0	0	0	0
1510	0	0	0	0
1520	0	0	0	0
1530	0	0	0	0
1538	0	0	0	0
1550	<1	0	0	0
1560	0	0	0	<1
1570	0	0	0	0
1600	0	0	0	0
1630	0	0	0	0
1660	0	0	0	0
1690	0	0	0	0
1700	<1	0	0	0
1710	0	0	0	0
1725	0	0	0	<1
1730	0	0	0	0
1745	0	<1	0	0
1750	0	0	0	0
1765	0	0	0	0
1775	0	0	0	0
1780	0	0	0	0
1785	0	0	0	0
1795	0	0	0	0
1800	0	0	0	0
1805	0	0	0	0
1810	0	0	0	0
1835	0	0	0	0
1850	0	0	<1	0
1852	0	0	<1	0
1865	0	0	0	<1
1878	0	0	0	0
1880	0	<1	0	0
1892	0	0	0	0
1895	0	0	0	0
1898	0	0	0	0
1905	0	0	0	0
1915	0	0	0	0
1925	0	0	0	0
1950	0	0	0	0
1972	0	0	0	<1
1977	0	0	0	0
1985	0	0	0	0
1995	0	0	0	0
2005	0	0	0	0
2007	0	0	0	0
2010	0	0	0	
2012	0	0	0	
2013	0	0	0	
2014	0	1	0	

Marks Tey (borehole 1A) percentages from published pollen diagrams

Depth (cm)	Plantago media	Polygonum	Caryophyllaceae	Compositae	Cruciferae	Epilobium
1060	0	0	0	0	<1	0
1100	0	0	0	<1	<1	0
1155	0	0	<1	<1	1	0
1205	0	0	0	0	1	0
1225	0	0	<1	0	1	0
1265	0	0	0	0	<1	0
1325	0	0	0	<1	<1	0
1355	0	<1	<1	0	<1	1
1385	0	0	<1	<1	<1	0
1415	0	0	<1	0	<1	0
1450	0	0	0	0	<1	0
1480	0	0	0	1	<1	0
1510	0	0	<1	0	1	0
1520	0	0	1	1	0	0
1530	0	0	1	<1	<1	0
1538	0	0	<1	1	1	0
1550	<1	0	0	1	<1	0
1560	0	0	<1	1	<1	0
1570	0	0	<1	<1	<1	0
1600	0	0	0	0	<1	0
1630	0	0	<1	1	0	0
1660	0	0	<1	0	0	0
1690	0	0	<1	0	0	0
1700	0	0	0	0	0	0
1710	0	0	<1	0	1	0
1725	0	0	<1	1	1	0
1730	0	0	<1	0	<1	0
1745	0	0	<1	<1	0	0
1750	0	0	<1	1	<1	0
1765	0	0	<1	<1	<1	0
1775	0	0	<1	<1	0	0
1780	0	0	<1	1	0	0
1785	<1	0	<1	<1	0	0
1795	0	0	<1	1	0	0
1800	0	0	<1	<1	0	0
1805	0	0	0	<1	0	0
1810	<1	0	<1	1	0	<1
1835	0	0	0	<1	0	0
1850	0	0	<1	<1	0	0
1852	0	0	0	<1	0	0
1865	0	0	<1	1	0	0
1878	<1	0	<1	<1	0	0
1880	0	0	0	<1	0	0
1892	0	0	0	0	0	0
1895	0	0	0	1	0	0
1898	0	0	1	<1	0	0
1905	<1	0	<1	<1	0	0
1915	<1	0	1	1	1	0
1925	0	0	<1	1	0	0
1950	0	0	0	<1	0	0
1972	0	0	<1	1	0	0
1977	0	0	<1	<1	0	0
1985	1	0	0	0	0	0
1995	0	0	0	<1	0	0
2005	<1	0	0	1	0	0
2007	0	0	<1	1	0	0
2010	0	1	0	1	0	0
2012	0	0	0	1	0	0
2013	0	0	0	4	0	0
2014	1	0	0	5	1	0

Marks Tey (borehole 1A) percentages from published pollen diagrams

Depth (cm)	Filipendula	Geranium	Labiatae	Leguminosae	Ranunculaceae	Rosaceae	Rubiaceae
1060	0	0	0	0	0	<1	0
1100	0	0	0	0	0	1	0
1155	0	0	0	0	0	1	0
1205	0	0	0	0	0	<1	1
1225	0	0	0	0	0	1	0
1265	0	0	0	0	<1	<1	0
1325	0	<1	0	0	0	<1	0
1355	1	1	0	0	0	0	0
1385	0	0	0	0	0	<1	1
1415	0	<1	0	0	0	0	0
1450	0	0	0	0	1	0	0
1480	<1	0	0	0	0	0	0
1510	0	0	0	0	0	0	0
1520	0	0	0	1	0	<1	0
1530	0	0	1	0	0	0	0
1538	0	<1	0	0	1	<1	0
1550	0	0	0	0	<1	<1	0
1560	<1	0	0	0	<1	1	0
1570	0	0	0	1	1	0	1
1600	0	0	0	0	1	1	0
1630	0	0	0	0	1	0	<1
1660	0	<1	0	0	0	<1	0
1690	0	0	1	0	<1	0	0
1700	0	0	0	0	0	<1	0
1710	0	<1	0	0	<1	<1	0
1725	0	0	0	0	0	0	0
1730	0	0	0	0	0	0	0
1745	0	<1	0	0	0	0	0
1750	1	0	0	1	0	1	0
1765	0	<1	0	0	<1	1	0
1775	0	0	0	0	<1	1	0
1780	0	0	0	0	0	0	0
1785	0	0	0	0	0	0	0
1795	1	0	0	0	<1	0	0
1800	0	0	0	0	<1	1	0
1805	0	0	0	0	<1	1	0
1810	1	0	0	0	0	<1	1
1835	<1	0	0	0	1	1	0
1850	0	0	<1	0	<1	<1	0
1852	0	0	0	0	<1	0	0
1865	0	0	0	0	0	0	0
1878	0	0	0	<1	<1	<1	0
1880	1	0	0	0	<1	<1	1
1892	1	<1	0	0	1	0	0
1895	0	0	0	0	0	<1	0
1898	0	0	0	0	0	0	0
1905	0	0	0	0	0	<1	0
1915	0	0	0	0	<1	0	1
1925	0	0	<1	0	0	<1	0
1950	0	0	0	0	0	0	0
1972	0	0	0	0	<1	<1	<1
1977	0	0	0	0	<1	<1	0
1985	0	0	0	0	<1	0	0
1995	0	0	0	0	1	0	0
2005	0	0	0	0	1	0	0
2007	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0
2013	0	0	0	0	1	0	0
2014	0	0	0	0	2	0	0

Marks Tey (borehole 1A) percentages from published pollen diagrams

Depth (cm)	Rumex	Succisa	Thalictrum	Umbelliferae	Urtica	Valeriana
1060	0	0	0	0	0	0
1100	0	0	0	0	0	0
1155	0	0	0	1	0	0
1205	1	0	1	0	0	0
1225	0	0	0	0	0	0
1265	0	0	0	0	0	0
1325	0	0	0	0	0	0
1355	0	0	0	0	0	0
1385	0	0	0	0	0	0
1415	0	0	0	1	0	0
1450	0	0	<1	<1	0	0
1480	0	0	0	0	0	0
1510	0	0	0	0	0	0
1520	0	0	0	<1	0	0
1530	1	0	0	1	0	0
1538	0	0	0	1	1	0
1550	0	0	0	1	0	0
1560	0	0	0	0	1	<1
1570	0	0	0	1	1	0
1600	0	0	0	<1	1	0
1630	0	0	<1	1	0	<1
1660	0	0	0	0	0	0
1690	0	0	0	0	0	0
1700	0	0	0	0	0	0
1710	0	0	0	<1	0	0
1725	0	0	0	1	<1	0
1730	0	0	0	<1	1	0
1745	1	0	0	1	0	0
1750	0	0	0	<1	0	0
1765	0	0	0	<1	0	0
1775	0	0	<1	0	0	0
1780	0	0	<1	1	0	0
1785	0	0	1	<1	0	0
1795	0	0	0	1	0	0
1800	0	0	0	0	0	0
1805	0	0	0	0	0	0
1810	0	0	0	1	0	0
1835	0	0	0	1	0	0
1850	<1	0	1	1	0	0
1852	0	0	<1	1	0	0
1865	0	<1	0	<1	0	0
1878	0	0	0	0	0	0
1880	0	0	1	0	0	0
1892	0	0	0	0	0	0
1895	0	0	0	0	0	0
1898	0	0	0	<1	0	0
1905	0	0	<1	0	0	0
1915	0	0	1	1	0	0
1925	0	0	0	<1	0	0
1950	0	0	1	1	0	0
1972	0	0	<1	<1	0	0
1977	0	0	<1	1	0	0
1985	0	0	1	1	0	0
1995	0	0	1	0	0	0
2005	0	0	2	2	0	0
2007	0	0	1	1	0	0
2010	0	0	2	1	0	0
2012	0	0	1	1	0	<1
2013	0	0	0	1	0	0
2014	0	0	0	1	0	0

Marks Tey (borehole III) percentages from published pollen diagrams

Depth (cm)	Betula	Pinus	Abies	Picea	Ulmus	Quercus	Tilia cordata	Fraxinus	Alnus	Acer
100	10	35	14	1	0	0	0	0	4	0
153	13	30	2	0	0	0	0	0	3	0
175	12	31	1	1	0	0	0	0	0	0
200	12	17	2	1	0	0	0	0	3	0
225	14	17	5	1	0	2	0	0	4	0
250	18	19	4	1	0	0	0	0	4	0
275	16	22	9	1	1	1	0	0	4	0
300	20	34	4	1	0	0	0	0	4	0
325	24	26	4	1	1	0	0	0	3	0
345	12	23	11	1	1	<1	0	0	8	<1
370	14	26	16	2	0	0	0	0	12	0
385	9	29	19	3	0	3	0	0	10	0
400	16	27	11	1	2	<1	0	0	11	<1
415	12	27	10	3	<1	1	0	2	7	0
430	11	25	18	2	1	3	0	2	16	0
450	8	24	9	1	1	1	0	1	11	0
470	11	29	9	4	<1	1	0	<1	10	0
490	12	28	14	1	0	0	0	0	9	0
505	10	22	7	2	0	<1	0	0	7	0
525	11	28	10	2	0	<1	0	0	11	0
555	9	9	29	5	<1	2	<1	1	30	0
605	7	9	38	2	2	9	<1	0	20	0
655	5	8	35	1	2	8	<1	1	21	<1
685	8	9	29	1	3	7	1	1	23	0

Marks Tey (borehole III) percentages from published pollen diagrams

Depth (cm)	Carpinus	Pterocarya	Taxus	Corylus	Salix	Juniperus	Hedera	Ilex	Buxus
100	0	0	0	0	0	0	0	0	0
153	0	0	0	4	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0
200	0	<1	0	0	0	0	0	0	0
225	1	0	0	0	0	0	0	0	0
250	0	0	0	<1	0	0	0	0	0
275	1	0	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0	0	0
325	0	0	0	1	1	0	0	0	0
345	<1	0	0	4	0	0	0	0	0
370	0	0	0	<1	0	0	0	0	0
385	<1	<1	0	0	0	0	0	0	0
400	2	0	0	1	0	0	0	0	1
415	<1	2	0	4	1	0	<1	0	0
430	0	1	0	1	0	0	0	0	0
450	0	1	0	5	1	0	0	0	0
470	0	1	0	1	<1	0	<1	0	0
490	0	<1	0	0	0	0	0	0	0
505	0	1	0	1	0	2	0	0	1
525	0	<1	0	<1	0	0	0	0	0
555	0	1	1	3	0	0	0	<1	0
605	5	1	1	2	0	0	<1	1	<1
655	3	0	4	3	0	0	<1	<1	<1
685	1	0	4	1	1	1	<1	0	<1

Marks Tey (borehole III) percentages from published pollen diagrams

Depth (cm)	Frangula	Vitis	Type X	Gramineae	Cyperaceae	Armeria	Artemisia	Calluna
100	0	0	0	14	0	0	3	0
153	0	0	0	28	0	0	3	2
175	0	0	0	24	2	0	9	2
200	0	0	0	34	3	2	14	1
225	0	0	0	26	2	0	13	2
250	0	0	1	23	1	0	4	2
275	0	0	<1	18	1	0	6	1
300	0	0	0	21	1	0	2	1
325	0	0	0	27	1	0	0	1
345	0	0	0	22	2	0	1	1
370	0	0	0	7	1	0	2	3
385	0	0	0	9	1	0	1	4
400	0	0	0	4	<1	0	1	<1
415	0	0	0	5	1	0	0	3
430	0	0	0	7	4	0	0	2
450	0	0	1	5	3	0	0	6
470	0	0	0	8	2	0	1	3
490	0	0	0	6	1	0	0	10
505	<1	0	0	9	4	0	<1	3
525	0	0	0	10	2	0	0	3
555	0	0	0	4	0	0	0	<1
605	0	0	0	2	0	0	1	1
655	0	0	1	1	1	0	<1	<1
685	0	1	<1	4	1	0	0	0

Marks Tey (borehole III) percentages from published pollen diagrams

Depth (cm)	Chenopodiaceae	Empetrum	Erica cf terminalis	Ericaceae	Plantago media
100	0	2	0	0	0
153	1	1	0	0	0
175	1	1	0	0	2
200	1	1	0	2	0
225	1	4	0	0	0
250	1	4	0	2	0
275	1	4	0	0	0
300	0	1	0	0	0
325	0	1	0	0	1
345	0	4	0	0	<1
370	0	12	1	0	0
385	0	10	1	0	0
400	1	12	<1	<1	0
415	<1	14	2	0	0
430	1	8	2	2	0
450	1	8	1	3	0
470	0	10	1	<1	0
490	0	15	1	0	0
505	<1	11	5	0	0
525	0	15	0	1	0
555	0	3	0	0	0
605	<1	1	0	0	0
655	<1	1	0	0	0
685	0	2	0	0	0

Marks Tey (borehole III) percentages from published pollen diagrams

Depth (cm)	Plantago maritima	Polygonum aviculare type	Polygonum bistotra type	Helianthemum
100	0	0	0	0
153	0	2	0	0
175	0	0	0	0
200	0	0	0	0
225	0	0	0	0
250	0	0	0	0
275	1	2	0	0
300	1	0	<1	0
325	0	0	0	0
345	0	<1	0	0
370	0	0	0	0
385	0	0	0	0
400	0	0	0	0
415	0	0	0	0
430	0	0	0	0
450	0	0	0	0
470	0	0	0	0
490	0	0	0	0
505	0	0	0	2
525	0	0	0	0
555	0	0	0	0
605	0	0	0	0
655	0	0	0	0
685	1	0	0	0

Marks Tey (borehole III) percentages from published pollen diagrams

Depth (cm)	Linum anglicum type	Polemonium	Campanulaceae	Caryophyllaceae	Compositae
100	0	0	0	5	3
153	0	0	0	3	5
175	0	0	0	4	4
200	0	0	0	1	2
225	0	0	0	2	3
250	0	0	0	2	3
275	0	0	1	2	3
300	0	1	0	1	3
325	0	0	0	0	1
345	0	0	1	1	2
370	0	0	0	0	1
385	0	0	0	0	1
400	0	0	0	2	2
415	0	0	0	<1	<1
430	0	0	0	1	1
450	0	0	0	2	3
470	0	0	0	1	1
490	0	0	0	<1	1
505	<1	0	0	2	1
525	0	0	0	<1	1
555	0	0	0	0	<1
605	0	0	0	<1	<1
655	0	0	0	0	<1
685	0	0	0	0	0

Marks Tey (borehole III) percentages from published pollen diagrams

Depth (cm)	Cruciferae	Filipendula	Leguminosae	Ranunculaceae	Rosaceae	Rubiaceae
100	1	0	0	8	0	0
153	0	0	0	3	0	0
175	0	2	0	2	0	0
200	1	2	0	1	0	<1
225	1	1	0	1	0	0
250	2	2	0	2	0	<1
275	<1	1	0	1	0	1
300	1	1	0	1	0	0
325	0	0	<1	1	0	<1
345	0	0	0	3	0	0
370	0	0	0	3	0	0
385	0	0	0	0	0	0
400	<1	0	0	2	0	0
415	2	2	0	<1	0	0
430	0	0	0	1	0	0
450	2	0	0	1	0	1
470	0	2	<1	1	0	<1
490	0	0	0	0	0	0
505	2	2	1	0	0	<1
525	0	0	<1	0	0	2
555	0	0	0	0	<1	0
605	<1	0	<1	<1	<1	0
655	<1	0	0	0	<1	0
685	0	0	0	0	0	0

Marks Tey (borehole III) percentages from published pollen diagrams

Depth (cm)	Thalictrum	Umbelliferae	Lythrum	Rumex	Succisa	Valeriana officianalis
100	0	0	0	0	0	0
153	0	0	0	0	0	0
175	2	0	0	0	0	0
200	1	0	0	0	0	0
225	0	0	0	0	0	0
250	2	1	0	0	0	0
275	1	1	0	0	0	0
300	1	1	0	0	0	0
325	1	3	0	1	0	0
345	1	1	0	0	0	1
370	0	0	0	0	0	0
385	0	0	0	0	0	0
400	<1	1	0	0	0	1
415	2	0	0	0	0	0
430	0	1	0	0	0	0
450	0	0	0	0	0	0
470	1	0	0	0	0	0
490	0	0	0	0	0	<1
505	1	2	0	0	1	0
525	1	1	0	0	0	<1
555	0	<1	0	0	0	0
605	0	0	0	0	0	0
655	0	0	1	0	0	0
685	0	0	0	0	0	0

Nechells percentages from published pollen diagrams

Depth (cm)	Betula	Pinus	Ulmus	Quercus	Fraxinus	Tilia	Alnus	Taxus	Picea	Abies	Acer	Carpinus
238	4	9	0	2	0	0	78	<1	18	0	0	0
244	12	24	<1	2	0	1	66	<1	4	<1	0	0
250	7	36	0	<1	0	<1	50	0	5	5	0	0
274	7	29	2	2	0	0	49	0	2	3	0	0
290	6	19	0	2	0	0	80	1	1	<1	0	0
299	4	26	0	2	0	<1	75	1	9	1	0	0
305	6	28	2	2	0	<1	61	2	7	6	0	0
335	3	8	<1	3	0	1	82	3	2	3	0	0
351	5	12	2	5	0	0	58	8	8	25	0	0
366	2	10	0	3	0	0	74	6	2	10	0	0
375	3	9	<1	<1	0	0	76	5	2	21	0	0
381	3	11	0	2	0	0	73	4	10	10	0	0
390	4	10	0	2	0	0	70	9	9	20	0	0
396	2	5	0	2	0	0	59	2	10	39	0	0
405	3	6	2	2	0	2	69	2	23	3	0	0
411	4	3	3	4	0	2	73	9	15	1	<1	0
421	3	3	2	7	0	<1	70	5	20	2	0	<1
436	4	3	<1	8	0	2	82	5	15	0	2	1
451	3	3	0	8	0	2	58	5	41	0	1	1
457	3	3	<1	9	0	2	71	4	24	<1	2	1
472	4	3	2	8	0	2	73	8	28	0	2	1
488	3	3	<1	7	0	2	75	9	22	<1	2	0
503	2	3	2	14	2	2	74	10	4	0	2	0
518	2	3	1	10	3	2	80	10	5	0	<1	0
527	2	3	1	9	2	<1	82	10	1	0	0	0
777	4	6	<1	8	2	2	77	11	2	0	0	0
786	5	8	<1	7	2	3	65	12	2	0	0	0
792	5	5	1	8	3	2	70	10	2	0	0	0
805	7	5	3	10	0	3	60	13	2	0	0	0
811	4	5	3	10	0	4	59	15	2	0	0	0
817	3	9	3	9	1	5	60	15	2	0	0	0
838	4	3	3	10	3	5	61	20	2	0	0	0
847	3	11	3	19	3	1	62	12	2	0	0	0
853	2	5	3	7	3	5	68	18	3	0	0	0
869	2	3	3	10	3	4	59	22	0	0	0	0
878	2	3	4	20	3	2	50	21	1	0	0	0
884	1	9	3	7	3	2	65	19	1	0	0	0
893	2	5	4	6	3	6	71	8	3	0	0	0
908	2	4	3	7	4	2	70	9	5	0	0	0
924	2	4	3	11	2	<1	70	9	<1	0	0	0
930	1	4	3	6	1	6	70	14	<1	0	0	0
945	4	4	2	9	1	5	72	10	0	0	0	0
960	2	4	2	9	1	2	60	20	<1	0	0	0
975	2	5	2	7	3	2	58	30	<1	0	0	0
991	2	4	3	10	2	4	42	36	<1	0	0	0
1006	2	3	2	15	2	2	43	33	0	0	0	0
1030	1	3	3	11	2	2	69	28	<1	0	0	0
1033	1	3	3	9	2	2	67	32	0	0	0	0
1042	2	3	3	9	2	2	63	31	0	0	0	0
1052	2	3	4	11	3	<1	68	28	0	0	0	0
1067	3	3	2	17	5	<1	64	0	<1	0	0	0
1082	3	3	3	16	0	2	65	4	0	0	0	0
1091	4	2	3	24	1	0	64	0	0	0	0	0
1097	4	3	3	26	2	0	60	0	0	0	0	0
1103	4	3	4	25	3	0	60	0	0	0	0	0
1113	4	3	0	35	4	2	65	0	0	0	0	0
1122	7	4	<1	28	2	0	69	0	0	0	0	0
1128	8	5	<1	43	2	0	38	0	0	0	0	0
1143	15	5	<1	58	2	0	18	0	0	0	0	0
1158	28	4	<1	51	6	0	10	0	0	0	0	0
1167	14	3	3	58	4	0	19	0	0	0	0	0
1173	14	9	2	75	3	0	4	0	0	0	0	0
1180	30	8	4	55	3	0	3	0	0	0	0	0
1189	32	9	2	51	4	2	5	0	0	0	0	0
1204	53	10	0	32	5	0	4	0	0	0	0	0
1219	40	9	2	49	4	0	2	0	0	0	0	0
1234	23	9	<1	58	10	0	4	0	0	0	0	0
1250	23	10	<1	51	10	0	3	0	0	0	0	0
1265	21	11	2	49	12	0	3	0	0	0	0	0
1280	32	6	2	44	6	0	2	0	0	0	0	0
1295	38	9	2	33	9	0	2	0	0	0	0	0
1311	33	7	3	28	9	0	1	0	0	0	0	0
1326	69	7	4	21	3	0	2	0	0	0	0	0
1341	59	19	5	22	5	0	2	0	0	0	0	0
1356	72	11	3	14	2	0	2	0	0	0	0	0
1372	73	18	3	11	0	0	3	0	0	0	0	0
1387	82	10	3	8	2	0	3	0	0	0	0	0
1402	75	18	5	7	0	0	0	0	0	0	0	0
1417	79	11	0	6	2	0	2	0	0	0	0	0

Nechells percentages from published pollen diagrams

Depth (cm)	Betula	Pinus	Ulmus	Quercus	Fraxinus	Tilia	Alnus	Taxus	Picea	Abies	Acer	Carpinus
1426	78	20	1	6	0	0	0	0	0	0	0	0
1433	86	10	2	4	0	<1	<1	0	0	0	0	0
1448	84	11	2	3	0	0	2	0	0	0	0	0
1463	92	8	1	4	0	0	<1	0	0	0	0	0
1478	89	10	0	3	<1	0	0	0	0	0	0	0
1494	95	4	0	4	0	0	0	0	0	0	0	0
1509	98	4	0	0	0	0	0	0	0	0	0	0
1515	49	4	0	<1	0	0	0	0	0	0	0	0
1524	40	4	0	0	0	0	0	0	0	0	0	0
1530	30	3	0	0	0	0	<1	0	0	0	0	0
1539	9	4	0	0	0	0	0	0	0	0	0	0
1548	12	5	0	0	0	<1	1	0	0	0	0	0
1551	7	<1	0	1	0	0	<1	0	0	0	0	0
1554	2	1	0	3	0	<1	0	0	0	0	0	0
1558	2	3	0	1	0	0	0	0	0	0	0	0
1564	0	1	0	1	0	0	0	0	0	0	0	0
1573	5	0	0	0	0	0	0	0	0	0	0	0

Nechells percentages from published pollen diagrams

Depth (cm)	Corylus	Hippophae	Buxus	Ephedra	Viscum	Juniperus	Salix	Hedera	Ilex	Sambucus
238	19	0	0	0	0	0	0	<1	0	0
244	6	0	0	0	0	0	3	0	<1	0
250	5	0	0	0	0	0	3	0	0	0
274	11	0	0	0	0	<1	3	0	0	0
290	11	0	0	0	0	0	3	0	0	0
299	10	0	0	0	0	0	0	0	0	0
305	3	0	0	0	0	0	0	<1	<1	0
335	2	0	0	0	0	0	<1	<1	<1	0
351	2	0	0	0	0	0	2	<1	0	0
366	2	0	0	0	0	0	4	0	0	0
375	2	0	0	0	0	0	7	<1	0	0
381	2	0	0	0	0	0	1	0	0	0
390	6	0	0	0	0	0	<1	0	0	0
396	5	0	0	0	0	0	<1	<1	0	0
405	9	0	0	0	0	0	0	<1	<1	0
411	22	0	0	0	0	0	1	<1	0	0
421	9	0	0	0	0	0	0	1	<1	0
436	13	0	0		<1	0	0	1	1	0
451	16	0	0	0	0	0	0	<1	<1	<1
457	18	0	0	0	0	0	0	0	0	0
472	19	0	0	0	0	0	0	2	<1	2
488	18	0	0		<1	0	0	2	<1	2
503	12	0	0	0	0	0	0	2	2	2
518	15	0	0	0	0	0	0	0	0	2
527	19	0	0	0	0	0	0	<1	<1	2
777	27	0	0	0	0	0	0	0	0	2
786	37	0	0	0	0	0	0	0	3	2
792	44	0	0	0	<1	0	0	3	2	2
805	34	0	0	0	0	0	0	2	2	2
811	40	0	0	0	0	0	0	<1	2	2
817	45	0	0	0	0	0	0	0	2	1
838	36	0	0	0	0	0	0	2	4	<1
847	28	0	0	0	0	0	0	2	0	2
853	32	0	0	0	0	0	0	2	2	2
869	33	0	0	0	0	0	0	2	2	2
878	15	0	0	0	0	0	0	3	2	2
884	31	0	0	0	0	0	0	2	2	2
893	21	0	0	0	0	0	0	2	<1	0
908	33	0	0	0	0	0	0	4	2	2
924	13	0	0	0	0	0	0	2	2	0
930	22	0	0	0	0	0	0	0	1	0
945	29	0	0	0	0	0	0	0	0	0
960	16	0	0	0	0	0	0	1	<1	0
975	24	0	0	0	0	0	0	0	2	0
991	20	0	0	0	0	0	0	0	2	0
1006	10	0	0	0	0	0	0	0	0	0
1030	21	0	<1	0	<1	0	0	1	2	0
1033	12	0	0	0	0	0	0	3	2	0
1042	11	0	0	0	0	0	0	3	3	0
1052	8	0	0	0	0	0	0	4	2	0
1067	7	0	0	0	0	0	0	2	1	0
1082	7	0	0	0	0	0	0	2	<1	0
1091	7	0	0	0	0	0	0	2	1	0
1097	10	0	0	0	0	0	0	4	<1	0
1103	5	0	0	0	0	0	0	3	<1	0
1113	5	0	0	0	0	0	0	2	1	0
1122	2	0	0	0	0	0	0	<1	<1	0
1128	7	0	0	0	0	0	0	<1	<1	0
1143	4	0	0	0	0	0	2	2	1	0
1158	4	0	0	0	0	0	2	2	0	0
1167	5	0	0	0	0	2	2	2	0	0
1173	5	0	0	0	0	2	2	<1	0	0
1180	5	0	0	0	0	0	2	2	0	0
1189	1	0	0	0	0	3	2	2	<1	0
1204	4	0	0	<1	0	3	6	2	0	0
1219	1	0	0	0	0	0	2	<1	<1	0
1234	4	0	0	0	0	0	2	1	0	0
1250	4	0	0	0	0	0	0	<1	0	0
1265	2	0	0	0	0	0	3	3	0	0
1280	2	0	0	0	0	0	3	2	0	0
1295	2	0	0	0	0	0	3	1	0	0
1311	2	0	0	0	0	0	3	0	0	0
1326	0	2	0	0	0	0	3	0	0	0
1341	0	0	0	0	0	5	6	0	0	0
1356	2	0	0	0	0	4	6	0	0	0
1372	0	0	0	0	0	0	3	0	0	0
1387	0	0	0	0	0	6	5	0	0	0
1402	2	0	0	0	0	6	5	<1	0	0
1417	0	1	0	0	0	5	4	0	0	0

Nechells percentages from published pollen diagrams

Depth (cm)	Corylus	Hippophae	Buxus	Ephedra	Viscum	Juniperus	Salix	Hedera	Ilex	Sambucus
1426	0	2	0	0	0	10	5	0	0	0
1433	0	2	0	0	0	6	4	0	0	0
1448	0	2	0	0	0	6	8	0	0	0
1463	0	2	0	0	0	6	8	0	0	0
1478	0	0	0	0	0	5	8	0	0	0
1494	0	0	0	0	0	5	11	0	0	0
1509	0	0	0	0	0	5	7	0	0	0
1515	0	1	0	0	0	5	8	0	0	0
1524	0	5	0	0	0	9	13	0	0	0
1530	0	9	0	0	0	4	5	0	0	0
1539	0	8	0	0	0	3	5	0	0	0
1548	0	55	0	0	0	8	<1	0	0	0
1551	0	50	0	0	0	6	0	0	0	0
1554	0	70	0	0	0	7	5	0	0	0
1558	0	90	0	0	0	6	0	0	0	0
1564	0	70	0	0	0	<1	0	0	0	0
1573	0	62	0	0	0	0	0	0	0	0

Quinton percentages from published pollen diagrams

Depth (cm)	**Betula**	**Pinus**	**Abies**	**Picea**	**Ulmus**	**Quercus**	**Tilia**	**Hippophae**	**Fraxinus**	**Carpinus**
650	2	0	0	0	0	0	0	0	0	0
655	10	1	0	0	0	0	0	0	0	0
665	20	5	0	2	0	0	0	0	0	0
675	11	4	0	0	0	0	0	0	0	0
680	22	10	0	2	0	0	0	0	0	0
685	19	3	0	0	0	0	0	0	0	0
690	9	2	0	0	0	0	0	0	0	0
695	5	2	0	0	0	0	0	0	0	0
700	5	2	0	0	0	0	0	0	0	0
725	2	2	0	0	0	0	0	0	0	0
735	5	1	0	0	0	0	0	0	0	0
737	10	1	0	0	0	0	0	0	0	0
740	20	5	0	0	0	0	0	0	0	0
742	35	6	0	1	0	0	0	0	0	0
745	29	8	0	1	0	0	<1	0	0	0
750	32	15	<1	1	0	0	0	0	0	0
755	35	10	0	2	0	0	0	0	0	0
757	25	10	0	3	0	<1	0	0	0	0
780	29	9	0	3	0	0	0	0	0	0
800	27	60	0	9	0	1	0	0	0	0
815	27	45	8	10	0	1	0	0	0	0
824	21	41	13	8	0	1	0	0	0	0
826	49	25	3	10	0	1	0	0	0	<1
828	38	32	1	20	0	1	<1	0	0	1
845	70	20	3	10	0	1	0	0	0	1
855	19	20	1	50	0	1	0	0	0	1
870	32	16	1	9	0	2	<1	0	0	<1
880	38	13	3	9	0	1	<1	0	0	0
905	18	22	3	33	0	1	<1	0	0	0
915	25	12	1	22	0	1	0	0	0	0
925	30	19	12	15	0	1	0	0	0	0
935	25	12	5	30	0	1	<1	0	0	0
945	30	12	5	8	0	1	0	0	0	0
955	30	16	12	8	0	5	0	0	0	<1
975	20	15	10	33	0	2	<1	0	0	0
985	30	15	11	10	0	2	0	0	0	<1
1000	19	15	21	29	0	2	<1	0	0	0
1020	25	13	20	20	0	2	0	0	0	<1
1030	24	19	20	11	0	1	0	0	0	1
1045	22	12	20	8	0	1	2	0	<1	1
1065	29	11	19	9	<1	1	<1	0	0	1
1080	32	10	12	8	0	1	0	0	0	2
1100	16	20	39	10	0	1	0	0	0	1
1110	15	20	48	10	0	1	0	0	0	0
1125	21	26	22	8	0	1	0	0	0	<1
1135	21	29	30	6	<1	<1	0	0	0	1
1145	16	19	31	11	0	1	0	0	0	1
1155	19	19	36	7	<1	<1	<1	0	0	0
1160	24	19	35	6	0	0	0	0	0	0
1175	30	19	18	4	<1	0	0	0	0	0
1200	24	25	30	7	0	<1	0	0	0	0
1210	24	15	30	3	0	<1	0	0	<1	0
1224	7	5	60	20	0	1	0	0	0	0
1226	9	2	25	59	0	1	0	0	0	0
1245	9	1	40	39	0	1	<1	0	0	0
1255	5	1	25	50	0	1	0	0	0	<1
1275	9	30	10	30	<1	<1	2	0	1	<1
1285	9	0	0	30	2	12	0	0	1	0
1300	5	4	2	40	1	10	1	0	10	<1
1302	6	4	2	36	1	40	1	0	5	0
1320	10	1	0	11	2	55	1	0	0	0
1330	5	6	0	12	1	50	<1	0	1	1
1340	9	5	<1	2	<1	25	<1	0	1	0
1350	9	5	0	2	0	25	1	0	2	1
1370	10	4	0	0	2	30	1	0	1	1
1395	8	5	0	1	<1	40	<1	0	0	1
1405	9	5	0	<1	0	20	1	0	5	1
1420	5	5	0	<1	<1	20	1	0	0	<1
1435	5	3	0	0	0	19	1	0	1	0
1450	5	3	0	<1	<1	30	4	0	1	0
1460	5	3	0	0	0	20	6	0	4	0
1475	5	4	0	<1	1	35	3	0	0	0
1500	6	2	0	0	0	42	3	0	<1	<1
1515	5	7	0	<1	0	35	9	0	0	<1
1530	5	3	0	0	0	43	0	0	9	0
1550	2	3	0	0	<1	50	<1	0	1	0
1560	11	3	0	<1	<1	60	<1	0	1	0
1570	9	3	0	0	0	65	<1	0	<1	0
1590	10	4	0	0	0	65	0	0	<1	0

Quinton percentages from published pollen diagrams

Depth (cm)	Betula	Pinus	Abies	Picea	Ulmus	Quercus	Tilia	Hippophae	Fraxinus	Carpinus
1610	11	3	0	0	0	82	0	0	0	0
1620	13	3	0	0	<1	70	0	0	<1	0
1630	18	3	<1	2	0	52	<1	0	1	0
1650	17	3	0	0	0	66	0	0	2	0
1660	39	3	0	0	0	50	0	0	0	0
1675	31	7	0	0	0	59	0	0	<1	0
1695	18	2	0	0	<1	80	0	0	1	0
1710	28	7	0	0	1	68	0	0	1	0
1730	40	10	0	0	1	50	0	0	0	0
1740	22	1	0	0	1	82	0	0	0	0
1750	32	1	0	0	0	69	0	0	0	0
1765	22	3	0	0	2	78	0	0	0	0
1767	55	4	0	0	1	30	0	0	0	0
1780	80	10	0	0	1	10	0	0	0	0
1790	85	7	0	0	1	9	0	0	0	0
1800	85	10	0	0	<1	6	0	0	0	0
1815	80	11	0	0	0	9	0	0	0	0
1825	82	15	0	0	0	7	0	0	0	0
1840	80	11	0	0	0	9	0	0	0	0
1855	90	9	0	0	0	9	0	0	0	0
1870	25	1	0	0	0	1	0	0	0	0
1890	60	3	0	0	0	1	0	0	0	0
1915	40	0	0	0	0	1	0	0	0	0
1925	40	0	0	0	0	1	0	0	0	0
1935						1				
1945	75	3	0	0	0	0	0	0	0	0
1950	30	0	0	0	0	0	0	0	0	0
1965										
1980										
2000	55	7	0	0	0	0	0	0	0	0
2015	10	2	0	0	0	0	0	1	0	0
2025	9	2	0	0	0	0	0	3	0	0
2035	10	1	0	0	0	0	0	12	0	0
2050	60	1	0	0	0	0	0		0	0
2070								2		
2085	80	1	0	0	0	0	0	0	0	0
2100	50	1	0	0	0	0	0	0	0	0

Quinton percentages from published pollen diagrams

Depth (cm)	Fagus	Corylus	Taxus	Ilex	Alnus	Hedera	Salix	Juniperus	Type X
650	0	0	0	0	1	0	0	0	0
655	0	0	0	0	5	0	0	0	0
665	0	0	0	0	9	0	0	15	0
675	0	0	0	0	1	0	2	0	0
680	0	0	0	0	1	0	2	0	0
685	0	0	0	0	1	0	4	0	0
690	0	0	0	0	1	0	0	0	0
695	0	0	0	0	1	0	0	0	0
700	0	0	0	0	1	0	0	0	0
725	0	0	0	0	1	0	0	0	0
735	0	0	0	0	5	0	<1	0	0
737	0	0	0	0	1	0	<1	0	0
740	0	0	0	0	1	0	1	0	0
742	0	0	0	0	5	0	1	<1	<1
745	0	1	0	0	1	0	1	<1	0
750	0	1	0	0	1	0	1	<1	0
755	0	1	0	0	1	0	<1	1	0
757	0	2	0	0	11	0	4	1	0
780	0	1	0	0	6	0	0	5	0
800	0	0	0	0	1	0	0	1	0
815	0	0	0	0	1	0	0	0	0
824	0	0	0	0	1	0	0	0	0
826	0	1	0	0	34	0	<1	0	0
828	1	2	0	0	14	0	1	0	0
845	1	2	0	0	12	0	<1	<1	0
855	1	0	0	0	19	0	1	1	0
870	1	5	2	0	32	0	1	1	<1
880	<1	1	<1	0	33	0	1	1	0
905	0	0	0	0	21	0	0	0	0
915	0	1	0	0	30	0	0	<1	0
925	0	4	0	0	45	0	<1	0	0
935	0	1	0	0	25	0	<1	0	0
945	0	4	0	<1	39	0	1	0	0
955	0	1	2	0	38	0	2	<1	<1
975	0	1	1	<1	20	0	1	0	0
985	0	1	2	0	23	0	2	0	<1
1000	0	0	<1	0	19	0	1	0	0
1020	0	2	<1	0	29	0	2	<1	0
1030	0	2	0	0	25	0	2	0	0
1045	<1	2	<1	0	29	0	<1	1	<1
1065	<1	4	2	<1	35	0	0	0	0
1080	0	7	0	0	24	0	0	4	0
1100	0	<1	0	0	17	<1	0	0	0
1110	0	0	<1	0	10	0	0	0	0
1125	0	0	1	0	19	0	0	1	0
1135	<1	0	1	0	25	0	<1	0	0
1145	0	0	1	0	19	0	0	0	0
1155	0	0	0	0	18	0	0	0	0
1160	0	2	<1	0	20	0	0	0	0
1175	0	2	0	<1	21	0	0	0	0
1200	0	2	0	0	19	0	0	0	0
1210	0	2	0	0	23	0	0	0	0
1224	0	2	0	0	12	0	0	0	0
1226	0	2	0	0	10	0	0	0	0
1245	0	3	0	0	11	0	0	0	0
1255	0	3	0	0	11	0	0	0	<1
1275	0	0	0	0	14	0	0	0	<1
1285	0	2	0	0	39	0	0	0	0
1300	0	9	1	0	18	0	0	0	0
1302	<1	1	2	0	10	0	0	0	0
1320	0	1	0	0	11	0	0	0	0
1330	0	20	0	0	12	0	0	0	0
1340	0	28	2	0	29	0	0	0	0
1350	0	29	4	<1	27	0	<1	0	0
1370	<1	28	1	1	19	0	0	0	0
1395	0	21	4	1	14	<1	0	0	0
1405	0	27	10	2	42	0	0	0	0
1420	<1	50	1	2	20	0	0	0	0
1435	0	19	10	3	20	0	0	0	0
1450	<1	31	1	1	19	0	0	0	0
1460	1	15	3	1	33	1	0	0	0
1475	1	18	3	1	29	2	0	0	0
1500	1	12	3	<1	33	1	0	0	0
1515	<1	19	3	1	29	2	0	0	0
1530	0	10	4	2	30	1	0	<1	0
1550	<1	10	1	2	31	1	0	0	<1
1560	0	5	1	2	31	0	<1	0	0
1570	<1	3	1	<1	21	<1	0	0	0
1590	0	2	1	<1	19	<1	0	0	0

Quinton percentages from published pollen diagrams

Depth (cm)	Fagus	Corylus	Taxus	Ilex	Alnus	Hedera	Salix	Juniperus	Type X
1610	0	2	0	0	10	0	0	0	0
1620	0	5	1	<1	10	0	<1	0	0
1630	0	1	1	0	23	<1	0	0	0
1650	0	1	1	0	2	0	0	0	0
1660	0	1	0	0	1	0	0	<1	0
1675	0	<1	0	0	1	<1	0	0	<1
1695	0	<1	0	0	<1	0	<1	<1	0
1710	0	0	0	0	1	<1	0	1	0
1730	0	0	0	0	<1	<1	0	1	0
1740	0	2	0	0	1	0	0	1	0
1750	0	0	0	0	1	0	0	1	0
1765	0	0	0	0	1	0	0	<1	0
1767	0	0	0	0	1	0	<1	<1	0
1780	0	0	0	0	1	0	0	1	0
1790	0	0	0	0	<1	0	0	1	0
1800	0	0	0	0	<1	0	0	5	0
1815	0	0	0	0	<1	0	0	1	0
1825	0	0	0	0	2	0	0	0	0
1840	0	0	0	0	2	0	1	0	0
1855	0	0	0	0	1	0	1	1	0
1870	0	0	0	0	<1	0	0	0	0
1890	0	0	0	0	<1	0	0	0	0
1915	0	0	0	0	0	0	1	1	0
1925	0	0	0	0	0	0	1	1	0
1935							1	0	0
1945	0	0	0	0	0	0	1	1	0
1950	0	0	0	0	0	0	1	0	0
1965									
1980									
2000	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	<1	<1	0
2025	0	0	0	0	0	0	0	0	0
2035	0	0	0	0	0	0	<1	0	0
2050	0	0	0	0	0	0	0	0	0
2070							1		
2085	0	0	0	0	0	0	0	0	0
2100	0	0	0	0	0	0	0	0	0

St Cross South Elmham percentages from published pollen diagrams

Depth (cm)	Pollen count	Betula	Pinus	Ulmus	Quercus	Tilia	Alnus	Carpinus	Fraxinus	Acer
245	743	2	4	5	10	1	37	<1	<1	<1
260	938	2	4	20	11	2	30	<1	0	1
275	562	4	9	5	10	2	31	1	0	0
295	693	5	4	3	17	2	30	<1	0	1
310	575	4	7	1	18	2	30	<1	1	1
315	733	3	5	3	19	1	30	1	0	<1
320	606	2	8	3	11	2	31	<1	<1	1
330	570	3	6	1	20	2	30	<1	0	1
345	558	5	9	1	15	<1	30	<1	0	1
350	602	8	9	3	22	1	29	<1	<1	1
360	713	11	8	2	19	1	23	1	<1	0
375	509	10	8	2	21	<1	20	<1	0	<1
390	616	12	9	2	18	1	31	<1	0	0
400	312	8	9	4	14	2	33	<1	0	1
500	521	5	9	3	9	2	30	<1	0	<1
600	680	6	6	5	10	2	30	0	0	<1
700	566	8	8	5	13	3	42	<1	0	<1
750	633	5	7	3	11	3	46	0	0	<1
800	523	9	9	3	19	4	23	0	0	0
850	644	19	4	1	17	6	23	0	2	0
955	640	46	23	<1	20	<1	<1	0	0	0
1050	558	83	3	0	0	0	0	0	0	<1

St Cross South Elmham percentages from published pollen diagrams

Depth (cm)	Abies	Picea	Taxus	Pterocarya	Corylus	Salix	Juniperus	Hippophae	Hedera	Ilex
245	<1	2	1	0	29	0	0	0	<1	1
260	0	2	1	0	21	<1	0	0	1	1
275	0	1	2	0	28	0	0	0	1	1
295	0	2	3	0	27	0	0	0	1	<1
310	0	1	2	0	27	<1	0	0	<1	1
315	0	2	1	0	28	<1	<1	0	1	1
320	0	2	2	<1	31	<1	0	0	1	<1
330	0	1	2	<1	29	0	0	0	1	<1
345	0	2	2	0	28	0	0	0	0	<1
350	0	1	1	0	19	0	0	0	1	0
360	0	1	2	0	13	<1	<1	0	<1	0
375	0	1	1	0	11	<1	<1	0	0	0
390	0	1	<1	0	10	<1	0	0	<1	<1
400	0	1	1	0	19	0	0	0	2	<1
500	<1	1	3	0	28	0	<1	0	<1	<1
600	<1	1	4	0	29	0	0	0	<1	1
700	0	3	9	0	0	0	0	0	1	<1
750	0	2	1	0	13	0	2	0	1	<1
800	0	<1	7	0	15	0	<1	0	3	<1
850	0	1	8	0	12	<1	<1	0	1	<1
955	0	<1	0	0	0	3	2	1	0	0
1050	0	<1	0	0	0	2	2	2	0	0

St Cross South Elmham percentages from published pollen diagrams

Depth (cm)	Viburnum	Gramineae	Cyperaceae	Ericales	Compositae (tub)	Artemisia
245	<1	1	0	1	0	0
260	0	1	<1	<1	0	<1
275	0	1	<1	0	0	0
295	<1	1	0	<1	<1	0
310	0	1	<1	0	0	0
315	<1	1	<1	<1	<1	<1
320	<1	1	<1	1	0	0
330	0	1	0	<1	0	0
345	0	<1	0	<1	0	0
350	0	0	<1	<1	0	0
360	0	9	<1	1	0	0
375	0	16	1	1	<1	1
390	0	10	<1	<1	1	1
400	0	1	0	1	0	0
500	0	1	1	0	0	0
600	0	<1	<1	<1	0	0
700	0	<1	<1	2	0	<1
750	0	1	0	0	<1	<1
800	0	1	2	<1	0	0
850	0	<1	<1	<1	<1	0
955	0	2	1	0	0	<1
1050	0	4	1	<1	<1	<1

St Cross South Elmham percentages from published pollen diagrams

Depth (cm)	Centaurea nigra	Cirsium/Carduus	Compositae (lig)	Caryophyllaceae
245	0	0	0	<1
260	0	0	0	<1
275	0	0	0	0
295	0	0	0	0
310	0	0	0	0
315	<1	0	0	0
320	0	0	0	<1
330	0	0	0	0
345	0	0	0	<1
350	0	0	0	0
360	1	<1	<1	<1
375	1	<1	<1	0
390	<1	0	1	<1
400	0	0	0	<1
500	<1	0	<1	<1
600	0	0	<1	0
700	0	0	<1	<1
750	0	0	0	0
800	0	<1	0	0
850	0	0	0	<1
955	0	0	<1	0
1050	0	0	<1	<1

St Cross South Elmham percentages from published pollen diagrams

Depth (cm)	Chenopodiaceae	Cruciferae	Filipendula	Geranium	Leguminosae	Plantago lanceolate
245	<1	0	0	0	0	0
260	0	<1	0	0	0	0
275	0	<1	0	0	0	0
295	0	0	0	0	0	0
310	0	<1	0	0	0	0
315	0	<1	0	0	0	0
320	0	0	0	0	0	0
330	0	<1	0	0	0	0
345	0	0	<1	0	0	0
350	0	0	<1	0	0	0
360	0	<1	<1	0	<1	<1
375	0	<1	<1	0	<1	<1
390	0	<1	0	<1	<1	<1
400	0	0	0	<1	0	0
500	0	<1	0	0	0	0
600	<1	0	<1	0	0	0
700	0	0	<1	0	0	0
750	0	0	0	<1	0	0
800	0	0	0	0	0	0
850	<1	<1	<1	<1	0	0
955	0	0	<1	0	0	0
1050	<1	<1	0	0	0	<1

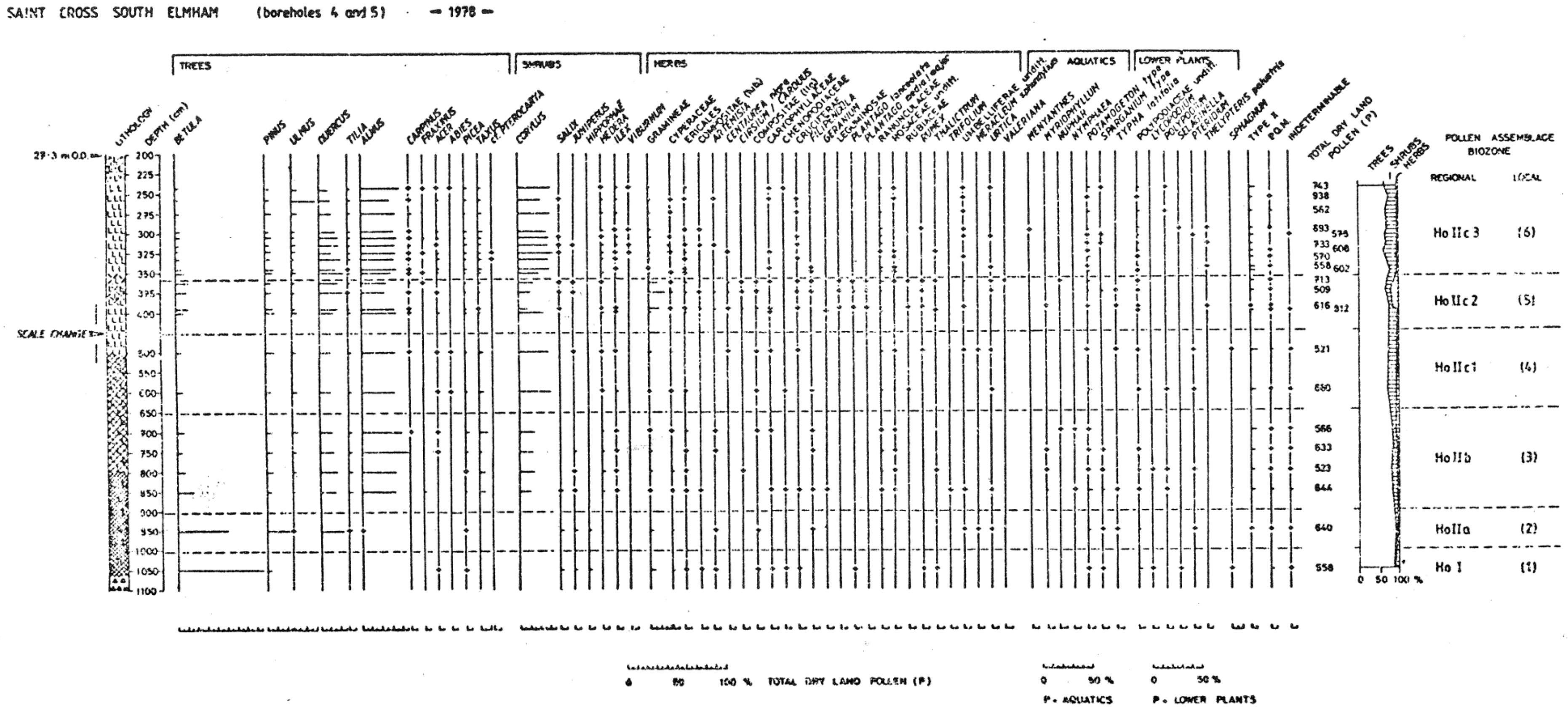
St Cross South Elmham percentages from published pollen diagrams

Depth (cm)	Plantago media/major	Ranunculaceae	Rosaceae	Rubiaceae	Rumex	Thalictrum
245	0	1	<1	0	0	0
260	0	0	<1	0	0	0
275	0	1	0	0	0	0
295	0	1	0	0	<1	0
310	0	1	0	0	0	0
315	0	1	0	0	0	0
320	0	<1	<1	0	0	<1
330	0	0	<1	0	0	0
345	0	1	<1	0	0	0
350	0	1	<1	0	0	0
360	<1	2	<1	<1	<1	<1
375	<1	0	0	0	<1	0
390	<1	0	0	<1	<1	0
400	0	0	0	0	0	<1
500	0	1	<1	0	<1	0
600	0	1	0	<1	0	0
700	0	<1	<1	0	0	0
750	0	1	<1	0	0	0
800	0	1	<1	0	0	<1
850	0	<1	<1	0	0	0
955	0	0	0	0	0	0
1050	0	1	0	0	<1	<1

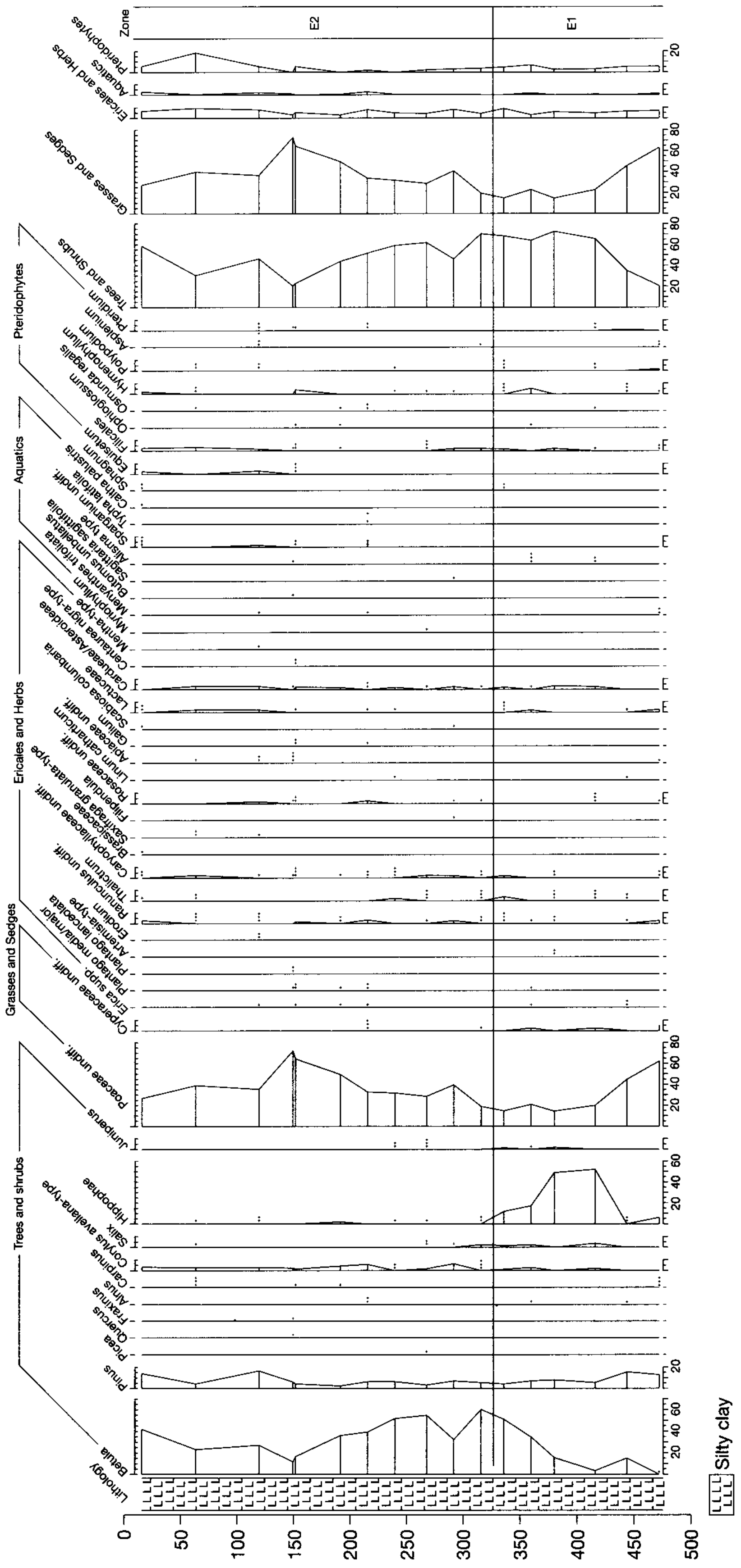
St Cross South Elmham percentages from published pollen diagrams

Depth (cm)	Trifolium	Umbelliferae	Heracleum sphondylium	Urtica	Valeriana	Type X
245	0	<1	0	<1	0	3
260	0	<1	0	0	0	2
275	0	<1	0	0	0	2
295	0	<1	0	0	0	2
310	0	<1	0	<1	0	2
315	0	0	0	0	0	2
320	0	0	0	0	0	2
330	0	<1	0	0	0	2
345	0	0	0	<1	0	3
350	0	0	0	0	0	3
360	0	1	0	<1	<1	3
375	0	0	0	<1	0	3
390	<1	0	0	0	0	<1
400	0	0	0	0	0	3
500	0	<1	<1	<1	0	4
600	0	0	0	<1	0	3
700	0	0	0	0	0	4
750	0	0	0	0	0	3
800	0	0	0	0	0	3
850	<1	<1	0	<1	0	3
955	0	<1	<1	<1	0	<1
1050	0	0	0	0	0	0

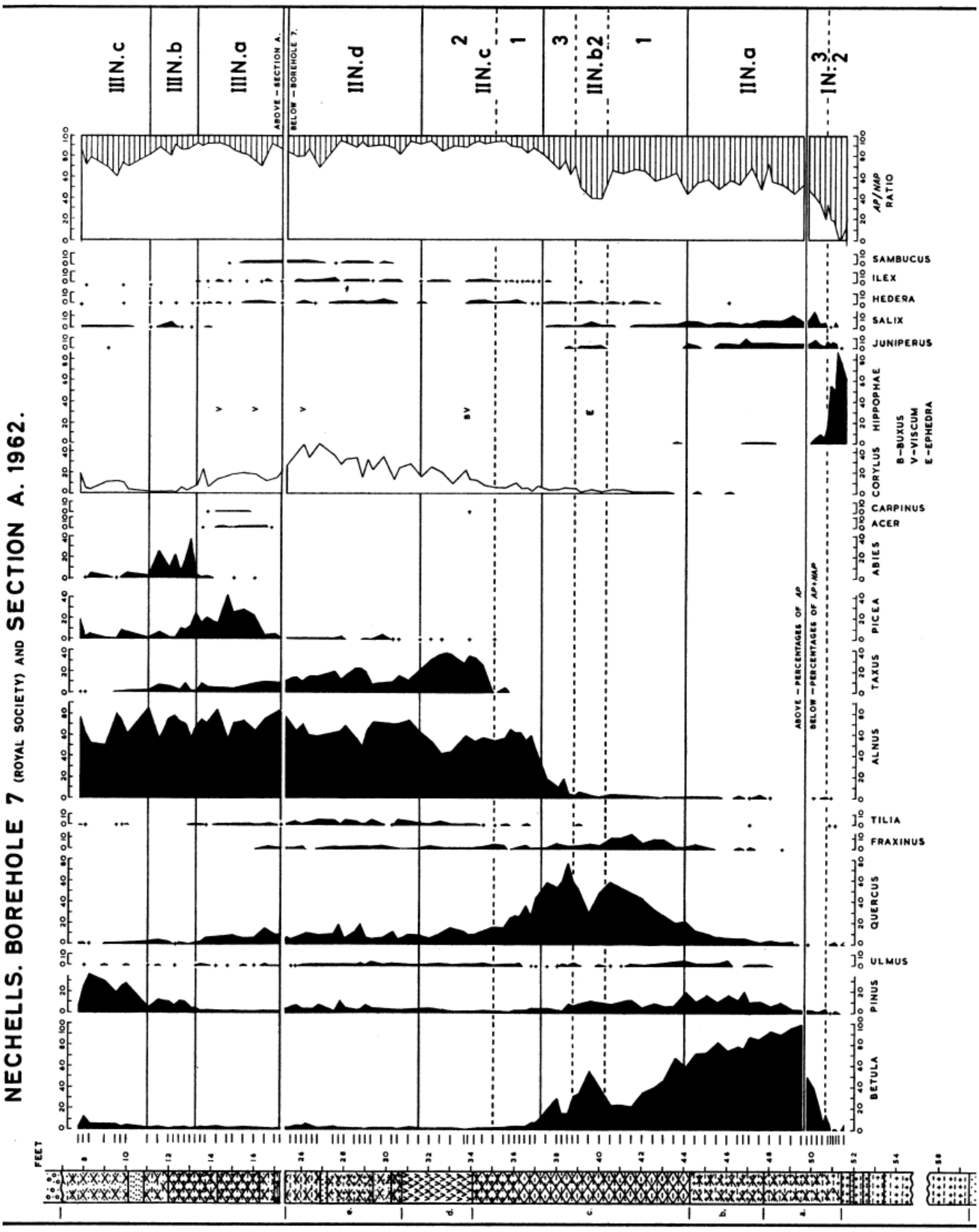
Published pollen diagrams



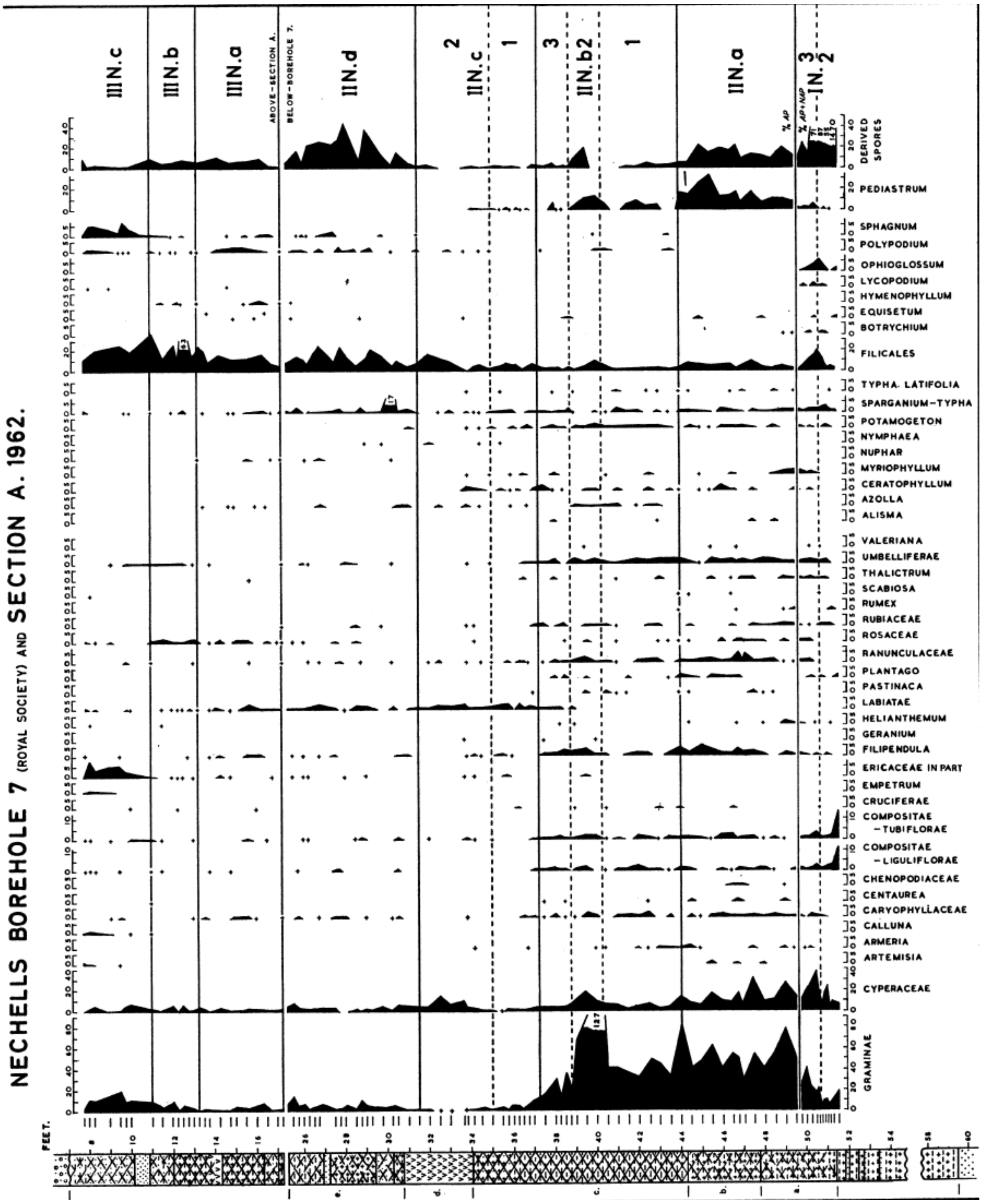
St Cross South Elmham (Coxon, 1984)



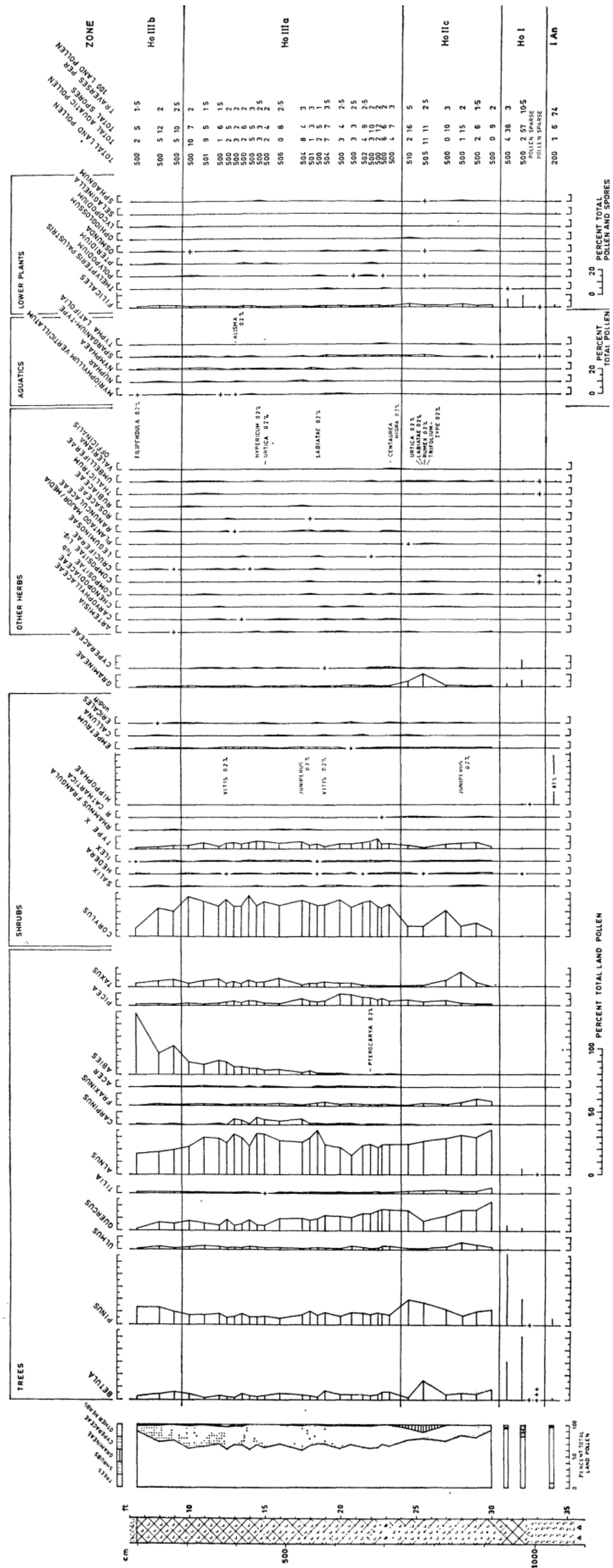
Elveden (Ashton et al, 2005)



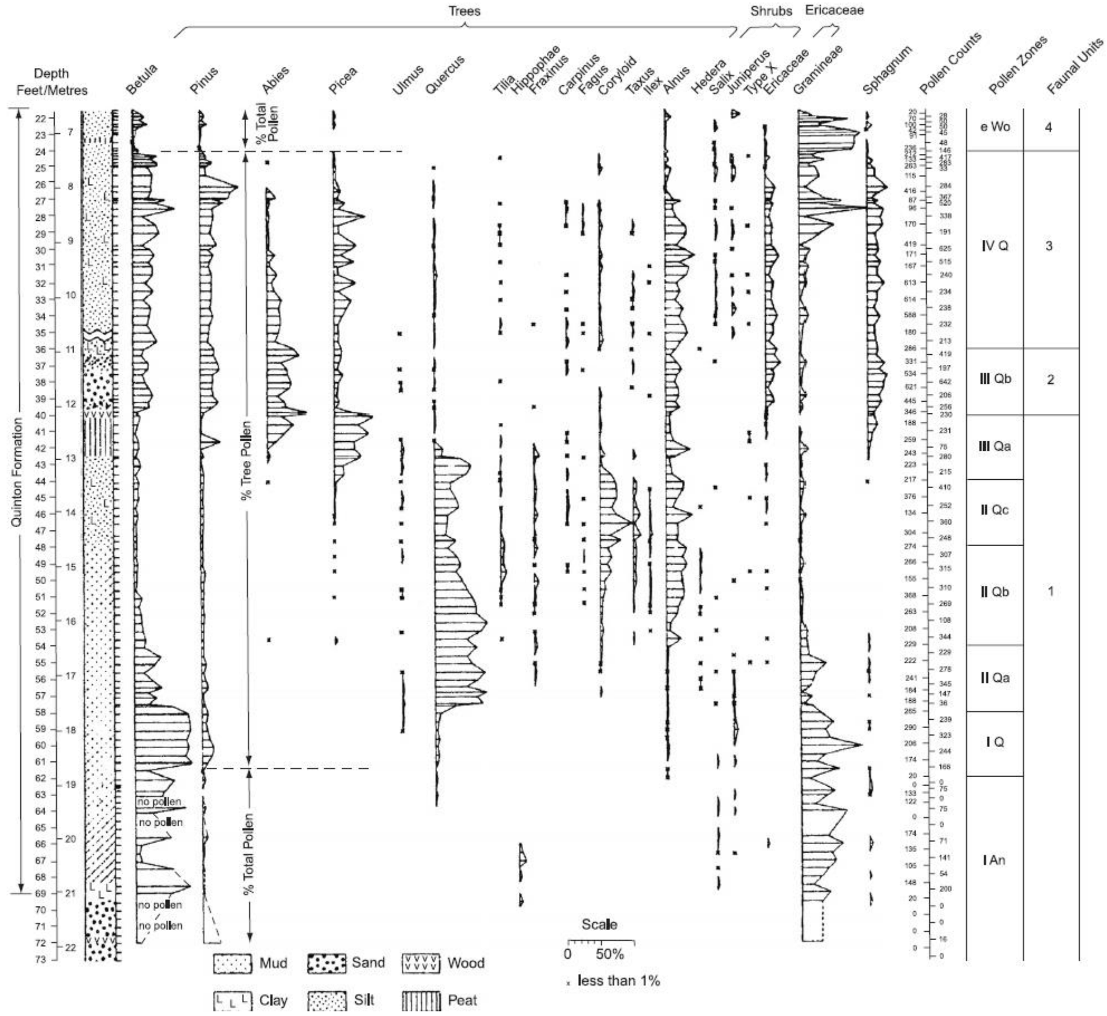
Nechells (Kelly, 1964)



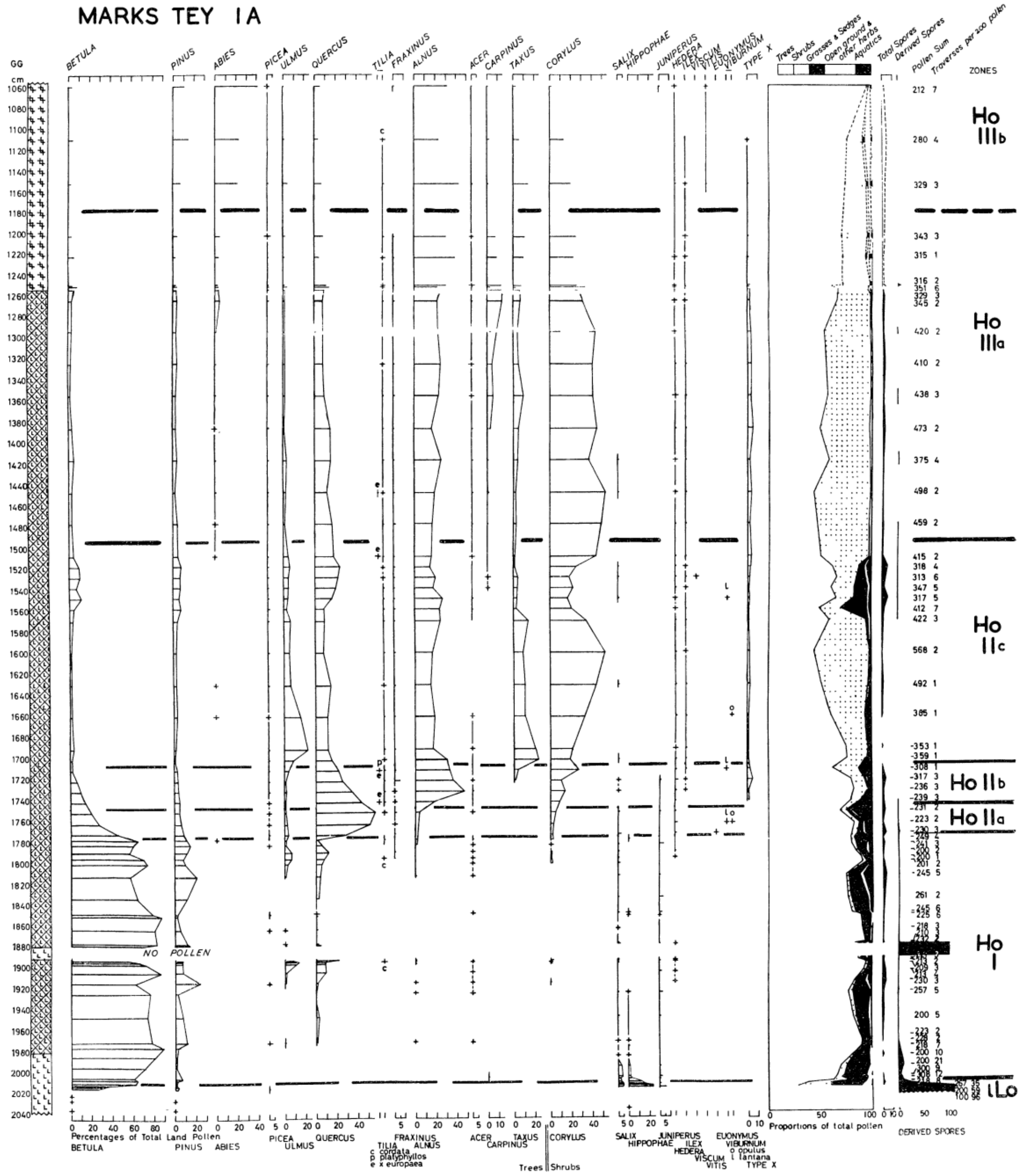
Nechells (Kelly, 1964)



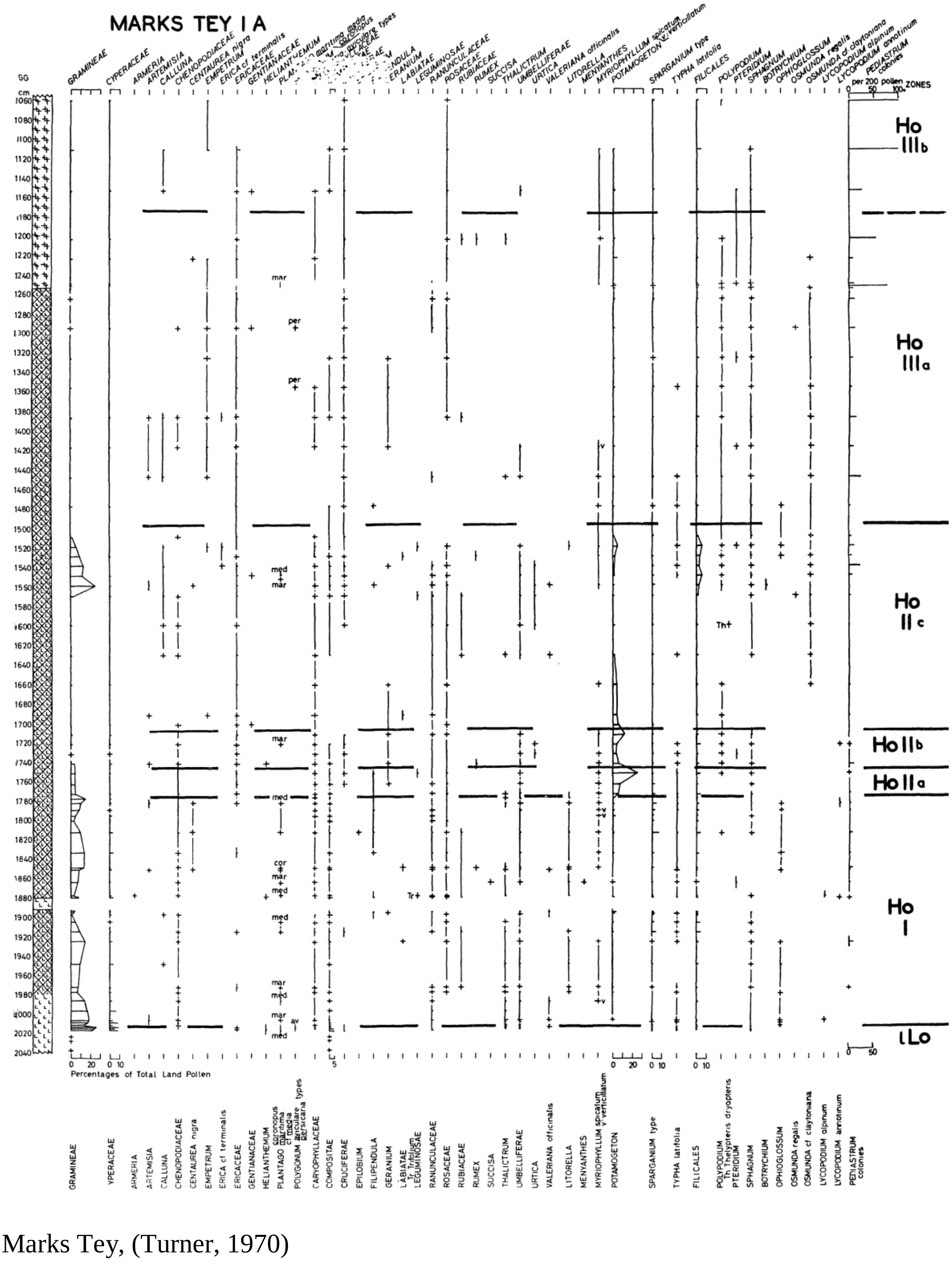
Barford (Philips, 1970)



Quinton (Coope et al, 2007)



Marks Tey, (Turner, 1970)



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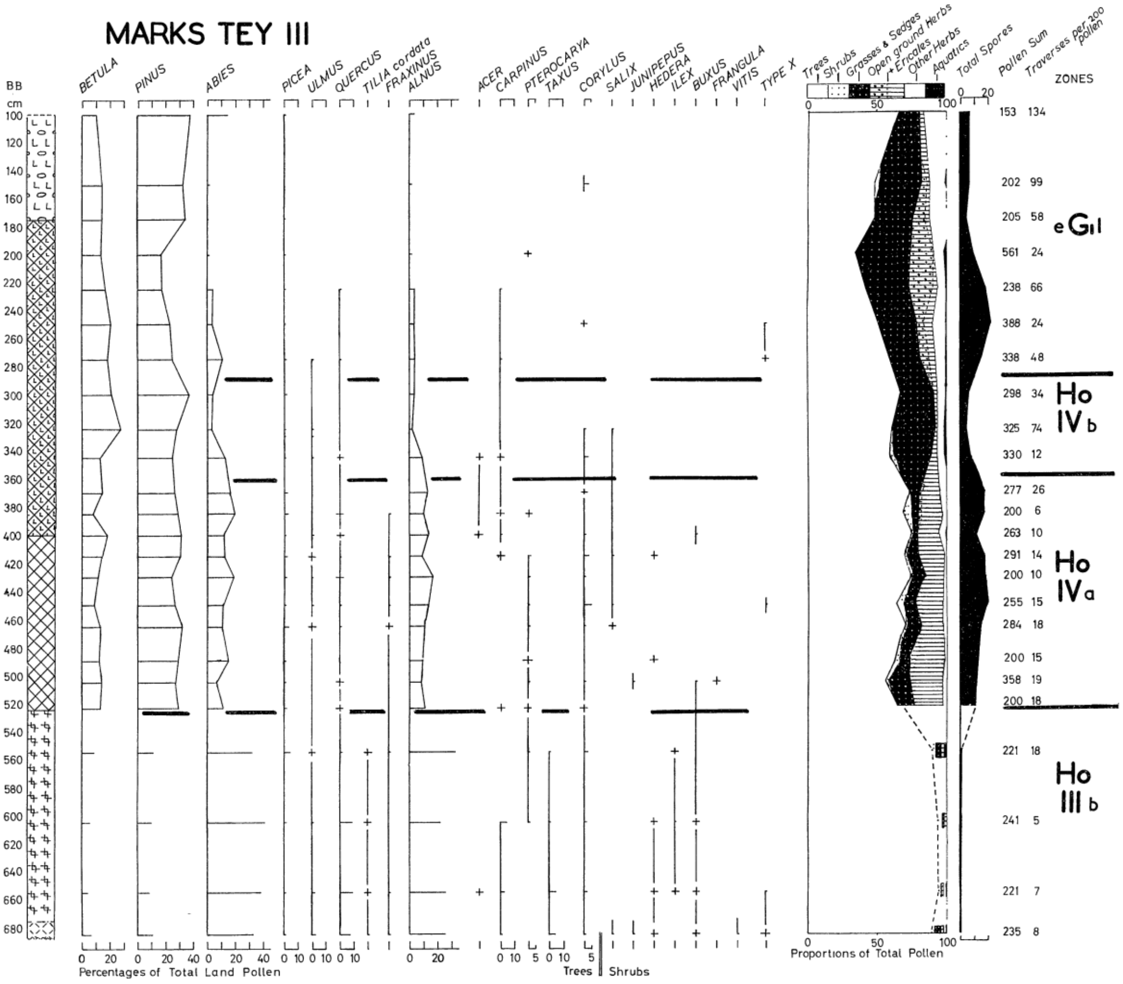
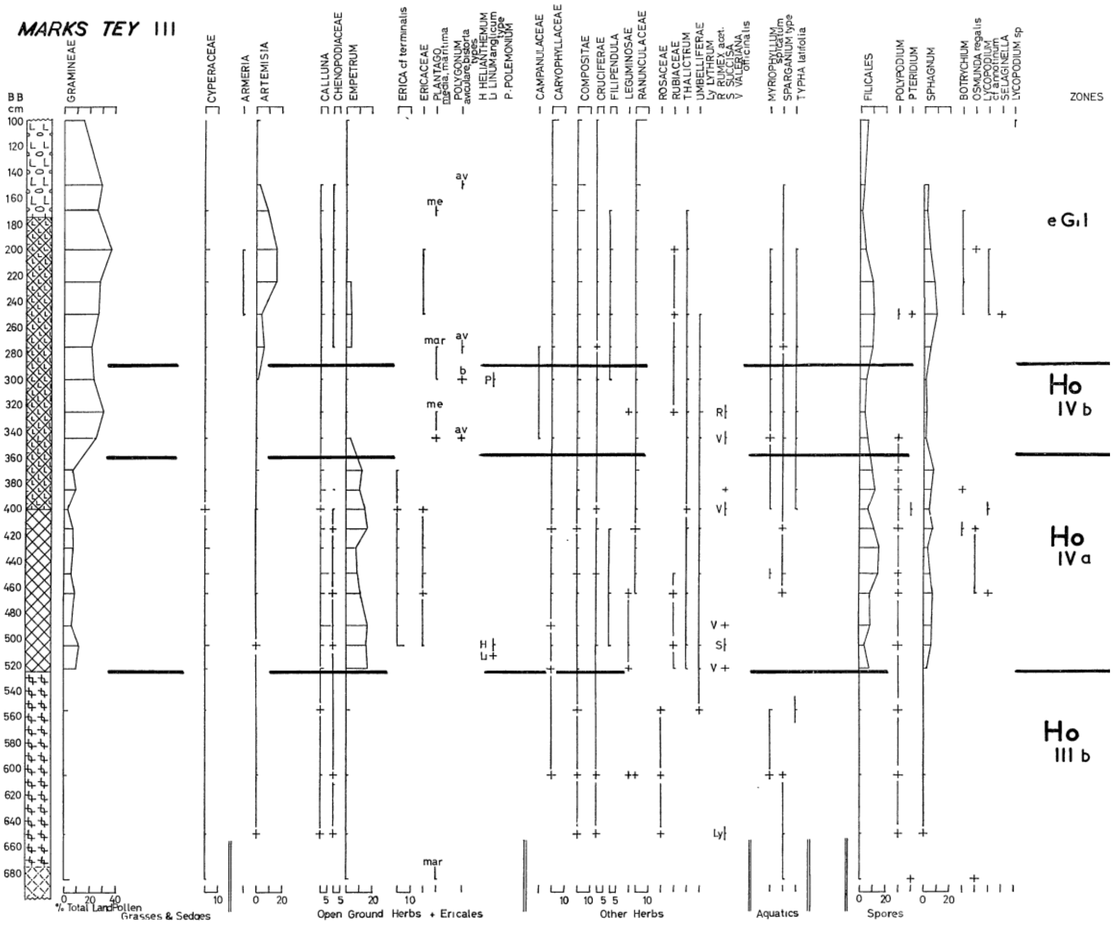


Marks Tey, (Turner, 1970)



Marks Tey, (Turner, 1970)

Pollen presence/absence for final model input

	Athelington presence or absence input (1=presence, 0=absence)														
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Cabe**	**Frex**	**Ac**	**Abal**	**Piab**	**Taba**	**Pte**	**Coav**	**Juco**
440	0	1	0	0	0	1	0	0	0	1	1	1	1	0	1
490	0	1	0	1	0	1	0	0	1	1	1	1	1	1	1
510	1	1	0	0	0	1	0	0	1	1	1	1	0	0	1
538	0	1	0	1	0	1	0	0	1	1	1	1	0	1	0
556	0	1	0	0	0	1	0	0	0	1	1	1	1	0	1
622	0	1	1	1	1	1	0	1	1	1	1	1	0	1	0
642	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1
688	1	1	1	1	1	1	1	1	0	0	1	1	0	1	0
700	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1
724	1	1	1	1	1	1	1	1	0	0	1	1	0	1	0
768	1	1	1	1	0	0	1	1	0	0	1	1	0	0	0
792	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0
814	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0
834	1	1	0	0	0	0	0	1	1	0	0	1	0	0	0

	Athelington presence or absence input (1=presence, 0=absence)					
Depth (cm)	**Hehe**	**Ilaq**	**Cavu**	**Fi**	**San**	**Emni**
440	0	0	0	0	1	1
490	1	1	0	1	1	0
510	0	0	1	0	1	0
538	1	0	0	1	0	0
556	1	0	0	0	1	1
622	1	1	0	0	0	1
642	1	1	0	0	0	0
688	1	0	0	0	0	0
700	0	0	0	1	0	0
724	1	1	1	0	0	0
768	1	0	0	1	0	1
792	0	0	0	0	0	0
814	0	0	0	0	0	0
834	0	0	0	0	0	0

	Barford presence or absence input (1=presence, 0=absence)												
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Cabe**	**Frex**	**Ac**	**Abal**	**Pte**	**Piab**	**Taba**	**Coav**
198	1	1	1	1	1	1	1	0	0	1	0	1	1	1
244	1	1	1	1	1	1	0	1	1	1	0	1	1	1
274	1	1	1	1	1	1	1	1	1	1	0	1	1	1
302	1	1	1	1	1	1	0	1	1	1	0	1	1	1
336	1	1	1	1	1	1	0	1	1	1	0	1	1	1
366	1	1	1	1	1	1	1	1	1	1	0	1	1	1
380	1	1	1	1	1	1	0	1	1	1	0	1	1	1
396	1	1	1	1	1	1	1	1	1	1	0	1	1	1
412	1	1	1	1	1	1	1	1	0	1	0	1	1	1
426	1	1	1	1	1	1	0	1	1	1	0	1	1	1
442	1	1	1	1	1	1	1	1	0	1	0	1	1	1
457	1	1	1	1	1	1	1	1	1	1	0	1	1	1
487	1	1	1	1	1	1	1	1	1	1	0	1	1	1
534	1	1	1	1	1	1	1	1	0	1	0	1	1	1
549	1	1	1	1	1	1	1	1	0	1	0	1	1	1
564	1	1	1	1	1	1	1	1	1	1	0	1	1	1
580	1	1	1	1	1	1	1	1	1	1	0	1	1	1
608	1	1	1	1	1	1	1	1	1	1	0	1	1	1
631	1	1	1	1	1	1	1	1	1	0	0	1	1	1
655	1	1	1	1	1	1	0	1	1	0	0	1	1	1
670	1	1	1	1	1	1	1	1	1	0	1	1	1	1
685	1	1	1	1	1	1	1	1	1	1	0	1	1	1
692	1	1	1	1	1	1	1	1	1	0	0	1	1	1
707	1	1	1	1	1	1	0	1	1	1	0	1	1	1
746	1	1	1	1	1	1	1	1	0	0	0	1	1	1
775	1	1	1	1	1	1	0	1	0	0	0	1	1	1
821	1	1	1	1	1	1	0	1	0	0	0	1	1	1
852	1	1	1	1	1	1	0	1	0	0	0	1	1	1
875	1	1	1	1	1	1	0	1	0	0	0	1	1	1
914	1	1	1	1	1	1	1	1	0	0	0	1	0	1

	Barford presence or absence input (1=presence, 0=absence)							
Depth (cm)	**Sam**	**Hehe**	**Ilaq**	**Rhca**	**Hirh**	**Juco**	**Emni**	**Cavu**
198	0	1	1	0	0	0	1	0
244	1	0	1	0	0	0	1	1
274	0	0	1	0	0	0	1	0
302	1	1	0	0	0	0	1	0
336	0	0	1	0	0	0	0	0
366	0	1	1	0	0	0	1	0
380	0	1	1	0	0	0	1	0
396	0	1	0	0	0	0	1	0
412	0	1	1	0	0	0	1	0
426	0	1	1	0	0	0	1	0
442	0	1	1	0	0	0	1	0
457	1	0	1	0	0	0	1	0
487	0	1	1	0	0	0	0	1
534	0	1	1	0	0	1	1	0
549	1	1	1	0	0	0	1	0
564	0	1	1	0	0	0	1	0
580	0	1	1	0	0	0	1	1
608	1	0	1	0	0	0	1	0
631	1	1	1	0	0	0	1	0
655	1	1	1	0	0	0	1	1
670	0	1	1	0	0	0	1	0
685	0	1	1	0	0	0	1	0
692	1	1	1	1	0	0	1	0
707	1	1	1	0	0	0	1	0
746	1	1	0	1	0	0	1	1
775	0	1	1	1	0	0	1	0
821	0	1	1	0	0	0	1	0
852	1	1	1	0	0	1	1	0
875	1	1	1	1	0	0	1	0
914	0	1	1	0	0	0	1	0

	Elveden presence or absence input (1=presence, 0=absence)												
Depth (cm)	**Be**	**Pisy**	**Piab**	**Qud**	**Frex**	**Al**	**Cabe**	**Coav**	**San**	**Hirh**	**Juco**	**Plla**	**Fi**
15	1	1	0	0	0	0	0	1	0	0	0	0	0
65	1	1	0	0	0	0	1	1	1	1	0	0	0
125	1	1	0	0	0	0	0	1	0	1	0	0	0
150	1	1	0	1	1	0	0	1	0	0	0	1	0
152	1	1	0	0	0	0	1	1	0	0	0	0	0
185	1	1	0	0	0	0	1	1	0	1	0	0	0
220	1	1	0	0	0	1	0	1	0	0	0	0	0
240	1	1	0	0	0	0	0	1	0	1	1	0	0
270	1	1	1	0	0	0	0	0	1	1	1	0	0
290	1	1	0	0	0	0	0	1	1	0	0	0	1
315	1	1	0	0	0	1	0	1	1	1	0	0	0
335	1	1	0	0	0	0	0	0	1	1	1	0	0
360	1	1	0	0	0	0	0	1	1	1	1	0	0
375	1	1	0	0	0	0	0	0	0	1	1	0	0
420	1	1	0	0	0	0	0	1	1	1	0	0	0
445	1	1	0	0	0	1	0	0	0	1	0	0	0
465	1	1	0	0	0	0	1	0	0	1	0	0	0

	Hoxne (main sequence) presence or absence input (1=presence, 0=absence)															
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Fasy**	**Cabe**	**Frex**	**Ac**	**Abal**	**Piab**	**Taba**	**Sam**	**Coav**	**San**
180	0	1	1	1	1	1	0	0	0	0	1	1	0	0	1	1
192	1	1	1	1	1	1	0	0	0	0	1	1	0	0	1	0
260	0	1	0	1	1	1	0	0	1	0	0	0	0	0	1	1
272	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0
279	1	1	1	1	1	1	0	0	0	0	0	1	0	1	1	0
288	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	0
296	1	1	1	1	1	1	0	0	1	1	0	1	0	0	1	0
310	1	1	1	1	1	1	1	0	1	0	0	1	0	0	1	0
320	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
326	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
334	1	1	1	1	1	1	0	0	1	1	1	1	0	0	1	0
342	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
356	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
384	0	1	1	1	1	1	0	0	1	1	0	1	0	0	1	0
392	0	1	1	1	1	1	1	0	1	0	0	1	0	0	1	0
408	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
416	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
432	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	0
444	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
464	1	1	1	1	1	1	0	1	1	0	0	0	1	0	1	0
480	0	1	1	1	1	1	0	1	1	0	0	1	1	0	1	0
496	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
512	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
528	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0
544	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0
556	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
576	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
592	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0
637	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
648	1	1	0	1	1	1	0	0	1	0	0	1	0	0	1	0
656	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	0
672	1	1	1	1	1	1	0	0	1	0	0	1	1	0	1	0
682	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
692	1	1	1	1	1	1	0	0	0	0	0	0	1	0	1	0
706	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0
720	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
746	1	1	1	1	1	1	0	1	0	0	0	1	0	0	1	0
760	1	1	0	1	1	1	0	0	1	0	0	1	0	0	1	0
776	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	0
784	1	1	1	1	1	1	1	0	1	0	0	1	0	0	1	0
794	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	0
801	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0
808	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0
816	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0
824	1	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0

	Hoxne (main sequence) presence or absence input (1=presence, 0=absence)							
Depth (cm)	**Hirh**	**Hehe**	**Ilaq**	**Emni**	**Fi**			
180	0	1	0	0	0			
192	0	0	0	0	0			
260	0	0	0	1	0			
272	0	1	0	0	0			
279	0	0	1	1	0			
288	1	1	0	0	0			
296	0	0	1	0	0			
310	0	0	0	0	0			
320	0	1	1	0	1			
326	0	0	1	0	0			
334	0	1	1	0	0			
342	0	1	0	1	0			
356	0	1	1	0	0			
384	0	1	1	1	0			
392	0	0	1	1	0			
408	0	0	1	1	0			
416	0	1	0	1	0			
432	0	0	1	0	0			
444	0	0	1	1	0			
464	0	1	1	0	0			
480	0	1	1	0	0			
496	0	1	1	0	0			
512	0	1	1	1	0			
528	0	1	1	1	0			
544	0	1	1	0	0			
556	0	1	1	1	0			
576	0	1	1	1	0			
592	0	1	0	1	0			
637	0	1	1	1	0			
648	0	1	1	0	0			
656	0	1	0	1	0			
672	0	1	0	0	0			
682	0	1	0	0	0			
692	0	1	0	1	0			
706	0	1	0	0	0			
720	1	0	0	1	0			
746	1	1	0	1	1			
760	0	1	0	1	0			
776	1	1	0	0	0			
784	1	1	0	0	0			
794	1	1	0	0	0			
801	0	0	0	0	0			
808	0	1	0	1	0			
816	1	0	0	0	0			
824	1	0	1	0	1			

	Hoxne (Stratum C) presence or absence input (1=presence, 0=absence)																	
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Cabe**	**Ac**	**Abal**	**Piab**	**Sam**	**Coav**	**San**	**Hirh**	**Hehe**	**Ilaq**	**Cavu**	**Emni**
4	1	1	1	1	1	1	0	0	1	1	0	1	0	0	0	0	0	1
20	0	1	1	1	1	1	0	0	1	1	0	1	0	0	0	0	0	1
28	1	1	1	1	1	1	0	0	1	1	0	1	0	0	0	0	0	1
40	1	1	1	1	1	1	1	0	1	1	0	1	0	1	0	0	0	1
60	1	1	1	1	1	1	0	0	1	1	0	1	0	1	1	0	0	1
68	1	1	1	1	1	1	1	0	1	1	0	1	1	0	0	1	1	1
76	1	1	1	1	1	1	0	0	1	1	1	1	0	0	1	0	0	1
100	0	1	0	1	0	1	0	0	1	1	0	1	1	0	0	0	0	1
108	1	1	1	1	1	1	0	1	1	1	0	1	0	0	0	1	0	1
116	0	1	0	1	1	1	1	0	1	1	0	1	1	1	0	0	1	1
132	1	1	1	1	0	1	1	0	1	1	0	1	0	1	1	1	0	1
152	1	1	0	1	0	1	0	0	1	1	0	1	0	0	0	0	0	1

	Marks Tey (borehole 1A) presence or absence input (1=presence, 0=absence)																		
Depth (cm)	**Be**	**Pisy**	**Abal**	**Piab**	**Ul**	**Qud**	**Ti**	**Frex**	**Al**	**Ac**	**Cabe**	**Taba**	**Coav**	**San**	**Hirh**	**Juco**	**Hehe**	**Ilaq**	**Vial**
1060	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0
1100	1	1	1	1	1	1	1	0	1	0	1	1	1	0	0	0	0	0	0
1155	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	0
1205	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0
1225	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	1	1	0
1265	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1325	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1355	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1385	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1415	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0
1450	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0
1480	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1510	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	1	1	0
1520	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1	1	0
1530	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1
1538	1	1	0	1	1	1	1	1	1	0	1	1	1	0	0	0	1	1	0
1550	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	0	1	0	0
1560	1	1	0	1	1	1	1	1	1	1	0	1	1	0	0	0	1	1	0
1570	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1	1	0
1600	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1	1	0
1630	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	0	1	1	0
1660	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	1	1	0
1690	1	1	0	1	1	1	1	1	1	1	0	1	1	0	0	0	1	1	0
1700	1	1	0	1	1	1	1	0	1	0	0	1	1	1	0	0	1	1	0
1710	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1	1	0
1725	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	0
1730	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	0
1745	1	1	0	1	1	1	1	1	1	0	0	0	1	0	0	0	1	0	0
1750	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0	1	1	0	0
1765	1	1	0	1	1	1	0	1	1	0	0	0	1	0	0	0	1	0	0
1775	1	1	0	1	1	1	0	1	1	0	0	0	1	1	0	1	0	0	0
1780	1	1	1	0	1	1	1	0	1	1	0	0	1	0	1	0	0	0	0
1785	1	1	0	1	1	1	0	0	1	1	0	0	1	1	0	1	0	0	0
1795	1	1	0	0	1	1	0	1	0	1	0	0	1	1	0	0	1	0	0
1800	1	1	0	0	1	1	1	0	0	1	0	0	1	1	0	0	0	0	0
1805	1	1	0	0	1	1	1	0	0	1	0	0	0	1	0	0	0	0	0
1810	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	1	0	0	0
1835	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0
1850	1	1	0	1	0	1	0	0	0	1	0	0	0	1	1	1	0	0	0
1852	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
1865	1	1	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0
1878	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0
1880	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0
1892	1	1	0	0	1	1	0	0	1	0	0	0	0	1	0	0	1	0	0
1895	1	1	0	0	1	1	1	0	1	1	0	0	1	1	0	1	1	0	0
1898	1	1	0	0	1	1	0	0	1	0	0	0	1	1	0	0	0	0	0
1905	1	1	0	0	1	1	0	0	0	1	0	0	0	0	0	1	1	0	0
1915	1	1	0	1	1	1	0	0	1	1	0	0	1	0	0	0	1	0	0
1925	1	1	0	0	0	1	0	0	1	1	0	0	0	1	1	1	0	0	0
1950	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0
1972	1	1	0	1	1	0	0	0	1	1	0	0	0	1	1	0	0	0	0
1977	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1985	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
1995	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
2005	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0
2007	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2010	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
2012	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
2013	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2014	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0

	Marks Tey (borehole 1A) presence or absence input (1=presence, 0=absence)								
Depth (cm)	**Eueu**	**Arma**	**Cavu**	**Emni**	**Plme**	**Fi**			
1060	0	0	0	1	0	0			
1100	0	0	1	1	0	0			
1155	0	0	1	0	0	0			
1205	0	0	0	0	0	0			
1225	0	0	0	1	0	0			
1265	0	0	0	0	0	0			
1325	0	0	0	1	0	0			
1355	0	0	0	0	0	1			
1385	0	0	1	1	0	0			
1415	0	0	0	1	0	0			
1450	0	0	1	1	0	0			
1480	0	0	0	0	0	1			
1510	0	0	0	0	0	0			
1520	0	0	1	1	0	0			
1530	0	0	0	0	0	0			
1538	0	0	1	0	0	0			
1550	0	0	0	0	1	0			
1560	0	0	0	0	0	1			
1570	0	0	1	0	0	0			
1600	0	0	0	0	0	0			
1630	0	0	1	0	0	0			
1660	0	0	0	0	0	0			
1690	0	0	0	1	0	0			
1700	0	0	0	0	0	0			
1710	0	0	0	0	0	0			
1725	0	0	0	0	0	0			
1730	0	0	0	0	0	0			
1745	0	0	0	0	0	0			
1750	0	0	0	0	0	1			
1765	0	0	0	0	0	0			
1775	1	0	0	0	0	0			
1780	0	0	0	0	0	0			
1785	0	0	0	0	1	0			
1795	0	0	0	0	0	1			
1800	0	0	0	0	0	0			
1805	0	0	0	0	0	0			
1810	0	0	0	0	1	1			
1835	0	0	0	0	0	1			
1850	0	0	0	0	0	0			
1852	0	0	0	0	0	0			
1865	0	0	0	0	0	0			
1878	0	1	0	0	1	0			
1880	0	0	0	0	0	1			
1892	0	0	0	0	0	1			
1895	0	0	0	0	0	0			
1898	0	0	1	0	0	0			
1905	0	0	0	0	1	0			
1915	0	0	0	0	1	0			
1925	0	0	0	0	0	0			
1950	0	0	0	0	0	0			
1972	0	0	0	0	0	0			
1977	0	0	0	0	0	0			
1985	0	0	0	0	1	0			
1995	0	0	0	0	0	0			
2005	0	0	0	0	0	0			
2007	0	0	0	0	0	0			
2010	0	0	0	0	0	0			
2012	0	0	0	0	0	0			
2013	0	0	0	0	0	0			
2014	0	0	0	0	1	0			

	Marks Tey (borehole III) presence or absence input (1=presence, 0=absence)															
Depth (cm)	**Be**	**Pisy**	**Abal**	**Piab**	**Ul**	**Qud**	**Ti**	**Frex**	**Al**	**Ac**	**Cabe**	**Pte**	**Taba**	**Coav**	**San**	**Juco**
100	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0
153	1	1	1	0	0	0	0	0	1	0	0	0	0	1	0	0
175	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
200	1	1	1	1	0	0	0	0	1	0	0	1	0	0	0	0
225	1	1	1	1	0	1	0	0	1	0	1	0	0	0	0	0
250	1	1	1	1	0	0	0	0	1	0	0	0	0	1	0	0
275	1	1	1	1	1	1	0	0	1	0	1	0	0	0	0	0
300	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0
325	1	1	1	1	1	0	0	0	1	0	0	0	0	1	1	0
345	1	1	1	1	1	1	0	0	1	1	1	0	0	1	0	0
370	1	1	1	1	0	0	0	0	1	0	0	0	0	1	0	0
385	1	1	1	1	0	1	0	0	1	0	1	1	0	0	0	0
400	1	1	1	1	1	1	0	0	1	1	1	0	0	1	0	0
415	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	0
430	1	1	1	1	1	1	0	1	1	0	0	1	0	1	0	0
450	1	1	1	1	1	1	0	1	1	0	0	1	0	1	1	0
470	1	1	1	1	1	1	0	1	1	0	0	1	0	1	1	0
490	1	1	1	1	0	0	0	0	1	0	0	1	0	0	0	0
505	1	1	1	1	0	1	0	0	1	0	0	1	0	1	0	1
525	1	1	1	1	0	1	0	0	1	0	0	1	0	1	0	0
555	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	0
605	1	1	1	1	1	1	1	0	1	0	1	1	1	1	0	0
655	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0
685	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1

	Marks Tey (borehole III) presence or absence input (1=presence, 0=absence)							
Depth (cm)	**Hehe**	**Ilaq**	**Buse**	**Fral**	**Cavu**	**Emni**	**Plme**	**Poav**
100	0	0	0	0	0	1	0	0
153	0	0	0	0	1	1	0	1
175	0	0	0	0	1	1	1	0
200	0	0	0	0	1	1	0	0
225	0	0	0	0	1	1	0	0
250	0	0	0	0	1	1	0	0
275	0	0	0	0	1	1	0	1
300	0	0	0	0	1	1	0	0
325	0	0	0	0	1	1	1	0
345	0	0	0	0	1	1	1	1
370	0	0	0	0	1	1	0	0
385	0	0	0	0	1	1	0	0
400	0	0	1	0	1	1	0	0
415	1	0	0	0	1	1	0	0
430	0	0	0	0	1	1	0	0
450	0	0	0	0	1	1	0	0
470	1	0	0	0	1	1	0	0
490	0	0	0	0	1	1	0	0
505	0	0	1	1	1	1	0	0
525	0	0	0	0	1	1	0	0
555	0	1	0	0	1	1	0	0
605	1	1	1	0	1	1	0	0
655	1	1	1	0	1	1	0	0
685	1	0	1	0	0	1	0	0

	Nechells presence or absence input (1=presence, 0=absence)														
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Frex**	**Tico**	**Al**	**Taba**	**Piab**	**Abal**	**Ac**	**Cabe**	**Coav**	**Hirh**	**Buse**
238	1	1	0	1	0	0	1	1	1	0	0	0	1	0	0
244	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0
250	1	1	0	1	0	1	1	0	1	1	0	0	1	0	0
274	1	1	1	1	0	0	1	0	1	1	0	0	1	0	0
290	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
299	1	1	0	1	0	1	1	1	1	1	0	0	1	0	0
305	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0
335	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0
351	1	1	1	1	0	0	1	1	1	1	0	0	1	0	0
366	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
375	1	1	1	1	0	0	1	1	1	1	0	0	1	0	0
381	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
390	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
396	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
405	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0
411	1	1	1	1	0	1	1	1	1	1	1	0	1	0	0
421	1	1	1	1	0	1	1	1	1	1	0	1	1	0	0
436	1	1	1	1	0	1	1	1	1	0	1	1	1	0	0
451	1	1	0	1	0	1	1	1	1	0	1	1	1	0	0
457	1	1	1	1	0	1	1	1	1	1	1	1	1	0	0
472	1	1	1	1	0	1	1	1	1	0	1	1	1	0	0
488	1	1	1	1	0	1	1	1	1	1	1	0	1	0	0
503	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0
518	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0
527	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
777	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
786	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
792	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
805	1	1	1	1	0	1	1	1	1	0	0	0	1	0	0
811	1	1	1	1	0	1	1	1	1	0	0	0	1	0	0
817	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
838	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
847	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
853	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
869	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
878	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
884	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
893	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
908	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
924	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
930	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
945	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
960	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
975	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
991	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
1006	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
1030	1	1	1	1	1	1	1	1	1	0	0	0	1	0	1
1033	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
1042	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
1052	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
1067	1	1	1	1	1	1	1	0	1	0	0	0	1	0	0
1082	1	1	1	1	0	1	1	1	0	0	0	0	1	0	0
1091	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1097	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1103	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1113	1	1	0	1	1	1	1	0	0	0	0	0	1	0	0
1122	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1128	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1143	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1158	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1167	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1173	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1180	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1189	1	1	1	1	1	1	1	0	0	0	0	0	1	0	0
1204	1	1	0	1	1	0	1	0	0	0	0	0	1	0	0
1219	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1234	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1250	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1265	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1280	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1295	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1311	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1326	1	1	1	1	1	0	1	0	0	0	0	0	0	1	0
1341	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0
1356	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1372	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0
1387	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0
1402	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0
1417	1	1	0	1	1	0	1	0	0	0	0	0	0	1	0
1426	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0
1433	1	1	1	1	0	1	1	0	0	0	0	0	0	1	0

	Nechells presence or absence input (1=presence, 0=absence)														
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Frex**	**Tico**	**Al**	**Taba**	**Piab**	**Abal**	**Ac**	**Cabe**	**Coav**	**Hirh**	**Buse**
1448	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0
1463	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0
1478	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0
1494	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
1509	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1515	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0
1524	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0
1530	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0
1539	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0
1548	1	1	0	0	0	1	1	0	0	0	0	0	0	1	0
1551	1	1	0	1	0	0	1	0	0	0	0	0	0	1	0
1554	1	1	0	1	0	1	0	0	0	0	0	0	0	1	0
1558	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0
1564	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0
1573	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0

	Nechells presence or absence input (1=presence, 0=absence)									
Depth (cm)	**Vial**	**Juco**	**San**	**Hehe**	**Ilaq**	**Sam**	**Arma**	**Emni**	**Fi**	**Epdi**	**Cavu**
238	0	0	0	1	0	0	0	1	1	0	1
244	0	0	1	0	1	0	0	1	0	0	1
250	0	0	1	0	0	0	0	1	0	0	1
274	0	1	1	0	0	0	0	1	0	0	1
290	0	0	1	0	0	0	0	1	1	0	0
299	0	0	0	0	0	0	0	0	0	0	0
305	0	0	0	1	1	0	0	0	0	0	1
335	0	0	1	1	1	0	0	0	0	0	1
351	0	0	1	1	0	0	0	0	0	0	0
366	0	0	1	0	0	0	0	0	0	0	0
375	0	0	1	1	0	0	0	0	0	0	0
381	0	0	1	0	0	0	0	0	0	0	0
390	0	0	1	0	0	0	0	0	1	0	0
396	0	0	1	1	0	0	0	0	0	0	0
405	0	0	0	1	1	0	0	0	0	0	0
411	0	0	1	1	0	0	0	0	0	0	0
421	0	0	0	1	1	0	0	0	1	0	0
436	1	0	0	1	1	0	0	0	1	0	0
451	0	0	0	1	1	1	0	0	0	0	0
457	0	0	0	0	0	0	0	0	0	0	0
472	0	0	0	1	1	1	0	0	1	0	0
488	1	0	0	1	1	1	0	0	1	0	0
503	0	0	0	1	1	1	0	0	0	0	0
518	0	0	0	0	0	1	0	0	0	0	0
527	0	0	0	1	1	1	0	0	0	0	0
777	0	0	0	0	0	1	0	0	1	0	0
786	0	0	0	0	1	1	0	0	0	0	0
792	0	0	0	1	1	1	0	0	1	0	0
805	0	0	0	1	1	1	0	0	0	0	0
811	0	0	0	1	1	1	0	0	0	0	0
817	0	0	0	0	1	1	0	0	1	0	0
838	0	0	0	1	1	1	0	0	1	0	0
847	0	0	0	1	0	1	0	0	0	0	0
853	0	0	0	1	1	1	0	0	0	0	0
869	0	0	0	1	1	1	0	0	0	0	0
878	0	0	0	1	1	1	0	0	0	0	0
884	0	0	0	1	1	1	0	0	0	0	0
893	0	0	0	1	1	0	0	0	0	0	0
908	0	0	0	1	1	1	0	0	0	0	0
924	0	0	0	1	1	0	0	0	0	0	0
930	0	0	0	0	1	0	0	0	1	0	0
945	0	0	0	0	0	0	0	0	1	0	0
960	0	0	0	1	1	0	0	0	0	0	0
975	0	0	0	0	1	0	0	0	0	0	0
991	0	0	0	0	1	0	0	0	0	0	0
1006	0	0	0	0	0	0	0	0	0	0	0
1030	1	0	0	1	1	0	0	0	0	0	0
1033	0	0	0	1	1	0	1	0	1	0	0
1042	0	0	0	1	1	0	0	0	1	0	0
1052	0	0	0	1	1	0	0	0	1	0	0
1067	0	0	0	1	1	0	0	0	0	0	0
1082	0	0	0	1	1	0	0	0	1	0	0
1091	0	0	0	1	1	0	0	0	0	0	0
1097	0	0	0	1	1	0	0	0	1	0	0
1103	0	0	0	1	1	0	0	0	0	0	0
1113	0	0	0	1	1	0	1	0	0	0	0
1122	0	0	0	1	1	0	0	0	0	0	0
1128	0	0	0	1	1	0	0	0	0	0	0
1143	0	0	1	1	1	0	0	0	1	0	0
1158	0	0	1	1	0	0	0	0	1	0	0
1167	0	1	1	1	0	0	0	0	1	0	0
1173	0	1	1	1	0	0	0	0	1	0	0
1180	0	0	1	1	0	0	0	0	1	0	0
1189	0	1	1	1	1	0	0	0	1	0	0
1204	0	1	1	1	0	0	1	0	1	1	0
1219	0	0	1	1	1	0	1	0	1	0	0
1234	0	0	1	1	0	0	0	0	1	0	0
1250	0	0	0	1	0	0	0	0	0	0	0
1265	0	0	1	1	0	0	1	0	1	0	0
1280	0	0	1	1	0	0	1	0	1	0	0
1295	0	0	1	1	0	0	1	0	1	0	0
1311	0	0	1	0	0	0	1	0	0	0	0
1326	0	0	1	0	0	0	1	0	1	0	0
1341	0	1	1	0	0	0	1	0	1	0	0
1356	0	1	1	0	0	0	1	0	1	0	0
1372	0	0	1	0	0	0	0	0	1	0	0
1387	0	1	1	0	0	0	0	0	1	0	0
1402	0	1	1	1	0	0	0	0	1	0	0
1417	0	1	1	0	0	0	0	0	1	0	0
1426	0	1	1	0	0	0	0	0	1	0	0
1433	0	1	1	0	0	0	1	0	1	0	0

	Nechells presence or absence input (1=presence, 0=absence)										
Depth (cm)	**Vial**	**Juco**	**San**	**Hehe**	**Ilaq**	**Sam**	**Arma**	**Emni**	**Fi**	**Epdi**	**Cavu**
1448	0	1	1	0	0	0	0	0	1	0	0
1463	0	1	1	0	0	0	0	0	1	0	0
1478	0	1	1	0	0	0	1	0	0	0	0
1494	0	1	1	0	0	0	1	0	1	0	0
1509	0	1	1	0	0	0	0	0	1	0	0
1515	0	1	1	0	0	0	1	0	1	0	0
1524	0	1	1	0	0	0	1	0	1	0	0
1530	0	1	1	0	0	0	0	0	0	0	0
1539	0	1	1	0	0	0	0	0	1	0	0
1548	0	1	1	0	0	0	0	0	0	0	0
1551	0	1	0	0	0	0	0	0	1	0	0
1554	0	1	1	0	0	0	0	0	1	0	0
1558	0	1	0	0	0	0	0	0	0	0	0
1564	0	1	0	0	0	0	0	0	0	0	0
1573	0	0	0	0	0	0	0	0	0	0	0

	Quinton presence or absence input (1=presence, 0=absence)																	
Depth (cm)	**Be**	**Pisy**	**Abal**	**Piab**	**Ul**	**Qud**	**Ti**	**Hirh**	**Frex**	**Cabe**	**Fasy**	**Coav**	**Taba**	**Ilaq**	**Al**	**Hehe**	**San**	**Juco**
650	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
655	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
665	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1
675	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
680	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0
685	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
690	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
695	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
700	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
725	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
735	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
737	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
740	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
742	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1
745	1	1	0	1	0	0	1	0	0	0	0	1	0	0	1	0	1	1
750	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	1	1
755	1	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	1	1
757	1	1	0	1	0	1	0	0	0	0	0	1	0	0	1	0	1	1
780	1	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	1
800	1	1	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	1
815	1	1	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0
824	1	1	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0
826	1	1	1	1	0	1	0	0	0	1	0	1	0	0	1	0	1	0
828	1	1	1	1	0	1	1	0	0	1	1	1	0	0	1	0	1	0
845	1	1	1	1	0	1	0	0	0	1	1	1	0	0	1	0	1	1
855	1	1	1	1	0	1	0	0	0	1	1	0	0	0	1	0	1	1
870	1	1	1	1	0	1	1	0	0	1	1	1	1	0	1	0	1	1
880	1	1	1	1	0	1	1	0	0	0	1	1	1	0	1	0	1	1
905	1	1	1	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0
915	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0	0	1
925	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0	1	0
935	1	1	1	1	0	1	1	0	0	0	0	1	0	0	1	0	1	0
945	1	1	1	1	0	1	0	0	0	0	0	1	0	1	1	0	1	0
955	1	1	1	1	0	1	0	0	0	1	0	1	1	0	1	0	1	1
975	1	1	1	1	0	1	1	0	0	0	0	1	1	1	1	0	1	0
985	1	1	1	1	0	1	0	0	0	1	0	1	1	0	1	0	1	0
1000	1	1	1	1	0	1	1	0	0	0	0	0	1	0	1	0	1	0
1020	1	1	1	1	0	1	0	0	0	1	0	1	1	0	1	0	1	1
1030	1	1	1	1	0	1	0	0	0	1	0	1	0	0	1	0	1	0
1045	1	1	1	1	0	1	1	0	1	1	1	1	1	0	1	0	1	1
1065	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0
1080	1	1	1	1	0	1	0	0	0	1	0	1	0	0	1	0	0	1
1100	1	1	1	1	0	1	0	0	0	1	0	1	0	0	1	0	0	0
1110	1	1	1	1	0	1	0	0	0	0	0	0	1	0	1	1	0	0
1125	1	1	1	1	0	1	0	0	0	1	0	0	1	0	1	0	0	1
1135	1	1	1	1	1	1	0	0	0	1	1	0	1	0	1	0	1	0
1145	1	1	1	1	0	1	0	0	0	1	0	0	1	0	1	0	0	0
1155	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	0
1160	1	1	1	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0
1175	1	1	1	1	1	0	0	0	0	0	0	1	0	1	1	0	0	0
1200	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0	0	0
1210	1	1	1	1	0	1	0	0	1	0	0	1	0	0	1	0	0	0
1224	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0	0	0
1226	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0	0	0
1245	1	1	1	1	0	1	1	0	0	0	0	1	0	0	1	0	0	0
1255	1	1	1	1	0	1	0	0	0	1	0	1	0	0	1	0	0	0
1275	1	1	1	1	1	1	1	0	1	1	0	0	0	0	1	0	0	0
1285	1	0	0	1	1	1	0	0	1	0	0	1	0	0	1	0	0	0
1300	1	1	1	1	1	1	1	0	1	1	0	1	1	0	1	0	0	0
1302	1	1	1	1	1	1	1	0	1	0	1	1	1	0	1	0	0	0
1320	1	1	0	1	1	1	1	0	0	0	0	1	0	0	1	0	0	0
1330	1	1	0	1	1	1	1	0	1	1	0	1	0	0	1	0	0	0
1340	1	1	1	1	1	1	1	0	1	0	0	1	1	0	1	0	0	0
1350	1	1	0	1	0	1	1	0	1	1	0	1	1	1	1	0	1	0
1370	1	1	0	0	1	1	1	0	1	1	1	1	1	1	1	0	0	0
1395	1	1	0	1	1	1	1	0	0	1	0	1	1	1	1	1	0	0
1405	1	1	0	1	0	1	1	0	1	1	0	1	1	1	1	0	0	0
1420	1	1	0	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0
1435	1	1	0	0	0	1	1	0	1	0	0	1	1	1	1	0	0	0
1450	1	1	0	1	1	1	1	0	1	0	1	1	1	1	1	0	0	0
1460	1	1	0	0	0	1	1	0	1	0	1	1	1	1	1	1	0	0
1475	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1	1	0	0
1500	1	1	0	0	0	1	1	0	1	1	1	1	1	1	1	1	0	0
1515	1	1	0	1	0	1	1	0	0	1	1	1	1	1	1	1	0	0
1530	1	1	0	0	0	1	0	0	1	0	0	1	1	1	1	1	0	1
1550	1	1	0	0	1	1	1	0	1	0	1	1	1	1	1	1	0	0
1560	1	1	0	1	1	1	1	0	1	0	0	1	1	1	1	0	1	0
1570	1	1	0	0	0	1	1	0	1	0	1	1	1	1	1	1	0	0

	Quinton presence or absence input (1=presence, 0=absence)																	
Depth (cm)	**Be**	**Pisy**	**Abal**	**Piab**	**Ul**	**Qud**	**Ti**	**Hirh**	**Frex**	**Cabe**	**Fasy**	**Coav**	**Taba**	**Ilaq**	**Al**	**Hehe**	**San**	**Juco**
1590	1	1	0	0	0	1	0	0	1	0	0	1	1	1	1	1	0	0
1610	1	1	0	0	0	1	0	0	0	0	0	1	0	1	1	0	0	0
1620	1	1	0	0	1	1	0	0	1	0	0	1	1	1	1	0	1	0
1630	1	1	1	1	0	1	1	0	1	0	0	1	1	0	1	1	0	0
1650	1	1	0	0	0	1	0	0	1	0	0	1	1	0	1	0	0	0
1660	1	1	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	1
1675	1	1	0	0	0	1	0	0	1	0	0	1	0	0	1	1	0	0
1695	1	1	0	0	1	1	0	0	1	0	0	1	0	0	1	0	1	1
1710	1	1	0	0	1	1	0	0	1	0	0	0	0	0	1	1	0	1
1730	1	1	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	1
1740	1	1	0	0	1	1	0	0	0	0	0	1	0	0	1	0	0	1
1750	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1
1765	1	1	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	1
1767	1	1	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1
1780	1	1	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	1
1790	1	1	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	1
1800	1	1	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	1
1815	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1
1825	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
1840	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0
1855	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1
1870	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
1890	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
1915	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
1925	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
1945	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
1950	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2000	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2015	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
2025	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
2035	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
2050	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2085	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2100	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

	St Cross South Elmham presence or absence input (1=presence, 0=absence)													
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Cabe**	**Frex**	**Ac**	**Abal**	**Piab**	**Taba**	**Pte**	**Coav**
245	1	1	1	1	1	1	1	1	1	1	1	1	0	1
260	1	1	1	1	1	1	1	0	1	0	1	1	0	1
275	1	1	1	1	1	1	1	0	0	0	1	1	0	1
295	1	1	1	1	1	1	1	0	1	0	1	1	0	1
310	1	1	1	1	1	1	1	1	1	0	1	1	0	1
315	1	1	1	1	1	1	1	0	1	0	1	1	0	1
320	1	1	1	1	1	1	1	1	1	0	1	1	1	1
330	1	1	1	1	1	1	1	0	1	0	1	1	1	1
345	1	1	1	1	1	1	1	0	1	0	1	1	0	1
350	1	1	1	1	1	1	1	1	1	0	1	1	0	1
360	1	1	1	1	1	1	1	1	0	0	1	1	0	1
375	1	1	1	1	1	1	1	0	1	0	1	1	0	1
390	1	1	1	1	1	1	1	0	0	0	1	1	0	1
400	1	1	1	1	1	1	1	0	1	0	1	1	0	1
500	1	1	1	1	1	1	1	0	1	1	1	1	0	1
600	1	1	1	1	1	1	0	0	1	1	1	1	0	1
700	1	1	1	1	1	1	1	0	1	0	1	1	0	0
750	1	1	1	1	1	1	0	0	1	0	1	1	0	1
800	1	1	1	1	1	1	0	0	0	0	1	1	0	1
850	1	1	1	1	1	1	0	1	0	0	1	1	0	1
955	1	1	1	1	1	1	0	0	0	0	1	0	0	0
1050	1	1	0	0	0	0	0	0	1	0	1	0	0	0

	St Cross South Elmham presence or absence input (1=presence, 0=absence)					
Depth (cm)	**Sam**	**Juco**	**Hirh**	**Hehe**	**Ilaq**	**Plla**
245	0	0	0	1	1	0
260	1	0	0	1	1	0
275	0	0	0	1	1	0
295	0	0	0	1	1	0
310	1	0	0	1	1	0
315	1	1	0	1	1	0
320	1	0	0	1	1	0
330	0	0	0	1	1	0
345	0	0	0	0	1	0
350	0	0	0	1	0	0
360	1	1	0	1	0	1
375	1	1	0	0	0	1
390	1	0	0	1	1	1
400	0	0	0	1	1	0
500	0	1	0	1	1	0
600	0	0	0	1	1	0
700	0	0	0	1	1	0
750	0	1	0	1	1	0
800	0	1	0	1	1	0
850	1	1	0	1	1	0
955	1	1	1	0	0	0
1050	1	1	1	0	0	1

Sensitivity testing for species diversity

	Athelington all species 1 input													
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Cabe**	**Frex**	**Ac**	**Abal**	**Piab**	**Taba**	**Pte**	
440	0	1	0	0	0	1	0	0	0	1	1	1	1	
490	0	1	0	1	0	1	0	0	1	1	1	1	1	
510	1	1	0	0	0	1	0	0	1	1	1	1	0	
538	0	1	0	1	0	1	0	0	1	1	1	1	0	
556	0	1	0	0	0	1	0	0	0	1	1	1	1	
622	0	1	1	1	1	1	0	1	1	1	1	1	0	
642	1	1	1	1	1	1	1	1	0	1	1	1	0	
688	1	1	1	1	1	1	1	1	0	0	1	1	0	
700	1	1	1	1	1	1	1	1	1	1	1	1	0	
724	1	1	1	1	1	1	1	1	0	0	1	1	0	
768	1	1	1	1	0	0	1	1	0	0	1	1	0	
792	1	1	0	0	0	0	0	1	1	0	0	0	0	
814	1	1	0	0	0	0	0	1	0	0	0	0	0	
834	1	1	0	0	0	0	0	1	1	0	0	1	0	
	Athelington all species 1 input													
Depth (cm)	**Coav**	**Juco**	**Hehe**	**Ilaq**	**Visy**	**Cavu**	**Fi**	**San**	**Emni**	**Clma**	**Motr**	**Chpo**	**Lyeu**	**Sasc**
440	0	1	0	0	0	0	0	1	1	1	1	0	0	0
490	1	1	1	1	1	0	1	1	0	1	0	1	0	0
510	0	1	0	0	1	1	0	1	0	1	0	1	1	0
538	1	0	1	0	1	0	1	0	0	0	1	0	0	0
556	0	1	1	0	1	0	0	1	1	0	0	0	0	1
622	1	0	1	1	0	0	0	0	1	1	0	0	0	0
642	1	1	1	1	0	0	0	0	0	1	0	1	0	1
688	1	0	1	0	0	0	0	0	0	1	0	0	0	0
700	0	1	0	0	0	0	1	0	0	1	0	0	0	0
724	1	0	1	1	0	1	0	0	0	1	1	0	0	0
768	0	0	1	0	0	0	1	0	1	1	1	0	0	0
792	0	0	0	0	0	0	0	0	0	1	0	0	0	0
814	0	0	0	0	0	0	0	0	0	1	0	1	0	0
834	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Athelington all species 1 input													
Depth (cm)	**Plla**	**Poav**	**Rafl**	**Ruca**	**Gapa**	**Ruac**	**Thmi**							
440	0	0	0	0	1	0	0							
490	0	0	1	1	1	0	1							
510	1	1	1	1	0	0	0							
538	0	0	1	1	1	0	0							
556	0	0	1	0	1	0	1							
622	0	0	1	0	1	0	1							
642	0	0	1	0	0	0	0							
688	0	0	1	0	0	0	0							
700	0	0	1	0	0	1	0							
724	0	0	1	1	0	0	0							
768	0	0	1	0	0	0	0							
792	0	0	1	0	0	0	1							
814	0	0	1	0	0	1	1							
834	0	0	1	0	0	0	1							

	Athelington all species 2 input												
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Cabe**	**Frex**	**Ac**	**Abal**	**Piab**	**Taba**	**Pte**
440	0	1	0	0	0	1	0	0	0	1	1	1	1
490	0	1	0	1	0	1	0	0	1	1	1	1	1
510	1	1	0	0	0	1	0	0	1	1	1	1	0
538	0	1	0	1	0	1	0	0	1	1	1	1	0
556	0	1	0	0	0	1	0	0	0	1	1	1	1
622	0	1	1	1	1	1	0	1	1	1	1	1	0
642	1	1	1	1	1	1	1	1	0	1	1	1	0
688	1	1	1	1	1	1	1	1	0	0	1	1	0
700	1	1	1	1	1	1	1	1	1	1	1	1	0
724	1	1	1	1	1	1	1	1	0	0	1	1	0
768	1	1	1	1	0	0	1	1	0	0	1	1	0
792	1	1	0	0	0	0	0	1	1	0	0	0	0
814	1	1	0	0	0	0	0	1	0	0	0	0	0
834	1	1	0	0	0	0	0	1	1	0	0	1	0
	Athelington all species 2 input												
Depth (cm)	**Coav**	**Juco**	**Hehe**	**Ilaq**	**Visy**	**Cavu**	**Fi**	**San**	**Emni**	**Clma**	**Stho**	**Chpo**	**Tesc**
440	0	1	0	0	0	0	0	1	1	1	1	0	0
490	1	1	1	1	1	0	1	1	0	1	0	1	0
510	0	1	0	0	1	1	0	1	0	1	0	1	1
538	1	0	1	0	1	0	1	0	0	0	1	0	0
556	0	1	1	0	1	0	0	1	1	0	0	0	0
622	1	0	1	1	0	0	0	0	1	1	0	0	0
642	1	1	1	1	0	0	0	0	0	1	0	1	0
688	1	0	1	0	0	0	0	0	0	1	0	0	0
700	0	1	0	0	0	0	1	0	0	1	0	0	0
724	1	0	1	1	0	1	0	0	0	1	1	0	0
768	0	0	1	0	0	0	1	0	1	1	1	0	0
792	0	0	0	0	0	0	0	0	0	1	0	0	0
814	0	0	0	0	0	0	0	0	0	1	0	1	0
834	0	0	0	0	0	0	0	0	0	1	0	0	0
Depth (cm)	**Athelington all species 2 input**												
440	**Sasc**	**Plla**	**Poav**	**Rafl**	**Crmo**	**Gapa**	**Ruac**	**Thmi**					
490	0	0	0	0	0	1	0	0					
510	0	0	0	1	1	1	0	1					
538	0	1	1	1	1	0	0	0					
556	0	0	0	1	1	1	0	0					
622	1	0	0	1	0	1	0	1					
642	0	0	0	1	0	1	0	1					
688	1	0	0	1	0	0	0	0					
700	0	0	0	1	0	0	0	0					
724	0	0	0	1	0	0	1	0					
768	0	0	0	1	1	0	0	0					
792	0	0	0	1	0	0	0	0					
814	0	0	0	1	0	0	0	1					
834	0	0	0	1	0	0	1	1					
	0	0	0	1	0	0	0	1					

	Barford all species 1 input													
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Cabe**	**Frex**	**Ac**	**Abal**	**Pte**	**Piab**	**Taba**	
198	1	1	1	1	1	1	1	0	0	1	0	1	1	
244	1	1	1	1	1	1	0	1	1	1	0	1	1	
274	1	1	1	1	1	1	1	1	1	1	0	1	1	
302	1	1	1	1	1	1	0	1	1	1	0	1	1	
336	1	1	1	1	1	1	0	1	1	1	0	1	1	
366	1	1	1	1	1	1	1	1	1	1	0	1	1	
380	1	1	1	1	1	1	0	1	1	1	0	1	1	
396	1	1	1	1	1	1	1	1	1	1	0	1	1	
412	1	1	1	1	1	1	1	1	0	1	0	1	1	
426	1	1	1	1	1	1	0	1	1	1	0	1	1	
442	1	1	1	1	1	1	1	1	0	1	0	1	1	
457	1	1	1	1	1	1	1	1	1	1	0	1	1	
487	1	1	1	1	1	1	1	1	1	1	0	1	1	
534	1	1	1	1	1	1	1	1	0	1	0	1	1	
549	1	1	1	1	1	1	1	1	0	1	0	1	1	
564	1	1	1	1	1	1	1	1	1	1	0	1	1	
580	1	1	1	1	1	1	1	1	1	1	0	1	1	
608	1	1	1	1	1	1	1	1	1	1	0	1	1	
631	1	1	1	1	1	1	1	1	1	0	0	1	1	
655	1	1	1	1	1	1	0	1	1	0	0	1	1	
670	1	1	1	1	1	1	1	1	1	0	1	1	1	
685	1	1	1	1	1	1	1	1	1	1	0	1	1	
692	1	1	1	1	1	1	1	1	1	0	0	1	1	
707	1	1	1	1	1	1	0	1	1	1	0	1	1	
746	1	1	1	1	1	1	1	1	0	0	0	1	1	
775	1	1	1	1	1	1	0	1	0	0	0	1	1	
821	1	1	1	1	1	1	0	1	0	0	0	1	1	
852	1	1	1	1	1	1	0	1	0	0	0	1	1	
875	1	1	1	1	1	1	0	1	0	0	0	1	1	
914	1	1	1	1	1	1	1	1	0	0	0	1	0	
	Barford all species 1 input													
Depth (cm)	**Coav**	**Sam**	**Hehe**	**Ilaq**	**Rhca**	**Hirh**	**Visy**	**Juco**	**Emni**	**Cavu**	**Clma**			
198	1	0	1	1	0	0	0	0	1	0	0			
244	1	1	0	1	0	0	0	0	1	1	0			
274	1	0	0	1	0	0	0	0	1	0	0			
302	1	1	1	0	0	0	0	0	1	0	0			
336	1	0	0	1	0	0	0	0	0	0	1			
366	1	0	1	1	0	0	0	0	1	0	1			
380	1	0	1	1	0	0	1	0	1	0	0			
396	1	0	1	0	0	0	0	0	1	0	1			
412	1	0	1	1	0	0	0	0	1	0	0			
426	1	0	1	1	0	0	0	0	1	0	0			
442	1	0	1	1	0	0	0	0	1	0	1			
457	1	1	0	1	0	0	0	0	1	0	0			
487	1	0	1	1	0	0	0	0	0	1	1			
534	1	0	1	1	0	0	0	1	1	0	0			
549	1	1	1	1	0	0	0	0	1	0	0			
564	1	0	1	1	0	0	0	0	1	0	0			
580	1	0	1	1	0	0	1	0	1	1	1			
608	1	1	0	1	0	0	0	0	1	0	0			
631	1	1	1	1	0	0	0	0	1	0	0			
655	1	1	1	1	0	0	0	0	1	1	0			
670	1	0	1	1	0	0	0	0	1	0	1			
685	1	0	1	1	0	0	0	0	1	0	1			
692	1	1	1	1	1	0	0	0	1	0	1			
707	1	1	1	1	0	0	0	0	1	0	1			
746	1	1	1	0	1	0	0	0	1	1	0			
775	1	0	1	1	1	0	0	0	1	0	1			
821	1	0	1	1	0	0	0	0	1	0	0			
852	1	1	1	1	0	0	0	1	1	0	1			
875	1	1	1	1	1	0	0	0	1	0	0			
914	1	0	1	1	0	0	0	0	1	0	0			

	Barford all species 1 input										
Depth (cm)	**Motr**	**Chpo**	**Sasc**	**Plla**	**Rafl**	**Ruca**	**Thmi**	**Gapa**	**Fi**	**Urdi**	**Ruac**
198	0	0	0	0	0	0	0	0	1	0	0
244	0	0	0	0	1	0	0	0	0	0	0
274	0	0	0	0	0	0	0	0	0	0	0
302	0	0	0	0	0	0	0	1	0	0	0
336	0	0	0	0	0	0	1	0	0	0	0
366	1	1	0	0	0	0	1	0	0	0	0
380	0	0	0	0	1	1	0	0	0	0	0
396	0	0	0	0	1	0	0	0	0	0	0
412	1	0	1	0	0	0	0	0	0	0	0
426	0	0	0	0	0	0	0	0	0	0	0
442	0	0	0	0	0	0	0	0	0	1	0
457	0	0	0	0	0	0	0	0	0	1	0
487	1	0	0	0	0	0	0	0	0	0	0
534	0	0	0	0	1	0	0	1	0	0	0
549	0	0	0	0	1	1	0	0	0	0	0
564	0	0	1	0	0	0	0	0	0	0	0
580	1	1	0	0	1	0	0	0	0	0	0
608	0	0	0	0	1	0	0	0	0	0	0
631	0	1	0	0	0	0	0	0	0	0	0
655	1	0	0	0	0	0	0	0	0	0	0
670	0	0	1	0	0	0	0	0	0	0	0
685	0	0	0	0	0	0	0	0	0	0	0
692	0	0	0	0	0	1	0	0	0	0	0
707	1	0	0	0	1	0	0	0	0	0	0
746	0	0	0	1	0	0	0	0	0	0	0
775	0	0	0	1	0	0	0	0	0	1	1
821	0	1	0	0	0	0	0	0	0	0	0
852	0	0	0	0	0	0	0	0	0	0	0
875	0	0	0	0	0	0	0	0	0	0	0
914	0	0	0	0	0	0	0	0	0	0	0

	Barford all species 2 input													
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Cabe**	**Frex**	**Ac**	**Abal**	**Pte**	**Piab**	**Taba**	**Coav**
198	1	1	1	1	1	1	1	0	0	1	0	1	1	1
244	1	1	1	1	1	1	0	1	1	1	0	1	1	1
274	1	1	1	1	1	1	1	1	1	1	0	1	1	1
302	1	1	1	1	1	1	0	1	1	1	0	1	1	1
336	1	1	1	1	1	1	0	1	1	1	0	1	1	1
366	1	1	1	1	1	1	1	1	1	1	0	1	1	1
380	1	1	1	1	1	1	0	1	1	1	0	1	1	1
396	1	1	1	1	1	1	1	1	1	1	0	1	1	1
412	1	1	1	1	1	1	1	1	0	1	0	1	1	1
426	1	1	1	1	1	1	0	1	1	1	0	1	1	1
442	1	1	1	1	1	1	1	1	0	1	0	1	1	1
457	1	1	1	1	1	1	1	1	1	1	0	1	1	1
487	1	1	1	1	1	1	1	1	1	1	0	1	1	1
534	1	1	1	1	1	1	1	1	0	1	0	1	1	1
549	1	1	1	1	1	1	1	1	0	1	0	1	1	1
564	1	1	1	1	1	1	1	1	1	1	0	1	1	1
580	1	1	1	1	1	1	1	1	1	1	0	1	1	1
608	1	1	1	1	1	1	1	1	1	1	0	1	1	1
631	1	1	1	1	1	1	1	1	1	0	0	1	1	1
655	1	1	1	1	1	1	0	1	1	0	0	1	1	1
670	1	1	1	1	1	1	1	1	1	0	1	1	1	1
685	1	1	1	1	1	1	1	1	1	1	0	1	1	1
692	1	1	1	1	1	1	1	1	1	0	0	1	1	1
707	1	1	1	1	1	1	0	1	1	1	0	1	1	1
746	1	1	1	1	1	1	1	1	0	0	0	1	1	1
775	1	1	1	1	1	1	0	1	0	0	0	1	1	1
821	1	1	1	1	1	1	0	1	0	0	0	1	1	1
852	1	1	1	1	1	1	0	1	0	0	0	1	1	1
875	1	1	1	1	1	1	0	1	0	0	0	1	1	1
914	1	1	1	1	1	1	1	1	0	0	0	1	0	1
	Barford all species 2 input													
Depth (cm)	**Sam**	**Hehe**	**Ilaq**	**Rhca**	**Hirh**	**Visy**	**Juco**	**Emni**	**Cavu**	**Clma**	**Stho**			
198	0	1	1	0	0	0	0	1	0	0	0			
244	1	0	1	0	0	0	0	1	1	0	0			
274	0	0	1	0	0	0	0	1	0	0	0			
302	1	1	0	0	0	0	0	1	0	0	0			
336	0	0	1	0	0	0	0	0	0	1	0			
366	0	1	1	0	0	0	0	1	0	1	1			
380	0	1	1	0	0	1	0	1	0	0	0			
396	0	1	0	0	0	0	0	1	0	1	0			
412	0	1	1	0	0	0	0	1	0	0	1			
426	0	1	1	0	0	0	0	1	0	0	0			
442	0	1	1	0	0	0	0	1	0	1	0			
457	1	0	1	0	0	0	0	1	0	0	0			
487	0	1	1	0	0	0	0	0	1	1	1			
534	0	1	1	0	0	0	1	1	0	0	0			
549	1	1	1	0	0	0	0	1	0	0	0			
564	0	1	1	0	0	0	0	1	0	0	0			
580	0	1	1	0	0	1	0	1	1	1	1			
608	1	0	1	0	0	0	0	1	0	0	0			
631	1	1	1	0	0	0	0	1	0	0	0			
655	1	1	1	0	0	0	0	1	1	0	1			
670	0	1	1	0	0	0	0	1	0	1	0			
685	0	1	1	0	0	0	0	1	0	1	0			
692	1	1	1	1	0	0	0	1	0	1	0			
707	1	1	1	0	0	0	0	1	0	1	1			
746	1	1	0	1	0	0	0	1	1	0	0			
775	0	1	1	1	0	0	0	1	0	1	0			
821	0	1	1	0	0	0	0	1	0	0	0			
852	1	1	1	0	0	0	1	1	0	1	0			
875	1	1	1	1	0	0	0	1	0	0	0			
914	0	1	1	0	0	0	0	1	0	0	0			

	Barford all species 2 input									
Depth (cm)	**Chpo**	**Sasc**	**Plla**	**Rafl**	**Crmo**	**Thmi**	**Gapa**	**Fi**	**Urdi**	**Ruac_h**
198	0	0	0	0	0	0	0	1	0	0
244	0	0	0	1	0	0	0	0	0	0
274	0	0	0	0	0	0	0	0	0	0
302	0	0	0	0	0	0	1	0	0	0
336	0	0	0	0	0	1	0	0	0	0
366	1	0	0	0	0	1	0	0	0	0
380	0	0	0	1	1	0	0	0	0	0
396	0	0	0	1	0	0	0	0	0	0
412	0	1	0	0	0	0	0	0	0	0
426	0	0	0	0	0	0	0	0	0	0
442	0	0	0	0	0	0	0	0	1	0
457	0	0	0	0	0	0	0	0	1	0
487	0	0	0	0	0	0	0	0	0	0
534	0	0	0	1	0	0	1	0	0	0
549	0	0	0	1	1	0	0	0	0	0
564	0	1	0	0	0	0	0	0	0	0
580	1	0	0	1	0	0	0	0	0	0
608	0	0	0	1	0	0	0	0	0	0
631	1	0	0	0	0	0	0	0	0	0
655	0	0	0	0	0	0	0	0	0	0
670	0	1	0	0	0	0	0	0	0	0
685	0	0	0	0	0	0	0	0	0	0
692	0	0	0	0	1	0	0	0	0	0
707	0	0	0	1	0	0	0	0	0	0
746	0	0	1	0	0	0	0	0	0	0
775	0	0	1	0	0	0	0	0	1	1
821	1	0	0	0	0	0	0	0	0	0
852	0	0	0	0	0	0	0	0	0	0
875	0	0	0	0	0	0	0	0	0	0
914	0	0	0	0	0	0	0	0	0	0

	Hoxne (main sequence) all species 1 input															
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Fasy**	**Cabe**	**Frex**	**Ac**	**Abal**	**Piab**	**Taba**	**Sam**	**Coav**	**San**
180	0	1	1	1	1	1	0	0	0	0	1	1	0	0	1	1
192	1	1	1	1	1	1	0	0	0	0	1	1	0	0	1	0
260	0	1	0	1	1	1	0	0	1	0	0	0	0	0	1	1
272	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0
279	1	1	1	1	1	1	0	0	0	0	0	1	0	1	1	0
288	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	0
296	1	1	1	1	1	1	0	0	1	1	0	1	0	0	1	0
310	1	1	1	1	1	1	1	0	1	0	0	1	0	0	1	0
320	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
326	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
334	1	1	1	1	1	1	0	0	1	1	1	1	0	0	1	0
342	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
356	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
384	0	1	1	1	1	1	0	0	1	1	0	1	0	0	1	0
392	0	1	1	1	1	1	1	0	1	0	0	1	0	0	1	0
408	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
416	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
432	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	0
444	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
464	1	1	1	1	1	1	0	1	1	0	0	0	1	0	1	0
480	0	1	1	1	1	1	0	1	1	0	0	1	1	0	1	0
496	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
512	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
528	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0
544	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0
556	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
576	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
592	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0
637	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
648	1	1	0	1	1	1	0	0	1	0	0	1	0	0	1	0
656	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	0
672	1	1	1	1	1	1	0	0	1	0	0	1	1	0	1	0
682	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
692	1	1	1	1	1	1	0	0	0	0	0	0	1	0	1	0
706	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0
720	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
746	1	1	1	1	1	1	0	1	0	0	0	1	0	0	1	0
760	1	1	0	1	1	1	0	0	1	0	0	1	0	0	1	0
776	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	0
784	1	1	1	1	1	1	1	0	1	0	0	1	0	0	1	0
794	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	0
801	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0
808	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0
816	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0
824	1	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0

	Hoxne (main sequence) all species 1 input													
Depth (cm)	**Hirh**	**Hehe**	**Ilaq**	**Emni**	**Fi**	**Plla**	**Rafl**	**Ruac**	**Thmi**	**Poan**	**Chpo**	**Clma**	**Motr**	**Lyeu**
180	0	1	0	0	0	0	0	0	0	0	0	1	0	0
192	0	0	0	0	0	0	1	0	0	1	0	1	0	0
260	0	0	0	1	0	0	1	0	0	0	0	1	1	0
272	0	1	0	0	0	0	0	0	0	0	0	1	0	0
279	0	0	1	1	0	0	0	0	0	0	0	1	0	0
288	1	1	0	0	0	0	1	0	0	0	0	1	1	0
296	0	0	1	0	0	1	1	1	0	1	1	1	1	0
310	0	0	0	0	0	1	1	0	0	1	1	1	0	0
320	0	1	1	0	1	1	1	0	0	0	0	1	1	0
326	0	0	1	0	0	0	0	0	0	0	1	1	1	0
334	0	1	1	0	0	1	0	1	0	0	0	1	0	0
342	0	1	0	1	0	0	0	1	0	0	1	1	0	0
356	0	1	1	0	0	0	1	0	0	0	0	1	1	0
384	0	1	1	1	0	0	0	0	0	0	0	1	1	0
392	0	0	1	1	0	0	0	0	0	0	0	1	1	0
408	0	0	1	1	0	0	1	0	0	0	0	1	1	0
416	0	1	0	1	0	0	0	0	0	0	1	1	1	0
432	0	0	1	0	0	0	0	0	0	0	0	1	0	0
444	0	0	1	1	0	0	0	0	0	0	1	1	1	0
464	0	1	1	0	0	0	1	0	0	0	0	1	0	0
480	0	1	1	0	0	0	1	0	0	0	0	1	0	0
496	0	1	1	0	0	0	0	0	0	0	0	0	1	0
512	0	1	1	1	0	0	0	0	0	0	0	1	0	0
528	0	1	1	1	0	0	0	0	0	0	0	1	0	0
544	0	1	1	0	0	0	0	0	0	0	0	1	0	0
556	0	1	1	1	0	0	0	0	0	0	0	1	1	0
576	0	1	1	1	0	0	0	0	0	0	0	1	0	0
592	0	1	0	1	0	0	0	0	0	0	0	1	1	0
637	0	1	1	1	0	0	0	0	0	0	0	1	0	0
648	0	1	1	0	0	0	0	0	0	0	0	1	0	0
656	0	1	0	1	0	0	0	0	0	0	0	1	1	0
672	0	1	0	0	0	0	0	0	0	0	0	0	1	1
682	0	1	0	0	0	0	0	0	0	0	0	1	1	0
692	0	1	0	1	0	0	0	0	0	0	0	1	0	0
706	0	1	0	0	0	0	0	0	0	0	0	1	0	0
720	1	0	0	1	0	0	1	0	1	0	1	1	0	0
746	1	1	0	1	1	0	1	0	1	0	0	1	1	0
760	0	1	0	1	0	0	1	0	1	0	0	1	1	0
776	1	1	0	0	0	0	0	0	1	0	0	1	0	0
784	1	1	0	0	0	0	1	0	0	0	0	1	0	0
794	1	1	0	0	0	0	0	0	0	0	1	1	0	0
801	0	0	0	0	0	0	0	0	0	0	0	1	0	0
808	0	1	0	1	0	0	1	0	0	0	1	1	1	0
816	1	0	0	0	0	0	1	0	1	0	0	1	0	0
824	1	0	1	0	1	0	0	0	1	0	0	1	1	0

	Hoxne (main sequence) all species 1 input			
Depth (cm)	**Sasc**	**Ruca**	**Gapa**	
180	0	0	0	
192	0	1	0	
260	0	0	0	
272	0	0	1	
279	0	0	0	
288	0	0	0	
296	0	0	1	
310	0	0	0	
320	0	0	0	
326	0	1	1	
334	0	0	0	
342	0	0	0	
356	0	0	0	
384	0	0	0	
392	0	0	0	
408	0	0	0	
416	0	0	0	
432	0	0	0	
444	0	1	0	
464	0	0	0	
480	0	0	0	
496	0	0	0	
512	0	0	0	
528	0	0	0	
544	0	0	0	
556	0	0	0	
576	0	0	0	
592	0	0	0	
637	0	0	0	
648	0	0	0	
656	0	0	0	
672	0	0	0	
682	0	0	0	
692	0	1	0	
706	0	0	0	
720	0	0	0	
746	1	0	0	
760	0	0	1	
776	0	0	0	
784	0	0	0	
794	0	0	0	
801	0	0	0	
808	0	0	0	
816	0	0	0	
824	0	0	0	

	Hoxne (main sequence) all species 2 input															
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Fasy**	**Cabe**	**Frex**	**Ac**	**Abal**	**Piab**	**Taba**	**Sam**	**Coav**	**San**
180	0	1	1	1	1	1	0	0	0	0	1	1	0	0	1	1
192	1	1	1	1	1	1	0	0	0	0	1	1	0	0	1	0
260	0	1	0	1	1	1	0	0	1	0	0	0	0	0	1	1
272	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0
279	1	1	1	1	1	1	0	0	0	0	0	1	0	1	1	0
288	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	0
296	1	1	1	1	1	1	0	0	1	1	0	1	0	0	1	0
310	1	1	1	1	1	1	1	0	1	0	0	1	0	0	1	0
320	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
326	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
334	1	1	1	1	1	1	0	0	1	1	1	1	0	0	1	0
342	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
356	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
384	0	1	1	1	1	1	0	0	1	1	0	1	0	0	1	0
392	0	1	1	1	1	1	1	0	1	0	0	1	0	0	1	0
408	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
416	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
432	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	0
444	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
464	1	1	1	1	1	1	0	1	1	0	0	0	1	0	1	0
480	0	1	1	1	1	1	0	1	1	0	0	1	1	0	1	0
496	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
512	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
528	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0
544	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0
556	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
576	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
592	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0
637	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
648	1	1	0	1	1	1	0	0	1	0	0	1	0	0	1	0
656	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	0
672	1	1	1	1	1	1	0	0	1	0	0	1	1	0	1	0
682	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
692	1	1	1	1	1	1	0	0	0	0	0	0	1	0	1	0
706	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0
720	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0
746	1	1	1	1	1	1	0	1	0	0	0	1	0	0	1	0
760	1	1	0	1	1	1	0	0	1	0	0	1	0	0	1	0
776	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	0
784	1	1	1	1	1	1	1	0	1	0	0	1	0	0	1	0
794	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	0
801	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0
808	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0
816	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0
824	1	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0

	Hoxne (main sequence) all species 2 input													
Depth (cm)	**Hirh**	**Hehe**	**Ilaq**	**Emni**	**Fi**	**Plla**	**Rafl**	**Ruac**	**Thmi**	**Poan**	**Chpo**	**Clma**	**Stho**	**Tesc**
180	0	1	0	0	0	0	0	0	0	0	0	1	0	0
192	0	0	0	0	0	0	1	0	0	1	0	1	0	0
260	0	0	0	1	0	0	1	0	0	0	0	1	1	0
272	0	1	0	0	0	0	0	0	0	0	0	1	0	0
279	0	0	1	1	0	0	0	0	0	0	0	1	0	0
288	1	1	0	0	0	0	1	0	0	0	0	1	1	0
296	0	0	1	0	0	1	1	1	0	1	1	1	1	0
310	0	0	0	0	0	1	1	0	0	1	1	1	0	0
320	0	1	1	0	1	1	1	0	0	0	0	1	1	0
326	0	0	1	0	0	0	0	0	0	0	1	1	1	0
334	0	1	1	0	0	1	0	1	0	0	0	1	0	0
342	0	1	0	1	0	0	0	1	0	0	1	1	0	0
356	0	1	1	0	0	0	1	0	0	0	0	1	1	0
384	0	1	1	1	0	0	0	0	0	0	0	1	1	0
392	0	0	1	1	0	0	0	0	0	0	0	1	1	0
408	0	0	1	1	0	0	1	0	0	0	0	1	1	0
416	0	1	0	1	0	0	0	0	0	0	1	1	1	0
432	0	0	1	0	0	0	0	0	0	0	0	1	0	0
444	0	0	1	1	0	0	0	0	0	0	1	1	1	0
464	0	1	1	0	0	0	1	0	0	0	0	1	0	0
480	0	1	1	0	0	0	1	0	0	0	0	1	0	0
496	0	1	1	0	0	0	0	0	0	0	0	0	1	0
512	0	1	1	1	0	0	0	0	0	0	0	1	0	0
528	0	1	1	1	0	0	0	0	0	0	0	1	0	0
544	0	1	1	0	0	0	0	0	0	0	0	1	0	0
556	0	1	1	1	0	0	0	0	0	0	0	1	1	0
576	0	1	1	1	0	0	0	0	0	0	0	1	0	0
592	0	1	0	1	0	0	0	0	0	0	0	1	1	0
637	0	1	1	1	0	0	0	0	0	0	0	1	0	0
648	0	1	1	0	0	0	0	0	0	0	0	1	0	0
656	0	1	0	1	0	0	0	0	0	0	0	1	1	0
672	0	1	0	0	0	0	0	0	0	0	0	0	1	1
682	0	1	0	0	0	0	0	0	0	0	0	1	1	0
692	0	1	0	1	0	0	0	0	0	0	0	1	0	0
706	0	1	0	0	0	0	0	0	0	0	0	1	0	0
720	1	0	0	1	0	0	1	0	1	0	1	1	0	0
746	1	1	0	1	1	0	1	0	1	0	0	1	1	0
760	0	1	0	1	0	0	1	0	1	0	0	1	1	0
776	1	1	0	0	0	0	0	0	1	0	0	1	0	0
784	1	1	0	0	0	0	1	0	0	0	0	1	0	0
794	1	1	0	0	0	0	0	0	0	0	1	1	0	0
801	0	0	0	0	0	0	0	0	0	0	0	1	0	0
808	0	1	0	1	0	0	1	0	0	0	1	1	1	0
816	1	0	0	0	0	0	1	0	1	0	0	1	0	0
824	1	0	1	0	1	0	0	0	1	0	0	1	1	0

	Hoxne (main sequence) all species 2 input			
Depth (cm)	**Sasc**	**Crmo**	**Gapa**	
180	0	0	0	
192	0	1	0	
260	0	0	0	
272	0	0	1	
279	0	0	0	
288	0	0	0	
296	0	0	1	
310	0	0	0	
320	0	0	0	
326	0	1	1	
334	0	0	0	
342	0	0	0	
356	0	0	0	
384	0	0	0	
392	0	0	0	
408	0	0	0	
416	0	0	0	
432	0	0	0	
444	0	1	0	
464	0	0	0	
480	0	0	0	
496	0	0	0	
512	0	0	0	
528	0	0	0	
544	0	0	0	
556	0	0	0	
576	0	0	0	
592	0	0	0	
637	0	0	0	
648	0	0	0	
656	0	0	0	
672	0	0	0	
682	0	0	0	
692	0	1	0	
706	0	0	0	
720	0	0	0	
746	1	0	0	
760	0	0	1	
776	0	0	0	
784	0	0	0	
794	0	0	0	
801	0	0	0	
808	0	0	0	
816	0	0	0	
824	0	0	0	

	Hoxne (Stratum C) all species 1 input														
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Cabe**	**Ac**	**Abal**	**Piab**	**Sam**	**Coav**	**San**		
4	1	1	1	1	1	1	0	0	1	1	0	1	0		
20	0	1	1	1	1	1	0	0	1	1	0	1	0		
28	1	1	1	1	1	1	0	0	1	1	0	1	0		
40	1	1	1	1	1	1	1	0	1	1	0	1	0		
60	1	1	1	1	1	1	0	0	1	1	0	1	0		
68	1	1	1	1	1	1	1	0	1	1	0	1	1		
76	1	1	1	1	1	1	0	0	1	1	1	1	0		
100	0	1	0	1	0	1	0	0	1	1	0	1	1		
108	1	1	1	1	1	1	0	1	1	1	0	1	0		
116	0	1	0	1	1	1	1	0	1	1	0	1	1		
132	1	1	1	1	0	1	1	0	1	1	0	1	0		
152	1	1	0	1	0	1	0	0	1	1	0	1	0		
	Hoxne (Stratum C) all species 1 input														
Depth (cm)	**Hirh**	**Hehe**	**Ilaq**	**Clma**	**Cavu**	**Emni**	**Motr**	**Chpo**	**Plla**	**Poav**	**Rafl**	**Ruca**	**Gapa**	**Ruac**	**Thmi**
4	0	0	0	1	0	1	1	0	0	0	1	0	1	0	1
20	0	0	0	1	0	1	1	0	0	0	1	0	0	0	1
28	0	0	0	1	0	1	1	1	0	0	1	0	0	0	1
40	1	0	0	1	0	1	1	0	0	0	1	0	0	1	0
60	1	1	0	1	0	1	1	0	0	1	0	0	0	0	1
68	0	0	1	1	1	1	1	0	0	1	0	0	0	0	0
76	0	1	0	1	0	1	1	1	0	1	0	0	0	0	1
100	0	0	0	1	0	1	1	0	0	1	0	0	0	0	1
108	0	0	1	1	0	1	0	1	1	0	0	0	0	0	1
116	1	0	0	1	1	1	1	0	1	0	0	0	1	0	0
132	1	1	1	1	0	1	0	0	0	0	0	1	0	1	0
152	0	0	0	1	0	1	0	0	0	0	0	1	0	1	0

	Hoxne (Stratum C) all species 2 input													
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Cabe**	**Ac**	**Abal**	**Piab**	**Sam**	**Coav**	**San**	**Hirh**
4	1	1	1	1	1	1	0	0	1	1	0	1	0	0
20	0	1	1	1	1	1	0	0	1	1	0	1	0	0
28	1	1	1	1	1	1	0	0	1	1	0	1	0	0
40	1	1	1	1	1	1	1	0	1	1	0	1	0	1
60	1	1	1	1	1	1	0	0	1	1	0	1	0	1
68	1	1	1	1	1	1	1	0	1	1	0	1	1	0
76	1	1	1	1	1	1	0	0	1	1	1	1	0	0
100	0	1	0	1	0	1	0	0	1	1	0	1	1	0
108	1	1	1	1	1	1	0	1	1	1	0	1	0	0
116	0	1	0	1	1	1	1	0	1	1	0	1	1	1
132	1	1	1	1	0	1	1	0	1	1	0	1	0	1
152	1	1	0	1	0	1	0	0	1	1	0	1	0	0

			Hoxne (Stratum C) all species 2 input											
Depth (cm)	**Hehe**	**Ilaq**	**Clma**	**Cavu**	**Emni**	**Stho**	**Chpo**	**Plla**	**Poav**	**Rafl**	**Crmo**	**Gapa**	**Ruac**	**Thmi**
4	0	0	1	0	1	1	0	0	0	1	0	1	0	1
20	0	0	1	0	1	1	0	0	0	1	0	0	0	1
28	0	0	1	0	1	1	1	0	0	1	0	0	0	1
40	0	0	1	0	1	1	0	0	0	1	0	0	1	0
60	1	0	1	0	1	1	0	0	1	0	0	0	0	1
68	0	1	1	1	1	1	0	0	1	0	0	0	0	0
76	1	0	1	0	1	1	1	0	1	0	0	0	0	1
100	0	0	1	0	1	1	0	0	1	0	0	0	0	1
108	0	1	1	0	1	0	1	1	0	0	0	0	0	1
116	0	0	1	1	1	1	0	1	0	0	0	1	0	0
132	1	1	1	0	1	0	0	0	0	0	1	0	1	0
152	0	0	1	0	1	0	0	0	0	0	1	0	1	0

	Marks Tey (borehole 1A) all species 1 input															
Depth (cm)	**Be**	**Pisy**	**Abal**	**Piab**	**Ul**	**Qud**	**Ti**	**Frex**	**Al**	**Ac**	**Cabe**	**Taba**	**Coav**	**San**	**Hirh**	**Juco**
1060	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1
1100	1	1	1	1	1	1	1	0	1	0	1	1	1	0	0	0
1155	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	0
1205	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
1225	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0
1265	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
1325	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
1355	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
1385	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
1415	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1450	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1480	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
1510	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0
1520	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0
1530	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0
1538	1	1	0	1	1	1	1	1	1	0	1	1	1	0	0	0
1550	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	0
1560	1	1	0	1	1	1	1	1	1	1	0	1	1	0	0	0
1570	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0
1600	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0
1630	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	0
1660	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0
1690	1	1	0	1	1	1	1	1	1	1	0	1	1	0	0	0
1700	1	1	0	1	1	1	1	0	1	0	0	1	1	1	0	0
1710	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0
1725	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	1
1730	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0	0
1745	1	1	0	1	1	1	1	1	1	0	0	0	1	0	0	0
1750	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0	1
1765	1	1	0	1	1	1	0	1	1	0	0	0	1	0	0	0
1775	1	1	0	1	1	1	0	1	1	0	0	0	1	1	0	1
1780	1	1	1	0	1	1	1	0	1	1	0	0	1	0	1	0
1785	1	1	0	1	1	1	0	0	1	1	0	0	1	1	0	1
1795	1	1	0	0	1	1	0	1	0	1	0	0	1	1	0	0
1800	1	1	0	0	1	1	1	0	0	1	0	0	1	1	0	0
1805	1	1	0	0	1	1	1	0	0	1	0	0	0	1	0	0
1810	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	1
1835	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1
1850	1	1	0	1	0	1	0	0	0	1	0	0	0	1	1	1
1852	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
1865	1	1	0	1	1	1	0	0	0	0	0	0	0	0	1	0
1878	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0
1880	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1
1892	1	1	0	0	1	1	0	0	1	0	0	0	0	1	0	0
1895	1	1	0	0	1	1	1	0	1	1	0	0	1	1	0	1
1898	1	1	0	0	1	1	0	0	1	0	0	0	1	1	0	0
1905	1	1	0	0	1	1	0	0	0	1	0	0	0	0	0	1
1915	1	1	0	1	1	1	0	0	1	1	0	0	1	0	0	0
1925	1	1	0	0	0	1	0	0	1	1	0	0	0	1	1	1
1950	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1
1972	1	1	0	1	1	0	0	0	1	1	0	0	0	1	1	0
1977	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1985	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0
1995	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1
2005	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0
2007	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0
2010	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1
2012	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1
2013	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0
2014	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1

	Marks Tey (borehole 1A) all species 1 input													
Depth (cm)	**Hehe**	**Ilaq**	**Vial**	**Visy**	**Eueu**	**Vila**	**Arma**	**Cavu**	**Emni**	**Plme**	**Poav**	**Ruac**	**Thmi**	**Urdi**
1060	1	0	0	1	0	0	0	0	1	0	0	0	0	0
1100	0	0	0	0	0	0	0	1	1	0	0	0	0	0
1155	1	1	0	1	0	0	0	1	0	0	0	0	0	0
1205	0	1	0	0	0	0	0	0	0	0	0	1	1	0
1225	1	1	0	0	0	0	0	0	1	0	0	0	0	0
1265	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1325	1	1	0	0	0	0	0	0	1	0	0	0	0	0
1355	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1385	1	1	0	0	0	0	0	1	1	0	0	0	0	0
1415	1	1	0	0	0	0	0	0	1	0	0	0	0	0
1450	1	1	0	0	0	0	0	1	1	0	0	0	1	0
1480	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1510	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1520	1	1	0	0	0	0	0	1	1	0	0	0	0	0
1530	1	1	1	0	0	0	0	0	0	0	0	1	0	0
1538	1	1	0	0	0	1	0	1	0	0	0	0	0	1
1550	1	0	0	0	0	1	0	0	0	1	0	0	0	0
1560	1	1	0	0	0	0	0	0	0	0	0	0	0	1
1570	1	1	0	0	0	0	0	1	0	0	0	0	0	1
1600	1	1	0	0	0	0	0	0	0	0	0	0	0	1
1630	1	1	0	0	0	0	0	1	0	0	0	0	1	0
1660	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1690	1	1	0	0	0	0	0	0	1	0	0	0	0	0
1700	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1710	1	1	0	0	0	1	0	0	0	0	0	0	0	0
1725	1	1	0	0	0	0	0	0	0	0	0	0	0	1
1730	1	1	0	0	0	0	0	0	0	0	0	0	0	1
1745	1	0	0	0	0	0	0	0	0	0	0	1	0	0
1750	1	0	0	0	0	1	0	0	0	0	0	0	0	0
1765	1	0	0	0	0	1	0	0	0	0	0	0	0	0
1775	0	0	0	0	1	0	0	0	0	0	0	0	1	0
1780	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1785	0	0	0	0	0	0	0	0	0	1	0	0	1	0
1795	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1800	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1805	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1810	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1835	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1850	0	0	0	0	0	0	0	0	0	0	0	1	1	0
1852	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1865	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1878	0	0	0	0	0	0	1	0	0	1	0	0	0	0
1880	1	0	0	0	0	0	0	0	0	0	0	0	1	0
1892	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1895	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1898	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1905	1	0	0	0	0	0	0	0	0	1	0	0	1	0
1915	1	0	0	0	0	0	0	0	0	1	0	0	1	0
1925	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1950	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1972	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1977	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1985	0	0	0	0	0	0	0	0	0	1	0	0	1	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2010	0	0	0	0	0	0	0	0	0	0	1	0	1	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2013	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	1	0	0	0	0

	Marks Tey (borehole 1A) all species 1 input							
Depth (cm)	**Clma**	**Chpo**	**Motr**	**Fi**	**Lyeu**	**Rafl**	**Ruca**	**Gapa**
1060	1	0	0	0	0	0	1	0
1100	0	0	0	0	0	0	1	0
1155	1	0	1	0	0	0	1	0
1205	1	0	0	0	0	0	1	1
1225	1	0	1	0	0	0	1	0
1265	0	0	0	0	0	1	1	0
1325	0	0	0	0	0	0	1	0
1355	0	0	1	1	0	0	0	0
1385	1	1	1	0	0	0	1	0
1415	1	1	1	0	0	0	0	0
1450	0	0	0	0	0	1	0	0
1480	1	0	0	1	0	0	0	0
1510	0	1	1	0	0	0	0	0
1520	0	0	1	0	0	0	1	0
1530	1	0	1	0	1	0	0	1
1538	0	0	1	0	0	1	1	0
1550	1	0	0	0	0	1	1	0
1560	1	0	1	1	0	1	1	0
1570	1	1	1	0	0	1	0	0
1600	0	0	0	0	0	1	1	0
1630	0	1	1	0	0	1	0	0
1660	1	0	1	0	0	0	1	0
1690	0	0	1	0	1	1	0	0
1700	1	1	0	0	0	0	1	0
1710	1	0	1	0	0	1	1	0
1725	1	1	1	0	0	0	0	0
1730	1	0	1	0	0	0	0	0
1745	1	1	1	0	0	0	0	1
1750	1	0	1	1	0	0	1	0
1765	0	0	1	0	0	1	1	0
1775	1	1	1	0	0	1	1	0
1780	1	0	1	0	0	0	0	0
1785	1	0	1	0	0	0	0	0
1795	1	0	1	1	0	1	0	0
1800	1	0	1	0	0	1	1	0
1805	0	0	0	0	0	1	1	0
1810	1	1	1	1	0	0	1	0
1835	1	1	0	1	0	1	1	0
1850	1	1	1	0	1	1	1	1
1852	1	0	0	0	0	1	0	0
1865	1	1	1	0	0	0	0	0
1878	1	1	1	0	0	1	1	0
1880	1	0	0	1	0	1	1	0
1892	0	0	0	1	0	1	0	0
1895	0	0	0	0	0	0	1	0
1898	1	1	1	0	0	0	0	0
1905	1	0	1	0	0	0	1	0
1915	1	1	1	0	0	1	0	0
1925	1	1	1	0	1	0	1	0
1950	1	0	0	0	0	0	0	0
1972	1	1	1	0	0	1	1	0
1977	1	1	1	0	0	1	1	0
1985	1	1	0	0	0	1	0	0
1995	1	0	0	0	0	1	0	0
2005	1	1	0	0	0	1	0	0
2007	1	1	1	0	0	0	0	0
2010	1	1	0	0	0	0	0	0
2012	1	0	0	0	0	0	0	0
2013	1	0	0	0	0	1	0	0
2014	1	0	0	0	0	1	0	0

	Marks Tey (borehole 1A) all species 2 input															
Depth (cm)	**Be**	**Pisy**	**Abal**	**Piab**	**Ul**	**Qud**	**Ti**	**Frex**	**Al**	**Ac**	**Cabe**	**Taba**	**Coav**	**San**	**Hirh**	**Juco**
1060	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1
1100	1	1	1	1	1	1	1	0	1	0	1	1	1	0	0	0
1155	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	0
1205	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
1225	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0
1265	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
1325	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
1355	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
1385	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
1415	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1450	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1480	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
1510	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0
1520	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0
1530	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0
1538	1	1	0	1	1	1	1	1	1	0	1	1	1	0	0	0
1550	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	0
1560	1	1	0	1	1	1	1	1	1	1	0	1	1	0	0	0
1570	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0
1600	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0
1630	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	0
1660	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0
1690	1	1	0	1	1	1	1	1	1	1	0	1	1	0	0	0
1700	1	1	0	1	1	1	1	0	1	0	0	1	1	1	0	0
1710	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0
1725	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	1
1730	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0	0
1745	1	1	0	1	1	1	1	1	1	0	0	0	1	0	0	0
1750	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0	1
1765	1	1	0	1	1	1	0	1	1	0	0	0	1	0	0	0
1775	1	1	0	1	1	1	0	1	1	0	0	0	1	1	0	1
1780	1	1	1	0	1	1	1	0	1	1	0	0	1	0	1	0
1785	1	1	0	1	1	1	0	0	1	1	0	0	1	1	0	1
1795	1	1	0	0	1	1	0	1	0	1	0	0	1	1	0	0
1800	1	1	0	0	1	1	1	0	0	1	0	0	1	1	0	0
1805	1	1	0	0	1	1	1	0	0	1	0	0	0	1	0	0
1810	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	1
1835	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1
1850	1	1	0	1	0	1	0	0	0	1	0	0	0	1	1	1
1852	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
1865	1	1	0	1	1	1	0	0	0	0	0	0	0	0	1	0
1878	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0
1880	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1
1892	1	1	0	0	1	1	0	0	1	0	0	0	0	1	0	0
1895	1	1	0	0	1	1	1	0	1	1	0	0	1	1	0	1
1898	1	1	0	0	1	1	0	0	1	0	0	0	1	1	0	0
1905	1	1	0	0	1	1	0	0	0	1	0	0	0	0	0	1
1915	1	1	0	1	1	1	0	0	1	1	0	0	1	0	0	0
1925	1	1	0	0	0	1	0	0	1	1	0	0	0	1	1	1
1950	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1
1972	1	1	0	1	1	0	0	0	1	1	0	0	0	1	1	0
1977	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1985	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0
1995	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1
2005	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0
2007	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0
2010	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1
2012	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1
2013	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0
2014	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1

	Marks Tey (borehole 1A) all species 2 input													
Depth (cm)	**Hehe**	**Ilaq**	**Vial**	**Visy**	**Eueu**	**Viop**	**Arma**	**Cavu**	**Emni**	**Plme**	**Poav**	**Ruac**	**Thmi**	**Urdi**
1060	1	0	0	1	0	0	0	0	1	0	0	0	0	0
1100	0	0	0	0	0	0	0	1	1	0	0	0	0	0
1155	1	1	0	1	0	0	0	1	0	0	0	0	0	0
1205	0	1	0	0	0	0	0	0	0	0	0	1	1	0
1225	1	1	0	0	0	0	0	0	1	0	0	0	0	0
1265	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1325	1	1	0	0	0	0	0	0	1	0	0	0	0	0
1355	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1385	1	1	0	0	0	0	0	1	1	0	0	0	0	0
1415	1	1	0	0	0	0	0	0	1	0	0	0	0	0
1450	1	1	0	0	0	0	0	1	1	0	0	0	1	0
1480	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1510	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1520	1	1	0	0	0	0	0	1	1	0	0	0	0	0
1530	1	1	1	0	0	0	0	0	0	0	0	1	0	0
1538	1	1	0	0	0	1	0	1	0	0	0	0	0	1
1550	1	0	0	0	0	1	0	0	0	1	0	0	0	0
1560	1	1	0	0	0	0	0	0	0	0	0	0	0	1
1570	1	1	0	0	0	0	0	1	0	0	0	0	0	1
1600	1	1	0	0	0	0	0	0	0	0	0	0	0	1
1630	1	1	0	0	0	0	0	1	0	0	0	0	1	0
1660	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1690	1	1	0	0	0	0	0	0	1	0	0	0	0	0
1700	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1710	1	1	0	0	0	1	0	0	0	0	0	0	0	0
1725	1	1	0	0	0	0	0	0	0	0	0	0	0	1
1730	1	1	0	0	0	0	0	0	0	0	0	0	0	1
1745	1	0	0	0	0	0	0	0	0	0	0	1	0	0
1750	1	0	0	0	0	1	0	0	0	0	0	0	0	0
1765	1	0	0	0	0	1	0	0	0	0	0	0	0	0
1775	0	0	0	0	1	0	0	0	0	0	0	0	1	0
1780	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1785	0	0	0	0	0	0	0	0	0	1	0	0	1	0
1795	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1800	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1805	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1810	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1835	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1850	0	0	0	0	0	0	0	0	0	0	0	1	1	0
1852	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1865	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1878	0	0	0	0	0	0	1	0	0	1	0	0	0	0
1880	1	0	0	0	0	0	0	0	0	0	0	0	1	0
1892	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1895	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1898	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1905	1	0	0	0	0	0	0	0	0	1	0	0	1	0
1915	1	0	0	0	0	0	0	0	0	1	0	0	1	0
1925	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1950	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1972	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1977	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1985	0	0	0	0	0	0	0	0	0	1	0	0	1	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2010	0	0	0	0	0	0	0	0	0	0	1	0	1	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2013	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	1	0	0	0	0

	Marks Tey (borehole 1A) all species 2 input							
Depth (cm)	**Clma**	**Chpo**	**Motr**	**Fi**	**Lyeu**	**Rafl**	**Ruca**	**Gapa**
1060	1	0	0	0	0	0	1	0
1100	0	0	0	0	0	0	1	0
1155	1	0	1	0	0	0	1	0
1205	1	0	0	0	0	0	1	1
1225	1	0	1	0	0	0	1	0
1265	0	0	0	0	0	1	1	0
1325	0	0	0	0	0	0	1	0
1355	0	0	1	1	0	0	0	0
1385	1	1	1	0	0	0	1	0
1415	1	1	1	0	0	0	0	0
1450	0	0	0	0	0	1	0	0
1480	1	0	0	1	0	0	0	0
1510	0	1	1	0	0	0	0	0
1520	0	0	1	0	0	0	1	0
1530	1	0	1	0	1	0	0	1
1538	0	0	1	0	0	1	1	0
1550	1	0	0	0	0	1	1	0
1560	1	0	1	1	0	1	1	0
1570	1	1	1	0	0	1	0	0
1600	0	0	0	0	0	1	1	0
1630	0	1	1	0	0	1	0	0
1660	1	0	1	0	0	0	1	0
1690	0	0	1	0	1	1	0	0
1700	1	1	0	0	0	0	1	0
1710	1	0	1	0	0	1	1	0
1725	1	1	1	0	0	0	0	0
1730	1	0	1	0	0	0	0	0
1745	1	1	1	0	0	0	0	1
1750	1	0	1	1	0	0	1	0
1765	0	0	1	0	0	1	1	0
1775	1	1	1	0	0	1	1	0
1780	1	0	1	0	0	0	0	0
1785	1	0	1	0	0	0	0	0
1795	1	0	1	1	0	1	0	0
1800	1	0	1	0	0	1	1	0
1805	0	0	0	0	0	1	1	0
1810	1	1	1	1	0	0	1	0
1835	1	1	0	1	0	1	1	0
1850	1	1	1	0	1	1	1	1
1852	1	0	0	0	0	1	0	0
1865	1	1	1	0	0	0	0	0
1878	1	1	1	0	0	1	1	0
1880	1	0	0	1	0	1	1	0
1892	0	0	0	1	0	1	0	0
1895	0	0	0	0	0	0	1	0
1898	1	1	1	0	0	0	0	0
1905	1	0	1	0	0	0	1	0
1915	1	1	1	0	0	1	0	0
1925	1	1	1	0	1	0	1	0
1950	1	0	0	0	0	0	0	0
1972	1	1	1	0	0	1	1	0
1977	1	1	1	0	0	1	1	0
1985	1	1	0	0	0	1	0	0
1995	1	0	0	0	0	1	0	0
2005	1	1	0	0	0	1	0	0
2007	1	1	1	0	0	0	0	0
2010	1	1	0	0	0	0	0	0
2012	1	0	0	0	0	0	0	0
2013	1	0	0	0	0	1	0	0
2014	1	0	0	0	0	1	0	0

	Marks Tey (borehole III) all species 1 input													
Depth (cm)	**Be**	**Pisy**	**Abal**	**Piab**	**Ul**	**Qud**	**Ti**	**Frex**	**Al**	**Ac**	**Cabe**	**Pte**	**Taba**	**Coav**
100	1	1	1	1	0	0	0	0	1	0	0	0	0	0
153	1	1	1	0	0	0	0	0	1	0	0	0	0	1
175	1	1	1	1	0	0	0	0	0	0	0	0	0	0
200	1	1	1	1	0	0	0	0	1	0	0	1	0	0
225	1	1	1	1	0	1	0	0	1	0	1	0	0	0
250	1	1	1	1	0	0	0	0	1	0	0	0	0	1
275	1	1	1	1	1	1	0	0	1	0	1	0	0	0
300	1	1	1	1	0	0	0	0	1	0	0	0	0	0
325	1	1	1	1	1	0	0	0	1	0	0	0	0	1
345	1	1	1	1	1	1	0	0	1	1	1	0	0	1
370	1	1	1	1	0	0	0	0	1	0	0	0	0	1
385	1	1	1	1	0	1	0	0	1	0	1	1	0	0
400	1	1	1	1	1	1	0	0	1	1	1	0	0	1
415	1	1	1	1	1	1	0	1	1	0	1	1	0	1
430	1	1	1	1	1	1	0	1	1	0	0	1	0	1
450	1	1	1	1	1	1	0	1	1	0	0	1	0	1
470	1	1	1	1	1	1	0	1	1	0	0	1	0	1
490	1	1	1	1	0	0	0	0	1	0	0	1	0	0
505	1	1	1	1	0	1	0	0	1	0	0	1	0	1
525	1	1	1	1	0	1	0	0	1	0	0	1	0	1
555	1	1	1	1	1	1	1	1	1	0	0	1	1	1
605	1	1	1	1	1	1	1	0	1	0	1	1	1	1
655	1	1	1	1	1	1	1	1	1	1	1	0	1	1
685	1	1	1	1	1	1	1	1	1	0	1	0	1	1
	Marks Tey (borehole III) all species 1 input													
Depth (cm)	**San**	**Juco**	**Hehe**	**Ilaq**	**Buse**	**Fral**	**Visy**	**Cavu**	**Emni**	**Plme**	**Poav**	**Ruac**	**Clma**	
100	0	0	0	0	0	0	0	0	1	0	0	0	0	
153	0	0	0	0	0	0	0	1	1	0	1	0	0	
175	0	0	0	0	0	0	0	1	1	1	0	0	1	
200	0	0	0	0	0	0	0	1	1	0	0	0	1	
225	0	0	0	0	0	0	0	1	1	0	0	0	1	
250	0	0	0	0	0	0	0	1	1	0	0	0	1	
275	0	0	0	0	0	0	0	1	1	0	1	0	1	
300	0	0	0	0	0	0	0	1	1	0	0	0	1	
325	1	0	0	0	0	0	0	1	1	1	0	1	1	
345	0	0	0	0	0	0	0	1	1	1	1	0	1	
370	0	0	0	0	0	0	0	1	1	0	0	0	1	
385	0	0	0	0	0	0	0	1	1	0	0	0	1	
400	0	0	0	0	1	0	0	1	1	0	0	0	1	
415	1	0	1	0	0	0	0	1	1	0	0	0	1	
430	0	0	0	0	0	0	0	1	1	0	0	0	1	
450	1	0	0	0	0	0	0	1	1	0	0	0	1	
470	1	0	1	0	0	0	0	1	1	0	0	0	1	
490	0	0	0	0	0	0	0	1	1	0	0	0	1	
505	0	1	0	0	1	1	0	1	1	0	0	0	1	
525	0	0	0	0	0	0	0	1	1	0	0	0	1	
555	0	0	0	1	0	0	0	1	1	0	0	0	0	
605	0	0	1	1	1	0	0	1	1	0	0	0	0	
655	0	0	1	1	1	0	0	1	1	0	0	0	1	
685	1	1	1	0	1	0	1	0	1	0	0	0	1	
	Marks Tey (borehole III) all species 1 input													
Depth (cm)	**Arma**	**Chpo**	**PocaEU**	**Motr**	**Fi**	**Rafl**	**Ruca**	**Gapa**	**Thmi**					
100	0	0	0	1	0	1	0	0	0					
153	0	1	0	1	0	1	0	0	0					
175	0	1	0	1	1	1	0	0	1					
200	1	1	0	1	1	1	0	1	1					
225	0	1	0	1	1	1	0	0	0					
250	0	1	0	1	1	1	0	1	1					
275	0	1	0	1	1	1	0	1	1					
300	0	0	1	1	1	1	0	0	1					
325	0	0	0	0	0	1	0	1	1					
345	0	0	0	1	0	1	0	0	1					
370	0	0	0	0	0	1	0	0	0					
385	0	0	0	0	0	0	0	0	0					
400	0	1	0	1	0	1	0	0	1					
415	0	1	0	1	1	1	0	0	1					
430	0	1	0	1	0	1	0	0	0					
450	0	1	0	1	0	1	0	1	0					
470	0	0	0	1	1	1	0	1	1					
490	0	0	0	1	0	0	0	0	0					
505	0	1	0	1	1	0	0	1	1					
525	0	0	0	1	0	0	0	1	1					
555	0	0	0	0	0	0	1	0	0					
605	0	1	0	1	0	1	1	0	0					
655	0	1	0	0	0	0	1	0	0					
685	0	0	0	0	0	0	0	0	0					

	Marks Tey (borehole III) all species 2 input												
Depth (cm)	**Be**	**Pisy**	**Abal**	**Piab**	**Ul**	**Qud**	**Ti**	**Frex**	**Al**	**Ac**	**Cabe**	**Pte**	**Taba**
100	1	1	1	1	0	0	0	0	1	0	0	0	0
153	1	1	1	0	0	0	0	0	1	0	0	0	0
175	1	1	1	1	0	0	0	0	0	0	0	0	0
200	1	1	1	1	0	0	0	0	1	0	0	1	0
225	1	1	1	1	0	1	0	0	1	0	1	0	0
250	1	1	1	1	0	0	0	0	1	0	0	0	0
275	1	1	1	1	1	1	0	0	1	0	1	0	0
300	1	1	1	1	0	0	0	0	1	0	0	0	0
325	1	1	1	1	1	0	0	0	1	0	0	0	0
345	1	1	1	1	1	1	0	0	1	1	1	0	0
370	1	1	1	1	0	0	0	0	1	0	0	0	0
385	1	1	1	1	0	1	0	0	1	0	1	1	0
400	1	1	1	1	1	1	0	0	1	1	1	0	0
415	1	1	1	1	1	1	0	1	1	0	1	1	0
430	1	1	1	1	1	1	0	1	1	0	0	1	0
450	1	1	1	1	1	1	0	1	1	0	0	1	0
470	1	1	1	1	1	1	0	1	1	0	0	1	0
490	1	1	1	1	0	0	0	0	1	0	0	1	0
505	1	1	1	1	0	1	0	0	1	0	0	1	0
525	1	1	1	1	0	1	0	0	1	0	0	1	0
555	1	1	1	1	1	1	1	1	1	0	0	1	1
605	1	1	1	1	1	1	1	0	1	0	1	1	1
655	1	1	1	1	1	1	1	1	1	1	1	0	1
685	1	1	1	1	1	1	1	1	1	0	1	0	1
	Marks Tey (borehole III) all species 2 input												
Depth (cm)	**Coav**	**San**	**Juco**	**Hehe**	**Ilaq**	**Buse**	**Fral**	**Visy**	**Cavu**	**Emni**	**Plme**	**Poav**	
100	0	0	0	0	0	0	0	0	0	1	0	0	
153	1	0	0	0	0	0	0	0	1	1	0	1	
175	0	0	0	0	0	0	0	0	1	1	1	0	
200	0	0	0	0	0	0	0	0	1	1	0	0	
225	0	0	0	0	0	0	0	0	1	1	0	0	
250	1	0	0	0	0	0	0	0	1	1	0	0	
275	0	0	0	0	0	0	0	0	1	1	0	1	
300	0	0	0	0	0	0	0	0	1	1	0	0	
325	1	1	0	0	0	0	0	0	1	1	1	0	
345	1	0	0	0	0	0	0	0	1	1	1	1	
370	1	0	0	0	0	0	0	0	1	1	0	0	
385	0	0	0	0	0	0	0	0	1	1	0	0	
400	1	0	0	0	0	1	0	0	1	1	0	0	
415	1	1	0	1	0	0	0	0	1	1	0	0	
430	1	0	0	0	0	0	0	0	1	1	0	0	
450	1	1	0	0	0	0	0	0	1	1	0	0	
470	1	1	0	1	0	0	0	0	1	1	0	0	
490	0	0	0	0	0	0	0	0	1	1	0	0	
505	1	0	1	0	0	1	1	0	1	1	0	0	
525	1	0	0	0	0	0	0	0	1	1	0	0	
555	1	0	0	0	1	0	0	0	1	1	0	0	
605	1	0	0	1	1	1	0	0	1	1	0	0	
655	1	0	0	1	1	1	0	0	1	1	0	0	
685	1	1	1	1	0	1	0	1	0	1	0	0	
	Marks Tey (borehole III) all species 2 input												
Depth (cm)	**Ruac**	**Clma**	**Arma**	**Chpo**	**PocaEU**	**Stho**	**Fi**	**Rafl**	**Crmo**	**Gapa**	**Thmi**		
100	0	0	0	0	0	1	0	1	0	0	0		
153	0	0	0	1	0	1	0	1	0	0	0		
175	0	1	0	1	0	1	1	1	0	0	1		
200	0	1	1	1	0	1	1	1	0	1	1		
225	0	1	0	1	0	1	1	1	0	0	0		
250	0	1	0	1	0	1	1	1	0	1	1		
275	0	1	0	1	0	1	1	1	0	1	1		
300	0	1	0	0	1	1	1	1	0	0	1		
325	1	1	0	0	0	0	0	1	0	1	1		
345	0	1	0	0	0	1	0	1	0	0	1		
370	0	1	0	0	0	0	0	1	0	0	0		
385	0	1	0	0	0	0	0	0	0	0	0		
400	0	1	0	1	0	1	0	1	0	0	1		
415	0	1	0	1	0	1	1	1	0	0	1		
430	0	1	0	1	0	1	0	1	0	0	0		
450	0	1	0	1	0	1	0	1	0	1	0		
470	0	1	0	0	0	1	1	1	0	1	1		
490	0	1	0	0	0	1	0	0	0	0	0		
505	0	1	0	1	0	1	1	0	0	1	1		
525	0	1	0	0	0	1	0	0	0	1	1		
555	0	0	0	0	0	0	0	0	1	0	0		
605	0	0	0	1	0	1	0	1	1	0	0		
655	0	1	0	1	0	0	0	0	1	0	0		
685	0	1	0	0	0	0	0	0	0	0	0		

	Nechells all species 1 input														
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Frex**	**Tico**	**Al**	**Taba**	**Piab**	**Abal**	**Ac**	**Cabe**	**Coav**	**Hirh**	**Buse**
238	1	1	0	1	0	0	1	1	1	0	0	0	1	0	0
244	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0
250	1	1	0	1	0	1	1	0	1	1	0	0	1	0	0
274	1	1	1	1	0	0	1	0	1	1	0	0	1	0	0
290	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
299	1	1	0	1	0	1	1	1	1	1	0	0	1	0	0
305	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0
335	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0
351	1	1	1	1	0	0	1	1	1	1	0	0	1	0	0
366	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
375	1	1	1	1	0	0	1	1	1	1	0	0	1	0	0
381	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
390	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
396	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
405	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0
411	1	1	1	1	0	1	1	1	1	1	1	0	1	0	0
421	1	1	1	1	0	1	1	1	1	1	0	1	1	0	0
436	1	1	1	1	0	1	1	1	1	0	1	1	1	0	0
451	1	1	0	1	0	1	1	1	1	0	1	1	1	0	0
457	1	1	1	1	0	1	1	1	1	1	1	1	1	0	0
472	1	1	1	1	0	1	1	1	1	0	1	1	1	0	0
488	1	1	1	1	0	1	1	1	1	1	1	0	1	0	0
503	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0
518	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0
527	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
777	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
786	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
792	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
805	1	1	1	1	0	1	1	1	1	0	0	0	1	0	0
811	1	1	1	1	0	1	1	1	1	0	0	0	1	0	0
817	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
838	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
847	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
853	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
869	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
878	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
884	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
893	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
908	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
924	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
930	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
945	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
960	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
975	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
991	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
1006	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
1030	1	1	1	1	1	1	1	1	1	0	0	0	1	0	1
1033	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
1042	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
1052	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
1067	1	1	1	1	1	1	1	0	1	0	0	0	1	0	0
1082	1	1	1	1	0	1	1	1	0	0	0	0	1	0	0
1091	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1097	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1103	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1113	1	1	0	1	1	1	1	0	0	0	0	0	1	0	0
1122	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1128	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1143	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1158	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1167	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1173	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1180	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1189	1	1	1	1	1	1	1	0	0	0	0	0	1	0	0
1204	1	1	0	1	1	0	1	0	0	0	0	0	1	0	0
1219	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1234	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1250	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1265	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1280	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1295	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1311	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1326	1	1	1	1	1	0	1	0	0	0	0	0	0	1	0
1341	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0
1356	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1372	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0
1387	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0
1402	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0
1417	1	1	0	1	1	0	1	0	0	0	0	0	0	1	0

	Nechells all species 1 input														
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Frex**	**Tico**	**Al**	**Taba**	**Piab**	**Abal**	**Ac**	**Cabe**	**Coav**	**Hirh**	**Buse**
1426	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0
1433	1	1	1	1	0	1	1	0	0	0	0	0	0	1	0
1448	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0
1463	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0
1478	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0
1494	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
1509	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1515	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0
1524	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0
1530	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0
1539	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0
1548	1	1	0	0	0	1	1	0	0	0	0	0	0	1	0
1551	1	1	0	1	0	0	1	0	0	0	0	0	0	1	0
1554	1	1	0	1	0	1	0	0	0	0	0	0	0	1	0
1558	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0
1564	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0
1573	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0

	Nechells all species 1 input													
Depth (cm)	**Vial**	**Juco**	**San**	**Hehe**	**Ilaq**	**Sam**	**Arma**	**Emni**	**Fi**	**Epdi**	**Clma**	**Cavu**	**Motr**	**Chpo**
238	0	0	0	1	0	0	0	1	1	0	1	1	0	0
244	0	0	1	0	1	0	0	1	0	0	1	1	0	0
250	0	0	1	0	0	0	0	1	0	0	1	1	0	0
274	0	1	1	0	0	0	0	1	0	0	1	1	1	0
290	0	0	1	0	0	0	0	1	1	0	1	0	1	0
299	0	0	0	0	0	0	0	0	0	0	1	0	0	0
305	0	0	0	1	1	0	0	0	0	0	1	1	0	0
335	0	0	1	1	1	0	0	0	0	0	1	1	0	0
351	0	0	1	1	0	0	0	0	0	0	1	0	0	0
366	0	0	1	0	0	0	0	0	0	0	1	0	0	0
375	0	0	1	1	0	0	0	0	0	0	1	0	0	0
381	0	0	1	0	0	0	0	0	0	0	1	0	0	0
390	0	0	1	0	0	0	0	0	1	0	1	0	0	0
396	0	0	1	1	0	0	0	0	0	0	1	0	1	0
405	0	0	0	1	1	0	0	0	0	0	1	0	0	0
411	0	0	1	1	0	0	0	0	0	0	1	0	1	0
421	0	0	0	1	1	0	0	0	1	0	1	0	0	0
436	1	0	0	1	1	0	0	0	1	0	1	0	0	0
451	0	0	0	1	1	1	0	0	0	0	1	0	0	0
457	0	0	0	0	0	0	0	0	0	0	1	0	1	0
472	0	0	0	1	1	1	0	0	1	0	1	0	1	0
488	1	0	0	1	1	1	0	0	1	0	1	0	1	0
503	0	0	0	1	1	1	0	0	0	0	1	0	0	0
518	0	0	0	0	0	1	0	0	0	0	1	0	0	0
527	0	0	0	1	1	1	0	0	0	0	1	0	1	0
777	0	0	0	0	0	1	0	0	1	0	1	0	0	0
786	0	0	0	0	1	1	0	0	0	0	1	0	1	0
792	0	0	0	1	1	1	0	0	1	0	1	0	0	0
805	0	0	0	1	1	1	0	0	0	0	1	0	0	0
811	0	0	0	1	1	1	0	0	0	0	1	0	0	0
817	0	0	0	0	1	1	0	0	1	0	1	0	1	0
838	0	0	0	1	1	1	0	0	1	0	1	0	1	0
847	0	0	0	1	0	1	0	0	0	0	1	0	1	0
853	0	0	0	1	1	1	0	0	0	0	0	0	1	0
869	0	0	0	1	1	1	0	0	0	0	1	0	0	0
878	0	0	0	1	1	1	0	0	0	0	1	0	0	0
884	0	0	0	1	1	1	0	0	0	0	1	0	1	0
893	0	0	0	1	1	0	0	0	0	0	1	0	0	0
908	0	0	0	1	1	1	0	0	0	0	1	0	0	0
924	0	0	0	1	1	0	0	0	0	0	1	0	1	0
930	0	0	0	0	1	0	0	0	1	0	1	0	1	0
945	0	0	0	0	0	0	0	0	1	0	1	0	0	0
960	0	0	0	1	1	0	0	0	0	0	1	0	0	0
975	0	0	0	0	1	0	0	0	0	0	1	0	0	0
991	0	0	0	0	1	0	0	0	0	0	1	0	0	0
1006	0	0	0	0	0	0	0	0	0	0	1	0	0	0
1030	1	0	0	1	1	0	0	0	0	0	1	0	0	0
1033	0	0	0	1	1	0	1	0	1	0	1	0	1	0
1042	0	0	0	1	1	0	0	0	1	0	1	0	0	0
1052	0	0	0	1	1	0	0	0	1	0	1	0	0	0
1067	0	0	0	1	1	0	0	0	0	0	1	0	0	0
1082	0	0	0	1	1	0	0	0	1	0	1	0	0	0
1091	0	0	0	1	1	0	0	0	0	0	1	0	0	0
1097	0	0	0	1	1	0	0	0	1	0	1	0	0	0
1103	0	0	0	1	1	0	0	0	0	0	1	0	0	0
1113	0	0	0	1	1	0	1	0	0	0	1	0	1	0
1122	0	0	0	1	1	0	0	0	0	0	1	0	1	0
1128	0	0	0	1	1	0	0	0	0	0	1	0	1	0
1143	0	0	1	1	1	0	0	0	1	0	1	0	1	0
1158	0	0	1	1	0	0	0	0	1	0	1	0	1	0
1167	0	1	1	1	0	0	0	0	1	0	1	0	0	0
1173	0	1	1	1	0	0	0	0	1	0	1	0	1	0
1180	0	0	1	1	0	0	0	0	1	0	1	0	0	0
1189	0	1	1	1	1	0	0	0	1	0	1	0	1	0
1204	0	1	1	1	0	0	1	0	1	1	1	0	1	0
1219	0	0	1	1	1	0	1	0	1	0	1	0	1	0
1234	0	0	1	1	0	0	0	0	1	0	1	0	0	0
1250	0	0	0	1	0	0	0	0	0	0	1	0	1	0
1265	0	0	1	1	0	0	1	0	1	0	1	0	1	0
1280	0	0	1	1	0	0	1	0	1	0	1	0	1	0
1295	0	0	1	1	0	0	1	0	1	0	1	0	1	0
1311	0	0	1	0	0	0	1	0	0	0	1	0	0	0
1326	0	0	1	0	0	0	1	0	1	0	1	0	1	0
1341	0	1	1	0	0	0	1	0	1	0	1	0	0	0
1356	0	1	1	0	0	0	1	0	1	0	1	0	1	0
1372	0	0	1	0	0	0	0	0	1	0	1	0	1	0
1387	0	1	1	0	0	0	0	0	1	0	1	0	1	0
1402	0	1	1	1	0	0	0	0	1	0	1	0	1	0
1417	0	1	1	0	0	0	0	0	1	0	1	0	1	1

	Nechells all species 1 input													
Depth (cm)	**Vial**	**Juco**	**San**	**Hehe**	**Ilaq**	**Sam**	**Arma**	**Emni**	**Fi**	**Epdi**	**Clma**	**Cavu**	**Motr**	**Chpo**
1426	0	1	1	0	0	0	0	0	1	0	1	0	1	1
1433	0	1	1	0	0	0	1	0	1	0	1	0	1	1
1448	0	1	1	0	0	0	0	0	1	0	1	0	1	0
1463	0	1	1	0	0	0	0	0	1	0	1	0	1	0
1478	0	1	1	0	0	0	1	0	0	0	1	0	1	0
1494	0	1	1	0	0	0	1	0	1	0	1	0	1	1
1509	0	1	1	0	0	0	0	0	1	0	1	0	1	0
1515	0	1	1	0	0	0	1	0	1	0	1	0	1	0
1524	0	1	1	0	0	0	1	0	1	0	1	0	1	0
1530	0	1	1	0	0	0	0	0	0	0	1	0	1	0
1539	0	1	1	0	0	0	0	0	1	0	1	0	1	0
1548	0	1	1	0	0	0	0	0	0	0	1	0	1	0
1551	0	1	0	0	0	0	0	0	1	0	1	0	1	0
1554	0	1	1	0	0	0	0	0	1	0	1	0	0	0
1558	0	1	0	0	0	0	0	0	0	0	1	0	0	0
1564	0	1	0	0	0	0	0	0	0	0	1	0	0	0
1573	0	0	0	0	0	0	0	0	0	0	1	0	0	0

	Nechells all species 1 input						
Depth (cm)	**Lyeu**	**Plla**	**Rafl**	**Ruca**	**Gapa**	**Ruac**	**Thmi**
238	1	0	0	0	0	0	0
244	0	0	0	1	0	0	0
250	1	0	0	1	0	0	0
274	0	0	0	1	0	0	0
290	0	0	0	0	0	0	0
299	1	0	0	0	0	0	0
305	1	0	1	0	0	0	0
335	0	0	1	1	0	0	0
351	1	0	0	1	0	0	0
366	1	0	0	1	0	0	0
375	1	0	0	1	0	0	0
381	1	0	0	1	0	0	0
390	0	0	0	1	0	0	0
396	1	0	1	1	0	0	0
405	1	0	0	1	0	0	0
411	0	0	0	0	0	0	0
421	1	0	0	1	0	0	0
436	1	0	0	1	0	0	0
451	1	0	0	0	0	0	0
457	0	0	0	1	0	0	0
472	1	0	1	1	0	0	1
488	1	0	0	0	0	0	0
503	1	0	0	1	0	0	0
518	1	0	0	1	0	0	0
527	1	0	1	1	0	0	0
777	1	0	0	1	0	0	0
786	1	0	0	0	0	0	0
792	1	0	0	1	0	0	0
805	1	0	1	0	0	0	0
811	1	0	0	0	0	0	0
817	1	0	1	0	0	0	0
838	1	0	0	0	0	0	0
847	1	0	1	1	0	0	0
853	1	0	0	0	0	0	0
869	1	0	1	0	1	0	0
878	1	0	0	1	0	0	0
884	1	0	0	0	0	0	0
893	1	0	0	0	0	0	0
908	0	0	0	0	1	0	0
924	1	0	1	0	0	0	0
930	0	0	0	0	0	0	0
945	1	0	0	0	0	0	0
960	1	0	0	0	0	0	0
975	1	0	1	0	0	0	0
991	1	0	1	0	0	0	0
1006	1	0	0	0	0	0	0
1030	1	0	0	0	0	0	0
1033	1	0	1	0	1	0	0
1042	1	0	0	1	1	0	0
1052	1	0	1	0	0	0	0
1067	1	0	1	0	0	0	0
1082	1	0	0	0	0	0	0
1091	1	0	1	0	0	0	0
1097	1	0	0	0	0	0	0
1103	1	0	1	0	0	0	0
1113	1	0	1	0	0	0	1
1122	1	0	1	0	0	0	0
1128	1	0	0	0	1	0	0
1143	1	0	1	0	1	0	0
1158	1	1	1	0	0	0	1
1167	1	0	1	0	1	0	0
1173	0	1	1	1	1	0	0
1180	1	0	1	0	0	0	0
1189	0	0	1	0	0	0	0
1204	0	1	1	1	1	0	0
1219	0	0	1	0	1	0	0
1234	0	0	1	0	1	0	0
1250	0	0	1	1	1	0	1
1265	0	1	0	0	0	0	0
1280	0	0	1	0	0	0	0
1295	0	0	1	0	1	0	0
1311	0	0	1	1	1	0	1
1326	0	1	0	1	0	0	0
1341	0	1	1	1	0	1	0
1356	0	1	1	1	1	0	0
1372	0	0	1	0	0	0	0
1387	0	1	1	0	0	0	1
1402	0	1	1	1	0	0	0
1417	0	1	1	0	1	0	1

	Nechells all species 1 input						
Depth (cm)	Lyeu	Plla	Rafl	Ruca	Gapa	Ruac	Thmi
1426	0	1	1	1	0	1	1
1433	0	0	1	1	0	0	1
1448	0	0	1	1	1	0	1
1463	0	0	1	0	1	0	0
1478	0	0	1	0	1	1	0
1494	0	0	1	1	1	1	1
1509	0	0	1	0	1	0	1
1515	0	0	1	1	1	0	1
1524	0	1	1	1	0	0	1
1530	0	1	1	1	1	0	1
1539	0	0	1	0	0	0	1
1548	0	1	0	0	1	0	1
1551	0	0	0	0	1	0	1
1554	0	0	0	0	1	1	0
1558	0	0	0	0	1	1	0
1564	0	0	0	0	1	1	0
1573	0	1	0	0	0	0	0

	Nechells all species 2 input														
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Frex**	**Tico**	**Al**	**Taba**	**Piab**	**Abal**	**Ac**	**Cabe**	**Coav**	**Hirh**	**Buse**
238	1	1	0	1	0	0	1	1	1	0	0	0	1	0	0
244	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0
250	1	1	0	1	0	1	1	0	1	1	0	0	1	0	0
274	1	1	1	1	0	0	1	0	1	1	0	0	1	0	0
290	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
299	1	1	0	1	0	1	1	1	1	1	0	0	1	0	0
305	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0
335	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0
351	1	1	1	1	0	0	1	1	1	1	0	0	1	0	0
366	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
375	1	1	1	1	0	0	1	1	1	1	0	0	1	0	0
381	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
390	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
396	1	1	0	1	0	0	1	1	1	1	0	0	1	0	0
405	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0
411	1	1	1	1	0	1	1	1	1	1	1	0	1	0	0
421	1	1	1	1	0	1	1	1	1	1	0	1	1	0	0
436	1	1	1	1	0	1	1	1	1	0	1	1	1	0	0
451	1	1	0	1	0	1	1	1	1	0	1	1	1	0	0
457	1	1	1	1	0	1	1	1	1	1	1	1	1	0	0
472	1	1	1	1	0	1	1	1	1	0	1	1	1	0	0
488	1	1	1	1	0	1	1	1	1	1	1	0	1	0	0
503	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0
518	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0
527	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
777	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
786	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
792	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
805	1	1	1	1	0	1	1	1	1	0	0	0	1	0	0
811	1	1	1	1	0	1	1	1	1	0	0	0	1	0	0
817	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
838	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
847	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
853	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
869	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
878	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
884	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
893	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
908	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
924	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
930	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
945	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
960	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
975	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
991	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0
1006	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
1030	1	1	1	1	1	1	1	1	1	0	0	0	1	0	1
1033	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
1042	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
1052	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
1067	1	1	1	1	1	1	1	0	1	0	0	0	1	0	0
1082	1	1	1	1	0	1	1	1	0	0	0	0	1	0	0
1091	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1097	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1103	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1113	1	1	0	1	1	1	1	0	0	0	0	0	1	0	0
1122	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1128	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1143	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1158	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1167	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1173	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1180	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1189	1	1	1	1	1	1	1	0	0	0	0	0	1	0	0
1204	1	1	0	1	1	0	1	0	0	0	0	0	1	0	0
1219	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1234	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1250	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1265	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1280	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1295	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1311	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1326	1	1	1	1	1	0	1	0	0	0	0	0	0	1	0
1341	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0
1356	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0
1372	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0
1387	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0
1402	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0
1417	1	1	0	1	1	0	1	0	0	0	0	0	0	1	0

	Nechells all species 2 input														
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Frex**	**Tico**	**Al**	**Taba**	**Piab**	**Abal**	**Ac**	**Cabe**	**Coav**	**Hirh**	**Buse**
1426	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0
1433	1	1	1	1	0	1	1	0	0	0	0	0	0	1	0
1448	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0
1463	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0
1478	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0
1494	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
1509	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1515	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0
1524	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0
1530	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0
1539	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0
1548	1	1	0	0	0	1	1	0	0	0	0	0	0	1	0
1551	1	1	0	1	0	0	1	0	0	0	0	0	0	1	0
1554	1	1	0	1	0	1	0	0	0	0	0	0	0	1	0
1558	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0
1564	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0
1573	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0

	Nechells all species 2 input													
Depth (cm)	**Vial**	**Juco**	**San**	**Hehe**	**Ilaq**	**Sam**	**Arma**	**Emni**	**Fi**	**Epdi**	**Clma**	**Cavu**	**Stho**	**Chpo**
238	0	0	0	1	0	0	0	1	1	0	1	1	0	0
244	0	0	1	0	1	0	0	1	0	0	1	1	0	0
250	0	0	1	0	0	0	0	1	0	0	1	1	0	0
274	0	1	1	0	0	0	0	1	0	0	1	1	1	0
290	0	0	1	0	0	0	0	1	1	0	1	0	1	0
299	0	0	0	0	0	0	0	0	0	0	1	0	0	0
305	0	0	0	1	1	0	0	0	0	0	1	1	0	0
335	0	0	1	1	1	0	0	0	0	0	1	1	0	0
351	0	0	1	1	0	0	0	0	0	0	1	0	0	0
366	0	0	1	0	0	0	0	0	0	0	1	0	0	0
375	0	0	1	1	0	0	0	0	0	0	1	0	0	0
381	0	0	1	0	0	0	0	0	0	0	1	0	0	0
390	0	0	1	0	0	0	0	0	1	0	1	0	0	0
396	0	0	1	1	0	0	0	0	0	0	1	0	1	0
405	0	0	0	1	1	0	0	0	0	0	1	0	0	0
411	0	0	1	1	0	0	0	0	0	0	1	0	1	0
421	0	0	0	1	1	0	0	0	1	0	1	0	0	0
436	1	0	0	1	1	0	0	0	1	0	1	0	0	0
451	0	0	0	1	1	1	0	0	0	0	1	0	0	0
457	0	0	0	0	0	0	0	0	0	0	1	0	1	0
472	0	0	0	1	1	1	0	0	1	0	1	0	1	0
488	1	0	0	1	1	1	0	0	1	0	1	0	1	0
503	0	0	0	1	1	1	0	0	0	0	1	0	0	0
518	0	0	0	0	0	1	0	0	0	0	1	0	0	0
527	0	0	0	1	1	1	0	0	0	0	1	0	1	0
777	0	0	0	0	0	1	0	0	1	0	1	0	0	0
786	0	0	0	0	1	1	0	0	0	0	1	0	1	0
792	0	0	0	1	1	1	0	0	1	0	1	0	0	0
805	0	0	0	1	1	1	0	0	0	0	1	0	0	0
811	0	0	0	1	1	1	0	0	0	0	1	0	0	0
817	0	0	0	0	1	1	0	0	1	0	1	0	1	0
838	0	0	0	1	1	1	0	0	1	0	1	0	1	0
847	0	0	0	1	0	1	0	0	0	0	1	0	1	0
853	0	0	0	1	1	1	0	0	0	0	0	0	1	0
869	0	0	0	1	1	1	0	0	0	0	1	0	0	0
878	0	0	0	1	1	1	0	0	0	0	1	0	0	0
884	0	0	0	1	1	1	0	0	0	0	1	0	1	0
893	0	0	0	1	1	0	0	0	0	0	1	0	0	0
908	0	0	0	1	1	1	0	0	0	0	1	0	0	0
924	0	0	0	1	1	0	0	0	0	0	1	0	1	0
930	0	0	0	0	1	0	0	0	1	0	1	0	1	0
945	0	0	0	0	0	0	0	0	1	0	1	0	0	0
960	0	0	0	1	1	0	0	0	0	0	1	0	0	0
975	0	0	0	0	1	0	0	0	0	0	1	0	0	0
991	0	0	0	0	1	0	0	0	0	0	1	0	0	0
1006	0	0	0	0	0	0	0	0	0	0	1	0	0	0
1030	1	0	0	1	1	0	0	0	0	0	1	0	0	0
1033	0	0	0	1	1	0	1	0	1	0	1	0	1	0
1042	0	0	0	1	1	0	0	0	1	0	1	0	0	0
1052	0	0	0	1	1	0	0	0	1	0	1	0	0	0
1067	0	0	0	1	1	0	0	0	0	0	1	0	0	0
1082	0	0	0	1	1	0	0	0	1	0	1	0	0	0
1091	0	0	0	1	1	0	0	0	0	0	1	0	0	0
1097	0	0	0	1	1	0	0	0	1	0	1	0	0	0
1103	0	0	0	1	1	0	0	0	0	0	1	0	0	0
1113	0	0	0	1	1	0	1	0	0	0	1	0	1	0
1122	0	0	0	1	1	0	0	0	0	0	1	0	1	0
1128	0	0	0	1	1	0	0	0	0	0	1	0	1	0
1143	0	0	1	1	1	0	0	0	1	0	1	0	1	0
1158	0	0	1	1	0	0	0	0	1	0	1	0	1	0
1167	0	1	1	1	0	0	0	0	1	0	1	0	0	0
1173	0	1	1	1	0	0	0	0	1	0	1	0	1	0
1180	0	0	1	1	0	0	0	0	1	0	1	0	0	0
1189	0	1	1	1	1	0	0	0	1	0	1	0	1	0
1204	0	1	1	1	0	0	1	0	1	1	1	0	1	0
1219	0	0	1	1	1	0	1	0	1	0	1	0	1	0
1234	0	0	1	1	0	0	0	0	1	0	1	0	0	0
1250	0	0	0	1	0	0	0	0	0	0	1	0	1	0
1265	0	0	1	1	0	0	1	0	1	0	1	0	1	0
1280	0	0	1	1	0	0	1	0	1	0	1	0	1	0
1295	0	0	1	1	0	0	1	0	1	0	1	0	1	0
1311	0	0	1	0	0	0	1	0	0	0	1	0	0	0
1326	0	0	1	0	0	0	1	0	1	0	1	0	1	0
1341	0	1	1	0	0	0	1	0	1	0	1	0	0	0
1356	0	1	1	0	0	0	1	0	1	0	1	0	1	0
1372	0	0	1	0	0	0	0	0	1	0	1	0	1	0
1387	0	1	1	0	0	0	0	0	1	0	1	0	1	0
1402	0	1	1	1	0	0	0	0	1	0	1	0	1	0
1417	0	1	1	0	0	0	0	0	1	0	1	0	1	1

	Nechells all species 2 input													
Depth (cm)	**Vial**	**Juco**	**San**	**Hehe**	**Ilaq**	**Sam**	**Arma**	**Emni**	**Fi**	**Epdi**	**Clma**	**Cavu**	**Stho**	**Chpo**
1426	0	1	1	0	0	0	0	0	1	0	1	0	1	1
1433	0	1	1	0	0	0	1	0	1	0	1	0	1	1
1448	0	1	1	0	0	0	0	0	1	0	1	0	1	0
1463	0	1	1	0	0	0	0	0	1	0	1	0	1	0
1478	0	1	1	0	0	0	1	0	0	0	1	0	1	0
1494	0	1	1	0	0	0	1	0	1	0	1	0	1	1
1509	0	1	1	0	0	0	0	0	1	0	1	0	1	0
1515	0	1	1	0	0	0	1	0	1	0	1	0	1	0
1524	0	1	1	0	0	0	1	0	1	0	1	0	1	0
1530	0	1	1	0	0	0	0	0	0	0	1	0	1	0
1539	0	1	1	0	0	0	0	0	1	0	1	0	1	0
1548	0	1	1	0	0	0	0	0	0	0	1	0	1	0
1551	0	1	0	0	0	0	0	0	1	0	1	0	1	0
1554	0	1	1	0	0	0	0	0	1	0	1	0	0	0
1558	0	1	0	0	0	0	0	0	0	0	1	0	0	0
1564	0	1	0	0	0	0	0	0	0	0	1	0	0	0
1573	0	0	0	0	0	0	0	0	0	0	1	0	0	0

	Nechells all species 2 input						
Depth (cm)	**Tesc**	**Plla**	**Rafl**	**Crmo**	**Gapa**	**Ruac**	**Thmi**
238	1	0	0	0	0	0	0
244	0	0	0	1	0	0	0
250	1	0	0	1	0	0	0
274	0	0	0	1	0	0	0
290	0	0	0	0	0	0	0
299	1	0	0	0	0	0	0
305	1	0	1	0	0	0	0
335	0	0	1	1	0	0	0
351	1	0	0	1	0	0	0
366	1	0	0	1	0	0	0
375	1	0	0	1	0	0	0
381	1	0	0	1	0	0	0
390	0	0	0	1	0	0	0
396	1	0	1	1	0	0	0
405	1	0	0	1	0	0	0
411	0	0	0	0	0	0	0
421	1	0	0	1	0	0	0
436	1	0	0	1	0	0	0
451	1	0	0	0	0	0	0
457	0	0	0	1	0	0	0
472	1	0	1	1	0	0	1
488	1	0	0	0	0	0	0
503	1	0	0	1	0	0	0
518	1	0	0	1	0	0	0
527	1	0	1	1	0	0	0
777	1	0	0	1	0	0	0
786	1	0	0	0	0	0	0
792	1	0	0	1	0	0	0
805	1	0	1	0	0	0	0
811	1	0	0	0	0	0	0
817	1	0	1	0	0	0	0
838	1	0	0	0	0	0	0
847	1	0	1	1	0	0	0
853	1	0	0	0	0	0	0
869	1	0	1	0	1	0	0
878	1	0	0	1	0	0	0
884	1	0	0	0	0	0	0
893	1	0	0	0	0	0	0
908	0	0	0	0	1	0	0
924	1	0	1	0	0	0	0
930	0	0	0	0	0	0	0
945	1	0	0	0	0	0	0
960	1	0	0	0	0	0	0
975	1	0	1	0	0	0	0
991	1	0	1	0	0	0	0
1006	1	0	0	0	0	0	0
1030	1	0	0	0	0	0	0
1033	1	0	1	0	1	0	0
1042	1	0	0	1	1	0	0
1052	1	0	1	0	0	0	0
1067	1	0	1	0	0	0	0
1082	1	0	0	0	0	0	0
1091	1	0	1	0	0	0	0
1097	1	0	0	0	0	0	0
1103	1	0	1	0	0	0	0
1113	1	0	1	0	0	0	1
1122	1	0	1	0	0	0	0
1128	1	0	0	0	1	0	0
1143	1	0	1	0	1	0	0
1158	1	1	1	0	0	0	1
1167	1	0	1	0	1	0	0
1173	0	1	1	1	1	0	0
1180	1	0	1	0	0	0	0
1189	0	0	1	0	0	0	0
1204	0	1	1	1	1	0	0
1219	0	0	1	0	1	0	0
1234	0	0	1	0	1	0	0
1250	0	0	1	1	1	0	1
1265	0	1	0	0	0	0	0
1280	0	0	1	0	0	0	0
1295	0	0	1	0	1	0	0
1311	0	0	1	1	1	0	1
1326	0	1	0	1	0	0	0
1341	0	1	1	1	0	1	0
1356	0	1	1	1	1	0	0
1372	0	0	1	0	0	0	0
1387	0	1	1	0	0	0	1
1402	0	1	1	1	0	0	0
1417	0	1	1	0	1	0	1

	Nechells all species 2 input						
Depth (cm)	**Tesc**	**Plla**	**Rafl**	**Crmo**	**Gapa**	**Ruac**	**Thmi**
1426	0	1	1	1	0	1	1
1433	0	0	1	1	0	0	1
1448	0	0	1	1	1	0	1
1463	0	0	1	0	1	0	0
1478	0	0	1	0	1	1	0
1494	0	0	1	1	1	1	1
1509	0	0	1	0	1	0	1
1515	0	0	1	1	1	0	1
1524	0	1	1	1	0	0	1
1530	0	1	1	1	1	0	1
1539	0	0	1	0	0	0	1
1548	0	1	0	0	1	0	1
1551	0	0	0	0	1	0	1
1554	0	0	0	0	1	1	0
1558	0	0	0	0	1	1	0
1564	0	0	0	0	1	1	0
1573	0	1	0	0	0	0	0

	St Cross South Elmham all species 1 input												
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Cabe**	**Frex**	**Ac**	**Abal**	**Piab**	**Taba**	**Pte**
245	1	1	1	1	1	1	1	1	1	1	1	1	0
260	1	1	1	1	1	1	1	0	1	0	1	1	0
275	1	1	1	1	1	1	1	0	0	0	1	1	0
295	1	1	1	1	1	1	1	0	1	0	1	1	0
310	1	1	1	1	1	1	1	1	1	0	1	1	0
315	1	1	1	1	1	1	1	0	1	0	1	1	0
320	1	1	1	1	1	1	1	1	1	0	1	1	1
330	1	1	1	1	1	1	1	0	1	0	1	1	1
345	1	1	1	1	1	1	1	0	1	0	1	1	0
350	1	1	1	1	1	1	1	1	1	0	1	1	0
360	1	1	1	1	1	1	1	1	0	0	1	1	0
375	1	1	1	1	1	1	1	0	1	0	1	1	0
390	1	1	1	1	1	1	1	0	0	0	1	1	0
400	1	1	1	1	1	1	1	0	1	0	1	1	0
500	1	1	1	1	1	1	1	0	1	1	1	1	0
600	1	1	1	1	1	1	0	0	1	1	1	1	0
700	1	1	1	1	1	1	1	0	1	0	1	1	0
750	1	1	1	1	1	1	0	0	1	0	1	1	0
800	1	1	1	1	1	1	0	0	0	0	1	1	0
850	1	1	1	1	1	1	0	1	0	0	1	1	0
955	1	1	1	1	1	1	0	0	0	0	1	0	0
1050	1	1	0	0	0	0	0	0	1	0	1	0	0
	St Cross South Elmham all species 1 input												
Depth (cm)	**Coav**	**Sam**	**Juco**	**Hirh**	**Hehe**	**Ilaq**	**Vila**	**Plla**	**Clma**	**Motr**	**Chpo**		
245	1	0	0	0	1	1	1	0	0	1	1		
260	1	1	0	0	1	1	0	0	1	1	0		
275	1	0	0	0	1	1	0	0	1	0	0		
295	1	0	0	0	1	1	1	0	0	0	0		
310	1	1	0	0	1	1	0	0	1	0	0		
315	1	1	1	0	1	1	1	0	1	0	0		
320	1	1	0	0	1	1	1	0	1	1	0		
330	1	0	0	0	1	1	0	0	0	0	0		
345	1	0	0	0	0	1	0	0	0	1	0		
350	1	0	0	0	1	0	0	0	1	0	0		
360	1	1	1	0	1	0	0	1	1	1	0		
375	1	1	1	0	0	0	0	1	1	0	0		
390	1	1	0	0	1	1	0	1	1	1	0		
400	1	0	0	0	1	1	0	0	0	1	0		
500	1	0	1	0	1	1	0	0	1	1	0		
600	1	0	0	0	1	1	0	0	1	0	1		
700	0	0	0	0	1	1	0	0	1	1	0		
750	1	0	1	0	1	1	0	0	0	0	0		
800	1	0	1	0	1	1	0	0	1	0	0		
850	1	1	1	0	1	1	0	0	1	1	1		
955	0	1	1	1	0	0	0	0	1	0	1		
1050	0	1	1	1	0	0	0	1	1	1	1		
	St Cross South Elmham all species 1 input												
Depth (cm)	**Fi**	**Sasc**	**Plme**	**Rafl**	**Ruca**	**Gapa**	**Ruac**	**Thmi**	**Urdi**				
245	0	0	0	1	1	0	0	0	1				
260	0	0	0	0	1	0	0	0	0				
275	0	0	0	1	0	0	0	0	0				
295	0	0	0	1	0	0	1	0	0				
310	0	0	0	1	0	0	0	0	1				
315	0	0	0	1	0	0	0	0	0				
320	0	0	0	1	1	0	0	1	0				
330	0	0	0	0	1	0	0	0	0				
345	1	0	0	1	1	0	0	0	1				
350	1	0	0	1	1	0	0	0	0				
360	1	1	1	1	1	1	0	1	1				
375	1	1	1	0	0	0	1	0	1				
390	0	1	1	0	0	1	1	0	0				
400	0	0	0	0	0	0	1	1	0				
500	0	0	0	1	1	0	0	0	1				
600	1	0	0	1	0	1	1	0	1				
700	1	0	0	1	1	0	0	0	0				
750	0	0	0	1	1	0	0	0	0				
800	0	0	0	1	1	0	0	1	0				
850	1	0	0	1	1	0	0	0	1				
955	1	0	0	0	0	0	0	0	1				
1050	0	0	1	0	0	0	1	1	0				

	St Cross South Elmham all species 2 input												
Depth (cm)	Be	Pisy	Ul	Qud	Ti	Al	Cabe	Frex	Ac	Abal	Piab	Taba	Pte
245	1	1	1	1	1	1	1	1	1	1	1	1	0
260	1	1	1	1	1	1	1	0	1	0	1	1	0
275	1	1	1	1	1	1	1	0	0	0	1	1	0
295	1	1	1	1	1	1	1	0	1	0	1	1	0
310	1	1	1	1	1	1	1	1	1	0	1	1	0
315	1	1	1	1	1	1	1	0	1	0	1	1	0
320	1	1	1	1	1	1	1	1	1	0	1	1	1
330	1	1	1	1	1	1	1	0	1	0	1	1	1
345	1	1	1	1	1	1	1	0	1	0	1	1	0
350	1	1	1	1	1	1	1	1	1	0	1	1	0
360	1	1	1	1	1	1	1	1	0	0	1	1	0
375	1	1	1	1	1	1	1	0	1	0	1	1	0
390	1	1	1	1	1	1	1	0	0	0	1	1	0
400	1	1	1	1	1	1	1	0	1	0	1	1	0
500	1	1	1	1	1	1	1	0	1	1	1	1	0
600	1	1	1	1	1	1	0	0	1	1	1	1	0
700	1	1	1	1	1	1	1	0	1	0	1	1	0
750	1	1	1	1	1	1	0	0	1	0	1	1	0
800	1	1	1	1	1	1	0	0	0	0	1	1	0
850	1	1	1	1	1	1	0	1	0	0	1	1	0
955	1	1	1	1	1	1	0	0	0	0	1	0	0
1050	1	1	0	0	0	0	0	0	1	0	1	0	0
	St Cross South Elmham all species 2 input												
Depth (cm)	Coav	Sam	Juco	Hirh	Hehe	Ilaq	Viop	Plla	Clma	Stho	Chpo		
245	1	0	0	0	1	1	1	0	0	1	1		
260	1	1	0	0	1	1	0	0	1	1	0		
275	1	0	0	0	1	1	0	0	1	0	0		
295	1	0	0	0	1	1	1	0	0	0	0		
310	1	1	0	0	1	1	0	0	1	0	0		
315	1	1	1	0	1	1	1	0	1	0	0		
320	1	1	0	0	1	1	1	0	1	1	0		
330	1	0	0	0	1	1	0	0	0	0	0		
345	1	0	0	0	0	1	0	0	0	1	0		
350	1	0	0	0	1	0	0	0	1	0	0		
360	1	1	1	0	1	0	0	1	1	1	0		
375	1	1	1	0	0	0	0	1	1	0	0		
390	1	1	0	0	1	1	0	1	1	1	0		
400	1	0	0	0	1	1	0	0	0	1	0		
500	1	0	1	0	1	1	0	0	1	1	0		
600	1	0	0	0	1	1	0	0	1	0	1		
700	0	0	0	0	1	1	0	0	1	1	0		
750	1	0	1	0	1	1	0	0	0	0	0		
800	1	0	1	0	1	1	0	0	1	0	0		
850	1	1	1	0	1	1	0	0	1	1	1		
955	0	1	1	1	0	0	0	0	1	0	1		
1050	0	1	1	1	0	0	0	1	1	1	1		
	St Cross South Elmham all species 2 input												
Depth (cm)	Fi	Sasc	Plmj	Rafl	Crmo	Gapa	Ruac	Thmi	Urdi				
245	0	0	0	1	1	0	0	0	1				
260	0	0	0	0	1	0	0	0	0				
275	0	0	0	1	0	0	0	0	0				
295	0	0	0	1	0	0	1	0	0				
310	0	0	0	1	0	0	0	0	1				
315	0	0	0	1	0	0	0	0	0				
320	0	0	0	1	1	0	0	1	0				
330	0	0	0	0	1	0	0	0	0				
345	1	0	0	1	1	0	0	0	1				
350	1	0	0	1	1	0	0	0	0				
360	1	1	1	1	1	1	0	1	1				
375	1	1	1	0	0	0	1	0	1				
390	0	1	1	0	0	1	1	0	0				
400	0	0	0	0	0	0	1	1	0				
500	0	0	0	1	1	0	0	0	1				
600	1	0	0	1	0	1	1	0	1				
700	1	0	0	1	1	0	0	0	0				
750	0	0	0	1	1	0	0	0	0				
800	0	0	0	1	1	0	0	1	0				
850	1	0	0	1	1	0	0	0	1				
955	1	0	0	0	0	0	0	0	1				
1050	0	0	1	0	0	0	1	1	0				

Sensitivity testing for taxonomic precision

	Hoxne (main sequence) aggregate														
Depth (cm)	**Be**	**Pinn**	**Ul**	**Qud**	**Ti**	**Al**	**Fasy**	**Cabe**	**Frex**	**Ac**	**Abal**	**Piab**	**Taba**	**Sam**	**Coav**
180	0	1	1	1	1	1	0	0	0	0	1	1	0	0	1
192	1	1	1	1	1	1	0	0	0	0	1	1	0	0	1
260	0	1	0	1	1	1	0	0	1	0	0	0	0	0	1
272	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1
279	1	1	1	1	1	1	0	0	0	0	0	1	0	1	1
288	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1
296	1	1	1	1	1	1	0	0	1	1	0	1	0	0	1
310	1	1	1	1	1	1	1	0	1	0	0	1	0	0	1
320	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1
326	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1
334	1	1	1	1	1	1	0	0	1	1	1	1	0	0	1
342	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1
356	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1
384	0	1	1	1	1	1	0	0	1	1	0	1	0	0	1
392	0	1	1	1	1	1	1	0	1	0	0	1	0	0	1
408	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1
416	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1
432	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1
444	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1
464	1	1	1	1	1	1	0	1	1	0	0	0	1	0	1
480	0	1	1	1	1	1	0	1	1	0	0	1	1	0	1
496	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1
512	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1
528	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1
544	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1
556	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1
576	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1
592	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1
637	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1
648	1	1	0	1	1	1	0	0	1	0	0	1	0	0	1
656	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1
672	1	1	1	1	1	1	0	0	1	0	0	1	1	0	1
682	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1
692	1	1	1	1	1	1	0	0	0	0	0	0	1	0	1
706	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1
720	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1
746	1	1	1	1	1	1	0	1	0	0	0	1	0	0	1
760	1	1	0	1	1	1	0	0	1	0	0	1	0	0	1
776	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1
784	1	1	1	1	1	1	1	0	1	0	0	1	0	0	1
794	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1
801	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1
808	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1
816	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1
824	1	1	1	1	1	0	0	1	0	0	0	0	0	0	1

	Hoxne (main sequence) aggregate					
Depth (cm)	**San**	**Hirh**	**Hehe**	**Ilaq**	**Emni**	**Fi**
180	1	0	1	0	0	0
192	0	0	0	0	0	0
260	1	0	0	0	1	0
272	0	0	1	0	0	0
279	0	0	0	1	1	0
288	0	1	1	0	0	0
296	0	0	0	1	0	0
310	0	0	0	0	0	0
320	0	0	1	1	0	1
326	0	0	0	1	0	0
334	0	0	1	1	0	0
342	0	0	1	0	1	0
356	0	0	1	1	0	0
384	0	0	1	1	1	0
392	0	0	0	1	1	0
408	0	0	0	1	1	0
416	0	0	1	0	1	0
432	0	0	0	1	0	0
444	0	0	0	1	1	0
464	0	0	1	1	0	0
480	0	0	1	1	0	0
496	0	0	1	1	0	0
512	0	0	1	1	1	0
528	0	0	1	1	1	0
544	0	0	1	1	0	0
556	0	0	1	1	1	0
576	0	0	1	1	1	0
592	0	0	1	0	1	0
637	0	0	1	1	1	0
648	0	0	1	1	0	0
656	0	0	1	0	1	0
672	0	0	1	0	0	0
682	0	0	1	0	0	0
692	0	0	1	0	1	0
706	0	0	1	0	0	0
720	0	1	0	0	1	0
746	0	1	1	0	1	1
760	0	0	1	0	1	0
776	0	1	1	0	0	0
784	0	1	1	0	0	0
794	0	1	1	0	0	0
801	0	0	0	0	0	0
808	0	0	1	0	1	0
816	0	1	0	0	0	0
824	0	1	0	1	0	1

	Hoxne (main sequence) separate species (pen, rob, ul)																
Depth (cm)	Bepe	Pisy	Ulgl	Quro	Tico	Algl	Fasy	Cabe	Frex	Acca	Abal	Piab	Taba	Sani	Coav	Saca	Hirh
180	0	1	1	1	1	1	0	0	0	0	1	1	0	0	1	1	0
192	1	1	1	1	1	1	0	0	0	0	1	1	0	0	1	0	0
260	0	1	0	1	1	1	0	0	1	0	0	0	0	0	1	1	0
272	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0	0
279	1	1	1	1	1	1	0	0	0	0	0	1	0	1	1	0	0
288	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	0	1
296	1	1	1	1	1	1	0	0	1	1	0	1	0	0	1	0	0
310	1	1	1	1	1	1	1	0	1	0	0	1	0	0	1	0	0
320	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0
326	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0
334	1	1	1	1	1	1	0	0	1	1	1	1	0	0	1	0	0
342	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0
356	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0
384	0	1	1	1	1	1	0	0	1	1	0	1	0	0	1	0	0
392	0	1	1	1	1	1	1	0	1	0	0	1	0	0	1	0	0
408	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0
416	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0
432	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	0	0
444	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0
464	1	1	1	1	1	1	0	1	1	0	0	0	1	0	1	0	0
480	0	1	1	1	1	1	0	1	1	0	0	1	1	0	1	0	0
496	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0
512	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0
528	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0
544	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0
556	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0
576	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0
592	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0	0
637	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0
648	1	1	0	1	1	1	0	0	1	0	0	1	0	0	1	0	0
656	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	0	0
672	1	1	1	1	1	1	0	0	1	0	0	1	1	0	1	0	0
682	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	0
692	1	1	1	1	1	1	0	0	0	0	0	0	1	0	1	0	0
706	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0	0
720	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1	0	1
746	1	1	1	1	1	1	0	1	0	0	0	1	0	0	1	0	1
760	1	1	0	1	1	1	0	0	1	0	0	1	0	0	1	0	0
776	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	0	1
784	1	1	1	1	1	1	1	0	1	0	0	1	0	0	1	0	1
794	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	0	1
801	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0	0
808	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0
816	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	1
824	1	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0	1

	Hoxne (main sequence) separate species (pen, rob, ul)					
Depth (cm)	Hehe	Ilaq	Emni	Fiul		
180	1	0	0	0		
192	0	0	0	0		
260	0	0	1	0		
272	1	0	0	0		
279	0	1	1	0		
288	1	0	0	0		
296	0	1	0	0		
310	0	0	0	0		
320	1	1	0	1		
326	0	1	0	0		
334	1	1	0	0		
342	1	0	1	0		
356	1	1	0	0		
384	1	1	1	0		
392	0	1	1	0		
408	0	1	1	0		
416	1	0	1	0		
432	0	1	0	0		
444	0	1	1	0		
464	1	1	0	0		
480	1	1	0	0		
496	1	1	0	0		
512	1	1	1	0		
528	1	1	1	0		
544	1	1	0	0		
556	1	1	1	0		
576	1	1	1	0		
592	1	0	1	0		
637	1	1	1	0		
648	1	1	0	0		
656	1	0	1	0		
672	1	0	0	0		
682	1	0	0	0		
692	1	0	1	0		
706	1	0	0	0		
720	0	0	1	0		
746	1	0	1	1		
760	1	0	1	0		
776	1	0	0	0		
784	1	0	0	0		
794	1	0	0	0		
801	0	0	0	0		
808	1	0	1	0		
816	0	0	0	0		
824	0	1	0	1		

	Hoxne (main sequence) separate species (pub, pub, vu)													
Depth (cm)	**Bepu**	**Pisy**	**Ulgl**	**Qupu**	**Tico**	**Algl**	**Fasy**	**Cabe**	**Frex**	**Acca**	**Abal**	**Piab**	**Taba**	**Sani**
180	0	1	1	1	1	1	0	0	0	0	1	1	0	0
192	1	1	1	1	1	1	0	0	0	0	1	1	0	0
260	0	1	0	1	1	1	0	0	1	0	0	0	0	0
272	1	1	1	1	0	1	0	0	0	0	0	1	0	0
279	1	1	1	1	1	1	0	0	0	0	0	1	0	1
288	1	1	1	1	1	1	0	1	1	0	0	1	0	0
296	1	1	1	1	1	1	0	0	1	1	0	1	0	0
310	1	1	1	1	1	1	1	0	1	0	0	1	0	0
320	1	1	1	1	1	1	0	0	1	0	0	1	0	0
326	1	1	1	1	1	1	0	0	1	0	0	1	0	0
334	1	1	1	1	1	1	0	0	1	1	1	1	0	0
342	1	1	1	1	1	1	0	0	1	0	0	1	0	0
356	0	1	1	1	1	1	0	0	1	0	0	1	0	0
384	0	1	1	1	1	1	0	0	1	1	0	1	0	0
392	0	1	1	1	1	1	1	0	1	0	0	1	0	0
408	0	1	1	1	1	1	0	0	1	0	0	1	0	0
416	0	1	1	1	1	1	0	0	1	0	0	1	0	0
432	1	1	1	1	1	1	0	1	1	0	0	1	0	0
444	0	1	1	1	1	1	0	0	1	0	0	1	0	0
464	1	1	1	1	1	1	0	1	1	0	0	0	1	0
480	0	1	1	1	1	1	0	1	1	0	0	1	1	0
496	1	1	1	1	1	1	0	0	1	0	0	1	0	0
512	1	1	1	1	1	1	0	0	1	0	0	1	0	0
528	1	1	1	1	1	1	0	0	0	0	0	0	0	0
544	1	1	1	1	1	1	0	0	0	0	0	0	0	0
556	1	1	1	1	1	1	0	0	1	0	0	1	0	0
576	1	1	1	1	1	1	0	0	1	0	0	1	0	0
592	1	1	1	1	1	1	0	0	0	0	0	1	0	0
637	1	1	1	1	1	1	0	0	1	0	0	1	0	0
648	1	1	0	1	1	1	0	0	1	0	0	1	0	0
656	1	1	1	1	1	1	0	1	1	0	0	1	0	0
672	1	1	1	1	1	1	0	0	1	0	0	1	1	0
682	1	1	1	1	1	1	0	0	1	0	0	1	0	0
692	1	1	1	1	1	1	0	0	0	0	0	0	1	0
706	1	1	1	1	1	1	0	0	0	0	0	1	0	0
720	1	1	1	1	1	1	0	0	1	0	0	1	0	0
746	1	1	1	1	1	1	0	1	0	0	0	1	0	0
760	1	1	0	1	1	1	0	0	1	0	0	1	0	0
776	1	1	1	1	1	1	0	0	1	0	0	0	0	0
784	1	1	1	1	1	1	1	0	1	0	0	1	0	0
794	1	1	1	1	1	1	0	0	1	0	0	0	0	0
801	1	1	1	1	1	1	0	0	0	0	0	1	0	0
808	1	1	1	1	1	0	0	0	0	0	0	0	0	0
816	1	1	1	1	1	0	0	0	0	0	0	0	0	0
824	1	1	1	1	1	0	0	1	0	0	0	0	0	0

	Hoxne (main sequence) separate species (pub, pub, vu)							
Depth (cm)	**Coav**	**Saca**	**Hirh**	**Hehe**	**Ilaq**	**Emni**	**Fivu**	
180	1	1	0	1	0	0	0	
192	1	0	0	0	0	0	0	
260	1	1	0	0	0	1	0	
272	1	0	0	1	0	0	0	
279	1	0	0	0	1	1	0	
288	1	0	1	1	0	0	0	
296	1	0	0	0	1	0	0	
310	1	0	0	0	0	0	0	
320	1	0	0	1	1	0	1	
326	1	0	0	0	1	0	0	
334	1	0	0	1	1	0	0	
342	1	0	0	1	0	1	0	
356	1	0	0	1	1	0	0	
384	1	0	0	1	1	1	0	
392	1	0	0	0	1	1	0	
408	1	0	0	0	1	1	0	
416	1	0	0	1	0	1	0	
432	1	0	0	0	1	0	0	
444	1	0	0	0	1	1	0	
464	1	0	0	1	1	0	0	
480	1	0	0	1	1	0	0	
496	1	0	0	1	1	0	0	
512	1	0	0	1	1	1	0	
528	1	0	0	1	1	1	0	
544	1	0	0	1	1	0	0	
556	1	0	0	1	1	1	0	
576	1	0	0	1	1	1	0	
592	1	0	0	1	0	1	0	
637	1	0	0	1	1	1	0	
648	1	0	0	1	1	0	0	
656	1	0	0	1	0	1	0	
672	1	0	0	1	0	0	0	
682	1	0	0	1	0	0	0	
692	1	0	0	1	0	1	0	
706	1	0	0	1	0	0	0	
720	1	0	1	0	0	1	0	
746	1	0	1	1	0	1	1	
760	1	0	0	1	0	1	0	
776	1	0	1	1	0	0	0	
784	1	0	1	1	0	0	0	
794	1	0	1	1	0	0	0	
801	1	0	0	0	0	0	0	
808	1	0	0	1	0	1	0	
816	1	0	1	0	0	0	0	
824	1	0	1	0	1	0	1	

	Marks Tey (Borehole 1A) aggregate																		
Depth (cm)	**Be**	**Pinn**	**Abal**	**Piab**	**Ul**	**Qud**	**Ti**	**Frex**	**Al**	**Acca**	**Cabe**	**Taba**	**Coav**	**San**	**Hirh**	**Juco**	**Hehe**	**Ilaq**	**Vial**
1060	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0
1100	1	1	1	1	1	1	1	0	1	0	1	1	1	0	0	0	0	0	0
1155	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	0
1205	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0
1225	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	1	1	0
1265	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1325	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1355	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1385	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1415	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0
1450	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0
1480	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1510	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	1	1	0
1520	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1	1	0
1530	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1
1538	1	1	0	1	1	1	1	1	1	0	1	1	1	0	0	0	1	1	0
1550	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	0	1	0	0
1560	1	1	0	1	1	1	1	1	1	1	0	1	1	0	0	0	1	1	0
1570	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1	1	0
1600	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1	1	0
1630	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	0	1	1	0
1660	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	1	1	0
1690	1	1	0	1	1	1	1	1	1	1	0	1	1	0	0	0	1	1	0
1700	1	1	0	1	1	1	1	0	1	0	0	1	1	1	0	0	1	1	0
1710	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1	1	0
1725	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	0
1730	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	0
1745	1	1	0	1	1	1	1	1	1	0	0	0	1	0	0	0	1	0	0
1750	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0	1	1	0	0
1765	1	1	0	1	1	1	0	1	1	0	0	0	1	0	0	0	1	0	0
1775	1	1	0	1	1	1	0	1	1	0	0	0	1	1	0	1	0	0	0
1780	1	1	1	0	1	1	1	0	1	1	0	0	1	0	1	0	0	0	0
1785	1	1	0	1	1	1	0	0	1	1	0	0	1	1	0	1	0	0	0
1795	1	1	0	0	1	1	0	1	0	1	0	0	1	1	0	0	1	0	0
1800	1	1	0	0	1	1	1	0	0	1	0	0	1	1	0	0	0	0	0
1805	1	1	0	0	1	1	1	0	0	1	0	0	0	1	0	0	0	0	0
1810	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	1	0	0	0
1835	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0
1850	1	1	0	1	0	1	0	0	0	1	0	0	0	1	1	1	0	0	0
1852	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
1865	1	1	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0
1878	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0
1880	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0
1892	1	1	0	0	1	1	0	0	1	0	0	0	0	1	0	0	1	0	0
1895	1	1	0	0	1	1	1	0	1	1	0	0	1	1	0	1	1	0	0
1898	1	1	0	0	1	1	0	0	1	0	0	0	1	1	0	0	0	0	0
1905	1	1	0	0	1	1	0	0	0	1	0	0	0	0	0	1	1	0	0
1915	1	1	0	1	1	1	0	0	1	1	0	0	1	0	0	0	1	0	0
1925	1	1	0	0	0	1	0	0	1	1	0	0	0	1	1	1	0	0	0
1950	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0
1972	1	1	0	1	1	0	0	0	1	1	0	0	0	1	1	0	0	0	0
1977	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1985	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
1995	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
2005	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0
2007	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2010	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
2012	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
2013	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2014	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0

	Marks Tey (Borehole 1A) aggregate					
Depth (cm)	**Eueu**	**Arma**	**Cavu**	**Emni**	**Plme**	**Fi**
1060	0	0	0	1	0	0
1100	0	0	1	1	0	0
1155	0	0	1	0	0	0
1205	0	0	0	0	0	0
1225	0	0	0	1	0	0
1265	0	0	0	0	0	0
1325	0	0	0	1	0	0
1355	0	0	0	0	0	1
1385	0	0	1	1	0	0
1415	0	0	0	1	0	0
1450	0	0	1	1	0	0
1480	0	0	0	0	0	1
1510	0	0	0	0	0	0
1520	0	0	1	1	0	0
1530	0	0	0	0	0	0
1538	0	0	1	0	0	0
1550	0	0	0	0	1	0
1560	0	0	0	0	0	1
1570	0	0	1	0	0	0
1600	0	0	0	0	0	0
1630	0	0	1	0	0	0
1660	0	0	0	0	0	0
1690	0	0	0	1	0	0
1700	0	0	0	0	0	0
1710	0	0	0	0	0	0
1725	0	0	0	0	0	0
1730	0	0	0	0	0	0
1745	0	0	0	0	0	0
1750	0	0	0	0	0	1
1765	0	0	0	0	0	0
1775	1	0	0	0	0	0
1780	0	0	0	0	0	0
1785	0	0	0	0	1	0
1795	0	0	0	0	0	1
1800	0	0	0	0	0	0
1805	0	0	0	0	0	0
1810	0	0	0	0	1	1
1835	0	0	0	0	0	1
1850	0	0	0	0	0	0
1852	0	0	0	0	0	0
1865	0	0	0	0	0	0
1878	0	1	0	0	1	0
1880	0	0	0	0	0	1
1892	0	0	0	0	0	1
1895	0	0	0	0	0	0
1898	0	0	1	0	0	0
1905	0	0	0	0	1	0
1915	0	0	0	0	1	0
1925	0	0	0	0	0	0
1950	0	0	0	0	0	0
1972	0	0	0	0	0	0
1977	0	0	0	0	0	0
1985	0	0	0	0	1	0
1995	0	0	0	0	0	0
2005	0	0	0	0	0	0
2007	0	0	0	0	0	0
2010	0	0	0	0	0	0
2012	0	0	0	0	0	0
2013	0	0	0	0	0	0
2014	0	0	0	0	1	0

	Marks Tey (borehole 1A) separate species (pen, rob, ul)																
Depth (cm)	**Bepe**	**Pisy**	**Abal**	**Piab**	**Ulgl**	**Quro**	**Tico**	**Frex**	**Algl**	**Acca**	**Cabe**	**Taba**	**Coav**	**Saca**	**Hirh**	**Juco**	**Hehe**
1060	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1
1100	1	1	1	1	1	1	1	0	1	0	1	1	1	0	0	0	0
1155	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	0	1
1205	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
1225	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	1
1265	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1
1325	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1
1355	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1
1385	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1
1415	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1
1450	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1
1480	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1
1510	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	1
1520	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1
1530	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0	1
1538	1	1	0	1	1	1	1	1	1	0	1	1	1	0	0	0	1
1550	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	0	1
1560	1	1	0	1	1	1	1	1	1	1	0	1	1	0	0	0	1
1570	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1
1600	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1
1630	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	0	1
1660	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	1
1690	1	1	0	1	1	1	1	1	1	1	0	1	1	0	0	0	1
1700	1	1	0	1	1	1	1	0	1	0	0	1	1	1	0	0	1
1710	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1
1725	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	1	1
1730	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0	0	1
1745	1	1	0	1	1	1	1	1	1	0	0	0	1	0	0	0	1
1750	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0	1	1
1765	1	1	0	1	1	1	0	1	1	0	0	0	1	0	0	0	1
1775	1	1	0	1	1	1	0	1	1	0	0	0	1	1	0	1	0
1780	1	1	1	0	1	1	1	0	1	1	0	0	1	0	1	0	0
1785	1	1	0	1	1	1	0	0	1	1	0	0	1	1	0	1	0
1795	1	1	0	0	1	1	0	1	0	1	0	0	1	1	0	0	1
1800	1	1	0	0	1	1	1	0	0	1	0	0	1	1	0	0	0
1805	1	1	0	0	1	1	1	0	0	1	0	0	0	1	0	0	0
1810	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	1	0
1835	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0
1850	1	1	0	1	0	1	0	0	0	1	0	0	0	1	1	1	0
1852	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
1865	1	1	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0
1878	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0
1880	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1	1
1892	1	1	0	0	1	1	0	0	1	0	0	0	0	1	0	0	1
1895	1	1	0	0	1	1	1	0	1	1	0	0	1	1	0	1	1
1898	1	1	0	0	1	1	0	0	1	0	0	0	1	1	0	0	0
1905	1	1	0	0	1	1	0	0	0	1	0	0	0	0	0	1	1
1915	1	1	0	1	1	1	0	0	1	1	0	0	1	0	0	0	1
1925	1	1	0	0	0	1	0	0	1	1	0	0	0	1	1	1	0
1950	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0
1972	1	1	0	1	1	0	0	0	1	1	0	0	0	1	1	0	0
1977	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
1985	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
1995	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
2005	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
2007	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
2010	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
2012	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
2013	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
2014	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	0

	Marks Tey (borehole 1A) separate species (pen, rob, ul)								
Depth (cm)	**Ilaq**	**Vial**	**Eueu**	**Arma**	**Cavu**	**Emni**	**Plme**	**Fiul**	
1060	0	0	0	0	0	1	0	0	
1100	0	0	0	0	1	1	0	0	
1155	1	0	0	0	1	0	0	0	
1205	1	0	0	0	0	0	0	0	
1225	1	0	0	0	0	1	0	0	
1265	1	0	0	0	0	0	0	0	
1325	1	0	0	0	0	1	0	0	
1355	1	0	0	0	0	0	0	1	
1385	1	0	0	0	1	1	0	0	
1415	1	0	0	0	0	1	0	0	
1450	1	0	0	0	1	1	0	0	
1480	1	0	0	0	0	0	0	1	
1510	1	0	0	0	0	0	0	0	
1520	1	0	0	0	1	1	0	0	
1530	1	1	0	0	0	0	0	0	
1538	1	0	0	0	1	0	0	0	
1550	0	0	0	0	0	0	1	0	
1560	1	0	0	0	0	0	0	1	
1570	1	0	0	0	1	0	0	0	
1600	1	0	0	0	0	0	0	0	
1630	1	0	0	0	1	0	0	0	
1660	1	0	0	0	0	0	0	0	
1690	1	0	0	0	0	1	0	0	
1700	1	0	0	0	0	0	0	0	
1710	1	0	0	0	0	0	0	0	
1725	1	0	0	0	0	0	0	0	
1730	1	0	0	0	0	0	0	0	
1745	0	0	0	0	0	0	0	0	
1750	0	0	0	0	0	0	0	1	
1765	0	0	0	0	0	0	0	0	
1775	0	0	1	0	0	0	0	0	
1780	0	0	0	0	0	0	0	0	
1785	0	0	0	0	0	0	1	0	
1795	0	0	0	0	0	0	0	1	
1800	0	0	0	0	0	0	0	0	
1805	0	0	0	0	0	0	0	0	
1810	0	0	0	0	0	0	1	1	
1835	0	0	0	0	0	0	0	1	
1850	0	0	0	0	0	0	0	0	
1852	0	0	0	0	0	0	0	0	
1865	0	0	0	0	0	0	0	0	
1878	0	0	0	1	0	0	1	0	
1880	0	0	0	0	0	0	0	1	
1892	0	0	0	0	0	0	0	1	
1895	0	0	0	0	0	0	0	0	
1898	0	0	0	0	1	0	0	0	
1905	0	0	0	0	0	0	1	0	
1915	0	0	0	0	0	0	1	0	
1925	0	0	0	0	0	0	0	0	
1950	0	0	0	0	0	0	0	0	
1972	0	0	0	0	0	0	0	0	
1977	0	0	0	0	0	0	0	0	
1985	0	0	0	0	0	0	1	0	
1995	0	0	0	0	0	0	0	0	
2005	0	0	0	0	0	0	0	0	
2007	0	0	0	0	0	0	0	0	
2010	0	0	0	0	0	0	0	0	
2012	0	0	0	0	0	0	0	0	
2013	0	0	0	0	0	0	0	0	
2014	0	0	0	0	0	0	1	0	

	Marks Tey (borehole 1A) separate species (pub, pub, vu)																
Depth (cm)	**Be**	**Pisy**	**Abal**	**Piab**	**Ulgl**	**Qud**	**Tico**	**Frex**	**Algl**	**NA.xy**	**Acca**	**Cabe**	**Taba**	**Coav**	**Saca**	**Hirh**	**Juco**
1060	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	0	1
1100	1	1	1	1	1	1	1	0	1	0	0	1	1	1	0	0	0
1155	1	1	1	1	1	1	1	0	1	0	1	1	1	1	0	0	0
1205	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0
1225	1	1	1	1	1	1	1	1	1	0	0	1	1	1	0	0	0
1265	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0
1325	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0
1355	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0
1385	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0
1415	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0
1450	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0
1480	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0
1510	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0
1520	1	1	0	1	1	1	1	1	1	0	0	0	1	1	0	0	0
1530	1	1	0	1	1	1	1	1	1	0	0	1	1	1	1	0	0
1538	1	1	0	1	1	1	1	1	1	0	0	1	1	1	0	0	0
1550	1	1	0	1	1	1	1	1	1	0	1	0	1	1	1	0	0
1560	1	1	0	1	1	1	1	1	1	0	1	0	1	1	0	0	0
1570	1	1	0	1	1	1	1	1	1	0	0	0	1	1	0	0	0
1600	1	1	0	1	1	1	1	1	1	0	0	0	1	1	0	0	0
1630	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	0
1660	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0
1690	1	1	0	1	1	1	1	1	1	0	1	0	1	1	0	0	0
1700	1	1	0	1	1	1	1	0	1	0	0	0	1	1	1	0	0
1710	1	1	0	1	1	1	1	1	1	0	0	0	1	1	0	0	0
1725	1	1	0	1	1	1	1	1	1	0	1	0	1	1	1	0	1
1730	1	1	0	1	1	1	1	1	1	0	1	0	0	1	1	0	0
1745	1	1	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0
1750	1	1	0	1	1	1	1	1	1	0	1	0	0	1	1	0	1
1765	1	1	0	1	1	1	0	1	1	0	0	0	0	1	0	0	0
1775	1	1	0	1	1	1	0	1	1	0	0	0	0	1	1	0	1
1780	1	1	1	0	1	1	1	0	1	0	1	0	0	1	0	1	0
1785	1	1	0	1	1	1	0	0	1	0	1	0	0	1	1	0	1
1795	1	1	0	0	1	1	0	1	0	0	1	0	0	1	1	0	0
1800	1	1	0	0	1	1	1	0	0	0	1	0	0	1	1	0	0
1805	1	1	0	0	1	1	1	0	0	0	1	0	0	0	1	0	0
1810	1	1	0	0	1	1	0	0	1	0	1	0	0	0	1	0	1
1835	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1
1850	1	1	0	1	0	1	0	0	0	0	1	0	0	0	1	1	1
1852	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
1865	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0
1878	1	1	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0
1880	1	1	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1
1892	1	1	0	0	1	1	0	0	1	0	0	0	0	0	1	0	0
1895	1	1	0	0	1	1	1	0	1	0	1	0	0	1	1	0	1
1898	1	1	0	0	1	1	0	0	1	0	0	0	0	1	1	0	0
1905	1	1	0	0	1	1	0	0	0	0	1	0	0	0	0	0	1
1915	1	1	0	1	1	1	0	0	1	0	1	0	0	1	0	0	0
1925	1	1	0	0	0	1	0	0	1	0	1	0	0	0	1	1	1
1950	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1
1972	1	1	0	1	1	0	0	0	1	0	1	0	0	0	1	1	0
1977	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1985	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
1995	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
2005	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0
2007	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
2010	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
2012	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
2013	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
2014	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1

	Marks Tey (borehole 1A) separate species (pub, pub, vu)								
Depth (cm)	**Hehe**	**Ilaq**	**Vial**	**Eueu**	**Arma**	**Cavu**	**Emni**	**Plme**	**Fivu**
1060	1	0	0	0	0	0	1	0	0
1100	0	0	0	0	0	1	1	0	0
1155	1	1	0	0	0	1	0	0	0
1205	0	1	0	0	0	0	0	0	0
1225	1	1	0	0	0	0	1	0	0
1265	1	1	0	0	0	0	0	0	0
1325	1	1	0	0	0	0	1	0	0
1355	1	1	0	0	0	0	0	0	1
1385	1	1	0	0	0	1	1	0	0
1415	1	1	0	0	0	0	1	0	0
1450	1	1	0	0	0	1	1	0	0
1480	1	1	0	0	0	0	0	0	1
1510	1	1	0	0	0	0	0	0	0
1520	1	1	0	0	0	1	1	0	0
1530	1	1	1	0	0	0	0	0	0
1538	1	1	0	0	0	1	0	0	0
1550	1	0	0	0	0	0	0	1	0
1560	1	1	0	0	0	0	0	0	1
1570	1	1	0	0	0	1	0	0	0
1600	1	1	0	0	0	0	0	0	0
1630	1	1	0	0	0	1	0	0	0
1660	1	1	0	0	0	0	0	0	0
1690	1	1	0	0	0	0	1	0	0
1700	1	1	0	0	0	0	0	0	0
1710	1	1	0	0	0	0	0	0	0
1725	1	1	0	0	0	0	0	0	0
1730	1	1	0	0	0	0	0	0	0
1745	1	0	0	0	0	0	0	0	0
1750	1	0	0	0	0	0	0	0	1
1765	1	0	0	0	0	0	0	0	0
1775	0	0	0	1	0	0	0	0	0
1780	0	0	0	0	0	0	0	0	0
1785	0	0	0	0	0	0	0	1	0
1795	1	0	0	0	0	0	0	0	1
1800	0	0	0	0	0	0	0	0	0
1805	0	0	0	0	0	0	0	0	0
1810	0	0	0	0	0	0	0	1	1
1835	0	0	0	0	0	0	0	0	1
1850	0	0	0	0	0	0	0	0	0
1852	0	0	0	0	0	0	0	0	0
1865	0	0	0	0	0	0	0	0	0
1878	0	0	0	0	1	0	0	1	0
1880	1	0	0	0	0	0	0	0	1
1892	1	0	0	0	0	0	0	0	1
1895	1	0	0	0	0	0	0	0	0
1898	0	0	0	0	0	1	0	0	0
1905	1	0	0	0	0	0	0	1	0
1915	1	0	0	0	0	0	0	1	0
1925	0	0	0	0	0	0	0	0	0
1950	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	1	0
1995	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	1	0

Sensitivity testing for thresholds

Hoxne (main sequence) 1% threshold (1=presence, 0=absence)														
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Cabe**	**Frex**	**Abal**	**Piab**	**Coav**	**Hehe**	**Ilaq**	**Fi**
180	0	1	0	1	0	1	0	0	1	0	1	1	0	0
192	0	1	0	1	0	1	0	0	1	1	1	0	0	0
260	0	1	0	1	0	1	0	0	0	0	1	0	0	0
272	0	1	1	1	0	1	0	0	0	0	1	1	0	0
279	1	1	0	1	0	1	0	0	0	0	1	0	1	0
288	1	1	1	1	0	1	0	0	0	0	1	1	0	0
296	1	1	1	1	0	1	0	0	0	0	1	0	1	0
310	1	1	1	1	0	1	0	0	0	0	1	0	0	0
320	1	1	1	1	1	1	0	0	0	0	1	1	1	1
326	1	1	1	1	0	1	0	0	0	0	1	0	1	0
334	1	1	1	1	0	1	0	0	0	0	1	1	1	0
342	1	1	1	1	1	1	0	0	0	0	1	1	0	0
356	0	1	1	1	0	1	0	0	0	0	1	1	1	0
384	0	1	1	1	1	1	0	1	0	0	1	1	1	0
392	0	1	1	1	0	1	0	1	0	0	1	0	1	0
408	0	1	1	1	1	1	0	0	0	0	1	0	1	0
416	0	1	1	1	0	1	0	0	0	0	1	1	0	0
432	0	1	1	1	1	1	0	0	0	0	1	0	1	0
444	0	1	1	1	0	1	0	0	0	0	1	0	1	0
464	1	1	1	1	1	1	0	0	0	0	1	1	1	0
480	0	1	1	1	0	1	0	0	0	0	1	1	1	0
496	1	1	1	1	0	1	0	0	0	0	1	1	1	0
512	1	1	1	1	0	1	0	0	0	0	1	1	1	0
528	1	1	1	1	0	1	0	0	0	0	1	1	1	0
544	1	1	1	1	0	1	0	0	0	0	1	1	1	0
556	1	1	1	1	0	1	0	0	0	0	1	1	1	0
576	1	1	1	1	0	1	0	0	0	0	1	1	1	0
592	1	1	1	1	1	1	0	0	0	0	1	1	0	0
637	1	1	1	1	1	1	0	0	0	0	1	1	1	0
648	1	1	0	1	1	1	0	0	0	0	1	1	1	0
656	1	1	1	1	1	1	0	0	0	0	1	1	0	0
672	1	1	0	1	1	1	0	0	0	0	1	1	0	0
682	1	1	0	1	1	1	0	0	0	0	1	1	0	0
692	1	1	0	1	0	1	0	0	0	0	1	1	0	0
706	1	1	0	1	0	1	0	0	0	0	1	1	0	0
720	1	1	0	1	1	1	0	0	0	0	1	0	0	0
746	1	1	0	1	1	1	0	0	0	0	1	1	0	1
760	1	1	0	1	1	0	0	0	0	0	1	1	0	0
776	1	1	0	1	0	0	0	1	0	0	1	1	0	0
784	1	1	0	1	0	0	0	0	0	0	1	1	0	0
794	1	1	0	1	0	0	0	0	0	0	1	1	0	0
801	1	1	1	1	0	0	0	0	0	0	1	0	0	0
808	1	1	1	1	0	0	0	0	0	0	0	1	0	0
816	1	1	1	1	0	0	0	0	0	0	0	0	0	0
824	1	1	0	1	0	0	0	0	0	0	0	0	1	1

Hoxne (main sequence) 4% threshold (1=presence, 0=absence)											
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Abal**	**Coav**	**Hehe**	**Ilaq**	**Fi**
180	0	1	0	1	0	1	1	0	1	0	0
192	0	1	0	1	0	1	0	1	0	0	0
260	0	1	0	1	0	1	0	1	0	0	0
272	0	0	1	1	0	1	0	1	1	0	0
279	0	0	0	1	0	1	0	1	0	1	0
288	1	1	1	1	0	1	0	1	1	0	0
296	1	1	0	1	0	1	0	1	0	1	0
310	1	1	0	1	0	1	0	1	0	0	0
320	1	1	0	1	0	1	0	1	1	1	1
326	1	1	1	1	0	1	0	1	0	1	0
334	0	1	1	1	0	1	0	1	1	1	0
342	0	1	1	1	0	1	0	1	1	0	0
356	0	1	0	1	0	1	0	1	1	1	0
384	0	1	0	1	0	1	0	1	1	1	0
392	0	1	1	1	0	1	0	1	0	1	0
408	0	1	0	1	1	1	0	1	0	1	0
416	0	1	0	1	0	1	0	1	1	0	0
432	0	1	1	1	0	1	0	1	0	1	0
444	0	1	1	1	0	1	0	1	0	1	0
464	0	1	1	1	0	1	0	1	1	1	0
480	0	1	1	1	0	1	0	1	1	1	0
496	0	1	1	1	0	1	0	1	1	1	0
512	0	1	1	1	0	1	0	1	1	1	0
528	0	1	1	1	0	1	0	1	1	1	0
544	0	1	0	1	0	1	0	1	1	1	0
556	0	1	0	1	0	1	0	1	1	1	0
576	0	1	0	1	0	1	0	1	1	1	0
592	0	1	0	1	0	1	0	1	1	0	0
637	0	1	0	1	0	1	0	1	1	1	0
648	0	1	0	1	0	1	0	1	1	1	0
656	0	0	0	1	0	1	0	1	1	0	0
672	0	1	0	1	0	1	0	1	1	0	0
682	1	1	0	1	1	1	0	1	1	0	0
692	0	1	0	1	0	1	0	0	1	0	0
706	1	1	0	1	0	1	0	0	1	0	0
720	1	1	0	1	0	1	0	0	0	0	0
746	1	1	0	1	1	1	0	1	1	0	1
760	1	1	0	1	1	0	0	0	1	0	0
776	1	1	0	1	0	0	0	0	1	0	0
784	1	1	0	1	0	0	0	0	1	0	0
794	1	1	0	1	0	0	0	0	1	0	0
801	1	1	0	1	0	0	0	0	0	0	0
808	1	1	0	1	0	0	0	0	1	0	0
816	1	1	0	1	0	0	0	0	0	0	0
824	1	1	0	1	0	0	0	0	0	1	1

Hoxne (main sequence) Kuhl threshold (1=presence, 0=absence)																				
Depth (cm)	**Be**	**Pisy**	**Ul**	**Qud**	**Ti**	**Al**	**Fasy**	**Frex**	**Ac**	**Abal**	**Piab**	**Taba**	**Sam**	**Coav**	**San**	**Hirh**	**Hehe**	**Ilaq**	**Emni**	**Fi**
180	0	1	0	1	1	1	0	0	0	1	1	0	0	1	1	0	1	0	0	0
192	0	1	0	1	1	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0
260	0	1	0	1	1	1	0	0	0	0	0	0	0	1	1	0	0	0	1	0
272	0	1	1	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0
279	1	1	0	1	0	1	0	0	0	0	0	0	1	1	0	0	0	1	1	0
288	1	1	1	1	0	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0
296	1	1	1	1	1	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0
310	1	1	1	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0
320	1	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	1	0	1
326	1	1	1	1	0	1	0	1	0	0	0	0	0	1	0	0	0	1	0	0
334	0	1	1	1	1	1	0	0	1	1	0	0	0	1	0	0	1	1	0	0
342	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	1	0
356	0	1	1	1	0	1	0	1	0	0	0	0	0	1	0	0	1	1	0	0
384	0	1	1	1	1	1	0	1	1	0	0	0	0	1	0	0	1	1	1	0
392	0	1	1	1	0	1	1	1	0	0	0	0	0	1	0	0	0	1	1	0
408	0	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0	0	1	1	0
416	0	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	0	1	0
432	0	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0
444	0	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0	0	1	1	0
464	0	1	1	1	1	1	0	0	0	0	0	1	0	1	0	0	1	1	0	0
480	0	1	1	1	1	1	0	1	0	0	0	1	0	1	0	0	1	1	0	0
496	1	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	1	0	0
512	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	1	1	0
528	1	1	1	1	0	1	0	0	0	0	0	0	0	1	0	0	1	1	1	0
544	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	1	0	0
556	1	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	1	1	0
576	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	1	1	0
592	0	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	1	0
637	1	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0	1	1	1	0
648	1	1	0	1	1	1	0	0	0	0	0	0	0	1	0	0	1	1	0	0
656	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	1	0
672	1	1	0	1	1	1	0	1	0	0	0	1	0	1	0	0	1	0	0	0
682	1	1	0	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0
692	1	1	0	1	0	1	0	0	0	0	0	1	0	1	0	0	1	0	1	0
706	1	1	0	1	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0
720	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0
746	1	1	0	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	1	1
760	1	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0
776	1	1	0	1	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0
784	1	1	0	1	0	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0
794	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
801	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
808	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
816	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
824	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1

	Marks Tey (borehole 1A) 1% threshold (1=presence, 0=absence)																		
Depth (cm)	**Be**	**Pisy**	**Abal**	**Piab**	**Ul**	**Qud**	**Ti**	**Frex**	**Al**	**Ac**	**Cabe**	**Taba**	**Coav**	**San**	**Hirh**	**Juco**	**Hehe**	**Ilaq**	**Vial**
1060	1	1	1	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0
1100	1	1	1	0	0	1	0	0	1	0	1	1	1	0	0	0	0	0	0
1155	1	1	1	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1205	1	1	1	0	0	1	0	0	1	0	1	1	1	0	0	0	0	1	0
1225	1	1	1	0	0	1	0	0	1	0	1	1	1	0	0	0	1	1	0
1265	1	1	1	0	0	1	0	0	1	0	1	1	1	0	0	0	1	1	0
1325	1	1	0	0	1	1	0	0	1	0	1	1	1	0	0	0	1	1	0
1355	1	1	0	0	1	1	0	0	1	0	1	1	1	0	0	0	1	1	0
1385	1	1	0	0	0	1	0	0	1	0	1	1	1	0	0	0	1	1	0
1415	1	1	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1450	1	1	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1480	1	1	0	0	0	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1510	1	1	0	0	1	1	0	0	1	0	0	0	1	0	0	0	1	1	0
1520	1	1	0	0	1	1	0	0	1	0	0	0	1	0	0	0	1	1	0
1530	1	1	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	1
1538	1	1	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1550	1	1	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	0	0
1560	1	1	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1570	1	1	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1600	0	1	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1630	1	1	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1660	1	1	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1690	1	1	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1700	1	0	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1710	1	1	0	0	1	1	1	0	1	0	0	1	1	0	0	0	1	1	0
1725	1	1	0	0	0	1	0	1	1	0	0	0	1	0	0	0	1	1	0
1730	1	1	0	0	1	1	0	0	1	0	0	0	1	0	0	0	1	1	0
1745	1	1	0	0	0	1	1	0	1	0	0	0	1	0	0	0	1	0	0
1750	1	1	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	0	0
1765	1	1	0	0	1	1	0	0	1	0	0	0	1	0	0	0	1	0	0
1775	1	1	0	0	1	1	0	0	1	0	0	0	1	1	0	0	0	0	0
1780	1	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
1785	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
1795	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
1800	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1805	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1810	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1835	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
1850	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1852	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1865	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1878	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1880	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0
1892	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
1895	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
1898	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1905	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
1915	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
1925	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
1950	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1972	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1977	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
2005	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2007	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2010	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2012	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2013	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2014	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0

	Marks Tey (borehole 1A) 1% threshold (1=presence, 0=absence)							
Depth (cm)	**Eueu**	**Arma**	**Cavu**	**Emni**	**Plme**	**Fi**		
1060	0	0	0	0	0	0		
1100	0	0	1	1	0	0		
1155	0	0	1	0	0	0		
1205	0	0	0	0	0	0		
1225	0	0	0	0	0	0		
1265	0	0	0	0	0	0		
1325	0	0	0	0	0	0		
1355	0	0	0	0	0	1		
1385	0	0	1	0	0	0		
1415	0	0	0	0	0	0		
1450	0	0	1	0	0	0		
1480	0	0	0	0	0	1		
1510	0	0	0	0	0	0		
1520	0	0	1	0	0	0		
1530	0	0	0	0	0	0		
1538	0	0	1	0	0	0		
1550	0	0	0	0	1	0		
1560	0	0	0	0	0	1		
1570	0	0	1	0	0	0		
1600	0	0	0	0	0	0		
1630	0	0	1	0	0	0		
1660	0	0	0	0	0	0		
1690	0	0	0	0	0	0		
1700	0	0	0	0	0	0		
1710	0	0	0	0	0	0		
1725	0	0	0	0	0	0		
1730	0	0	0	0	0	0		
1745	0	0	0	0	0	0		
1750	0	0	0	0	0	1		
1765	0	0	0	0	0	0		
1775	1	0	0	0	0	0		
1780	0	0	0	0	0	0		
1785	0	0	0	0	1	0		
1795	0	0	0	0	0	1		
1800	0	0	0	0	0	0		
1805	0	0	0	0	0	0		
1810	0	0	0	0	1	1		
1835	0	0	0	0	0	1		
1850	0	0	0	0	0	0		
1852	0	0	0	0	0	0		
1865	0	0	0	0	0	0		
1878	0	1	0	0	1	0		
1880	0	0	0	0	0	1		
1892	0	0	0	0	0	1		
1895	0	0	0	0	0	0		
1898	0	0	1	0	0	0		
1905	0	0	0	0	1	0		
1915	0	0	0	0	1	0		
1925	0	0	0	0	0	0		
1950	0	0	1	0	0	0		
1972	0	0	0	0	0	0		
1977	0	0	0	0	0	0		
1985	0	0	0	0	1	0		
1995	0	0	0	0	0	0		
2005	0	0	0	0	1	0		
2007	0	0	0	0	0	0		
2010	0	0	0	0	0	0		
2012	0	0	0	0	0	0		
2013	0	0	0	0	0	0		
2014	0	0	0	0	1	0		

	Marks Tey (borehole 1A) 4% threshold (1=presence, 0=absence)																		
Depth (cm)	**Be**	**Pisy**	**Abal**	**Piab**	**Ul**	**Qud**	**Ti**	**Frex**	**Al**	**Ac**	**Cabe**	**Taba**	**Coav**	**San**	**Hirh**	**Juco**	**Hehe**	**Ilaq**	**Vial**
1060	0	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0
1100	0	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0
1155	0	1	1	0	0	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1205	0	0	1	0	0	1	0	0	1	0	1	1	1	0	0	0	0	1	0
1225	1	0	0	0	0	0	0	0	1	0	1	1	1	0	0	0	1	1	0
1265	0	0	0	0	0	1	0	0	1	0	1	1	1	0	0	0	1	1	0
1325	0	0	0	0	0	1	0	0	1	0	1	1	1	0	0	0	1	1	0
1355	0	0	0	0	0	1	0	0	1	0	1	1	1	0	0	0	1	1	0
1385	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1415	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1450	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	1	0
1480	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	1	0
1510	0	1	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	1	0
1520	1	1	0	0	1	1	0	0	1	0	0	0	1	0	0	0	1	1	0
1530	1	1	0	0	1	1	0	0	1	0	0	0	1	0	0	0	1	1	1
1538	1	1	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	1	0
1550	1	1	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	0	0
1560	0	1	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	1	0
1570	0	0	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1600	0	0	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1630	0	0	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1660	0	0	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1690	0	0	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1700	0	0	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0
1710	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	1	0
1725	1	0	0	0	0	1	0	1	1	0	0	0	1	0	0	0	1	1	0
1730	1	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	1	0
1745	1	1	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	0	0
1750	1	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0
1765	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
1775	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1780	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1785	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1795	1	1	0	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0
1800	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1805	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1810	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1835	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1850	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1852	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1865	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1878	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1880	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
1892	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
1895	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
1898	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1905	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
1915	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
1925	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1950	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1972	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1977	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
2012	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2013	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2014	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0

	Marks Tey (borehole 1A) 4% threshold (1=presence, 0=absence)							
Depth (cm)	**Eueu**	**Arma**	**Cavu**	**Emni**	**Plme**	**Fi**		
1060	0	0	0	0	0	0		
1100	0	0	1	1	0	0		
1155	0	0	1	0	0	0		
1205	0	0	0	0	0	0		
1225	0	0	0	0	0	0		
1265	0	0	0	0	0	0		
1325	0	0	0	0	0	0		
1355	0	0	0	0	0	1		
1385	0	0	1	0	0	0		
1415	0	0	0	0	0	0		
1450	0	0	1	0	0	0		
1480	0	0	0	0	0	1		
1510	0	0	0	0	0	0		
1520	0	0	1	0	0	0		
1530	0	0	0	0	0	0		
1538	0	0	1	0	0	0		
1550	0	0	0	0	1	0		
1560	0	0	0	0	0	1		
1570	0	0	1	0	0	0		
1600	0	0	0	0	0	0		
1630	0	0	1	0	0	0		
1660	0	0	0	0	0	0		
1690	0	0	0	0	0	0		
1700	0	0	0	0	0	0		
1710	0	0	0	0	0	0		
1725	0	0	0	0	0	0		
1730	0	0	0	0	0	0		
1745	0	0	0	0	0	0		
1750	0	0	0	0	0	1		
1765	0	0	0	0	0	0		
1775	1	0	0	0	0	0		
1780	0	0	0	0	0	0		
1785	0	0	0	0	1	0		
1795	0	0	0	0	0	1		
1800	0	0	0	0	0	0		
1805	0	0	0	0	0	0		
1810	0	0	0	0	1	1		
1835	0	0	0	0	0	1		
1850	0	0	0	0	0	0		
1852	0	0	0	0	0	0		
1865	0	0	0	0	0	0		
1878	0	1	0	0	1	0		
1880	0	0	0	0	0	1		
1892	0	0	0	0	0	1		
1895	0	0	0	0	0	0		
1898	0	0	1	0	0	0		
1905	0	0	0	0	1	0		
1915	0	0	0	0	1	0		
1925	0	0	0	0	0	0		
1950	0	0	1	0	0	0		
1972	0	0	0	0	0	0		
1977	0	0	0	0	0	0		
1985	0	0	0	0	1	0		
1995	0	0	0	0	0	0		
2005	0	0	0	0	1	0		
2007	0	0	0	0	0	0		
2010	0	0	0	0	0	0		
2012	0	0	0	0	0	0		
2013	0	0	0	0	0	0		
2014	0	0	0	0	1	0		

	Marks Tey (borehole 1A) Kuhl threshold (1=presence, 0=absence)																		
Depth (cm)	**Be**	**Pisy**	**Abal**	**Piab**	**Ul**	**Qud**	**Ti**	**Frex**	**Al**	**Ac**	**Cabe**	**Taba**	**Coav**	**San**	**Hirh**	**Juco**	**Hehe**	**Ilaq**	**Vial**
1060	1	1	1	0	0	1	0	1	1	1	1	1	0	0	0	1	1	0	0
1100	1	1	1	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0
1155	0	1	1	0	1	1	1	0	1	1	1	1	1	0	0	0	1	1	0
1205	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0	0	1	0
1225	1	1	1	0	0	1	0	1	1	0	1	1	1	0	0	0	1	1	0
1265	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1325	1	1	1	0	1	1	0	1	1	1	1	1	1	0	0	0	1	1	0
1355	0	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1385	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1415	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0
1450	1	1	1	0	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0
1480	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0	1	1	0
1510	1	1	1	0	1	1	0	1	1	1	0	1	1	0	0	0	1	1	0
1520	1	1	0	0	1	1	0	1	1	0	0	1	1	0	0	0	1	1	0
1530	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	1	1	1
1538	1	1	0	0	1	1	1	1	1	0	1	1	1	0	0	0	1	1	0
1550	1	1	0	0	1	1	1	1	1	1	0	1	1	1	0	0	1	0	0
1560	1	1	0	0	1	1	1	1	1	1	0	1	1	0	0	0	1	1	0
1570	1	1	0	0	1	1	1	1	1	0	0	1	1	0	0	0	1	1	0
1600	0	1	0	0	1	1	1	1	1	0	0	1	1	0	0	0	1	1	0
1630	0	1	1	0	1	1	0	1	1	0	0	1	1	1	0	0	1	1	0
1660	0	1	1	0	1	1	1	1	1	1	0	1	1	0	0	0	1	1	0
1690	1	1	0	0	1	1	1	1	1	1	0	1	1	0	0	0	1	1	0
1700	0	1	0	0	1	1	0	0	1	0	0	1	1	1	0	0	1	1	0
1710	0	1	0	0	1	1	1	1	1	0	0	1	1	0	0	0	1	1	0
1725	1	1	0	0	0	1	1	1	1	1	0	1	1	1	0	1	1	1	0
1730	1	1	0	0	1	1	1	0	1	1	0	0	1	1	0	0	1	1	0
1745	1	1	0	0	0	1	1	0	1	0	0	0	1	0	0	0	1	0	0
1750	1	1	0	0	0	1	0	1	1	1	0	0	1	1	0	1	1	0	0
1765	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
1775	1	1	0	0	1	1	0	1	0	0	0	0	0	1	0	1	0	0	0
1780	1	1	1	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0
1785	1	1	0	0	0	1	0	0	0	1	0	0	0	1	0	1	0	0	0
1795	1	1	0	0	1	1	0	1	0	1	0	0	0	1	0	0	1	0	0
1800	1	1	0	0	1	1	0	0	0	1	0	0	0	1	0	0	0	0	0
1805	1	1	0	0	1	1	0	0	0	1	0	0	0	1	0	0	0	0	0
1810	1	1	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0
1835	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
1850	1	1	0	0	0	0	0	0	0	1	0	0	0	1	1	1	0	0	0
1852	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
1865	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1878	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
1880	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1	1	0	0
1892	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0
1895	1	1	0	0	1	1	0	0	0	1	0	0	0	1	0	1	1	0	0
1898	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0
1905	1	1	0	0	0	1	0	0	0	1	0	0	0	0	0	1	1	0	0
1915	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
1925	1	1	0	0	0	0	0	0	0	1	0	0	0	1	1	1	0	0	0
1950	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
1972	1	1	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0
1977	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1985	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
1995	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
2005	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0
2007	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2010	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
2012	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
2013	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2014	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0

	Marks Tey (borehole 1A) Kuhl threshold (1=presence, 0=absence)							
Depth (cm)	**Eueu**	**Arma**	**Cavu**	**Emni**	**Plme**	**Fi**		
1060	0	0	0	1	0	0		
1100	0	0	1	1	0	0		
1155	0	0	1	0	0	0		
1205	0	0	0	0	0	0		
1225	0	0	0	1	0	0		
1265	0	0	0	0	0	0		
1325	0	0	0	1	0	0		
1355	0	0	0	0	0	1		
1385	0	0	1	1	0	0		
1415	0	0	0	1	0	0		
1450	0	0	1	1	0	0		
1480	0	0	0	0	0	1		
1510	0	0	0	0	0	0		
1520	0	0	1	1	0	0		
1530	0	0	0	0	0	0		
1538	0	0	1	0	0	0		
1550	0	0	0	0	1	0		
1560	0	0	0	0	0	1		
1570	0	0	1	0	0	0		
1600	0	0	0	0	0	0		
1630	0	0	1	0	0	0		
1660	0	0	0	0	0	0		
1690	0	0	0	1	0	0		
1700	0	0	0	0	0	0		
1710	0	0	0	0	0	0		
1725	0	0	0	0	0	0		
1730	0	0	0	0	0	0		
1745	0	0	0	0	0	0		
1750	0	0	0	0	0	1		
1765	0	0	0	0	0	0		
1775	1	0	0	0	0	0		
1780	0	0	0	0	0	0		
1785	0	0	0	0	1	0		
1795	0	0	0	0	0	1		
1800	0	0	0	0	0	0		
1805	0	0	0	0	0	0		
1810	0	0	0	0	1	1		
1835	0	0	0	0	0	1		
1850	0	0	0	0	0	0		
1852	0	0	0	0	0	0		
1865	0	0	0	0	0	0		
1878	0	1	0	0	1	0		
1880	0	0	0	0	0	1		
1892	0	0	0	0	0	1		
1895	0	0	0	0	0	0		
1898	0	0	1	0	0	0		
1905	0	0	0	0	1	0		
1915	0	0	0	0	1	0		
1925	0	0	0	0	0	0		
1950	0	0	1	0	0	0		
1972	0	0	0	0	0	0		
1977	0	0	0	0	0	0		
1985	0	0	0	0	1	0		
1995	0	0	0	0	0	0		
2005	0	0	0	0	1	0		
2007	0	0	0	0	0	0		
2010	0	0	0	0	0	0		
2012	0	0	0	0	0	0		
2013	0	0	0	0	0	0		
2014	0	0	0	0	1	0		